**Late Pleistocene Tephrostratigraphy
of the
Eastern Bay of Plenty Region,
New Zealand**

VOLUME I

by

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Frontispiece : "White Island" — so named for the plumes of white steam that often surround this active volcano in the Bay of Plenty.

(as seen from Kohioawa Beach, near Matata)

Abstract

This thesis has produced the compilation of a complete tephrostratigraphic record of the eastern Bay of Plenty, New Zealand. About fifty Late Pleistocene tephra (i.e. those older than the Rotoiti eruption), ranging in age from c. 600 to 50 ka, are recorded in a terrestrial sequence of loess and paleosols in the eastern Bay of Plenty. Tephra correlations are based on the distinctive physical characteristics of the airfall beds and confirmed by microprobe analysis of glass shards ("fingerprinting"). Chemical analysis of hornblendes and titanomagnetites is used as a supplementary correlation tool where the tephra are too weathered to retain glass. The eastern Bay of Plenty deposits are divided into seven subgroups with their boundaries marked either by major tephra or by significant changes in the paleo-climate indicator deposits such as loess and paleosols. These subgroups, and their estimated age ranges, are:

Subgroup	no. of tephra	Period of deposition
<i>post-Rotoiti</i>	~22	c. 50 - 60 ka - present
Kukumoa	>7	c. 240 - 50 - 60 ka
Huntress Creek	6	c. 285 - 240 ka
Torere	≥15	c. 325 - 285 ka
Murupara	8	c. 340 - 325 ka
Tablelands	6	c. 400 - 340 ka
Ohiwa Harbour	≥7	c. 475 - 400 ka
Reeves	≥4	c. 550(?) - 475 ka

Age control on the eastern Bay of Plenty tephra has been obtained by fitting the paleoclimatic information inferred from field observations to the Low Latitude Stack (LLS) and SPECMAP oxygen isotope curves, with correlations to a few well dated eruptives providing key time planes within this record; in particular, the Mamaku Ignimbrite (correlates to the Kutarere Tephra), and the Kaingaroa (Kaingaroa), Matahina (Matahina) and Rangitaiki (Kohioawa) Ignimbrites.

Tentative correlations of several eastern Bay of Plenty tephra to the western, coastal central, and southeast-central Bay of Plenty areas (Tauranga, Matata cliffs and Reporoa, respectively) have been achieved. Three additional subgroups are proposed: the Welcome Bay (with at least 6 tephra) in the west, the Ohinekoao (14 tephra) in the coastal central, and the Reihana (13 tephra) in the southeast-central Bay of Plenty; all of which overlap in time with the eastern Bay of Plenty stratigraphy.

The tephra recorded in the Bay of Plenty have been used to estimate the ages of formation and uplift rates for many of the landforms that are observed throughout the region. A tectonic regime of subsidence in the west towards Tauranga, block faulting on either side of the subsiding Whakatane Graben in the central Bay of Plenty, and further large scale block faulting towards the far eastern margin of the Bay of Plenty has been proposed.

Activity at the Okataina Volcanic Centre is now thought to have initiated at or before c. 370 ka, with the eruption of the Paerata Tephra. This tephra has a distribution pattern consistent with an Okataina source, and contains abundant cummingtonite, which is a signature mineral within tephra from the Okataina Volcanic Centre during the late Quaternary time period. However, the much older, but less well understood, Reeves-A and Wilson Tephra—both with estimated ages of c. 0.5 Ma—also contain cummingtonite, which indicates that activity may have been initiated at a much earlier time, or that a volcanic centre other than Okataina has produced cummingtonite.

Activity in the Rotorua Volcanic Centre prior to the eruption of the Mamaku Ignimbrite is also indicated, as is activity at the Reporoa Volcanic Centre prior to the Kaingaroa Ignimbrite eruption.

Acknowledgements

For my Father, to whom I dedicate this thesis

— may he be happy with all that he achieved...

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Chapter One : Introduction

1-1 General Introduction

The northern and central parts of the North Island of New Zealand have undergone sporadic volcanic activity through much of the Neogene, primarily due to the subduction of the Pacific Plate beneath the Indo-Australian Plate.

In the late Oligocene and early Miocene, and again in the mid Miocene, northwest trending arcs of andesite volcanoes developed on the western, then on the eastern side of the Northland Peninsula. Then about 6 million years ago a major change in the type of volcanism took place with extensive rhyolitic eruptions occurring in the northwest trending "Hauraki Volcanic Region" [Cole & Lewis, 1981] (Figure 1-1). The Coromandel Peninsula at this stage had consisted mainly of andesitic arc volcanoes but both rhyolite and andesite was erupted throughout the Pliocene and into the early Pleistocene.

The change to rhyolitic volcanism is thought to be due to the development of an extensional marginal basin (i.e. back arc spreading; Figure 1-2). The axis of spreading has moved eastward and rotated clockwise [Cole & Lewis, 1981] over time from the ancient northwest trend to the north-northeast trend of the active present day Taupo Volcanic Zone (T.V.Z.).

Other volcanic areas in New Zealand that have been active since this time have predominantly erupted basalt.

The Alexandra Volcanics [Kear, 1960] are comprised of several cones of varying size which have erupted 55 km³ of basalts and olivine andesites. The field was active from 2.74–1.60 Ma [Briggs *et al.*, 1989].

The Auckland Volcanics include basalts erupted in the South Auckland field, active from 1.56–0.51 Ma [Briggs *et al.*, 1989], as well as those basalts in the the Auckland field, active from 60 ka to present [Heming, 1980]. This latter field is still considered to be active.

The Taranaki Volcanic Centre has been active since the late Pleistocene with several large andesitic stratovolcanoes being formed and subsequently eroded. Egmont is the most recent volcano and has been active from *c.* 130 ka to the present [Alloway, 1989]. This field also is regarded as still active.

Figure 1-1 : Active Quaternary Volcanic Zones in the North Island, New Zealand [after Cole, 1979].

The Northland volcanic field, located in the Bay of Islands and in the Whangarei districts, has been active throughout the Quaternary. Basalt is the dominant eruptive with the most recent eruptions having occurred <2 ka ago [Wellman, 1962] suggesting that this area is probably still active.

The Tuhua Volcanic Centre consists of the Mayor Island volcano which has been active since *c.* 130 ka [Houghton, *et al.*, 1992]. The lavas are all rhyolitic but of an unusual composition, per-alkaline as opposed to the calc-alkaline of the T.V.Z. eruptives, with the dominant mineral in the pantelleritic lavas being aegirine. This centre is considered to be active.

The Taupo Volcanic Zone (T.V.Z.) is a 20–40 km wide zone extending 300 km north-northeast from Ohakune to White Island. The zone is a back-arc/marginal basin and is probably an onshore continuation of the Havre Trough, a back-arc spreading area associated with the Kermadec Trench subduction zone [Lewis & Pantin, 1981].

Figure 1-2 : Schematic model of the Indo-Australian/Pacific Plate Boundary in the North Island, New Zealand [from Cole, 1981].

Situated on the eastern edge of the Taupo Volcanic Zone is an arc system of andesite/dacite volcanoes, the most prominent being Tauhara, Edgecumbe, and White Island. These volcanoes can be directly related to the subduction of the Pacific plate [Cole, 1984] (Figure 1-2).

The Tongariro Volcanic Centre, located at the southern tip of the T.V.Z., consists of four major andesitic stratovolcanoes: Ruapehu, Tongariro, Kakaramaea, and Pihanga.

This centre is also considered to part of the arc system, and probably became active in the Lower Pleistocene, as andesite pebbles are present in sediments of this age near Wanganui [Williams, 1986]. The oldest exposed lavas in this centre have been dated by K-Ar at 260 ka [Stipp, 1968] and the dominant lava types are andesite, low silica andesite, and olivine bearing andesite.

Further north in the T.V.Z., rhyolitic volcanism is dominant. The surface expression of volcanism in this region is limited to caldera lakes infilling "inverse volcanoes" [Walker, 1981], and smaller scattered rhyolite domes.

Geophysical surveys were first carried out in the T.V.Z. in the late 1950's. These surveys showed a large negative gravity anomaly associated with the zone [Mondriniak & Studt, 1959] with Mesozoic basement greywacke downfaulted into a broad 250–1000 m deep depression. Several isolated and more pronounced depressions over 2 km in depth occur within the zone [Woodward & Ferry, 1973; 1974] and are thought to represent the significant subsidence that has occurred beneath the centres of volcanism [Rogan, 1982].

1-2 Volcanic Centres in the Taupo Volcanic Zone

The Okataina, Rotorua, Maroa and Taupo Volcanic Centres (Figure 1-3) were originally defined by the clustering of known and/or inferred vent sites, but also have significant basement depressions. The Mangakino and Kapenga Volcanic Centres were defined from geophysical data [Rogan, 1982], although the former was suspected to exist from grain size data and ignimbrite distribution [Blank, 1965]. The depressions have been correlated with collapse structures resulting from the withdrawal of acidic melts from beneath the volcanic centres.

The rhyolitic volcanic centres are considered to be the remnants of multiple and overlapping calderas formed during voluminous ignimbrite-producing eruptions. These ignimbrites form sheets which cover much of the central North Island, within and on either side of the T.V.Z.

The Mangakino Volcanic Centre, situated at the western edge of the T.V.Z., was active from approx. 1.6 to 0.9 million years ago [Pringle *et al.*, 1992; Houghton *et al.*, 1995] and was the source of many of the ignimbrites found in the King Country to the west of the T.V.Z. [Blank, 1965; Wilson, 1986]. The ignimbrites from which the above ages were obtained (using $^{40}\text{Ar}/^{39}\text{Ar}$ on plagioclase) are some of the earliest volcanic deposits seen in the T.V.Z. and thus the age of 1.6 Ma may be considered to date the onset of silicic T.V.Z. volcanism.

Little research has been carried out on Kapenga-sourced volcanic deposits and only a few ignimbrites have been identified as originating from this centre [Houghton *et al.*, 1995]. Found in the Matahina basin to the south of the Mamaku Plateau, these ignimbrites have ages of $\approx 0.77\text{--}0.68$ Ma [Houghton *et al.*, 1995]. Much younger eruptions from this area have also occurred, including the c. 50–65 ka Earthquake Flat Tephra, but there is no evidence for more recent activity.

The Reporoa basin is now thought to represent a caldera from which several eruptions were sourced, in particular the Kaingaroa Ignimbrites [Nairn *et al.*, 1994], at c. 230 ka [Houghton *et al.*, 1995] to 285 ka. The basement is over 2 km below sea-level in the Reporoa basin [Rogan, 1980] and is therefore deep enough to be a volcanic centre, but the volume of eruptives is likely to be relatively small in comparison to the recognized centres.

Only one major eruption is considered to have originated from the Rotorua Volcanic Centre: the Mamaku Ignimbrite. This deposit is the youngest major welded ignimbrite in the T.V.Z. and has been dated at 140 ± 80 ka (fission-track on glass) [Murphy & Seward, 1981], 230 ± 12 ka (isothermal plateau fission-track on glass) [Shane *et al.*, 1994], and 220 ± 10 ka ($^{40}\text{Ar}/^{39}\text{Ar}$) [Houghton *et al.*, 1995]. Lake Rotorua is situated in the caldera produced by this eruption.

The Maroa Volcanic Centre has erupted a large number of lava domes and several small-volume ignimbrites, but lacks an associated large-volume ignimbrite as each of the other volcanic centres has produced [Wilson *et al.*, 1986]. Age data is limited for the Maroa Centre, but activity probably commenced at about 300 ka and has continued to near present.

The Maroa and Taupo Volcanic Centres are situated at either end of a basin containing a great thickness of densely welded Whakamaru Ignimbrite, the largest ignimbrite to have been recorded in the T.V.Z. ($\geq 1000 \text{ km}^3$; [Wilson *et al.*, 1984]). It has been proposed that this basin is an infilled caldera, and the eruptive source of the Whakamaru Ignimbrite [Wilson *et al.*, 1986]. The postulated caldera (Whakamaru Caldera) may be classed as another volcanic centre, now extinct, or as the forerunner of both the Taupo and especially the Maroa Volcanic Centres. The age of the Whakamaru Ignimbrite is thought to be 0.33–0.35 Ma [Pringle *et al.*, 1992; Houghton *et al.*, 1995] and volcanic activity from the Whakamaru Centre, both before or after this eruption, is poorly understood. The Whakamaru Ignimbrite may consist of two or more separate eruptions spanning several thousand years [Wilson *et al.*, 1986].

There is little age data on early Taupo Volcanic Centre volcanics but this centre is assumed to have commenced activity at some time between 330 and 100 ka. Several particularly large eruptions have occurred in the Taupo Centre, notably the Kawakawa Tephra [Vucetich & Howorth, 1976a] and the Taupo Tephra [Froggatt, 1982], erupted at 22 ka and 1.8 ka respectively.

The Okataina Volcanic Centre has been active in very recent times, with the occurrence of the Tarawera Tephra eruption in 1886 A.D. This centre began activity at some stage prior to the eruption of the Matahina Ignimbrite [Carr, 1984; Bailey & Carr, 1994] at c. 0.34 ± 0.02 Ma [Black *et al.*, 1994], and has produced several large ignimbrites and many plinian airfall deposits.

The Taupo and Okataina Volcanic Centres have both been sources of eruption in the last 2 000 years and Maroa within the last 15 000 years [Froggatt & Lowe, 1990], and are therefore regarded as still active.

Figure 1-3 : Volcanic Centres in the Taupo Volcanic Zone.

(Dacite volcanoes: 1 = White Island; 2 = Motuhora Island; 3 = Edgecumbe;
4 = Maungakakamea; 5 = Maungaongaonga; 6 = Tauhara; 7 = Motuoapa; 8 = Horohoro)

There is some geophysical evidence for the existence of a body of acidic magma within the basement beneath the Okataina Volcanic Centre [Rogan, 1982] but no evidence for magma under any of the other centres. However, as no gravity data has been gathered over Lake Taupo, where the main collapse area for

the Taupo Volcanic Centre is located [Wilson *et al.*, 1986], the presence of magma at depth cannot be excluded.

The lavas of the Taupo Volcanic Zone have all been calc-alkaline and very dominantly rhyolitic; 12 000 km³ or approx. 98% of the total [Cole, 1979]. Most of the remainder (260 km³ or approx. 2%) is composed of andesite and a small amount of low-alumina basalt from the Tongariro Volcanic Centre. A small amount of dacite (5 km³) has also been erupted forming isolated cones throughout the T.V.Z., of which White Island is still active. A further 2 km³ of high-alumina basalt has been erupted in the Taupo-Rotorua area and is probably related to basaltic dykes emplaced as a consequence of extension within the back-arc basin [Cole & Lewis, 1981]. Extension in the Taupo Volcanic Zone is demonstrated by the presence of normal faults, which are common, and the absence of strike-slip faulting [Cole, 1981].

The acidic eruptives of the T.V.Z. are widely accepted to be derived from the partial melting of crustal rocks, namely the greywacke and argillite basement [Ewart & Stipp, 1968]. Although ⁸⁷Sr/⁸⁶Sr data is inconclusive, as it could be obtained either by partial melting of "western basement" or fractionation of a more basic melt, data from trace element studies are inconsistent with basalt fractionation [Reid, 1993]. Furthermore, oxygen-isotope data supports partial melting. However, experimental melts of either the "western basement" (Waipapa Terrane), or the "eastern basement" (Torlesse) sedimentary pile, do not closely resemble rhyolites from the T.V.Z. [Conrad *et al.*, 1988]. The rhyolites are more likely to represent melting of a more diopside-normative lower crust, or fractionation of arc-related mafic-intermediate magmas.

Several high-silica rhyolites from the Okataina Volcanic Centre contain the mineral cummingtonite, thereby constraining the depth of crystallization. Experimental crystallization studies confirm that cummingtonite forms at pressures equivalent to shallow (≤ 10 km) depths, probably in the roof zone of a shallow crustal magma chamber, and that these rhyolites are likely to represent fractionated magmas [Nicholls *et al.*, 1992].

However, the lack of eruptives of the more mafic parent material presents a problem. The vast volume of rhyolitic eruptives requires an even larger volume of parent magma if fractionation is indeed the petrogenetical process, and this is not seen. Only a small percentage of the total lavas exposed at the surface in the T.V.Z. consist of basalt, andesite or dacite, and nor do these denser and more magnetic lavas also show up in sufficient volumes in geophysical surveys. However, it may be that the parent magmas are located at great depths, and have yet to be discovered. Some andesites have been found at depth in the T.V.Z. — in drill-holes sunk in geothermal areas — and one drill-hole is known to bottom out in diorite [Browne *et al.*, 1992]. The lack of evidence for a parent magma is not proof of its nonexistence. The debate over the origin of T.V.Z. magma is on-going.

1-3 Previous Geological Studies in the Taupo Volcanic Zone

There have been many geological studies conducted within the Taupo Volcanic Zone, with the earliest studies dating back more than 100 years.

Hochstetter, in the late 1850's, was the first to geologically survey the area. He published a geological map and description of the central portion of the North Island. Hochstetter recognized four different volcanic zones and named one — "the Taupo Zone" [Hochstetter, 1864 in Fleming, 1959]. Further work was carried out by Hutton in the 1890's, who described the eruptive rocks, and by Henderson and Grange, in the 1920's and 1930's; the latter two authors mapped several areas in detail.

Grange [1937] developed the idea that the volcanic belt occupied an extensive structural depression which he named the "Rotorua-Taupo Graben". This term, although useful, was inaccurate since the graben actually extends from Lake Taupo through to the Bay of Plenty coast and off-shore to White Island. Rotorua itself is actually situated on a subsidiary structure [Mondriniak & Studt, 1959] and they introduced the term — "Taupo-White Island Depression".

Healy, in 1962, defined the 'Taupo Volcanic Zone' as "a 10–15 mile wide belt extending across the centre of North Island in a north-east direction for 190 miles" [in Thompson, 1964]. Martin [1961], however, used the term "Taupo Volcanic Zone" for both the subsided graben, and the area of volcanic rock — mainly voluminous plateau-forming ignimbrite sheets — found to the east and west of the graben.

This writer prefers the term "Central Volcanic Region" for this area of volcanic rocks, which includes the 'Taupo Volcanic Zone' as a belt of subsidence and volcanic eruption within it (Figure 1-3).

Grindley [1960], and Healy et al. [1964] mapped the Taupo Volcanic Zone at 1:250 000 scale (Taupo — sheet 8 & Rotorua — sheet 5 respectively). More recently, the Tarawera area was mapped in greater detail (1:50 000) [Nairn, 1989b].

The first detailed studies of the cover-bed stratigraphy in the T.V.Z. were conducted by soil scientists investigating trace-element and nutrient-poor soils and their relationship to the health of livestock [Taylor, 1930; Grange & Taylor, 1932].

Later soil scientists, such as Kear (1959), Kear & Schofield (1959), Ward (1967), and Pullar (1967a & b), continued their research into the types of soils that were formed from volcanic ash, and the process of soil formation. Knowledge of the age of the parent tephra, and hence the age of the soils, was of great value in these studies and thus the tephrostratigraphic study of the vast number of volcanic deposits existing in New Zealand was initiated.

Baumgart [1954] described in detail the Holocene eruptive deposits in the Taupo area, and Vucetich & Pullar [1964] worked on Holocene tephra in the Rotorua area. Vucetich & Pullar [1969, 1973]; Pullar & Birrell [1973a & 1973b]; and Pullar, Birrell & Heine [1973] extended the stratigraphic knowledge further back in time and attempted correlation of tephra throughout the central North Island.

Since then many researchers have studied the volcanic deposits found both within the T.V.Z. and throughout New Zealand, and gradually, using innovations in technology as they occur, a stratigraphy of events has been established. The current state of knowledge concerning the tephrostratigraphy and tephrochronology of T.V.Z. eruptives is summarised in Chapter 2.

1-4 Aim of Thesis

The key to understanding the history of the Central Volcanic Region is in understanding the stratigraphy of the volcanic deposits. Early tephrostratigraphic researchers in the Taupo Volcanic Zone studied the most accessible deposits; that is the tephras nearest to the land surface. Older tephras were buried, often to great depths, by a thick mantle of the more recent tephras.

As forestry developed, the number of good deep exposures showing older strata increased dramatically in a direct relationship with the number of forestry roads and deep road cuttings being constructed. More outcrops enabled researchers to increase the tephrostratigraphic knowledge beyond the Holocene.

The exposure of the much older tephras (pre-Rotoiti) is much more limited than that of younger tephras, because near source the older tephras are deeply buried by thick sequences of the young eruptives and by ignimbrite sheets sometimes up to 100 m thick. A great deal of erosion is required to gain any exposure at all, but because of this erosion whole sequences of strata are often not represented.

Due to this limited exposure, relatively little research has been carried out on the older airfall tephras. Research into the more ancient eruptions has tended to concentrate on the large widespread ignimbrites and the scattered rhyolitic and dacitic domes.

Welded ignimbrite forms hard, relatively erosion-resistant sheets which are often consolidated enough to form vertical cliffs, as do the volcanic domes. Forestry road cuttings have also improved the number and accessibility of outcrops. Although exposure of ignimbrites is relatively common, because they are deposited as flows, the ignimbrites follow the paleo-topography and the stratigraphic relationships between the different eruptions can be difficult to establish.

Large ignimbrite eruptions are not the only eruptive events to have occurred in the T.V.Z.; in fact they are relatively rare. There have been many eruptions which have produced airfall tephra only, or with small limited pyroclastic flows. As airfall events are more common than ignimbrites, greater stratigraphic detail is obtained from studying the airfall tephras. However, the airfall deposits are generally unconsolidated and easily eroded, allowing near source exposures to occur only where firmer ignimbrites have capped and protected the airfall deposits from erosion.

In areas distal to the source of eruption there are sections which display thick sequences of airfall tephra. At these sites the thickness of the individual tephras is reduced and therefore the depth of section required to show the older eruptives is not as great as those near source.

Coastal sections in the eastern Bay of Plenty (Figure 1-4) have perhaps the best record of late Pleistocene tephra. Near-horizontal marine and fluvial terraces are common and are ideal sites for tephra

accumulation and preservation. Rapid uplift in some areas has also allowed observation of tephras deposited in a marine environment.

Figure 1-4 : Sketch map of the North Island of New Zealand, showing area of research.

The object of this study is to compile a detailed stratigraphy of the pre-Rotoiti tephras found in the Bay of Plenty region. This will enable a late-Pleistocene volcanic history of the northern part of the Taupo Volcanic Zone to be developed. Each individual unit will be described in detail so that the thesis can also be used as an identification guide to the volcanic deposits in the eastern Bay of Plenty.

The individual tephra layers form widespread time-planes which are instrumental in the relative (and numerical) dating of landscape features, and the calculation of uplift rates. Hence a detailed geographical and geological history of the region can be developed, with special reference to the glacio-eustatic sea-level curves and oxygen isotope stage record.

The tephrostratigraphic column thus developed may be used as a standard for correlation of other tephra-bearing sequences found throughout the country.

Chapter Two : Tephra Review

Over the last 50 years, the more recent tephra erupted from the Taupo Volcanic Zone (i.e. "post-Rotoiti") have undergone detailed study. The history of these studies has been well documented in Lowe (1990).

All the post-Rotoiti tephra known to have erupted are summarised below (Table 2-1). "Late Quaternary tephra" [Vucetich & Pullar, 1969; Pain, 1975] is a convenient term used throughout this study when referring to the post-Rotoiti tephra (this also includes the Rotoiti Tephra Formation). Older, "pre-Rotoiti" tephra are the focus of this work, and all tephra of this age found in the Bay of Plenty region are detailed in Chapters 6 to 13. These "older" tephra will be referred to as "late Pleistocene tephra". Early to mid-Pleistocene tephra are found elsewhere in New Zealand (e.g. the Wanganui basin), but the oldest tephra found in the Bay of Plenty region are considered to be much younger, erupted c. 600 ka at oldest. This work will attempt to correlate the late Pleistocene tephra found in the Bay of Plenty with the known Pleistocene ignimbrite and tephra stratigraphy throughout New Zealand.

Research of late Pleistocene eruptives has progressed on two fronts :

- 1) On the large widespread ignimbrites found in the Central Volcanic Region; and
- 2) On airfall tephra which have been preserved within loess sequences, or in marine, lacustrine, or fluvial sediment.

Research of Pleistocene airfall tephra erupted from the T.V.Z. has been concentrated in two areas:

- 1) Distal areas such as the Wanganui and Hawkes Bay–Wairarapa basins, and in deep sea drill-cores east of New Zealand;
- 2) Relatively proximal areas, upwind of the T.V.Z., in the Central Volcanic Region (C.V.R.).

Due to a shortage of well-preserved exposures, the stratigraphy of older eruptions is not well understood. The accepted stratigraphy is summarised below (Table 2-2.1, 2-2.2, & 2-4).

Table 2-1 : Late Quaternary rhyolitic tephra from the T.V.Z.

tephra	symbol	source	volume (km ³)	age (ka)
Tarawera Tephra	Tr	Okataina	[2.5]	1886AD
Rotomahana Mud	Tm		<1	
Tarawera Scoria	Trs		2	
Kaharoa Tephra	Ka	Okataina	6	770 ± 20
Kaharoa Igb.	-		<1	
Kaharoa Ash.	-		5	
Taupo Tephra	Tp	Taupo	[87.5]	1850 ± 10
Taupo Igb.	Tpi		70	
Taupo Lapilli	Tl		12	
Rotongaio Ash	Rn		1	
Hatepe Ash	Hta		2.5	
Hatepe Lapilli	Htl		2	
Mapara Tephra	Mp	Taupo	2	2160 ± 25
Whakaipo Tephra	Wo	Taupo	2	2685 ± 20
Waimihia Tephra	Wm	Taupo	[19]	3280 ± 20
Waimihia Igb.	Wmi		14	
Waimihia Lapilli	Wml		5	
Rotokawau Tephra	Rw	Okataina	0.7	3440 ± 70
Stent Tephra* ⁴	St	Taupo?	?	c. 4000
unnamed tephra* ³	-	Taupo	-	c. 4300* ³
Hinemaiaia Tephra	Hm	Taupo	3	4510 ± 20
Whakatane Tephra	Wk	Okataina	10	4830 ± 20
Motutere Tephra	Mt	Taupo	1	5430 ± 60
Tuhua Tephra	Tu	Tuhua	1	6130 ± 30
Mamaku Tephra	Ma	Okataina	6	7250 ± 20
Rotoma Tephra	Rm	Okataina	12	8530 ± 10
Opepe Tephra	Op	Taupo	4	9050 ± 40
Poronui Tephra	Po	Taupo	3	9810 ± 50
Karapiti Tephra	Kp	Taupo	2	9820 ± 80
Waiohau Tephra	Wh	Okataina	18	11 850 ± 60
Rotorua Tephra	Rr	Okataina	7	13 080 ± 50
Puketarata Tephra	Pk	Maroa	1	c. 14 000
unnamed tephra	-	Tuhua	-	c. 14 500
Rerewhakaaitu Tephra	Rk	Okataina	7	14 700 ± 110
Okareka Tephra	Ok	Okataina	8	c. 18 000
Te Rere Tephra	Te	Okataina	6	21 100 ± 320
Kawakawa Tephra	Kk	Taupo	[220]	22 590 ± 230
Oruanui Igb.	Ou		150	
Aokautere Ash	Ao		70	
Poihipi Tephra	P	Taupo	1	c. 23 000
Okaia Tephra	O	Taupo	7	c. 23 500
Omataroa Tephra	Om	Okataina	[21]	28 220 ± 630
Omataroa Igb.	-		5	
Omataroa Lapilli	-		16	
Awakeri Tephra	Aw	Okataina	2	c. 29 000
Mangaone Tephra	Mn	Okataina		c. 30 000
Mangaone Igb.	-		6	35 300 ± 2200* ²
Mangaone Lapilli	-		16	c. 33 000* ¹
Hauparu Tephra	Hu	Okataina	10	35 870 ± 1270 39 000 ± 5600* ²
Te Mahoe Tephra	Tm	Okataina	0.3	c. 39 000
Maketu Tephra	Mk	Okataina	15	c. 41 000
Tahuna Tephra	Ta	Okataina	2	c. 43 000
Ngamotu Tephra	Nt	Okataina	2	c. 45 000
Tihoi Tephra	Ti	Taupo	5	c. 46 000
Waihora Tephra	W	Taupo	1	c. 47 000
Otake Tephra	Oe	Taupo	2	c. 48 000
Earthquake Flat Tephra	-	Kapenga	[7]	c. 50 000
Rifle Range Ash	Ra		2	
Earthquake Flat Igb.	Ea		5	
Rotoiti Tephra	-	Okataina	[241]	c. 50 000
Rotoehu Ash	Re		90	
Rotoiti Igb.	Rb		150	
Matahi Scoria	Mb		1	

*¹ = [Naim, 1981]; *² = [McGlone et al., 1984]; *³ [Eden et al., 1993];*⁴ = [Alloway et al., 1994]; all others from [Froggatt & Lowe, 1990].

2-1 Post-Rotoiti Tephrochronology

This summary of post-Rotoiti tephra erupted from the rhyolitic centres in the T.V.Z. is chiefly derived from Froggatt & Lowe [1990], and presented in Table 2-1 (opposite).

Only airfall tephra and ignimbrites are included in this summary; rhyolitic and dacitic lavas being excluded due to their small areal extent and limited age control. The dacitic Mt. Edgecumbe volcano was active during the Holocene, but no reports of airfall dacitic tephra have been published. The less well-distributed andesitic eruptives from the Tongariro Volcanic Centre are also excluded, but two of the larger rhyolitic tephra from Mayor Island (Tuhua Volcanic Centre) — deposited on the mainland, are included.

It is now believed that there were many distinct eruptive episodes within the individual tephra listed (Table 2-1), including at least six within the stratigraphic unit called the Hinemaiaia Tephra [Wilson, 1993]. The time intervals between these eruptive episodes were too short for recognisable paleosol development to be recognised, but each episode is a significant event volcanologically, and for the environment of surrounding area. The unnamed tephra erupted c. 4300 ka ago [Eden *et al.*, 1993] is likely to be one of the eruptives comprising the Hinemaiaia Tephra.

Several of the eruptions listed, namely those forming the Rotoiti Tephra, Kawakawa Tephra and the Taupo Tephra, were very large and had widely distributed airfall tephra. These "big" eruptive events have been used as stratigraphic markers across much of the North Island and have been fundamental to the development of the volcanic history of the T.V.Z.

The Rotoiti Tephra [Froggatt & Lowe, 1990] was erupted from the northern part of the Okataina Volcanic Centre [Vucetich & Pullar, 1969] at c. 50 ka, and its airfall component (Rotoehu Ash) is widespread across the entire Bay of Plenty region. This tephra has been studied in detail by Vucetich & Pullar [1969], Nairn [1971], & Nairn [1981], and is discussed further in Chapter 4.

The Kawakawa Tephra Formation [Vucetich & Howorth, 1976a] was erupted from the Taupo Volcanic Centre [Self & Sparks, 1978] c. 22 600 yrs ago [Froggatt & Lowe, 1990] and is distributed over most of New Zealand, even to the Chatham Islands [Mildenhall, 1976]. This tephra has been studied in detail by Vucetich & Pullar [1969], Vucetich & Howorth [1976a], Self & Sparks [1978], Self [1983], and Self & Healy [1987]. The Kawakawa Tephra eruption marks the end of one phase of volcanism within Taupo centre, and the beginning of a 12 000 year hiatus in activity.

The Kawakawa Tephra was erupted in the midst of the last glacial and is preserved in loess deposits throughout the country, becoming an ubiquitous component in late Quaternary paleoclimatic studies in New Zealand.

The Taupo Tephra was the most recent large eruption to occur in the T.V.Z. and has been studied in detail by Froggatt [1982], Wilson [1985], and Wilson & Walker [1985]. The Taupo Ignimbrite was a voluminous low-aspect ratio ignimbrite [Walker *et al.*, 1980] which caused a great deal of damage to the indigenous forest in the central North Island around 1 850 years B.P.

Table 2-2 : Pre-Rotoiti ignimbrites from the Taupo Volcanic Zone.

Ignimbrites	Source	Volume (km ³)	Age (Ma)	References
Rotoiti Igb.	Okataina	>240	c. 0.05 - 0.065	(see chapter four)
! - Pukeahua Igb.	Maroa	>3	?	10
! - Orakonui Igb.	Maroa	>10	?	10,8
Mamaku Igb.	Rotorua	>300	0.22 ± 0.01 [†] 0.23 ± 0.012 [#] 0.14 ± 0.08~	21,8,5 19 6
! - unnamed brown igb.	Taupo	?	?	10,8
! - Atiamuri Igb.	Maroa	30-100	?	21,10,8
! - Ohakuri Igb.	Maroa	30-100	c. 0.27	21,13,10,8
Kaingaroa Igbs.	Reporoa	100 >75	0.23 ± 0.01 [#] 0.24 ± 0.05~ 0.15 ± 0.03 [^]	21,8,5,4,1 12 3
Pokai Igb.	Kapenga	100	-	13
[Onuku Pyroclastics]	Okataina	40	-	12,5
Chimp Igb.	Kapenga	30-100	?	21,13
Matahina Igb.	Okataina	220	0.28 ± 0.01 [#] 0.34 ± 0.02 [†] 0.28 ± 0.03~ 0.26 ± 0.04 [^]	21,8,5,4,1 20 18 3
[Bonisch Pyroclastics]	Okataina	-	0.30 ± 0.03~	18,14
Whakamaru Group Igb.'s -Whakamaru	Whakamaru	>1000	0.32 ± 0.02 [#] 0.330 ± 0.004 [#] 0.37 ± 0.02~ 0.33 ± 0.05 [^] 0.34 ± 0.03~ 0.32 ± 0.03 [#] 0.34 ± 0.01 [#] 0.39 ± 0.05~ 0.30 ± 0.04 [^]	10,5,4 21 16 15 3 18 21 21 15 3
-Rangitaiiki -Manunui -Te Whaiti				
?-Waiotapu Igb.(east)	Reporoa?	?	-	11
Quartz-biotite Igbs.	Okataina	90	0.38 ± 0.05~	15,12,11,8,5,4
[Waiora Formation]	?	?	-	11
Paeroa Igb.	Kapenga?	>50	0.33 ± 0.01 [#] 0.334 ± 0.002 [#] 0.37 ± 0.02~ 0.37 ± 0.03 ^{\$}	21 16,4,1 15 11
Te Weta Igb.	Kapenga?	?	0.32 ± 0.04 [#]	21,11,4,1
Te Kopia Igb.	Kapenga?	>60	0.34 ± 0.01 [#] 0.37 ± 0.04~ 0.58 ± 0.08 [^]	21,11,4,1 15 3
Waiotapu Igb.(west)	Kapenga	100-300	0.71 ± 0.06 [#]	21,13,11,6
Marshall Igb.	Kapenga?	>50	0.95 ± 0.03 [#] 0.91 ± 0.02 [#] 0.52 ± 0.14~	21,13,4,1 17,9 6
"I" Igb. "I"				
Kaahu Igb.	Mangakino	<0.5	0.92 ± 0.07 [#]	17,10,9
Igb. "G"	?	?	?	9
Rahopaka Igb.	?	?	0.72 ± 0.16~	6
Rocky Hill Igb.	Mangakino	>300	1.00 ± 0.05 [#] 0.97 ± 0.02 [#] 0.954 ± 0.025 [#]	21,9,8,2,1 17 16
Tikorangi Igb.	?	?	0.89 ± 0.04 [#]	21,6
Pukerimu Igb.	?	?	1.03 ± 0.18~	6
unit "E"	Mangakino	>300	0.97 ± 0.04 [#] 1.01 ± 0.06 [#]	21,9,8 17
Ahuroa Igb.	Mangakino	100-300	1.18 ± 0.02 [#] 1.19 ± 0.03 [#] 0.65 ± 0.09 [^]	21,9,8,2,1 17 3
unit "D"	Mangakino	100-300	1.20 ± 0.04 [#] 1.18 ± 0.02 [#]	21,9,8 17
Ongatiti Igb.	Mangakino	>300	1.21 ± 0.04 [#] 1.23 ± 0.02 [#] 1.251 ± 0.060 [#] 0.75 ± 0.08 [^]	21,9,8,2,1 17 16 3
igb. "C"	Mangakino	30-100	1.68 ± 0.07 [#] 1.62 ± 0.11 [#]	21,9,8 17
igb. "B"	Mangakino	30-100	1.53 ± 0.04 [#] 1.51 ± 0.02 [#]	21,9,8 17
Ngaroma Igb.	Mangakino	100-300	1.55 ± 0.05 [#] 1.603 ± 0.022 [#]	21,9,8,2 16

\$ = K-Ar; ^ = fission-track (glass);

~ = fission-track (zircon);

† = isothermal plateau fission-track (glass);

= ⁴⁰Ar/³⁹Ar (sanidines & plagioclase)

- references listed below Table 2-3 (page 14)

Several other tephra, although not so voluminous or widespread, were deposited preferentially downwind in the eastern Bay of Plenty. Both the Omataroa Tephra and the Mangaone Tephra form thick deposits in many of the sections studied in this work and have been useful in the correlation of sections. As many of the "late Quaternary" tephra have quite thick deposits in the eastern Bay of Plenty, they cannot be disregarded in stratigraphic studies within this region (see Chapter 4).

2-2 Pre-Rotoiti Ignimbrite Eruptions from the Taupo Volcanic Zone

Because of their nature (flow deposits), ignimbrites follow the paleo-topography and can vary widely in thickness, welding, grain-size and composition. Also, several flows may occur within a single eruption, each having its own distribution, and unlike an airfall tephra, the thicknesses of a flow does not grade to zero with distance, but may stop abruptly. The stratigraphic relationships between the different ignimbrite eruptions are therefore frequently difficult to establish.

The stratigraphy of the ignimbrites found in the C.V.R., as it is presently understood, is summarised in Table 2-2.1 opposite.

Most of the Okataina Volcanic Centre eruptives were studied in detail by Nairn [1981], the Mangakino eruptives by Wilson [1986], and the Maroa eruptives by Wilson et al. [1986].

Previous summaries were also compiled by Martin [1961], Briggs [1973], and Wilson et al. [1984].

The Whakamaru Group ignimbrites consist of several ignimbrite sheets which in different localities have different names. It is still unclear whether the ignimbrites are the result of one very large eruption, with the different sheets being separate flow members within it; or whether the group consists of several different eruptions occurring within a period of 5000–50 000 years [Pringle et al., 1991].

The Rangitaiki and Whakamaru ignimbrites are believed to be the same eruption, as are the probably slightly older Manunui and Te Whaiti ignimbrites [Wilson et al., 1986].

The Paeroa Group ignimbrites (Paeroa, Te Weta, & Te Kopia) may also be correlatives of the Whakamaru Group, on the basis of their similar mineralogies and ages [Pringle et al., 1991].

Units below the double line near the centre of Table 2-2.1 (older than the Te Kopia Ignimbrite) are considered too old to have been recorded in the eastern Bay of Plenty stratigraphy. The land surfaces here are thought to be ≤ 650 ka old, and apart from a sequence near Matata, and one near Ohiwa, the exposed uplifted marine sediments are younger still.

The Waiotapu (east) Ignimbrite [Keall, 1988] is considered to have erupted from a source near Waiotapu due to its great thickness in this area. The closest recognised volcanic centres (V.C.) to this locality are the Reporoa V.C., and the Kapenga V.C. However, the ignimbrite may simply have ponded in a local depression here after erupting some greater distance away.

The ignimbrites listed in Table 2-2.2 are recognised in the Tauranga area and although most were probably erupted from the T.V.Z., specific correlations to the deposits in the C.V.R. are still uncertain.

Table 2-2.2 : Ignimbrites found in the Tauranga area.

Ignimbrites	Source	Volume (km ³)	Age (Ma)	References
Waimakariri Igb.	?	?	c. 0.18	7
Te Ranga Igb.	?	?	c. 0.3	7
Te Puna Igb.	?	?	c. 0.4	7
Wairoa Igb.	?	?	c. 0.6	7
Waiteariki Igb.	?	?	0.84 ± 0.11 [^]	7,3
Aongatete Igb.	Coromandel?	?	1.26	7
		?	0.86 ± 0.14 [^]	3

[^] = fission track-glass

* References for Tables 2-2.1 & 2-2.2

(***Bold italicized highlights*** : the reference contains specific mention of the age of the tephra)

1 = Martin, [1961]	8 = Wilson et al., [1984]	15 = Kohn et al., [1992]
2 = Blank, [1965]	9 = Wilson, [1986]	16 = Pringle et al., [1992]
3 = Kohn, [1973]	10 = Wilson et al., [1986]	17 = Briggs et al., [1993]
4 = Briggs [1973]	11 = Keall, [1988]	18 = Kohn, pers.comm. [1994]
5 = Nairn, [1981]	12 = Nairn, [1989b]	19 = Shane et al., [1994]
6 = Murphy & Seward [1981]	13 = Houghton et al. [1991]	20 = Black et al., [1994]
7 = Harmsworth, [1983]	14 = Nairn, pers.comm. [1991]	21 = Houghton et al., [1995]

2-3 Pleistocene Airfall Tephra in the Central Volcanic Region

The prevailing wind direction in New Zealand is from the west (especially at stratospheric altitudes) and hence those areas situated just to the west of the T.V.Z., such as the King Country and Waikato regions, have much lower tephra accumulation rates than those in the east. Only the largest T.V.Z. eruptions, as well as a few deposited during conditions of abnormal wind direction, have been deposited in western areas in thicknesses sufficient to be preserved and recognised as individual events. The tephrostratigraphic column is therefore much condensed to the west and north of the T.V.Z.

Due to the slow rate of deposition in this region, the tephra spend a greater length of time at the weathering (soil) surface between burial events (i.e. eruptions), and the Pleistocene tephra in these areas are extremely weathered. The greater relative input of andesitic and basaltic tephra from the not too distant Tongariro, Taranaki, Alexandra and Auckland volcanic fields also increases the rate of weathering. Rhyolitic ash weathers at a much slower rate than its more mafic counterparts and therefore tephra of similar age in areas of less relative mafic/silicic deposition are much less weathered, and have more primary physical characteristics preserved and available for identification purposes.

2-3.1 Kauroa Ash

The Kauroa Ash Formation [Ward, 1967] was defined as the 17 oldest ash beds at the Woodstock Farm section near Raglan on the west coast of the North Island. It is separated from the overlying Hamilton Ash Formation by an erosional unconformity. The lowermost Kauroa Ash bed is considered to have an age of 2.25 Ma due to its close association with K-Ar dated basaltic tuffs erupted from the nearby Alexandra Volcanic Field [Briggs *et al.*, 1989]. The topmost Kauroa Ash bed — the Waiterimu Ash [Ward, 1967], is believed also to be much older than the tephra studied in this work, and the Kauroa Ash Formation is therefore not represented in the eastern Bay of Plenty.

2-3.2 Hamilton Ash

The Hamilton Ash Formation [Ward, 1967] was defined as all those tephra in the Waikato region that lay above the older Kauroa ashes. Ten beds were recorded, but the top few tephra were recognised as the Kawakawa and Rotoiti Tephra [Pain, 1975], and later workers have used the formation name to describe the weathered tephra found between the Rotoiti Tephra and Kauroa Ash Formations.

The basal layers of the Hamilton Ash Formation (Ha-1 & Ha-2) were designated the Ohinewai Tephra [Ward, 1967]. This tephra has been described as two variants with differing characteristics caused by differential weathering under two separate weathering regimes. The "Te Uku" variant (Ha-2) is strongly weathered, and the original structure of the parent tephra is almost completely destroyed. It has large halloysite nodules near the base and the base itself is generally cemented to a depth of up to 5 cm with manganese-stained halloysite. The cemented base envelopes a layer of abundant crystals, which is a characteristic feature of the Ohinewai Tephra wherever it is seen. The "Huntly" variant (Ha-1) has undergone much less weathering, and the paleosol is not far advanced below the middle of the bed. The crystal-rich base grades into finer clayey material above, suggesting that the tephra underwent gravitational sorting while airborne [Ward, 1967]. A possible alternative explanation for the presence of a crystal-rich base is a coarse grained crystal-rich plinian eruption followed by a fine grained, crystal-depleted co-ignimbrite ash, as described by Sparks & Walker [1973]. The Ohinewai Tephra has been correlated via glass chemistry to the Rangitawa Tephra [Froggatt *et al.*, 1986; Kohn *et al.*, 1992], which is the airfall component of the voluminous, crystal-rich Whakamaru Ignimbrite eruption, dated at *c.* 350 ka.

Attempts were made to correlate the Ohinewai Tephra across the Waikato region and into the Bay of Plenty. A weathered tephra with similar characteristics to the Te Uku variant of the Ohinewai Tephra was recorded in several sections along the coast of the Bay of Plenty, from Sapphire Springs (near Tauranga) to Opape (near Opotiki) [Vucetich *et al.*, 1978]. This tephra occurs at the base of the "undifferentiated brown tuffs" (or ashes) [Pullar *et al.*, 1973], a sequence of extremely weathered tephra which directly underlies the Rotoiti Tephra in Bay of Plenty coastal sections. The undifferentiated brown ashes were thought to be equivalent to the Hamilton Ash Formation, and from its stratigraphic position relative to marine terraces and other tephra, an age of 150 ka was suggested for the basal tephra.

Later research rejected this correlation with the Ohinewai Tephra, and the weathered tephra in the Bay of Plenty was renamed tephra "X" [Vucetich *et al.*, 1981]. However, much work was published using the name "Hamilton Ash" for the "undifferentiated brown ashes" [Selby *et al.*, 1971; Chappell, 1975; Hull, 1977; Vucetich *et al.*, 1978; Kirkman & Pullar, 1978; Harmsworth, 1983].

The miscorrelation occurred at a section at Puketirau [Paul Froggatt, pers. comm. 1993]. The erroneous correlation was based on degree of weathering and "expected" thickness [Vucetich *et al.*, 1981] of the tephra. The airfall Ohinewai Tephra (named the Aratora Tephra in this area) was expected to be present at this site, but was instead represented by an ignimbrite (Puketirau Tephra/Ignimbrite = Whakamaru Ignimbrite = Ohinewai Tephra). Tephra "X", which has similar characteristics to the Aratora Tephra (= Ohinewai) in this area, was misidentified as the Aratora here, and thence correlated to the Tauranga area and across the coastal Bay of Plenty.

Because of the lack of outcrops between the Waikato area and Puketirau, "hand over hand" field mapping (i.e. correlations from one site to another nearby site, and from there to the next, and so forth) was not possible. Glass chemistry — if the tephras are not too weathered — can be an invaluable aid in situations such as these.)

2-3.3 Pahoia Tuffs

The term "Pahoia Tuffs" [Pullar *et al.*, 1973] was used to describe the weathered tephtras underlying the undifferentiated brown tuffs in the coastal Bay of Plenty region. These tephtras were described as pale coloured tuffs with the basal bed at the type locality resting on volcanic rock. Fifteen beds, with a total thickness of 20 m, and two marked unconformities make up the Pahoia Tuffs at its type section [Hull, 1977].

Harmsworth [1983] used the name "Pahoia Tephtras" for all the tephtras in the Tauranga basin found below the "Hamilton Ash Formation" (see above), and suggests that they may possibly include some correlatives of the Kauroa Ash Formation. The Pahoia Tephtras around Tauranga are intercalated with fluvial sediment and include pyroclastic flow deposits. They differ from the overlying ashes by their much paler yellow and grey colours. The Hamilton Ash/undifferentiated brown tuffs have dark brown, red, and orange colours.

Most of the tephtras described in Chapters 6 to 13 are thought to be within the time range encompassed by the Pahoia Tuffs, and this work details the individual eruptions found within this portmanteau unit. Unfortunately, the type section for the Pahoia Tuffs was not found by this worker (incorrect grid reference in Harmsworth, 1983) and hence they were not directly studied. Harmsworth [1983] describes fourteen Pahoia Tephtras in a section at Omokoroa: "Oa" (base) to "On" (top). Here they are very weathered and few primary characteristics remain which may enable identification and correlation to other sites.

2-3.4 Little Waihi Formation

Chappell [1975] defined tephra deposits of similar age to the Pahoia Tephra in his studies of marine terraces and uplift rates along the coastal Bay of Plenty well to the east. The Little Waihi Formation was described as a 40 m thick, near-source volcanic deposit, containing several very thick pumiceous beds with some very large lithics within them. Erosional boundaries are common and there are well bedded — "banded" — tephra at the top. The base of the Little Waihi Formation overlies an erosional unconformity into bedded pumiceous silts and sands, named the "undifferentiated pumice beds" [Chappell, 1975].

Further work revealed the fluvial nature of much of the Little Waihi Formation, and it was subdivided into the Upper Little Waihi Formation and the Newdicks Tufts (lower part) [in Hull, 1977]. The two units are separated by an erosional unconformity, and the undifferentiated brown ashes (erroneously called the Hamilton Ash) occur above.

The above formations were used in attempts to correlate marine terraces along the Bay of Plenty coast [Chappell, 1975]. However, difficulties occur when fluvial deposits are used for lateral correlations across large distances, as they are generally confined to channels and have very irregular distributions and thicknesses. Airfall tephra which mantle the landscape are much more reliable marker beds.

2-3.5 Tablelands Tephra Formation

In the eastern Bay of Plenty, near Opotiki, several sections exposing many "older" tephra and paleosols can be found. The Tablelands Tephra Formation [Iso *et al.*, 1982] was defined, specifically from a section on Tablelands Road [W15/887462], as "the airborne volcanic ash deposits that are disconformably overlain by the Hamilton Ash [actually the undifferentiated brown ashes] and conformably overlie the Ohiwa gravels".

The Ohiwa gravels [Chappell, 1975] are weathered gravels which occur in many sections (generally at the base) throughout the eastern Bay of Plenty. However, the amount of weathering and the stratigraphic position of this unit varies from section to section and the gravels cannot be used as a reliable stratigraphic marker. The Waiotahi gravels described in this work are a correlative of a part of the Ohiwa gravels whose stratigraphic position is consistent and understood.

The Tablelands Tephra Formation was further divided into upper and lower members. Fission-track ages of between 0.18 and 0.21 Ma were obtained for several tephra layers belonging to the lower member of the Tablelands Tephra Formation [Iso *et al.*, 1982], but incorrect correlations between sites casts doubt on which tephra were actually dated.

Miscorrelations and a lack of detailed descriptions of the tephra within it make the Tablelands Tephra Formation almost worthless as guide to more detailed tephra studies in the eastern Bay of Plenty. The formation is an equivalent to the Pahoia Tufts (Tephra) found in the western Bay of Plenty.

2-4 Distal Taupo Volcanic Zone Eruptives in Pleistocene Sedimentary Basins

The Wanganui Basin has a good record of Taupo Volcanic Zone tephra layers which have been used to correlate marine terraces found throughout the area. The ages of these distal tephra layers are very important in establishing the regional stratigraphy and therefore many researchers have studied the tephrostratigraphy of this region.

Similar basins in the Hawkes Bay and Wairarapa regions also contain sections showing distal T.V.Z. eruptives. Fluvially reworked tephra layers are common, as well as primary airfall and occasional ignimbrites (e.g. Potaka Ignimbrite [Shane, 1993]). The major tephra layers found in these and other distal areas are summarised in Table 2-4. Many of the minor tephra layers are not included.

Table 2-4 : Pleistocene tephra layers found in distal sedimentary basins.

Tephra	Age (Ma)	Ref.	Tephra	Age (Ma)	Ref.
Kawakawa T.	0.022	8	Kaukatea Tephra	1.006 ± 0.021 [#]	11
T-6		8		0.57 ± 0.08 [^]	4
Rangitatau T.	c. 0.24-0.30	10	= Kidnappers-(B) T.	1.098 ± 0.105 [#]	13,9
Upper Griffin Rd. T.	?	8	= Mt Gordon Tephra	0.56 ± 0.16~	6
Middle Griffin Rd. T.	?	8	Potaka Tephra	1.05 ± 0.05 [†]	12
Lower Griffin Rd. T.	?	8		1.001 ± 0.011 [#]	11
Fordell Tephra	c. 0.32	10		0.64 ± 0.18~	6
Mt Curl Tephra*	0.34 ± 0.03~	10		0.61 ± 0.06 [^]	4,2
	0.24 ± 0.05~	7	= Kidnappers-(A) T.	1.073 ± 0.050 [#]	13,9
	0.23 ± 0.06~	6	= Kidnappers T.	0.85 ± 10 [^]	3
	0.23 ± 0.03 [^]	1	T-128	1.237 ± 0.069 [#]	11
= Rangitawa Tephra	0.35 ± 0.04 [†]	12	Rewa Tephra	1.429 ± 0.056 [#]	11
	0.35 ± 0.04~	10		0.74 ± 0.09 [^]	4,2
	0.37 ± 0.05~	7	Mangapipi Tephra	0.88 ± 0.13 [^]	4,2
	0.39 ± 0.01 [^]	5	Ridge Tephra	1.04 ± 0.15 [^]	4,2
	0.38 ± 0.04 [^]	4,2	Pakihikura Tephra	1.63 ± 0.15 [†]	13
Kidnappers-(F) T.	?	9		1.656 ± 0.025 [#]	11
Kidnappers-(E) T.	?	9		1.06 ± 0.18~	6
Kidnappers-(D) T.	0.877 ± 0.034 [#]	11,9		1.26 ± 0.12 [^]	5
= Trig. N Tephra	0.32 ± 0.07 [^]	3		1.06 ± 0.16 [^]	4,2
Kidnappers-(C) T.	c. 0.9	13,9	Mangahou Tephra	1.26 ± 17 [^]	2
=Rabbit Gully T.	0.37 ± 0.10~	6	Ohingaiti Tephra	1.78 ± 0.44~	6
	0.36 ± 0.08 [^]	3		1.50 ± 0.21 [^]	4,2

[#] = ⁴⁰Ar/³⁹Ar; ~ = FT zircon; [^] = FT glass; [†] = ITPFT glass

* References for Table 2-4

1 = Milne, [1973]	8 = Pillans, [1988]
2 = Seward, [1974]	9 = Black, [1992]
3 = Seward, [1975]	10 = Kohn et al., [1992]
4 = Seward, [1976]	11 = Shane, [1993]
5 = Boellstorff & Te Punga, [1977]	12 = Alloway et al., [1993]
6 = Seward, [1979]	13 = Shane, pers. comm. [1993]
7 = Pillans & Kohn, [1981]	

As shown in Tables 2-2 & 2-4, fission track dating of glass shards has given consistently younger ages than those obtained by other methods. Many of the ages produced were later found to conflict with paleomagnetic data from the same units. Problems with annealing of the tracks and of under- or over-etching have gradually been recognised [Seward, 1979; Naeser *et al.*, 1981] and much of the early results are now suspect. Generally the results have erred on the young side, and therefore the early fission tracks on glass can be used as minimum ages only.

Recently, the iso-thermal plateau fission track (ITPFT) dating technique has been developed [Westgate, 1989] and appears to have remedied the problems of both under-etching and annealing. ITPFT ages are similar to those obtained by the $^{40}\text{Ar}/^{39}\text{Ar}$ isotopic dating method, indicating that the ITPFT technique is reliable.

Fission track dating on zircons has in the past also produced ages that are too young, but calibrating the samples with a well dated standard of similar age [Kohn *et al.*, 1992] produces ages in agreement with other dating techniques.

Correlations of the distal airfall tephra to the more proximal ignimbrite deposits found throughout the Central Volcanic Region have been difficult to attain. Due to the patchy preservation of both the ignimbrites and the airfall tephra, complete sections showing the entire stratigraphy do not exist. Chemical correlations have been attempted [Kohn, 1973; Froggatt, 1983; Shane, 1993], but welded (and semi-welded) ignimbrites have generally undergone a great deal of hydrothermal alteration and little material is found with its original chemistry intact.

The exceptions to this rule occur where a plinian airfall tephra is found preserved immediately below an ignimbrite flow unit deposited as part of the subsequent stage of the eruption. Usually the airfall layer is not observed due to lack of exposure, or because when ignimbrites are emplaced, they often erode deeply into the underlying, less consolidated material. Nevertheless, where this airfall layer is present, glass can be extracted from the often unaltered pumices and compared with distal tephra elsewhere in the country.

An example of this is the comparison of unaltered pumices obtained from the base of the Whakamaru Ignimbrite eruption, perhaps the largest eruption in the mid to late Pleistocene, to glass shards in distal airfall deposits. The unaltered glass chemistry of the Whakamaru eruptives matches that of an extremely widespread tephra layer which is found at over thirty localities throughout the country. Many different names for this tephra unit have been published; the more significant of these being the Ohinewai Ash, Rangitawa Pumice and Mt. Curl Tephra.

The Rangitawa Tephra was proposed as a name for this tephra due to historical precedence [Kohn *et al.*, 1992], and all other names have now lapsed. The age of the Rangitawa Tephra is within the error of that of the Whakamaru Group Ignimbrites, and is now accepted as a correlative of the whole or part of this group.

2-5 Tephras from the Taupo Volcanic Zone found in Deep Sea Sediments

Cores of deep sea sediment were taken to the east and northeast of New Zealand during the mid 1960's and early 1970's (see *Watkins & Huang, 1977* for locations) and several macroscopic, and many more microscopic, rhyolitic tephra layers were recorded [*Ninkovich, 1968; Watkins & Huang, 1977*]. On the basis of their distribution pattern, the tephras in these cores are thought to have erupted from New Zealand. The sediments were originally dated using their paleomagnetic record and inferred sedimentation rates, though fission track ages on glass were later produced [*Kohn, 1973; Seward, 1974*].

Recent advances in dating with $^{40}\text{Ar}/^{39}\text{Ar}$ has led to a new age estimate for the Brunhes/Matuyama paleomagnetic boundary of 0.78 Ma [*Baksi et al., 1992; Spell & McDougall, 1992*]. This replaces the previously accepted age of 0.73 Ma, causing an adjustment to the sedimentation rates. The estimated ages of these tephras have therefore been revised upwards (older).

Chemical analyses of glass shards taken from the deep sea cores have been compared with those from onshore sequences [*Froggatt, 1983; Shane & Froggatt, 1991*] and possible correlations have been obtained.

The rhyolitic tephra layers in the deep-sea cores, together with their original [from *Ninkovich, 1968; Kohn, 1973*] and revised ages, and their chemical correlatives [from *Froggatt, 1983; Shane & Froggatt, 1991; Black, 1992; Shane, pers. comm. 1993*], are summarised in Table 2-5.

Table 2-5 : Pleistocene rhyolitic tephras in deep sea sediments.

deep-sea cores				old age (Ma)	revised age (Ma)	tephra correlation	tephra age (Ma)
RC9-110	RC9-113	RC9-114	RC12-215				
—	—	B6?	B6?	—	—	Taupo Tephra	0.002
—	—	B5	B5	—	—	?	—
F	—	B4	B4	—	—	Kaingaroa Igb.	0.24
E	E	B3	B3	0.27	0.29	Matahina Igb.	0.28
D	D	B2	B2	0.31 0.32 ± 0.05 [^]	0.33	Rangitawa Tephra	0.35 ± 0.04
—	C	B1	B1	0.67	0.72	?	—
—	B	M6	M6	0.73	0.78	Kidnappers-C) T.	—
—	A	—	M5	0.86 0.88 ± 0.16 [*]	0.92	Potaka Tephra	1.00 ± 0.01
—	—	—	M4	1.07 1.01 ± 0.12 [^]	1.14	Ahuroa Igb. [#]	1.19 ± 0.03
—	—	—	M3	1.13 1.15 ± 0.23 [*]	1.21	Ongatiti Igb. [#]	1.23 ± 0.02

* = fission-track (glass) [*Kohn, 1973*];

[^] = fission-track (glass) [*Seward, 1974*];

[#] correlated by age and paleomagnetic data only, no chemical data available.

Chapter Three : Tephra Identification Methods

The tephra in this study have been identified and correlated using several different techniques, both physical and geochemical. The various methods are listed below in order of their usefulness and importance in this study:

- physical characteristics of each eruptive;
- stratigraphic relationships to the surrounding units;
- microprobe geochemistry of the glass shards found in each eruptive;
- microprobe geochemistry of the titanomagnetites found in each eruptive;
- microprobe geochemistry of the primary minerals found in each eruptive;
- ferromagnesian mineral assemblage of each eruptive.

Each method of identification, with examples, is discussed in detail below.

3-1 Tephra Correlation using Physical Characteristics of Tephra

Several tephra in the eastern Bay of Plenty have very distinctive physical characteristics which are not duplicated by any other eruptives in this area. These tephra can be tentatively identified by their physical characteristics alone, and can be positively identified in conjunction with any other tephra above or below which also have distinctive features.

The tephra with distinctive features can then be traced from site to site and the stratigraphy of the units above and below, which are not as distinctive, can be developed.

The physical characteristics studied for each tephra consist of:

- bedding;
- thickness;
- abundance and types of lithics and free crystals;
- clast size, including lithics and crystals;
- colour;
- sorting of the deposit;

continued over...

- dominantly glass shards or pumiceous;
- weathering.

Also used in conjunction with the physical characteristics, but not included within this method, are the stratigraphic paleoclimatic indicators (see sect. 3-3).

Generally all the above features are used together to develop a unique picture of how each individual tephra appears in the field. The characteristics of each tephra in this study are presented in the chapters detailing the individual eruptives (Chapters 6 to 13), listed under the heading "Diagnostic Features".

The diagnostic features are generally only applicable to the eastern Bay of Plenty region, and in other areas (e.g. on a different dispersal axis) the tephtras may show different characteristics. Widespread correlations require additional techniques also, but the development of the stratigraphy must come first, and for this the physical characteristics of the tephtras are the most useful.

3-1.1 Bedding of the deposit

The types of bedding found in the eruptives and the relative thickness of each layer are the most important physical features for identification purposes. The characteristics to look for are:

- the presence or lack of bedding (i.e. massive), and how easily is it seen;
- how well bedded: many thin beds or only a few thicker beds;
- how well defined: sharp contacts or gradational;
- the presence of reverse or normally graded beds;
- shower bedding;
- parallel or wavy bedding, pinch and swell features, or even cross-bedding.

Cross-bedding usually indicates subaqueous deposition which may disguise other physical characteristics and increase the chance of a mixture of glass shards. Pinch and swell features may indicate a surge or pyroclastic flow deposit. "Shower bedding" can be prominent or vague, and is indicative of airfall deposits.

The Mangaone, Rotoiti, Opotiki–Torere-I, and Kohioawa Tephtras are examples of how bedding can be used to distinguish between tephtras.

The Mangaone Tephra is strongly reverse graded, with a four-fold increase in clast size from base to top. The Rotoiti Tephra has many thin beds in its lower half and a massive slightly shower bedded upper half. The Opotiki and Torere-I Tephtras together form one stratigraphic unit with five separate beds that can be traced individually across much of the coastal Bay of Plenty. The Kohioawa Tephra can be divided up into four separate units, which again can be traced individually across much of the coastal Bay of Plenty.

3-1.2 Thickness

The thickness of the deposit is related to the volume of the eruption, dispersal direction, and distance from source. Deposition in a subaqueous environment may cause some over-thickening of the deposit and such sections should be used with care. Tracing the thickness from site to site can indicate the direction of source, and/or whether any erosion has occurred.

The Matahina and Kohioawa Tephra can occasionally be tentatively identified by their thickness alone as few others tephra in the eastern Bay of Plenty are as thick as these.

3-1.3 Abundance and types of lithics, and free crystals

Some tephra contain abundant lithics (e.g. Matahina, Anaputa), whereas others are almost lithic free (e.g. Huntress-B). A few deposits, such as the Otarawairere Tephra, contain many visible crystals, either free in the deposit, or within pumices. There is considerable variation in the types of lithics in different eruptives. The Anaputa and Bonisch Tephra contain abundant chunks of black obsidian, while the lithics in the Matahina and Hiwarau Tephra are composed of grey rhyolite. Quartz and plagioclase generally dominate the large crystal fraction, but the Jackson and Ohiwa-B Tephra also contain very large hornblende crystals.

3-1.4 Clast size, including lithics and crystals

Clast size is generally related to the distance from the eruptive source, but within each area there are some tephra that contain very large pumices (e.g. Hiwarau, Matahina), while others are composed of fine ash (e.g. Torere-A, Ohiwa Hill). As well as indicating distance from source, the size of the lithics and crystals can be useful in tephra identification; for example, Matahina lithics are very large, and the Otarawairere and Jackson Tephra contain very large crystals.

3-1.5 Colour

The individual layers within a tephra may have unusual and distinctive colours. White is the most common colour of rhyolitic pumice, though pale yellow (Paerata), grey, and cream colours also occur. The ash layers, also, are generally white, but grey (Anaputa), pinkish orange (Matahina, Bonisch), and occasionally reddish (Torere-A) layers do occur. Several of the sandy ash layers within the Opotiki Tephra have different colour shades of grey and buff, possibly related to grain size, sorting, and the proportion of shards. The presence of black obsidian within a white pumice layer can create a speckled appearance (Anaputa), and the presence of many grey lithics may cause the entire unit to appear this colour rather than white.

Weathering may also influence colour. Several very weathered tephra have a ginger/orange-brown colour (e.g. Kutarere, Tirohanga), while others weather to become a bright white clay (e.g. Hiwarau, Ohiwa-B).

In contrast to these, basaltic tephra are generally black, and andesitic tephra brown.

3-1.6 Weathering

Some tephra, such as the Tirohanga, are extremely weathered, while others are pristine and totally unweathered (e.g. Opotiki). Weathering often affects the colour of the deposit, almost always affects the grain-size, and occasionally alters the mineral assemblage and glass composition. Most of the terrestrially deposited Ohiwa Harbour subgroup tephra have undergone extreme weathering in the past, with no glass remaining in the deposit, all of it having altered to clay. Even the minerals have suffered; the biotite contains many holes, has wavy (rippled) surfaces, and is gold in colour rather than black. The hornblende is strongly etched and eroded, rather than smooth and reflective, and although hypersthene is likely to have been present originally, there is no trace of it in the present day.

The formation of clay can alter the original physical characteristics of a tephra. As the glass in the larger pumices alters to clay, the pumices decompose under pressure and the tephra becomes finer grained and much thinner (e.g. Hiwarau). No coarse pumice can be seen in very weathered tephra deposits even though pumice is known to survive for some time within paleosols.

In weathered tephra that still contain glass, the analytical totals of the glass analyses are generally lower, probably due to greater hydration.

The presence or lack of paleosols in the top of the tephra, and their thickness if present, can be a useful diagnostic feature. Paleosol development, however, varies from site to site due to climatic and local topography influences and must be used cautiously.

3-1.7 Sorting of the deposit

Generally, pyroclastic flows are very poorly sorted, while airfall deposits are quite well sorted, though some are better sorted than others. The Opotiki and Hiwarau Tephra have very good sorting, the Matahina and Paerata Tephra moderate sorting, and the Ruatuna-D and Kohioawa-2 Tephra layers are poorly sorted.

3-1.8 Shard / pumice ratio

Most of the tephra in this study are pumiceous, containing clasts — both small and large — that are highly vesicular. Some eruptives, however, are composed almost entirely of glass shards (e.g. Opotiki, Reid's Reserve). The matrix of pyroclastic flows are also composed predominantly of glass shards.

3-2 Tephra Correlation using Stratigraphic Relationships of the Surrounding Units

Even if a tephra has few distinguishing physical features, and no glass from it has been analysed, it can still be tentatively identified by its stratigraphic position alone. The requirement for this is that the stratigraphic position of the surrounding tephra is known, and that they can be identified. If at all known sites where a particular stratigraphic position is seen, only one tephra, "B", exists between two chemically or physically distinctive tephra, "A" and "C", it is likely that at another site where only one tephra is seen between two tephra identified as "A" and "C", the unknown unit is tephra "B". The Torere-L Tephra was often identified in this way, using the distinctive glass chemistry of the tephra which bracket it.

In addition, the paleoclimatic indicators; such as whether the tephra is contained within loess (e.g. Huntress-B, -C, & -D) or has loess above only or below only, or whether the tephra rests on a paleosol and/or has a paleosol developed into it; can be very useful for tephra identification.

3-3 Microprobe Geochemistry of Glass Shards

After using the physical features to identify the major eruptives and develop the stratigraphy, each tephra unit was chemically "fingerprinted". This involved analysing ten or more glass shards from each eruptive to determine a mean composition. The chemical "fingerprint" was then used to identify tephra which have few other distinguishing characteristics, or to correlate entire sections in other regions, where the physical characteristics of the tephra may be different. In distal areas where the tephra layers are very thin, chemical fingerprinting may be the easiest, or the only means of correlation. The history of using glass chemistry for the correlation of eruptives is reviewed below. The technique used in this study is also presented, with some examples.

3-3.1 Review of the use of glass chemistry for correlations

Researchers in the 1950's, 1960's, and 1970's attempted to chemically fingerprint and correlate eruptions using both major and trace element geochemistry on bulk rock samples. However, the heterogeneity of bulk rock samples can render this technique to be inaccurate.

The first volcanic deposits from the T.V.Z. to be studied in detail were the large ignimbrite sheets that formed the plateaus of the central volcanic region. Ignimbrites, however, are often extremely heterogeneous, being mobile fluidized masses that tend to segregate components in response to their size and density, the larger pumices rising and the denser crystals and lithics sinking. Further complications occur where several flows and/or surges of differing size, velocity and fluidization have been deposited during the same eruption. The use of mineralogical and chemical analyses of bulk whole rock samples is therefore highly dependent upon where the sample was taken from; for example, a lithic lag layer,

pumice concentration zone, or crystal rich layer. Also, any lithics of wall rock or entrained country rock included within the sample will not represent the eruption magma composition, but that of a previous eruption, perhaps from a different source. Inclusion of this extraneous material within the bulk sample will alter the chemical composition away from that of the primary magma and affect possible correlations to other deposits.

The above problems also occur to a lesser extent when using airfall tephtras instead of ignimbrites. They too are not completely homogeneous and the distal deposits have been subjected to sedimentary fractionation [Westgate & Gorton, 1981].

A further difficulty is that, as ignimbrites are emplaced hot, they often undergo vapour phase alteration of the glass and minerals. In such cases the more mobile elements, especially iron and sodium, are depleted, and others, especially potassium, enriched. The use of selected pumices from ignimbrites removes most, but not all, of the inhomogeneity problems. It does not, however, remove the possibility of alteration, or of compositional zoning [Hildreth & Mahood, 1985].

In many respects especially where chemistry is involved, the airfall tephtras are better to study than ignimbrites. The use of a pure glass separate, derived from airfall ash and/or pumice, for chemical comparisons between tephtra layers solves many of the above problems. Volcanic glass is formed from the rapid quenching of magma with little or no crystallisation of mineral phases, and thus should be representative of the bulk geochemistry of the magma at the time of eruption. As a result, the glass chemistry within a single eruption is usually either approximately homogeneous, or defines a distinct trend [Westgate & Gorton, 1981].

Analyses of glass separates have been carried out with some success using a number of techniques including X-ray fluorescence, atomic absorption, and neutron activation analysis [Borchardt *et al.*, 1971; Cormie *et al.*, 1981]. However, bulk glass analyses are problematic in that the shards inevitably contain inclusions and microlites, there may be detrital glass reworked from older eruptives (although this is rare), and the possible occurrence of foreign particles and weathering products on the surface of the shards and pumice [Westgate & Gorton, 1981]. Further problems occur where layered and mixed magma chambers exist, and when two different eruptions are occur simultaneously.

The grain discrete method, which uses an electron microprobe to analyse individual glass shards, eliminates most of the inhomogeneity problems, as different chemical populations of glass within the sample can be identified and characterised [Smith & Westgate, 1969]. Microprobe analyses on glass shards have been used very successfully throughout the world to characterise, identify, and correlate tephtras and tephtric deposits.

The use of microprobe chemical analysis on discrete glass shards obtained from the basal unwelded parts of pyroclastic flows, and also from the plinian airfall tephtras occasionally found beneath them, has enhanced the correlation of many New Zealand ignimbrites [Froggatt, 1983]. It has also enabled the correlation of several distal airfall tephtras to these ignimbrite deposits [Shane & Froggatt, 1991; Shane, 1993]. However, only the largest eruptions deposited material in the distal areas. Many more eruptions occurred in which the tephtras were deposited only in areas relatively close to source. Exposures of these

less widely distributed tephra are not common near source due to the great thickness of the younger deposits above. They are generally only seen where there has been a large amount of erosion, and the ignimbrites have acted as protecting "cap rocks". Such sections are rare, however, and the best overall stratigraphic record is found in the near distal areas downwind from source — just beyond the range of the thick welded ignimbrite deposits — where the overlying airfall deposits are much thinner. The coastal Bay of Plenty region is therefore one of the best areas in which to study the older tephra from the T.V.Z.

3-3.2 Analytical procedure

The methods used for field sampling and to obtain a glass separate from the bulk sample are the same as those outlined in Froggatt & Gosson [1982]:

- The samples were generally taken from the lower third of the deposit to remove the possibility of contamination due to æolian reworking and soil development processes. The coarser units were also preferentially sampled to avoid the incorporation of xenolithic material which is more likely to occur in the finer, more fragmented material.
- Several to many pumice lapilli were selected (depending on size), washed, and crushed using a porcelain pestle and mortar. The resultant material was periodically removed for wet-sieving through nylon cloth until almost all of the material had been crushed to $<250\text{ }\mu\text{m}$, and the 63–250 μm fraction (2–4 f) was retained. If the tephra sample did not contain lapilli then the whole sample was wet-sieved first and the material $>250\text{ }\mu\text{m}$ crushed so that the 63–250 μm fraction was representative of the entire sample greater than silt size. In some instances, especially if the tephra was very fine, only the initial sieve fraction was retained and the $>250\text{ }\mu\text{m}$ fraction, if any, was not crushed and hence not used. An ultra-sonic probe was used to break up aggregates in very clay-rich weathered samples. The particular crushing process that each sample underwent is recorded with the glass chemistry analyses for each sample in Appendices-(F) to -(K) (i.e. crushed pumices, crushed total sample, or matrix only).
- The sieved samples were generally oven dried as most were not required for dating. Samples for dating purposes should be air dried only, or have only a short period in a warm oven. After drying, the magnetic fraction (titanomagnetites, ilmenites and Fe-oxides) was separated and collected using a large hand magnet. This step is required so that the very magnetic minerals do not clog the magnetic separator, decreasing its efficiency and ability to split the sample.
- A Frantz Isodynamic Magnetic Separator (initially model L-1) was used to separate out the different magnetic susceptibility fractions. Progressive side slope settings (forward slope constant @ 20°) and varying the amperage produced the following fractions in the more magnetic split:-
 - 20° @ 0.6 A = ferromagnesian minerals, some magnetite and ilmenite, and glass with magnetite inclusions;
 - 15° @ 1.0 A = weathered glass, glass with ferromagnesian inclusions, and weathered biotite;

continued over...

- 5° @ 1.3 A = virtually pure glass.

The non-magnetic minerals, such as quartz and feldspar remained in the less magnetic fraction of the final split.

Halfway through this work the separator was upgraded (model LB-1) and new settings of 0.35 A, 0.55 A, and 1.15 A, all at 20° forward slope and 20° side slope, were used to split the same magnetic susceptibility fractions.

- Microprobe mounts were made with samples of the near-pure glass separate embedded in epoxy resin, ground to ≈0.1 mm thickness and polished. The polished surface was carbon coated to provide a conductive surface.

The Inter-INQUA committee on tephrochronology have made recommendations for the standardisation of chemical analyses of tephra deposits [Froggatt, 1992], and these recommendations have been followed in this work:

- The JEOL-733 "superprobe" (WDS) electron microprobe at the Analytical Facility, Victoria University of Wellington was used for the glass chemistry analysis.
- The first half of this work was carried out as described in Froggatt [1983], using the "Jascal" program, with analytical conditions of 8.0 nA beam current, an accelerating voltage of 15 kV, a 10–15 µm beam diameter, and the mean values of 3×10 second counts at peak position after a peak search. With three spectrometers attached to the microprobe, four runs were required to complete the analysis. However, it was observed that the 3×10 second counts often did not occur at the true peak position for sodium, giving artificially low values for this particular elemental oxide. This problem will be discussed further in section 3-3.3.
- The second half of this work was carried out with the same microprobe, but with updated software which used 12×2 second counts while varying the spectrometer position across the peak and integrating under the curve produced. A beam current of 8.0 nA at 15 kV, and a beam diameter of 10–15 µm was retained. A comparison between the original and updated systems will be discussed in section 3-3.3.
- Glass standards KN-18 (comenditic obsidian), VG-A99 (basaltic glass USNM 113498/1), and VG-568 (rhyolitic glass USNM 72854) were regularly analysed to check for machine drift and to determine whether recalibration was required. Analyses of the standards are presented in Appendix-(E).
- At least 10 individual shards were analysed for each sample, more for samples which showed a mixture of two or more different chemistries. The analyses were normalised, that is recalculated to 100%, with the deficiency from 100% recorded as "water by difference". The analyses were then examined for heterogeneity and any significant outliers were removed before calculation of means and standard deviations.

The analyses are presented in tables of similar format to Table 3-3.1. Each individual analysis (including outliers) is presented in Appendices-(F) to -(K).

Table 3-3.1 : Example of glass chemistry table found in text (Matahina Tephra).

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Huntress Creek	78.55	12.25	0.11	1.03	0.10	0.82	#3.38	3.63	0.19	4.27	9	1.00
**01501	0.37	0.11	0.02	0.07	0.02	0.06	0.16	0.19	0.03	1.15		
Ngatiawa lookout	77.77	12.36	0.19	1.08	0.14	0.91	3.66	3.67	0.23	5.57	10	0.88*
04306	0.27	0.18	0.07	0.10	0.05	0.10	0.13	0.11	0.04	0.63		
Awakeri Springs	77.32	12.55	0.14	1.11	0.11	0.90	3.84	3.75	0.28	4.76	10	0.92*
04404	0.37	0.19	0.04	0.12	0.04	0.08	0.12	0.17	0.04	1.10		
Ngatiawa lookout	78.30	12.24	0.23	1.12	0.15	1.12	3.65	3.03	0.18	6.12	2	0.82*
04306b	0.20	0.12	0.03	0.03	0.04	0.05	0.05	0.10	0.06	0.81		

Notes on Table 3-3.1 / Chemical analyses

- a. All element analyses calculated on a water free basis.
- b. All Fe calculated as FeO.
- c. Water calculated by difference from 100%.

The top line of data from the Huntress Creek site (sample 01501) are the means from nine normalised analyses, plus the water by difference. The second line, immediately below, shows the standard deviations of the data for the nine analyses. The analyses of the sample from Ngatiawa lookout show a mixture of two chemical types, ten analyses of the type Matahina chemistry (04306), and two analyses of something different (04306b).

The far right column shows the similarity coefficients (S.C.) of each sample compared with sample 01501. The "***" symbol denotes the sample that all others in the table are compared with, and which is also generally the type section for the tephra.

If there is a major and a minor component, then the minor component sample number has a "b" added to it (e.g. 04306b), and is placed at the bottom of the table with a single line space between it and the major component analyses above. If there is more than one minor component then a "c" or "d" may be required, also with spaces. If the two different chemistries are present in roughly equal amounts then both an "a" and "b" are used, indicating that there is no major component as such., although "a" is generally slightly more common than "b". The proportion of the different chemical types is calculated from all occurrences of the tephra, resulting in "a" being less common than "b" in some samples. A smaller space (4 point) is used to denote separate flow members within an ignimbrite (e.g. Kaingaroa Ignimbrite-Table 11-1.1), and a larger space (several lines) is used to denote two different eruptives within the same table (e.g. Tables 3-3.2, 3-3.3). Most tables within the text are located on the page facing the text in which they are discussed.

3-3.3 Analytical problems encountered with microprobe analysis

The loss of alkali elements during electron microprobe analysis, especially sodium, and to a lesser extent potassium; and the concomitant increase in the non-mobile elements, particularly silicon [Nielsen & Sigurdsson, 1981; Hunt & Hill, 1993]; is a continuing problem with studies of this sort.

To minimise the loss of Na_2O and K_2O , a defocused beam (10–15 μm) was used, with a relatively low beam current (8.0 nA), and the utilisation of many shorter counts rather than long continuous counts. Na_2O and K_2O were analysed for first to minimise their exposure to the electron beam before measurement. The continuing loss of these elements can be measured by the increase in SiO_2 which was analysed last. Other workers have used larger beam diameters to limit Na_2O loss (e.g. 20 μm *Pillans*, 1988; *Shane*, 1993), but the majority of the glass in this study was highly vesicular with narrow vesicle walls. In many cases a 10 μm beam diameter was barely narrow enough to avoid analysing beyond the shard.

The initial microprobe work used a peak search, then 3×10 second counts which gave Na_2O values ≈ 10 –15% lower than later work. Later analyses used the integrated area under the peak, rather than apparent peak intensity, and was less susceptible to peak shifts.

Those analyses which for any reason had much lower Na_2O values than the other analyses of that sample were deemed to be unreliable and not included in the data set. Analyses with moderately lower Na_2O values have been incorporated into the chemistry of the sample, but if there were many of these lower values the mean of the Na_2O values was significantly reduced. In the chemical data tables throughout Chapters 6 to 13, those samples believed to have artificially low means for Na_2O wt.% have a "#" symbol associated with their Na_2O values (e.g. Table 3-3.1). The acknowledgement of probable Na-depletion allows a more complete understanding of the glass chemistry comparisons between samples, and may explain why some similarity coefficients (marked with "**") are lower than expected for the same eruptive.

The loss of Na_2O during peak search did not occur when analysing the glass standards, perhaps because the thickness of glass in the standards was much greater than in the highly vesicular glass samples from the Bay of Plenty tephtras.

Although the updated peak area (integration) system reduces Na_2O loss and produces more representative sodium values, the updated system appears to produce more variable FeO analyses, and also gives more variable and slightly higher values for TiO_2 . The standard deviations for both these elemental oxides are higher than for the earlier peak height system. The type of analytical program used is recorded for each sample as "(pksearch)" or "{integr}" and presented with the complete analytical data in Appendix-(F).

The loss of Na_2O during the analysis causes SiO_2 , which was the last element oxide to be measured in each run, to have artificially high values after normalisation. The values for SiO_2 throughout this work average ≈ 77 –79%, with all of the tephtras falling into the rhyolitic field, but these values may be 1–3% higher than their real values. Several of the tephtras which have only moderately higher SiO_2 values (e.g. Ohinekoao-E & Ohinekoao-I) may therefore be dacites rather than rhyolites.

The totals for each analysis generally did not add up to 100%, usually being 94–96%, and sometimes much lower (about 91–92%). The low totals are regarded as typical for volcanic glass and thought to be due to hydration [*Smith & Westgate*, 1969]. This was confirmed when samples were heated to 1000° C and the weight loss measured [*Froggatt*, 1983]. The amount of water of hydration can

Table 3-3.2 : Glass chemistry comparison of high and low analytical totals (see water content) for the same tephra — after normalisation.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Kaingaroa Ignimbrite											
Old Waiotapu Rd	78.42	11.98	0.14	1.15	0.10	0.84	3.47	3.74	0.17	0.76	11
06101	0.15	0.08	0.03	0.10	0.02	0.05	0.10	0.11	0.03	0.46	
Reihana Road	77.65	12.21	0.19	1.21	0.12	0.83	3.67	3.86	0.27	6.16	7
06213	0.27	0.16	0.07	0.19	0.02	0.09	0.08	0.17	0.05	1.18	
Huntress-D Tephra											
Huntress Creek	77.70	12.53	0.14	1.23	0.11	0.84	3.68	3.59	0.18	5.86	12
01510	0.30	0.19	0.03	0.09	0.03	0.06	0.10	0.14	0.04	0.69	
Hiwarau	78.37	11.94	0.15	1.22	0.12	0.87	3.54	3.62	0.18	2.85	12
02712	0.37	0.13	0.05	0.12	0.02	0.05	0.12	0.16	0.03	1.24	
Otarawairere Tephra											
Tablelands	78.42	12.21	0.10	0.82	0.09	0.71	3.02	4.59	0.15	3.84	9
02106	0.18	0.14	0.01	0.06	0.02	0.04	0.10	0.09	0.02	0.70	
Otarawairere	77.19	12.81	0.11	0.91	0.10	0.70	3.46	4.58	0.21	8.56	11
04110	0.17	0.19	0.03	0.05	0.03	0.05	0.15	0.10	0.04	0.76	

Table 3-3.3 : Glass chemistry comparison of pumice and obsidian from the same eruptions.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Anaputa Tephra											
Anaputa Point	77.61	12.53	0.16	1.27	0.17	1.24	3.59	3.28	0.17	3.07	9
00502	0.20	0.14	0.04	0.09	0.01	0.06	0.17	0.11	0.02	0.96	
Anaputa Point obs.	77.47	12.42	0.16	1.37	0.16	1.25	3.69	3.35	0.14	-0.65	9
00503	0.14	0.23	0.03	0.11	0.01	0.05	0.13	0.11	0.03	1.09	
Huntress Creek	76.39	13.08	0.18	1.46	0.19	1.25	3.90	3.31	0.24	5.01	13
01523	0.22	0.13	0.04	0.11	0.05	0.06	0.13	0.10	0.04	0.97	
Murupara-E Tephra											
Pahekeheke	78.53	12.18	0.10	0.98	0.09	0.75	3.41	3.83	0.17	5.74	17
00402	0.24	0.08	0.02	0.07	0.02	0.05	0.21	0.18	0.02	0.97	
Anaputa Point	78.10	12.21	0.09	1.04	0.09	0.79	3.68	3.91	0.15	-0.29	13
00504	0.21	0.09	0.01	0.06	0.02	0.04	0.12	0.10	0.02	0.46	

vary areally for a single tephra and therefore normalisation of the data is required before correlations between sites can be attempted [Froggatt, 1992].

Hunt and Hill [1993] disagree, and suggest that such high water contents may be associated with selective leaching of the glass, consequently altering the primary geochemical fingerprint, and rendering the glass chemistry correlation technique non-viable. They also suggest that normalisation is undesirable due to the fact that in any vertical sample inhomogeneity will affect X-rays of differing energy to varying degrees, such that each element would require a unique (and indeterminable) 'normalisation' operation. They propose that analytical totals below 95% be discarded, and that totals >98% be preferred.

In this study, however, only about half of the glass analyses had analytical totals of >95%, and very few >98%. A few tephra samples contained fractions with both high and low analysis totals, and after normalisation they retained, or even increased their chemical homogeneity. Tephtras identified as being the same on physical and stratigraphic grounds, but having differing analytical totals, were also found to be chemically indistinguishable after normalisation (see Table 3-3.2, and Table 8-3: Murupara-C Tephra for one of the better examples). The only differences that can be seen are slightly lower SiO₂ and slightly higher Al₂O₃ values for the samples with lower totals. These two element oxides are of lesser importance in the chemical correlation techniques used in this study and hence the correlations achieved are not believed to be significantly affected. Two non-vesicular obsidian samples were also analysed; one from lithics within the pumiceous Anaputa Tephra airfall (00503), and the other part of an obsidian dome stratigraphically and chemically correlated to the Murupara-E Tephra (00504). Both of these samples gave totals of >100%, with the percentage over 100% due to either; the increase over time of the SiO₂ wt.% (due to loss of Na₂O) during analysis, or slightly inaccurate SiO₂ calibration. The vesicular pumice — from the tephtras in which the obsidian lithics were sampled — had much lower totals, but upon normalisation chemically matched the non-hydrous obsidian (Table 3-3.3). Generally the younger post-Rotoiti tephtras had much higher totals (c. 96–98%) than the older deposits, which suggests that age is an important factor in the analytical totals, as would be expected if the low totals were due to post-depositional hydration.

The results cited above indicate that the variation in totals is most likely the result of either the amount of volatiles in the melt together with the amount of post-depositional hydration, or the varying thickness of the vesicular glass shard walls. X-ray generation occurs beneath the sample surface in a pear-shaped volume which, in thin grains, may encompass the mounting epoxy or "empty" subsurface vesicles [Hunt & Hill, 1993]. Other possible reasons for low totals are if the carbon coating is too thick or too thin, or if the shard surface contains scratches, cracks, pits or surface relief. Areas of such surface irregularity could be and were avoided in this work, but as the majority of the glass found in the Bay of Plenty was highly vesicular and the vesicle walls narrow, vesicularity may be the major cause of the low totals.

As the normalisation procedure produced chemical results which agree well with correlations based on stratigraphic positions and physical characteristics, all data have been normalised throughout this thesis. The original (raw) total for each analysis (in Appendix-(F)), and for the means (throughout text),

may be found by subtracting the water by difference from 100%. The raw individual elemental oxide values can then be found by multiplying by the raw total %.

Individual analyses with anomalously low totals were not included within the means. All analyses with totals lower than 90% were discarded, except for sample (01518 – Kutarere Tephra) which had few shards and consistent totals of 88–91%. This sample was very weathered, and >95% of the glass had decomposed to clay. Under the electron microprobe a few shards could be seen to be partially altered to clay. Nevertheless, the elemental oxide values after normalisation for the few shards remaining were consistent and realistic, and chemically matched analyses of this tephra from other sites that were less weathered.

Occasionally the analyses of TiO_2 and MgO gave values lower than the microprobe detection limit (generally <0.06% for TiO_2 , <0.04% for MgO), even though the majority of the analyses from the same sample gave values significantly higher (e.g. 0.12% and 0.10% average respectively for most tephtras with this problem). The low analytical values are not believed to represent the true values of the element oxides, and although the means are little changed, the standard deviations become unreasonably high if the values below detection limit were arbitrarily put at 0.00%. These low values were therefore ignored in the calculations of means for the particular element oxides of each tephtra sample (e.g. 12 analyses with 1 below detection limit resulted in a mean calculated from the 11 remaining analyses of that element). The below threshold analyses are denoted as "n.d." (not detected) in the analyses presented in appendices-(F) to -(K).

3-3.4 Correlation techniques using glass chemistry

The comparison of volcanic glass geochemistry for correlation purposes can be carried out in many ways, such as similarity coefficients, coefficients of variation, two component variation diagrams, ternary diagrams, and more recently discriminant function analysis.

The basic premise of glass chemistry correlations is that the chemical variability within a single tephtra is significantly less than the variability between tephtras [Pillans, 1988]. This is usually true, especially when there are few eruptives to distinguish between as is the case in very distal areas [Westgate, 1969; Froggatt, 1983; Sarna-Wojcicki *et al.*, 1987; Pillans, 1988; Busacca *et al.*, 1989; Shane & Froggatt, 1991]. However, when there are many tephtras, the tephtra chemistries often overlap or repeat, making it impossible to correlate tephtras via their glass chemistry characteristics alone. Nevertheless, it is possible to discriminate between many eruptions which have significantly different chemistries and thus cannot be correlatives. Where no significant chemical difference is apparent, the two tephtras may represent the same eruption, or a different event with a similar chemistry. Other data such as stratigraphic position, radiometric age, paleomagnetic orientation, and shard morphology are then required.

Similarity coefficients (S.C.'s) [Borchardt *et al.*, 1972] have been applied successfully in the past to correlate tephtra deposits [Sarna-Wojcicki *et al.*, 1987; Shane & Froggatt, 1991; Busacca *et al.*, 1992]

may be found by subtracting the water by difference from 100%. The raw individual elemental oxide values can then be found by multiplying by the raw total %.

Individual analyses with anomalously low totals were not included within the means. All analyses with totals lower than 90% were discarded, except for sample (01518 – Kutarere Tephra) which had few shards and consistent totals of 88–91%. This sample was very weathered, and >95% of the glass had decomposed to clay. Under the electron microprobe a few shards could be seen to be partially altered to clay. Nevertheless, the elemental oxide values after normalisation for the few shards remaining were consistent and realistic, and chemically matched analyses of this tephra from other sites that were less weathered.

Occasionally the analyses of TiO_2 and MgO gave values lower than the microprobe detection limit (generally <0.06% for TiO_2 , <0.04% for MgO), even though the majority of the analyses from the same sample gave values significantly higher (e.g. 0.12% and 0.10% average respectively for most tephtras with this problem). The low analytical values are not believed to represent the true values of the element oxides, and although the means are little changed, the standard deviations become unreasonably high if the values below detection limit were arbitrarily put at 0.00%. These low values were therefore ignored in the calculations of means for the particular element oxides of each tephtra sample (e.g. 12 analyses with 1 below detection limit resulted in a mean calculated from the 11 remaining analyses of that element). The below threshold analyses are denoted as "n.d." (not detected) in the analyses presented in appendices-(F) to -(K).

3-3.4 Correlation techniques using glass chemistry

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Figure 3-1 : Two separate tephra with single components; Otawairere Tephra (02106) and Opotiki-(2) Tephra (02210)

Figure 3-2 : Single tephra with one outlier shard from the dominant component; Murupara-A Tephra (sample - 04602)

Figure 3-3 : Tephra with a multi-component glass chemical assemblage; Torere-I(1) Tephra (sample - 02709)

Figure 3-4 : Tephra with a wide distribution and no plainly visible individual components; Ohinekoao-M Tephra (sample - 00905)

1992] using glass chemistry. This technique compares each element oxide individually and then the mean of the quotient is used. An S.C. value of 1.00 means that the two chemical data sets are identical.

The similarity coefficient formula is:

$$S.C.(A,B) = \sum_{i=1}^n \frac{R_i}{n}$$

- where S.C.(A,B) = similarity coefficient between analyses of tephra A & B; i = element number; n = number of elements; $R_i = X_{iA}/X_{iB}$ or X_{iB}/X_{iA} , whichever is ≤ 1.0 ; X_{iA} = concentration of element i in sample A; X_{iB} = concentration of element i in sample B [Busacca *et al.*, 1992].

In this study, similarity coefficients were used initially to compare glass analyses to confirm the stratigraphic correlations, and later to limit the possible correlatives of unidentified tephra. The S.C.'s were calculated on eight element oxides — all those listed in the chemical tables except for Cl, which did not vary significantly between eruptives, and water, which varied greatly between even the same eruptives due to post-depositional weathering.

Due to the large number of tephra samples analysed, portraying the similarity coefficients in table format for more than a few samples at one time was impractical. Therefore only one sample was selected as being representative of each tephra (generally from their type sections), this being compared with all the other samples, or suspected samples, of that tephra, and the similarity coefficients (S.C.'s) presented in the same tables as the glass chemistry (see Table 3-3.1). The representative samples from all tephra within each subgroup were compared with each other and presented as a table of similarity coefficients in the introduction to each subgroup (Chapters 7 to 12).

In the latter stages of this thesis, the author became accustomed to the extent of chemical variation within and between tephra, and for many samples the glass chemistries were initially visually scanned for differences. It was found that FeO, CaO and K₂O, were of greater use for discriminating between tephra than other elements, though TiO₂ and MgO were also occasionally useful. Previous workers have also found the above element oxides to be the most diagnostic (e.g. Smith & Westgate, 1969).

Usually S.C.'s of >0.92 suggest possible correlatives for New Zealand tephra [Shane & Froggatt, 1991; Froggatt, 1992], but this value varies with the origin of the tephra being sampled, and higher values have been used (e.g. >0.95 [Busacca, 1992]). In this work, the correlations based upon physical characteristics and stratigraphic position generally have S.C.'s of >0.92, and often >0.95. However, many other tephra known to be different eruptives also have S.C.'s of >0.92, and some >0.95, which means that this chemical correlation technique can only be used in conjunction with other diagnostic tephra features, chemical or physical.

Another statistical comparison technique used to distinguish between and correlate tephra are coefficients of variation [Borchardt *et al.*, 1971; Froggatt, 1983]. This technique gives similar results to Similarity coefficients and was not used in this work.

Figure 3-5 : Comparison of glass chemistry analyses between tephras at the Torere West & Reihana Road sections

Figure 3-6 : Comparison between sites of the means — together with standard deviations (1 s.d.) — of glass chemistry analyses from the upper Torere subgroup tephras [Torere West (022) & Reihana Road (062)]

sites, with the shaded ellipses representing the range of one standard deviation from the mean. The individual tephra are generally much more clearly delineated, with the Torere-N Tephra now readily distinguished. Nevertheless, the Torere-L and Torere-O Tephra still cannot be separated.

Multi-variate discriminate function analysis (DFA) has been applied to New Zealand tephra [Stokes & Lowe, 1988; Shane & Froggatt, 1991; Stokes *et al.*, 1992]. Simple two component scatter diagrams and ternary plots compare two or three components only, but the DFA statistical technique simultaneously compares the chemistries of the tephra in many different dimensions, with each analysed element oxide being a separate axis. DFA gives a numerical result as well as a graphical comparison and can thus deal with much more data than simple Similarity coefficients and two and three component plots. The use of DFA was beyond the scope of this project, but one run-through of part of the data set in this thesis showed that it can readily discriminate between most tephra within the Huntress Creek, Torere, and Murupara subgroups at the Huntress Creek site.

3-4 Tephra Correlation using Microprobe Geochemistry of Primary Minerals

The various minerals that are to be found in tephra and have been analysed with the microprobe in this study include (in order of usefulness):

- Fe-Ti oxides (titanomagnetite & ilmenite);
- amphiboles (hornblende & cummingtonite);
- biotite;
- pyroxenes (hypersthene & augite); and
- alkali and plagioclase feldspars.

Apatite geochemistry can be useful in tephra identification and correlation, but this mineral was not separated or analysed in this study. Each of these mineral groups is discussed separately below.

3-4.1 Microprobe geochemistry of Fe-Ti oxides (titanomagnetites)

Correlations can be made between tephra using the chemistry of their titanomagnetite (Fe-Ti oxide) minerals [King *et al.*, 1982; Smith & Leeman, 1982; Busacca *et al.*, 1992]. These minerals are very sensitive to the conditions of initial crystallisation and exhibit a considerable range of compositions in igneous rocks [Westgate & Gorton, 1981]. Like glass, Fe-Ti oxides are ubiquitous in volcanic rocks, but they have an advantage over glass for identification purposes in that they are relatively resistant to weathering and survive in very weathered tephra where all the glass has been altered to clay [King *et al.*, 1982]. In addition, they can easily be extracted from the bulk sieved sample with a hand-magnet.

Trace element analysis of a bulk titanomagnetite sample can distinguish between many different eruptives [Kohn, 1970], but grain discrete methods of analysis (i.e. microprobe) should be used as there

are often detrital titanomagnetites present, especially from any enclosing loess deposits [Kohn, 1979]. Where detrital Fe-Ti oxides are present, it is best to analyse grains which have volcanic glass attached [Busacca *et al.*, 1992]. It has been noted that many tephra contain multiple titanomagnetite populations [Westgate & Gorton, 1981; King *et al.*, 1982], but often the mixture of populations itself is distinctive.

Ilmenites appear to be more diagnostic than titanomagnetites, but few were analysed from the tephra in this work. Microprobe analyses of ilmenites, in conjunction with the glass chemistry, have been found to be better at distinguishing between eruptives than either method alone [Busacca *et al.*, 1992].

The titanomagnetite analyses were conducted with the same microprobe as for the glasses, but with a focused beam ($\approx 2 \mu\text{m}$) and a 12.0 nA beam current at 15 kV. The ilmenite standard (USNM 96189 from the Ilmen Mountains, Russia) was used for calibration of the microprobe. The analyses were studied for homogeneity, and the outliers removed for separate mean calculations. Also included within the tables in Chapter 14 and in Appendix-(G) is the "Stormer" model for ulvöspinel Molar proportions in cubic oxide. Fe_2O_3 contents were determined by assuming stoichiometry and using the "Oxcalc-3" computer program.

The titanomagnetite analyses were visually scanned to indicate possible correlatives, though similarity coefficients were also calculated using six element oxides. The threshold S.C. values for determining a chemical match (between two samples) was not known for titanomagnetites, though something similar to glass (e.g. 0.90) appears likely. The most abundant element oxides, FeO, Fe_2O_3 and TiO_2 , were also the most variable. Al_2O_3 , MgO and MnO were present in much smaller amounts but were just as useful for correlation purposes. SiO_2 , ZnO, and Cr_2O_3 were near or below detection limits and were not included in the S.C. calculations. More of the element oxides contain significant variations in titanomagnetites than in glass, suggesting that discriminant function analysis (DFA) [King *et al.*, 1982; Beaudoin & King, 1986], which was not attempted in this work, would be a better technique than S.C.'s for correlating tephra using the Fe-Ti oxides. Like glass though, positive correlations cannot be made using only simple binary plots of the oxides [King *et al.*, 1982], and the correlations in this work are only tentative. The results, however, do show that titanomagnetite geochemistry can be used to differentiate between some New Zealand tephra.

The titanomagnetites of only a few of the tephra deposits in the Bay of Plenty have been analysed. These were mostly from the extremely weathered tephra (e.g. those in the Ohiwa Harbour and Kukumoa subgroup), as well as their suspected correlatives that elsewhere are less weathered (i.e. contain glass).

Several of the deposits contained multiple titanomagnetite populations, but there was usually a dominant component. The weathered tephra correlated to each other by their stratigraphic position and physical characteristics also correlated well by their titanomagnetite geochemistry (e.g. Tirohanga, Jackson). However, the less weathered possible correlatives showed similar trends, but significantly different chemistries. It is uncertain whether the differences are due to their not being correlatives, or to differential weathering and alteration of their titanomagnetite minerals.

The most likely form of weathering to occur is exsolution lamellae of ilmenite within the magnetite grains. Exsolution forms a composite titanomagnetite – ferrian-ilmenite grain, with the magnetite being of lower ulvöspinel content than the primary grain [Himmelberg & Ford, 1977]. The bulk composition of the grain does not alter. Several North American workers studying Fe-Ti oxides have reported not seeing exsolution lamellae in magnetites found in tephra deposits (King *et al.*, 1982; Smith & Leeman, 1982), and studies in New Zealand have found grains showing exsolution features to be rare [Lowe, 1988]. Exsolution features were not looked for in this project, but they are probably more common within ignimbrites which have maintained a high temperature for a considerable length of time, rather than cooler airfall tephra deposits. If all, or almost all, of the analyses on the titanomagnetites showed consistent values for each elemental oxide (each analysis on a different grain), then it can safely be assumed that exsolution had not occurred. A few tephtras (e.g. Waingarara Ignimbrite) were found to have quite variable titanomagnetite compositions, and it is suspected that some alteration has occurred in these cases.

Few ilmenites were analysed in this study, precluding the use of titanomagnetite-ilmenite pair crystallisation temperatures for tephra differentiation [Smith & Leeman, 1982].

The Fe-Ti oxide analyses are presented and discussed in Chapter 14, and in Appendix-(G).

3-4.2 Microprobe geochemistry of amphiboles

Changes in amphibole composition appear to be related to magma temperature and variations in hornblende geochemistry have previously been used to distinguish between eruptives [Smith & Leeman, 1982]. Amphiboles appear to be more resistant to weathering than glass, surviving in even the most weathered tephra deposits in the B.O.P. However, these minerals are not an ubiquitous component in all tephtras, thus limiting the usefulness of this techniques.

The amphibole analyses in this work were carried out using the same conditions as those for the Fe-Ti oxides, using the Engels amphibole and hornblende (P.S.U. 4-190) standards for microprobe calibration.

Grain discrete methods of chemical analysis of amphiboles is preferred because of their relative sparsity, and because multiple populations of hornblendes are not uncommon [Westgate & Gorton, 1981]. With the microprobe, only a small number of grains need to be separated out and analysed to produce a representative chemistry.

As with the titanomagnetites, generally only amphiboles from the most weathered tephra deposits in this study (Reeves & Ohiwa Harbour subgroup tephtras), and their less weathered suspected correlatives (Ohinekoao subgroup tephtras) were analysed.

For hornblendes, the most useful element oxides for discriminating between eruptives were Al_2O_3 , TiO_2 , CaO , and Na_2O . FeO , MnO and MgO were also helpful, but SiO_2 , though it had the highest concentration, had a within-sample variation similar to the between-sample variation and so was not

particularly useful. Similarity coefficients were calculated using the eight element oxides listed above, but as with the titanomagnetites the threshold S.C. value for determining whether two samples match chemically is not known, though again a value of "0.90" appears likely.

Hornblende geochemistries readily distinguished between the Tirohanga and Jackson Tephra, but not between the Jackson and Ohiwa-B Tephra. All hornblende analyses are presented and discussed in Chapter 14, and in Appendix-(H).

Cummingtonites have also been used to identify tephra [Smith & Leeman, 1982], and several tephra in this study were found to contain this mineral. The most useful discriminating element oxides were FeO and MgO, with MnO and CaO being almost as good. For similarity coefficient calculations, SiO₂, TiO₂, Al₂O₃, and Na₂O were also used.

The cummingtonites were chemically very similar to hypersthene, except that they contained significantly higher Al₂O₃ (1–3% vs 0–1%) and had lower totals (95–98% vs 99–101%) due to the presence of structural water. The cummingtonites also have a small, but measurable and consistent, concentration of Na₂O ($\leq 0.5\%$); whereas pyroxenes have Na₂O values below detection.

As an example of their potential in this work, the Paerata Tephra cummingtonites were significantly different from those of the Rotoiti Tephra, and both could be distinguished from the older Reeves-A Tephra.

All cummingtonite analyses are presented and discussed in Chapter 14, and in Appendix-(I).

3-4.3 Microprobe geochemistry of biotite

Biotite analyses were carried out using the same conditions as those for the Fe-Ti oxides and hornblendes, using the biotite (P.S.U. 5-110) standard for microprobe calibration.

Biotites from several tephra were analysed. There appear to be significant differences in FeO, TiO₂, and K₂O between the eruptives, but it is uncertain how much of this is primary rather than related to weathering and vermiculisation [Rose *et al.*, 1981].

Insufficient analyses were obtained on known correlatives to determine the range for each tephra. Available biotite analyses are presented and discussed in Chapter 14, and in Appendix-(J).

3-4.4 Microprobe geochemistry of pyroxenes

Pyroxene analyses were carried out using the same conditions as those for the Fe-Ti oxides and hornblendes, using the pyroxene (P.S.U. Px-1) standard for microprobe calibration.

Pyroxenes from several tephra were analysed, but there was very little variation between different eruptives. Perhaps the most useful element oxides for differentiating between eruptives were FeO and MgO, especially the FeO/MgO ratio, but even this usually had a greater within-sample variation than between-sample variation. Glass chemistry was found to be much more diagnostic, as the very weathered

tephra deposits which no longer contain glass generally no longer contain hypersthene either. Thus the analysis of hypersthene for correlation purposes was deemed to be not particularly useful.

The only deposit that had a distinctive pyroxene chemistry was the Westend Tephra which had a mixture of ferro-hypersthene and hypersthene, both of which were distinctive. All other pyroxene analyses lie between these, near the ferro-hypersthene / hypersthene boundary. Only two augites were analysed.

The pyroxene analyses are presented and discussed in Chapter 14, and in Appendix-(K).

3-4.5 Microprobe geochemistry of feldspars

Feldspar analyses were conducted using the same conditions as those for the Fe-Ti oxides and hornblendes, but only a small number of analyses were carried out. The within-sample variation appeared to be of a similar magnitude to the between-sample variation and hence it was decided that analyses of feldspars were not worthwhile and no analyses are presented.

3-5 Tephra Correlation using Ferromagnesian Mineral Assemblage

As all mineral species in a given tephra bed persist to the most distant part of the documented fall-out zone [Westgate & Gorton, 1981], phenocryst assemblage, especially the ferromagnesian minerals, can be used for correlation purposes.

Many researchers have carried out detailed investigations into the petrology and chemistry of the rhyolite lavas and ignimbrites found in the T.V.Z. Ewart, in the late 1960's and 1970's, used the characteristic mineral assemblages of the eruptives to categorize and aid correlation of the deposits. Five assemblages of ferromagnesian minerals were recognized. Work by Kohn [1973] further defined these ferromagnesian groups, adding an additional assemblage.

The various ferromagnesian mineral assemblages (with the diagnostic minerals underlined) are:-

- (i) hypersthene ± augite ± hornblende;
- (ii) hypersthene + hornblende ± augite;
- (iii) hypersthene + hornblende + biotite
- (iv) hypersthene + cummingtonite ± hornblende
- (v) hypersthene + augite ± olivine (uncommon assemblage)
- (vi) aegirine ± riebeckite ± ænigmatite ± olivine ± tuhualite
(only from the Tuhua Volcanic Centre)

[from Ewart *et al.*, 1975; Kohn, 1973; Froggatt & Lowe, 1990]

The magnetic separate containing the ferromagnesian minerals (obtained from the Frantz during processing for the glass separate) was studied under a non-polarised reflected light microscope for each tephra in this study, and the observed minerals identified on the basis of their colour and habit.

Hypersthene crystals were recognised by their generally pale to transparent colour and the fact that they generally have jagged, shattered ends. Occasionally octagonal crystals were seen and these have been described in the text as pyroxene rather than hypersthene. Hornblende crystals were recognised by their generally shiny lustre, dark green/black/brown colour, and their distinctive $60^{\circ}/120^{\circ}$ edge angle. In the extremely weathered samples, the hornblende crystals sometimes have strongly etched (rough) sides, are no longer shiny, and occasionally have shattered ends like less weathered hypersthene. Cummingtonite crystals were slightly more acicular than hornblendes, but also had the distinctive $60^{\circ}/120^{\circ}$ ($54-56^{\circ}/126-124^{\circ}$) edge angle of the amphibole group. Their colour, however, was much lighter, pale yellow-green to translucent. There is some overlap in features though, and cummingtonite could only be positively distinguished under a petrographic microscope, or by its microprobe chemistry (although this is very similar to hypersthene). Biotite crystals were recognised by their distinctive hexagonal plate-like flakes. Even though they were sometimes broken, the 120° edge angle on the thin flakes could easily be recognised. Occasionally stacks (or books) of flakes could be seen. Fresh unweathered biotite was black, but the weathered crystals were a pale gold colour, and some were translucent-to-white. The weathered "vermiculised" biotite crystals were often eroded, with holes piercing through flakes and books. Augite was only recognised under the petrographic microscope or by its microprobe chemistry.

Occasionally no ferromagnesian minerals were seen, because of either: a very small sample and/or separate; or a low concentration of minerals in the sample.

After preliminary identification, grain mounts of some samples were studied in more detail under a petrographic microscope. Whole crystals from the ferromagnesian separate were sprinkled onto a slide coated with a mounting medium such as Canada balsam, heated, and a cover slip placed on top.

A limited number of microprobe analyses were also useful for confirming the presence of some minerals (e.g. augite & cummingtonite). Microprobe mounts of the ferromagnesian minerals were prepared in the same way as for the glass separate.

Cummingtonite was identified under the petrographic microscope by its long, narrow, acicular crystals; its pale yellow-brown colours together with pleochroism; its high order pinks, greens, yellows and purples under crossed-polarised light; and its relatively low (compared with common calcic hornblende), although still inclined, extinction angles. The hornblende crystals are normally much thicker, and their birefringence colours are lower and often masked by the red-brown colour of the grains. Moreover, the colour in the hornblendes, although mostly deep, includes a paler (creamy yellow?) region at the edge of the grain, whereas the colour in cummingtonites continues right to the edge. Cummingtonite is also optically positive, whereas hornblende is generally optically negative.

Hypersthene and augite crystals were recognised by their straight and inclined extinction angles respectively, and augites lack of pleochroism. The jagged ends of the hypersthene crystals were also very distinctive.

Within the text of Chapters 6 to 13, the relative abundances of the minerals in the ferromagnesian mineral assemblage have been represented as below; by bold highlighting, underlining, and italics.

bold underlined = almost all of the ferromagnesian separate ($\approx >90\%$)

bold = abundant ($\approx 60\text{--}90\%$)

underlined = essential ($\approx 30\text{--}60\%$)

plain text = common ($\approx 10\text{--}30\%$)

italic = present ($\approx <10\%$)

italic (t) = trace ($\approx <4\%$)

The minerals are listed in decreasing abundance, with the most common first, least common last.

Most of the tephra in this study had ferromagnesian mineral assemblages of group (ii), with group (iii) being the next most common. Types (i) and (iv) were also present but were rare. Types (v) and (vi) were not recognised. The ferromagnesian mineral assemblage alone was not enough to identify a tephra, but the presence of biotite can preclude correlation in many cases. However, the presence and abundance of biotite is related to the amount of K_2O in the melt, which glass chemistry can also determine. In extremely weathered tephra though, where no glass remains, the ferromagnesian mineral assemblage becomes very important for identification and correlation, although generally in such deposits the hypersthene also no longer exists.

Total phenocryst content and the plagioclase/quartz ratio have also been used previously to distinguish between and classify volcanic deposits in the C.V.R. [Martin, 1961; Ewart, 1967]. These techniques were not attempted in this work.

3-6 Tephra Correlation Techniques Not Used In This Study

Other tephra correlation techniques include:

- trace element geochemistry (Westgate & Gorton, 1981; Sarna-Wojcicki *et al.*, 1987; Preece *et al.*, 1992; Shane, 1993, among others);
- physical characteristics of the glass shards and minerals (e.g. shard morphology; types of micro-phenocryst inclusions (Westgate & Gorton, 1981); refractive indices (Rose *et al.*, 1981));
- remanent paleomagnetism (secular variation) (Cox, 1971; Froggatt, 1988; Pillans & Wright, 1990; Shane, 1993; Shane *et al.*, 1994); and
- radiometric dating (Hildreth & Mahood, 1985; Alloway *et al.*, 1993; Shane, 1993).

None of these techniques were used in this study.

Chapter Four : Post-Rotoiti Eruptives in the Eastern Bay of Plenty

This chapter will deal with the Rotoiti Tephra, and all the readily observed, macroscopic, post-Rotoiti tephtras that are to be found in the coastal eastern Bay of Plenty. These tephtras form an integral part of the tephrostratigraphy here, but as they have been previously studied by earlier researchers, detailed descriptions will not be presented in this work. Only the very thickest of the many post-Rotoiti tephtras deposited here during this time period will be detailed below. A full summary of the post-Rotoiti tephtras, or "late Quaternary tephtras", is presented in Chapter 2.

The coastal eastern Bay of Plenty area is defined for the purposes of this thesis as being the near-coastal sections east of Whakatane–Ohope, as most of the sections showing the "mid- to late Pleistocene tephtras" described in this thesis occur in this area. Few sections are located outside this region, several occur in the north-central or western coastal Bay of Plenty, and several more in the Kaingaroa Forest to the southeast. Furthermore, the post-Rotoiti tephrostratigraphy in these other areas differs significantly from that in the coastal eastern Bay of Plenty region.

The Rotoiti and post-Rotoiti tephtras are seen in virtually every section in the eastern Bay of Plenty and knowledge of their distribution and physical characteristics is vital to understanding the uppermost part of the stratigraphy observed in the field. The tephtras range in age from c. 50 ka (Rotoiti Tephra), to the present. The scarcity of eruptions recorded in the eastern Bay of Plenty over this time period compared with the total number of known eruptions (Table 2-1), gives an indication of the proportion of the total eruptions that are likely have been recorded in regard to the older deposits studied in this thesis.

The more common "late Quaternary" airfall eruptives occurring in the eastern Bay of Plenty are the Okareka, Kawakawa, Omataroa, Awakeri, Mangaone, Tahuna–Ngamotu (undifferentiated) and Rotoiti tephtras. Only the Omataroa, Mangaone and Rotoiti Tephtras form thick deposits.

Many other eruptions occurred during this time, but either they were dispersed in a different direction and not deposited in the eastern Bay of Plenty region, or they dusted this area with ash <10 cm thick. This thickness does not appear to be sufficient to have allowed preservation in the strong weathering and soil-forming environment that has existed in the warm climate following the last glacial (c. 14 ka). However, two eruptions, the Rotoma and Waiohau Tephtras (erupted respectively at 8.5 &

11.9 ka), were deposited in reasonable thicknesses (>40 cm thick), and should therefore be preserved here [Pullar, 1973]. That these two tephtras were not recognised by this worker is possibly due to the type of sections studied; deep road cuttings and coastal cliffs where the very top of the section cannot be reached. Furthermore, the uppermost part of the sections studied in this thesis were not inspected and/or recorded in as much detail as the pre-Rotoiti tephtras, as the post-Rotoiti tephtras were not the major focus of this work. Most sections were recorded from the Rotoiti or Mangaone Tephtra downwards (see Appendix-L).

The best preserved eastern Bay of Plenty sites of the "late Quaternary" tephtras are the Torere School, Awaawakino, Hawai and Copenhagen Road sections. The tephtras are much thicker towards the west at McCoy Road and Ngatiawa lookout, but these and other sections further to the west are very close to source and identification becomes more difficult due to the presence of many less widespread tephtras.

Only the three largest of the several "late Quaternary" tephtras that are found in the eastern Bay of Plenty are discussed in the following pages. These are the Omataroa, Mangaone and Rotoiti Tephtras. They are discussed in order of stratigraphy from top to base; i.e. youngest to oldest. This listing is in the reverse stratigraphic order of deposition because when dealing with deposits close to the soil surface it is often simplest to list the units in this manner, so that the deposits may be counted down from the top. The older pre-Rotoiti tephtras discussed in later chapters have been listed in true stratigraphic order of deposition.

4-1 Omataroa and Mangaone Tephtras

Both the Omataroa and Mangaone Tephtras were studied in detail by Howorth [1975] and much of the following information has been taken from his work. These two tephtras, along with six others less well represented in the eastern Bay of Plenty area, belong to the "Mangaone Tephtra Subgroup" [Howorth, 1975; Froggatt & Lowe, 1990] which was erupted from the Okataina Volcanic Centre between c. 28 ka and c. 45 ka.

Good, easily accessible reference sections for the Omataroa and Mangaone Tephtras in the eastern Bay of Plenty include the Ngatiawa lookout, Hawai, Kutarere and Kukumoa cutting sites.

In the coastal eastern Bay of Plenty, the Omataroa Tephtra is generally the first thick pumiceous deposit to be seen below the modern soil surface. At a very few sites in the northern and eastern Bay of Plenty (e.g. Hawai, Torere School, Awaawakino) the Kawakawa Tephtra can be seen between the modern soil and the Omataroa Tephtra. Other "Mangaone Subgroup" tephtras are also seen at these sites. The Omataroa Tephtra generally overlies a paleosol developed directly into the Mangaone Tephtra, with no loess or other tephtras present between. The Mangaone Tephtra generally overlies a paleosol developed into loess which extends down to the top of the paleosol developed into the Rotoiti Tephtra.

Table 4-1 : Glass chemistry of the Omataroa Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
McCoy Road	77.36	12.87	0.23	1.18	0.18	1.07	4.01	2.89	0.20	5.73	17	1.00
**03903	0.26	0.39	0.06	0.10	0.03	0.06	0.20	0.15	0.07	1.39		
\$—\$	77.94	12.69	0.16	1.09	0.17	1.05	3.93	2.82	0.16	4.42	25	0.93
(Froggatt)	0.34	0.24	0.04	0.10	0.02	0.06	0.21	0.31	0.05	2.47		

\$—\$ = Omataroa Tephra glass chemistry [pers. comm. *Paul Froggatt*, 1991]

Table 4-2 : Glass chemistry of the Mangaone Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Torere School	77.38	12.88	0.19	1.22	0.20	1.24	3.97	2.77	0.16	2.12	18	0.96
01302	0.41	0.19	0.03	0.08	0.04	0.09	0.18	0.08	0.03	1.02		
Huntress Creek	77.40	13.17	0.19	1.28	0.21	1.15	3.65	2.74	0.20	5.72	12	1.00
**01513	0.43	0.29	0.04	0.10	0.03	0.09	0.13	0.12	0.05	1.32		
McCoy Road	77.13	13.03	0.28	1.13	0.24	1.18	4.10	2.75	0.16	3.33	14	0.91
03906	0.40	0.34	0.05	0.08	0.03	0.09	0.16	0.12	0.04	0.77		
Ngatiawa lookout	76.90	13.23	0.21	1.08	0.19	1.23	4.12	2.85	0.19	6.03	5	0.93
04308	0.17	0.11	0.06	0.13	0.04	0.04	0.14	0.07	0.05	0.50		
\$—\$	78.28	12.78	0.17	1.12	0.20	1.18	3.88	2.27	0.12	4.13	18	0.93
(Froggatt)	0.26	0.12	0.04	0.07	0.02	0.05	0.27	0.12	0.03	1.01		

\$—\$ = Mangaone Tephra glass chemistry [pers. comm. *Paul Froggatt*, 1991]

Diagnostic features in the coastal eastern Bay of Plenty:**Omataroa Tephra:**

- Gives an overall impression of a massive, non-graded pumice lapilli deposit 0.5–1 m thick, generally white or pale yellow, but occasionally an orange/ginger colour due to staining. The pumices are still plainly visible in these "stained" sections (e.g. Hawai) and so it cannot be mistaken for the Kutarere Tephra.

Mangaone Tephra : (see Photo-2)

- Consists of a strongly reverse-graded pumice lapilli layer 1–3 m thick (depending on distance from source). Some black obsidian lithics can also be seen.
- A thinner (5–20 cm) and finer grained, coarse ash and lapilli, basal layer exists, separated by the above coarse reverse-graded unit by a slight erosional boundary. The basal layer shows little bedding and is non-graded.
- The overall impression of the tephra is of strongly reverse-graded pumice throughout.

Chemistry and mineralogy:

Neither of the Omataroa and Mangaone Tephra were included in the major part of this thesis topic, but analyses were carried out at several sites where the stratigraphy required confirmation.

The glass chemistry of both tephra (Tables 4-1.1, & 4-1.2 respectively) is quite similar to each other, though the Omataroa has slightly lower CaO and slightly higher K₂O wt.% than the Mangaone. Both chemistries are similar to several other tephra within the Mangaone Tephra Subgroup, but are rather distinctive when compared with the older "late Pleistocene tephra". Their most distinct chemical features are their low K₂O and high Na₂O wt.%'s ($4.0 = \text{Na}_2\text{O} > \text{K}_2\text{O} \approx 2.8$). They also have moderately high values for CaO, TiO₂, MgO and Al₂O₃.

The Omataroa and Mangaone Tephra both have a ferromagnesian mineral assemblage of:

hornblende + hypersthene

Distribution, size and source:

The Omataroa Tephra is believed to have been sourced near the eastern edge of the Okataina Volcanic Centre near Kawerau [Howorth, 1975], and has an estimated airfall tephra volume of 16 km³ [Froggatt & Lowe, 1990]. This, however, may be a severe underestimate as there are few known sections along its thickest dispersal axis, towards the southeast (Fig. 4-1).

The Mangaone Tephra was sourced between Lake Rotoma and Kawerau in the Okataina Volcanic Centre [Howorth, 1975], and also has an estimated airfall tephra volume of 16 km³ [Froggatt & Lowe, 1990]. The distribution of the Mangaone Tephra shows that it was highly preferentially dispersed along the coast towards the northeast (Fig. 4-2).

Both tephra were associated with small unwelded pyroclastic flows of limited areal extent.

Figure 4-1 : Isopach map of Omataroa Tephra distribution, thicknesses in metres [from Pullar, (1973), and with additional thicknesses from sites studied in this work]

Figure 4-2 : Isopach map of Mangaone Tephra distribution; thicknesses in metres [from Pullar, (1973), and with additional thicknesses from sites studied in this work]

Age

The Omataroa Tephra has ^{14}C ages ranging from $27\,900 \pm 1200$ yr B.P. to $29\,700 \pm 1500$ yr B.P. [McGlone *et al.*, 1984], with a mean pooled age of $28\,220 \pm 630$ yr B.P. [Froggatt & Lowe, 1990].

There is some debate over the true age of the Mangaone Tephra. ^{14}C ages on material associated with its eruption have been inconsistent and range from $26\,100 \pm 800$ yr B.P. to $35\,300 \pm 2200$ yr B.P. [McGlone *et al.*, 1984], with a pooled mean age of $27\,730 \pm 350$ yr B.P. An age of c. 30 ka to perhaps 35 ka is accepted here.

4.2 Rotoiti Tephra (Rotoehu Ash)

The Rotoiti Tephra is one of the largest to have come from the northern TVZ, and probably the largest in the last 250 ka from the Okataina Volcanic Centre. The tephra has a near circular distribution and has similar thickness, physical characteristics, chemistry, and mineralogy at Tauranga, as it does at Opotiki (Fig. 4-3). It thus provides an easily identifiable marker horizon for the top of the pre-Rotoiti tephrae studied in this thesis.

The Rotoiti Tephra was first described by Vucetich and Pullar [1969], and the airfall part of this eruption named the Rotoehu Ash. The airfall deposit has now been re-classified to member status of a larger formation and is now regarded as one of three members of the Rotoiti Tephra Formation [Froggatt & Lowe, 1990]. The formation is comprised, from oldest to youngest, of: the Matahi Scoria, Rotoehu Ash, and Rotoiti Ignimbrite. The Matahi Scoria was first noted by Grange [1937] and has been studied in detail by Pullar & Nairn [1972]. The ignimbrite was originally mapped as the Rotoiti Breccia [Healy *et al.*, 1964]

As only the Rotoehu Ash member of the Rotoiti Tephra eruption is observed in the eastern Bay of Plenty, this airfall deposit will be the only member described in detail below. In keeping with the new terminology it will be referred to here and throughout the remainder of this thesis, as the Rotoiti Tephra.

The type section of the airfall component of the Rotoiti Tephra (i.e. Rotoehu Ash) has been designated as occurring at W15/623519, along the highway between Whakatane and Ohope [Vucetich & Pullar, 1969; Froggatt & Lowe, 1990]. It is seen at most sites across the eastern Bay of Plenty, and good reference sections are found at Ngatiawa lookout, Kutarere, Hawaii, Mimiha Stream and Kukumoa cutting.

Diagnostic features in the coastal eastern Bay of Plenty:

- The upper half of the tephra consists predominantly of pumice lapilli.
- The lower half of the tephra consists of many alternating layers of fine ash and sandy ash beds (Photo-2; Photo-52). These beds represent at least 35 separate fall units [Nairn, 1981], which

continued over...

Figure 4-3 : Isopach map of the Rotoiti Tephra (Rotoehu Ash); thicknesses in centimetres [after Pullar, 1973]. Shaded area shows extent of Rotoiti Ignimbrite (breccia).

in weathered sections become conspicuous due to wind and rain action, and often form a hollow in the cliff face (see Photo-60).

- The tephra often rests upon an extremely weathered paleosol — "last-interglacial paleosol" — developed into weathered tephra and loess. Occasionally, especially in the eastern Bay of Plenty, there is a ≈ 0.5 m thick loess deposit between the base of the tephra and the underlying paleosol.
- In freshly excavated deep road cuttings, the water table is perched on the impervious clay beds of the paleosol underlying the more porous, pumiceous beds of the Rotoiti Tephra, and the tephra is often marked by a line of springs [Vucetich & Pullar, 1969].
- The ferromagnesian mineral assemblage of the tephra contains significant amounts of cummingtonite, usually a rare mineral in volcanic deposits.
- Near source, the tephra is directly underlain by the black Matahi Scoria, which in turn rests on the "last-interglacial paleosol" below.

In this work, the Rotoiti Tephra was generally identified throughout the Bay of Plenty by its physical characteristics and stratigraphic position. In a few cases (e.g. Torere School), the presence of cummingtonite was used as an additional identification technique.

Rotoiti Ignimbrite:

- Consists of several unwelded pumiceous pyroclastic flow deposits, up to 50 m thick at the coast to the north of the Okataina Volcanic Centre. The flows are intercalated with airfall deposits of the Rotoiti Tephra.

Matahi Scoria:

- ≤ 15 cm of black, basaltic vesicular lapilli (scoria) with a minor amount of rhyolite lapilli and ash [Pullar & Nairn, 1972]. This unit is only seen in the near source region.

Stratigraphic relationships:

The top of the Rotoiti Tephra has undergone weathering to some extent, but generally not enough to be considered a well-developed paleosol. In most cases there is up to 25 cm of weathered ash at the top of the tephra which is overlain by weathered loess, and by the Mangaone Tephra. At very distal sites near Cape Runaway (e.g. at Waiotuma) there is much more soil development, with up to 50 cm of well-developed soil present, again overlain by the Mangaone Tephra.

To the south of the Okataina Volcanic Centre, the Rotoiti Tephra is conformably overlain by the Earthquake Flat Tephra with no significant time interval between the two [Nairn & Kohn, 1973]. The two tephrae are considered to be coeval eruptions. The Earthquake Flat Tephra has not been recorded in the northeastern Bay of Plenty region, but can be distinguished from the Rotoiti Tephra only by its chemistry, greater biotite content, and lack of cummingtonite.

Table 4-2.1 : Glass chemistry of the Rotoiti Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Torere School 01303	78.55 0.19	12.25 0.09	0.13 0.03	0.90 0.07	0.14 0.02	0.86 0.05	3.76 0.17	3.31 0.07	0.12 0.02	2.35 1.08	11	0.93
Huntress Creek **01516	78.33 0.47	12.55 0.37	0.17 0.04	0.95 0.06	0.16 0.03	0.83 0.05	3.59 0.21	3.24 0.15	0.20 0.04	4.15 2.04	9	1.00
Ngatiawa lookout 04307	78.24 0.41	12.31 0.30	0.16 0.04	0.97 0.12	0.16 0.02	0.86 0.06	3.79 0.10	3.25 0.15	0.26 0.04	4.91 1.82	10	0.98
Waihora Road 06501	78.97 0.21	11.96 0.10	0.15 0.03	0.89 0.05	0.13 0.03	0.82 0.03	3.65 0.14	3.32 0.08	0.15 0.02	1.63 0.96	10	0.94
Waihapokopoko 07702	78.78 0.20	12.23 0.09	0.14 0.03	0.90 0.05	0.14 0.03	0.90 0.05	3.49 0.20	3.30 0.06	0.15 0.02	2.90 0.71	12	0.94
Ohiva Loop Road 08505	77.91 0.21	12.53 0.18	0.13 0.04	0.97 0.15	0.15 0.02	0.86 0.07	3.89 0.10	3.38 0.07	0.18 0.07	2.80 1.73	5	0.94
Omaio 09304	78.27 0.17	12.35 0.15	0.21 0.04	0.93 0.06	0.15 0.03	0.93 0.06	3.82 0.12	3.09 0.17	0.25 0.03	6.76 0.88	11	0.94
\$-\$ (Froggatt)	79.08 0.42	11.96 0.21	0.14 0.03	0.91 0.10	0.12 0.04	0.81 0.08	#3.37 0.30	3.41 0.29	0.20 0.03	4.07 0.86	14	0.92*

\$-\$ = Rotoiti Tephra glass chemistry [pers. comm. Paul Froggatt, 1991]

Table 4-2.2 : Similarity coefficients (S.C.'s) of all post-Rotoiti analyses in this study.

youngest	03903	Frogg.	01302	01513	03906	04308	Frogg.	01303	01516	04307	06501	07702	08505	09304	Frogg.	oldest
Omataroa 03903	1.00															
Omataroa Frogg.	0.93	1.00														
Mangaone 01302	0.94	0.92	1.00													
Mangaone 01513	0.92	0.90	0.96	1.00												
Mangaone 03906	0.92	0.87	0.92	0.91	1.00											
Mangaone 04308	0.96	0.92	0.96	0.93	0.92	1.00										
Mangaone Frogg.	0.90	0.92	0.94	0.93	0.90	0.92	1.00									
Rotoiti 01303	0.83	0.88	0.82	0.81	0.78	0.82	0.83	1.00								
Rotoiti 01516	0.87	0.91	0.86	0.86	0.81	0.86	0.87	0.93	1.00							
Rotoiti 04307	0.87	0.93	0.86	0.85	0.82	0.86	0.87	0.96	0.98	1.00						
Rotoiti 06501	0.82	0.88	0.81	0.82	0.77	0.81	0.82	0.96	0.94	0.94	1.00					
Rotoiti 07702	0.83	0.89	0.82	0.82	0.78	0.82	0.83	0.98	0.94	0.94	0.96	1.00				
Rotoiti 08505	0.85	0.90	0.84	0.82	0.80	0.84	0.84	0.97	0.94	0.96	0.93	0.95	1.00			
Rotoiti 09304	0.90	0.91	0.87	0.87	0.84	0.90	0.86	0.92	0.94	0.94	0.91	0.92	0.92	1.00		
Rotoiti Frogg.	0.80	0.86	0.79	0.79	0.75	0.79	0.80	0.94	0.92	0.91	0.96	0.96	0.93	0.88	1.00	

boxed areas = believed to be correlatives

The contact between the Rotoehu Ash and the Matahi Scoria is conformable and without any observable paleosol development.

The base of the Rotoiti Tephra generally overlies a widespread paraconformity [Vucetich & Pullar, 1969], represented by a thick, very strongly developed reddish brown soil (see Photo-52), produced by extreme weathering of the loess and tephra parent material. It is thought to have formed during the last-interglacial, and perhaps also the penultimate interglacial (oxygen isotope stages-5 and perhaps -7), when the temperatures were warm enough to promote rapid soil development. The paraconformity often has an erosional aspect to it. At many sites (e.g. Ngatiawa lookout, Paerata Ridge Road, Kukumoa cutting), the Rotoiti Tephra is observed to overlie a strongly undulating soil surface with several metres of relief, yet bedding seen within and below the paleosol is near-horizontal (Photo-2(a)).

At other sites throughout the Bay of Plenty, especially in the area east of Opotiki, a unit of unweathered loess lies between the Rotoiti Tephra and the very weathered paleosol (see Photo-61). Here all the beds are near-horizontal and erosional breaks have not been recognised; hence the sequence is thought to be conformable.

Chemistry and mineralogy:

The glass chemistry of the Rotoiti Tephra was determined from several sections in order to fingerprint the tephra chemically, and also to confirm the method of using physical characteristics of tephra for correlations purposes.

The glass chemistry of the Rotoiti Tephra (Table 4-2.1) is not particularly distinctive, with moderate FeO and CaO values. Generally the shards are fresh with little hydration, thus giving relatively high totals, and low values for water. Of the alkali elements, $\text{Na}_2\text{O} > \text{K}_2\text{O} > 3.0 \text{ wt\%}$, which is uncommon amongst older mid- to late Pleistocene Tephra from the TVZ.

The Waihora Road section has been studied by previous workers and the sample from here (06501) is used as a chemical reference for the newly studied sections. The chemistries of all three tephra detailed in this chapter are compared using similarity coefficients (Table 4-2.2)

The Rotoiti Tephra has a ferromagnesian mineral assemblage of:

cummingtonite + hornblende ± hypersthene

Previous workers have given the ferromagnesian mineral assemblage of the Rotoiti Tephra as:-

hypersthene ± cummingtonite ± calcic hornblende
[Froggatt & Lowe, 1990]

Distribution, size and source:

Isopach maps for the airfall Rotoiti Tephra were constructed by Vucetich & Pullar [1969] and by Pullar [1973] (Fig. 4-3). Nairn [1972] used the isopach maps to estimate an eruptive volume of $\geq 50 \text{ km}^3$ for this deposit. A more recent estimate of 90 km^3 [Froggatt & Lowe, 1990] includes the additional thickness of airfall units that exist within the pyroclastic flow sequence. Even so this volume

is probably an underestimate as some of the tephra was dispersed over the ocean (in the Bay of Plenty) [Pillans & Wright, 1992], where thicknesses can only be determined from the sparse sea-floor drill hole cores.

The inferred source of the Rotoiti Tephra (Rotoehu Ash) is in the northern part of the Haroharo Caldera [Nairn, 1981] in the Okataina Volcanic Centre. The multiple bedding, fine grain size in the basal part, and the presence of pisolites within several beds [Nairn, 1981], indicate that the eruption was in part phreatomagmatic. The eruption was a major caldera-producing event, and possibly initiated volcanism in the Haroharo area.

The Rotoiti Ignimbrite was also erupted from the Haroharo Caldera at the northern edge of the Okataina Volcanic Centre, and flowed northwards towards and well beyond the present coastline [Nairn, 1981]. The volume of eruptive material in the Rotoiti Ignimbrite is estimated at $\approx 150 \text{ km}^3$, equivalent to 80 km^3 of magma [Froggatt & Lowe, 1990].

The Matahi Scoria is only poorly exposed, with a maximum thickness of approximately 15 cm and an inferred source in the Lake Rotoma area. It has an estimated eruptive volume of 1 km^3 [Froggatt & Lowe, 1990] and has not been recognised in the eastern Bay of Plenty.

Age

Determining the age of the Rotoiti Tephra is problematic and many different techniques have been used to date this eruption.

Radiometric ^{14}C ages of $>41\,000 \text{ yr B.P.}^\#$ [Thompson, 1968], $\geq 42\,000 \text{ yr B.P.}$ [Nairn & Kohn, 1973], and $>44\,200$ [Pullar & Heine, 1971 in McGlone *et al.*, 1984], are close to or beyond the current limits of the dating technique [McGlone *et al.*, 1984]. The finite ^{14}C ages obtained for several tephras only slightly higher in the stratigraphic sequence (e.g. Hauparu Tephra @ $39\,000 \pm 5600 \text{ ka}$; Mangaone Tephra @ $35\,300 \pm 2200 \text{ ka}$ [McGlone *et al.*, 1984]) suggest that the age of the Rotoiti Tephra is likely to be *c.* 50 ka. Loess stratigraphy on the Mamaku Plateau also supports an age of *c.* 50 ka [Kennedy, 1988].

Berryman [1992] reported an age of $52 \pm 7 \text{ ka}$ based upon stratigraphic relationships of the tephra to aeolian deposits on raised shore platforms (marine terraces) at Mahia Peninsula. The platforms have been correlated to the well-dated (Uranium series on corals) Huon Peninsula marine terraces in Papua New Guinea and to the oxygen isotope stage record. The tephra is found in loess overlying the *c.* 59 ka cut surface and must therefore be younger than this surface.

$^{230}\text{Th}/^{238}\text{U}$ radioactive disequilibrium dating [Ota *et al.*, 1989] gave an age of $71 \pm 6 \text{ ka}$ for the Rotoiti Tephra. However, this much older age is not well constrained and should be considered a maximum age only [Froggatt & Lowe, 1990].

[#] All New Zealand radiocarbon ages use the Libby half-life of 5568 years.

Wilson et al. [1992] reported an age of 64 ± 4 ka for the Rotoiti Tephra, based on whole-rock K-Ar age determinations on pantelleritic lavas from Mayor Island which bracket the tephra. This age appears to be precise and realistic, but conflicts with Berryman's stratigraphic evidence.

Electron spin resonance (ESR) dating on quartz from the Rotoiti Ignimbrite [Buhay et al., 1992] gave an age of 45.2 ± 8.2 ka.

In the coastal eastern Bay of Plenty, the Rotoiti Tephra overlies a loess unit resting on the last-interglacial paleosol. Some weathering is observable within the top of the tephra, with loess generally overlying this indicating that the tephra was probably deposited within the latter part of $\delta^{18}\text{O}$ stage-4, with an age of 50–65 ka.

It is clear that most of the laboratory ages are not in agreement with one another and a consensus on the exact age for the Rotoiti Tephra eruption is still some way off. For the purposes of this study the age of the Rotoiti Tephra Formation has been taken to be c. 50 ka.

Chapter Five : Pre-Rotoiti Eruptives in the Bay of Plenty

This chapter will discuss the overall tephrostratigraphy of the Bay of Plenty region, presenting a composite stratigraphic column and individual stratigraphic columns from representative and other important sections.

Over sixty pre-Rotoiti tephtras in the Bay of Plenty region have been placed in a stratigraphic framework in this work. They range in age from c. 50 ka to 700 ka with most of the age control coming from paleoclimatic data (see Chapter 15). Some radiometric age control has been obtained by correlating several tephtras in the eastern Bay of Plenty with previously dated widespread ignimbrite eruptions found in the Central Volcanic Region. Positive correlations have been made to the Matahina and Kaingaroa Ignimbrites, as well as less definite but probable correlations to the Mamaku and Whakamaru Ignimbrites.

Tephtra correlations between sections were achieved using the distinctive physical characteristics of the airfall beds and confirmed by microprobe analysis of glass shards, titanomagnetites and hornblendes.

The deposits in the eastern Bay of Plenty have been divided into seven subgroups, with either major tephtras or significant paleo-climate indicator deposits (i.e. loess and paleosols) marking their boundaries. Each subgroup occupies an approximately equal thickness in the coastal eastern Bay of Plenty stratigraphy, though there is a wide range in the number of tephtras present in each. Each subgroup also has a manageable number of tephtras for naming purposes. The tephtras have been designated code names, with the subgroup listed first, and all the tephtras within that subgroup listed alphabetically in chronological order of eruption. Use of the code names avoid a vast proliferation of individual tephtra names. Only the thickest, most widespread, or in some other way very distinctive tephtras — that is those tephtras most useful for correlation purposes — have been given individual names.

In the stratigraphic sections shown throughout this chapter; Kuk- = Kukumoa-, Welc- = Welcome- (for Welcome Bay), Hun- (or Hunt-) = Huntress- (for Huntress Creek), Tor- = Torere-, Reih- = Reihana-, Mur- (or Muru-) = Murupara-, Tab- = Tablelands-, Ohi- = Ohiwa- (for Ohiwa Harbour), Rv- = Reeves.

The division into subgroups will be discussed in detail at the end of the chapter.

5-1 Stratigraphic Sections in the Eastern Bay of Plenty

The pre-Rotoiti tephrostratigraphy of the Bay of Plenty was pieced together from many separate sections, of which the more important are presented and individually discussed in detail in the following pages, from these with the youngest deposits to those with the oldest.

5-1.1 Copenhagen Road

The Copenhagen Road section is located near Te Kaha, about half-way towards Cape Runaway on the eastern edge of the Bay of Plenty [X14/233737]. The section occurs as a cut through the base of a hill at the landward edge of the last-interglacial ("Otamaroa") marine terrace. It consists of 7–8 m of tephra, loess, paleosol and colluvium layers, resting on a greywacke surface (Figure 5-1; Photo 1 & 1(a)).

The top of the section has undergone some erosion, but in several areas the present day soil can be seen to have weathered into a sandy ash layer. This layer overlies a paleosol developed into a sandy ash and lapilli layer, which from its reverse graded nature and stratigraphic position below the present day soil surface is thought to be the Mangaone Tephra.

The tephra beneath this was identified as the Rotoiti Tephra from its physical characteristics: a coarse upper half overlying well bedded alternating finer ash and sandy ash layers; and by the presence of cummingtonite in its ferromagnesian mineral assemblage.

Below the Rotoiti is a reasonably well developed paleosol in a sandy ash layer, the Wairuru Tephra. This tephra overlies a weak paleosol that has developed into a weathered sandy ash deposit containing rare very large pumices (up to 5 cm across) and angular greywacke rock fragments. This deposit has been interpreted as being a colluvial toe-slope which has over-thickened the airfall tephra and allowed it to be recognised as a separate unit (Copenhagen Tephra). This tephra overlies another tephric colluvium deposit (Torere School Tephra), also with a weakly developed paleosol in its top.

Below the Torere School Tephra there exists a dark, well-developed reddish paleosol weathered into what is also believed to be colluvium that overlies the highly irregular surface of the greywacke basement (see Photo 62). This surface undulates with several metres of relief, but not enough is exposed laterally to determine if it is a marine cut surface, or a buried terrestrial erosion surface. If marine cut, it must be of at least penultimate interglacial age as it is higher than the Otamaroa Terrace.

The major feature of the Copenhagen Road section is the absence of the thick, extremely weathered "last-interglacial paleosol". Usually this paleosol is found either directly underlying the Rotoiti Tephra, or underlying a loess unit just below the Rotoiti. Only a few sections containing deposits of this age do not show the paleosol (e.g. Waihapokopoko, Torere School), and it is at such sites only that the Wairuru, Copenhagen and Torere School Tephra can be recognised. Elsewhere these three tephra are not as over-thickened and are generally much more weathered.

Figure 5-1 : Full stratigraphic section of the Copenhagen Road site

Figure 5-2 : Full stratigraphic section of the Kukumoa cutting site

The Copenhagen section is therefore thought to represent the uppermost portion of the stratigraphy studied in this thesis. It is possible that the reddish paleosol correlates to a redder region found within the "last-interglacial paleosol" at the Kukumoa cutting section, and may have formed only during the very warmest period of oxygen isotope stage-5, that is stage-5e.

5-1.2 Kukumoa cutting

The Kukumoa section is located [W15/843469] on Highway-2 just west of Opotiki (Photo 2 & 2(a)). The section is ≈ 11 m thick, with the Rotoiti Tephra occurring about half-way down (Figure 5-2). Both the Rotoiti and Mangaone Tephra are identifiable by their distinctive bedding characteristics and stratigraphic position in relation to the present day soil surface.

The Rotoiti Tephra directly overlies a dark, very thick, extremely weathered and well structured paleosol which has developed into an erosional surface. Due to its massive clay nature, the lower part of the paleosol has been interpreted here as being weathered loess. Three thin pale grey-white clay layers within this weathered loess are believed to represent extremely weathered and compacted tephra units. No glass remains in these three weathered tephra, but analysis of titanomagnetites indicates that the deposits are not the same as those found at Copenhagen Road (see Chapter 14).

The lowermost of the three weathered tephra rests on a paleosol, containing many pumice flecks, developed into a very weathered sandy tephra, the Kutarere. This tephra has a yellow-orange, almost ginger appearance with occasional clay nodules, many points of manganese concentrations, and a basal firm white clay layer, speckled with black manganese concretions. The tephra, although weathered, does contain some glass which can be used, along with its distinctive appearance, to correlate it to sites in the eastern Bay of Plenty, in particular to the Huntress Creek section, only a few hundred metres to the west. The Kutarere Tephra at Kukumoa overlies a reasonably well developed paleosol extending below road level.

5-1.3 Huntress Creek

The Huntress Creek section [W15/833472] is located parallel to Huntress Creek, next to where it is crossed by a Highway-2 bridge, just west of Opotiki (Photo 3 & 3(a)). It is one of the longest (time wise) and most complete sections found in the Bay of Plenty region. The section is at the sea-cliff end of what was probably a long, narrow promontory during the high sea-levels of the Holocene and last-interglacial time periods.

At the very top of the section (Figure 5-3), the Omataroa, Mangaone and Rotoiti Tephra can be recognised by their physical characteristics, glass chemistry, and stratigraphic position in relation to the present day soil surface.

Below the Rotoiti Tephra is a thin layer of loess, then a dark, very well developed paleosol. The next three to four metres down is not visible due to dense vegetation cover and slumping of the paleosol material. In a few places the weathered yellow-orange Kutarere Tephra can be recognised, resting on a

paleosol, and with a paleosol developed into its top. White clay streaks within the underlying paleosol indicate that it has developed through at least one tephra layer and into the loess below. Small discrete lenses of white ash "creamcakes" (Huntress-E Tephra) occur at a certain level within this loess.

There is a sharp boundary between the base of the loess and the top of the thick, coarse pumice lapilli of the Huntress-D Tephra (Photo-45). The base of this tephra is finer (fine sand) and more crystal- and lithic-rich. Unweathered loess continues below, with the sandy ash of the Huntress-C Tephra, and the pumice and sandy ash of the Huntress-B Tephra lying within it. A paleosol has developed, though, in the loess immediately below the Huntress-B Tephra. The Kaingaroa Tephra, found within this loess, can be recognised by its well bedded sandy ash and pumice lapilli layers and has been correlated to the Kaingaroa Ignimbrite eruption via its glass chemistry and stratigraphic position.

The Kaingaroa Tephra overlies a weak paleosol in a weathered tephra unit containing two dispersed but recognisable ash layers. Elsewhere up to six tephra are known to exist within this portion of the stratigraphy. The combined Torere-I – Opotiki Tephra (between which there is no break) are the first tephra units thick enough to have partially resisted the weathering below the Kaingaroa, although the upper unit of the Torere-I Tephra is generally unrecognisable. Huntress Creek is one of the few sites where all three units of the Opotiki Tephra can be seen. Its basal, well sorted buff sandy ash rests on a paleosol developed into loess. The Ohiwa Hill Tephra is patchy within this loess but is recognisable by its basal pink ash above an extremely bioturbated contact. Further below is a white clay, containing many small rhyolitic lithics throughout (Photo-33). The clay is all that remains of the very weathered Hiwarau Tephra.

The Hiwarau Tephra overlies a reasonably well structured paleosol which has developed into fine loess or weathered ash. A distinctive white – pink/red – white layered fine ash tephra (Torere-A) is visible at the base of this paleosol, resting on the weathered sandy top of the Matahina Tephra.

The Matahina Tephra consists of coarse pumice lapilli and large rhyolitic lithics (Photo-29). A distinctive basal pinkish-orange ash overlies a line of coarse pumice and a reasonably well developed paleosol. This paleosol has weathered into and through several obsidian rich tephra, of which only patchy remnants can be seen. The slightly reverse graded sandy ash of the Bonisch Tephra is readily visible near the base of the section, with the Murupara-C Tephra beneath it requiring digging to view. Below the Murupara-C Tephra exists a massive, light yellowish-brown fine sand unit (loess), which was augered to a depth of >2 m before the top of another tephra unit was discovered. Glass from this buried unit matched that of the Kohioawa Tephra, fitting well with the known stratigraphy from other sections.

The Huntress Creek section (Figure 5-3), when combined with the Kukumoa section just a few hundred metres up the road, represents an almost complete tephrostratigraphic record for the eastern Bay of Plenty–Opotiki area, down to the Kohioawa/Rangitawa eruption.

Huntress Creek

Figure 5-3 : Full stratigraphic section of the Huntress Creek site

5-1.4 Hiwarau

The Hiwarau section is a coastal cliff sequence (Photo-4 & 4(a)) in the south-eastern part of Ohiwa Harbour [W15/722450]. Its tephrostratigraphy is very similar to the Huntress Creek section, except that stratigraphically it extends slightly deeper and is not complete to the top.

There is a very well developed paleosol at the top of the section but this unit could not be reached. The relative thickness of the paleosol and the lack of tephra identifiable from a distance within it, suggests that the very top of the stratigraphic column is missing here, probably due to localised erosion. The first tephra unit that can be recognised is the Huntress-D (Figure 5-4).

The tephra below the Huntress-D, down to the Hiwarau Tephra, are much the same here as at Huntress Creek, except that there is a slight erosional contact in the paleosol below the Huntress-B Tephra, the Torere-I – Opotiki Tephra are thicker, and the Ohiwa Hill Tephra thinner.

The Hiwarau Tephra here consists of >1 m of massive pumice lapilli, not clay as at Huntress Creek, but still has small rhyolitic lithics scattered throughout. There is little paleosol development beneath it, and small creamcakes of white ash (Torere-B Tephra) occur near the top of a loess layer. The white and red ash of the Torere-A Tephra is not far below, resting on the weathered top of the Matahina Tephra. The Matahina is much the same as that at Huntress Creek, but the tephra below it are much better preserved at Hiwarau.

The Murupara-G Tephra exists only as weathered ash at the base of a reasonably well developed paleosol, with the tephra layers below separated from each other by the paleosols that have developed into their tops. Here, the Murupara-C Tephra overlies the Murupara-A Tephra, which was not recognised at Huntress Creek, and which in turn rests on a weak paleosol developed into >1.5 m of massive loess.

The base of this loess has an erosional contact with a thick pumiceous tephra. This tephra, the Kohioawa Tephra, consists of a pumice lapilli bed, overlying a shower bedded pumice lapilli unit, then a pinkish sandy ash unit, and a basal crystal rich sandy ash and lapilli unit. The tephra rests on a paleosol developed in weathered loess, which in turn overlies a yellowish pumice and sandy ash — the Paerata Tephra. The Paerata Tephra is distinguished by its pale yellow colour and the abundance of cummingtonite in its ferromagnesian mineral assemblage. The yellow Paerata Tephra directly overlies the well bedded grey ash and sandy ash of the Tablelands-D Tephra. This tephra occurs at the base of the section, at the high-tide mark, with only the top of a weak paleosol glimpsed below.

The Hiwarau section generally confirms the stratigraphy developed from the Huntress Creek section, with the physical characteristics and glass chemistries of many tephra matching well between these two sites.

Figure 5-4 : Full stratigraphic section of the Hiwarau site

5-1.5 Otarawairere

The Otarawairere section is located on the Kohi Point walk-way, and at beach level, between Westend–Ohope and Otarawairere Bay [W15/637532], just east of Whakatane. The understood stratigraphy of this section goes slightly deeper than that of Hiwarau, but less is recorded at the top. Nevertheless, it confirms the stratigraphy developed elsewhere (e.g. the Huntress Creek, Hiwarau & Tablelands sections).

In total, the composite Otarawairere section is ≥ 50 m thick, but the uppermost 10^+ m could not be reached easily, nor could much of the lower half, and therefore much was not studied closely. Detailed study was carried out from the Bonisch Tephra downwards (Figure 5-5), although the Matahina and Anaputa Tephra were noted nearby, and the Kaingaroa and Opotiki Tephra were recognisable in the cliffs above.

The sandy ash of the Bonisch Tephra and the white ash of the Murupara-C Tephra are both thicker here than further to the east, and the Otarawairere section is the only site where the weathered pumice of the Murupara-B Tephra is observed. The Murupara-A Tephra is also present, resting on 1.5 m of grey loess.

The base of the loess, like that at Hiwarau, has an erosional contact with the Kohioawa Tephra below. The erosion, however, is less significant at Otarawairere, and the uppermost very well bedded ash unit of the Kohioawa Tephra is displayed. The well bedded ash unit overlies in sequence the pumice lapilli unit, the pinkish sandy ash unit, and the basal pumice and sandy ash unit. The Kohioawa Tephra is up to 4 m thick here, and this thickness is rivalled only in the Kohioawa section along the coastal cliffs west of Matata.

The Kohioawa Tephra rests on a weathered loess paleosol, which overlies the yellowish coarse sandy ash and pumice of the Paerata Tephra. The well bedded grey ash of the Tablelands-D Tephra is well exposed immediately below the Paerata. A weakly developed paleosol occurs below the Tablelands-D Tephra, and in some places (but not all) an area of paler ash, the Tablelands-C Tephra, can be seen within it. The paleosol continues downwards to unweathered white sandy ash, the Otarawairere Tephra, which contains biotite and large quartz crystals.

The Otarawairere Tephra rests on a paleosol developed into a sandy matrix containing well bedded beach pebbles/gravels (Photo-65). Below the ≈ 2 m thick pebble/gravel layer lies ≈ 2.5 m of massive light brown sand, then a thick unit of very fine sandy silt. This part of the section could not be reached, but is plainly visible in the cliff face both from above and below.

Viewing the cliff from the coastal rock platform ≈ 40 m below (Photo-5 & 5(a)), a cut surface can be seen in the basement greywacke, ≈ 15 m above the shore. Overlying this surface is a sand unit containing pockets of gravel, and a tephra (Westend Tephra). The "Westend Tephra" has what appears to be a reasonably well developed paleosol in its top, its chemistry is unique and unusual, and its position within the overall stratigraphy is uncertain. Above the sand-gravel unit lie bedded sands with no gravels, eventually to be replaced by 6–10 m of the very fine sandy silt mentioned above.

Otarawairere

Figure 5-5 : Stratigraphic section of the Otawairere site

5-1.6 Tablelands Road

The Tablelands section is located on Tablelands Road [W15/887462-888464] as it rises up to the top of the high terrace just east of Opotiki.

Near the terrace surface, in the upper part of the section, the Mangaone and Rotoiti Tephra can be recognised (Figure 5-6). The Rotoiti Tephra rests on a very well developed reddish-brown paleosol weathered into loess/clay, which ≈ 3.5 m below grades into the yellow-orange Kutarere Tephra. Previous workers have recorded a few thin tephra within this paleosol [*Iso et al.*, 1982], similar to those found at Kukumoa. The upper boundary to the Kutarere Tephra is irregular and erosional, and the tephra rests on a well developed paleosol in the loess below.

A cliff section lower down the road shows a stratigraphically lower sequence of loess and tephra (Photo-6 & 6(a)), but the section is very dry and crumbly and fine detail is often masked. At the top are the very well bedded ash layers of the upper unit of the Kohioawa Tephra. The lower units of this tephra are not particularly well preserved here and some faint cross-bedding can be seen. Immediately below the Kohioawa is a paleosol developed in loess, with the pale yellow sandy ash of the Paerata Tephra below, in turn resting on the grey ash of the Tablelands-D Tephra.

A weak paleosol in loess separates the Tablelands-D Tephra from the sandy ash of the Otarawairere Tephra, which in turn rests on a well structured paleosol developed in loess and/or the ash and sandy ash of the Tablelands-A Tephra (Photo-17).

The Tablelands-A Tephra rests on an extremely weathered and well developed paleosol. A paler band ≈ 0.5 m down within the paleosol indicates the presence of a very weathered tephra (Ohiwa-G). The paleosol grades into weathered loess which becomes much more tephric at about 2 m depth, and grades into the very weathered Ohiwa-F Tephra. This tephra overlies a paleosol developed into the weathered ginger-brown Tirohanga Tephra. The colour of the Tirohanga Tephra is distinctive, as are the very large clay nodules scattered throughout it, and the manganese rich white clay layer at its base. Below the basal clay layer is a loess unit containing lenses of a very weathered biotite rich tephra and occasional clay nodules.

The loess overlies extremely weathered gravels, which can be easily broken by spade, and sometimes by hand. Over the edge the road in the valley below can be seen a few outcrops of hard unweathered, fluvially deposited greywacke gravels of quite coarse grain size. The gravels are thought to represent the same period of fluvial deposition as the Waiotahi Gravels found to the west of Opotiki.

The Tablelands Road section shows both the upper and lower parts of the eastern Bay of Plenty tephrostratigraphy, but little can be seen of the middle part here, though it is well exposed at the nearby Burchett section. Nevertheless, the lower part Tablelands Road section continues the stratigraphy downwards and shows a rare, continuous sequence from the distinctive Kohioawa and Paerata Tephra, to the Tirohanga Tephra.

Tablelands Road

Figure 5-6 : Full stratigraphic section of the Tablelands Road site

5-1.7 Flax Hill Point

The Flax Hill Point section is located at the base of a headland in Ohiwa Harbour, with the Flax Hill property above [W15/748466]. The section is small and in two parts, with the upper part containing the Kohioawa, Paerata and Tablelands-D Tephtras, and one other basal weathered ash resting within weathered loess (Figure 5-7). This basal ash is either the Tablelands-C or the Otarawairere Tephtra.

Slumping and vegetation hide the intervening deposits, and the next part of the section commences with a well developed paleosol in very weathered loess which grades into a very weathered tephra (Ohiwa-F). This tephra is separated by a thin loess layer from the dark brown paleosol in the top of Tirohanga Tephtra. The ginger-brown colour of this tephra, and the basal clay layer and nodules, are identical to the characteristics found in the Tirohanga Tephtra elsewhere, with the exposure at this section probably the best preserved.

Below the Tirohanga Tephtra are three extremely weathered tephtras within very weathered loess. The lower of the three (Ohiwa-B Tephtra) occurs at the high-tide mark and has well bedded, multicoloured clay layers that are rich in biotite. Weathered loess separates the Ohiwa-B from the Jackson Tephtra below, which in turn rests on a paleosol developed into weathered gravels. The Jackson Tephtra contains very large (5 mm) phenocrysts of quartz and feldspar, and has abundant weathered biotite. The thickness of the Jackson Tephtra here is uncertain, as it was not revealed in the headland cliff, but within the floor of the harbour itself. The thickness of the paleosol at the top of the gravels is also uncertain and appears to be variable suggesting the possibility of an erosional break at the base of the Jackson Tephtra.

The Flax Hill Point section is the only site in the eastern Bay of Plenty known to show both the Ohiwa-C and Ohiwa-D Tephtras.

5-1.8 Reeves

The Reeves section occurs at the end of a headland into Ohiwa Harbour, on Ohiwa Loop Road not far from its junction with Reeves Road [W15/751463]. The section has two significant erosional unconformities within it, one at the base of the Rotoiti Tephtra, the other not far below the Matahina Tephtra (Figure 5-8; Photo-7 & 7(a)).

The upper sequence of paleosol, Omataroa, Mangaone, and Rotoiti Tephtras is similar to that found elsewhere, as is the extremely weathered paleosol below the Rotoiti Tephtra. Many white clay streaks and a few ash-clay layers were seen within this "last-interglacial paleosol" but were not studied in detail.

The first unweathered deposit to be identified below the Rotoiti Tephtra (second unweathered tephtra observed below...) is the Torere-I – Opotiki Tephtras (considered as one unit). The stratigraphy here is much the same as that found at Huntress Creek and at Hiwarau, though the Matahina Tephtra is more compact and thinner, and the tephtras below it are more weathered. The Bonisch and Murupara-C Tephtras could not be identified solely by their physical characteristics, and glass chemistry was required for positive identification.

Figure 5-7 : Full stratigraphic section of the Flax Hill Point site

The second major unconformity stretches diagonally in an almost straight line across the section from top left to bottom right. Stratigraphically the unconformity is overlain by weathered ash, or possibly loess, with the first identifiable eruptive to overlie it being the Murupara-C Tephra. It may be that this lower unconformity is related to the erosion seen elsewhere between the Kohioawa Tephra and the thick loess unit above it.

The highest identifiable deposit seen below the unconformity is a white weathered tephra-clay. Many metres of weathered colluvial debris unconformably overlies this tephra-clay, possibly related to the major unconformity itself. Alternatively the debris may be relatively recent in origin as its contact with the late Quaternary tephra is not readily observed.

Below the white weathered tephra-clay is a yellowish-brown paleosol in weathered tephra. This lower tephra is also white, and contains abundant biotite and very large quartz and feldspar crystals. No glass remains in either of these tephra, suggesting a likely correlation to the Ohiwa-B and Jackson Tephra respectively. If they were less weathered and glass were present, then the deposits could possibly be correlatives to the Otarawairere and Tablelands-A Tephra instead.

Below the "Jackson Tephra" (tentative) is a well developed paleosol in loess and tephra. The paleosol grades into less weathered loess with an orange, very weathered tephra (Reeves-C) at its base. The Reeves-C Tephra rests on a paleosol developed into more weathered loess. The loess becomes greyer and less weathered downwards, and contains a very weathered multicoloured tephra-clay unit (Reeves-B) within it.

Below the loess there is an unweathered, very white, glass-rich ash. This ash is the uppermost unit of the Reeves-A Tephra, and overlies a sandy ash unit, then well bedded tephric sand and ash layers. The bottommost unit is almost certainly subaqueously deposited, but it is uncertain where, in this section, the exact boundary between the subaqueous and terrestrial (subaerial) environment occurs. The Reeves-C Tephra is thought to rest on a terrestrial paleosol and so the boundary is somewhere between the base of the section and here, probably within the Reeves-A Tephra deposit.

Below the base of the Reeves-A Tephra lies a thin layer of greenish-grey silt, over relatively unweathered fluvial gravels at the base of the section. The silt may or may not be a paleosol. The large unconformity does not erode far into the relatively consolidated fluvial gravels, which are also found at the base of the far right of the section.

If the identification of the biotite and crystal-rich white tephra-clay as the Jackson Tephra is correct, then the Reeves section is the most representative site for the tephra of this age. The only other section to show these tephra is the Ohiwa Harbour Road section, which in this time range is represented by marine and fluvial deposits, not subaerial. The tephra and paleosol sequence is superficially similar to that of the lower part of the Tablelands section, but the Reeves-A Tephra definitely does not correlate to the Jackson or Ohiwa-B Tephra. The basal tephra in the Reeves section contains some cummingtonite, but only a small proportion of biotite, has a glass chemistry which is unlikely to be associated with biotite rich deposits (moderate rather than high K_2O), and does not contain large phenocrysts.

Reeves

Figure 5-8. Full stratigraphic section of the Reeves site

5-2 Correlations to Sections Found Elsewhere in the Bay of Plenty

Several sections found in areas other than the eastern Bay of Plenty provide a more detailed stratigraphic framework for the eruptives within the time range under study. They also contribute stratigraphic information on additional tephra that are not recorded in the eastern Bay of Plenty, but may possibly be found further afield. The Murupara Highway cuttings, Bonisch, Pahekeheke and Reihana Road sections in the Kaingaroa Forest, the Downer and Tikorangi Road sections in the Tokoroa Forest, the coastal cliff sections west of Matata, and the Welcome Bay and Omokoroa East sections around Tauranga Harbour have all been useful in determining the overall stratigraphy. A few of these sections will be discussed in detail here, and related to the eastern Bay of Plenty stratigraphy as seen in the Huntress Creek and Torere West sections (sect. 5-3; Figure 5-18).

5-2.1 Reihana Road

The Reihana Road section [U17/092097] is located between Reporoa and Waiotapu, ≈ 30 km south-east of Rotorua (Photo-8 & 8(a)). It is a very thick section, not all of which is shown in Figure 5-9.

The upper part of the section contains the lower unwelded portion of the main Kaingaroa Ignimbrite. Boulders of welded ignimbrite can be seen scattered around, and cliffs of welded ignimbrite are present at the same level on the opposite side of the valley, indicating that the welding commences not far above. Below the unwelded Kaingaroa Ignimbrite is another, thinner ignimbrite (≥ 3 m), with ≈ 6 m of airfall and surge deposits separating the two. The base of the lower ignimbrite, which is also part of the Kaingaroa eruptive episode, is shown at the top of the section described in Figure 5-9.

Below the lower ignimbrite is a sandy ash containing many thin pumice lapilli beds (often only a single line of lapilli in each bed). The number of lapilli within the sandy ash decreases downwards to the point where they are just scattered throughout rather than in individual layers. Continuing down, the matrix becomes much finer and the lines and layers of lapilli return, but again become fewer as the matrix coarsens downwards. At the base of this, a firm white ash over a thin sandy ash layer marks the boundary to the pisolitic ash beds below. Over 4 m of pisolitic ash occurs, broken only by a 0.5 m thick layer of sandy ash, and another 0.5 m thick bed of normally graded pumice lapilli. The accretionary lapilli are often > 2 cm across. All deposits down to this height are part of the Kaingaroa Tephra.

The Kaingaroa Tephra rests on a dark paleosol developed in the ash of the Reihana-M Tephra (Photo-44; Photo-46). At this site the boundary between these two tephra is generally sub-horizontal but in some places is quite erosional (e.g. at the far right of the section; see Photo-8). The Torere-O Tephra has only a very thin paleosol, an organic-rich layer, in its topmost sandy ash bed, beneath which are the coarse pumice lapilli and large obsidian lithics that comprise the bulk of the tephra found below. The Torere-N Tephra below is much finer with more distinct bedding, but also has only a very thin organic-rich layer, which is often difficult to distinguish, at its upper surface. The Torere-M Tephra has a more developed paleosol at its top, with the bulk of this tephra consisting of shower bedded granular

Figure 5-9: Part of (majority of) the stratigraphic section of the Reihana Road site

pumice lapilli. The Torere-L Tephra below consists of much coarser pumice with large obsidian lithics, but again has only a very thin organic-rich layer at its top. A small erosional feature, or surge deposit, appears to exist within the lower part of tephra. The paleosol in the top of the Torere-K Tephra below is slightly more developed, with the tephra consisting of a single massive sandy ash layer which has a distinctive glass chemistry.

A generally sub-horizontal, but occasionally erosional, boundary separates the Torere-K and Reihana-G Tephra. The latter consists of a fine grey ash which contains some accretionary lapilli (less than in the Kaingaroa), grading into a fine grained pyroclastic flow (Reihana Ignimbrite). The Reihana-G Tephra also has a very distinctive glass chemistry. The tephra overlies, with what appears to be only a slight erosional boundary but may be more significant, the uppermost shower bedded pumice unit of the very thick Reihana-F Tephra. This shower bedded unit rests on a thick (≥ 5 m), massive white pumice bed which makes up the bulk of this tephra.

The Reihana-F Tephra rests on a firm, dark paleosol developed into the Reihana-E Tephra. This tephra has an irregular boundary with the cemented scoria and ash of the Terrace Road Basalt below, which in turn rests directly on the sandy ash of the Reihana-C Tephra. It is possible that the Reihana-C and Reihana-E Tephra are, in fact, the same unit, with the entire eruption of Terrace Road Basalt occurring during the middle part of their eruption (coeval eruptions). The Torere-B Tephra is generally fine grained, has only a very weak paleosol in its top, and contains occasional lapilli and obsidian lithic layers. At the base of the section the Torere-A Tephra has a more developed paleosol in its fine grained top, and coarsens downwards, with white pumice overlying pinkish pumice, which overlies more white pumice. This colour change, together with its glass chemistry, is the major reason that this eruptive is correlated to the Torere-A Tephra in the coastal eastern Bay of Plenty area.

A short distance down the road, at about the same topographic height as the base of the section just described, can be seen the top of the Matahina Ignimbrite. The ignimbrite is overlain by a white pumice layer, then a pinkish pumice layer. A channel has eroded into this pumice, with fluvial and colluvial channel fill deposits occurring above. The pumice layers here chemically match the layers (described) at the base of the previous section and are thus believed to be the same deposit; the Torere-A Tephra.

The tephra in the Reihana section can be directly correlated, both by the physical characteristics and the glass chemistry, to the eruptives present in the Torere West section in the coastal Bay of Plenty east of Opotiki. This comparison has increased the reliability of the stratigraphic correlations determined elsewhere, increased the number of tephra recognised within the overall stratigraphy, and provided proof of the identity and stratigraphic position of the Kaingaroa Tephra in the coastal eastern Bay of Plenty.

5-2.2 Torere West

The Torere West section is located on Highway-35 at the western end of Torere Bay [X15/028507], ≈ 15 km east of Opotiki. The section is much thinner than that at Reihana, but covers almost exactly the same time period.

Figure 5-10: Enlarged stratigraphic section of the Torere West site

The well bedded base of the Kaingaroa Tephra is observed at the top of the section (Figure 5-10; Photo-9 & 9(a)). The deposits above the Kaingaroa are not visible, having been hidden by vegetation and/or removed by erosion. The base of the section is thought to have been deposited in a marine environment, with thick sequences of sand and tephric sand. The basal sand was not analysed but the faintly bedded tephric sand above has identical glass chemistry to the Torere-A Tephra.

Below the Kaingaroa Tephra is a well developed, dark brown paleosol in the top of the ash of the Torere-O Tephra. The paleosol contains charcoal and the burning may have enhanced soil development. Below the paleosol is a sequence of tephra interspersed with layers of organic-rich silts and lignite. The Torere-M Tephra here consists of only a pale, intermittent, ~1 cm thick wavy ash layer within brown-black lignite. The six tephra, Kaingaroa to Torere-K can be correlated to the Reihana section via their glass chemistry, with only the Reihana-M Tephra missing. The physical bedding characteristics of each tephra are also consistent with these correlations.

The physical characteristics and glass chemistry of the Torere-I and Opotiki Tephra (together) are very distinctive throughout the coastal eastern Bay of Plenty, and thus the Kaingaroa Tephra, stratigraphically not far above, can be readily identified in many sections.

The Torere West section is one of two sites where the Torere-G Tephra has been recognised, and one of three sites for the Torere-E Tephra. The Hiwarau Tephra is also well exposed here, indicating that its dispersal axis was probably towards the northeast. The white ash creamcakes just below the Torere-B Tephra have not yet been analysed and may represent a previously unknown eruptive, or are more likely due to reworking of the tephra above into the sediment.

5-2.3 Bonisch Road

The Bonisch section [V16/300207] is located 300 m south of the intersection of Ngamotu and Bonisch Roads, in the northern Kaingaroa Forest. The bulk of the cliff face is composed of Matahina Ignimbrite, but the lower 10 m shows the underlying tephra well (Figure 5-11).

The very coarse pumice and lithics of the pre-ignimbrite Matahina plinian airfall deposit rest on the irregular surface of a dark, and well developed paleosol. This paleosol has weathered into the ash of the Murupara-G Tephra. Only very thin paleosols separate the remaining tephra, indicating that the eruption rate was quite rapid. This section, and the Pahekeheke and Anaputa sections, are the only places where the Murupara-G, Anaputa and Murupara-E Tephra can be readily distinguished. In the coastal eastern Bay of Plenty these three tephra generally cannot be separated, mainly because weathering has destroyed most of their physical characteristics. Often only dispersed lenses of obsidian rich ash and pumice, believed to represent the Anaputa Tephra, can be seen.

In contrast, the speckled appearance of the upper units of the Bonisch Tephra, along with the basal massive white pumice and the intervening pink ash, can be used to identify the tephra in many sections across the eastern Bay of Plenty. The base of the Bonisch Tephra is not visible at the Bonisch Road site or at Pahekeheke, but the tephra can be seen in its entirety at the Murupara Highway cuttings.

Bonisch Road

Figure 5-11: Full stratigraphic section of the Bonisch Road site

Murupara-(2)

Figure 5-12: Full stratigraphic section of the Murupara-(2) site

5-2.4 Murupara-(2)

The Murupara section is located [V17/316991] in a deep road cutting just northwest of Murupara on Highway-38 (Photo-10 & 10(a)). The Matahina Ignimbrite occurs at the top of the section, and the Rangitaiki Ignimbrite (Whakamaru) at the base. Between these two flow deposits are seven airfall tephra (Figure 5-12).

Beneath the coarse pumice and lithics of the Matahina airfall is a well developed dark paleosol with an irregular upper surface. On close inspection the Murupara-G, Anaputa and Murupara-E Tephra can be tentatively identified. All three of these tephra are stained dark brown and the very thin weathered layers in their upper surfaces are difficult to distinguish.

The speckled nature of the upper part of the Bonisch Tephra is distinctive, as is its central pink ash overlying massive white pumice, but the basal well sorted grey sandy ash is not seen at any other section and may not be of primary airfall origin. Below this sandy ash is a weak paleosol in a very well sorted fine pumice sand. On the basis of its well sorted nature and light grey colour, this deposit was identified as being tephric-loess: an aeolian deposit composed predominantly of reworked tephra; generally glass shards.

This tephric-loess unit directly overlies well bedded sandy ash and ash in the upper part of the Murupara-C Tephra. Elsewhere, this well bedded unit is much thinner and therefore it is considered likely that aeolian reworking and over-thickening occurred here. The basal white ash of the Murupara-C Tephra is its most diagnostic characteristic, and here this ash rests on a slight erosional surface in tephric-loess (Photo-23).

The Murupara-A Tephra is seen below, lying within the tephric-loess, and consists of shower bedded pumice lapilli. The Murupara-(2) section is the only near source site where the Murupara-A Tephra is seen. The underlying loess rests on the unwelded top of the Rangitaiki Ignimbrite, but the exact contact is difficult to determine as both the loess and ignimbrite consist predominantly of fine sand sized glass shards. The unwelded pyroclastic flow grades into welded ignimbrite not far below. At other places within this section, both the unwelded flow unit and the Murupara-A Tephra have been removed by erosion, and the tephric-loess beneath the Murupara-C Tephra rests directly on the shaved (eroded) surface of welded Rangitaiki Ignimbrite.

5-2.5 Downer Road

The Downer Road section is located in the pine plantations on the Mamaku Plateau, ≈ 7.5 km northeast of Tokoroa [T16/646335], as the road heads steeply down and northwards to Opakau Stream. The section shows three ignimbrite deposits; the Pokai, Chimp, and Whakamaru; and many interbedded, and therefore well preserved, airfall tephra and paleosols (Figure 5-13). However, as this section was not studied in detail, correlations of these tephra to other areas remain tentative.

Downer Road

Figure 543 : Full stratigraphic section of the Downer Road site

The basal deposit consists of highly altered and/or weathered Whakamaru Ignimbrite, the upper portions of which have been removed by erosion, leaving a shaved surface. A paleosol has been developed into the upper part of this eroded ignimbrite surface.

Above this surface are at least six airfall tephra to the base of the airfall tephra beneath the Chimp Ignimbrite. The lower four tephra are each ≈ 0.5 m thick, generally fine grained (ash and sandy ash), and have paleosols developed into their upper thirds. The upper two tephra are both much thicker (>2 m thick), but also generally fine grained with paleosols developed in their upper surfaces.

The Chimp ignimbrite is ≈ 10 m thick here, apparently totally unwelded, and directly overlies a thin layer (≈ 10 cm) of coarse airfall pumice lapilli, over very firm silt/ash (0.5 m thick). The glass chemistry of this ignimbrite deposit is distinctive and matches well with that of the Reihana-G and Torere-I Tephra, and also that of the Waimakariri Ignimbrite.

Above the Chimp Ignimbrite is a thin ash layer with a very weak paleosol in its top, overlain by the very thick "Downer Tephra" [name from *Neil Kennedy*, pers. comm. 1992]. The Downer Tephra consists of a single, massive, generally white (base sometimes stained pink-orange), granular pumice lapilli bed, 4–5 m thick. The top part of this tephra contains a very dark, brown-black paleosol.

Above this paleosol are two fine grained tephra, each ≈ 0.5 m thick with black paleosols developed into their upper halves. The uppermost paleosol is overlain by a pinkish pumice layer; this in turn is overlain by ≥ 5 m of unwelded pumiceous Pokai Ignimbrite (the top of which is not seen) which is the uppermost deposit in this section.

Based on the absence of Mamaku Ignimbrite near the top (even though it is found nearby), and the presence of the Whakamaru Ignimbrite at its base, the Downer Road section is thought to cover a similar time range to that of the Murupara and Reihana sections combined. The similarity of stratigraphic positions and glass chemistries suggests a correlation between the Chimp and Reihana Ignimbrites (and Waimakariri), and indicates that there may be a correlation between the Kaingaroa and Pokai Ignimbrites, although this latter correlation is far from certain. The airfall tephra between the ignimbrites exposed at this section are yet to be studied in detail and could confirm or disprove these correlations.

5-2.6 Welcome Bay

The Welcome Bay section is located on a headland (site of a Maori pa) on the western side of Welcome Bay [U14/907820], in the eastern part of Tauranga Harbour just east of Tauranga city. A road cutting on the landward side of this headland is also useful. Fluvially reworked pumice and rhyolitic clasts can be seen at the top of this section, and the Waimakariri Ignimbrite at the base, just above sea-level (Figure 5-14). This ignimbrite is now believed to be a possible correlative of the Chimp Ignimbrite at Downer Road, and possibly also the Reihana-G Ignimbrite. The fluvial deposits at the top of the section have been correlated to the post-depositional erosion of the Mamaku Ignimbrite [*Harmsworth*, 1983]. The deposits have eroded into a pumiceous tephra which has identical glass chemistry to the Mamaku Ignimbrite / Kutarere Tephra. Therefore, the Welcome Bay section is thought to correlate to the upper

Welcome Bay

Figure 5-14: Full stratigraphic section of the Welcome Bay site, proxy for the Tauranga region

middle part of the Huntress Creek section. However, the glass chemistries are generally very similar among the various tephra erupted during this time period, and their physical characteristics can not be readily correlated from the east to the west of the Bay of Plenty region. The tephra identifications at the Welcome Bay site thus remain tentative, and as the Welcome-F and Welcome-C Tephra are not recognised in the eastern Bay of Plenty, the tephra in the Tauranga area have been placed in their own separate subgroup (Welcome Bay subgroup).

The Welcome-D Tephra is a well bedded deposit containing large free crystals and lithics. It has the same glass chemistry as the Huntress-D Tephra and its physical characteristics are similar to that of the basal layer of this eruptive at Huntress Creek, but much thicker. The upper massive pumice is not recognised at Welcome Bay.

The Welcome-B Tephra rests within loess, and has a glass chemistry similar to the Huntress-B and Kaingaroa Tephra. It could therefore correlate to either of these two tephra.

The fluviially deposited pumice underlying the Welcome-B Tephra is a widespread deposit thought to be related to post-depositional erosion of the Waimakariri Ignimbrite which lies just below [Harmsworth, 1983].

5-2.7 The coastal cliffs west of Matata

(Kohioawa cliffs, Ohinekoao Reserve, Wilson's farm-(1) and Wilson's farm-(5))

The coastal cliffs west of Matata show a sequence of deposits from the post-Rotoiti airfall eruptives to marine and fluvial sediments perhaps 0.75 Ma old. The sequence is well exposed due to the slight tilting of the sediments, with the youngest deposits found in the west near Otamarakau, and the oldest near Matata in the east (Figure 5-15).

Several Mangaone Subgroup tephra (notably the Hauparu Tephra) occur in the cliffs near Otamarakau, and travelling from west to east these tephra rise to expose the very thick Rotoiti Ignimbrite that underlies them. The ignimbrite is interbedded with many airfall units from the same eruption, and together the deposit has a thickness of >70 m.

The first pre-Rotoiti deposits seen occur opposite Pikowai Reserve camping ground. Here there is a thick (≈ 40 m) sequence of fluviially deposited pumiceous sands, called the "Pikowai pyroclastics" [Bailey & Carr, 1994] (see Chapter 13). Near their base is a thick airfall pumice unit, named here as the "Pikowai Tephra". This eruptive is a tentative correlative of the Hiwarau Tephra (or possibly Opotiki Tephra) found within the Torere subgroup further to the east. The Pikowai pyroclastics appear to directly overlie the Matahina Ignimbrite, but the contact is only seen in this one place. Further to the east, the Rotoiti Pyroclastics — ignimbrite with basal and intercalated airfall units — directly overlie a significant erosional boundary into the Matahina Ignimbrite, and the Pikowai pyroclastics are not present [Bailey & Carr, 1994]. Either this predominantly fluvial unit was confined within a paleo-river course, or has been totally eroded out everywhere but the Pikowai Reserve section.

The middle and lower flow members of the Matahina Ignimbrite, together >50 m thick, cap the cliffs from just east of Mimiha Stream. Throughout this area, the Matahina eruptives directly overlie

marine/estuarine sediment, and are therefore thought to have been deposited in a lagoonal environment. The estimated age of the Matahina eruption is *c.* 0.33 Ma (see Chapter 14), placing it within the high sea-level stand of $\delta^{18}\text{O}$ stage-9 and indicating that the interglacial coastline at that time was in a similar position to that at present.

A section through the cliffs at V15/366631 (Kohioawa cliffs section; Figure 5-16 & repeated in Appendix-O) shows that the marine/estuarine sand below the Matahina is only a few metres thick, and has an erosional contact with the uppermost unit of the airfall Kohioawa Tephra. Other than the Matahina Tephra, the Murupara subgroup tephra are not present here and are thought to have been removed by erosion during the sea-level rise at the $\delta^{18}\text{O}$ stage-10/stage-9 boundary. The base of the marine/estuarine sand is quite pumiceous and probably represents reworking of the Murupara subgroup tephra in a near-shore environment. Elsewhere (e.g. Ohinekoao Stream slip), the Kohioawa Tephra itself has been completely removed by erosion, and the Paerata Tephra directly underlies the sand.

The Kohioawa Tephra is of subaerial airfall deposition, indicating that the sea-level at the time of its eruption was much lower than that during the deposition of the marine/estuarine sand, and that the coastline was some distance to the north. This tephra is separated from the underlying Paerata Tephra by an organic-rich silt layer which most likely represents a terrestrial paleosol that has subsequently been leached during submergence below sea-level. The Paerata, Tablelands-D and Tablelands-C Tephra are also subaerial airfall deposits, and are enclosed by organic-rich silt paleosols.

The silt below the Tablelands-C Tephra overlies a massive marine sand ≈ 6 m thick. This sand overlies a pumiceous sand unit, which from its large scale cross-bedding is thought to have been deposited in a high energy, shallow water environment. The pumiceous sand unit is ≈ 10 m thick and has a thin layer of granular pumice lapilli at its base. The pumice throughout this unit is thought to have come from the Otawairere Tephra eruption.

Below the pumiceous sands are much finer marine sands and silts, indicating a deeper environment of deposition. A reworked tephra layer is present near the base of the Kohioawa cliffs section ≈ 15 m below, and chemically and stratigraphically this layer has been correlated to the Tablelands-A Tephra. Fossils of upper Castlecliffian age [Healy & Ewart, 1965] can be found within the very fine sand enclosing this tephra deposit.

The Kohioawa cliffs section shows a shallowing upwards sequence until the deposition of terrestrial sediments. Erosion then occurred, with shallow marine/estuarine sands deposited above the erosional contact. The very thick Matahina Ignimbrite was then deposited and only fluvial and subaerial deposition has occurred since. This sequence of alternating marine and terrestrial deposition is indicative of glacio-eustatic sea-level fluctuation.

Just to the west of the Kohioawa cliff section, a small unnamed stream flows out from a canyon cut into the cliff sediments. On the western side of this canyon, ≈ 10 m up from its base, is a pumice bed consisting of large lapilli, lithics and crystals. This "tephra" has been named here as the Kohioawa Stream Tephra and is believed to be an airfall deposit which has only been slightly reworked. When tilting is compensated for, the tephra occurs at a similar topographic height as the Tablelands-A Tephra,

Figure 5-15 : East-west cross-section of cliff exposures along the Bay of Plenty coast between Matata and Pikowai [diagram from *Bailey & Carr, 1994*; plus some additions]. The gradual eastward rise of the Matahina Ignimbrite is due to post-Matahina structural uplift along the margin of the Whakatane Graben. Note erosional unconformity at base of Rotoiti Pyroclastics.

Figure 5-16: Stratigraphic sections of the coastal cliff exposures west of Matata

but they are believed not to be correlatives due to their slightly different glass chemistries and the significantly different natures of the enclosing sediments. Pumiceous sand and rounded gravel enclose the Kohioawa Stream Tephra, whereas fine fossiliferous sands enclose the Tablelands-A. A pumiceous sand unit ~20 m above the Kohioawa Stream Tephra may represent the Tablelands-A Tephra at this section, indicating that a fault (tentatively called the Kohioawa Stream Fault) with 10–15 m westward up-throw may exist somewhere along the stream bed. A height discordance of the base of the Matahina Ignimbrite lends support, though not certainty, to this hypothesis [Bailey & Carr, 1994].

A stream canyon at Ohinekoao Reserve [V15/369629], 0.5 km to the east, contains older pumiceous sediments and airfall tephra. The base of the Matahina Ignimbrite can be seen >40 m above the uppermost bed reachable here. The highest tephra at the Ohinekoao Reserve site is a pumiceous deposit within marine sands, designated the Ohinekoao-N Tephra. This pumiceous deposit could not be reached for close study but is in the correct stratigraphic position to be a correlative of the Kohioawa Stream Tephra.

The sand below the Ohinekoao-N Tephra becomes pumiceous at its base, where it overlies a 2 m thick, hard, brown massive silt containing many rounded pumices and rounded hard-rock pebbles scattered throughout (especially in its basal third). This silt unit probably represents a single large flood event, or possibly a laharic deposit.

Below the brown silt are >15 m of shower bedded airfall tephra (from the Ohinekoao-L at the top to Ohinekoao-A at the base), organic-rich silts (some of which are probably paleosols), cross-bedded pumiceous sands and silts with minor layers of silt rip-up clasts, and occasional massive non-pumiceous sediment. The depositional environment for these sediments is likely to have been shallow marine–estuarine–terrestrial. Massive sand, situated below the Ohinekoao-A Tephra, is indicative of a deeper marine environment, which suggests that the sediments above were deposited during a glacio-eustatic shallow water interlude within a deeper marine environment. It is the first shallow sequence seen below the Otawairere – Kohioawa Tephra, suggesting that deposition probably occurred during $\delta^{18}\text{O}$ stage-12.

The Ohinekoao-I and Ohinekoao-J Tephra have moderately distinctive physical characteristics and can be traced eastwards along the cliff face for 0.5 km to Ohinekoao Stream. On the other (eastern) side of this stream, at about the same topographical height, exists a single eruptive—the Herepuru Tephra. This tephra has totally different physical characteristics and glass chemistry from the Ohinekoao subgroup tephra found on the western side of the valley. The Herepuru Tephra also appears to be airfall, but lies within massive very fine sand, which is slightly pumiceous only immediately above the tephra. More than 10 m of sediment can be observed both above and below the tephra; with the fossiliferous sands below the tephra being of deeper deposition than Ohinekoao subgroup sediment.

No other tephric deposits can be seen in these sediments, indicating that there must be a fault coinciding with the place where the Ohinekoao Stream exits the coastal cliffs, probably also determining the course of this stream. This fault has been named here as the "Ohinekoao Fault". The Herepuru Tephra is best viewed on Herepuru Road, just before it turns inland, and can be traced eastwards for 400

metres to the next stream valley. The tephra is not recognised to the east of this point, but this may be due to lack of exposure rather than its non-existence.

On the basis of the regional tectonic regime and other nearby faults, the "Ohinekoao Fault" is expected to be normal in orientation, with relative uplift to the west. This movement would place the Ohinekoao subgroup as being older than the Herepuru Tephra. However, the deposits in the coastal cliffs between the Matahina Ignimbrite and the Ohinekoao subgroup tephra can be studied through binoculars, and the Herepuru Tephra was not plainly visible within these. Only one tephra is visible, and this, the Ohinekoao-N Tephra, has yet to be analysed. The Herepuru Tephra has very similar physical characteristics, mineralogy, and glass chemistry to the Kohioawa Stream Tephra, which is tentatively thought to be a correlative of the Ohinekoao-N Tephra. The Herepuru and Ohinekoao-N Tephra may thus correlate to each other, but there are several major problems with this correlation.

The Herepuru Tephra has an estimated age of c. 600 ka (K-Ar), and has limits of 0.46 to 0.95 Ma from planktonic index nannofossils [Nairn & Beanland, 1989]. This age is much older than that estimated for the Ohinekoao subgroup, with the Ohinekoao-N Tephra thought to be c. 420 ka old.

The sediment surrounding the Herepuru Tephra is much finer grained than that around the Ohinekoao-N and Kohioawa Stream Tephra, indicating that if it is a correlative of these, a rapid increase in the paleo-water depth towards the east must have occurred. There is some evidence to suggest that the paleo-water depth was increasing towards the east, but probably not this rapidly.

On Wilson's farm, several sections show different parts of the stratigraphic column. At the very top (Wilson's farm-(1) [V15/384618]) can be seen the Rotoiti Tephra overlying an unwelded pyroclastic flow. Slightly lower, the Matahina Ignimbrite has eroded into the deposits below it, namely the Kohioawa Tephra. The Kohioawa Tephra rests on an organic-rich silt/paleosol that overlies the Paerata and Tablelands-D Tephra. These are separated from the Tablelands-C Tephra by a thin organic-rich silt layer and 0.5 m of marine sand. There are many metres of sand below the Tablelands-C, becoming coarser, more pumiceous and with more distinct bedding (graded beds and cross-bedding) downwards.

At the very western end of the Wilson's farm-(1) section there are >10 m of slightly bedded marine sands, separated from the remainder of the section by a fault. This fault must therefore have been upthrown to the west by ≥ 10 m.

Much lower down topographically is the Wilson's farm-(5) section [V15/384620]. This section shows a sequence of airfall tephra, cross-bedded pumiceous sands, and rounded pumice gravels. The glass chemistry and general physical characteristics of the tephra found here match those found at Ohinekoao Reserve, and thus the two sites are believed to correlate with one another. The same tephra can be seen in the cliffs above the driveway approaching Wilson's farm, though they cannot be reached here. Along the side of the driveway itself occur highly pumiceous cross-bedded sands overlying a slightly pumiceous very fine sand. The fine sand gradually becomes more pumiceous downwards until a point where the pumice totally disappears and the sediment below is massive and non-pumiceous. This boundary marks the start of deposition of the "Wilson Tephra" in a deeper marine-shelf environment. The Wilson Tephra

is the lowermost tephra seen here — though up to 10 m of sediment is visible below it — and has a glass chemistry very different to that of the Herepuru Tephra.

Between the two Wilson's farm sections (-1) & (-5)), there are two outcrops of rounded pumice gravels which have chemistries very similar to each other, but different from that of the Herepuru Tephra. Due to lack of exposure, the Ohinekoao-N Tephra is not seen here.

Further west near Matata, up a track along Awatarai Stream, there occur up to 20 m of coarse fluvial gravels. The contact with the marine sequence above was not seen by this worker.

Compiling the full composite stratigraphic column from the above sections requires a knowledge of the various faults (including several that were previously unrecognised) and their offsets, and where significant erosion has occurred. An earlier generalised section by Healy & Ewart (1965) failed to recognise the Rotoiti Breccia east of Pikowai and thus repeated this unit within the stratigraphic column. Previous workers also failed to recognise the differences between the Herepuru Tephra and Ohinekoao subgroup tephra. The Herepuru Tephra and the sediments surrounding it have been studied previously in considerable detail, and their age is very important in ascertaining the complete stratigraphy.

The various scenarios for the Herepuru Tephra and its relationship to the Ohinekoao subgroup are:

- the Kohioawa Stream, Ohinekoao-N, and the Herepuru Tephra are the same, having an age of *c.* 420 ka, with the radiometric and microfossil ages determined for the Herepuru Tephra being in error. This allows the Ohinekoao Stream fault to be upthrown *c.* 20 m to the west;
- the Kohioawa Stream Tephra has an age of *c.* 420 ka, but despite its chemical and physical similarities to the Herepuru Tephra, they are not the same eruptive. The Ohinekoao-N and Kohioawa Stream Tephra are probably the same unit, with the Herepuru Tephra being much older (*c.* 600 ka). In this case the Ohinekoao Stream fault must be upthrown to the east, which is in the opposite direction to all the other major faults in the area;
- the Kohioawa Stream, Ohinekoao-N, and the Herepuru Tephra are the same, having an age of *c.* 500 ka or 600 ka, and the rest of Ohinekoao subgroup is older. No shallow water deposits were seen between the Ohinekoao-N and the Otawairere Tephra ($\delta^{18}\text{O}$ stage-10), suggesting deposition of the Ohinekoao subgroup during $\delta^{18}\text{O}$ stage-12. For the Ohinekoao subgroup to have been deposited during $\delta^{18}\text{O}$ stage-14, or stage-16, there must either be shallow water deposits that are present but not recognised, or an unrecognised erosional event somewhere in the cliff face which has removed any shallow water/terrestrial sediments that may have been deposited. The Ohinekoao Stream fault in this case is upthrown to the west;
- the Kohioawa Stream and Herepuru Tephra are the same, with an age of *c.* 600 ka, but the Ohinekoao-N Tephra is much younger (*c.* 420 ka). This age for the Kohioawa Stream Tephra requires a much greater throw on the Kohioawa Stream Fault than that estimated by the height discordances of the Matabina Ignimbrite; ≥ 60 m rather than ≈ 20 m. This could only be achieved by the following:

continued over...

- a great amount of erosion having occurred at some period between the time that the majority of faulting occurred at "Kohioawa Stream", and the eruption of the Matahina Ignimbrite; and/or
- there is another "unknown" fault, probably located in a small valley 150 m to the west of Kohioawa Stream, which can take up, in the opposite direction, much of the required movement of the "Kohioawa Stream" fault. The region between these postulated faults would thus be an uplifted fault block, or horst, but as the Matahina Ignimbrite does not cap the sediments between the two faults, and exposure in the cliffs is not good, there is little evidence either to confirm or disprove this hypothesis.

Further work in this area is required.

If the Herepuru Tephra is older and lies below the Ohinekoao subgroup, it must be at least 40 m below the Ohinekoao-I Tephra; that is ≥ 10 m below the Wilson Tephra. This height difference is necessary because ≈ 30 m of generally shallow water sediments are exposed between the Ohinekoao-I and Wilson Tephra, with the Herepuru Tephra not seen here. The stratigraphy below the Wilson Tephra is not well exposed, so it is possible that the Herepuru Tephra exists not too far below. The above scenario requires ≥ 40 m of eastwards up-throw at the Ohinekoao Stream fault (i.e. in the opposite direction to the other faults in the region). However, uplift of this magnitude is seemingly incompatible with the heights of the Ohinekoao subgroup tephra at the Wilson's farm-(5) section, and the presence of another fault is required, with an uplift of *c.* 20 m to the west. This fault could be located in the stream bed opposite the entrance to White Sands Motor Camp, or could be the fault seen at the Wilson's farm-(1) site. The region between the Ohinekoao Stream and the next fault to the east would also be an upthrown fault block (horst).

If the Ohinekoao subgroup is older than the Herepuru Tephra, and the "Ohinekoao Fault" is upthrown 20 m to the west, then this too is incompatible with the heights of the Ohinekoao subgroup tephra at the Wilson's farm-(5). Another fault is indicated, this time with a throw of *c.* 40 m up to the east. The most likely place for this fault to be located is in the stream bed opposite the entrance to White Sands Motor Camp. The area between the "Ohinekoao" and "White Sands" faults would thus be a graben.

The preferred explanation is that the ages determined for the Herepuru Tephra are incorrect, and it is *c.* 420 ka. However, this is improbable as both the nannofossil and K-Ar ages are unlikely to be in error. A *c.* 500 ka age for the Herepuru Tephra would also fit the stratigraphy, and although this age disagrees with the K/Ar date, it is consistent with the nannofossil ages. In this case the 50–70 m of sediment between the Matahina Ignimbrite and the Ohinekoao subgroup would contain subtle paleoenvironment changes not noticeable through binoculars.

It is more likely that the Kohioawa Stream and Herepuru Tephra are different; the former being ≈ 10 m above the Ohinekoao-I Tephra (Kohioawa Stream Tephra = Ohinekoao-N), and the other (Herepuru Tephra) being at least 40 m below the Ohinekoao-I Tephra, and only seen in one upthrown fault block at Herepuru Road.

The thick gravel unit at the base of the sequence is probably related to the very low sea-level of oxygen isotope stage-16, and may correlate to the Waiotahi Gravels.

5-3 **Compilation of an Overall Stratigraphy of the Mid-Late Quaternary for the eastern Bay of Plenty**

No single section shows the entire tephrostratigraphy of the eastern Bay of Plenty. Therefore the compilation of an overall stratigraphy requires that many sections be pieced together, and this can only be achieved if positive correlations of tephtras can be made between sites. The most useful sections for compiling an overall stratigraphy have been discussed in the previous pages and correlations between these sections are shown in Figure 5-17 (repeated in Appendix-O).

The most valuable tephtras in correlating between sites are the most distinctive, either by their physical characteristics, mineralogy or glass chemistry. Probably the three most useful eruptive deposits for correlative purposes in the eastern Bay of Plenty are probably the Torere-I – Opotiki, Matahina, and Paerata – Tablelands-D Tephtras. These tephtras have respectively been given the symbols O, M, and P in Figure 5-17 and will be discussed with other important tephtras below.

At the very top of the stratigraphy lie the Mangaone and Rotoiti (R) Tephtras. Together, these two tephtras are very distinctive, both physically and chemically, and are easily correlated throughout the eastern Bay of Plenty. The Kutarere (K) and Kaingaroa (Kg) Tephtras are also moderately distinctive but confusion with the Tirohanga and Rotoiti Tephtras respectively, can occur in some situations.

Taken as a group, the Torere-I, Opotiki (O) and Ohiwa Hill Tephtras are readily identifiable, with the basal very well sorted grey sandy ash of the Opotiki Tephtra being very distinctive. The shower bedded pumice of the overlying Torere-I Tephtra is often weathered, but has a distinctive glass chemistry, and the Ohiwa Hill Tephtra has a distinctive strongly bioturbated thin basal pink ash layer resting on loess.

The Matahina (M) Tephtra, with its coarse pumice and rhyolitic lithics and basal pink-orange ash overlying a line of pedologically reworked pumice, has been used as a stratigraphic control point in more eastern Bay of Plenty sections than any other tephtra. The identification of the Matahina, along with the Kaingaroa and Kohioawa Tephtras, is vital for tying down the eastern Bay of Plenty tephrostratigraphy to the T.V.Z. ignimbrite chronology.

The Kohioawa Tephtra is the thickest tephtra seen in the coastal Bay of Plenty, and its distinctive bedding is often useful for correlation, but generally only when associated with the underlying Paerata (P) Tephtra. This latter tephtra always has a pale yellow colour not seen in any other deposit, and is immediately underlain by the well bedded grey ash of the Tablelands-D Tephtra. The Paerata Tephtra is also unmistakable in that its ferromagnesian mineral assemblage is dominated by the mineral cummingtonite.

Figure 5-17: Correlations between the major stratigraphic sections

Figure 5-18: Comparison of sections across widespread areas of the Bay of Plenty

Only two other deposits are especially distinctive; the Tirohanga (T) Tephra and the Jackson (J) Tephra. The former has an unusual ginger (dark yellow-orange) colour; whereas the latter has a huge abundance of golden weathered biotite, as well as very large quartz, feldspar and hornblende crystals.

Basing initial correlations on these physical and mineralogical characteristics, the glass chemistry of most tephras was next determined. The results generally confirmed the initial correlations, and allowed the identification of many more individual tephras, which could then also be correlated and their distribution patterns studied.

For the sections outside the coastal eastern Bay of Plenty, glass chemistry was the major means of identification and correlation. The relationships of these sections to the eastern Bay of Plenty stratigraphy are shown in Figure 5-18 (repeated in Appendix-O).

The overall stratigraphy for the eastern Bay of Plenty has been compiled from all the sections studied in this region and presented in Figure 5-19 (repeated in Appendix-O). Out of a total of 66 tephras in the Bay of Plenty with their approximate stratigraphic positions ascertained, 49 can be found in the eastern Bay of Plenty.

In this diagram (Figure 5-19), the grain size of the deposit is portrayed by the width of the column, and by the different shadings. Shadings are also used to distinguish between loess, paleosols, tephras, and gravels. Tephras that are known to exist in the eastern Bay of Plenty stratigraphy but were too thin to be displayed effectively in the full composite stratigraphic column (e.g. those from the upper Torere West section), are portrayed as arrows on the right hand side of the column (Figure 5-19). Tephras which are known to exist from the other sections discussed in this chapter (e.g. Reihana), are shown as arrows on the left hand side of the section in their approximate stratigraphic positions.

5-4 Division of Overall Stratigraphy into Subgroups

The pre-Rotoiti stratigraphy of the eastern Bay of Plenty has been divided into seven subgroups. From youngest to oldest the subgroups are:

- Kukumoa;
- Huntress Creek;
- Torere;
- Murupara;
- Tablelands;
- Ohiwa Harbour;
- Reeves.

Figure 5-19 : Full composite stratigraphic column for the eastern Bay of Plenty.

The base of the Rotoiti Tephra marks the upper boundary of the Kukumoa subgroup, which includes all the deposits down to the base of the Kutarere Tephra where the Huntress Creek subgroup begins. The base of the Kaingaroa Tephra marks the next boundary, and the upper weathered surface of the Matabina Tephra (base of the Torere-A Tephra) marks the contact between the Torere and Murupara subgroups. Where present, the top of the weak paleosol developed into the thick loess layer above the Kohioawa Tephra marks the next boundary (base of Murupara-A Tephra), otherwise the top of the loess itself is the boundary. The upper surface of the thick, very weathered paleosol in the lower part of the Tablelands section — that is the base of Tablelands-A Tephra — marks the boundary between the Tablelands subgroup (above) and Ohiwa Harbour subgroup below. The base of the Ohiwa Harbour subgroup has been placed at the base of the Jackson Tephra. At most sections this boundary equates with the top of the very weathered Waiotahi Gravels, but at two sites, Reeves and Ohiwa Harbour Road, several tephra below the Jackson Tephra can be seen.

These older tephra have been placed within the Reeves subgroup. However, the distinction between the Reeves and Ohiwa Harbour subgroups is tentative at present because the tephra identifications at the Reeves section are as yet unconfirmed. The Reeves subgroup may yet be found to be part of the Ohiwa Harbour subgroup.

Several sections have been studied in areas other than the eastern Bay of Plenty, and while the stratigraphic positions of most of the tephra found in these various sections are well understood, the positions of some tephra are only approximately known. Where the exact stratigraphic position of any tephra found outside the eastern Bay of Plenty is not fully understood within the eastern Bay of Plenty stratigraphy, the tephra has been assigned to an additional, separate subgroup — hence the Welcome Bay, Reihana and Ohinekoao subgroups. Where the stratigraphic position is known exactly, but the tephra is not present in the eastern Bay of Plenty stratigraphy, it has also been assigned to one of these separate subgroups.

For example, several tephra found in sections around Tauranga Harbour do not occur in the eastern Bay of Plenty. These tephra have been assigned to the Welcome Bay subgroup, but are included within the chapter describing the Huntress Creek subgroup (Chapter 11), as their stratigraphic positions are known and equate to that of the Huntress Creek subgroup.

Several tephra found at the Reihana Road section cannot yet be placed in their precise stratigraphic positions within the Torere subgroup and have therefore been assigned to the Reihana subgroup. As only a few tephra at Reihana Road have uncertain stratigraphic positions, the subgroup as a whole, apart from the Kaingaroa eruptives, has been included in the chapter describing the Torere subgroup deposits.

The Ohinekoao Reserve and Wilson's farm sections together contain many tephra whose stratigraphic positions are only partially understood, but are believed to correlate with tephra of the Ohiwa Harbour subgroup in the eastern Bay of Plenty. The two sequences (Ohinekoao & Ohiwa Harbour) are found in different areas and were deposited in different environments. No correlations between any of the individual units of these two sequences have been confirmed, and therefore the deposits

have been placed into separate subgroups. As many tephtras are involved, the Ohinekoao and Ohiwa Harbour subgroups are discussed in separate chapters.

Although each subgroup occupies an approximately equal thickness in the coastal eastern Bay of Plenty stratigraphy, there is a large range in the number of tephtras present in each, and in the length of time during which each subgroup was deposited. Differences in the rates of deposition and/or the preservation are the cause of these discrepancies. The Torere and Murupara subgroups each contain a large number of eruptives, though they were deposited over only moderate time spans. The large number of tephtras recorded is thought to be due more to their better preserved record than to an increased eruption rate. Both the Torere and Murupara subgroups are well exposed in near source sections, which allows the distinction of eruptions which are too thin in distal regions to be identified as separate units (e.g. Murupara-E). The upper part of the Torere subgroup is also well preserved within organic-rich sediments (such as lignites) at a few distal sections (i.e. Torere West, Opape), allowing very thin tephtras to be recorded (e.g. Torere-J, -M). The strongly weathered subgroups (e.g. Kukumoa, Ohiwa Harbour) may have contained just as many eruptives as those that are better preserved, but the extreme weathering may have destroyed them as recognisable tephtra deposits and incorporated them through pedogenic processes within thick paleosols.

The following chapters detail the individual eruptives in each subgroup, and incorporate tephtras of the same age found elsewhere (for example; the description of the Torere subgroup in Chapter 10 includes the Reihana subgroup).

Chapter 13 is concerned with sections which, for a number of reasons, have unknown or uncertain positions within the stratigraphic record. The tephtras within these sections are occasionally quite thick or extremely well preserved, and may represent parts of the tephrostratigraphic record which are not well represented elsewhere — for example, the Kukumoa, Ohiwa Harbour and/or Ohinekoao subgroups, or even older). Some sections (e.g. Te Piki) are found in areas far from the major area of study in this thesis (i.e. Ohiwa Harbour – Opotiki), and the tephtras at these far removed sites cannot be correlated using their physical characteristics and "hand over hand" techniques. Time constraints, or late discovery, have not allowed the detailed inspection of a number of other sites, some of which are now believed to be quite important. The stratigraphic positions of many of these sections are yet to be established.

Chapter Six : Reeves and Ohiwa Harbour subgroups

The Reeves and Ohiwa Harbour subgroups are combined in this chapter because the former subgroup is recognised from one or perhaps two sites only, and therefore is not widespread enough to be discussed separately. Where it is seen, the Reeves subgroup conformably underlies the Ohiwa Harbour subgroup, separating these deposits from the underlying Waiotahi Gravels. Elsewhere, the Ohiwa Harbour subgroup directly overlies the Waiotahi Gravels and the Reeves subgroup either cannot have been deposited at these sites, or was removed after deposition. Another alternative is that the Reeves subgroup does not exist and the deposits thought to represent it have been misidentified. Nevertheless, these two subgroups together include all deposits found in the eastern Bay of Plenty from the top of the very weathered and well developed paleosol below the Tablelands-A Tephra, down to the top of the Waiotahi Gravels.

The boundary between the Reeves subgroup and the Ohiwa Harbour subgroup occurs at the base of the Jackson Tephra. There is a very weathered paleosol below this tephra which has developed into the Reeves-D Tephra below.

A complication to this stratigraphy is the existence of the Ohinekoao subgroup in the coastal cliffs west of Matata. This subgroup may correspond in time and contain the same tephras as the Ohiwa Harbour and Reeves subgroups. However, the correlations between these two areas are still tentative due to the very different weathering conditions that existed in each area.

The Ohiwa Harbour and Reeves subgroups have undergone extreme weathering in a terrestrial environment, causing the obliteration of most primary physical characteristics. Further, all the glass in these deposits has been altered to clay, rendering correlations via glass chemistry impossible.

The Ohinekoao subgroup was deposited in a shallowing marine–estuarine–terrestrial sequence, that was then preserved from weathering by the deposition of many tens of metres of marine sediment above. The tephras in this subgroup retain unweathered glass shards, though many of the physical characteristics seen are thought to be related to subaqueous deposition, and are therefore not comparable to those in the eastern Bay of Plenty in any case.

Until positive correlations can be made between the Ohiwa Harbour and Ohinekoao subgroups, the deposits in these two areas should be discussed separately; hence a separate chapter: "Ohinekoao subgroup" (Chapter 7).

The Reeves subgroup contains at least four tephras, Reeves-A to Reeves-D; and the Ohiwa Harbour subgroup at least seven, Ohiwa-A (or Jackson) to Ohiwa-G.

The ages of the Reeves and Ohiwa Harbour subgroups, and the tephras within them, has been estimated by fitting the paleoclimatic data gathered from the Bay of Plenty sections to the SPECMAP and Bassinot LLS oxygen isotope ($\delta^{18}\text{O}$) records (see Chapter 15).

The Reeves subgroup contains tephras interbedded with loess, but has a strongly weathered paleosol at its top, developed into both loess and tephra. These deposits indicate a cool glacial climate becoming warmer at the very top.

The Ohiwa Harbour subgroup also generally contains tephras interbedded with loess, although some tephras contain paleosols in their upper part. There is also a thick very weathered paleosol developed into loess and tephra at the top of the subgroup. The paleosol is very thick and appears similar to the paleosol at the top of the Kukumoa subgroup. This latter paleosol is thought to have been produced by weathering over a period of perhaps 100 ka or greater, including two periods of warm interglacial climate. The time required for the development and weathering of the paleosol at the top of the Ohiwa Harbour subgroup is uncertain, but weathering over more than one interglacial period may not necessarily be required. This is because the climate during $\delta^{18}\text{O}$ stage-11 is believed to have been possibly the warmest to have occurred during the past million years [Burckle, 1993].

The Ohiwa Harbour subgroup is thought to have been deposited during $\delta^{18}\text{O}$ stage-12, and includes the weathering (i.e. the paleosol) that occurred during $\delta^{18}\text{O}$ stage-11. Therefore, the Reeves subgroup was probably deposited during $\delta^{18}\text{O}$ stage-14, and includes at its top the weathering that occurred during $\delta^{18}\text{O}$ stage-13. It is possible, though less likely, that these two subgroups were deposited at an earlier time and underwent extreme weathering over a significantly longer time period (for example, deposition during $\delta^{18}\text{O}$ stages-16 through to 11, with weathering occurring throughout this time; see Chapter 15).

The Ohiwa Harbour Road West section shows the Ohiwa Harbour subgroup deposited in a terrestrial environment, resting on the uppermost Reeves subgroup tephra, which overlies marine sands. The marine sediment overlies very weathered fluvial gravels, which overlie marine or lacustrine sediment, in turn overlying less weathered fluvial gravels and a thick basal unit of marine sands and muds. This sequence (shown in Figure 16-5) is thought to represent alternating warm and cold interglacial and glacial periods and the concomitant glacio-eustatic sea-level rise and fall. This sequence confirms that the Ohiwa Harbour subgroup — here occurring as subaerial deposits in a terrestrial environment — was deposited during a cooler glacial period, and the upper part of the Reeves subgroup below deposited in a warmer interglacial period. The lower Reeves subgroup tephras were not recognised here.

The best fit estimates from the oxygen isotope record give an age range for the Ohiwa Harbour subgroup of 475 ka to 400 ka, and for the Reeves subgroup of 550 ka to 475 ka (see Figure 15-4). Alternatively, but less likely, the Ohiwa Harbour subgroup may range from 550 ka to 400 ka, and the Reeves subgroup from 625 ka to 550 ka (see Figure 15-5).

The tephtras in the Reeves and Ohiwa Harbour subgroups, together with their estimated ages and minimum volumes, are: –

Ohiwa-G	c. 410–420 ka	> 2 km ³
Ohiwa-F	c. 450 ka	≥ 10 km ³
Tirohanga	c. 455 ka	≥ 10 km ³
Ohiwa-D	c. 462 ka	> 2 km ³
Ohiwa-C	c. 466 ka	> 2 km ³
Ohiwa-B	c. 470 ka	≥ 10 km ³
Jackson	c. 475 ka	≥ 20 km ³
Reeves-D	c. 485 ka	? km ³
Reeves-C	c. 520 ka	≥ 5 km ³
Reeves-B	c. 540 ka	≥ 5 km ³
Reeves-A	c. 550 ka	≥ 10 km ³

As there are few sites showing the tephtras in these two subgroups, isopach maps could not be constructed and the source areas for the eruptions are unknown. Variations in the thickness and exposure of the Ohiwa Harbour and Reeves subgroups across the coastal Bay of Plenty are shown in Figure 6-1, with correlations between sites also marked.

The mineralogy, titanomagnetite geochemistry and hornblende geochemistry, suggests at least two different batches of magma within the Ohiwa Harbour subgroup, probably associated with different sources (see Chapter 14). The Jackson, Ohiwa-B and Ohiwa-D Tephtras fall into a group that is quartz- and biotite-rich, whereas the Ohiwa-C and Tirohanga Tephtras belong to another group that contains less quartz and little biotite. The Ohiwa-F Tephtra contains little biotite, but has titanomagnetite geochemistry similar to that of the "Jackson group". The Ohiwa-G Tephtra also contains quartz and biotite, but should probably be grouped with the Tablelands-A Tephtra. Whether these two latter eruptives are related to the "Jackson group" is unknown.

Few analyses have been carried out on Reeves subgroup tephtras, but they appear to contain less biotite than the "Jackson group".

The quartz- and biotite-rich tephtras in the Ohiwa Harbour subgroup are considered not to be correlatives of the "Quartz-biotite ignimbrites" because the radiometric ages of these ignimbrites [Nairn, 1989b] are significantly younger than the age estimates for the Jackson and Ohiwa-B Tephtras.

The Reeves subgroup takes its name from the Reeves section (see Photo-7 & 7(a)), found near the intersection of Reeves and Ohiwa Loop Roads [W15/751463] at the eastern end of Ohiwa Harbour. This site shows the greatest number of tephtras seen in this subgroup. The uppermost tephtra, and possibly some of those lower down, can also be found at the Ohiwa Harbour Road West section [W15/764468], on the western side of Ohiwa Hill.

Figure 6-1 : Stratigraphy of the Reeves & Ohiwa Harbour subgroups in the coastal eastern Bay of Plenty (see appendix-(M) for key)

Table 6-1 : Glass chemistry of the Reeves-A Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	[#] Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Reeves	78.07	12.17	0.14	0.98	0.14	0.93	3.41	3.94	0.22	6.39	13	1.00
**01905	0.21	0.07	0.03	0.08	0.03	0.05	0.14	0.10	0.07	0.68		
Reeves	78.26	12.13	0.12	0.99	0.13	1.00	[#] 3.11	4.12	0.15	3.84	8	0.95*
01903	0.20	0.13	0.03	0.07	0.02	0.07	0.08	0.08	0.02	0.66		

The Ohiwa Harbour Road West section is better preserved than the Flax Hill Point section [W15/748466], though the uppermost and lowermost parts are obscured here. The upper to middle parts of the subgroup are best exposed at the Tablelands Road section [W15/887462], while the middle to lowermost parts are best seen at the Ohiwa Harbour Road West section. The lowermost parts are also visible at the Jackson Road [X15/955468] and Reeves sections.

The eleven tephra known to exist in these two subgroups are presented in the following pages in stratigraphic order of deposition (i.e. from oldest to youngest).

6-1 Reeves-A Tephra

The Reeves-A Tephra is only seen at the Reeves section and is the basal tephra in the Reeves subgroup. Its **diagnostic features** include: (see Photo-11)

- An uppermost unit of massive very bright white ash (90 cm thick).
- A middle unit of fine sandy ash (65 cm thick).
- A basal unit (80 cm thick) consisting of many well bedded ash, and coarse and fine sandy ash layers, with irregular thicknesses of the basal beds.
- Presence of cummingtonite in the ferromagnesian mineral assemblage.
- Unweathered glass shards are abundant, in comparison to the tephra above in which no glass is preserved.

Stratigraphic relationships:

The upper part of the Reeves-A Tephra does not contain a paleosol and is directly overlain by loess.

The lower part of the tephra is thought to have been deposited in a subaqueous environment, on the basis of the well preserved nature of its glass and the irregular thicknesses of the many multicoloured ash and sandy ash layers at its base. The base of the supposedly water-lain tephra rests on a thin layer of greenish silt, below which are >1.5 m of fluvial gravels (Photo-11). The silt may represent the weathering at the top of the gravels.

Chemistry and mineralogy:

The glass from two different layers within the Reeves-A Tephra (Table 6-1) was analysed: the middle (sample 01903) and the upper (sample 01905). Both samples have similar chemistries, though not particularly distinctive, with moderate values for most major element oxides except for K₂O which is higher than average. These chemistries are similar to those of the Ohinekoao-A, Ohinekoao-B and Ohinekoao-G Tephra.

The Reeves-A Tephra (upper) has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene

The Reeves-A Tephra (middle) has a ferromagnesian mineral assemblage consisting of:

hornblende + cummingtonite + biotite + hypersthene

Discussion:

The source of the Reeves-A Tephra is unknown. The presence of cummingtonite in the ferromagnesian mineral assemblage has previously been used as proof of an Okataina source. However, the age of this eruptive is thought to be much older than the initiation of activity at the Okataina Volcanic Centre. Either a source other than Okataina has at some stage erupted cummingtonite, or the Okataina Volcanic Centre is much older than previously believed.

The deposit is significantly reworked and the basal half, at least, is probably over-thickened. For these reasons no accurate estimate of volume can be made, though its likely to be at least in the order of 5–10 km³.

6-2 Reeves-B Tephra

The Reeves-B Tephra is only seen at the Reeves section and is believed to be the second tephra deposited in the Reeves subgroup.

The tephra is enclosed by loess, with the Reeves-A Tephra lying 50 cm below, and the Reeves-C Tephra 1.1 m above, resting on a paleosol into the loess. The Reeves-B Tephra is very weathered and its **physical characteristics** are:

- 25–30 cm thick, white and orange weathered tephra.
- A basal purplish lithic rich layer (3 cm thick).

No glass was found in the Reeves-B Tephra deposit.

The Reeves-B Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene + biotite

The source and size of this tephra are unknown.

6-3 Reeves-C Tephra

The Reeves-C Tephra is only seen at the Reeves section and is believed to be the third tephra deposited in the Reeves subgroup.

The Reeves-C Tephra is very weathered, and rests on a thick weathered loess paleosol. A further 60 cm of loess extends above to the base of the Reeves-D Tephra.

The **physical characteristics** of the Reeves-C tephra are:

- 25 cm of an orange, highly weathered tephra.

No glass was found in the Reeves-C Tephra.

The Reeves-C Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende + *biotite*

The source and size of the Reeves-C Tephra are unknown.

6-4 Reeves-D Tephra

The Reeves-D Tephra is believed to be the fourth and uppermost tephra deposited in the Reeves subgroup. It is believed to exist at two sites, at the Reeves and at the Ohiwa Harbour Road West sections, but identification of such weathered tephra is suspect and correlations remain tentative.

At the Reeves section the Reeves-D Tephra appears to be a weathered, very tephric-rich loess, occurring at the base of a well developed paleosol. The Jackson Tephra rests on this paleosol. The Reeves-D Tephra rests on non-tephric loess below, and can be distinguished from this loess by the tephra's 10YR 6/6 - "bright yellowish brown" colour.

At Ohiwa Harbour Road West it consists of 35 cm of recognisable tephra at the base of a very weathered silty paleosol containing vertical cracks (Photo-12). The Jackson Tephra directly overlies this paleosol. The Reeves-D Tephra here rests on white, well sorted medium sand, believed to have been deposited in a marine environment. The physical characteristics of the Reeves-D Tephra at the Ohiwa Harbour Road West section are:

- 25 cm of unconsolidated weathered sandy ash, overlying 5 cm of fine ash-clay, which in turn overlies 5 cm of basal grey bedded ash-clay.

No sample was taken of this tephra, but it is unlikely that it contains unweathered glass. The ferromagnesian mineral assemblage is not known.

The correlation of this tephra between the Reeves and Ohiwa Harbour Road West sections is based upon the similar stratigraphy of the Jackson Tephra and the thick weathered paleosol. It is possible that the tephra at Ohiwa Harbour Road West is a Reeves subgroup tephra other than Reeves-D (e.g. Reeves-B), but there is no reliable evidence for this. The tephra is better preserved at Ohiwa Harbour Road West, as it was deposited in a subaqueous environment.

6-5 Jackson Tephra

The Jackson Tephra is believed to exist at four sections in the eastern Bay of Plenty and is a distinctive stratigraphic unit wherever it is seen. It is believed to be the basal tephra deposited in the Ohiwa Harbour subgroup, and is hence also known as the Ohiwa-A Tephra.

The type section for the Jackson Tephra is at the Ohiwa Harbour Road West site. It is also well represented at the Jackson Road section, from which it takes its name. A very biotite-rich tephra found at the Reeves section is also thought to be the Jackson Tephra. It is visible at the Flax Hill section, but here it is only seen underfoot in the bed of the estuary and its true thickness cannot be determined. A mixed tephra and loess deposit at the base of the Tablelands section contains small pockets of a very biotite-rich weathered tephra that may also correlate to the Jackson Tephra.

Diagnostic features:

(see Photo-13)

- The upper half consists of unconsolidated, very weathered sandy ash containing abundant golden biotite flakes and very large quartz, feldspar and hornblende crystals. These crystals (especially the biotite) contrast with the clay matrix, giving a speckled appearance to this tephra. Two fine ash layers 0.5 cm thick occur 5 cm apart approximately mid-way through this upper layer.
- A middle layer, 20 cm thick, of very weathered fine sandy ash overlying 8 cm of weathered sandy ash-clay.
- A basal layer, 5 cm thick, consisting of 0.5 cm layers of well bedded, weathered ash-clay.
- At Jackson Road, the lower part of the tephra contains occasional large clay nodules.

This tephra generally gives an overall impression of a speckled ash layer due to the gold biotite "glitter", white feldspar and clear quartz crystals contrasting with the darker clay matrix and abundant black-brown manganese stains.

Stratigraphic relationships:

A paleosol appears to exist at the top of the Jackson Tephra, but on closer inspection this "paleosol" proves to be a layer of grey-brown very sticky clay which is believed to be compacted loess. The loess rests directly on top of the tephra, although the boundary appears to be gradual, and is 20–40 cm thick. Above it rests the Ohiwa-B Tephra.

The base of Jackson Tephra directly overlies a well developed paleosol. This paleosol has developed into: a tephra (Reeves-D) at the Ohiwa Harbour Road West and Reeves sections; into weathered gravels at the Flax Hill section; and into blue sandy clay over very weathered gravels at Jackson Road. Below the ≈3 m thick gravels at this latter site, is very weathered shattered greywacke.

Chemistry and mineralogy:

No glass remains in the Jackson Tephra; it has all been weathered to clay.

The Jackson Tephra has a ferromagnesian mineral assemblage consisting of:

biotite + hornblende

Biotite is abundant, but very weathered. The individual flakes and books are no longer black but a shiny gold colour, or occasionally even pale and wrinkled. The hornblendes are strongly etched, and although present in substantial amounts, are much less common than biotite. Hypersthene is not apparent, but it is assumed that it was originally been present and has since been totally weathered out.

The coarse crystal content and ferromagnesian mineral assemblage has suggested to some workers a correlation to the Rangitawa Tephra, but although the chemistry of the titanomagnetites is similar, there are significant differences in the hornblende chemistries which preclude correlation (see Chapter 14).

Distribution and size:

The Jackson Tephra must have originally been a relatively thick deposit, as after weathering and compaction it is still 80 cm thick at the eastern edge of Ohiwa Harbour and 50 cm thick to the east of Opotiki. Its source is unknown, but a minimum volume in the order of 20 km³ is likely.

6-6 Ohiwa-B Tephra

The Ohiwa-B Tephra is recognised at a minimum of four sites in the eastern Bay of Plenty and is believed to be the second tephra deposited in the Ohiwa Harbour subgroup.

The type section for the Ohiwa-B Tephra is the Flax Hill section. It is also well represented at the Jackson Road and Ohiwa Harbour Road West sections, and is likely to correlate to a biotite-rich white clay tephra found at the Reeves Road section. It probably also occurs near the bases of the Tirohanga and Tablelands sections, but is not well exposed at these sites.

Diagnostic features:

(see Photo-14)

- The tephra is generally <40 cm thick and very weathered, with the upper part visibly more weathered than the lower. The lower portion consists of alternating 5 cm thick beds of pink and bright white clay (altered glass). The clay is very "sticky" and contains a great deal of interstitial water.
- A basal layer of fine sand, consisting mainly of crystals and lithics.
- The tephra is biotite-rich, although not so much as the Jackson Tephra, and the biotite is less weathered than that in the Jackson (i.e. some black grains remain).

Stratigraphic relationships:

Directly overlying the Ohiwa-B Tephra is weathered loess. This loess has a yellow/orange colour, is occasionally mottled, and grades into the weathered top of the tephra. The loess is 20 cm thick at Flax Hill where the Ohiwa-C Tephra overlies it, and 60 cm thick at Jackson Road where the Tirohanga Tephra is the first tephra recognised above it. The loess at Ohiwa Harbour Road West is also 60 cm thick, with either the Ohiwa-C or Ohiwa-D Tephra overlying it.

The base of the Ohiwa-B Tephra directly overlies 20–40 cm of loess which separates it from the Jackson Tephra.

Chemistry and mineralogy:

No glass remains in the Ohiwa-B Tephra; it has all been weathered to clay.

The Ohiwa-B Tephra has a ferromagnesian mineral assemblage consisting of:

biotite + hornblende

The biotite is very weathered; the hornblendes are strongly etched and slightly less common.

Discussion:

The ferromagnesian mineral assemblage, and hornblende and titanomagnetite geochemistry of the Ohiwa-B Tephra is similar to that of the Jackson Tephra and for this reason it is thought to have the same unknown source. The tephra, although very compacted, had at least a moderate eruptive volume, c. 5–10 km³ minimum.

6-7 Ohiwa-C Tephra

The Ohiwa-C tephra is recognised at only one or two sites in the eastern Bay of Plenty and is believed to be the third tephra deposited in the Ohiwa Harbour subgroup.

The only site where the Ohiwa-C Tephra has been positively recognised is the Flax Hill section. It is likely that a tephra in a similar stratigraphic position at Ohiwa Harbour Road West is the Ohiwa-D Tephra, with the Ohiwa-C Tephra lying unrecognised within the weathered loess below it.

The Ohiwa-C Tephra lies within weathered loess, with ~20 cm of loess separating it from the Ohiwa-D Tephra above and another 20 cm separating it from the Ohiwa-B Tephra below. Its **physical characteristics** are:

- 5–10 cm of pale very weathered ash-clay.

Chemistry and mineralogy:

No glass remains in the Ohiwa-C Tephra; it has all been weathered to clay.

The Ohiwa-C Tephra has a ferromagnesian mineral assemblage consisting of:

biotite + hornblende ± (?)

The biotite is very weathered and the hornblendes are strongly etched. Little of either mineral was seen, and the presence of some unidentified dark green-black crystals (?), probably hornblende, should be noted.

Discussion:

The titanomagnetite geochemistry of the Ohiwa-C Tephra shows a closer affinity to the Tirohanga Tephra than to the Jackson and Ohiwa-B Tephra. Therefore the Ohiwa-C and Tirohanga Tephra are likely to have the same source, as yet unknown. The dacitic Manawahe Volcano, located between Lake Rotoma and the coast (see Figure 16-3), may be a possible source.

6-8 Ohiwa-D Tephra

The Ohiwa-D Tephra is recognised at only one or two sites in the eastern Bay of Plenty and is believed to be the fourth tephra deposited in the Ohiwa Harbour subgroup.

The only site where the Ohiwa-D Tephra has been positively recognised is the Flax Hill section. A probable correlative of this tephra is visible near the top of the Ohiwa Harbour Road West section, although it is possible (but less likely) that this is the Ohiwa-C Tephra instead.

The Ohiwa-D Tephra lies within weathered loess, with ≈ 30 cm of loess separating it from the Tirohanga Tephra above and 20 cm of loess from the Ohiwa-C Tephra below. Its physical characteristics are:

- 5–10 cm of pale very weathered ash-clay at Flax Hill, and ≈ 20 cm of white weathered ash-clay at Ohiwa Harbour Road West.

Chemistry and mineralogy:

No glass remains in the Ohiwa-D Tephra; it has all been weathered to clay.

The Ohiwa-D Tephra has a ferromagnesian mineral assemblage consisting of:

biotite + hornblende + (?)

The biotite is very weathered, and the hornblendes and unknown dark green-black crystals (again probably hornblende) are strongly etched.

Discussion:

The titanomagnetite geochemistry of the Ohiwa-D Tephra is similar to that of the Jackson Road and Ohiwa-B Tephra, and therefore it is likely to have the same source.

6-9 Tirohanga Tephra

The Tirohanga Tephra is recognised at several sites in the eastern Bay of Plenty and is a distinctive stratigraphic unit wherever it is seen. It is believed to be the fifth tephra deposited in the Ohiwa Harbour subgroup and is thus also known as the Ohiwa-E Tephra.

The type section for the Tirohanga Tephra is the Flax Hill section. It is also well represented at the Tablelands and Tirohanga sections, and although extremely weathered (even more than usual), may also exist at the Jackson Road section. It may also be present near the top of the Ohiwa Harbour Road West section.

Diagnostic features:

(see Photo-15)

- A noticeable paleosol has developed into the top of the tephra.
- The tephra has an unusual ginger colour (10YR 7/8 - "yellow orange" at Tablelands), very similar to that of the Kutarere Tephra (sect. 12-1) but slightly darker.
- A basal layer consisting of a hard (cemented?) white clay bed, with abundant black manganese concretions giving it a speckled appearance.
- Contains large pale yellow-white clay nodules scattered throughout, often >5 cm across and up to 10 cm across at Jackson Road. Many manganese concretions are scattered throughout, with concentrations around the clay nodules.
- The upper part of the tephra contains particles of very coarse sand size, with finer weathered ash-clay below, above a basal fine sandy layer.

Stratigraphic relationships:

A strongly coloured brown paleosol is generally present at the top of the Tirohanga Tephra, usually with the Ohiwa-F Tephra resting directly on this. At Tirohanga the paleosol is not well developed, and at Flax Hill there is a 20 cm thick loess unit between these two tephrae.

The Tirohanga Tephra normally rests directly on loess, but at Tirohanga there appears to be a weak paleosol developed into the top of what is believed to be the Ohiwa-B Tephra (but may be the Jackson Tephra) below, and no loess is visible.

Chemistry and mineralogy:

No glass remains in the Tirohanga Tephra; it has all been weathered to clay.

The Tirohanga Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende $\pm$ *biotite(t)*

The ferromagnesian minerals are very weathered, with the hornblende crystals strongly etched. No hypersthene was seen, but it is assumed that it was originally present and has since been totally weathered out.

Distribution and size:

The Tirohanga Tephra is generally 40–50 cm thick throughout the eastern Bay of Plenty, even after weathering and compaction. Its source is unknown, though it may be the same as that of the Ohiwa-C Tephra, with the dacitic Manawahe Volcano as a possible source. It is believed, on the basis of its hornblende and titanomagnetite geochemistry, to have a different source from that of the Jackson and Ohiwa-B Tephra.

Discussion:

The physical characteristics of the Tirohanga Tephra are generally artefacts of the weathering that this tephra has undergone and therefore should be used with caution for correlation purposes. For example, the Kutarere and Ohinewai ("Te Uku" variant) Tephra have very similar physical characteristics to the Tirohanga (see sect. 12-1; Photo-53), but are definitely different tephra. At the Peach Road section (southwest of Tokoroa), the tephra immediately underlying the Whakamaru Ignimbrite, which is therefore a correlative of the Rangitawa Tephra, also has very similar physical characteristics to the Tirohanga Tephra. However, the titanomagnetite and hornblende geochemistry of the Tirohanga Tephra is very different from these "look-alikes".

The ginger colour may be related to the chemistry of the glass which the deposit originally contained. The glass of Tirohanga Tephra is presumed — from comparisons with tephra that have similar mineral chemistries but still retain glass — to have had a much higher proportion of FeO, MgO & CaO, and less K₂O, than most of the other tephra in the Ohiwa Harbour subgroup. The different proportions of element-oxides in the tephra glass may have affected the rate of weathering, or the type of weathering products formed.

From its mineral geochemistry, it is thought that the Tirohanga Tephra may be a correlative of the Ohinekoao-I Tephra (see sect. 7-10) found in marine sediments west of Matata. Their titanomagnetite geochemistries, although closer to each other than to any other tephra, are sufficiently different to question correlation. The estimated ages for the two eruptives are also slightly different, but the hornblendes are chemically identical.

6-10 Ohiwa-F Tephra

The Ohiwa-F Tephra is recognised at only a few sites in the eastern Bay of Plenty and is believed to be the sixth tephra deposited in the Ohiwa Harbour subgroup.

The type section for the Ohiwa-F Tephra is the Tablelands section, and it is also well represented at the Flax Hill and Tirohanga sections.

Diagnostic features:

- The tephra is extremely weathered and appears to be a tephric-rich loess. It coarsens and becomes more tephric towards its base (i.e. from medium sandy ash to weathered pumice flecks up to 6 mm across).
- An unusual yellowish colour (10YR 7/6 at its top and 10YR 8/6 at its base; both "yellow orange") that is much lighter than that of the Tirohanga Tephra below.

Stratigraphic relationships:

At the Tablelands section, a weak paleosol can be seen in the top of the Ohiwa-F Tephra (or possibly in the tephric-rich loess overlying the tephra). Elsewhere, the top of the tephra grades into weathered loess which becomes more weathered upwards into an extremely well developed paleosol.

The Ohiwa-F Tephra generally rests directly on the paleosol developed into the Tirohanga Tephra, although at Flax Hill there appears to be a small amount of loess separating these two eruptives.

Chemistry and mineralogy:

No glass remains in this tephra, it has all been weathered to clay.

The Ohiwa-F Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende ± *biotite(t)*

Hypersthene was not recorded, but it is assumed to have originally been present and to have since been totally weathered out.

Distribution and size:

The Ohiwa-F Tephra appears to be at least 30–50 cm thick, but this thickness is uncertain as the tephra's boundary to the weathered loess above is gradual and often difficult to determine. The source of the tephra is unknown, but titanomagnetite geochemistry suggests that it may be the same as that for the Jackson and Ohiwa-B Tephra.

6-11 Ohiwa-G Tephra

The Ohiwa-G Tephra is the uppermost tephra in the Ohiwa Harbour subgroup, and is only recognised at the Tablelands section in the eastern Bay of Plenty. It is a possible correlative of the Kohioawa Stream and/or Ohinekoao-N Tephra (see sect. 13-6 & 7-15 respectively), or possibly the Westend Tephra (see sect. 13-8).

At the Tablelands section, the Ohiwa-G Tephra rests within the top half metre of a very well developed paleosol (10YR 5/8 "yellowish brown") underlying the Tablelands-A Tephra (Photo-17). Several metres of extremely weathered loess-clay (10YR 6/6 "bright yellowish brown") lie between the Ohiwa-G Tephra and the weathered top of the Ohiwa-F Tephra below.

The physical characteristics of the Ohiwa-G Tephra are:

- Exists only as a very weathered intermittent bed of pale ash-silt.

Chemistry and mineralogy:

A few glass shards were observed in the sample of Ohiwa-G Tephra at Tablelands Road, but not sufficient to separate out for analysis. The glass chemistry of its suspected correlatives — the Westend Tephra and the Kohioawa Stream Tephra — are presented in Chapter 13.

The Ohiwa-G Tephra has a ferromagnesian mineral assemblage consisting of:

biotite + hornblende ± hypersthene(t)

Hypersthene occurs in this tephra, though only in trace amounts, and its presence, along with a trace of unweathered glass shards, indicates that this tephra deposit is significantly less weathered than those stratigraphically below. Hypersthene was probably more abundant at the time of deposition, but has since been preferentially weathered out.

Discussion:

The Ohiwa-G Tephra is thin; < 15 cm thick; but this is after it has been greatly compacted by soil forming processes. Its source is unknown, but its ferromagnesian mineral assemblage suggests that it may have the same source as the Jackson and Ohiwa-B Tephra, or more likely the Tablelands-A and Kohioawa Stream Tephra which are believed to be closer in age to the Ohiwa-G Tephra.

The correlation of the Ohiwa-G Tephra to the Kohioawa Stream Tephra remains tentative because it is based chiefly upon similar ferromagnesian assemblages and an assumed similarity of their stratigraphic positions. This position is not well defined in the marine sequence due to the lack of continuous outcrop above and below the reworked tephra, and the presence of faults nearby causing the stratigraphic relationships of the adjacent sediments to be uncertain.

The Westend Tephra has a significantly different ferromagnesian mineral assemblage and is therefore a less likely correlative.

Chapter Seven : Ohinekoao subgroup

The Ohinekoao subgroup is thought to correspond in time to the Reeves and Ohiwa Harbour subgroups, and contain many of the same tephras. The latter two subgroups are defined in the coastal eastern Bay of Plenty, whereas the Ohinekoao subgroup occurs at the central Bay of Plenty coast, just west of Matata. The Ohinekoao subgroup is found not far below what is confidently believed to be the basal Tablelands subgroup tephra, and the Ohiwa Harbour subgroup is in a similar stratigraphic position, in that it immediately underlies the Tablelands subgroup.

Some difficulty in correlating the tephras between these two areas has occurred due to the very different natures of the deposits. The Ohiwa Harbour and Reeves subgroups have undergone extreme weathering which has obliterated most primary physical characteristics and altered all glass to clay. The Ohinekoao subgroup is much less weathered, and the tephras still contain unweathered glass shards. The physical characteristics of their deposition have been retained, although many of these are thought to be related to subaqueous deposition. As the two areas are widely separated, however, any physical features that may have been preserved in western areas, may never have existed in the corresponding eastern tephras.

As glass chemistry could not be used to correlate between these two areas, correlations using hornblende and titanomagnetite geochemistry were attempted (see Chapter 14). However, the results were inconclusive and correlations between the two areas remain tentative.

The age of the Ohinekoao subgroup, and the tephras within it, have been estimated by fitting the paleoclimatic data gathered from the Bay of Plenty sections to the SPECMAP and Bassinot LLS oxygen isotope ($\delta^{18}\text{O}$) records (see Chapter 15).

The Ohinekoao subgroup was deposited in an estuarine-terrestrial environment, bounded both above and below by sediments deposited in a fully marine environment. This subgroup is therefore thought to represent deposition during a low relative sea-level associated with a glacial period. No estuarine-terrestrial sediments have been recognised between those of this subgroup and the top of the Tablelands subgroup, about 40 m above; only fossiliferous marine sands are present here. These sands represent deposition during a period of relatively high sea-level associated with an interglacial period. Since the

Tablelands subgroup is believed to have been deposited during $\delta^{18}\text{O}$ stage-10, the marine sands probably represent the high sea-level of $\delta^{18}\text{O}$ stage-11, and thus the Ohinekoao subgroup deposition would have occurred during $\delta^{18}\text{O}$ stage-12. The best fit estimates from the oxygen isotope record give an age range for the Ohinekoao subgroup of *c.* 475 ka to *c.* 420 ka.

This age is the same as that estimated (by the same method) for the Ohiwa Harbour subgroup (Chapters 6 & 15), but no direct dating has been carried out on any of the deposits in either subgroup.

It is possible, though unlikely, that the Ohinekoao subgroup is much older than this age estimate (see sect. 5-2.7). However, this does not preclude the aforementioned correlation between the Ohiwa Harbour and Ohinekoao subgroups, since it is also possible that the Ohiwa Harbour subgroup is much older than the preferred estimate — 475–420 ka (see Chapter 6).

Until positive correlations can be made between the Reeves–Ohiwa Harbour subgroups and the Ohinekoao subgroup, the deposits in these two areas should be discussed separately.

The Ohinekoao subgroup consists of all deposits seen at the Ohinekoao Reserve section, and those of equivalent age at Wilson's farm, that are thought to have been deposited during a period of low glacio-eustatic sea-level. Many of the tephra and tephric deposits within this subgroup can be readily traced along within the coastal cliffs west of Matata, and correlated to deposits at Wilson's farm. The basal tephra in the subgroup is the Ohinekoao-A Tephra.

This chapter will discuss all the tephra found in these areas whose stratigraphic positions are reasonably well constrained.

Many of the tephra under discussion are not represented by primary airfall or flow deposits, but by the presence of tephric sediment only. Within the sediment, most of the pure or almost pure pumice beds — those with near 100% tephric material — are believed to be related to and contemporaneous, or nearly so, with the eruptions that produced the material. It is thought that major floods occur immediately following many eruptions, and these wash the newly deposited and unconsolidated airfall tephra deposits off the surrounding landscape and into the fluvial and marine systems. Devegetation of the landscape during eruptions would assist erosion. Therefore the subaqueously deposited "tephra" may also, along with the primary airfall tephra, provide chrono-synchronous horizons.

Deposits consisting of less pumiceous sediment (<<50% tephric material) are believed to represent the reworking of older deposits. Glass chemistry often shows these units to have a mixture of glass with the presence of several different chemical types. Sometimes individual shard chemistries can be identified as originating from underlying eruptives. These mixed deposits are not treated as distinct tephra in general, but rather as reworked deposits derived from the tephra below. Occasionally, however, the only record of a tephra may be a subgroup of distinctive glass chemistry within one of these reworked deposits. In such cases, the unique subgroup of glass is treated as a distinct tephra, even though no definitive deposit can be associated with its eruption.

Table 7-0 : Similarity coefficients (S.C.'s) for representative chemistries of Ohinekoao subgroup tephras

oldest	O8401	O0913	O0912	O8402a	O8402b	O0910	O0904a	O0903	O0907	O0901	O0902	O8303	O0909	O0911	O7806	O7805
Wilson	1.00															
Ohinekoao-A	0.67	1.00														
Ohinekoao-B	0.68	0.95	1.00													
Ohinekoao-C(a)	0.75	0.87	0.89	1.00												
Ohinekoao-C(b)	0.66	0.95	0.94	0.85	1.00											
Ohinekoao-D	0.92	0.70	0.72	0.79	0.69	1.00										
Ohinekoao-E	0.83	0.60	0.61	0.66	0.58	0.80	1.00									
Ohinekoao-G	0.65	0.95	0.93	0.84	0.95	0.68	0.58	1.00								
Ohinekoao-H	0.85	0.76	0.78	0.86	0.75	0.88	0.74	0.73	1.00							
Ohinekoao-I	0.95	0.66	0.67	0.73	0.64	0.90	0.86	0.64	0.83	1.00						
Ohinekoao-J	0.72	0.86	0.87	0.91	0.84	0.76	0.63	0.84	0.82	0.70	1.00					
Ohinekoao-K	0.78	0.83	0.86	0.94	0.81	0.83	0.69	0.80	0.90	0.76	0.91	1.00				
Ohinekoao-L	0.74	0.89	0.91	0.96	0.86	0.78	0.65	0.85	0.85	0.72	0.92	0.94	1.00			
Ohinekoao-M	0.82	0.79	0.81	0.90	0.77	0.87	0.72	0.76	0.92	0.79	0.86	0.93	0.89	1.00		
Wilson's farm-(3) 07806	0.80	0.79	0.81	0.89	0.77	0.85	0.71	0.76	0.91	0.77	0.86	0.94	0.89	0.96	1.00	
Wilson's farm-(2) 07805	0.83	0.79	0.81	0.90	0.77	0.87	0.71	0.76	0.92	0.80	0.86	0.93	0.88	0.99	0.95	1.00
youngest																

tephras in boxed shaded area are believed to be the same eruptive

The tephtras that occur in the coastal cliff marine sequence west of Matata, from just below the Ohinekoao subgroup to just above, and their estimated ages and minimum volumes, are: –

Ohinekoao-N / Kohioawa Stream	c. 420–425 ka	?
Ohinekoao-M	c. 430–435 ka	≥ 4 km ³
Ohinekoao-L	c. 435–440 ka?	≥ 2 km ³
Ohinekoao-K	c. 440–445 ka?	≥ 5 km ³
Ohinekoao-J	c. 445–450 ka?	≥ 10 km ³
Ohinekoao-I	c. 450 ka?	≥ 5 km ³
Ohinekoao-H	c. 450–455 ka?	≥ 5 km ³
Ohinekoao-G	c. 465 or 455 ka?	?
Ohinekoao-F	c. 465 or 455 ka?	?
Ohinekoao-E	c. 465 or 455 ka?	?
Ohinekoao-D	c. 465–470 ka?	?
Ohinekoao-C	c. 470 ka?	?
Ohinekoao-B	c. 470 ka?	≥ 5 km ³
Ohinekoao-A	c. 475 ka?	≥ 10 km ³
Wilson	c. 490 ka?	?

In Chapter 15, the Ohinekoao and Ohiwa Harbour subgroups are treated as equivalents, with several individual tephra correlations presented, but the correlations are still very tentative and there are several minor differences in the paleo-environmental age record between the two areas. The ages above reflect the paleo-environmental record found in the coastal cliffs west of Matata, and although generally similar to those of the Ohiwa Harbour subgroup tephtras, are slightly different from those presented in Figure 15-4. Only two areas show moderate age differences, with the tephtras in the marine sequence (Ohinekoao Reserve) apparently slightly younger than those in the eastern Bay of Plenty. The Ohinekoao-E, -F, and -G Tephtras show the greatest difference and two possible ages for each are given here. The younger possible age of c. 455 ka for the Ohinekoao-E Tephtra may mean that it, rather than the Ohinekoao-I Tephtra, is the most likely correlative of the Tirohanga Tephtra.

Figure 7-1 shows a comparison of the glass chemistries of all tephtras within the Ohinekoao subgroup. There is a wide range of chemistries, and many of the tephtras can be readily identified via their glass chemistry alone. However, there are several groups of eruptives which each contain tephtras that are chemically indistinguishable. The Ohinekoao-J, -K, and -M Tephtras comprise one of these groups, while the Ohinekoao-A and -G Tephtras form another.

Similarity coefficients which compare the glass chemistries of all of the tephtras in the Ohinekoao subgroup, as well as the Wilson Tephtra, are presented in Table 7-0.

Several of the tephras in the Ohinekoao subgroup have high Al_2O_3 , FeO & CaO , and low SiO_2 contents relative to the bulk of the tephras in this study and may be rhyo-dacitic in nature. The Manawahe Volcano, located 10–15 km to the south, is a possible source of these tephras. Lavas from this dacitic volcano have been Kr–Ar dated at 0.425 ± 0.27 Ma [Stipp, 1968; Nairn & Beanland, 1989].

Figure 7-1 : Relative proportions of glass chemical means of selected element-oxides
— Ohinekoao subgroup tephras

The tephras in this subgroup can only be recognised at a few sections: the type section at Ohinekoao Reserve [V15/369629]; the coastal cliffs just to the east of here; on Wilson's farm driveway [V15/386622]; the cliffs above the driveway; and at Wilson's farm-(5) [V15/384620]. The Wilson's farm-(2), -(3), and -(4) sections contain deposits whose stratigraphic positions are still uncertain, and Wilson's farm-(1) contains the Tablelands subgroup and Matahina Ignimbrite.

Figure 7-2 (next page) shows a comparison between the Ohinekoao Reserve and Wilson's farm sections.

The fourteen tephras that are found in the Ohinekoao subgroup, and one slightly older eruptive, are presented in the following pages in stratigraphic order of deposition (i.e. from oldest to youngest).

Probable correlations to the Ohiwa Harbour and Reeves subgroups are also mentioned.

Figure 7-2 : Comparison between the stratigraphy of the Ohinekoao subgroup at the Ohinekoao Reserve and the Wilson's farm sections.

Table 7-1 : Glass chemistry of the Wilson Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Wilson's driveway	75.31	13.75	0.28	1.96	0.34	2.19	3.38	2.64	0.15	8.70	6
**08401	0.65	0.35	0.04	0.08	0.03	0.20	0.09	0.09	0.02	2.31	

7-1 Wilson Tephra

The Wilson Tephra is only recognised at one site — the Wilson's driveway section — and it stands alone, not belonging to any subgroup. This tephra may be of the same age as the Ohiwa Harbour or Reeves subgroup in the eastern Bay of Plenty, but is certainly older than the Ohinekoao subgroup. It was deposited within the deeper marine paleoenvironment associated with the interglacial high sea-level immediately prior to the lowering of sea-level and deposition of the Ohinekoao subgroup; probably during $\delta^{18}\text{O}$ stage-12.

The Wilson Tephra is not observed as an airfall deposit, but only as discrete reworked pumices within massive very fine sand. This sand unit is ~10 m thick; the base contains common pumice but, becomes less pumiceous upwards. It is overlain by unconsolidated, very pumiceous, cross-bedded medium/coarse sands deposited in a much shallower marine environment.

The Wilson pumiceous sand has a gradational basal contact with a non-pumiceous massive very fine sand, the thickness of which is at least 5 m (and probably >20 m).

The diagnostic features of the Wilson Tephra include:

- Pumices that are up to 2 cm across and contain large hornblende crystals.
- Distinctive rhyo-dacitic glass chemistry.
- Presence of cummingtonite in the ferromagnesian mineral assemblage.

Chemistry and mineralogy:

The glass chemistry of the Wilson Tephra (Table 7-1) has, in comparison with most of the tephra in this study, very high values of FeO & CaO; high Al_2O_3 , TiO_2 & MgO; and low SiO_2 & K_2O , with $\text{Na}_2\text{O} \gg \text{K}_2\text{O}$ (3.4 >> 2.7). The normalised chemical values show the Wilson Tephra to be rhyolitic, but before normalisation the data plot just inside the dacitic field; one of the few tephra data sets in this study to do so.

The Wilson Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende + *cummingtonite*

The dacitic nature of the glass in the Wilson Tephra deposit suggests that its source may be the nearby Manawahe Volcano. If this area is indeed the source, then the volume of the eruptives is likely to be small, because although large pumices exist, they were found as discrete lapilli and no tephra "layer" was recognised.

Table 7-2.1 : Glass chemistry of the Ohinekoao-A Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Ohinekoao Reserve	77.42	12.55	0.14	1.05	0.15	0.89	3.44	4.10	0.26	5.85	11
**00913	0.31	0.11	0.04	0.10	0.03	0.06	0.10	0.17	0.06	1.17	

Table 7-2.2 : Glass chemistry of reworked pumice believed to have been derived from the Ohinekoao-A Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 00913
Ohinekoao Reserve	77.70	12.35	0.10	0.96	0.14	0.85	3.51	4.13	0.28	6.17	10	0.94
00908a	0.14	0.09	0.03	0.05	0.04	0.06	0.18	0.14	0.05	0.84		
Wilson's driveway	77.38	12.43	0.15	0.98	0.14	0.81	3.46	4.39	0.27	3.65	5	0.95
08402b	0.51	0.19	0.03	0.01	0.05	0.04	0.23	0.14	0.09	1.85		

7-2 Ohinekoao-A Tephra

The Ohinekoao-A Tephra is the basal tephra in the Ohinekoao subgroup. As a primary airfall deposit, this tephra is only recognised at one site, the Ohinekoao Reserve section; but it is also thought to be present in reworked, pumiceous, cross-bedded shallow marine sands at Wilson's driveway.

Diagnostic features of the airfall deposit:

- The upper 40 cm of this tephra consists of two beds of granular pumice lapilli separated by thin layers of ash. This overlies:
- A normally graded bed (granular pumice to fine sandy ash) 16 cm thick, overlying:
- 5 cm of purplish ash, with some lapilli at top, overlying:
- 20 cm of pumice lapilli up to 1 cm across, overlying:
- 50 cm of ash, which overlies a basal layer (5 cm thick) of granular pumice lapilli.

Stratigraphic relationships:

The Ohinekoao-A Tephra at Ohinekoao Reserve rests directly on a 3 cm thick layer of organic-rich silt, over quartz-rich, iron stained marine sands, >0.5 m thick. The uppermost ash beds are directly overlain by 10 cm of brown organic-rich silt; and a thin bed of reworked rounded pumices, probably derived from the Ohinekoao-A Tephra itself, lies just above this.

Chemistry and mineralogy:

The glass chemistry of the Ohinekoao-A Tephra (Table 7-2.1) has moderate values for most major element oxides (including FeO & CaO), but has a higher than average K₂O wt.%. The primary tephra deposit is represented by sample 00913, while sample 00908a represents a reworked rounded pumice deposit lying ~0.5 m above (Table 7-2.2). This reworked pumice is likely to be derived from both the Ohinekoao-A and Ohinekoao-B Tephra; the former eruptive being the larger and probably the dominant source.

The Ohinekoao-A Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene + biotite ± augite

Discussion:

The Ohinekoao-A Tephra is 1.3 m thick at Ohinekoao Reserve, and the bulk of this deposit is believed to be airfall, although it may have been directly deposited in a subaqueous environment.

As material from this eruption was eroded from the surrounding landscape and redeposited as the overlying estuarine and shallow marine sediments, the tephra must have been of at least moderate size, and have covered the landscape to some depth. Its source is unknown, but from glass chemistry is thought not to be the Manawahe Volcano.

Table 7-3 : Glass chemistry of the Ohinekoao-B Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Ohinekoao Reserve	77.55	12.38	0.17	1.02	0.14	0.96	3.55	3.97	0.26	4.99	12
**00912	0.26	0.11	0.05	0.11	0.03	0.11	0.17	0.24	0.06	1.15	

The estimated age of the Ohinekoao-A Tephra, in conjunction with its ferromagnesian mineral assemblage, suggests a possible correlation to either the Jackson Tephra or Ohiwa-B Tephra in the Ohiwa Harbour subgroup.

7-3 Ohinekoao-B Tephra

The Ohinekoao-B Tephra is only recognised at one site — the Ohinekoao Reserve section — and is believed to be the second tephra deposited in the Ohinekoao subgroup.

This tephra is thought to be of primary airfall origin as it consists of 100% tephritic material with no evidence of reworking, such as cross-bedding or rounded grains. However, it rests on a layer of rounded pumice pebbles, probably derived from the underlying Ohinekoao-A Tephra. It is therefore believed to have been deposited in a subaqueous environment, and thus may have been slightly over-thickened.

Diagnostic features:

- The top layer consists of 14 cm of coarse sandy ash and granular pumice, with the upper surface showing some weathering.
- A thin (4 cm thick) fine ash bed separates the top layer from the basal coarse sandy ash layer (11 cm thick).

Stratigraphic relationships:

The top of the Ohinekoao-B Tephra appears to have undergone weathering and is directly overlain by 15 cm of brown organic-rich silt. Above this silt there is a pumiceous sand unit; the pumices being very rounded indicating their reworked nature.

The airfall Ohinekoao-B Tephra overlies a 2 cm thick layer of rounded reworked pumice lapilli which rests directly on a brown organic-rich silt paleosol over the Ohinekoao-A Tephra.

Chemistry and mineralogy:

The glass chemistry of the Ohinekoao-B Tephra (Table 7-3) shows moderate values for most major element oxides, although K_2O is slightly higher than average (≈ 4.0). Apart from a slightly lower K_2O content, this chemistry is very similar to that of the underlying Ohinekoao-A Tephra.

The purity of the glass chemistry (single population) indicates that the Ohinekoao-B Tephra is a primary deposit and not reworked.

The Ohinekoao-B Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene + biotite

Table 7-4 : Glass chemistry of reworked pumice believed to have been derived from the Ohinekoao-C Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 08402a	S.C. 08402b
Ohinekoao Reserve 00908b	77.16 0.23	12.65 0.12	0.19 0.04	1.21 0.08	0.20 0.02	1.22 0.15	3.61 0.04	3.54 0.12	0.23 0.03	6.42 0.52	4	0.98	0.84
Ohinekoao Reserve 00904b	76.19 0.30	13.33 0.25	0.19 0.04	1.26 0.06	0.16 0.03	1.26 0.18	3.65 0.09	3.78 0.22	0.17 0.04	7.67 0.89	5	0.95	0.85
Wilson's driveway **08402a	77.37 0.57	12.60 0.39	0.19 0.04	1.24 0.13	0.19 0.05	1.18 0.10	3.46 0.19	3.57 0.19	0.22 0.07	5.67 1.73	19	1.00	0.85
Ohinekoao Reserve 00908a	77.70 0.14	12.35 0.09	0.10 0.03	0.96 0.05	0.14 0.04	0.85 0.06	3.51 0.18	4.13 0.14	0.28 0.05	6.17 0.84	10	0.82	0.94
Wilson's driveway **08402b	77.38 0.51	12.43 0.19	0.15 0.03	0.98 0.01	0.14 0.05	0.81 0.04	3.46 0.23	4.39 0.14	0.27 0.09	3.65 1.85	5	0.85	1.00
Wilson's driveway 08402c	78.97 0.50	12.06 0.66	0.18 0.01	0.85 0.02	0.13 0.03	0.91 0.02	3.31 0.12	3.40 0.28	0.19 0.04	4.61 0.08	2	0.87	0.90

Figure 7-2 : The mixture of glass chemistries in the cross-bedded pumiceous sands at Wilson's driveway (sample 08402).

Discussion:

The Ohinekoao-B Tephra is 30 cm thick at Ohinekoao Reserve, where it is believed to be airfall. Its chemical and mineralogical similarity to the Ohinekoao-A Tephra suggests that they have a common source, as yet unknown, and are perhaps from the same magma batch.

On the basis of its estimated age and ferromagnesian mineral assemblage, the Ohinekoao-B Tephra is a possible correlative of the Ohiwa-B Tephra in the Ohiwa Harbour subgroup.

7-4 Ohinekoao-C Tephra

Glass from the Ohinekoao-C Tephra has only been recognised at two sites, and only within reworked deposits. This glass is believed to represent the third tephra deposited in the Ohinekoao subgroup.

The Ohinekoao-C Tephra forms the dominant glass type in a reworked deposit at the Wilson's driveway section, and a minor component in a reworked deposit at Ohinekoao Reserve. These deposits represent the first occurrence of this moderately distinctive glass type. The eruption which produced this distinctive glass occurred at some unknown time before the deposition of the reworked pumiceous sediment, but probably only shortly before. However, it is possible that the Ohinekoao-C Tephra was erupted before the Ohinekoao-B, or perhaps even the Ohinekoao-A Tephra.

The sediment containing Ohinekoao-C Tephra pumice at Ohinekoao Reserve is 75 cm thick and bounded by organic-rich silt layers; 9 cm thick above, and 15 cm thick below.

At Wilson's driveway, the cross-bedded medium/coarse sand which contains pumice derived from the Ohinekoao-C Tephra is ≥ 6 m thick. This pumiceous unit is the same as that which contains reworked Ohinekoao-A Tephra.

Chemistry and mineralogy:

The pumiceous sand unit at Ohinekoao Reserve (sample 00908) contains a mixture of glass from two eruptives (Table 7-4). The major component (00908a) is thought to be reworked Ohinekoao-A Tephra (or perhaps Ohinekoao-B) as it has near identical glass chemistry to the thick airfall deposit found only a few metres below. The minor glass component (00908b) is totally different, with moderately high values for FeO & CaO, and $\text{Na}_2\text{O} \approx \text{K}_2\text{O}$. This glass is quite distinctive compared with the tephtras found both above and below, and has been designated as being from the Ohinekoao-C Tephra.

Pumice with this chemistry is also present in a layer, also with mixed chemistry, not far above (sample 00904b), and within cross-bedded medium/coarse pumiceous sands at Wilson's driveway. This latter unit contains a mixture of shards of at least three different chemistries; samples 08402a, b, and c (Fig. 7-3; Table 7-4).

The greater part of the glass in this pumiceous deposit is derived from the Ohinekoao-C Tephra (A = 08402a). A secondary glass population is probably derived from the Ohinekoao-A Tephra (B), and a third glass population has an unknown parent tephra. As this third population only occurs in a very minor

Table 7-5 : Glass chemistry of the Ohinekoao-D Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Ohinekoao Reserve	74.87	13.66	0.29	1.89	0.35	1.73	3.66	3.36	0.19	5.68	11
**00910	0.69	0.44	0.08	0.18	0.02	0.15	0.14	0.16	0.03	1.26	

quantity, contamination during sampling and processing cannot be totally ruled out and the glass has not been designated as a separate eruptive. A single shard forms a fourth group of glass.

The Ohinekoao-C Tephra is only one of several components in these reworked deposits, and therefore the ferromagnesian mineral assemblage of this tephra cannot be determined.

7-5 Ohinekoao-D Tephra

The Ohinekoao-D Tephra is only recognised at one site — the Ohinekoao Reserve section — and is believed to be the fourth tephra deposited in the Ohinekoao subgroup.

The tephra consists of a single thin sandy ash layer, only 4 cm thick. It is recognisable by its distinctive glass chemistry, and the contrast of its pale colour against the surrounding dark organic-rich deposits, which form a layer 10–20 cm thick above, and 9 cm thick below.

Chemistry and mineralogy:

The glass chemistry of the Ohinekoao-D Tephra (Table 7-5) is distinctive with very high FeO & CaO wt.%; high Al₂O₃, TiO₂ & MgO; and low SiO₂ & K₂O, with Na₂O (3.7) > K₂O (3.4). This chemistry is similar to that of the older Wilson Tephra, but has significantly lower CaO and higher K₂O. Ohinekoao-D glass plots close to the dacitic field and may be considered to be a rhyo-dacite.

The Ohinekoao-D Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende ± augite(t) ± biotite?(t)

Discussion:

The Ohinekoao-D Tephra is believed to be airfall, and as it is only 4 cm thick it is thought to have a small volume. Its source is unknown, but is possibly be the Manawahe Volcano.

The estimated age and ferromagnesian mineral assemblage of the Ohinekoao-D Tephra suggest a possible correlation with the Ohiwa-C Tephra in the eastern Bay of Plenty. However, the tephra is thicker there than at Ohinekoao Reserve, and this is unlikely with a Manawahe sourced eruptive.

7-6 Ohinekoao-E Tephra

The Ohinekoao-E Tephra is only recognised at one site — the Ohinekoao Reserve section — and is believed to be the fifth tephra deposited in the Ohinekoao subgroup.

The Tephra lies within dark organic-rich silt; 5–10 cm thick above; and 10 cm below, which grades down into >3 m of paler, less organic-rich silt and fine sand.

Table 7-6.1 : Glass chemistry of the Ohinekoao-E Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Ohinekoao Reserve	72.65	14.50	0.42	2.46	0.63	2.55	3.74	2.86	0.20	7.13	7	1.00
**00904a	0.16	0.22	0.04	0.16	0.04	0.12	0.11	0.07	0.06	1.35		
Ohinekoao Reserve	76.19	13.33	0.19	1.26	0.16	1.26	3.65	3.78	0.17	7.67	5	0.66
00904b	0.30	0.25	0.04	0.06	0.03	0.18	0.09	0.22	0.04	0.89		

Table 7-6.2 : Glass chemistry of reworked pumice believed to have been derived from the Ohinekoao-E Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 00904a
Ohinekoao Reserve	72.57	14.54	0.47	2.51	0.60	2.43	3.80	2.87	0.20	5.33	6	0.97
00906a	0.70	0.39	0.07	0.12	0.09	0.11	0.24	0.15	0.04	1.66		

Diagnostic features:

- An upper layer (10 cm thick) of fine ash containing occasional pockets of coarse sandy ash.
- A basal layer, highly variable in thickness (≈ 5 cm thick on average), of coarse sandy ash and granular pumice lapilli up to 1 cm across.
- Has a distinctive glass chemistry.

Chemistry and mineralogy:

The glass chemistry of the Ohinekoao-E Tephra (Table 7-6.1) shows that it contains a mixture of shards from two eruptives.

The dominant type has a very distinctive chemistry, with extremely high FeO & CaO wt.%; high Al_2O_3 ; and very low SiO_2 & K_2O ; with Na_2O (3.7) $\gg$ K_2O (2.9). It also has a very high TiO_2 wt.% and an extremely high MgO content; the highest of any tephra seen in this study. This chemistry, when normalised, plots just within the rhyolitic field, but before normalisation plots as a dacite.

The secondary chemical component is a good match with the Ohinekoao-C Tephra and is believed to represent some reworking of that tephra into the deposit. The layer sampled was the coarse basal unit, which, due its highly variable nature, is not likely to be a primary deposit.

Material from the Ohinekoao-E Tephra is also believed to have been reworked into cross-bedded pumiceous sediment (sample 00906a) which lies 1 m above (Table 7-6.2). This pumiceous sediment (sand and silt) contains glass from two different tephtras, the other being the Ohinekoao-G Tephra.

The ferromagnesian mineral assemblage of the deposit containing the Ohinekoao-E Tephra is:

hypersthene + hornblende + biotite

Due to its mixed glass chemistry, these minerals are unlikely to represent the true ferromagnesian mineral assemblage of the tephra and should be used with caution.

Discussion:

It is uncertain whether the deposit containing Ohinekoao-E Tephra glass is predominantly airfall, or whether it contains a significant amount of reworked material. There is some physical evidence for the reworking of an underlying tephra deposit into the basal bed of this tephra, and the glass chemistry supports this, but the upper part of the tephra may be primary airfall. Therefore the true thickness of the Ohinekoao-E Tephra is not known. The Ohinekoao-E glass chemistry, although significantly different, shows some similarities to the Wilson and Ohinekoao-D Tephtras. Therefore it also has the Manawahe Volcano as a possible source.

The tephric layer containing Ohinekoao-E Tephra glass is the first in the Ohinekoao subgroup containing this distinctive glass chemistry. Deposition probably occurred at the same time as, or only slightly after the Ohinekoao-E eruption.

The Ohinekoao-E Tephra is a possible correlative of the Ohiwa-C Tephra, or less likely, to the Tirohanga Tephra, in the eastern Bay of Plenty.

Table 7-8.1 : Glass chemistry of the Ohinekoao-G Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Ohinekoao Reserve	77.93	12.14	0.14	1.00	0.12	0.85	3.41	4.21	0.21	6.13	12
**00903	0.44	0.45	0.03	0.12	0.01	0.04	0.18	0.23	0.06	1.54	

Table 7-8.2 : Glass chemistry of reworked pumice believed to have been derived from the Ohinekoao-G Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 00903
Ohinekoao Reserve	77.29	12.73	0.17	1.00	0.10	0.85	3.39	4.18	0.30	3.08	7	0.95
00906b	0.50	0.29	0.05	0.15	0.03	0.06	0.16	0.14	0.04	2.10		

7-7 Ohinekoao-F Tephra

The Ohinekoao-F Tephra is only seen at one site — the Ohinekoao Reserve section — and is believed to be the sixth tephra deposited in the Ohinekoao subgroup.

The Ohinekoao-F Tephra is seen only as thin (2 cm thick) pockets of fine white ash, within dark organic-rich silts — 2–5 cm thick above the ash to the base of the Ohinekoao-G Tephra; and 5–10 cm below, to the top of the Ohinekoao-E Tephra.

No samples were taken of the Ohinekoao-F Tephra and hence no glass chemistry or ferromagnesian mineral assemblage is presented.

7-8 Ohinekoao-G Tephra

The Ohinekoao-G Tephra is only recognised at one site — the Ohinekoao Reserve section — and is believed to be the seventh tephra deposited in the Ohinekoao subgroup.

This tephra consists of a single layer of ash and fine sandy ash 4–7 cm thick, within dark black/brown organic-rich silt; 2–5 cm thick below the ash, and 20 cm thick above. The top of the organic-rich silt above has an erosional boundary to brown-grey silts and several metres of reworked pumiceous sediment.

Chemistry and mineralogy:

The glass chemistry of the Ohinekoao-G Tephra (Table 7-8.1) has moderate values for most major element oxides, (e.g. $1.0 \approx \text{FeO}$; $\text{CaO} \approx 0.8$), except for K_2O which is higher than average. Only one chemical type is present, indicating that this is a primary tephra deposit. The glass chemistry, apart from its slightly higher K_2O wt.%, is similar to that of the Ohinekoao-A and Ohinekoao-B Tephtras.

Sample 00906b (Table 7-8.2) comes from the pumiceous sand unit just above, which contains a mixture of glass types. The other major chemical type in this sample matches that of the Ohinekoao-E Tephra.

The Ohinekoao-G Tephra has a ferromagnesian mineral assemblage consisting of:

biotite + hornblende

Discussion:

The Ohinekoao-G Tephra is only 5 cm thick, and is thus believed to have only a small volume. The source of this tephra is unknown, but may be the same as that of the Ohinekoao-A and Ohinekoao-B Tephtras.

On the basis of its estimated age and ferromagnesian mineral assemblage, the Ohinekoao-G Tephra is a possible correlative of the Ohiwa-D Tephra in the eastern Bay of Plenty.

Table 7-9 : Glass chemistry of the Ohinekoao-H Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Ohinekoao Reserve	76.36	13.22	0.21	1.62	0.25	1.62	3.54	2.99	0.19	2.70	10
**00907	0.37	0.26	0.03	0.15	0.02	0.11	0.13	0.11	0.04	1.68	

7-9 Ohinekoao-H Tephra

The Ohinekoao-H Tephra is only recognised at one site — the Ohinekoao section — and is believed to be the eighth tephra deposited in the Ohinekoao subgroup.

At this section the tephra is believed to be of airfall origin.

Diagnostic features:

- Consists of a single moderately thick (35 cm) bed of pumice lapilli which appears to have undergone some weathering.
- Has a distinctive glass chemistry.

Stratigraphic relationships:

The Ohinekoao-H Tephra has a gradual upper boundary to a 10 cm thick, dark organic-rich silt which probably represents terrestrial paleosol development. The Ohinekoao-I Tephra rests on this paleosol.

The Ohinekoao-H Tephra directly overlies a 1 m thick bed of very fine sand and silt, which in turn overlies a 2 m thick bed of reworked pumiceous sands and silts.

Chemistry and mineralogy:

The glass chemistry of the Ohinekoao-H Tephra (Table 7-9) is relatively distinctive. It has high FeO & CaO, and low K₂O, with Na₂O (3.5) > K₂O (3.0). This glass chemistry shows some similarities to those of the Wilson and Ohinekoao-D Tephra; but has significantly lower wt.% values for K₂O, CaO, TiO₂ & MgO.

The Ohinekoao-H Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende ± augite(t) ± biotite(t)

Discussion:

The Ohinekoao Tephra is 35 cm thick, and appears to represent a primary airfall deposit. Its source is unknown, and on the basis of its estimated age and ferromagnesian mineral assemblage it is a possible correlative of the Tirohanga Tephra in the eastern Bay of Plenty.

7-10 Ohinekoao-I Tephra

The Ohinekoao-I Tephra is believed to be the ninth tephra deposited in the Ohinekoao subgroup. It is recognised at several sites in the cliffs west of Matata.

The Ohinekoao Reserve section has been designated the type section for the Ohinekoao-I Tephra. The tephra is also recognised at the Wilson's farm-(5) section, though here it is believed to have been reworked; and in the coastal cliffs running parallel to the road between these two sections.

Table 7-10.1 : Glass chemistry of the Ohinekoao-I Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	*Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Ohinekoao Reserve	74.75	13.92	0.31	1.99	0.41	2.31	#3.41	2.74	0.16	4.87	9	1.00
**00901	0.75	0.28	0.04	0.16	0.10	0.19	0.42	0.14	0.03	0.96		
Wilson's farm-(5)	74.51	13.89	0.30	2.00	0.36	2.19	3.74	2.80	0.20	3.78	11	0.96*
08304	0.28	0.14	0.06	0.13	0.05	0.09	0.13	0.11	0.05	0.51		

Table 7-10.2 : Glass chemistry of reworked pumice believed to have been derived from the Ohinekoao-I Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 00901
Wilson's farm-(5)	74.69	13.75	0.33	2.05	0.41	2.11	3.68	2.81	0.19	6.51	13	0.96*
08302	0.48	0.46	0.06	0.13	0.06	0.18	0.21	0.16	0.05	2.24		

Diagnostic features:

(see Photo-16)

- At Ohinekoao Reserve and in the coastal cliffs just to the east, the tephra consists of a single, clast supported, very coarse pumice lapilli layer (pumice up to 5 cm across). This layer has a variable thickness — ranging from 40 to 80 cm.
- At Wilson's farm-(5), the tephra is represented by 30 cm of granular pumice lapilli (≤ 1 cm across).
- Pumices from this tephra are highly vesicular and are generally very buoyant.

Stratigraphic relationships:

The Ohinekoao-I Tephra at Ohinekoao Reserve has a thin (5 cm thick), organic-rich silt/paleosol at its top, with the Ohinekoao-J Tephra resting directly on this. The Ohinekoao-I Tephra directly overlies 10 cm of a dark organic-rich silt/paleosol.

At Wilson's farm-(5) the tephra is overlain by a 1 m thick bed of pumiceous silt, with a 30 cm thick layer of compacted and cemented pumice lapilli overlying this. The compacted pumice bed is believed to be reworked Ohinekoao-I Tephra as there are non-tephric pebbles occurring in the basal part of the unit. Above this reworked unit occur more pumiceous sands and silts. The tephra overlies ≥ 1 m of shallow marine sands and silts at the base of the section.

Chemistry and mineralogy:

The glass chemistry of the Ohinekoao-I Tephra (Table 7-10.1) is very distinctive. It has very high wt.% FeO & CaO; high Al_2O_3 , TiO_2 & MgO ; and low SiO_2 & K_2O , with Na_2O (3.7) $\gg$ K_2O (2.8).

The tephra is rhyolitic, but plots very close to the dacite field before normalisation. The glass chemistry is similar to that of the Wilson Tephra and approximately half-way between those of the Ohinekoao-D and Ohinekoao-E Tephrae. The parent magmas of all of these eruptives are believed to be related.

Sample 08302 (Table 7-10.2) comes from the compact pumice layer just above the first appearance of Ohinekoao-I Tephra glass at the Wilson's farm-(5) section (sample 08304) and is believed to be reworked from either the primary deposit below, or from the nearby terrestrial landscape.

The Ohinekoao-I Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene

Discussion:

The Ohinekoao-I Tephra is 40–80 cm thick at Ohinekoao Reserve and 30 cm thick at Wilson's farm-(5). This variation in thickness and the difference in the grain size — up to 5 cm across at one site and ≤ 1 cm at the other — between these two sections, suggests that the deposit at one or both sites is reworked, rather than primary airfall. It is unclear whether the single bed of Ohinekoao-I Tephra at Ohinekoao Reserve represents the upper compact layer, or the underlying airfall, at Wilson's farm-(5).

The source of the Ohinekoao-I tephra is unknown, but it is likely to be the same as that for the Wilson, Ohinekoao-D, and Ohinekoao-E Tephra; possibly the Manawahe Volcano.

The Ohinekoao-I Tephra, and the Ohinekoao-J Tephra above it, are an easily recognisable pair of tephra in the cliff face running parallel to the coast and road. The Ohinekoao-I Tephra's buoyant pumices would have enhanced its transport in the fluvial and marine environments, and in conjunction with its very distinctive glass chemistry, the tephra may be a useful tool for correlation between other areas containing late Castlecliffian marine and fluvial deposits.

On the basis of its estimated age and ferromagnesian mineral assemblage, the Ohinekoao-I Tephra is the most likely Ohinekoao subgroup correlative of the Tirohanga Tephra in the eastern Bay of Plenty.

7-11 Ohinekoao-J Tephra

The Ohinekoao-J Tephra is recognised at several sites in the cliffs west of Matata, and is believed to be the tenth tephra deposited in the Ohinekoao subgroup.

The Ohinekoao Reserve section has been designated as the type section for the Ohinekoao-J Tephra. The tephra is also seen at the Wilson's farm-(5) section and in the coastal cliffs running parallel to the road between these two sections.

At both Ohinekoao Reserve and Wilson's farm-(5), the **diagnostic feature** of the Ohinekoao-J Tephra is:

- A single, massive, granular pumice and lapilli bed ~100 cm thick (max. clast size = 1.5 cm across) (see Photo-7-1).

Stratigraphic relationships:

The Ohinekoao-J Tephra at Ohinekoao Reserve is directly overlain by 70 cm of cross-bedded, highly pumiceous sand and rounded pumice lapilli gravels (clasts up to 5 cm across). These gravels have presumably been reworked from the underlying tephra, or perhaps from the Ohinekoao-K Tephra, and are overlain by coarse sand which contains only occasional pumice clasts. At Wilson's farm-(5), 10 cm of silt, then 10 cm of reversed graded fine sand, and a further 3 cm of silt separate the Ohinekoao-J Tephra from the Ohinekoao-K Tephra above.

At Ohinekoao Reserve, the Ohinekoao-J Tephra rests on a weak organic-rich silt paleosol at the top of the Ohinekoao-I Tephra. At Wilson's farm-(5), the Ohinekoao-J Tephra overlies 30 cm of silt, some organic-rich, which becomes more pumiceous downwards to a reworked Ohinekoao-I pumice layer.

Table 7-11.1 : Glass chemistry of the Ohinekoao-J Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	*Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Ohinekoao Reserve	77.75	12.84	0.16	1.35	0.16	1.30	*2.70	3.55	0.19	6.91	12	1.00
**00902	0.28	0.12	0.03	0.08	0.03	0.07	0.22	0.14	0.05	1.10		
Wilson's farm-(5)	77.19	12.97	0.14	1.45	0.15	1.28	3.16	3.54	0.13	4.52	14	0.95*
08301	0.49	0.20	0.03	0.09	0.03	0.04	0.30	0.14	0.03	1.28		

Table 7-11.2 : Glass chemistry of reworked pumice believed to have been derived from the Ohinekoao-J Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 00902
Ohinekoao Reserve	75.99	13.27	0.23	1.44	0.22	1.36	3.59	3.74	0.18	5.16	25	0.87*
00905a	0.43	0.36	0.06	0.25	0.06	0.13	0.25	0.34	0.06	2.28		

Chemistry and mineralogy:

The glass chemistry of the Ohinekoao-J Tephra (Table 7-11.1) is significantly different from chemistries of the underlying tephtras, but similar to several pumiceous beds above. It has high, rather than very high, wt.% FeO & CaO; and moderate values for the other major element oxides.

Sample 00905a (Table 7-11.2) was taken from a pumiceous sand unit lying several metres above the Ohinekoao-J Tephra at Ohinekoao Reserve, and may represent reworked Ohinekoao-J Tephra, or possibly reworked Ohinekoao-K Tephra.

The Ohinekoao-J Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene + biotite (?)

Biotite was seen in the Wilson's farm-(5) sample, but not in the Ohinekoao Reserve sample.

Discussion:

The Ohinekoao-J Tephra shows consistent physical characteristics where it can be seen in the cliffs paralleling the road running east from the Ohinekoao Reserve section. This tephra, along with the underlying Ohinekoao-I Tephra, can be readily traced along in the cliffs for 500 m to the Ohinekoao Stream, and can be recognised again further along and much higher in the cliffs at Wilson's farm.

The Ohinekoao-J Tephra is 100 cm thick at both the Ohinekoao Reserve and Wilson's farm-(5) sections, indicating that the deposit is primary airfall. If this is a true airfall thickness, then the tephra must have had at least a moderate volume; and perhaps a much larger volume if its tentative correlation to the Ohiwa-F Tephra in the eastern Bay of Plenty is correct.

7-12 Ohinekoao-K Tephra

The Ohinekoao-K Tephra is believed to be the eleventh tephra deposited in the Ohinekoao subgroup. It is a primary deposit at only one site, the Wilson's farm-(5) section, but is also thought to be present as pumice in a reworked deposit 2–3 m above the Ohinekoao-J Tephra at the Ohinekoao Reserve section.

At Wilson's Farm, the Ohinekoao-K Tephra consists of 60 cm of clast-supported angular pumice lapilli. The angular nature indicates that little or no reworking has occurred and that the deposit is likely to be primary airfall. Immediately above the tephra, separated from it by an erosional boundary, is a bed of rounded pumice gravel clasts.

At Ohinekoao Reserve, in the same stratigraphic position as the Ohinekoao-K Tephra, there are cross-bedded, highly pumiceous sands which contain rounded pumice gravel clasts up to 5 cm across. These gravels, which directly overlie the Ohinekoao-J Tephra, may correlate to the Ohinekoao-K Tephra, or may be reworked Ohinekoao-J Tephra. Directly below the Ohinekoao-K Tephra at Wilson's farm-(5) lies a thin layer of silt, over reversed graded fine sand on top of the Ohinekoao-J Tephra.

Table 7-12.1 : Glass chemistry of the Ohinekoao-K Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Wilson's farm-(5)	76.15	13.23	0.18	1.46	0.20	1.37	3.57	3.59	0.24	9.33	13
**08303	0.34	0.17	0.04	0.12	0.04	0.06	0.06	0.09	0.04	0.87	

Table 7-12.2 : Glass chemistry of reworked pumice possibly derived from the Ohinekoao-K Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 08303
Ohinekoao Reserve	75.99	13.27	0.23	1.44	0.22	1.36	3.59	3.74	0.18	5.16	25	0.95
00905a	0.43	0.36	0.06	0.25	0.06	0.13	0.25	0.34	0.06	2.28		
Wilson's farm-(2)	75.55	13.27	0.23	1.46	0.23	1.39	3.95	3.67	0.26	3.28	12	0.94
07806	0.36	0.29	0.06	0.11	0.04	0.12	0.11	0.16	0.05	0.77		
Wilson's farm-(3)	76.47	12.91	0.25	1.51	0.24	1.35	3.53	3.51	0.24	3.75	11	0.93
07805	0.33	0.15	0.08	0.11	0.04	0.06	0.10	0.11	0.02	0.97		

Chemistry and mineralogy:

The glass chemistry of the Ohinekoao-K Tephra (Table 7-12.1) is very similar to that of the Ohinekoao-J Tephra, except for slightly higher values of Al_2O_3 , FeO , CaO , TiO_2 & MgO . The differences in SiO_2 & Na_2O content between the two tephtras is likely to be due to the difference in the analytical procedure used (see sect. 3-3).

Sample 00905a (Table 7-12.2) represents glass from the pumiceous sand unit 2–3 m above the Ohinekoao-J Tephra at Ohinekoao Reserve. Sample 07805 comes from a pumiceous sand deposit containing reworked rounded pumices at Wilson's farm-(3), which is believed to be at the same topographic and stratigraphic height as the pumice gravels immediately above the Ohinekoao-K Tephra at Wilson's farm-(5).

The Ohinekoao-K Tephra has a ferromagnesian mineral assemblage consisting of:

biotite + hornblende

This ferromagnesian mineral assemblage is difficult to reconcile with the glass chemistry, as normally biotite is found in large quantities only in tephtras with glass chemistries containing >4.0 wt.% K_2O .

Discussion:

Similarity of glass chemistry makes it virtually impossible to separate the Ohinekoao-J, Ohinekoao-K and Ohinekoao-M Tephtras. The parent eruptives for any reworked tephtric deposits are also difficult to determine. These three tephtras are likely to have originated from the same source; as yet unknown. The angular pumice exhibited by the Ohinekoao-K deposit at Wilson's farm-(5) determined that this deposit was not reworked, but a separate primary eruptive.

7-13 Ohinekoao-L Tephra

The Ohinekoao-L Tephra is only recognised at one site — the Ohinekoao Reserve section — and is believed to be the twelfth tephra deposited in the Ohinekoao subgroup.

- The tephra is believed to be of airfall origin; its distinguishing **physical characteristic** being a 20 cm thick layer containing thin alternating beds of sandy ash.

The tephra is overlain by 30 cm of silt, grey at the base but becoming browner and more organic-rich upwards; with pumiceous and pebbly sands above. It rests upon a weak paleosol which contains scattered brown pumice. This paleosol has developed into a unit of slightly pumiceous sands and silts overlying the highly pumiceous sand and pumice gravel found above the Ohinekoao-J Tephra.

Table 7-13: Glass chemistry of the Ohinekoao-L Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Ohinekoao Reserve **00909	76.79 0.37	12.97 0.27	0.17 0.04	1.32 0.10	0.18 0.05	1.12 0.10	3.53 0.11	3.69 0.11	0.22 0.03	3.75 1.43	10	1.00
Ohinekoao Reserve 00909b	77.74 0.30	12.54 0.24	0.14 0.01	0.97 0.02	0.15 0.04	0.85 0.12	3.37 0.07	3.98 0.19	0.25 0.07	3.18 2.19	3	0.87

Chemistry and mineralogy:

The glass chemistry of the Ohinekoao-L Tephra (Table 7-13) shows a mixture of two chemical types. The dominant chemical type has only a moderately high FeO wt.%, and moderate values for the other major element oxides.

The secondary chemical type is similar to that of the Ohinekoao-A Tephra.

The Ohinekoao-L Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene + biotite

Discussion:

The bedding of the Ohinekoao-L Tephra, and the fact that it appears to rest upon a weak paleosol, indicates that the tephra represents a primary airfall deposit. The cause of the mixture of glass is uncertain, but it may be due to mixing during the eruption process.

7-14 Ohinekoao-M Tephra

The Ohinekoao-M Tephra is only recognised at one site — the Ohinekoao Reserve section — and is believed to be the thirteenth tephra deposited in the Ohinekoao subgroup.

The tephra is believed to be of airfall origin and its **physical characteristics** consist of:

- An upper 10 cm thick layer of white fine ash.
- Two middle units; 4 cm of granular pumice lapilli over 7 cm of well sorted coarse sandy ash.
- A 15 cm thick basal layer of reverse graded granular pumice to coarse lapilli (up to 1 cm across).

Stratigraphic relationships:

The Ohinekoao-M Tephra is overlain by a 2 m thick unit of hard brown massive silt. A line of rounded pumice lapilli separates the tephra from this silt, throughout which many rounded pumice and harder rock lithics are scattered — lithics being more common in basal third. The silt unit is thought to represent a single depositional event, possibly a lahar or hyper-concentrated stream-flow, or a very large flood.

Below the Ohinekoao-M Tephra is a 50 cm thick unit of silt; the upper 5–10 cm of which is organic-rich, which overlies the pumiceous and pebbly sand just above the Ohinekoao-L Tephra.

Table 7-14.1 : Glass chemistry of the Ohinekoao-M Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Ohinekoao Reserve	76.40	13.05	0.25	1.42	0.24	1.36	3.61	3.49	0.19	6.31	11
**00911	0.34	0.20	0.09	0.12	0.05	0.07	0.10	0.11	0.05	1.51	

Table 7-14.2 : Glass chemistry of reworked pumice possibly derived from the Ohinekoao-M Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 00911
Wilson's farm-(2)	75.55	13.27	0.23	1.46	0.23	1.39	3.95	3.67	0.26	3.28	12	0.96
07806	0.36	0.29	0.06	0.11	0.04	0.12	0.11	0.16	0.05	0.77		
Wilson's farm-(3)	76.47	12.91	0.25	1.51	0.24	1.35	3.53	3.51	0.24	3.75	11	0.99
07805	0.33	0.15	0.08	0.11	0.04	0.06	0.10	0.11	0.02	0.97		

Chemistry and mineralogy:

The glass chemistry of the Ohinekoao-M Tephra (Table 7-14.1) has a higher than average FeO & CaO wt.%, and moderately high values for TiO₂ & MgO. This chemistry is very similar to those of the Ohinekoao-J and Ohinekoao-K Tephra.

Sample 07806 (Table 7-14.2) represents glass from a reworked pumiceous sand and gravel layer at Wilson's farm-(2), which is a likely correlative of the Ohinekoao-M Tephra in this area. Sample 07805 is from a similar unit at Wilson's farm-(3), found topographically 12 m lower, and tentatively identified as reworked Ohinekoao-K Tephra. Much work remains to be done in this area since the Ohinekoao-N Tephra is also a possible correlative of this upper reworked deposit.

The Ohinekoao-M Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene

Discussion:

The Ohinekoao-M Tephra is 36 cm thick at Ohinekoao Reserve. Its well bedded nature, together with the reverse grading of the basal layer, suggests that the deposit was deposited as airfall. Its source is unknown, but from its glass chemistry the tephra is thought to have the same origin as the Ohinekoao-J and Ohinekoao-K Tephra, and possibly also the Ohinekoao-H Tephra.

7-15 Ohinekoao-N Tephra

The Ohinekoao-N Tephra is believed to be the fourteenth tephra deposited in the Ohinekoao subgroup. It is seen high up in the cliffs above the Ohinekoao Reserve section where it could not be reached. It is likely that this tephra is a correlative of the more accessible Kohioawa Stream Tephra (see sect. 13-6), or perhaps the Westend Tephra (see sect. 13-8). It is also be a possible correlative of the uppermost tephra in the Ohiwa Harbour subgroup in the eastern Bay of Plenty — the Ohiwa-G Tephra (see sect. 6-11).

The Ohinekoao-N Tephra can be seen through binoculars as a 1 m thick layer of pumice. It is uncertain whether this pumice is an airfall deposit, or a bed of reworked pumice.

This pumice layer is overlain by >15 m of what appears to be fine sand, and underlain 2–3 m of fine sand, followed by 2–3 m of pumiceous sand to the top of the brown silt (lahar/flood) deposit below.

The Kohioawa Stream Tephra lies within cross-bedded pumiceous sand and gravel, thought to occur 15–20 m below the Tablelands-A Tephra.

No samples could be taken of the Ohinekoao-N Tephra deposit at Ohinekoao Reserve, but glass chemistry is available for the Kohioawa Stream Tephra, and for the Westend Tephra (sect. 13-6, and 13-8 respectively).

Discussion:

Very little is known about the Ohinekoao-N Tephra apart from its stratigraphic position and hence its approximate age. The Kohioawa Stream Tephra, found in the coastal cliffs 700 m to the west, also has an estimated age of c. 420–430 ka, and is ≈ 1 m thick. These two tephras are likely correlatives, but much more work is required in the coastal cliff sequence to confirm this.

The Ohinekoao-N Tephra lies in the same approximate stratigraphic position as the Ohiwa-G Tephra in the Ohiwa Harbour subgroup, but so do several other tephras found in upper part of the Ohinekoao subgroup.

The Ohinekoao-N Tephra may instead be a correlative of the Westend Tephra (see sect. 13-8), though this latter eruptive has an uncertain stratigraphic position.

Chapter Eight : Tablelands subgroup

The Tablelands subgroup includes all deposits in the coastal central and eastern Bay of Plenty from the top of the very weathered and well developed paleosol below the Tablelands-A Tephra, to the top of the weak paleosol developed into the loess above the Kohioawa Tephra (i.e. base of the Murupara-A Tephra).

Six tephra deposits are recognised within this subgroup, one of which, the Kohioawa, forms the thickest airfall unit seen in this study. A generalised stratigraphy of the Tablelands subgroup as it exists in the coastal eastern Bay of Plenty is presented in Figure 8-1.

The age of the Tablelands subgroup and the tephras within it have been estimated by fitting the paleoclimatic data gathered from the Bay of Plenty sections to the SPECMAP and Bassinot LLS $\delta^{18}\text{O}$ records (see Chapter 15). In the lower part of the subgroup paleosols have developed into the tephras, whereas in the upper part there are unweathered massive loess layers between the tephras. In the marine sequence west of Matata, the subgroup was deposited in a shallowing upwards environment believed to be associated with glacio-eustatic sea-level fall. The Tablelands subgroup thus represents deposition at first in a relatively warm climate, which then cooled into full glacial conditions, specifically, from the latter part of oxygen isotope stage-11, through all of stage-10. The best fit estimates give an age range for this subgroup of c. 400 ka to 340 ka, with an average of one eruption per 10 000 years.

The tephras that occur in the Tablelands subgroup and their estimated ages and minimum volumes, are: –

Kohioawa	c. 350 ka	>30 km ³
≡ <i>Whakamaru Ignimbrite</i>	" "	c. 1000 km ³
≡ <i>Rangitawa</i>	" "	c. 700 km ³
Paerata	c. 370 ka	≥ 15 km ³
Tablelands-D	c. 370 ka	> 1.5 km ³
Tablelands-C	c. 375 ka	> 1 km ³
Otarawairere	c. 385 ka	≥ 10 km ³
Tablelands-A	c. 400 ka	> 5 km ³

Figure 8-1 : Generalised stratigraphy of the Tablelands subgroup in the coastal eastern Bay of Plenty (see appendix-(M) for key)

There are not enough sites showing the tephra in this subgroup to enable the construction of isopach maps which could pin-point the source area for these eruptions. However, some of the tephra thicknesses and distributions in the coastal Bay of Plenty suggest an Okataina source. The volumes (listed previous page) were calculated using this source, which also happens to be the closest, and therefore are minimum values only.

Most of the eruptives observed in the Tablelands subgroup form thick deposits and have large minimum volume estimates ($\geq 10 \text{ km}^3$). Fewer smaller eruptives are preserved in this subgroup than in any other.

The tephra within the Tablelands subgroup generally have similar glass chemistries and ferromagnesian assemblages; their relatively high K_2O melts resulting in an abundance of biotite. Many of these eruptives therefore cannot be separated by their glass chemistry alone, in particular the Otarawairere, Tablelands-C, Tablelands-D and Kohioawa-(b) Tephra (Fig.8-2). These four eruptions are all likely to have the same source, perhaps even originating from the same magma batch. They are probable correlatives of the "Paeroa Group" ignimbrites (see Table 2-2) which are thought to have erupted from the Kapenga Volcanic Centre. The "Quartz-biotite ignimbrites" are also possible correlatives.

Figure 8-2 : Relative proportions of the analytical means of selected element-oxides — from many samples of tephra within the Tablelands subgroup, plus the Matahina Ignimbrite.

Two tephra, the Kohioawa and the Tablelands-A, have mixed glass chemistry assemblages. These mixtures are probably the result of simultaneous eruptions from different areas, but further work on this aspect is required. One of the components of the Kohioawa Tephra (a) is believed to be a correlative of

the Rangitawa Tephra, which is widespread across much of New Zealand and the surrounding ocean basins.

The Paerata Tephra, can be distinguished from the other eruptives on its glass chemistry alone, but also has a very distinctive ferromagnesian mineral assemblage consisting predominantly of cumingtonite. The presence of this mineral, and the areal distribution of the tephra, both suggest a source in the Okataina Volcanic Centre.

Similarity coefficients comparing the glass chemistries of all of the tephtras in the Tablelands subgroup, together with the Rangitawa Tephra, are presented in Table 8-0.

Table 8-0 : Similarity coefficients (S.C.'s) which compare representative chemistries of Tablelands subgroup tephtras.

<i>oldest</i>		02104a	02104b	04110	00810	04101	00811	01603a	01603b
Tablelands-A(a)	02104a	1.00							
Tablelands-A(b)	02104b	0.85	1.00						
Otarawairere	04110	0.92	0.79	1.00					
Tablelands-C	00810	0.88	0.76	0.92	1.00				
Tablelands-D	04101	0.84	0.73	0.89	0.95	1.00			
Paerata	00811	0.90	0.92	0.84	0.80	0.77	1.00		
Kohioawa(a)	01603a	0.92	0.88	0.88	0.84	0.81	0.89	1.00	
Kohioawa(b)	01603b	0.85	0.74	0.88	0.95	0.95	0.75	0.82	1.00
Rangitawa	08001	0.93	0.88	0.89	0.85	0.81	0.91	0.97	0.82
<i>youngest</i>									

The best area to view the stratigraphy of the Tablelands subgroup is in the coastal cliffs at Kohioawa [W15/366631], just west of Matata. The tephtras here were deposited in shallow marine and estuarine environments which allowed good preservation. The Otawairere [W15/637532] and Tablelands Road [W15/887462] (Photo-6) sections also show this subgroup well, except for the lowermost tephra — at Otawairere; and uppermost tephra — at Tablelands. The Tablelands-C Tephra is difficult to distinguish in the more eastern areas, and is only sparsely preserved at Otawairere. The subgroup is present at the Waiotahi cliff section [W15/799482], but can only be observed through binoculars from the base of the section. The Brown's driveway section also contains a good exposure of the Tablelands subgroup, although here many of the tephtras are thought to been deposited in a sub-aqueous environment, possibly lacustrine.

Figure 8-3 shows variations in the thickness and exposure of the Tablelands subgroup across the coastal Bay of Plenty. Correlations between sites are marked.

The six tephtras known to exist in the Tablelands subgroup are presented in the following pages in stratigraphic order of deposition (from oldest to youngest).

Table 8-1 : Glass chemistry of the Tablelands-A Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C. 02104a
Kohioawa cliffs	78.46	12.19	0.12	0.94	0.11	0.88	#3.17	4.02	0.16	4.65	6	0.97
00804a	0.23	0.09	0.02	0.06	0.02	0.07	0.06	0.13	0.03	0.32		
Tablelands	78.62	12.07	0.11	0.95	0.11	0.85	#3.03	4.12	0.15	5.48	9	1.00
**02104a	0.43	0.26	0.01	0.08	0.03	0.10	0.15	0.24	0.04	0.72		
												S.C. 02104b
Kohioawa cliffs	78.52	12.18	0.14	1.12	0.16	1.17	#3.18	3.37	0.16	4.30	5	0.85
00804b	0.19	0.10	0.03	0.08	0.04	0.11	0.07	0.06	0.03	0.55		0.97
Tablelands	78.80	11.99	0.15	1.14	0.15	1.21	#3.10	3.32	0.14	5.08	7	0.85
*02104b	0.23	0.07	0.03	0.08	0.03	0.09	0.14	0.18	0.01	1.09		1.00

8-1 Tablelands-A Tephra

The Tablelands-A Tephra is the basal deposit in the Tablelands subgroup, but is recognised at only a few sites in the coastal Bay of Plenty.

The type section for the Tablelands-A Tephra is at Tablelands Road, and it is present in other sections showing the Tablelands Terrace cover-beds (e.g. Tirohanga & Brown's driveway). The only other area where this tephra is recognised is in the marine sequence at Kohioawa cliffs where it is present as a pumiceous sand unit.

Diagnostic features:

- Found generally as a weathered white ash, but still recognisable as being tephric.
- Its glass chemistry contains a distinctive mixture of two chemical types.
- Directly overlies a brown very weathered and well developed paleosol.

Stratigraphic relationships:

In the upper part of the Tablelands-A Tephra at the type section, and at Brown's driveway, there is a moderately well developed paleosol exhibiting a reasonable amount of soil structure. The Otarawairere Tephra rests on this paleosol.

Immediately below the Tablelands-A Tephra there is a thick, dark (10YR 5/8 – "yellowish brown"), very strongly weathered paleosol developed into loess (see Photo-17). The upper surface of this paleosol near-horizontal, with only a small amount of relief, and marks the boundary between the Tablelands subgroup (above) and the Ohiwa Harbour subgroup (below).

In the marine sequence at Kohioawa cliffs, the Tablelands-A Tephra overlies fossiliferous, grey fine sand; and is itself overlain by ≥ 15 m of massive grey-brown sand that contains no pumice. The fossils (see appendix-(C)) are all shallow water species existing on soft substrate—generally inner shelf—and occur over a time range from Nukumaruan/Castlecliffian to recent.

Chemistry and mineralogy:

The glass chemistry of the Tablelands-A Tephra (Table 8-1) is interesting in that it contains a mixture of two different chemical types (Fig. 8-4). The two chemistries are quite dissimilar, and it is more likely that two separate chemical clusters exist, rather than one highly variable chemistry scattered over a wide range.

The two chemical types are present in roughly equal amounts and although neither of them is particularly distinctive, the combination of the two may be. As the Tablelands-A Tephra has only been analysed at two sites, the consistency of its mixed chemistry—and thus its distinctiveness—has yet to be fully tested.

Chemistry type "b" is unusual in having a rather low wt.% K_2O —lower than usual for the tephra contained in this study—and having $CaO \geq FeO$.

Figure 8-4 : Individual glass shard chemical analyses of the Tablelands-A Tephra
— relative proportions of selected element-oxides

The Tablelands-A Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene + biotite

These ferromagnesian minerals represent the combined assemblage from both glass chemical types. Hypersthene, and to some extent hornblende, are preferentially weathered out, and hence at the more weathered sites (e.g. Tablelands Road) biotite is the dominant mineral in the ferromagnesian mineral assemblage.

Discussion:

Ascertaining the true thickness of the Tablelands-A Tephra is difficult as it is generally weathered and has a not inconsiderable depth of paleosol developed into its upper parts. The thickness of the relatively unweathered tephra in sections near Opotiki is >20 cm, but if part of its paleosol is included, a thickness of ≈ 0.5 m is possible.

The mixture of glass chemistries in the Tablelands-A Tephra is useful for correlations in the eastern Bay of Plenty but may be a hindrance for more widespread correlations. The mixture of glass could be the result of magma mixing, or coeval eruptions from two separate sources. If the mixture is the result of a two coeval eruptions, the proportions of the two chemical types may vary in different areas of the country

due to the different distributions of the two eruptives. The ferromagnesian mineral assemblage may also vary accordingly.

The Tablelands-A(b) chemistry is a possible match to one of the Quartz-biotite ignimbrites analysed in this study [sample-09401]. Although the other Quartz-biotite ignimbrite sample analysed [sample-09501] was chemically altered, a match to the Tablelands-A(a) type chemistry cannot be ruled out. An age of 0.38 ± 0.05 Ma [Nairn, 1989b; Kohn *et al.*, 1992] (Table 2-2) was determined for a sample of a Quartz-biotite ignimbrite taken from Totorā Road [G.R. V16/294249; or N77/099937 on older NZMS-1 maps), which compares favourably with the age estimated for the Tablelands-A Tephra in this study — 0.39–0.40 Ma (see Chapter 15). Further work is required to confirm this very tentative correlation.

8-2 Otarawairere Tephra

The Otarawairere Tephra is named after the section where it is best preserved. It is believed to be the second tephra deposited in the Tablelands subgroup, and is hence also known as the Tablelands-B Tephra.

The type section for the Otarawairere Tephra is the Otarawairere section. It is also recognised at the Tablelands, Burchett, Tirohanga, Brown's driveway and Pukeruru Point sections, and is present as coarse pumice lapilli in shallow marine pumiceous sands in the Kohioawa cliff section west of Matata.

Diagnostic features: (see Photo-18)

- Generally present as a massive white sandy ash. At the type section the tephra is coarser; containing small pumice lapilli.
- Contains abundant black biotite crystals which contrast well against the white ash matrix.
- Large quartz and feldspar crystals, several mm in length, are present within the ash, and also within the large pumices found in the marine sediments in the Kohioawa cliffs.

Stratigraphic relationships:

The upper half of the Otarawairere Tephra has generally been weathered, forming a weak to moderately developed paleosol. This paleosol occasionally forms a pedo-complex with the paleosol developed into and through the overlying Tablelands-C Tephra. In such cases, the Tablelands-C Tephra is not observed and the grey Tablelands-D Tephra is the first eruptive recognised above the Otarawairere.

The Otarawairere Tephra overlies a paleosol developed into: the Tablelands-A Tephra (at Tablelands; see Photo-17); a grey sand/silt resting on weathered gravels (at the Paerata & Pukeruru Point sections); and weathered beach gravels (at Otarawairere; see Photo-18).

At the Kohioawa cliff site, the Otarawairere Tephra exists as a pumiceous, cross-bedded shallow marine sand unit; which is ~10 m thick. The upper boundary of this sand is gradational to a pumice free orange-brown sand, while the lower contact is more well defined with a basal normally graded pumice lapilli and marine sand mixture overlying non-pumiceous grey-brown fine sand.

Table 8-2 : Glass chemistry of the Otawairere Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Kohioawa cliffs	78.25	12.26	0.11	0.79	0.09	0.68	#3.19	4.62	0.14	3.38	10	0.95*
00802	0.19	0.08	0.03	0.06	0.01	0.03	0.12	0.17	0.02	0.60		
Tablelands	78.42	12.21	0.10	0.82	0.09	0.71	#3.02	4.59	0.15	3.84	9	0.94*
02106	0.18	0.14	0.01	0.06	0.02	0.04	0.10	0.09	0.02	0.70		
Pukeruru Point	78.30	12.25	0.08	0.80	0.09	0.63	#3.15	4.58	0.16	4.87	9	0.91*
02504	0.20	0.14	0.02	0.09	0.03	0.08	0.10	0.14	0.04	0.62		
Otarawairere	77.19	12.81	0.11	0.91	0.10	0.70	3.46	4.58	0.21	8.56	11	1.00
**04110	0.17	0.19	0.03	0.05	0.03	0.05	0.15	0.10	0.04	0.76		
Burchett	77.25	12.60	0.10	0.95	0.09	0.69	3.52	4.63	0.23	4.86	6	0.96
04605	0.14	0.22	0.05	0.05	0.02	0.05	0.07	0.08	0.03	0.54		

Chemistry and mineralogy:

The glass chemistry of the Otawairere Tephra (Table 8-2) is very similar to several other tephras in the Tablelands subgroup — the Tablelands-C, Tablelands-D and Kohioawa Tephras. These tephras are characterised by low MgO, very low CaO, and very high K₂O contents. Few other tephras in this study have such distinctive chemistry and it is likely that all of these eruptives originated from the same source.

The Otawairere Tephra has a ferromagnesian mineral assemblage consisting of:

biotite + hornblende

Discussion:

The Otawairere Tephra both thickens and coarsens towards the west, though the coarse pumice in the marine sediments at Kohioawa cliffs is believed to have been washed in and not related to primary deposits. The thickness of the Otawairere Tephra is difficult to determine due to weathering in its upper half, but has been estimated at ≈ 0.5 m near Opotiki, and is ≈ 1 m thick at its type section near Whakatane.

The distribution pattern of the Otawairere Tephra suggests a source in the northern part of the T.V.Z., possibly the Okataina Volcanic Centre.

The Otawairere Tephra has an estimated age of *c.* 0.38–0.39 Ma (see Chapter 15). This age, together with its ferromagnesian mineral assemblage and the presence of large quartz and feldspar crystals, suggests a possible correlation of the Otawairere Tephra with the quartz-biotite ignimbrite(s); which have a similar age of 0.38 ± 0.05 Ma [Nairn, 1984; Nairn, 1989b; Kohn *et al.*, 1992] (see Table 2-2).

From stratigraphic drill-hole cores through the northern Kaingaroa Plateau [Nairn, 1984], the "Quartz-biotite tuffs" occur below the Rangitaiki Ignimbrite, and very closely underlie, or are mixed with, tuffs which contain fibrous yellow pumice lapilli; possibly similar to that found in the Paerata Tephra. A correlation between the Otawairere Tephra and the quartz-biotite ignimbrite(s) is thus not unreasonable.

The Otawairere Tephra may also/instead be a correlative of one of the Paeroa Group ignimbrites. Varying ages have been reported for these ignimbrites, including *c.* 370 ka for the Paeroa and *c.* 380 ka for the Te Kopia Ignimbrites [Kohn *et al.*, 1992], although the errors on these ages are rather large (see Table 2-2). The mineralogy of the Te Weta and Paeroa Ignimbrites match well with that of the Otawairere Tephra, but the older Te Kopia not so well [Keall, 1988]. The Paeroa Group ignimbrites are thought to have been erupted from a source near to the Paeroa Range where they are best seen [Keall, 1988], and their source therefore was probably in the Kapenga Volcanic Centre, although the Whakamaru Centre also remains a possibility.

There is insufficient data for an accurate tephra volume to be calculated, but for a northern T.V.Z. source, a minimum eruptive volume of ≈ 10 km³ has been estimated. If the correlation to the Paeroa Group ignimbrites is correct then the more southerly Kapenga (or Whakamaru) source area would significantly increase this volume estimate.

Table 8-3 : Glass chemistry of the Tablelands-C Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Kohioawa cliffs	78.02	12.31	0.11	0.83	0.08	0.56	#3.25	4.80	0.15	3.02	12	1.00
**00810	0.19	0.06	0.04	0.05	0.00	0.05	0.16	0.15	0.02	0.57		
Wilson's farm-(1)	77.75	12.26	0.16	0.78	0.08	0.59	3.42	4.79	0.18	4.08	11	0.94*
07803	0.39	0.36	0.06	0.09	0.02	0.04	0.13	0.15	0.05	1.14		

8-3 Tablelands-C Tephra

The Tablelands-C Tephra has only been recognised at a few sites and is believed to be the third tephra deposited in the Tablelands subgroup.

The type section for the Tablelands-C Tephra is in the coastal cliffs at Kohioawa. It is also well represented at the Wilson's farm-(1) section, and is present in the Otarawairere, Ohinekoao Stream slip, and possibly the Brown's driveway sections.

Diagnostic features:

- Generally present as a white ash. At the type section, the lower half consists of well bedded fine and sandy ash.
- Contains abundant biotite, as well as some hornblende.

Stratigraphic relationships:

The Tablelands-C Tephra at the type section lies within an organic-rich estuarine silt/paleosol, which overlies marine sands, and underlies the Tablelands-D Tephra. At the Wilson's farm-(1) site—just 2 km to the east—it rests on a thin organic-rich silt layer which overlies sand, and is overlain by 50 cm of fine sand, presumably marine, and then the Tablelands-D and Paerata Tephra. At Otarawairere, the tephra is weathered and lies within the paleosol beneath the Tablelands-D Tephra, which continues into the top of the Otarawairere Tephra below.

Where subaqueously deposited, both the upper and lower contacts are always sharp, but in the terrestrial deposits the contacts are often very difficult to distinguish.

Chemistry and mineralogy:

The glass chemistry of the Tablelands-C Tephra (Table 8-3) is very similar to several other tephra in the Tablelands subgroup—the Otarawairere, Tablelands-D and Kohioawa Tephra. These tephra are characterised by low MgO, very low CaO, and very high K₂O contents, and may all have originated from the same source.

The Tablelands-C Tephra has a ferromagnesian mineral assemblage consisting of:

biotite + hornblende.

The presence of noticeable amounts of hornblende in the Tablelands-C Tephra contrasts with that of other tephra in the Tablelands subgroup which have similar glass chemistries, and may be a method of distinguishing this eruptive.

Table 8-4 : Glass chemistry of the Tablelands-D Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Pukeruru Point 02505b	78.30 0.02	12.17 0.07	0.08 --	0.77 0.00	0.06 --	0.61 0.02	3.02 0.10	4.93 0.07	0.16 0.02	5.01 0.98	2	0.93*
Otarawairere 04105a	77.32 0.35	12.50 0.17	0.10 0.02	0.88 0.05	0.08 0.02	0.61 0.08	3.29 0.03	5.10 0.17	0.17 0.01	4.87 1.61	8	0.93
Otarawairere 04107	77.30 0.35	12.46 0.12	0.11 0.00	0.91 0.06	0.07 0.01	0.64 0.06	3.36 0.08	5.05 0.22	0.16 0.02	5.90 2.11	5	0.93
Otarawairere **04101	78.06 0.33	12.25 0.17	0.09 0.03	0.82 0.10	0.07 0.02	0.54 0.08	3.39 0.18	4.68 0.21	0.15 0.03	7.93 0.74	33	1.00

Distribution and size:

The Tablelands-C Tephra has not been recognised at enough sites over a wide enough area to get a reasonable idea of its distribution. It is 15-22 cm thick near Matata and 15-20 cm thick at Whakatane, but there are no other positive identifications. Its source is thus unknown, but on the basis of its glass chemistry is probably the same as that for the Otarawairere and Tablelands-D Tephra.

8-4 Tablelands-D Tephra

The Tablelands-D Tephra is intimately associated with the Paerata Tephra and has the same known range in the coastal central and eastern Bay of Plenty. It is believed to be the fourth tephra deposited in the Tablelands subgroup.

The Otarawairere section has been designated the type section for the Tablelands-D Tephra, though it is also well represented at the Kohioawa cliff and Tablelands sections. It is found wherever the Paerata Tephra is present.

Diagnostic features:

- Well bedded, alternating grey fine ash and pale yellow-grey coarse ash layers. The bedding contrasts with the massive pumice lapilli and coarse ash of the Paerata Tephra above (see Photo-18; Photo-19).
- Greyish colour contrasts very well with the pale yellow pumice of the Paerata Tephra above.
- Contains abundant biotite.

Stratigraphic relationships:

The upper contact of the Tablelands-D Tephra is sharp and distinct to the yellow coarse sandy ash of the Paerata Tephra (see Photo-19), but chemically the boundary is less distinct. The basal part of the Paerata Tephra has a mixture of both Tablelands-D and Paerata chemistry (see samples 02505a & b, and 04105a & b in Tables 8-4 & 8-5).

The lower contact is sharp to the paleosol developed into the Tablelands-C and/or Otarawairere Tephra below. In the marine sequence west of Matata, the Tablelands-D Tephra overlies a layer of organic-rich silt/paleosol (at Kohioawa cliff); and 0.5 m of marine sand over a thin organic-rich silt/paleosol (at Wilson's farm-(1)). The basal contact is always sharp.

Chemistry and mineralogy:

The glass chemistry of the Tablelands-D Tephra (Table 8-4) is very similar to several other tephras in the Tablelands subgroup — the Otarawairere, Tablelands-C and Kohioawa Tephra. These tephras are characterised by low MgO, very low CaO, and very high K₂O contents, and it is likely that they were all erupted from the same source.

Few samples of the Tablelands-D Tephra were taken for glass chemistry analysis for it was believed (at first) to be the basal part of the Paerata Tephra. Also, the physical characteristics of the Paerata and Tablelands-D Tephra together were distinctive enough for correlation purposes without resorting to glass chemistry.

Three samples were taken from the Otawairere section:

- 04101 = bulk sample of tephra
- 04107 = sample of yellow fine pumice sand layer near top of tephra
- 04105 = sample of coarse pumice sand just above highest grey bed, (i.e. base of Paerata Tephra).

Only sample 04105 showed any mixture of chemistries, and the greater proportion were of Tablelands-D type!

The Tablelands-D Tephra has a ferromagnesian mineral assemblage consisting of:

biotite $\pm$ *hornblende* (t)

Distribution and size:

The Tablelands-D Tephra has the same known distribution as the Paerata Tephra. (see sect. 8-5), and generally thickens towards the west; being ≈ 5 cm thick in sections near Opotiki, $\approx 10-15$ cm thick at Whakatane, but only $\approx 5-10$ cm thick near Matata. The size of the clasts also increases with thickness towards the west.

The near tripling of tephra thickness, and the coarsening of clast size towards Whakatane suggests that the source of the Tablelands-D Tephra was in the northern part of the T.V.Z.; probably the Okataina Volcanic Centre.

If the tentative correlation to the Paeroa Group ignimbrites for tephra with this type of glass chemistry is correct, then a source in the Kapenga Volcanic Centre is also possible.

Discussion:

For stratigraphic purposes in the eastern Bay of Plenty, the Paerata Tephra (see sect. 8-5) and the Tablelands-D Tephra could be combined as just one unit, but further work in other areas could show that these two tephra have quite different distributions. It is thus useful to separate the two eruptives. However, positive identification of the Tablelands-D Tephra via its glass chemistry alone is unlikely as there are many other tephra of similar age with the similar chemistry.

8-5 Paerata Tephra

The Paerata Tephra is very distinctive and forms thick deposits in the coastal central and eastern Bay of Plenty. It is believed to be the fifth tephra deposited in the Tablelands subgroup.

The Paerata Tephra takes its name from Paerata Ridge Road just west of Opotiki, where the tephra was first recognised, though its type section is at Otawairere. It is also well represented at the Kohioawa cliff, Brown's driveway, Flax Hill, and Tablelands sections, and present at the Burchett, Paerata, Pukeruru Point, Tirohanga, Ohiwa Beach, Ohinekoao Stream, and Hiwarau sections.

Diagnostic features:

- Massive, 0.5–1.0 m thick, pale yellow (2.5Y 8/6 – "yellow") coarse sandy ash (pumice up to 2 mm across); pumice coarsens to lapilli size towards the west.
- The yellow colour contrasts with the grey of the Tablelands-D Tephra which immediately underlies it, and the much darker yellowish brown weathered loess above (see Photo-18; Photo-19).
- Has a very distinctive ferromagnesian mineral assemblage — containing cummingtonite.
- Black obsidian lithics similar in size to the pumices are scattered throughout the tephra.
- Generally overlain by a firm, yellowish brown weathered loess layer which forms a prominent ridge or bulge in cliff faces (see Photo-21 & 21(a)).

Stratigraphic relationships:

It is uncertain whether the upper contact of the Paerata Tephra with the overlying unit of weathered loess is sharp or gradational, as the boundary is generally indistinct due to the weathering. At the Brown's driveway section, in which the tephra may have been subaqueously deposited, the upper part of the tephra consists of a thin ash layer directly overlain by dark loess with an even, distinct contact. At the Kohioawa cliff section, there is a sharp upper contact to an organic-rich silt/paleosol; is probably a water leached paleosol rather than estuarine silt.

At the Ohinekoao Stream slip site, a significant erosional unconformity that exists above the Kohioawa Tephra has removed much of the overlying stratigraphy, including the top of the Paerata Tephra.

The lower contact of the Paerata Tephra is visibly sharp; the yellow coarse ash resting directly on the grey well bedded Tablelands-D Tephra (see Photo-19). However, the chemistry of the glass shards shows that the contact is gradational as there is a mixture of glass from both tephras in the lower part of the Paerata (see samples 02505a & b, and 04105a & b in Tables 8-4 & 8-5). At the Brown's driveway section the Paerata Tephra has an erosional unconformity in its lower or basal part, and fell into a subaqueous, presumably lacustrine environment. The bulk of the tephra here contains fine laminations and is cross-bedded.

Table 8-5 : Glass chemistry of the Paerata Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Kohioawa cliff **00811	78.52 0.31	12.52 0.10	0.13 0.03	1.01 0.06	0.14 0.02	1.02 0.07	#3.03 0.14	3.54 0.16	0.12 0.01	5.21 0.58	9	1.00
Paerata Ridge Rd. 01602	78.73 0.27	12.22 0.17	0.12 0.03	0.99 0.08	0.13 0.03	1.02 0.05	#3.07 0.17	3.55 0.12	0.18 0.13	4.35 1.18	11	0.97
Tablelands 02105	78.32 0.24	12.58 0.14	0.13 0.04	0.95 0.09	0.15 0.04	1.13 0.08	#3.07 0.18	3.56 0.12	0.15 0.03	5.48 0.81	9	0.97
Pukeruru Point 02505a	78.60 0.31	12.28 0.08	0.13 0.03	1.00 0.07	0.13 0.04	1.05 0.05	#3.09 0.15	3.59 0.15	0.15 0.03	5.30 0.95	8	0.98
Hiwarau 02704	79.27 0.36	12.30 0.16	0.12 0.05	0.83 0.16	0.13 0.05	1.08 0.08	#2.69 0.19	3.50 0.11	0.19 0.05	6.21 0.77	11	0.93
Otarawairere 04105b	77.81 0.49	12.58 0.27	0.13 0.01	1.08 0.06	0.13 0.03	1.10 0.07	#3.31 0.19	3.69 0.02	0.17 0.03	7.62 0.48	3	0.96
Burchett 04606	77.57 0.39	12.71 0.21	0.15 0.04	1.01 0.09	0.18 0.05	1.04 0.07	3.46 0.12	3.69 0.16	0.21 0.06	5.68 1.55	7	0.93*
Wilson's farm-(1) 07804	78.44 0.53	12.39 0.49	0.17 0.04	0.98 0.05	0.15 0.03	1.04 0.07	3.28 0.10	3.42 0.14	0.16 0.05	4.34 1.11	10	0.94*

Chemistry and mineralogy:

The glass chemistry of the Paerata Tephra (Table 8-5) shows average values for all element oxides, but it is distinctive within the Tablelands subgroup as most of the other tephra in this subgroup have much higher K_2O values.

Several of the lower Na_2O values listed are artificially low due to the microprobe operating conditions (most analyses on this tephra were carried out using peak searches; see Chapter 3) and this should be taken into account when comparing glass chemistries. The Paerata Tephra appears to have been particularly susceptible to this loss of Na_2O .

The Paerata Tephra has a ferromagnesian mineral assemblage consisting of:

cummingtonite + hypersthene + hornblende + biotite

This ferromagnesian mineral assemblage is very distinctive and allows for the possibility of widespread correlations. Of the tephra contained within this study, only the Rotoiti Tephra has a similar concentration of cummingtonite, though the minerals in each have very different geochemistries (see Chapter 14). Biotite is only occasionally seen and is believed to be a contaminant from the Tablelands-D Tephra below.

Distribution and size:

The Paerata Tephra thickens towards the west, being ≈ 0.5 m thick in sections near Opotiki, ≈ 1 m thick at Whakatane, and ≈ 1.5 m thick near Matata. The size of the pumice clasts also increases from ≈ 2 mm across near Opotiki, to up to 2 cm across at Whakatane, and >1 cm across near Matata. The tephra has not been recognised anywhere else other than this coastal region of the Bay of Plenty; from the coastal cliffs near Matata in the west, to Tirohanga, 4 km east of Opotiki.

The pronounced thickening and coarsening towards the west suggests that the Paerata Tephra was erupted from the northern part of the T.V.Z., probably the Okataina Volcanic Centre. The presence of cummingtonite is consistent with this conclusion as over the last 50 ka this mineral has been restricted to eruptives from the Haroharo complex within the Okataina centre [Ewart, 1971]. It is unlikely, however, that the Haroharo complex was active at the time of the Paerata eruption, and although similar magmatic processes must have undoubtedly occurred, it need not have been within the Okataina centre.

Nevertheless, Nairn (1984) reported that "yellow, fibrous, pumice lapilli up to 6 cm across" were found not far below the Rangitaiki Ignimbrite in the "Northern Boundary Road Drill-hole-2" core. If these pumices belong to the Paerata Tephra, then it is likely from their size that the eruption had a nearby source; although this also depends upon whether the pumices were of airfall or flow origin.

There is insufficient data for an accurate tephra volume to be calculated, but for a Okataina source, a minimum eruptive volume of $\approx 15 \text{ km}^3$ has been estimated.

Discussion:

The Paerata Tephra represents a moderate to large eruption, probably from the Okataina Volcanic Centre c. 0.36–0.37 Ma ago. Its physical characteristics, glass chemistry, and the abundance of cummingtonite in its ferromagnesian mineral assemblage makes it a very useful tephra for correlation purposes, especially in the coastal eastern and central Bay of Plenty. However, its stratigraphic position, close to the very widely distributed Kohioawa/Rangitawa Tephra, means that its identification is probably not required for regional correlations.

It is most likely that the Paerata and Tablelands-D Tephra are coeval; the latter eruption beginning, and ending, earlier, but having some overlap with the Paerata eruption. These two tephras could be combined into one stratigraphic unit, but further work in other areas could show that the two tephras have quite different distributions and should therefore be treated as separate units.

8-6 Kohioawa Tephra

The Kohioawa Tephra is believed to be the sixth tephra deposited in the Tablelands subgroup. It has the thickest airfall deposits of any tephra recorded in this study, and has been correlated, in this study, to the very widespread Rangitawa Tephra — the airfall component of the Whakamaru Ignimbrite. However, a mixed glass chemistry in the Kohioawa Tephra complicates matters so that the correlation is not 100% certain. One glass chemistry component (type-a) is thought to be a correlative of the very widespread Rangitawa Tephra, and the other component (type-b) from an eruptive with a more nearby source in the northern T.V.Z. This second eruptive, although probably having a much lower total volume than the Rangitawa, is believed to comprise the majority of the Kohioawa Tephra seen in the coastal Bay of Plenty.

The Kohioawa Tephra is very well preserved at both the Kohioawa cliff and Otawairere sections, but as the latter is considerably more accessible, Otawairere has been designated as the type section. The tephra is also well represented in its entirety at the Wilson's farm-(1), Paerata, and Brown's driveway sections, and various layers within the tephra are well represented at the Hiwarau and Flax Hill sections. It is also present at the Tablelands, Burchett, Ohiwa Beach, and Pukeruru Point sections, though at the latter site it is greatly over-thickened and is thought to have been deposited by fluvial processes.

Diagnostic features:

The Kohioawa Tephra consists of four internally consistent units which have different characteristics, and can be recognised in most sections where the tephra is present (Photo-21, & 21(a)). The units are numbered from the base upwards, as Koh-(1) to Koh-(4), and are presented (next page) in stratigraphic order of deposition.

Kohioawa-(1):

- Generally consists of pumice lapilli and coarse ash; becomes coarser towards the west.
- Shower bedding is generally not seen and at some sites (e.g. Tablelands, Paerata) cross-bedding may be present. In some sections this unit is reverse graded (Burchett, Otarawairere), but in others it is not.
- The thickness of this unit often varies (slightly) laterally along section, and can vary substantially between sections; 25–100 cm thick throughout the coastal region.

Kohioawa-(2):

- A 15–25 cm thick bed of firm, pinkish ash, that exhibits some faint bedding and which contains large pumice lapilli scattered throughout. The pumice increases in size (1 cm to 3 cm) towards the west.
- Large lithics (3 cm across at Kohioawa) are also present — scattered throughout.
- Ash contains large quartz crystals; 2–3 mm across.

Kohioawa-(3):

- Consists of two (sometimes seen as only one) normally graded beds of coarse pumice lapilli. Up to 2 m thick at Kohioawa cliffs, 1–2 m elsewhere. Large lithics (1 cm long) are also present. Little shower bedding is seen.

Kohioawa-(4):

- 50–200 cm (variable) of many alternating fine ash and sandy ash beds, generally cm-bedded, often with contrasting colours. Occasional line or layer of granular pumice is also present.
- Near the top a massive fine white fine ash layer is sometimes recognised (>0.5 m thick at Otarawairere; see Photo-20). This ash is sometimes (as in the type section) overlain by another series of alternating fine and coarse ash beds.

In general:

- Seen as a very thick tephra (up to 4 m), very well bedded fine ash at the top; massive pumice lapilli in the middle; and a pinkish ash layer with occasional large pumices and lithics scattered throughout, 0.5–1.0 m from the base.
- Pumice contains large quartz crystals (2–4 mm across) and abundant biotite.
- Generally overlain by a massive grey very fine sand unit (loess), and overlies a firm, yellowish brown weathered loess layer that often forms a prominent ridge or bulge in cliff faces.
- Its glass chemistry contains a distinctive mixture of two chemical types.

Stratigraphic relationships:

The nature of the upper contact of the Kohioawa Tephra varies at different sites. At most sites there is an erosional boundary, with a thick, massive loess unit above. The amount of erosion also varies. Only minor erosion is thought to occur at Brown's driveway and Otarawairere, but at the Hiwarau and

Table 8-6.1 : Glass chemistry of the Kohioawa Tephra — unit Koh-1.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C. 01603a	S.C. 01603b
Ohiwa Beach 01801a	77.86 0.35	12.28 0.10	0.13 0.02	0.99 0.11	0.12 0.03	0.86 0.07	#3.03 0.12	4.57 0.19	0.18 0.05	4.01 0.75	6	0.95	0.83
Tablelands 02101	78.01 0.18	12.09 0.06	0.12 0.02	1.00 0.08	0.11 0.03	0.82 0.03	#3.14 0.09	4.50 0.11	0.23 0.03	3.71 0.81	10	0.95	0.85
Pukeruru Point 02502a	78.13 0.12	12.02 0.11	0.15 0.03	1.05 0.08	0.10 0.03	0.88 0.09	#3.13 0.05	4.39 0.20	0.21 0.05	2.03 0.75	6	0.96	0.83
Ohiwa Beach 01801b	77.99 0.34	12.39 0.19	0.09 0.02	0.79 0.09	0.07 --	0.57 0.07	#3.12 0.15	4.87 0.08	0.19 0.06	5.09 0.68	4	0.81	0.96
Pukeruru Point 02502b	78.24 0.29	12.15 0.07	0.07 --	0.85 0.09	0.09 0.02	0.60 0.07	#3.18 0.21	4.76 0.11	0.18 0.05	1.69 0.22	4	0.83	0.95

Table 8-6.2 : Glass chemistry of the Kohioawa Tephra — unit Koh-3.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C. 01603a	S.C. 01603b
Kohioawa cliffs 00801a	78.09 0.22	12.07 0.08	0.14 0.02	1.06 0.08	0.12 0.03	0.79 0.04	#2.97 0.08	4.58 0.15	0.21 0.01	4.09 0.19	7	0.97	0.83
Paerata Ridge Rd. **01603a	78.01 0.54	12.07 0.34	0.16 0.03	1.04 0.06	0.12 0.03	0.82 0.07	#3.17 0.16	4.48 0.15	0.22 0.07	3.54 2.36	9	1.00	0.82
Paerata Ridge Rd. 01601a	78.27 0.45	11.90 0.12	0.16 0.03	1.05 0.06	0.11 0.02	0.80 0.04	#3.11 0.20	4.38 0.13	0.22 0.06	2.27 1.15	6	0.98	0.82
Tablelands 02103a	78.17 0.18	12.02 0.11	0.18 0.04	1.02 0.07	0.11 0.03	0.85 0.06	#3.06 0.09	4.38 0.07	0.21 0.06	3.34 1.28	6	0.96	0.81
Burchett 04604	77.40	12.22	0.17	1.19	0.15	0.76	3.25	4.53	0.34	4.86	1	0.94*	0.79*
Wilson's farm-(1) 07802a	77.57 0.24	12.32 0.22	0.17 0.03	1.09 0.06	0.14 0.04	0.86 0.08	3.05 0.17	4.53 0.13	0.29 0.05	5.20 0.94	9	0.95*	0.79*
Kohioawa cliffs 00801b	78.27 0.14	12.22 0.07	0.08 --	0.82 0.07	--	0.55 0.01	#3.10 0.01	4.81 0.07	0.18 0.01	3.31 0.01	2	0.84	0.99
Paerata Ridge Rd. **01603b	78.37 0.29	12.15 0.20	0.08 0.02	0.80 0.07	0.08 0.01	0.57 0.03	#3.15 0.14	4.71 0.10	0.19 0.02	3.42 1.20	11	0.82	1.00
Paerata Ridge Rd. 01601b	78.54 0.09	11.97 0.04	0.11 0.03	0.76 0.08	0.10 0.03	0.56 0.02	#3.04 0.16	4.72 0.20	0.23 0.06	2.55 0.68	4	0.85	0.93
Tablelands 02103b	78.59 0.10	12.05 0.14	0.08 --	0.81 0.05	0.06 --	0.59 0.04	#3.10 0.16	4.66 0.11	0.20 0.03	3.55 0.44	4	0.80	0.96
Hiwarau 02705	78.33 0.17	12.19 0.09	0.12 0.04	0.80 0.06	0.07 0.01	0.56 0.04	#3.12 0.17	4.70 0.15	0.22 0.03	5.42 0.90	15	0.84	0.94
Wilson's farm-(1) 07802b	77.68 0.12	12.40 0.09	0.13 0.03	0.87 0.05	0.08 0.02	0.62 0.06	3.08 0.15	4.85 0.14	0.33 0.04	5.68 0.75	7	0.87*	0.92*

Table 8-6.3 : Glass chemistry of the Kohioawa Tephra — unit Koh-4.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 01603a	S.C. 01603b
Huntress Creek 01517a	77.76 0.04	12.31 0.15	0.18 --	1.08 0.00	0.14 0.02	0.94 0.03	3.81 0.10	3.64 0.19	0.21 0.03	5.78 1.39	2	0.90*	0.74*
Huntress Creek 01517b	77.56 0.40	12.44 0.31	0.13 0.03	0.86 0.06	0.06 0.02	0.58 0.05	3.47 0.17	4.73 0.24	0.20 0.04	5.01 1.12	9	0.83*	0.89*

Burchett sections, all of unit Koh-(4) and part of Koh-(3) has been removed. At the Ohinekoao Stream slip section all of the Kohioawa Tephra has been removed.

At the type section, the overlying loess unit is not massive and contains two regions (not distinct enough to be called beds) where small pumices can be seen. These pumiceous layers are thought to be related to æolian reworking of pre-existing tephra deposits, and the glass chemistry of pumice from the lowermost tephric-rich layer confirms this; containing a mixture of shards from both the Kohioawa and Paerata Tephra (see appendix-(F); sample [04108]).

At Kohioawa cliffs, a slight time break between the Koh-(3) and Koh-(4) units is suggested by the presence of a thin layer of slightly organic-rich silt. This break is not recognised elsewhere and further work in this area is indicated.

The lower contact of the Kohioawa Tephra is sharp, but often irregular, to a dark yellowish-brown weathered loess up to 0.5 m thick. At the Paerata section there is an erosional boundary which in some places has totally eroded out the tephra immediately below (i.e. Paerata).

At the Pukeruru Point site, the base of the Kohioawa Tephra is represented by a major channel erosion feature cut into and through the underlying tephra and gravels, and into much older marine sediments (see Photo-68). This channel was then filled by Kohioawa eruptives that are thought to have been fluvially deposited. The upper part of the pumiceous channel fill is overlain by fine sand, which grades upwards into a silt which may be loessic.

Chemistry and mineralogy:

The glass chemistry of the Kohioawa Tephra (Tables 8-6.1, 8-6.2, & 8-6.3), is grouped into the individual stratigraphic units which make up the tephra. The units are arranged in stratigraphic order of deposition; the basal unit (Koh-(1)) being presented first.

Sample-01517 (Huntress Creek) was obtained by augering well below (≈ 2 m) the base of the section, and the first pumiceous material retrieved below the massive loess layer was assumed to be from the Koh-(4) unit.

The glass chemistry of the Kohioawa Tephra is very interesting in that it is a mixture of two slightly different chemical types. The two chemistries are present in similar amounts with chemistry type-(a) slightly more common than chemistry type-(b). The differences between the two chemical types, although slight, are readily seen by eye (graphically and by scanning the data) and are consistent throughout all samples (e.g. Fig. 8-5).

Type-(a) glass chemistry has slightly lower K_2O (still high for tephra within this study), and higher FeO , MgO , & CaO wt. %'s than type-(b) glass chemistry.

The Koh-(b) chemistry is very similar to several other tephra in the Tablelands subgroup — the Otawairere, Tablelands-C and Tablelands-D Tephra. These eruptives all have very high K_2O , and very

Table 8-6.4 : Glass chemistry of the Kohioawa Tephra — unit Koh-3; matrix only.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C. 01603a	S.C. 01603b
Kohioawa cliffs 00808a	78.17 0.22	11.97 0.12	0.16 0.02	1.07 0.07	0.12 0.02	0.82 0.03	#3.06 0.21	4.39 0.13	0.24 0.02	3.35 0.85	9	0.99	0.81
Paerata Ridge Rd. 01604a	78.35 0.20	11.96 0.07	0.15 0.04	1.03 0.06	0.13 0.01	0.71 0.05	#2.95 0.16	4.47 0.12	0.25 0.02	3.10 0.63	8	0.95	0.82
Kohioawa cliffs 00808b	78.58 0.38	12.11 0.11	- - - - - -	0.91 0.03	0.08 - - -	0.54 0.01	#2.81 0.09	4.81 0.42	0.20 0.04	4.44 0.26	2	0.86	0.96
Paerata Ridge Rd. 01604b	78.59 0.30	12.03 0.05	- - - - - -	0.85 0.06	0.10 - - -	0.52 0.06	#3.09 0.32	4.70 0.19	0.19 0.03	3.02 1.07	4	0.89	0.95

Table 8-6.5 : Glass chemistry of the Kohioawa Tephra — unit Koh-3; single pumice lapilli only.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C. 01603a	S.C. 01603b
Kohioawa cliffs 00807	77.32 0.37	12.46 0.14	0.18 0.04	1.14 0.14	0.14 0.03	0.81 0.05	3.23 0.12	4.50 0.19	0.23 0.03	4.74 0.85	13	0.95*	0.79*
Kohioawa cliffs 00806	77.52 0.19	12.62 0.11	0.13 0.03	0.88 0.07	0.09 0.03	0.60 0.04	3.22 0.10	4.74 0.22	0.21 0.05	5.12 0.98	12	0.88*	0.91*
Kohioawa cliffs 00805	78.67 0.19	12.02 0.07	0.09 0.02	0.84 0.04	0.08 0.02	0.54 0.05	#2.93 0.09	4.73 0.18	0.21 0.03	3.48 0.44	8	0.82	0.96
Paerata Ridge Rd. 01605	78.04 0.14	12.26 0.08	0.11 0.07	0.92 0.08	0.08 0.02	0.65 0.05	#3.17 0.13	4.73 0.15	0.15 0.02	4.08 1.41	8	0.87	0.93
Paerata Ridge Rd. 01606	78.34 0.21	12.14 0.08	0.08 0.03	0.83 0.06	0.07 0.01	0.60 0.06	#3.11 0.07	4.67 0.16	0.20 0.02	3.59 0.39	11	0.82	0.97

Table 8-6.6 : Glass chemistry of the Kohioawa Tephra — unit Koh-3; many pumice lapilli crushed together.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C. 01603a	S.C. 01603b
Kohioawa cliffs 00809a	77.69 0.19	12.02 0.13	0.15 0.04	0.96 0.02	0.14 0.04	0.82 0.07	#3.25 0.06	4.68 0.08	0.29 0.09	3.12 0.70	3	0.96	0.82
Kohioawa cliffs 00809b	78.18 0.14	12.16 0.09	0.10 0.01	0.85 0.10	0.07 0.01	0.58 0.06	#3.13 0.11	4.81 0.14	0.18 0.02	3.56 0.25	10	0.83	0.95

low MgO & CaO contents (see Fig. 8-2), which are distinctive among the tephtras in this study and only found in this one group of tephtras within the Tablelands subgroup. These tephtras are believed to have been erupted from the same source, with the Kohioawa-(b) glass representing perhaps the final eruption of of this magma batch. The glass chemistries of these tephtras match so well, for such distinctive compositions, that it is likely that the glass from the Kohioawa Tephra consists two distinct chemical clusters, rather than one highly variable chemistry scattered over a wide range.

Figure 8-5 : Individual glass shard chemical analyses of the Kohioawa Tephra (three sites)
— relative proportions of selected element-oxides

In order to determine if this mixed chemistry is in fact real, a more detailed study was carried out on the tephra matrix (<250 μm), and on several individual pumice lapilli taken from the coarsest pumice bed (Koh-(3)).

Analyses on the matrix showed a mixture of shards of both chemical types (Table 8-6.4), with (type-(a) more common than type-(b)).

Analyses of individual lapilli were found to be "pure", with either type-(a), or type-(b) chemistry, but not a mixture of both (Table 8-6.5).

Also, a further selection of ≈ 20 pumice lapilli were washed (i.e. no matrix) and crushed together, and the analyses on this produced a mixed chemical assemblage (Table 8-6.6).

The fact that the individual pumices are "pure" and not mixed, indicates that the mixed chemistry for the entire tephra is not due to magma mixing. The large size of the pumice lapilli suggests also that æolian reworking cannot be the cause of the mixing, thus leaving simultaneous or coeval eruption as the most probable cause of the mixture of glass types.

Table 8-6.7 : Glass chemistry of possible correlatives of the Kohioawa Tephra: – Rangitawa Tephra (08001) & Te Whaiti Ignimbrite (08201).

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	[#] Na ₂ O	K ₂ O	Cl	water	no.	S.C. 01603a	S.C. 01603b
Rangitawa Stream 08001	77.95 0.15	12.24 0.12	0.14 0.02	1.06 0.06	0.12 0.02	0.82 0.04	[#] 3.19 0.07	4.23 0.12	0.25 0.03	3.01 0.68	13	0.97	0.82
Waipunga 08201	76.67 0.65	12.73 0.35	0.13 0.03	1.14 0.09	0.14 0.02	0.88 0.05	[#] 3.41 0.16	4.67 0.18	0.27 0.06	6.26 3.26	9	0.92	0.80
\$—\$ (Pillans)	78.03 0.39	12.13 0.14	0.15 0.04	1.03 0.06	0.12 0.02	0.78 0.06	3.35 0.22	4.22 0.15	0.19 0.04	5.86 1.14	32	0.97	0.82

\$—\$ = Rangitawa Tephra glass chemistry (Omahina Road) [Pillans, 1988]

Type-(a) chemistry is a good match to that of the widespread Rangitawa Tephra (Table 8-6.7), and as the Kohioawa Tephra lies in a similar stratigraphic position, a correlation between these two tephras is suggested here.

The Rangitawa Tephra sample was taken from its type section at Rangitawa Stream [S23/196165] in the Wanganui Basin. The Waipunga sample is of the basal unwelded pumice layer of the Te Whaiti Ignimbrite (a correlative of Whakamaru Ignimbrite), located near Waipunga Falls on Highway-5 between Taupo and Napier. It can be seen that both these samples are "pure" and do not consist of a mixture of different types of glass shards.

In general the Kohioawa Tephra has a ferromagnesian mineral assemblage consisting of:

biotite + hypersthene + hornblende

This assemblage is the combination of two separate ferromagnesian mineral assemblages, which was confirmed when individual pumices, or samples with predominantly one type of chemistry, were studied separately (e.g. [00801], [00808], [02101]; & [01517], [02705]). The pumices of chemistry type-(b) contain abundant black biotite and very large quartz phenocrysts, whereas the pumice of chemistry type-(a) contains much less biotite and have smaller quartz crystals.

Ferromagnesian mineral assemblage-[A] (chemistry type-(a)) consists of:

hypersthene + hornblende + biotite

Ferromagnesian mineral assemblage-[B] (chemistry type-(b)) consists of:

biotite + hornblende + hypersthene

Interestingly, the ferromagnesian mineral assemblage recorded in this study for the Rangitawa Tephra was:

hypersthene + hornblende

(biotite has been reported by other workers)

Distribution and size:

The distribution of the Kohioawa Tephra is difficult to determine due to the lack of sections, erosion within many of the sections, and also to the fact that it is thought to be a mixture from two coeval eruptions, possibly from different sources and having different distributions.

The thickness of the Koh-(1) unit varies unexpectedly from site to site and also within each site, and trends of thickening direction cannot easily be established. It is thickest at Paerata and Otawairere, but is thinner and highly variable near Matata.

The Koh-(2) unit has a reasonably constant thickness of 15–20 cm in all of sections across the coastal central and eastern Bay of Plenty.

The Koh-(3) unit definitely thickens towards the west, but also varies markedly in thickness between neighbouring sections. It is >2 m thick at Kohioawa but only 30 cm thick at Wilson's farm-(1). This unit is often partly eroded which may explain the variation.

The Koh-(4) unit also definitely thickens towards the west and is up to 2 m thick at Kohioawa. At several sites this unit has also suffered from erosion.

If the correlation of the Kohioawa Tephra (type-(a)) with the Rangitawa Tephra is correct, then this component of the Kohioawa Tephra (Koh-(a)) has the same source, the Whakamaru caldera (Figure 1-3) [Wilson *et al.*, 1986].

The other component of the Kohioawa Tephra (Koh-(b)) is believed, due to its near identical chemistry, to have originated in the same area as several other tephras in the Tablelands subgroup, the source for which is thought to be in the northern part of the T.V.Z., probably the Okataina, or possibly the Kapenga Volcanic Centres.

Using a southern Okataina source, a minimum eruptive volume of 50 km³ can be estimated for the Kohioawa Tephra from exposures in the coastal Bay of Plenty alone. This volume is likely to be significantly less than the true volume as at least one of the source areas is much further away than Okataina. It is impossible to accurately separate the two components—Rangitawa (type-a) and Kohioawa (type-b)—into their relative thicknesses. However, if the Rangitawa Tephra component is assumed to have a constant thickness of ≈ 1 m across much of the coastal eastern Bay of Plenty area, which is consistent with the estimated thickness of the Rangitawa Tephra in this region, the variation in thickness can then be entirely attributed to the Koh-(b) component. The Koh-(b) component can hence be referred to as the true Kohioawa Tephra, and has an estimated minimum eruptive volume of ≈ 30 km³, if from a southern Okataina source; and ≈ 50 km³ if from a Kapenga source. These volumes may of course be very much larger if the dispersal of the Kohioawa Tephra was in some other direction than the northeast. The type-(b) glass chemistry is not recognised as a component of the Rangitawa Tephra at its type section near Wanganui (Table 8-6.7), and also, to this workers knowledge, not recognised in any other sections in the southern and central North Island or in the South Island. This distribution is consistent with a northeasterly dispersal of the Kohioawa Tephra (type-(b)) from a northern T.V.Z. source.

Discussion:

The Kohioawa Tephra—due to its large thickness and distinctive bedding—is a very important marker horizon in the coastal central and eastern Bay of Plenty. Its glass chemistry suggests that it is a composite deposit formed from material derived from two coeval eruptions that occurred *c.* 0.35 Ma ago (see Chapter 15).

The Rangitawa Tephra is found across much of the country, and in deep sea cores >1000 km east of New Zealand, being 90 cm thick [Milne, 1973] at the Mt Curl section near Wanganui, almost 200 km southwest of its source. The very wide dispersal and the thickness of these deposits has lead to an

estimated volume of $c. 700 \text{ km}^3$ for the Rangitawa Tephra [Froggatt *et al.*, 1986]. In addition, the Whakamaru Group ignimbrites, with which this tephra has been correlated, have an estimated eruptive volume of $\geq 1000 \text{ km}^3$ [Wilson *et al.*, 1984]. The Rangitawa eruption was perhaps the largest single eruption (or group of eruptions) within New Zealand in the past million years.

The size of the Rangitawa Tephra suggests that it should be found in the Bay of Plenty region in at least a moderate thickness. The Kohioawa (type-a) and Murupara-C Tephra are the only deposits in the coastal Bay of Plenty that are good chemical matches to the Rangitawa Tephra. The Murupara-C Tephra occurs stratigraphically above the Rangitaiki Ignimbrite—which is believed to be a correlative of the Whakamaru Ignimbrite/Rangitawa Tephra—and thus cannot be the same unit. Therefore the most likely correlative of the Rangitawa Tephra in the coastal Bay of Plenty is the Kohioawa Tephra

The Whakamaru Ignimbrite eruption was so voluminous that the collapse of the Whakamaru Caldera, which had a large areal extent, could have produced tectonic movements that may have initiated volcanic activity in other areas; such as the Kohioawa-(b) eruptive. More detailed study is required on the Kohioawa Tephra to determine if there is any variation in the proportions of the two chemical components within the different layers of the deposit.

The Paeroa Group ignimbrites—which from oldest to youngest consist of the Te Kopia, Te Weta, and Paeroa Ignimbrites—are also possible correlatives of the Kohioawa Tephra eruption. This correlation is based on their similar ages (see Table 2-2) and the presence of quartz and biotite within them. Some workers, such as Pringle *et al.*, (1992), believe the Paeroa Group to be correlatives of the Whakamaru Group ignimbrites, while other workers, such as Keall, (1988); and Kohn *et al.*, (1992), believe that there are enough chemical and mineralogical differences between the two ignimbrite groups for them to be separate events. Paleomagnetic secular variation is consistent with these ignimbrites being of similar age to the Whakamaru Ignimbrite [Keall, 1988], but the results are not conclusive.

The Paeroa and Te Weta Ignimbrites contain abundant biotite—in significantly higher proportions than in the Whakamaru Group—and also have a very much higher sanidine content [Keall, 1988]. The abundance of biotite and sanidine can be related to a more potassic melt, and/or a more advanced fractionation of the melt. The Te Kopia Ignimbrite has a similar mineralogy and glass chemistry to the Whakamaru eruptives. Although different ages have been obtained for the separate ignimbrites within the Paeroa Group, little physical evidence exists for much, if any, time between ignimbrite flow units.

$^{40}\text{Ar}/^{39}\text{Ar}$ laser fusion dating on sanidines from these ignimbrites have produced weighted mean ages of $333 \pm 2 \text{ ka}$ for the Paeroa Ignimbrite; and $330 \pm 4 \text{ ka}$ for the Whakamaru Ignimbrite [Pringle *et al.*, 1992]. As the ages are nearly identical, and have only small errors, it is suggested here that these two ignimbrite eruptions are the two coeval events which comprise the Kohioawa Tephra in the coastal Bay of Plenty.

The relationship of the Paeroa Group ignimbrites to the Quartz-biotite Ignimbrites is not well understood, though both groups have abundant large quartz and biotite crystals, and are believed to be of a similar age; both underlying the Rangitaiki/Whakamaru Ignimbrite.

The Paeroa Group ignimbrites are thought to have erupted from a source near to the Paeroa Range where they are best seen [Keall, 1988], probably in the Kapenga Volcanic Centre. If Kapenga is the source for the Koh-(b) Tephra, then the eruptive volume is large, and it would be expected that shards of this chemical type should be found elsewhere in the country, or in deep sea cores to the east. The fact that no shards of this chemistry have been reported may be due to the northerly dispersal of this tephra. Also, the distribution and flow patterns of the Paeroa Group ignimbrites are not well understood, and they may instead have erupted from the southern Okataina Volcanic Centre, with a resultant smaller calculated eruptive volume.

Chapter Nine : Murupara subgroup

The Murupara subgroup includes all units found in the northern and eastern Bay of Plenty, from the top of the paleosol developed into the loess above the Kohioawa Tephra, to the top of the paleosol developed into deposits from the Matahina eruptive episode (i.e. base of the Torere-A Tephra).

The Murupara subgroup contains the Matahina eruptives, as well as what has previously been called the "Bonisch Pyroclastics" [Nairn, 1989b]. The "Bonisch Pyroclastics" were described as obsidian-rich pumice fall deposits; and the Anaputa and Bonisch Tephra indeed contain abundant obsidian lithics. Several sections near Murupara contain the entire subgroup and therefore its name has been taken from here. At the Bonisch Road site, the base of the subgroup—including the lowermost three tephra—is not exposed.

A diagram showing the general stratigraphy of the Murupara subgroup in the eastern Bay of Plenty is presented in Figure 9-1. The subgroup is generally only about 5 m thick in the coastal eastern Bay of Plenty; the Matahina Tephra alone comprising almost half of this.

All of the tephra in the Murupara subgroup have paleosols developed into their tops, and all rest on paleosols. The basal Murupara-A Tephra rests on a paleosol developed into the uppermost loess layer of the underlying Tablelands subgroup. No loess is seen in the Murupara subgroup near the coast, but tephric-loess is present in the lower part of the subgroup at the edge of the Kaingaroa Plateau near Murupara. This tephric-loess, though, is believed to be associated with an ameliorating climate rather than full glacial conditions, and the subgroup generally represents deposition in a relatively warm climate.

In the marine sequence exposed in the coastal cliffs west of Matata, the Matahina eruptives directly overlie a brown estuarine or marine sand unit. At the base of this sand there is an erosional unconformity which spans many tens of thousands of years. All tephra in the Murupara subgroup—other than the Matahina—are missing here, and the erosion has variably penetrated somewhat into the underlying Tablelands subgroup. The base of the sand at the Ohinekoao Stream slip site is tephric, containing occasional small reworked lenses of obsidian-rich pumice which may perhaps represent the Anaputa Tephra. It is suggested here that the brown sand represents a high sea-level stand, and the erosion at the base is due to sea-level rise at the end of a glacial period. This is consistent with the proposal that the Murupara subgroup was erupted during an interglacial.

Figure 9-1 : Generalised stratigraphy of the Murupara subgroup in the eastern Bay of Plenty (see appendix-(M) for key)

Figure 9-2 : Chemical comparison of all tephra in the Murupara subgroup; relative proportions of glass chemical means of selected element-oxide analyses

The age of the Murupara subgroup and the tephtras within it have been estimated by fitting the paleoclimatic data gathered from the Bay of Plenty sections to the SPECMAP and Bassinot LLS oxygen isotope ($\delta^{18}\text{O}$) records (see Chapter 15).

The best fit estimates (to the $\delta^{18}\text{O}$ curve) give an age range for the Murupara subgroup of c. 340 ka to 325 ka, with an average of one eruption per 1250 years.

The tephtras that occur in the Murupara subgroup and their estimated ages and volumes, are:

Matahina	c. 330 ka	$\geq 35 \text{ km}^3$
Murupara-G	c. 333 ka	$\geq 2 \text{ km}^3$
Anaputa	c. 334 ka	$> 5 \text{ km}^3$
Murupara-E	c. 334 ka	$\geq 4 \text{ km}^3$
Bonisch	c. 335 ka	$\geq 30 \text{ km}^3$
Murupara-C	c. 337 ka	$\geq 15 \text{ km}^3$
Murupara-B	c. 338 ka	$> 0.5 \text{ km}^3$
Murupara-A	c. 340 ka	$\geq 5 \text{ km}^3$

The frequency of volcanic activity during this time period appears to have been similar to that during the past 50 000 years, and several of the tephtras in the Murupara subgroup (Murupara-C, Bonisch & Matahina) have large eruptive volume estimates. The Matahina eruption, with its associated large ignimbrite (c. 220 km^3), is acknowledged as the largest known eruption to have been sourced in the Okataina Volcanic Centre [Wilson *et al.*, 1984].

The Matahina, Murupara-G, Anaputa, Murupara-E, Bonisch, and Murupara-B Tephtras almost certainly originated from the Okataina Volcanic Centre, and although it is possible that the Murupara-A Tephtra could have come from the Kapenga or Reporoa Volcanic Centre, and the Murupara-C Tephtra from the Whakamaru Volcanic Centre, it is most likely that they too originated from Okataina.

Figure 9-2 is a ternary plot which compares the relative proportions of the analytical means of glass from all tephtras in the Murupara subgroup. The chemical range is quite widepread, with the Anaputa Tephtra being the most distinctive. Stratigraphically adjacent tephtras in this subgroup generally have quite different chemistries, thus allowing chemical identifications on a sequence of eruptives to be readily achieved. Only the Bonisch and Murupara-E Tephtras could be confused using this technique, and the latter tephtra is rarely seen in the eastern Bay of Plenty.

These two eruptives both have moderately low CaO, and moderately high K_2O wt. %'s. The Murupara-C Tephtra is also similar but has a noticeably higher K_2O content.

The Murupara-A and Anaputa Tephtras have similar glass chemistries that are quite distinctive for the tephtras in this study — having high FeO & CaO, and low K_2O wt. %'s; and a high $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratio.

The glass from Matahina and Murupara-G Tephtras has a more moderate composition somewhere between the two groups above.

Similarity coefficients which compare the glass chemistries of the tephtras found in the Murupara subgroup are presented in Table 9-0.

Table 9-0 : Similarity coefficients (S.C.'s) for representative chemistries of Murupara subgroup tephtras.

<i>oldest</i>		10002	04112	02303	02305	00402	00502	00403	00201	00202	01501
Murupara-A	10002	1.00									
Murupara-B	04112	0.85	1.00								
Murupara-C	02303	0.76	0.89	1.00							
Bonisch	02305	0.77	0.90	0.96	1.00						
Murupara-E	00402	0.77	0.88	0.96	0.95	1.00					
Anaputa	00502	0.94	0.88	0.78	0.80	0.79	1.00				
Murupara-G	00403	0.86	0.93	0.87	0.89	0.87	0.88	1.00			
Matahina (plin)	00201	0.80	0.91	0.94	0.97	0.95	0.82	0.91	1.00		
Matahina (igb)	00202	0.85	0.97	0.88	0.90	0.88	0.88	0.95	0.91	1.00	
Matahina (fall)	01501	0.80	0.91	0.95	0.97	0.95	0.82	0.91	0.99	0.91	1.00
<i>youngest</i>											

The best place to view the stratigraphy of the lower part of the Murupara subgroup is at the Murupara-(2) section [G.R. V17/316991] (see Photo-10), while the best place to see the upper part is at the Bonisch [V16/300207] and Pahekeheke [V16/356186] sections. The Burchett section also shows this subgroup in its entirety, but the tephtras at this distal site are much thinner, and the upper three tephtras are strongly weathered. However, the individual distinctive layering within the tephtras in the lower part of the subgroup is still apparent. Other sections in the coastal Bay of Plenty also contain this subgroup (e.g., Hiwarau, Huntress Creek, Ohiwa Beach & Otawairere), but generally they either show less detail (than at Burchett), or whole segments are missing — for example the Huntress Creek section lacks the Murupara-A Tephra.

Figure 9-3 shows variations in the thickness and exposure of the Murupara subgroup throughout the Bay of Plenty region. Correlations between sites are marked.

The eight tephtras known to exist in the Murupara subgroup are presented in the following pages in stratigraphic order of deposition (from oldest to youngest).

9-1 Murupara-A Tephra

The Murupara-A Tephra is believed to be the first tephra deposited in the Murupara subgroup. It is recognised both in the coastal sections, and in the Kaingaroa forest.

The type section for the Murupara-A Tephra is at the Murupara-(2) site, but it is not seen at Murupara-(1). The tephra is also well preserved at the Hiwarau, Otawairere, and Burchett sections in the coastal Bay of Plenty, and is present at the Ohiwa Beach section, though glass from this latter site was not analysed.

Table 9-1 : Glass chemistry of the Murupara-A Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	[#] Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Hiwarau	78.75	11.91	0.16	1.14	0.17	1.27	[#] 3.06	3.43	0.15	5.86	8	0.91*
02703	0.19	0.12	0.03	0.09	0.03	0.05	0.14	0.10	0.02	0.61		
Otarawairere	77.24	12.65	0.27	1.21	0.22	1.29	3.54	3.38	0.21	7.48	10	0.94
04111	0.37	0.24	0.06	0.14	0.05	0.12	0.13	0.09	0.08	0.27		
Burchett	78.62	12.00	0.18	1.21	0.16	1.04	[#] 3.22	3.43	0.14	2.70	9	0.91*
04602	0.18	0.12	0.04	0.07	0.02	0.06	0.09	0.07	0.03	0.62		
Murupara-(2)	77.13	12.72	0.21	1.26	0.19	1.24	3.55	3.51	0.20	6.02	15	1.00
**10002	0.45	0.22	0.06	0.12	0.04	0.09	0.12	0.15	0.05	1.30		

Diagnostic features:

At Murupara-(2): (see Photo-22)

- Well bedded (shower bedded) pumice lapilli; up to 1 cm across. The basal half contains a greater proportion of the coarsest pumice, but also several thin ash layers.
- Contains lithics and crystals up to 2 mm across.

In the coastal Bay of Plenty:

- Generally a 10–15 cm thick unit of fine sandy ash.
- Is the first eruptive to overlie the massive, very thick, unweathered loess unit that occurs above the Kohioawa Tephra.

Stratigraphic relationships:

At its type section the Murupara-A Tephra is overlain by up to 60 cm of tephric-loess (see Photo-22). This loess has a highly variable thickness (20–60 cm), and contains a weak paleosol in its top. In the coastal Bay of Plenty, however, no loess is recognised, and the Murupara-A Tephra has a paleosol up to 30 cm thick developed into it. The coastal regions would have had a considerably less harsh climate than that which occurred on the Kaingaroa Plateau.

Tephric-loess is also present immediately below the Murupara-A Tephra at the type section. This underlying loess also has a highly variable thickness, 5–100 cm, and generally rests on the soft weathered top of the Rangitaiki Ignimbrite. Where the ignimbrite has been eroded (shaved) down to the hard (welded) surface, the Murupara-A Tephra is generally absent (see Figure 9-4).

In the coastal Bay of Plenty, the Murupara-A Tephra overlies a thick massive loess unit. At the Burchett section this loess has a weak sandy paleosol developed into its top, and at Hiwarau, the upper 10 cm of the loess contains pumice flecks which were probably emplaced—from above—by bioturbation at the loess/tephra boundary.

Chemistry and mineralogy:

The glass chemistry of the Murupara-A Tephra (Table 9-1) is not particularly distinctive, with FeO & CaO both ≈ 1.2 wt.%, and Na₂O values approximately equal to K₂O. Nevertheless, the chemistry is distinctive enough to be a useful diagnostic tool, especially as the two tephtras immediately overlying it have quite different chemistries.

The Murupara-A Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene

Distribution and size:

The Murupara-A Tephra has only been recognised at five sites. It is 1.1 m thick at Murupara, but its thickness is hard to determine in the coastal sites because of the paleosol that has developed into it. The unweathered (or only slightly weathered) tephra is generally only 10–15 cm thick, with the paleosol

Table 9-2 : Glass chemistry of the Murupara-B Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Otarawairere	77.54	12.62	0.15	1.07	0.13	0.83	3.50	3.96	0.23	7.87	9	1.00
**04112	0.18	0.12	0.04	0.09	0.03	0.06	0.12	0.19	0.05	0.84		

above being 25–40 cm thick, giving a maximum possible thickness of 0.5 m. It is thought that loess may account for some of this paleosol thickness, but an estimation of 25 cm for the airfall tephra thickness seems not unreasonable. The thickness of the Murupara-A Tephra does not vary much across the coastal Bay of Plenty, which suggests that either the source was quite some distance away, or that its major dispersal axis was towards the south. The greater thickness and coarser grain-size of the Murupara-A Tephra at the Murupara-(2) section—the most southern examined—is consistent with either of the above scenarios.

The glass chemistry is similar to that of the Anaputa Tephra which almost certainly originated in the Okataina area.

9-2 Murupara-B Tephra

The Murupara-B Tephra is believed to be the second eruptive deposited in the Murupara subgroup, but it is only recognised at one site — the Otawairere section.

At Otawairere, the Murupara-B Tephra is represented by lenses of weathered pumice lapilli (5–10 cm thick) lying within the paleosol, that occurs below the Murupara-C Tephra and has developed into the Murupara-A Tephra below.

Chemistry and mineralogy:

The Murupara-B Tephra has a glass chemistry (Table 9-2) very similar to that of the Murupara-C Tephra, although its FeO content may be slightly higher. More sites and analyses are required to confirm whether this difference is significant.

The Murupara-B Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende + *biotite*

Distribution and size:

The Murupara-B Tephra has only been recognised at the Otawairere site, where it exists as weathered pumice within a paleosol. The tephra thins rapidly towards the northeast and it is not recognised, being too thin to have been preserved as a visible layer. It is not recognised also in sections near Murupara. Either, the eruptive volume of the Murupara-B Tephra was very small, and/or its distribution was to the west or northwest. The size of the pumice at Otawairere indicates that the Murupara-B Tephra almost certainly originated within the Okataina Volcanic Centre.

More detailed study may find traces of glass from the Murupara-B Tephra within the paleosol between the Murupara-A and Murupara-C Tephrae.

9-3 Murupara-C Tephra

The Murupara-C Tephra is believed to be the third eruptive deposited in the Murupara subgroup, and it is recognised both in the coastal sections and in the Kaingaroa forest.

The type section for this tephra is at the Murupara-(1) site. It is twice as thick at the Murupara-(2) site, just down the road, but there it is thought to have been over-thickened by æolian processes. Nevertheless, much fine detail can be seen at this latter site and it can be considered to be a good reference section.

The Murupara-C Tephra is also recognised at the Hiwarau, Huntress Creek, Otarawairere and Burchett sections in the coastal Bay of Plenty, and is also present at the Ohiwa Beach section, although glass from this latter site was not analysed.

Diagnostic features:

Near Murupara: (see Photo-23)

- Upper part consists of shower bedded pumice and lithics.
- Middle part consists of well bedded sandy ash.
- Basal part consists of a fine white ash, overlying a thin basal sandy ash layer.

In the coastal Bay of Plenty:

- A basal white fine ash (5 cm thick), overlain by the remainder of the tephra; generally sandy ash.

Stratigraphic relationships:

At its type section the Murupara-C Tephra has a "dull reddish brown" paleosol developed into it. This paleosol is observed in all coastal Bay of Plenty sections. No loess is recognised within the paleosol, just weathered tephra. However, at the Murupara-(2) site the tephra is directly overlain by 30 cm of tephric-loess, which itself has a weak paleosol developed in its top.

At the type section the Murupara-C Tephra immediately overlies the shaved surface of the Rangitaiki Ignimbrite, whereas at the Murupara-(2) site it overlies tephric-loess (see Figure 9-4; Photo-23). Where this loess directly overlies eroded Rangitaiki Ignimbrite, the loess is unweathered, but where it overlies the Murupara-A Tephra, the top surface of the loess has some slight erosional relief and a weak paleosol developed into it.

In the coastal Bay of Plenty region the Murupara-C Tephra generally overlies a paleosol. At Ohiwa Beach, the tephra rests on a bioturbated paleosol surface, but at Huntress Creek, the Murupara-C Tephra overlies the massive loess unit at the top of the Tablelands subgroup. Here, for some unknown reason, the Murupara-A Tephra and associated paleosols are not present.

At the Reeves section, the Murupara-C Tephra overlies a paleosol developed into the surface of a significant erosional scarp (unconformity).

Table 9-3 : Glass chemistry of the Murupara-C Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Huntress Creek 01506	78.46 0.27	12.24 0.07	0.10 0.02	0.95 0.09	0.08 0.02	0.78 0.05	#3.26 0.14	4.01 0.10	0.16 0.03	5.25 0.65	10	0.97
Reeves Road 01909	77.44 0.33	12.78 0.10	0.14 0.05	0.95 0.12	0.11 0.04	0.79 0.07	3.59 0.18	4.04 0.10	0.19 0.03	7.66 0.77	10	0.93*
Murupara-(1) **02303	78.35 0.26	12.29 0.10	0.10 0.01	0.94 0.08	0.10 0.01	0.77 0.05	#3.23 0.24	4.11 0.16	0.16 0.02	3.71 0.76	9	1.00
Hiwarau 02702	78.81 0.33	12.09 0.11	0.09 0.02	0.94 0.07	0.09 0.02	0.79 0.03	#3.08 0.21	3.99 0.11	0.16 0.02	5.43 0.96	13	0.96
Otarawairere 04113	77.47 0.26	12.66 0.13	0.16 0.06	0.94 0.14	0.11 0.03	0.80 0.06	3.62 0.14	4.04 0.11	0.20 0.05	7.57 0.75	11	0.92*
Burchett 04601	78.67 0.15	12.17 0.05	0.11 0.02	1.00 0.07	0.09 0.02	0.77 0.05	#3.12 0.12	3.95 0.12	0.18 0.02	3.49 0.52	13	0.96

Chemistry and mineralogy:

The glass chemistry of the Murupara-C Tephra (Table 9-3) is reasonably distinctive, due to its moderately low CaO, and its high K₂O wt.%; which is higher than any other tephra in the Murupara subgroup. This chemistry is similar to that of the Rangitawa Tephra/Whakamaru Ignimbrite which is found not far below, and also to the Murupara-B Tephra immediately below.

The Murupara-C Tephra has a ferromagnesian mineral assemblage consisting of: -

biotite + hornblende + hypersthene

This assemblage is what is expected in tephra which have glass with relatively high K₂O wt.%. The biotite content of the Murupara-C Tephra appears to be higher than that in the Murupara-B Tephra, and this may be a way to distinguish between these two eruptives.

Distribution and size:

The Murupara-C Tephra has been recognised at two sites on the Kaingaroa Plateau and five sites in the coastal eastern Bay of Plenty. It is ~70 cm thick at Murupara-(1), but just 1 km down the road at Murupara-(2) it is 1.6–2.1 m thick. It is difficult to determine whether erosional thinning of the first site, or æolian thickening of the second, is the major cause of this thickness discrepancy. Probably both processes were occurring simultaneously and more sites are required to accurately assess the true thickness of the Murupara-C Tephra in this region.

In the coastal eastern Bay of Plenty area, the Murupara-C Tephra generally consists of ~20 cm of unweathered tephra, overlain by ~30 cm of weathered tephra paleosol. It is slightly thicker at the most westerly coastal site (i.e. Otawairere), where 45 cm of unweathered tephra is overlain by 35 cm of weathered tephra paleosol.

The thickness of the Murupara-C Tephra generally does not vary much across the coastal Bay of Plenty, except at Otawairere, suggesting that either the source was quite some distance away, or that its dispersal was more towards the east or south than northeast.

At all sites where the Murupara-C Tephra is recognised, the clast size is no coarser than sandy ash, even at Murupara. This fine grained nature is not inconsistent with it being a distal tephra from a much more distant source than that for most other tephra seen in the region. Its age and glass chemistry are very similar to the Rangitawa Tephra/Whakamaru Ignimbrite, which was erupted from the Whakamaru caldera much further to the south, but the Murupara-C Tephra is considered not to be a correlative of the Rangitawa Tephra for two reasons:

- i) The Murupara-C Tephra overlies, with some reasonable time interval, the Rangitaiki Ignimbrite — a correlative of the Rangitawa Tephra.
- ii) The Rangitawa Tephra was erupted during the latter part of the cool glacial period, $\delta^{18}\text{O}$ stage-10, while the Murupara-C Tephra was apparently erupted a warmer interglacial period, $\delta^{18}\text{O}$ stage-9, at c. 0.33–0.34 Ma.

The Murupara-C Tephra may have originated in the Whakamaru caldera, but is more likely to have come from the Okataina Volcanic Centre. The Murupara-C Tephra has a near identical glass chemistry to the Murupara-B, which from its coarse pumice clasts is thought to have been sourced nearby (i.e. Okataina), and it is possible that these two eruptives may have come from the same magma batch.

9.4 Bonisch Tephra

The Bonisch Tephra is believed to be the fourth eruptive deposited in the Murupara subgroup. It is recognised both in the coastal sections, and in the Kaingaroa forest; its name being taken (this work) from Bonisch Road in the Kaingaroa Forest. It is the major tephra deposit in the "Bonisch Pyroclastics" [Nairn, 1989b]; a catch-all term used for the obsidian-rich tephtras lying between the Matahina and Rangitaiki Ignimbrites. The Bonisch Tephra is also known here as the Murupara-D Tephra.

The best site to view the Bonisch Tephra is at the Bonisch Road section. Unfortunately, this site cannot be the type section as the base of the tephra is not exposed here. The type section for the Bonisch Tephra is hence deemed to be at the Murupara-(2) site. The entire tephra is also well represented at the Murupara-(1) and Murupara-(3) sites, and the middle portions only (of the tephra) at the Pahekeheke section.

In the coastal Bay of Plenty region, the Bonisch Tephra is recognised in the Otawairere, Hiwarau, Ohiwa Beach, Huntress Creek, and Burchett sections. It should also be present at the Reeves and Pukeruru Point sections, but all of the tephtras of the Murupara subgroup are very weathered here and the Bonisch Tephra could not be positively identified.

Diagnostic features:

On the Kaingaroa Plateau: (see Photo-24)

- An upper part consisting of well bedded ash and shower bedded pumice lapilli layers.
- A middle part consisting of a reverse graded layer of white pumice lapilli and black obsidian lithics (30-45 cm thick) which has a 'speckled' appearance; overlying:
 - a pink, normally graded fine to coarse ash (10-20 cm thick). Basal part of ash layer is often grey due to a high proportion of rhyolitic lithics.
- A basal part consisting of several reverse graded, shower bedded, white pumice lapilli beds; together often several metres in thickness.

In coastal Bay of Plenty: (see Photo-25)

- An upper layer of reverse graded coarse to fine ash, occasionally with a 'speckled' appearance.
- A middle layer of pinkish white fine ash (5-10 cm thick).
- A basal, unconsolidated, white sandy ash ($\approx$ 20 cm thick); often reverse graded.

Table 9-4 : Glass chemistry of the Bonisch Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Pahekeheke 00401	78.40 0.27	12.36 0.06	0.11 0.02	0.89 0.06	0.10 0.03	0.84 0.04	3.37 0.17	3.84 0.08	0.12 0.03	8.81 0.76	11	0.97
Huntress Creek 01503	79.21 0.23	12.14 0.09	0.11 0.02	1.01 0.08	0.10 0.02	0.90 0.04	#2.70 0.15	3.69 0.09	0.17 0.02	6.46 0.67	10	0.96
Murupara-(1) 02304	78.82 0.18	11.99 0.09	0.11 0.02	1.01 0.06	0.12 0.02	0.86 0.04	#3.13 0.14	3.87 0.06	0.14 0.02	3.20 0.79	10	0.96
Murupara-(1) **02305	78.71 0.18	12.33 0.11	0.11 0.03	0.98 0.11	0.10 0.03	0.81 0.06	#3.03 0.16	3.84 0.08	0.13 0.05	3.77 0.43	10	1.00
Hiwarau 02707	78.69 0.21	12.24 0.10	0.11 0.02	0.99 0.06	0.09 0.02	0.88 0.05	#3.09 0.13	3.74 0.13	0.17 0.02	5.91 0.70	15	0.97
Burchett 04603	78.83 0.19	12.15 0.09	0.13 0.03	1.05 0.06	0.10 0.03	0.74 0.07	#3.23 0.12	3.64 0.19	0.18 0.02	3.69 1.18	10	0.95

Figure 9-5: Isopach map of Bonisch Tephra distribution; (thicknesses in metres)

Stratigraphic relationships:

In most of the Kaingaroa Forest sections, the Bonisch Tephra has a weak brown paleosol developed into its uppermost sandy ash layer. This paleosol is moderately well developed at Pahekeheke. Throughout the coastal eastern Bay of Plenty, the Bonisch Tephra has a reasonably well developed paleosol (≈ 20 cm thick) in its upper layers. Resting on this paleosol are the Murupara-E and Anaputa Tephrae.

In the Kaingaroa Forest, the base of the Bonisch Tephra is observed in the three Murupara sections only. Here, the tephra overlies a paleosol developed into: weathered tephra (at Murupara-(1)); tephric-loess (at Murupara-(2); see Photo-23); or the shaved surface of the Rangitaiki Ignimbrite (at Murupara-(3)) (see Figure 9-4). The absence of several underlying tephrae at the Murupara-(1) and Murupara-(3) sites is probably due to *aeolian stripping* (erosion) of the unconsolidated deposits. The highest section topographically (i.e. Murupara-(3)) has had the most material removed, while the lowest (Murupara-(1)) is the best preserved. This lowest section even retains—in some places—part of the unwelded top of the Rangitaiki Ignimbrite. This stripping of the landscape was the dominant process in the Kaingaroa Plateau region during full glacial periods; the preservation of tephric-loess occurring only when the climate started to become less harsh.

In the coastal Bay of Plenty sections the Bonisch Tephra always rests on a paleosol weathered into the underlying deposits (see Photo-25).

Chemistry and mineralogy:

The glass chemistry of the Bonisch Tephra (Table 9-4) is not particularly distinctive, with all element oxides having moderate values, except for K_2O which is slightly higher than average.

The Bonisch Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende + biotite

Biotite is much less common than the other minerals, and was not seen in some samples (e.g. in the basal, crystal poor, white pumice lapilli).

Distribution and size:

The Bonisch Tephra has been positively identified at four sites on the Kaingaroa Plateau and at five sites in the coastal eastern Bay of Plenty. The recorded thicknesses of the tephra throughout the Bay of Plenty are shown in Figure 9-5.

On the Kaingaroa Plateau, the tephra is >4.4 m thick at Bonisch Road, and 2.9 m, 3.0 m and 2.5 m at the Murupara-(1), -(2) and -(3) sections respectively. Only the very top of, and a 2.2 m slice through the middle of this tephra is exposed at the Pahekeheke site, but here, based upon the coarse grain-size, it is thought to be similar in thickness to that at Bonisch Road.

The rapid thickening northwards from Murupara across the Kaingaroa Plateau indicates that the Bonisch Tephra was erupted from the Okataina Volcanic Centre.

breach—could have been the cause of the floods that are postulated as the source of the pinkish-grey tephric deposits beneath the main Matahina eruptives in coastal marine sediments.

The near source section at Anaputa Point contains surge deposits and an airfall bed with an unusually high proportion of biotite. These deposits may represent the initial vent clearing phase of the eruption.

The Matahina eruptives are composed of a mixture of two slightly different chemical types, one much more dominant than the other. This mixture is thought to have been caused by the eruption vent tapping the side of a zoned magma chamber, close to the boundary between the two magma types [Carr, 1984].

The Matahina Tephra is perhaps the most useful tephra marker horizon in the eastern Bay of Plenty stratigraphy.

Figure 9-4 : Comparison of erosion/preservation at the Murupara sections (see appendix-(M) for key)

In the coastal eastern Bay of Plenty area, the Bonisch Tephra varies in thickness; being ≈ 90 cm thick at Whakatane (Otarawairere), ≈ 70 cm thick on the eastern side of Ohiwa Harbour (Ohiwa Beach & Huntress Creek), and ≈ 50 cm thick east of Opotiki (Burchett). The grain-size of the Bonisch Tephra is observed also to increase towards the west. These data suggest an elongated dispersal in a due east, or just south of east direction as the most likely distribution pattern.

Several of the beds which comprise this tephra are thicker than expected at some sites if the easterly dispersal was consistent. For example, the reverse graded obsidian-rich pumice bed above the central fine ash layer is 70 cm thick at Murupara-(3), 45 cm thick at Murupara-(2), but only 20 cm thick at Bonisch Road. This slightly different distribution pattern is probably related to variations in the paleowind direction during the eruption, and suggests that the wind direction was perhaps more from the north during this part of the eruption sequence. The coarse pumice basal part of the eruption is much thinner at the Murupara-(3) site than at Bonisch Road and as these basal beds comprise the major part of the eruption, the predominant dispersal was towards the east.

Using the inferred distribution pattern a minimum eruptive volume of $25\text{--}30 \text{ km}^3$ has been estimated for the Bonisch Tephra. There is enough data to suggest that the maximum volume of the tephra cannot be very much greater than this minimum estimate; at most perhaps only double.

Discussion:

The Bonisch Tephra represents a moderate to large eruption from the Okataina Volcanic Centre at *c.* 0.33–0.34 Ma. The tephra is rich in obsidian lithics, and has a distinctive series of beds which allows correlation over a wide area. The bulk of the tephra is believed to have been dispersed in an easterly direction. At the Murupara-(1) site, the central fine ash layer has well defined, wavy draped bedding; suggesting that it may have undergone some rain flushing at this site.

A likely scenario for the Bonisch Tephra eruption follows:

- The initial eruptions were violent with thick, plinian, reverse graded, coarse pumice beds being rapidly deposited.
- The fine ash layers above this represent an hiatus or weakening in eruption activity as the ash settled out of the eruption column.
- The obsidian-rich beds above the ash represent renewed activity causing brecciation of vent filling obsidian domes and/or chilled margins at the walls of the magma chamber. These beds are interspersed with finer ash beds and the eruption at this stage is likely to have been intermittent.

Several slight erosional time breaks can be seen amongst the many well defined beds that comprise this eruptive, indicating that the Bonisch Tephra eruption was not instantaneous, but probably erupted over a period of many months.

Table 9-5 : Glass chemistry of the Murupara-E Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	*Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Pahekeheke	78.53	12.18	0.10	0.98	0.09	0.75	#3.41	3.83	0.17	5.74	17	1.00
**00402	0.24	0.08	0.02	0.07	0.02	0.05	0.21	0.18	0.02	0.97		
Anaputa Point	78.10	12.21	0.09	1.04	0.09	0.79	3.68	3.91	0.15	-0.29	13	0.96
00504	0.21	0.09	0.01	0.06	0.02	0.04	0.12	0.10	0.02	0.46		
Huntress Creek	78.53	12.17	0.10	1.03	0.10	0.88	#3.31	3.76	0.15	5.65	12	0.96
01502a	0.35	0.14	0.02	0.07	0.03	0.08	0.22	0.19	0.03	0.85		
Murupara-(2)	77.75	12.54	0.12	1.07	0.09	0.81	3.69	3.78	0.19	4.58	11	0.94*
10003a	0.20	0.14	0.04	0.07	0.03	0.10	0.12	0.16	0.03	0.97		

9-5 Murupara-E Tephra

The Murupara-E Tephra is believed to be the fifth eruptive deposited in the Murupara subgroup, and it is recognised in only a few sections on the Kaingaroa Plateau.

The type section for the Murupara-E Tephra is at Bonisch Road, though glass has not been analysed from here. The tephra is also very well represented at the Pahekeheke section, and is present at all three of the Murupara sections, although its internal bedding and its boundaries with the enclosing tephtras are difficult to distinguish in these sections.

The Murupara-E Tephra is not recognised as a separate tephra deposit in the coastal Bay of Plenty region, but has been detected as one of the components in a mixed population of glass within the weathered Anaputa Tephra. It is obscured by colluvium at the Otawairere section.

At Anaputa Point (Lake Rotoma), the Murupara-E Tephra is represented by an obsidian breccia; probably the remnants or edge of an obsidian dome.

Diagnostic features:

On the Kaingaroa Plateau: (see Photo-26)

- An upper part consisting of a grey ash with occasional layers and pockets of coarse ash and rare lapilli; overlying reverse graded ash to granular pumice.
- A middle part consisting of a pinkish grey ash.
- A basal part consisting of alternating beds of pumice lapilli and fine and coarse ash.

Stratigraphic relationships:

In most of the Kaingaroa Forest sections, the Murupara-E Tephra has a brown, very weak, organic-rich ash-paleosol developed into its uppermost ash bed (see Photo-26). The thickness of this paleosol ranges from 2 to 5 cm. Throughout the coastal eastern Bay of Plenty, the paleosol and the contact with the overlying Anaputa Tephra are not distinguishable.

At Anaputa Point, the boundary between the obsidian breccia and the Anaputa Tephra is mixed, with bedded ash infilling the relief in the surface of the breccia.

In the Kaingaroa Forest, the base of the Murupara-E Tephra is observed to overlie the paleosol developed into the Bonisch Tephra. At some sites this paleosol is thin, but at others (e.g. Pahekeheke) it is moderately developed.

Chemistry and mineralogy:

The glass chemistry of the Murupara-E Tephra (Table 9-5) is not particularly distinctive, with all element oxides having moderate values.

At two sites, Murupara-(2) and Huntress Creek, shards of Murupara-E Tephra chemistry are mixed with those of Anaputa Tephra chemistry. At Huntress Creek this mixture is probably due to sampling across the unrecognised boundary between the two weathered tephtras.

The Murupara-E Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene

Distribution and size:

The Murupara-E Tephra has been physically recognised at only five sites, all on the Kaingaroa Plateau, and chemically at one site, in the coastal eastern Bay of Plenty. It has a thickness of ≈ 1 m at Bonisch Road, 80 cm at Pahekeheke and between 30 and 50 cm at the three Murupara sections.

Since the thickest deposits of the Murupara-E Tephra are seen on the northern Kaingaroa Plateau, it is thought that the tephra was erupted from the Okataina Volcanic Centre. Furthermore, if—as is highly likely—the obsidian dome at Anaputa Point is a correlative of the Murupara-E Tephra, then the source area of the tephra lies very near to here — the southwestern shore of Lake Rotoma.

9-6 Anaputa Tephra

The Anaputa Tephra is believed to be the sixth eruptive deposited in the Murupara subgroup, and it is recognised in sections from the Kaingaroa Plateau to the coastal Bay of Plenty. The tephra is also known here as the Murupara-F Tephra.

The type section for the Anaputa Tephra, is in the cliffs at Anaputa Point, on the shore of Lake Rotoma. The tephra is also very well represented at the Pahekeheke section, and has been recognised at the Murupara-(1), Murupara-(2), Hiwarau and Huntress Creek sections. It should also be present at the Otarawairere, Burchett, Ohiwa Beach, Reeves and Pukeruru sections, but the glass chemistry has yet to be carried out which would confirm the tephra's presence.

Diagnostic features:

At Anaputa Point: (see Photo-26; Photo-27; Photo-28)

- A thick (up to 4.5 m) upper part, consisting of very well bedded (decimetre-bedding) alternating coarse ash and pumice lapilli layers. Most, but not all beds, contain abundant, large, crumbly obsidian lithics resulting in a 'speckled' appearance. Some beds contain up to 30% lithics. Maximum pumice size is up to 3 cm across, and lithics 2 cm across. Many beds have irregular thickness and some erosion has occurred between the deposition of some beds.
- A thin (10 cm thick) grey ash occurs in the middle of the tephra.
- A thick (1.5 m) basal part, consisting of poorly sorted coarse pumice lapilli and large obsidian lithics.

On the Kaingaroa Plateau:

- Generally two 'speckled' pumice lapilli layers separated by a grey ash layer. A few other thinner ash layers can be seen within the upper pumice bed. The upper part is much thinner than at Anaputa Point.

Table 9-6 : Glass chemistry of the Anaputa Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	[#] Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Pahekeheke	77.56	12.63	0.16	1.35	0.15	1.20	[#] 3.37	3.39	0.20	3.00	13	0.96
00404	0.62	0.40	0.05	0.14	0.03	0.12	0.11	0.04	0.05	1.01		
Anaputa Point	77.61	12.53	0.16	1.27	0.17	1.24	3.59	3.28	0.17	3.07	9	1.00
**00502	0.20	0.14	0.04	0.09	0.01	0.06	0.17	0.11	0.02	0.96		
Anaputa Point obs.	77.47	12.42	0.16	1.37	0.16	1.25	3.69	3.35	0.14	-0.65	9	0.98
00503	0.14	0.23	0.03	0.11	0.01	0.05	0.13	0.11	0.03	1.09		
Huntress Creek	76.39	13.08	0.18	1.46	0.19	1.25	3.90	3.31	0.24	5.01	13	0.94*
01523	0.22	0.13	0.04	0.11	0.05	0.06	0.13	0.10	0.04	0.97		
Huntress Creek	78.78	12.07	0.19	1.31	0.17	1.33	[#] 3.36	2.69	0.13	4.98	9	0.93
01502b	0.44	0.23	0.04	0.10	0.05	0.15	0.20	0.24	0.03	1.18		
Murupara-(1)	77.15	12.81	0.17	1.33	0.16	1.32	3.51	3.38	0.17	2.43	7	0.96
02302a	0.46	0.29	0.02	0.09	0.03	0.13	0.17	0.18	0.02	1.02		
Hiwarau	77.49	12.62	0.16	1.32	0.15	1.24	3.52	3.32	0.17	3.79	8	0.98
02706	0.35	0.15	0.03	0.06	0.02	0.06	0.16	0.11	0.03	1.61		

In the coastal Bay of Plenty region: (see Photo-29; Photo-30)

- The tephra is often very weathered with little of its internal bedding preserved. In patches where it is less weathered it consists of very well bedded alternating fine and coarse ash layers, often 'speckled' due to the presence of obsidian lithics.
- Generally identified by its distinctive glass chemistry and close association to the overlying and readily recognised Matahina Tephra.

Stratigraphic relationships:

In most of the Kaingaroa Forest sections the Anaputa Tephra has a weak paleosol developed into its uppermost ash bed (Photo-26; Photo-28), but at some sites (e.g. Murupara-(1)) this paleosol merges with that occurring above—between the Matahina and Murupara-G Tephra—and becomes quite thick (e.g. 40 cm). Throughout the coastal eastern Bay of Plenty, these two paleosols have merged and the true upper boundary of the Anaputa Tephra could not be distinguished (see Photo-29).

A thick paleosol is also seen at Anaputa Point, $\approx 6\text{--}7$ m up from its base, but it is unclear whether this paleosol is developed in the Anaputa Tephra, or in the Murupara-G Tephra with the boundary between the two tephrae not detected.

In the Kaingaroa Forest, the base of the Anaputa Tephra is seen to overlie a thin, very weak paleosol developed in the top of the Murupara-E Tephra (see Photo-26; Photo-28). This lower boundary is often not visible at the Murupara sites, or in the coastal eastern Bay of Plenty.

Chemistry and mineralogy:

The glass chemistry of the Anaputa Tephra (Table 9-6) is quite distinctive with only a few tephrae in this study having a similar chemistry. It has relatively high FeO & CaO ($\text{FeO} \approx \text{CaO} \approx 1.3$ wt.%), and a relatively low K_2O content resulting in an unusually high $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratio. Of all tephrae in the Murupara subgroup, only the Murupara-A Tephra has a chemistry similar to this, though several tephrae in the Torere subgroup are similar.

Sample "00503" represents glass from crushed obsidian lithics taken from the lower part of the Anaputa Tephra at Anaputa Point. These lithics were analysed to determine if they were primary (i.e. a result of the same magma eruption), or xenoliths from the obsidian breccia immediately below. The results confirm that the obsidian within the Anaputa Tephra is primary.

The Anaputa Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene

Distribution and size:

The Anaputa Tephra is found in many sites in the Bay of Plenty, from Murupara to Lake Rotoma to Opotiki, although in many areas (e.g. near Murupara & near Opotiki), strong weathering has rendered its true thickness difficult to determine. The paleosol below the Matahina Tephra has often developed

completely through the Murupara-G Tephra and into the Anaputa, and so the thickness of the paleosol cannot be used as an estimate of original tephra thickness.

The Anaputa Tephra is up to 6 m thick at Anaputa Point, and the size of the lithics here indicate a nearby source within the Okataina Volcanic Centre. The tephra is <1 m thick at the Bonisch and Pahekeheke sites and even thinner at Murupara and in coastal Bay of Plenty sections, but there are no firm indications of dispersal direction.

Discussion:

The Anaputa Tephra probably represents a moderate sized eruption from the Okataina Volcanic Centre, occurring at *c.* 0.33–0.34 Ma. It has an unusual chemistry and a high proportion of obsidian lithics which may, in the future, allow more widespread correlations.

The several small erosional features recognised within the upper part of this tephra, together with its well bedded nature, suggest that the latter part of the eruption was intermittent in nature, and as a whole may have occurred over a moderately lengthy time period. This extended eruption period may also explain its highly weathered nature in the coastal areas. As there may have been no large individual dumping of tephra here, soil organisms may have survived deposition and enhanced the weathering of the deposits.

9-7 Murupara-G Tephra

The Murupara-C Tephra is believed to be the seventh eruptive deposited in the Murupara subgroup, but it is only recognised individually at a few sites on the Kaingaroa Plateau.

The type section for the Murupara-G Tephra is at Pahekeheke Road, though it is also very well represented at the Bonisch Road site. The tephra is also probably present at Anaputa Point, but here the boundary between the Anaputa and Murupara-G Tephra is high up in the cliff and not readily observed. It may also have been eroded out here by the emplacement of the Matabina Ignimbrite. The Murupara-G Tephra is present at both the Murupara-(1) and Murupara-(2) sections, although here it is often too weathered to be distinguished. It is generally not recognised as a separate deposit in the coastal eastern Bay of Plenty, although at Hiwarau, the Murupara-G Tephra may be represented by 50 cm thick layer of weathered tephra resting on the paleosol developed into the Anaputa Tephra.

The physical characteristics of the Murupara-G Tephra generally consist of:

- ash with many thin lenses and lines of pumice lapilli (see Photo-26; Photo-28).

Table 9-7 : Glass chemistry of the Murupara-G Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Pahekeheke	78.41	12.18	0.14	1.14	0.12	0.99	#3.27	3.55	0.20	5.29	12	1.00
**00403	0.17	0.09	0.03	0.07	0.02	0.05	0.08	0.10	0.03	0.80		
Murupara-(1)	77.11	12.33	0.13	1.09	0.13	1.05	3.43	3.55	0.16	3.85	3	0.96
02302b	0.52	0.40	0.03	0.07	0.01	0.07	0.27	0.11	0.03	0.51		

Stratigraphic relationships:

The Murupara-G Tephra always has a reasonably dark paleosol developed into its upper layers (see Photo-28). The basal pumices of the overlying Matahina Tephra are sometimes seen to be mixed into the upper part of this paleosol. At several sites (e.g. Murupara-(1)) the upper surface of the paleosol shows some erosional relief.

Where the base of the Murupara-G Tephra is recognised, it rests upon a weak paleosol developed into the Anaputa Tephra.

Chemistry and mineralogy:

The glass chemistry of the Murupara-G Tephra (Table 9-7) is not particularly distinctive, with moderate FeO, CaO, Na₂O & K₂O wt.%'s, but it is quite distinctive for the tephtras found in the Murupara subgroup. The other tephtras in this subgroup generally have either higher FeO & CaO, and lower K₂O; or lower CaO and higher K₂O than the Murupara-G Tephra.

Sample "02302b" is a minor component of a mixed chemical assemblage; the major component having Anaputa type chemistry. This mixture is probably the result of pedological mixing, as the sample was taken from near the top of the Anaputa Tephra, within the thick paleosol that underlies the Matahina Tephra and developed completely through the Murupara-G Tephra.

The Murupara-G Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene

Distribution and size:

Due to its highly weathered nature, the Murupara-G Tephra is only recognised at a few sites and its distribution is poorly understood.

The Murupara-G Tephra is ~1 m thick in the central Kaingaroa forest, but has an undetermined, though definitely much smaller, thickness elsewhere. It is probably that the source of this tephra lies within the Okataina Volcanic Centre.

9-8 Matahina Tephra

The Matahina Tephra is associated with the voluminous "Matahina Ignimbrite" eruption, which has been studied in detail by Bailey [1957, 1965], Carr [1984], and Bailey & Carr [1994]. As the ignimbrite is such an important and widespread deposit, the airfall tephra becomes an important stratigraphic marker wherever it is found. The tephra is found throughout the eastern Bay of Plenty and has several distinctive physical characteristics which allow confident correlations to be made. The Matahina eruption is generally regarded as the largest eruption to have come from the Okataina Volcanic Centre, and it is believed to be the eighth tephra deposited in the Murupara subgroup. Hence it is also known here as the Murupara-H Tephra.

The type section for the Matahina Tephra is designated to be at the Huntress Creek section. The tephra here is complete and shows both its basal ash layer and its upper weathered top. The Matahina Tephra is thickest (≈ 3 m) in the Bonisch and the Pahekeheke sections, but at both these sites it is directly overlain by Matahina Ignimbrite, and the co-ignimbrite ash and the true upper contact of the Matahina eruptives cannot be observed.

Other sections where the Matahina Tephra is well represented are the Ngatiawa lookout, Otawairere, Hiwarau, Pukeruru Point, and Burchett sections. The airfall tephra is also present at the Reeves, Ohiwa Hill, Ohiwa Beach, and the Waitohi River sites.

In addition to the Bonisch and Pahekeheke sections, the tephra is also seen to underlie the ignimbrite in the Lake Matahina, Murupara-(1), Murupara-(2), Anaputa Point, Kohioawa cliffs, Herepuru Stream bridge, Herepuru Road-(2) and Ohinekoao Stream slip sections. Some erosion has accompanied—or just preceded—the emplacement of the ignimbrite at these sites and hence only the basal airfall beds are preserved.

The Matahina Ignimbrite is a very thick and widespread deposit is recognised at many sites. Its base, however, is known to be observed at the above sites only.

Diagnostic features:

In the coastal eastern Bay of Plenty: (see Photo-29; Photo-30)

- A basal fine pink (7.5YR 7/6 – "orange") ash layer, immediately overlying a thin and generally incomplete layer or line of pumice lapilli, which lies on and/or is mixed into the top of the underlying paleosol.
- A second less prominent fine white ash layer ≈ 20 cm above the basal ash.
- One of the thickest airfall pumice deposits in the eastern Bay of plenty; 1–3 m thick (≈ 2 m at Opotiki).
- The pumice in this tephra is some of the coarsest seen in the eastern Bay of plenty; lapilli ≈ 1 –3 cm across at Opotiki.
- Contains abundant large, light grey rhyolite lithics, the largest in any tephra in the region; 1–2 cm across at Opotiki.

Matahina Ignimbrite:

- Has a moderate crystal content, neither crystal poor or crystal-rich (3–9%). The plagioclase/quartz ratio ranges from 0.8–3.4, commonly 1–2. Salic phenocrysts greatly predominate. There is no change in crystal content with depth [Carr, 1984].
- In the coastal sections near Matata, the basal flow unit (unit-I) is only 5–10 m thick and consists of coarse white pumice in an ash matrix. This is overlain by ≥ 40 m of flow unit-II. The base of this unit has a characteristic salmon pinkish-orange colour. Columnar jointing related to weak or incipient welding is occasionally seen.

Stratigraphic relationships:

Both the upper and lower contacts of the Matahina Tephra at the type section are readily observable. At Huntress Creek, a weathered, brown sandy paleosol has developed into the top of the Matahina Tephra. The paleosol has little soil structure and is still quite sandy, probably due to the coarse grain-size of the substrate. The Torere-A Tephra rests directly on this paleosol. Where the Matahina Ignimbrite overlies the airfall tephra, the contact between the two is generally sharp, with occasional slight erosional relief.

The top of the Matahina Ignimbrite is generally not exposed, but at the Reihana Road section the top 10 cm of the uppermost flow unit (III)—here only 0.6 m thick—has a weak paleosol developed into it. The Torere-A Tephra again rests directly on this. At Awakeri Springs, a reasonable paleosol is developed into the Matahina deposit, but it is uncertain whether the Matahina here is ignimbrite or airfall, though ignimbrite is present in nearby areas.

At most sites in the eastern Bay of Plenty, the base of the Matahina Tephra directly overlies the paleosol developed into the Murupara-G and Anaputa Tephra. At some sites the basal pink ash lies on the paleosol, but at many others (e.g. Huntress Creek, Waiohau River, Hiwarau) the ash directly overlies a line of pumice lapilli which sits on and is mixed into the top few centimetres of the paleosol below (see Photo-30).

In the Kohioawa cliffs, the basal pink ash of the Matahina Tephra generally rests directly on a brown, well sorted fine sand (see Photo-64), believed to be marine in origin, probably estuarine. At some sites along the cliff face (e.g. Herepuru Stream bridge) a crystal-lithic phreatic unit [Bailey & Carr, 1994] can be found as cross-bedded lenses between the pink ash and the brown sand. This phreatic unit appears to represent a period of vent clearing explosions through the pre-existing strata, mainly the Rangitaiki Ignimbrite and rhyolite domes [Bailey & Carr, 1994].

At the Lake Matahina site [V16/448353], the Matahina Ignimbrite overlies airfall pumice and ash which rests directly on fluvial deposits of the Lukes Farm Formation [Healy *et al.*, 1964]; part of the Castlecliffian/Haweran Huka Group non-marine sediments. Here, and at Bonisch Road, the basal pink ash occurs at the base of the ignimbrite, and the airfall pumice below rests directly on the underlying deposits (e.g. Murupara-G paleosol, Lukes Farm F.).

In the western part of the Pukeruru Point section, the Matahina Tephra rests on weathered gravels and consists of a mixture of sand, pumice and weathered gravels, with occasional cross-bedding also recognised. The mixture suggests, perhaps, that the tephra was deposited in a sub-aqueous environment. The upper part of this deposit has a well developed paleosol in it. Subaerially deposited Matahina Tephra can be found topographically higher elsewhere in this section.

Overlying the Matahina Tephra at both the Otawairere and Ngatiawa lookout sites, is a firm, yellowish, weathered deposit which may represent an estuarine mud (Otarawairere Mudstone — Edbrooke, [1977]).

Table 9-8.1 : Glass chemistry of the pre-ignimbrite plinian airfall Matahina Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	[#] Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Herepuru Stream Br. **00201	78.68 0.45	12.13 0.17	0.11 0.02	1.01 0.04	0.10 0.02	0.84 0.05	[#] 3.42 0.18	3.59 0.11	0.18 0.03	3.81 1.64	11	1.00
Pahekeheke 00405	77.73 0.25	12.31 0.08	0.16 0.03	1.09 0.06	0.14 0.03	0.85 0.06	3.73 0.07	3.79 0.14	0.24 0.04	3.61 0.72	9	0.89
Anaputa Point 00501	78.68 0.30	12.07 0.08	0.12 0.03	0.96 0.07	0.09 0.02	0.89 0.02	[#] 3.44 0.17	3.62 0.12	0.17 0.02	4.39 0.89	8	0.96
Murupara-(1) 02301	78.36 0.22	12.20 0.17	0.12 0.01	0.99 0.10	0.11 0.03	0.88 0.04	[#] 3.43 0.11	3.79 0.08	0.19 0.03	3.53 0.60	8	0.96
Ohinekoao Strm.slip 03301	78.37 0.20	12.31 0.08	0.11 0.02	0.94 0.05	0.10 0.02	0.75 0.03	3.65 0.20	3.68 0.09	0.14 0.03	7.82 0.70	13	0.96
Murupara-(1) 02301b	78.18 0.09	12.19 0.19	0.14 0.05	1.05 0.05	0.15 0.01	1.17 0.07	3.59 0.19	3.36 0.25	0.17 n.d.	4.17 0.79	2	0.88

Table 9-8.2 : Glass chemistry of the Matahina Ignimbrite.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Herepuru Stream Br. **00202	77.81 0.26	12.26 0.11	0.14 0.02	1.11 0.08	0.13 0.04	0.88 0.09	3.63 0.10	3.81 0.11	0.24 0.06	6.93 0.35	8	1.00
Ohinekoao Strm.slip 03302	78.60 0.15	12.10 0.08	0.11 0.03	0.97 0.09	0.11 0.03	0.81 0.03	3.53 0.15	3.63 0.16	0.18 0.04	5.08 0.61	13	0.92
Reihana Road 06202	77.80 0.20	12.44 0.14	0.18 0.06	1.11 0.09	0.12 0.05	0.84 0.09	3.64 0.12	3.68 0.12	0.19 0.05	4.53 0.61	11	0.95
Wilson's farm-(1) 07801	77.99 0.49	12.20 0.37	0.19 0.05	1.03 0.07	0.12 0.02	0.90 0.07	3.72 0.13	3.64 0.10	0.21 0.06	2.83 0.88	10	0.94
Ridgeway 09601	78.62 0.28	12.15 0.33	0.14 0.04	1.01 0.08	0.11 0.03	0.85 0.05	3.21 0.11	3.72 0.18	0.19 0.04	3.11 0.98	12	0.95
Onuku-(1) 09801	77.70 0.29	12.41 0.22	0.14 0.04	1.05 0.08	0.13 0.05	0.87 0.06	3.66 0.09	3.83 0.11	0.23 0.05	3.81 1.28	11	0.99
\$—\$ (Froggatt)	78.22 0.27	12.36 0.22	0.09 0.04	1.08 0.14	0.09 0.01	0.76 0.09	3.71 0.25	3.61 0.17	— --	5.50 1.35	11	0.89*

\$—\$ = Matahina Ignimbrite glass chemistry; [Froggatt, 1983]

At the Herepuru Road-(2), Ohinekoao Stream slip (see Photo-31), Ngatiawa lookout, and perhaps Paerata Ridge Road sites, there is a massive pinkish-grey sandy ash between the fine pink ash which generally marks the base of the tephra, and the underlying brown marine sand. This sandy ash is 60 cm thick and 35 cm thick at Herepuru Road-(2) and Ohinekoao Stream respectively, but >1.5 m thick at Ngatiawa—where the base wasn't seen, and 45 cm thick at Paerata. The glass chemistry of this unit was analysed from Ohinekoao Stream (sample [03301]) and is a good match for Matahina. The sandy ash unit has been correlated to the crystal-lithic phreatic unit preceding the main Matahina eruption [Bailey & Carr, 1994], but as it has the same chemistry as the Matahina, the bulk of the crystal-lithic deposit must represent an early phase of the eruption and not reworked material. The grey sandy ash unit is not observed at other nearby sections that contain terrestrial deposits (e.g. Otawairere is <1 km from Ngatiawa), and the thickness of the unit does not decrease away from source as expected for an airfall deposit. It is thus suggested here that the sandy ash unit is tephric flood sediment deposited in an estuarine or marine environment and it is not present at all in terrestrial sections. The subsequent deposition of the Matahina Tephra, and more importantly the very thick ignimbrite, stopped further reworking of the sandy ash unit into other areas.

Chemistry and mineralogy:

The glass chemistry of the Matahina Tephra (Tables 9-8.1, 9-8.2 & 9-8.3) is not particularly unusual and all element oxides show moderate wt.% values. Nevertheless, as most of the tephrae of similar age have quite different chemistries, the Matahina's glass chemistry is still a useful tool for its identification. The Matahina, in this work, has generally been correlated by its physical characteristics, which was only later confirmed by glass chemistry.

A few samples show a minor secondary component which has a different glass chemistry. If each sample site was taken individually, the low proportion of these shards could be explained away as contamination or analytical error. However, the glass chemistry of this minor component is reasonably consistent from site to site, which suggests that this secondary glass component is real. Carr [1984] also reported a mixed chemical assemblage for the Matahina eruptives; the minor component having higher TiO_2 , MgO & CaO , and lower K_2O contents. This chemistry compares well with the analyses obtained in this study. Carr concluded that the Matahina eruption sequence was "an example of a zoned pluton erupted early in its evolution", or — a mixed magma eruption.

The Matahina Tephra has a ferromagnesian mineral assemblage consisting of: -

hornblende + hypersthene $\pm$ biotite

At most sites there is no biotite present, but at Anaputa Point, Reeves, Murupara-(1), Waiotahi River and Ohinekoao Stream slip, biotite comprises a significant proportion of the ferromagnesian mineral assemblage — occasionally more than hypersthene. Augite was detected in trace amounts in one sample only (Hiwarau). Carr [1984] also detected very few augites.

Table 9-8.3 : Glass chemistry of the airfall Matahina Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Huntress Creek 01508	78.61 0.18	12.14 0.07	0.18 0.04	1.02 0.06	0.16 0.04	1.03 0.05	#3.32 0.08	3.34 0.11	0.19 0.02	3.46 0.48	11	0.86
Huntress Creek **01501	78.55 0.37	12.25 0.11	0.11 0.02	1.03 0.07	0.10 0.02	0.82 0.06	#3.38 0.16	3.63 0.19	0.19 0.03	4.27 1.15	9	1.00
Reeves Road 01901	79.03 0.17	12.00 0.07	0.10 0.02	1.08 0.10	0.11 0.02	0.83 0.04	#3.09 0.16	3.64 0.11	0.16 0.03	3.47 0.75	8	0.96
Hiwarau 02708	79.06 0.21	12.14 0.13	0.13 0.04	1.04 0.08	0.11 0.02	0.89 0.05	#2.88 0.15	3.61 0.17	0.18 0.02	4.14 0.76	14	0.94
Waiotahi River 02901	78.78 0.17	12.21 0.11	0.10 0.02	1.04 0.09	0.10 0.02	0.83 0.04	#3.20 0.14	3.59 0.11	0.17 0.05	4.26 1.82	17	0.98
Otarawairere 04102	78.97 0.26	12.15 0.10	0.12 0.02	0.91 0.05	0.10 0.02	0.80 0.03	#3.29 0.21	3.53 0.11	0.20 0.02	6.18 0.40	11	0.96
Ngatiawa lookout 04306	77.77 0.27	12.36 0.18	0.19 0.07	1.08 0.10	0.14 0.05	0.91 0.10	3.66 0.13	3.67 0.11	0.23 0.04	5.57 0.63	10	0.88*
Awakeri Springs 04404	77.32 0.37	12.55 0.19	0.14 0.04	1.11 0.12	0.11 0.04	0.90 0.08	3.84 0.12	3.75 0.17	0.28 0.04	4.76 1.10	10	0.92*
Te Piki West 06701	78.48 0.39	12.15 0.11	0.12 0.03	1.03 0.09	0.11 0.02	0.93 0.07	3.49 0.17	3.55 0.19	0.14 0.02	1.76 0.86	14	0.96
Hiwarau 02708b	79.06 0.35	12.32 0.00	0.09 0.01	1.06 0.08	0.11 0.03	1.16 0.00	2.97 0.29	3.06 0.05	0.17 0.01	3.84 1.08	2	0.88
Waiotahi River 02901b	78.44 0.20	12.23 0.16	0.10 0.01	1.19 0.02	0.15 0.01	1.23 0.03	3.28 0.10	3.22 0.11	0.16 0.00	3.30 1.07	2	0.87
Otarawairere 04102b	79.08	11.99	0.16	1.16	0.16	1.07	3.32	2.92	0.13	6.97	1	0.84
Ngatiawa lookout 04306b	78.30 0.20	12.24 0.12	0.23 0.03	1.12 0.03	0.15 0.04	1.12 0.05	3.65 0.05	3.03 0.10	0.18 0.06	6.12 0.81	2	0.82

Figure 9-6 : Isopach map of Matahina airfall tephra & ignimbrite distribution (thicknesses in metres; ignimbrite distribution from Bailey & Carr, 1994)

Carr [1984] reported that biotite was "sparsely present in a few thin sections and in crystal concentrates of whole rock samples". He found no biotite in the crystal concentrates of pumice clasts and decided that its presence was unlikely to be related to primary crystallization of the Matahina magma. This worker, however, has crushed pumice from the Murupara-(1), Herepuru Stream bridge and Reeves sites and has detected some biotite in the crystal concentrates. Many of the biotite flakes found in these samples are quite weathered, though, compared with the other ferromagnesian minerals, and it is possible that some of the biotite may be of xenocrystal origin. Carr [1984] also reported that the biotite was "altered and magnetic, indicating an incipient breakdown to magnetite or maghemite" and suggested that a possible source of the biotite was "from biotite-rich lithic fragments". These small bits of country rock could be entrained within the deposit during vent widening episodes and would be more prevalent in the early (lower) eruptives and in the near source regions.

The greatest proportion of biotite in the Matahina Tephra was—in this study—found in the sample from Anaputa Point, where due to this high biotite content it was thought not to be a correlative of the Matahina [Carr, 1984]. However, the tephra at this site grades upwards into surge deposits that are directly overlain by an ignimbrite, which most workers (e.g. [Nairn, 1981]) have decided is indeed the Matahina Ignimbrite. Based upon the glass chemistry of the basal airfall tephra in this eruption sequence, and of the eruptives below this, there is little doubt that this biotite-rich tephra is in fact the Matahina.

Carr [1984] reported that hornblende was not present in the basal 20 cm of the airfall deposit at Murupara-(1), and determined that it was a uni-modal deposit of one chemical and mineralogical type. Above this and throughout the ignimbrite, the eruptive consists of a bimodal deposit. The hornblende poor component is thought to be the same as the minor component of the mixed chemical assemblage. The hornblende bearing pumice clasts also tended to have more calcic feldspars than the hornblende poor pumices [Carr, 1984].

Distribution and size:

At many sites it is difficult to establish the true thickness of the airfall Matahina Tephra because the overlying ignimbrite has eroded into it. It is also probable that co-ignimbrite airfall beds are intercalated with the several flow units of the ignimbrite, as has occurred within the Rotoiti Tephra [Nairn, 1972]. Thicknesses of the Matahina airfall tephra, and the distribution of the Matahina Ignimbrite are presented in Figure 9-6.

The thickest deposits of the pre-ignimbrite plinian airfall pumice occur in the Rotoiti Forest (part of the Kaingaroa forest) on the Kaingaroa Plateau; in the Bonisch (3.1 m thick) and Pahekeheke (2.7 m thick) sections.

In the coastal cliffs west of Matata, the airfall deposits underlying the ignimbrite are finer grained and much thinner; <1 m thick in both the Kohioawa cliffs and Herepuru Stream bridge sections.

In sections further east where the ignimbrite did not reach, the airfall deposits are both coarser grained and thicker; being ≈ 3.5 m thick (over-thickened?) at Ngatiawa lookout, ≈ 2 m thick (top eroded?) at Otawairere, and 1.6 m thick at Huntress Creek. However, at some sections around Ohiwa Harbour

the tephra is thinner (0.75–1.0 m), and either erosion has occurred at these sites; or the greater weathering seen at these sites has allowed greater compaction of the pumices to have occurred; or the Huntress Creek section is over-thickened. The latter site is the best preserved in respect to the weathering of pumice and recognition of shower bedding and therefore probably shows the true thickness, hence its designation as the type section.

The basal pink ash layer—which is the most diagnostic feature of the Matahina Tephra in the coastal Bay of Plenty—is not recognised at the base of the pre-ignimbrite airfall tephra in sections to the southeast of the source area (e.g. Lake Matahina, Bonisch). Instead it is believed to occur at the base of the ignimbrite, suggesting that the pumice beds that make up the bulk of the tephra at Huntress Creek are either co-ignimbrite deposits, or related to a post-ignimbrite plinian event. Alternatively the fine pink ash may have been dispersed preferentially towards the north and northeast.

A tephra occurring in uplifted marine sediments near Te Piki (Te Piki West site) at the northwest end of the Raukumara Peninsula, has an identical glass chemistry to that of the Matahina Tephra (Table 9-8.3). Fission track ages on the stratigraphically nearby Te Piki Tephra (see Chapter 15), and fossil assemblages in the marine sediments enclosing the tephra give ages similar to that for the Matahina eruptive. Therefore a correlation between the Te Piki West and Matahina Tephra has been accepted. The tephra at Te Piki West is 50 cm thick, which is considerable allowing for the distance from its source.

The distribution pattern suggests that a westerly wind was in operation during the eruption, dispersing the tephra towards the east. The lack of complete sections to the south and southeast does not allow a more accurate determination of wind direction.

Accepting that the tephra near Te Piki is in fact the Matahina, then the 3.5 m thickness at Ngatiawa is unrealistic. It is possible that the tephra is over-thickened at this site due to it being deposited in a sub-aqueous environment, or that this thickness includes a basal unit which is not airfall. Using the Otarawairere site thickness of ≈ 2 m gives a realistic distribution, with the projected tephra thickness at Te Piki close to what is actually observed for the "Te Piki West" Tephra. This distribution gives an minimum volume estimate of 35 km^3 .

A tephra comprised of glass that is chemically identical to the Matahina has been found in and sampled from deep sea sediment cores located well to the east of New Zealand [Ninkovich, 1967; Kohn, 1973]. Paleomagnetic data and constant sedimentation rates suggests an age for this tephra of 290 ka (Table 2-5; tephra "E"). No other large eruptions have been recorded as occurring at this time with glass chemistry similar to the Matahina, so correlation between the Matahina Tephra and tephra-"E" seems well based.

As tephra-"E" is found such a large distance away from its source, it must have been a very large and widespread eruption. A volume of 35 km^3 for this eruptive is thus not unrealistic.

The Matahina Ignimbrite is known to consist of three separate flow sheets [Bailey, pers. comm. 1990], of which only two (unit-I & unit-II) are widespread. Little time is thought to have passed between the emplacement of the different flow units as fumarole structures are observed to pass upwards from the basal flow (unit-I) into the middle (unit-II), crossing the crystal concentration zone separating the two [Bailey & Carr, 1994].

The basal flow unit has a maximum thickness of ≈ 50 m in the Tarawera area and thins away from source. The middle flow unit is the thickest of the three ignimbrite sheets, reaching a maximum thickness of up to 80 m in a fault angle depression along the western front of the Ikawhenua range, some 25 km east of its source. This area, in the Rangitaiki River valley just southeast of Matahina township, also coincides with the maximum combined thickness of all three flow sheets, ≈ 120 m, and here, the ignimbrite is densely welded [Bailey, 1965]. The ignimbrite is generally only partially, or incipiently welded at most other sites throughout the Bay of Plenty (e.g. near Matata).

The middle flow unit was able to flow over low saddles in the Ikawhenua Range and must therefore have had a velocity in excess of 56 m.s^{-1} (200 km/hr) [Carr, 1984].

Flow unit-III is the uppermost and thinnest of the three sheets (< 20 m), and the least widespread. The upper flow unit is believed to be exposed at the Reihana Road site (among others), where it is < 1 m thick and has a thin (10 cm thick) ash layer separating it from the middle flow.

The aspect ratio of the Matahina Ignimbrite has been calculated to be 1:900 [Carr, 1984], which is moderately high.

The source of the Matahina Ignimbrite, based on the size of lithic inclusions, is almost certainly within the Okataina Volcanic Centre [Bailey, 1965], probably in the Puhupuhi Basin near the eastern edge of this centre [Nairn, 1981]. Not far to the north of here, at Anaputa Point, the base of the Matahina Ignimbrite is underlain by what appears to be surge deposits. Generally surge deposits only occur reasonably close to source (i.e. ≤ 10 km), and their presence here also indicates an Okataina source for this eruptive.

The airfall tephra can be assumed to have the same source as the ignimbrite.

The volume of the ignimbrite eruption has been estimated at 220 km^3 [Bailey & Carr, 1994].

Discussion:

The Matahina eruption is thought to have occurred at c. 0.33 Ma ago, during the peak of the $\delta^{18}\text{O}$ stage-9 high sea-level. It produced a large ignimbrite (c. 220 km^3) and a very widespread tephra deposit with an estimated volume of $\geq 35 \text{ km}^3$ of material. In the eastern Bay of Plenty the tephra probably represents both the pre-ignimbrite plinian airfall, the co-ignimbrite ash, and perhaps a post-ignimbrite plinian deposit.

The basal pink ash present in the coastal sections is probably phreatomagmatic in origin, and is perhaps due to a caldera-lake being present in the source area during the early phases of eruption. Evaporation of the lake, and/or the physical removal of the lake waters—by blast, or by caldera-wall

Chapter Ten : Torere and Reihana subgroups

The Torere subgroup and the Reihana subgroup are combined in this chapter because although they are defined in separate areas and contain different eruptives, they have the same upper and lower boundaries. The two subgroups are therefore equivalent in time, but the correct stratigraphic positions and ages of some of the tephras within them are not sufficiently well constrained to amalgamate the two subgroups into one complete stratigraphy.

Both these subgroups include all of the deposits that occur between the top of the paleosol developed into the Matahina eruptives (ignimbrite and/or airfall tephra), up to the base of the Kaingaroa Tephra (at the top). The Reihana subgroup consists of the deposits found at the Reihana Road site—and presumably over much of the Kaingaroa Plateau, whereas the Torere subgroup contains the deposits found in the coastal eastern Bay of Plenty. The deposits in each area do not fully correspond with each other. The Reihana-C, -D, -E, -F, and -M Tephras are not recognised in coastal Bay of Plenty sections, while the Torere-C, -D, -E, -F, -G, -I, and perhaps Torere-H Tephras have not been recorded in the Reihana Road section.

It is believed that an unconformity exists at the Reihana Road site which has caused the removal of the deposits between the Torere-C and Torere-G Tephras. However, the exact position of this unconformity is uncertain. It could lie between the Terrace Road Basalt (Reihana-D) and the Reihana-E Tephra, or between the Reihana-E and Reihana-F Tephras, or between the Reihana-F and Reihana-G Tephras. At present it is thought to lie within the paleosol between the Reihana-E and Reihana-F Tephras. Another—though unlikely—possibility, is that the initial correlation of the Reihana-A Tephra to the Torere-A Tephra may be incorrect, and that it is instead a correlative of the Hiwarau Tephra (Torere-C). In this case, no unconformity is required; but the stratigraphic positions of several tephras still cannot be fully ascertained.

Figure 10-1 shows a generalised stratigraphy of the Torere subgroup as found in the eastern Bay of Plenty. It is usually about 6 m thick in the eastern areas, but is occasionally thinner depending on the amount of weathering that has occurred (especially to the Hiwarau Tephra).

Figure 10-1 : Generalised stratigraphy of the Torere subgroup in the coastal eastern Bay of Plenty
(see appendix-(M) for key)

The Torere and Reihana subgroups both comprise what has previously been called the "Onuku Pyroclastics" [Nairn, 1989b], which have been described as obsidian rich pumice fall deposits occurring between the Matahina and Kaingaroa Ignimbrites. Obsidian lithics are not particularly noticeable at the coast, but on the Kaingaroa Plateau there are several deposits of this age—in particular the Reihana-A, -B, -C & -I Tephra—which contain abundant obsidian. The two subgroups also correspond in part to the time range occupied by the "Galaxy Tephra" [Keiller, 1987], which occur between the Pokai and Chimp Ignimbrites in the southern Mamaku Plateau area.

The tephra that occur in the Torere and Reihana subgroups and their estimated ages, and volumes are: —

Reihana-M	c. 287 ka	$\geq 0.5 \text{ km}^3$
Torere-O	c. 288 ka	$\geq 8 \text{ km}^3$
Torere-N	c. 288 ka	$\geq 1 \text{ km}^3$
Torere-M	c. 290 ka	$\geq 1 \text{ km}^3$
Torere-L	c. 290 ka	$\geq 6 \text{ km}^3$
Torere-K	c. 292 ka	$\geq 8 \text{ km}^3$
Torere-J	c. 295 ka	$\geq 0.5 \text{ km}^3$
Torere-I	c. 295 ka	$\geq 5 \text{ km}^3$
Reihana-G Pisolitic Ash	c. 295 ka	$> 5 \text{ km}^3$
Reihana-G Ignimbrite	c. 295 ka	$\approx 50 \text{ km}^3$
Opotiki	c. 295 ka	$> 10 \text{ km}^3$
Reihana-F	c. 295 ka	$>> 5 \text{ km}^3$
Torere-G	c. 302 ka	$\geq 0.5 \text{ km}^3$
Ohiwa Hill	c. 305 ka	$\geq 6 \text{ km}^3$
Torere-E	c. 308 ka	$\geq 4 \text{ km}^3$
Torere-D	c. 310 ka	$\geq 1.5 \text{ km}^3$
Hiwarau	c. 315 ka	$\geq 25 \text{ km}^3$
Reihana-E	c. 318 ka	$\geq 1 \text{ km}^3$
Terrace Road Basalt	c. 318 ka	$\approx 1 \text{ km}^3$
Reihana-C	c. 318 ka	$\geq 1 \text{ km}^3$
Torere-B	c. 320 ka	$\geq 1.5 \text{ km}^3$
Torere-A	c. 325 ka	$>> 6 \text{ km}^3$

The ages of the Torere and Reihana subgroups, and the tephra within them, have been estimated by fitting the paleoclimatic data gathered from the Bay of Plenty sections to the SPECMAP and Bassinot LLS $\delta^{18}\text{O}$ records. In the coastal Bay of Plenty, only a few of the Torere subgroup tephra have loess between them, or exist as lenses within loess. Other tephra have paleosols developed into them, or were deposited as lenses within a thick, yet weakly weathered paleosol.

Deposition within the two subgroups is considered to have taken place during the later part of oxygen isotope stage-9 and the early part of oxygen isotope stage-8.

The best fit estimates (to the $\delta^{18}\text{O}$ record) give an age range for both of these subgroups of 325 ka to 285 ka, with an average of one eruption per 1900 years (see Chapter 15).

The Torere-I, Opotiki and Hiwarau Tephra almost certainly originated from the Okataina Volcanic Centre (V.C.), whereas the Reihana-M, Torere-O, Torere-L, Reihana-F, Terrace Road Basalt, Reihana-C, Torere-B and Torere-A Tephra were probably erupted from further south. This more southern source could have been in the southern part of the Okataina V.C.; or the eastern part of the Kapenga V.C.; or in the Reporoa V.C. More sections that contain these tephra are required to be studied before their sources, and volumes, can be better defined.

Figures 10-2 and 10-3 are ternary plots showing the relative proportions of the means of selected element oxide analyses of glass from both the Torere and the Reihana subgroup tephra. It is impossible to show clearly in one diagram the chemistries of all of the eruptives found in these two subgroups, and therefore they have been split into two. The subgroups have been informally divided into an "upper-part", and a "lower-part", with the split occurring at the distinctive Opotiki/Reihana-G/Torere-I Tephra group. The positioning of this boundary is also useful in that the stratigraphic positions of all of the tephra that occur in the upper-part are well understood in both the coastal Bay of Plenty and in the Kaingaroa Plateau areas.

The only eruptives in these two subgroups which have unique glass chemistries are the Reihana-G and Torere-K Tephra; and these are unique throughout all of the tephra studied in this work. Several other eruptives are chemically distinctive within either the lower or upper parts of the subgroup (e.g. Reihana-C, Opotiki, Torere-M, Torere-N). There also occur several groups of eruptives which have virtually identical glass chemistries. The Torere-D and Torere-I Tephra, and the Torere-A and Hiwarau Tephra in the lower-part; and the Torere-L, Torere-O and Reihana-M Tephra in the upper-part. Each of these groups of eruptives are likely to have originated from the same source, perhaps even the same magma batch.

The Reihana-G eruption is thought (from this study) to be the largest volcanic event that occurred during this time period, and has been correlated widely across the western Bay of Plenty via its distinctive glass chemistry. Its high proportion of FeO—relative to other tephra in this study—and high FeO/CaO ratio is very unusual and suggests a correlation to the Chimp Ignimbrite in the southern Mamaku Plateau, and to the Waimakariri Ignimbrite near Tauranga. The Reihana-G Tephra is thought to have originated from either the Kapenga V.C. or in the western part of the Rotorua V.C.

The Torere-A and Hiwarau Tephra — the latter only slightly younger than the former — are also considered to be major eruptives. The Torere-A Tephra has been tentatively correlated (this work) to the "Lower Griffin Road Tephra", which is found far to the southwest in the Wanganui Basin; and the Hiwarau Tephra has been tentatively correlated (this work) to the "Te Piki Tephra", which is found far to the northeast at the end of the Raukumara Peninsula. The Torere-A and Hiwarau Tephra are chemically

Table 10-0 : Similarity coefficients (S.C.'s) comparing representative glass chemistries of Torere & Reihana subgroup tephtras.

oldest	O1504	O1504b	O4402	O4402b	O6207	O6212	O2701	O2602	O1705	O1704	O1706	O8208	O1701	O6219	O6218	O2201	O2201b	O1404	O6205	O6203	O6208	O6206b	O6217	O6217b	O6214	O6204
Torere-A	1.00																									
Torere-A(b)	0.87	1.00																								
Torere-B	0.88	0.94	1.00																							
Torere-B(b)	0.91	0.92	0.84	1.00																						
Reihana-C	0.80	0.90	0.87	0.74	1.00																					
Reihana-E	0.82	0.92	0.82	0.78	0.92	1.00																				
Hiwarau	0.98	0.88	0.87	0.92	0.79	0.82	1.00																			
Torere-D	0.82	0.92	0.90	0.77	0.94	0.86	0.82	1.00																		
Torere-E	0.91	0.87	0.88	0.85	0.83	0.88	0.90	0.88	1.00																	
Ohia Hill	0.86	0.92	0.91	0.80	0.91	0.90	0.86	0.93	0.89	1.00																
Torere-G	0.94	0.91	0.92	0.87	0.84	0.86	0.93	0.87	0.93	0.91	1.00															
Reihana-F	0.84	0.94	0.90	0.80	0.92	0.91	0.85	0.91	0.84	0.90	0.87	1.00														
Opotiki-(2)	0.94	0.90	0.89	0.90	0.81	0.83	0.95	0.84	0.90	0.88	0.95	0.87	1.00													
Reihana-G (lgb)	0.92	0.85	0.88	0.88	0.77	0.81	0.91	0.79	0.85	0.83	0.91	0.83	0.92	1.00												
Reihana-G (ash)	0.91	0.85	0.88	0.89	0.76	0.81	0.90	0.79	0.86	0.83	0.90	0.83	0.92	0.97	1.00											
Torere-I(1)	0.82	0.91	0.89	0.77	0.93	0.93	0.82	0.96	0.87	0.92	0.87	0.89	0.84	0.79	0.79	1.00										
Torere-I(1b)	0.94	0.89	0.91	0.86	0.82	0.84	0.92	0.84	0.91	0.88	0.96	0.85	0.93	0.83	0.83	0.84	1.00									
Torere-J	0.75	0.68	0.67	0.78	0.62	0.64	0.75	0.64	0.70	0.68	0.71	0.66	0.74	0.75	0.75	0.64	0.73	1.00								
Torere-K	0.87	0.77	0.79	0.92	0.70	0.75	0.88	0.73	0.81	0.76	0.83	0.76	0.84	0.84	0.85	0.73	0.84	0.82	1.00							
Torere-L	0.84	0.95	0.93	0.79	0.93	0.93	0.84	0.93	0.85	0.92	0.89	0.94	0.85	0.82	0.81	0.94	0.87	0.65	0.75	1.00						
Torere-M	0.75	0.84	0.81	0.71	0.92	0.89	0.75	0.90	0.82	0.84	0.79	0.86	0.76	0.73	0.72	0.90	0.77	0.60	0.67	0.87	1.00					
Torere-M(b)	0.86	0.93	0.91	0.83	0.88	0.87	0.87	0.89	0.87	0.89	0.90	0.94	0.90	0.85	0.86	0.89	0.87	0.69	0.78	0.92	0.82	1.00				
Torere-N	0.90	0.95	0.96	0.86	0.85	0.89	0.91	0.88	0.88	0.91	0.93	0.91	0.92	0.90	0.90	0.87	0.91	0.69	0.82	0.90	0.80	0.92	1.00			
Torere-N(b)	0.94	0.89	0.90	0.90	0.80	0.84	0.93	0.82	0.91	0.87	0.93	0.87	0.93	0.92	0.93	0.82	0.94	0.73	0.87	0.85	0.75	0.89	0.94	1.00		
Torere-O	0.85	0.91	0.91	0.80	0.91	0.93	0.85	0.93	0.87	0.88	0.90	0.90	0.86	0.84	0.83	0.91	0.88	0.65	0.76	0.92	0.86	0.90	0.91	0.86	1.00	
Reihana-M	0.86	0.94	0.95	0.80	0.91	0.92	0.86	0.93	0.88	0.92	0.91	0.93	0.87	0.84	0.83	0.92	0.89	0.66	0.76	0.96	0.85	0.94	0.92	0.87	0.95	1.00
youngest																										

tephtras in boxed shaded area are believed to be the same eruptive

the northeast at the end of the Raukumara Peninsula. The Torere-A and Hiwarau Tephra are chemically identical, but the Torere-A Tephra distribution is believed to have been towards the south (e.g. Griffin Road), whereas the Hiwarau Tephra is thought to have been preferentially dispersed towards the northeast (e.g. Te Piki). Together these two eruptives form an almost iso-chronous stratigraphic marker across much of the North Island.

The Opotiki and Reihana-F Tephra may also have large eruptive volumes, and together with the Reihana-G and Torere-I Tephra were erupted within a very short, perhaps overlapping, time period. The amount of volcanic activity during this time period is thought to have been extremely high.

The unusual chemistry of the Torere-K Tephra—distinctively high TiO_2 and MgO contents—together with its relatively fine grain-size, suggest that the tephra originated from a source much further south than the other deposits, perhaps the Taupo Volcanic Centre.

Little data is available pertaining to the possible sources of the remainder of the tephra listed above.

Similarity coefficients that compare the glass chemistries of all of the tephra found in the Torere and Reihana subgroups are presented in Table 10-0.

A comparison of the stratigraphy in the Torere and Reihana subgroups is presented in Figure 10-4; the former subgroup represented by the Torere West section [X15/028507] in the eastern Bay of Plenty (see Photo-9), and the latter subgroup represented by the Reihana Road section [U/17/092097] in the Kaingaroa/Waiotapu Forest (see Photo-8). The positive correlations between the upper-parts of these two sections were obtained using the distinctive glass chemistry of several of the eruptives—in particular the Reihana-G, Torere-K, Torere-M and Torere-N Tephra (Figure 10-5). The Torere-L, Torere-O and Reihana-M Tephra were distinguished using their relative stratigraphic positions as glass chemistry could not differentiate between them.

Much of the stratigraphy of the Torere subgroup can also be seen at the Hokianga Island [W15/730456], Pukeruru Point [W15/737459] and Ohiwa Hill [W15/765468] sections.

Figure 10-6 shows the variations in thickness and exposure of the Torere and Reihana subgroup deposits throughout the Bay of Plenty region. Correlations between sites are marked.

The twenty-one tephra known to exist within these two subgroups are presented in the following pages in stratigraphic order of deposition (from oldest to youngest).

Figure 10-5 : Comparison between regions of the means & standard deviations (1 s.d.) of glass chemistry analyses from the upper Torere subgroup tephra [Torere West (022) & Reihana Road (062)]

Figure 10-4 : Comparison between the Torere subgroup — in the coastal eastern Bay of Plenty; and the Reihana subgroup — near Waitapu (see appendix-(M) for key)

Figure 10-6: Stratigraphy of the Torere subgroup along the eastern Bay of Plenty coast (see appendix-(M) for key)

10-1 Torere-A Tephra

The Torere-A Tephra is the basal deposit in the Torere subgroup, and although thin it is a distinctive and recognisable tephra throughout the eastern Bay of Plenty. The tephra is also believed to be equivalent to the basal Reihana subgroup deposit — the Reihana-A Tephra.

The type section for the Torere-A Tephra is designated to be at Reihana Road. Here it is >4 m thick and many individual beds can be studied in detail.

A useful reference site for the Torere-A Tephra is at the Awakeri Springs section. Here it occurs 0.5 m above road level, and although it is only 18 cm thick, it is representative of the tephra in the coastal eastern Bay of Plenty.

The Torere-A Tephra is also well preserved at the Ohiwa Hill and Huntress Creek sections, and is present at the Burchett, Reeves, Pukeruru Point, Ohiwa Beach and Hiwarau sections.

Diagnostic features:

In the coastal eastern Bay of Plenty: (Photo-32; Photo-33)

- A distinctively coloured pinkish-red [5YR 7/6 – "orange"] fine ash (≈5 cm thick) is bounded above and below by similar thicknesses of contrasting (colour) white fine ash. Where weathered, the pinkish-red creamcakes of ash stand out by their colour contrast to the surrounding paleosol.
- At Awakeri Springs the tephra is coarser grained with the enclosing white ash units consisting of sandy ash.

On the Kaingaroa Plateau:

- The basal 3 m of the tephra consists of >80 cm of white granular pumice lapilli; overlain by 105 cm of pink/orange coarse pumice (3 cm across maximum) which contains large obsidian lithics (up to 1.5 cm across); and is in turn overlain by 120 cm of white granular pumice.
- The upper 1 m of the tephra consists of alternating beds (≥10 cm thick) of white, grey, and pink ash; several beds having large obsidian and rhyolitic lithics (up to 1.5 cm across).

Stratigraphic relationships:

The upper contact of the Torere-A Tephra is defined by a gradual colour change over a few centimetres, from white fine ash to grey-green loess above.

The colour contrast between the basal white fine ash to the orange-brown sandy weathered tephra below is sharp, but the contact itself is often extremely bioturbated (Photo-32).

The basal subaqueous sediment at Torere West also has a sharp lower contact to a weathered tephra-rich paleosol, but its upper boundary here—to a grey silt (possibly loess)—is also sharp.

At Reihana Road, the white pumice of the Torere-A tephra rests directly on the light brown weathered surface of a thin ignimbrite; presumably Matahina-(III). No erosion is seen at this contact.

Table 10-1.1 : Glass chemistry of the Torere-A Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Huntress Creek **01504	77.35 0.66	12.82 0.30	0.18 0.03	1.31 0.11	0.19 0.04	1.28 0.11	3.35 0.25	3.37 0.09	0.19 0.06	5.69 0.82	18	1.00
Torere West 02212	77.48 0.26	12.69 0.12	0.16 0.03	1.33 0.11	0.22 0.05	1.34 0.06	3.39 0.26	3.30 0.11	0.15 0.03	5.06 0.80	8	0.96
Hiwarau 02710	77.66 0.32	12.82 0.16	0.18 0.03	1.25 0.09	0.20 0.04	1.31 0.09	#3.17 0.19	3.27 0.07	0.15 0.02	3.24 0.54	9	0.97
Awakeri Springs 04403	76.59 0.52	13.27 0.32	0.22 0.04	1.35 0.11	0.22 0.05	1.39 0.10	3.34 0.21	3.41 0.11	0.20 0.02	6.38 1.16	11	0.94
Reihana Road 06210	77.34 0.44	12.56 0.38	0.20 0.05	1.36 0.11	0.19 0.02	1.25 0.08	3.49 0.14	3.47 0.09	0.15 0.04	6.97 1.37	10	0.97
Reihana Road 06215	76.82 0.30	12.93 0.21	0.19 0.04	1.39 0.11	0.21 0.04	1.23 0.08	3.59 0.13	3.42 0.11	0.22 0.04	5.33 1.00	8	0.96*
												S.C. 01504b
Huntress Creek *01504b	78.15 0.53	12.26 0.19	0.19 0.03	1.01 0.07	0.13 0.05	0.97 0.09	3.31 0.21	3.81 0.25	0.19 0.07	4.87 1.28	6	0.87
Torere West 02212b	78.38 0.32	12.23 0.26	0.15 0.03	1.10 0.10	0.13 0.03	0.95 0.08	3.33 0.11	3.57 0.14	0.19 0.05	5.18 0.82	7	0.87
Hiwarau 02710b	78.75 0.30	12.21 0.06	0.13 0.01	0.94 0.11	0.10 0.02	0.96 0.06	#3.13 0.09	3.74 0.13	0.14 0.02	2.78 0.57	4	0.81
												0.91

Figure 10-7 : Comparison of individual glass shard chemical analyses from several sections — Torere-A Tephra

Table 10-1.2 : Glass chemistry of a possible correlative of the Torere-A Tephra — the "Lower Griffin Road Tephra".

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 01504
\$—\$ (Pillans)	77.02 0.36	12.72 0.30	0.26 0.09	1.25 0.03	0.24 0.03	1.26 0.10	3.71 0.15	3.41 0.18	0.11 0.09	3.64 2.02	6	0.91
												S.C. 01504b
\$—\$ (b) (Pillans)	78.02 0.15	12.38 0.15	0.15 0.02	1.10 0.01	0.13 0.01	0.99 0.07	3.55 0.21	3.69 0.16	0.05 0.03	6.51 0.93	4	0.87
												0.91*

\$—\$ = Lower Griffin Road Tephra at Mt. Curl [Pillans, 1988]

The upper contact of the Torere-A Tephra is with a 10 cm thick layer of brownish silt (loess?) which contains a paleosol developed into its top.

Chemistry and mineralogy:

The Torere-A Tephra contains a mixed assemblage of glass shards with two different chemical types (Table 10-1; Figure 10-7). Type-(a) chemistry is more prevalent than type-(b), and is a reasonably uncommon chemistry for the tephra in this study; containing relatively high wt.%'s of FeO & CaO. The Reihana Road and Awakeri Springs samples were the only samples not show this mixture. The samples from these two sections were taken from only a single ash layer, as opposed to a mixture of the several much thinner layers found at the other sites. It is possible that the individual ash layers within the tephra may represent separate eruptions with different chemistries. More work is required to determine if this is in fact the case.

The Torere-A Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene + biotite

Distribution and size:

The Torere-A Tephra is found at many sites in the coastal Bay of Plenty, from Awakeri Springs — south of Whakatane; to the Burchett section — east of Opotiki. The tephra is generally thin, only 10–15 cm thick where it is well preserved, and 20 cm thick at Awakeri Springs — its most westerly occurrence in the coastal area.

Within the Taupo Volcanic Zone there are few sections which show the top of the Matahina Ignimbrite eruption; upon which the Torere-A Tephra lies. At Reihana Road near Waiotapu, the top surface of the Matahina Ignimbrite is exposed, and a thick pinkish pumiceous tephra immediately overlies it. The total thickness of this tephra at Reihana Road has not been fully established as in one part of the section it is >80 cm thick — but its top has been eroded; while in a separate part of the section it is >4 m thick — but its base is not observed. However, the base of this latter part-section is very close to the top of the water table, which in pumiceous sediment indicates the presence of a harder, more impermeable layer just below. This impermeable layer is probably the top of the Matahina Ignimbrite which is found at a similar topographic level <20 m further along the road.

The relatively constant thickness and fine grain size of the Torere-A Tephra throughout the coastal Bay of Plenty suggests that its source was probably some distance away from the coast. From its thickness and the size of its lithics and pumice at Reihana Road, it is thought that the tephra was erupted from a nearby source, either the Reporoa V.C., or possibly the southern Okataina V.C.

The Lower Griffin Road Tephra has a similar glass chemistry (Table 10-1.2) to the Torere-A Tephra (& also to the Hiwarau Tephra). It also lies in approximately the same stratigraphic position — within the Burnand loess and Brunswick Dunesand [Pillans, 1988], not far above the interglacial weathering following the deposition of the Rangitawa Tephra (= Mt. Curl = Kohioawa).

Using only the sections in the coastal Bay of Plenty, and a Reporoa source with a northeast dispersal, a minimum eruptive volume of 6 km^3 has been estimated for the Torere-A Tephra. However, if the Lower Griffin Road Tephra and the Torere-A Tephra are correlatives, the tephra dispersal must have been towards the south and its volume much greater than that calculated above, perhaps $>25 \text{ km}^3$.

However, there is not yet enough data to confirm this correlation and so minimum eruptive volume of the Torere-A Tephra is at present deemed to be $>>6 \text{ km}^3$.

10-2 Torere-B Tephra

The Torere-B Tephra was the second eruptive deposited in the Torere subgroup. It is seen at only a few sites in the coastal Bay of Plenty, and at Reihana Road where it is also known as the Reihana-B Tephra.

The type section for the Torere-B Tephra is designated to be at Reihana Road, where it is very thick and presumed to be near its source of eruption. The Torere-B Tephra in the coastal eastern Bay of Plenty is much thinner and has very different physical characteristics. The best reference section for the tephra in this region is at the Awakeri Springs section, though it is also present at the Ohiwa Hill, Hiwarau and Torere West sections.

Diagnostic features:

In the coastal Bay of Plenty: (Photo-32)

- Occurs as discrete lenses of white fine ash in the uppermost part of a 0.5–1.0 m thick loess unit.
- At Torere West, a relatively thick continuous layer of fine white ash overlies a grey clay which contains an irregular series of white fine ash lenses 2 cm from its top. This irregular layer of ash could represent the airfall deposit of the eruption, with the continuous layer above likely—from its thickness—to be reworked and over-thickened.

On the Kaingaroa Plateau:

- Alternating beds of fine and coarse ash; 70 cm thick.
- Pink ash in middle contains occasional large pumice lapilli (2–3 cm across), and white ash layers above and below contain very large obsidian lithics (1–2 cm across).

Stratigraphic relationships:

The Torere-B Tephra in the coastal eastern Bay of Plenty lies very near the upper boundary of a loess unit. The top of the loess generally, but not always, has a paleosol developed into it, and at some sites (Pukeruru Point, Huntress Creek) the tephra is reworked into this paleosol and is not recognised as a separate layer. The Hiwarau Tephra rests directly on this paleosol surface. The grey silt that encloses the Torere-B Tephra at Torere West is most likely loess that fell into a subaqueous environment.

Table 10-2 : Glass chemistry of the Torere-B Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Torere West 02209	78.86 0.23	12.00 0.24	0.14 0.03	1.10 0.06	0.12 0.03	0.96 0.06	#3.01 0.15	3.67 0.09	0.16 0.02	5.02 1.15	8	0.92*
Awakeri Springs **04402	77.28 0.33	12.64 0.15	0.17 0.03	1.09 0.09	0.14 0.03	0.97 0.05	3.80 0.18	3.73 0.11	0.19 0.05	8.29 0.77	10	1.00
Reihana Road 06211	78.10 0.36	12.21 0.48	0.19 0.03	1.05 0.11	0.13 0.04	0.89 0.08	3.61 0.22	3.71 0.13	0.14 0.04	2.38 0.76	12	0.95
												S.C. 04402b
Torere West 02209b	77.79 0.12	12.51 0.10	0.28 0.01	1.24 0.13	0.17 0.06	1.28 0.08	#3.37 0.12	3.22 0.10	0.15 0.03	3.63 1.81	2	0.85
Awakeri Springs *04402b	76.50 0.47	13.02 0.25	0.26 0.17	1.26 0.13	0.23 0.06	1.33 0.15	3.71 0.10	3.49 0.35	0.23 0.03	8.06 0.08	2	0.84
Reihana Road 06211b	77.07 0.29	12.55 0.13	0.38 0.09	1.28 0.09	0.25 0.04	1.16 0.01	3.90 0.20	3.25 0.16	0.16 0.04	1.46 0.36	3	0.82
												0.91

Figure 10-8 : Comparison of individual glass shard chemical analyses of the Torere-B & Torere-A tephra

At Reihana Road, the Torere-B Tephra has a weak paleosol developed into it, and rests upon a weak paleosol developed into a brown silt at the top of the Torere-A Tephra below.

Chemistry and mineralogy:

The glass chemistry of the Torere-B Tephra (Table 10-2) is generally middle of the range for the tephtras in this study, but is noticeably different to the tephtras above and below. Its CaO wt.% is also slightly higher than other tephtras with similar values of FeO, Na₂O and K₂O.

The Torere-B Tephra contains glass of two different compositions, although the second type occurs in very minor amounts. The chemistry of the minor component is very similar to that of the Torere-A Tephra immediately below (see Figure 10-8) and may be a country rock contaminant entrained into the eruption column during the process of eruption.

The Torere-B Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende

Only a small amount of sample from one site only was studied, and thus this assemblage may not be accurate.

Distribution and size:

The Torere-B Tephra is only recognised in a few sites in the coastal Bay of Plenty region, where it exists only as a layer of discontinuous pockets of ash within loess; 10 cm thick at Awakeri Springs, 3 cm thick at Hiwarau, and 2 cm thick at Ohiwa Hill. Similar lenses of ash found in the same stratigraphic position at Torere West are 5 cm thick.

At Reihana Road (30 km south-southeast of Rotorua), the Torere-B Tephra is ~70 cm thick and contains very large obsidian lithics that indicate a relatively nearby source; either in the Reporoa V.C. or the southern Okataina V.C.

10-3 Reihana-C Tephra

The Reihana-C Tephra is believed to be the third eruptive deposited in the Reihana subgroup. It has only been recorded at Reihana Road — which therefore becomes its type section. The tephra has not been recognised in the coastal Bay of Plenty, where it is believed to lie stratigraphically between the Torere-B and Hiwarau (Torere-C) Tephtras.

The Reihana-C Tephra has **physical characteristics** consisting of:

- Up to 0.5 m of well sorted, soft (unconsolidated or loose) sandy ash; overlying 10 cm of pale fine ash. Separating these two beds is a thin layer of granular pumice lapilli and large lithics—up to 0.5 cm across.

Table 10-3 : Glass chemistry of the Reihana-C Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Reihana Road	78.55	11.82	0.15	0.98	0.11	0.71	3.24	4.30	0.16	4.13	14	1.00
**06207	0.47	0.37	0.04	0.10	0.03	0.08	0.23	0.23	0.03	1.76		

Stratigraphic relationships:

The Reihana-C Tephra rests on a weak paleosol developed in the top of the Torere-B Tephra below. The Terrace Road Basalt directly overlies the Reihana-C Tephra with a sharp contact, indicating that little or no time occurred between these two eruption events.

Chemistry and mineralogy:

The glass chemistry of the Reihana-C Tephra (Table 10-3) is moderately distinctive for the tephra in this study, with lower CaO, and much higher K₂O than average; and Na₂O << K₂O.

The Reihana-C Tephra has a ferromagnesian mineral assemblage consisting of
hypersthene + hornblende + biotite

Distribution and size:

The Reihana-C Tephra is 60 cm thick at the Reihana Road site, but the relatively fine grained nature of the tephra here suggests that Reihana Road is not in close proximity to the eruption source. From only one site it is impossible to accurately determine the source or size of this tephra.

10-4 Terrace Road Basalt

The Terrace Road Basalt is seen only locally in the Waiotapu Forest; recorded at one site only in this study — Reihana Road. It is believed to be the fourth tephra deposited in the Reihana subgroup, and is thus also known as the "Reihana-D Tephra". Stratigraphically it is thought to lie between the Torere-B and Hiwarau (Torere-C) Tephra.

The Terrace Road Basalt takes its name from its type area, which is designated to be in a small area of dissected terrain near Terrace Road in the Waiotapu Forest [Nairn, 1981]. It has been correlated to a basaltic scoria layer [Nairn, pers. comm. 1991] found at Reihana Road less than 2 km to the south, and it is from this latter section that its stratigraphic position was ascertained.

The following physical characteristics of the Terrace Road Basalt in its type area were described by Nairn (1981):

- Consists of "stratified, thin beds (5–15 cm) of generally flat-lying vesicular black scoria and coarse ash. The scoria beds are interbedded with thin rhyolitic sediments, and interspersed through the deposits are essential blocks of vesicular basalt and rare ignimbrite and rhyolitic lithics. The beds commonly display inverse grading.

The eruptive at Reihana Road consists of:

- Hard, dark, very consolidated iron cemented basaltic scoria. Very little detail could be observed.

Stratigraphic relationships:

The Terrace Road Basalt has a sharp contact to the Reihana-C Tephra below, and has a sharp and irregular boundary separating it from the overlying rhyolitic Reihana-E Tephra. It is uncertain how much time is represented by the upper contact, but it is possible that the boundary represents a significant unconformity. Very little detail of the bedding or weathering can be seen within the weathered and cemented basaltic scoria and more work is required here.

Chemistry and mineralogy:

No glass was separated from the Terrace Road Basalt in this work, but bulk rock X-Ray Fluorescence (X.R.F.) analyses have been carried out previously; presented in Nairn (1981).

Pyroxene and olivine were reported to be present in the Terrace Road Basalt [Nairn, 1981], but no studies of its ferromagnesian mineral assemblage were carried out in this study.

Discussion:

The Terrace Road Basalt has only been recorded in a small area in the Waiotapu Forest and is not thought to have been widely distributed. It is not represented in the stratigraphy of the coastal Bay of Plenty stratigraphy and almost certainly represents a very minor basaltic eruption, probably with a volume of $c. 1 \text{ km}^3$, from a predominantly rhyolitic volcanic field. The eruption is thought to have occurred at $c. 0.32 \text{ Ma}$, and been coeval with the Reihana-C Tephra, and perhaps also the Reihana-E Tephra.

Nairn (1981) believed the Terrace Road Basalt to be base surge and fall deposits from a small phreatomagmatic eruption.

10-5 Reihana-E Tephra

The Reihana-E Tephra is believed to be the fifth eruptive deposited in the Reihana subgroup. It has been recorded only at Reihana Road — which is thus its type section. The tephra has not been recognised in the coastal Bay of Plenty, where it is believed to lie stratigraphically between the Torere-B and Hiwarau (Torere-C) Tephrae.

The Reihana-C Tephra has **physical characteristics** consisting of:

- $\geq 30 \text{ cm}$ of fine ash, with occasional layers of pumice lapilli (up to 0.5 cm across).

Table 10-5 : Glass chemistry of the Reihana-E Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Reihana Road	77.37	12.60	0.13	1.00	0.12	0.90	3.58	4.06	0.26	5.88	16	1.00
**06212	0.41	0.30	0.05	0.13	0.04	0.10	0.19	0.28	0.07	1.93		

Stratigraphic relationships:

The Reihana-E Tephra rests directly on the irregular upper surface of the Terrace Road Basalt. The contact is sharp, but detection of any paleosol in the top of the very dark basalt is difficult (especially if it is only weakly developed). There may be very little time represented by this contact, or a significant unconformity; it is uncertain which is the case. An unconformity is believed to be present in this vicinity, but could instead be located within the paleosol just above the Reihana-E Tephra. A firm, consolidated paleosol has developed in the upper half of the Reihana-E Tephra; with the Reihana-F Tephra resting directly on this.

Chemistry and mineralogy:

The glass of the Reihana-E Tephra (Table 10-5) has a similar chemistry to that of the Reihana-C Tephra (Table 10-3), though it has slightly lower K₂O, and higher CaO contents. The chemistries are dissimilar enough for this worker to deem them to be from different eruptions.

The Reihana-E Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende

Discussion:

The Reihana-E Tephra is 30 to 60 cm thick at the Reihana Road site; its upper half weathered by the formation of a paleosol. The tephra is relatively fine grained suggesting that its source was some distance away, but with data from only one site it is impossible to accurately determine the tephra's source, or size.

It is possible that the Reihana-E Tephra is a continuation of the Reihana-C Tephra eruption found below the Terrace Road Basalt, with this latter unit undergoing eruption at the same time as the Reihana-C/-E Tephra. However, the slightly different glass chemistries of the two rhyolitic deposits above and below it, suggest that the Reihana-E Tephra is a different eruptive from the Reihana-C.

10-6 Hiwarau Tephra

The Hiwarau Tephra is recognised at many sites in the coastal Bay of Plenty, where it is often one of the thicker and coarser deposits seen. It is believed to be the third tephra deposited in the Torere subgroup, and is also known as the "Torere-C" Tephra. This tephra was not recognised at Reihana Road.

The type section for the Hiwarau Tephra is designated to be at Awakeri Springs. The tephra is also well represented at the Ohiwa Hill, Hiwarau, Pukeruru Point, Hokianga Island, Ohiwa Beach, Ngatiawa lookout and Torere West sections. It is also present at the Huntress Creek, Burchett and Reeves sections, although at these sites most of the glass in the tephra has been altered to a white clay.

Table 10-6.1 : Glass chemistry of the Hiwarau Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	*Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Ohiwa Hill	77.64	12.53	0.23	1.34	0.20	1.37	*3.13	3.39	0.19	3.61	8	0.95
01702	0.18	0.15	0.05	0.10	0.02	0.05	0.10	0.11	0.05	0.62		
Torere West	77.38	12.80	0.24	1.34	0.20	1.28	*3.25	3.43	0.12	4.87	11	0.96
02202	0.33	0.28	0.06	0.14	0.03	0.09	0.27	0.14	0.03	0.56		
Pukeruru Point	77.63	12.75	0.25	1.31	0.22	1.33	*2.83	3.45	0.30	2.77	8	0.93
02506	0.33	0.12	0.04	0.11	0.05	0.12	0.26	0.11	0.30	0.52		
Hiwarau	77.61	12.52	0.19	1.26	0.20	1.29	*3.37	3.38	0.17	3.01	10	1.00
**02701	0.29	0.21	0.02	0.08	0.02	0.07	0.09	0.10	0.03	0.75		
Ngatiawa lookout	77.18	12.71	0.21	1.28	0.22	1.20	3.68	3.34	0.19	4.59	14	0.95*
04305	0.20	0.10	0.06	0.15	0.03	0.10	0.14	0.12	0.03	0.69		
Awakeri Springs	76.90	12.84	0.23	1.36	0.23	1.34	3.57	3.34	0.18	4.62	10	0.94*
04401	0.44	0.23	0.07	0.08	0.03	0.10	0.17	0.06	0.02	1.01		
Torere West	78.41	12.29	0.14	1.12	0.13	0.95	3.31	3.48	0.18	4.78	5	0.87
02202b	0.53	0.41	0.05	0.10	0.04	0.10	0.24	0.13	0.03	0.23		
Torere West	78.48	12.32	0.19	0.84	0.12	0.83	3.33	3.73	0.16	4.53	2	0.85
02202c	0.31	0.00	0.10	0.07	0.01	0.05	0.07	0.27	0.00	0.08		
Ngatiawa lookout	77.72	12.30	0.16	1.20	0.13	0.80	3.58	3.86	0.25	4.98	2	0.86
04305b	0.02	0.02	0.04	0.10	0.02	0.01	0.10	0.15	0.12	0.85		

Table 10-6.2 : Glass chemistry of possible correlatives of the Hiwarau Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	*Na ₂ O	K ₂ O	Cl	water	no.	S.C. 02701
Pikowai Reserve	77.87	12.64	0.22	1.28	0.21	1.30	*2.92	3.42	0.17	4.91	8	0.95
03002	0.27	0.06	0.06	0.07	0.03	0.09	0.25	0.11	0.02	0.72		
Te Piki	77.15	12.83	0.19	1.33	0.22	1.37	3.45	3.37	0.09	3.85	10	0.97
06601	0.36	0.18	0.04	0.09	0.04	0.09	0.18	0.12	0.02	0.30		

Diagnostic features:

(see Photo-34; Photo-33)

- Where the tephra is well preserved it occurs as a thick, generally massive, well sorted white pumice lapilli, that contains many small grey rhyolitic lithics scattered throughout. The pumice is generally slightly finer towards the base and at many sites the very base has been compacted and altered to clay. This alteration is suspected to be caused by the presence of a perched water table—that rests on the consolidated and less permeable loess layer below—and a high rate of water flow through the porous basal pumice.
- At some sites (e.g. Huntress Creek), the tephra has been totally altered to a much compacted white clay (Photo-33). As the lithics remain unaltered, yet the tephra thickness has decreased by an order of magnitude, the grey rhyolitic lithics have been concentrated here and are much more common than in the pumiceous deposits. The tephra at these sites looks very lithic rich, even though the tephra originally had only an average abundance of lithics.
- Has a distinctive glass chemistry.
- The pumice of this tephra is very crystal poor, and the ferromagnesian and titanomagnetite minerals could not readily be separated in usable quantities.

Stratigraphic relationships:

The Hiwarau Tephra lies within loess, but generally the upper part of the tephra has a sandy paleosol weathered into it, though the degree of paleosol development varies. Less weathered loess overlies this paleosol (see Photo-36).

The tephra generally rests on a paleosol developed into loess. At some sites (e.g. Huntress Creek, Pukeruru Point) the paleosol is well developed, while at others (e.g. Hiwarau, Reeves) there is only unweathered loess.

Chemistry and mineralogy:

The glass chemistry of the Hiwarau Tephra (Table 10-6.1) is moderately distinctive for the tephtras in this study. It has quite high FeO & CaO contents ($\text{FeO} \approx \text{CaO}$), and a lower than average K_2O content, with $\text{Na}_2\text{O} \geq \text{K}_2\text{O}$.

It is uncertain whether the mixed chemical assemblages found in the Torere West and Ngatiawa samples are real, or a product of contamination and/or analytical error. The secondary glass chemistry component is similar to that of the Torere-B Tephra which directly underlies the Hiwarau.

A thick pumiceous tephra found at Pikowai Reserve (Pikowai Tephra; see Chapter 13) has an almost identical glass chemistry to the Hiwarau Tephra (Table 10-6.2). It also has an upper bed which has a different chemistry, similar to that of the secondary component found at Torere West. However, the stratigraphic position of the Pikowai Tephra is not well understood and its correlation to the Hiwarau Tephra remains tentative pending further study.

The Hiwarau Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene ± biotite (t)

The Hiwarau Tephra remarkably is poor in ferromagnesian minerals and the assemblage has been determined from only a small number of grains. Therefore the presence of biotite, which was not predicted from its glass chemistry, may be due to contamination.

Distribution and size:

The Hiwarau Tephra is ≥5 m thick at Awakeri Springs (top beyond reach), and up to 1.5 m thick in unweathered sections around Ohiwa Harbour. Its great thickness at Awakeri Springs strongly suggests that the tephra was erupted from the nearby Okataina V.C., and was dispersed in a north-easterly direction along the Bay of Plenty coast. It is unlikely that any source other than Okataina could produce airfall deposits this thick at Awakeri Springs.

The Te Piki Tephra, found in marine sediments far to the northeast — at the northwest end of the Raukumara Peninsula, has an identical glass chemistry (Table 10-6.2) to that of the Hiwarau Tephra. Tephrae stratigraphically adjacent to the Te Piki Tephra also show chemical matches to the major tephrae bracketing the Hiwarau. Fission-track ages (see Chapter 13) and fossil assemblages in marine sediments found in the Te Piki area indicate that a correlation between the Hiwarau and the Te Piki Tephrae is plausible. The massive white ash of the Te Piki Tephra also matches the physical characteristics expected for the distal Hiwarau Tephra, and therefore these two eruptives are tentatively correlated with each other.

If the Te Piki correlation is correct, an assumed Okataina source gives a minimum eruptive volume estimate of 25 km³ for the Hiwarau Tephra.

10-7 Torere-D Tephra

The Torere-D Tephra is believed to be the fourth tephra deposited in the Torere subgroup, and it has been positively recognised at only one site in the coastal Bay of Plenty, — at Hokianga Island (type section). The Torere-D Tephra is an possible, though unlikely, correlative of the Reihana-E Tephra found at Reihana Road in the Kaingaroa/Waiotapu forest.

The Torere-D Tephra has **physical characteristics** consisting of:

- Occurs as lenses of grey fine ash overlying a thinner layer of grey coarse ash. The fine ash contains bluish and creamy coloured layers near its base.

The Torere-D Tephra has a total thickness of 17 cm. It rests on a sandy paleosol developed into the underlying Hiwarau Tephra, and has a layer of weathered loess above.

Table 10-7 : Glass chemistry of the Torere-D Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Hokianga Island	78.43	12.15	0.13	1.04	0.11	0.87	#3.25	3.89	0.15	4.36	10	1.00
**02602	0.24	0.17	0.03	0.10	0.03	0.12	0.18	0.21	0.03	1.56		

Table 10-8 : Glass chemistry of the Torere-E Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Ohiwa Hill	77.89	12.49	0.12	1.29	0.14	1.26	3.20	3.49	0.17	5.09	7	1.00
**01705	0.51	0.21	0.03	0.10	0.05	0.12	0.24	0.09	0.02	0.86		
Torere West	78.97	12.09	0.16	1.05	0.11	1.07	#2.95	3.55	0.22	4.26	11	0.88
02203	0.28	0.17	0.06	0.08	0.03	0.06	0.21	0.11	0.12	0.76		
Hokianga Island	78.69	12.11	0.13	1.19	0.12	1.14	#2.99	3.57	0.16	5.52	10	0.93
02601	0.39	0.14	0.04	0.12	0.03	0.05	0.21	0.12	0.06	0.63		
Ohiwa Hill	78.77	12.18	0.20	1.01	0.18	1.04	3.16	3.32	0.20	5.87	3	0.86
01705b	0.13	0.10	0.03	0.07	0.01	0.04	0.31	0.14	0.02	0.57		

The Torere-D Tephra has yet to be recognised at any other sites in the Bay of Plenty. It was probably incorporated into the paleosol developed into the top of Hiwarau Tephra (see Photo-36) and too thin to be preserved as a visible layer. The other tephtras at the Hokianga Island section are thicker than they are at other nearby sections, in some cases up to twice as thick. There is no evidence for over-thickening here, so perhaps erosion and/or compaction have had greater effects at the other sites — where the Torere-D Tephra is not recognised.

Chemistry and mineralogy:

The glass from the Torere-D Tephra (Table 10-7) has average element oxide values (for the tephtras in this study); with wt.% FeO $\approx$ 1.0; FeO > CaO; and K₂O > Na₂O.

The Torere-D Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + biotite + *hypersthene*

10-8 Torere-E Tephra

The Torere-E Tephra is only recognised at a few sites in Bay of Plenty, and is believed to be the fifth tephra deposited in the Torere subgroup.

The type section for the Torere-E Tephra is designated to be at Hokianga Island, though it is also recognised at the much more accessible Ohiwa Hill and Torere West sections.

Diagnostic features:

- Generally consists of a coarse sandy ash, overlying a thinner white/grey fine ash. Separating these beds at Hokianga Island is a thin layer of grey-black fine sandy ash.
- The tephra is bounded both above and below by sandy weathered loess layers (Photo-36).

Chemistry and mineralogy:

The glass from the Torere-E Tephra (Table 10-8) has average element oxide values (for the tephtras in this study); with wt.% FeO $\approx$ 1.1; FeO $\approx$ CaO; and K₂O > Na₂O.

The Torere-E Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende

Discussion:

The Torere-E Tephra is 28 cm thick at Hokianga Island, and 15 cm thick at both Ohiwa Hill and Torere West. Only the dispersed, basal ash layer of the tephra is seen at the Ohiwa Hill site, and its thickness here is therefore a minimum only. The Torere-E Tephra has yet to be recognised at any other sites throughout the Bay of Plenty, probably due to its incorporation into the paleosol developed into the Hiwarau Tephra.

Table 10-9 : Glass chemistry of the Ohiwa Hill Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Huntress Creek	78.29	12.40	0.15	1.18	0.13	1.00	#3.10	3.60	0.16	4.24	10	1.00
**01505	0.32	0.27	0.03	0.07	0.02	0.06	0.18	0.17	0.03	0.50		
Ohiwa Hill	78.59	11.94	0.16	1.27	0.11	0.96	#3.05	3.81	0.19	3.88	10	0.95
01704	0.27	0.17	0.06	0.07	0.02	0.08	0.12	0.21	0.05	1.02		
Torere West	78.16	12.28	0.15	1.17	0.13	1.05	#3.10	3.79	0.18	5.39	22	0.99
02208	0.42	0.26	0.03	0.06	0.04	0.11	0.18	0.19	0.08	1.01		
Hokianga Island	78.54	12.19	0.15	1.19	0.12	1.00	#3.12	3.64	0.14	4.03	6	0.98
02603	0.31	0.26	0.04	0.05	0.04	0.05	0.22	0.25	0.03	0.89		
Ngatiawa lookout	77.72	12.43	0.17	1.19	0.15	0.99	3.59	3.59	0.17	4.22	20	0.95*
04302	0.26	0.25	0.05	0.10	0.04	0.11	0.12	0.16	0.04	1.51		
Ngatiawa lookout	78.08	12.29	0.12	0.96	0.13	0.77	3.51	3.94	0.19	4.71	14	0.90
04302b	0.23	0.28	0.05	0.08	0.03	0.05	0.14	0.19	0.04	1.14		

The loess enclosing the tephra is generally coarser than most loess units; being quite sandy in nature (especially at Ohiwa Hill). The coarse grain-size may be related to the proximity of the Ohiwa Harbour drainage system — the probable source area for the loess, and/or the abundance of sand sized pumice and glass, which having relatively low density is readily transported by the wind.

10-9 Ohiwa Hill Tephra

The Ohiwa Hill Tephra is recognised throughout the coastal eastern Bay of Plenty and its distinctive characteristics make it a useful tephra for correlation purposes. It is believed to be the sixth tephra deposited in the Torere subgroup, and takes its name from the section where it is most accessible.

The type section for the Ohiwa Hill Tephra is designated to be at Hokianga Island. A very good reference section can be found at Ohiwa Hill, and it is also recognised at the Hiwarau, Pukeruru Point, Reeves, Huntress Creek, Ngatiawa lookout, Burchett and Torere West sections.

Diagnostic features: (see Photo-36; Photo-35)

- Generally consists of a patchy layer or lenses (pockets/creamcakes) of a pale (2.5Y 8/4 – "pale yellow") fine ash; overlying a much thinner, pale pink (5YR 8/4 – "pale orange") fine ash. The basal pink ash layer has generally 10-15 % of the thickness of the white ash above. The pale colours of this tephra do not greatly contrast with that of the light brown loess which encloses it.
- The base of the tephra is very strongly bioturbated. This highly intricate, irregular surface has a sharp relief of up to 5 cm and often entirely pierces the basal pink ash, although the ash is still always present in an irregular bed of disjointed wedges.

Stratigraphic relationships:

The Ohiwa Hill Tephra has loess layers both above and below it, and at many sites the tephra occurs only as lenses within the loess. The upper contact is gradational, but the lower contact is generally sharp and highly irregular on a very small and detailed scale — probably due to the bioturbation of soil organisms trying to reach the new soil surface after burial by the ash (Photo-35).

Chemistry and mineralogy:

The glass from the Ohiwa Hill Tephra (Table 10-9) has moderate element-oxide values for the tephra in this study; with $\text{FeO} \approx 1.2 \text{ wt.}\%$, and $\text{Na}_2\text{O} \leq \text{K}_2\text{O}$. The sample from Ngatiawa lookout (04302) appears to be a mixture of two types of glass, but samples from the other sites do not show this mixture. This discrepancy has yet to be explained.

The Ohiwa Hill Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene $\pm$ biotite (t)

Table 10-10 : Glass chemistry of the Torere-G Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Ohiwa Hill	77.84	12.40	0.17	1.23	0.16	1.18	#3.27	3.61	0.16	4.35	8	1.00
**01706	0.29	0.25	0.04	0.05	0.05	0.15	0.15	0.32	0.04	0.58		
Torere West	76.16	13.19	0.23	1.36	0.23	1.25	3.89	3.52	0.19	6.23	14	0.88*
02215	0.42	0.19	0.06	0.13	0.08	0.14	0.22	0.14	0.04	0.72		
Ohiwa Hill	78.50	12.13	0.12	1.00	0.12	0.84	#3.38	3.87	0.16	4.84	3	0.86
01706b	0.58	0.21	0.02	0.06	0.03	0.06	0.08	0.30	0.03	1.14		
Torere West	77.42	12.57	0.18	1.10	0.13	0.80	3.79	3.75	0.26	5.16	2	0.89
02215	0.04	0.17	0.01	0.10	0.03	0.00	0.00	0.04	0.05	1.32		

Distribution and size:

The Ohiwa Hill Tephra is 40 cm thick at Hokianga Island, yet only 17 cm thick at Ohiwa Hill 5 km to the east, and only 20 cm thick at Ngatiawa lookout which is almost certainly closer to the tephra source area. Further east, the Ohiwa Hill Tephra is 10 cm thick at Huntress Creek, and it appears as 3 cm thick creamcakes within a reasonably well developed soil at the Burchett section. However, it is 25 cm thick at Torere West, a further 12 km to the east and in total some 30 km east of Hokianga Island. Much of the variation in thickness across the eastern Bay of Plenty is probably due to differences in preservation at each site; some sites suffering from more weathering than others.

Because of its irregular variation in thickness, the source of the Ohiwa Hill Tephra cannot be accurately determined from the coastal Bay of Plenty sections. The tephra always consists of fine ash and contains no coarser material, indicating that either its source must be some distance away from the coastal area, or only fine ash was erupted, perhaps from a phreatomagmatic eruption. The tephra is not recognised at Reihana Road suggesting a probable source in the Okataina V.C., and thus a likely phreatomagmatic style eruption.

10-10 Torere-G Tephra

The Torere-G Tephra is only recognised at a few sites in Bay of Plenty, and it is believed to be the seventh tephra deposited in the Torere subgroup.

The type section for the Torere-G Tephra is designated to be at Ohiwa Hill, though it is also recognised at the Hokianga Island, Reeves and Torere West sections.

The Torere-G Tephra has physical characteristics consisting of: (see Photo-35)

- Occurs as rare lenses (creamcakes) of fine white ash (5 cm thick) in a discontinuous layer within the uppermost part of a weathered loess unit. At Torere West the tephra occurs within a paleosol developed into this loess.

Chemistry and mineralogy:

The Torere-G Tephra contains a mixture of glass shards with two different chemistries (Table 10-10), though one component is much more common than the other. The dominant chemical type has $\text{FeO} \approx \text{CaO}$ (both ≥ 1.2 wt.%); and average values of Na_2O and K_2O . The chemistry of the minor component is very similar to that of the Matahina Tephra.

The Torere-G Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene

Table 10-11.1 : Glass chemistry of the Reihana-F Tephra; lower massive pumice layer.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Reihana Road **06208	78.05 0.45	12.08 0.21	0.20 0.05	1.11 0.07	0.12 0.04	0.78 0.05	3.35 0.22	4.10 0.22	0.22 0.04	5.18 1.17	18	1.00
Reihana Road 06208b	77.14 0.60	12.57 0.10	0.18 0.02	1.33 0.12	0.20 0.06	1.21 0.02	3.65 0.11	3.53 0.28	0.19 0.05	5.04 0.40	3	0.84

Table 10-11.2 : Glass chemistry of the Reihana-F Tephra; upper shower bedded layer.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 06208
Reihana Road 06216	77.69 0.35	12.21 0.20	0.17 0.03	1.10 0.12	0.11 0.03	0.88 0.10	3.41 0.12	4.21 0.14	0.22 0.03	4.95 0.78	10	0.95
Reihana Road 06216b	76.91 0.46	12.75 0.07	0.23 0.03	1.22 0.12	0.23 0.01	1.17 0.13	3.78 0.19	3.50 0.08	0.20 0.05	5.41 0.51	3	0.83

Discussion:

The Torere-G Tephra forms only discontinuous lenses in sections along the eastern Bay of Plenty coast, and hence it is not possible to get an accurate measurement of the true tephra thickness. The possibility of the inclusion of reworked Matahina material within the Torere-G Tephra deposit suggests that its source may have been in an area where the Matahina eruptives were quite thick — probably area the Okataina V.C.

10-11 Reihana-F Tephra

The Reihana-F Tephra has only been recognised at Reihana Road — its type section, where it occurs as a very thick airfall deposit. It is believed to be the sixth tephra deposited in the Reihana subgroup, and although a separate eruption, it is thought to lie in the same stratigraphic position as the Opotiki Tephra.

Diagnostic features: (see Photo-37)

- Top ≥ 35 cm consists of well shower bedded, white pumice lapilli; having an obvious lower contact with:
- The bulk of the tephra consists of ≈ 5 m of massive, coarse pumice lapilli (up to 3 cm across). Generally no bedding features are present, except for some faint shower bedding near the top.

Stratigraphic relationships:

The Reihana-F Tephra rests upon a 30 cm thick, very firm (cemented?) paleosol, developed into the top of loess(?) and/or the Reihana-E Tephra.

The Reihana-F Tephra has a sharp erosional upper contact with ≥ 10 cm relief. The Reihana-G Ignimbrite, which was probably the cause of the erosion, directly overlies this.

Chemistry and mineralogy:

The Reihana-F Tephra can be split into an upper, shower bedded member; and a lower, massive pumice lapilli member. Glass from both members has been analysed (Tables 10-11.1 & 10-11.2); both showing a similar mixture — containing shards with two different chemistries.

The major component of this mixture has elemental oxide values approximately midway between those of the the Reihana-C and Reihana-E Tephtras, except for FeO which is slightly higher than in both these older eruptions. The high K₂O content is unusual for the tephtras in this time period.

The minor component is a possible chemical match to the Opotiki Tephra (sect. 10-12) and therefore these two eruptions are tentatively believed to have been coeval.

The Reihana-F Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene

Figure 10-9 : Comparison between the glass chemistry of the Opotiki Tephra and the Torere-I Tephra that immediately overlies it

Distribution and size:

The Reihana-F Tephra is very thick (≥ 5 m) at the Reihana Road site, indicating that it is very near its source here. A source in the Reporoa V.C., or perhaps in the southern part of Okataina V.C. is thus postulated for this tephra. The major chemical component of the Reihana-F Tephra is not recorded in the coastal eastern Bay of Plenty sections and it is therefore believed to have had a more southerly dispersal—rather than north-northeast—from one of these two possible source areas.

It is impossible, from only one site, to accurately determine the source or size of the Reihana-F Tephra, but from its impressive thickness at Reihana Road, a minimum eruptive volume estimate of 5 km^3 can be calculated for this eruption — even if its source was <10 km away.

10-12 Opotiki Tephra

The Opotiki Tephra is widespread, and together with the tephra immediately overlying it (Torere-I) is easily recognised. It is therefore one of the better marker horizons in the late Pleistocene eastern Bay of Plenty stratigraphy. It is believed to be the eighth tephra deposited in the Torere subgroup and is also known here as the "Torere-H" Tephra.

The type section for the Opotiki Tephra is designated to be at Torere West. However, the basal unit of the tephra is not exposed at this site and is best seen at the Huntress Creek section. The tephra is also well represented at the Pukeruru Point, Hiwarau, Ohiwa Hill and Hokianga Island sections, and is present at the Reeves, Burchett and Ngatiawa lookout sections.

Diagnostic features:

(see Photo-38; Photo-39; Photo-41)

The Opotiki Tephra has been divided into three units, numbered from the base up "Op-1" to "Op-3", and presented in the following pages in order of deposition (i.e. oldest to youngest).

Opotiki-(1):

- A buff coloured (very pale brown/yellow), well sorted sandy ash layer; up to 5 cm thick where present. The ash consists predominantly of fine sand size glass shards. This unit is present at a few sites only (Huntress Creek, Reeves, Burchett) and appears to have pinch and swell variations in thickness. The reason for its irregular occurrence and variable thickness is as yet unknown.

Opotiki-(2):

- A grey (5Y 7/3 - "light yellow"), very well sorted coarse sandy ash layer; up to 20 cm thick at some sites, but <5 cm thick at others. The ash consists predominantly of glass shards of medium sand size, perhaps slightly coarser than in Op-3. Its darker grey colour contrasts markedly with the units above and below and is its main diagnostic feature.

continued over...

Opotiki-(3):

- A pale, light grey (7.5Y 8/2 - "light grey"), well sorted, massive sandy ash layer, usually ≈ 0.5 m thick in the eastern Bay of Plenty. The ash consists predominantly of medium sand sized glass shards. The shards in the basal few centimetres of this unit are of fine sand size, which enhances the sharp boundary to the unit below (Op-2) (usually defined by the sharp colour change). The uppermost few centimetres of this unit is also slightly finer than the bulk of the deposit.

In general, the physical features of the Opotiki Tephra cannot be separated from those of the tephra immediately above it (Torere-I Tephra), and together these deposits give an impression of shower bedded pumice (Torere-I) overlying a thicker layer ($\approx$ twice as thick) of very well sorted tephric sand (large glass shards), of which the lower 10 cm or so is an unusual dark yellowish-grey colour (Photo-38).

- Most of the tephtras in this study are pumiceous, but the Opotiki Tephra is one of the few that are composed predominantly of glass shards.

Stratigraphic relationships:

The upper contact of the Opotiki Tephra has not yet been precisely determined as no time break is recognised, but it is believed to be where the massive well sorted sand contacts the shower bedded pumice lapilli of the Torere-I Tephra. More detailed sampling and chemical analysis of this boundary region is required to precisely determine the position of the contact. It may be, however, that the boundary is gradational. It was only realised that the Opotiki and Torere-I Tephtras were different eruptives when microprobe analyses showed their contrasting glass chemistries (see Figure 10-9).

Figure 10-9 : Comparison between the glass chemistry of the Opotiki Tephra and the Torere-I Tephra that immediately overlies it

Table 10-12.1 : Glass chemistry of the Opotiki Tephra; unit Op-2.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Ohiwa Hill	78.00	12.50	0.20	1.20	0.18	1.18	#3.10	3.50	0.16	4.31	8	1.00
**01701	0.18	0.13	0.07	0.08	0.03	0.03	0.21	0.06	0.02	0.37		
Torere West	78.21	12.51	0.20	1.21	0.17	1.20	#2.80	3.53	0.15	5.78	9	0.98
02210	0.17	0.08	0.03	0.05	0.02	0.04	0.16	0.10	0.03	0.90		

Table 10-12.2 : Glass chemistry of the Opotiki Tephra; unit Op-3.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C. 01701
Ohiwa Hill	78.10	12.53	0.19	1.16	0.23	1.27	#3.04	3.30	0.19	4.07	10	0.94
01703	0.32	0.17	0.06	0.11	0.04	0.11	0.15	0.14	0.02	0.62		
Torere West	77.87	12.77	0.22	1.14	0.22	1.22	#3.11	3.30	0.15	3.48	9	0.95
02211	0.32	0.09	0.04	0.05	0.04	0.05	0.24	0.09	0.03	0.70		
Ngatiawa lookout	77.57	12.33	0.18	1.23	0.16	1.17	3.45	3.67	0.24	5.67	11	0.95*
04303	0.26	0.14	0.05	0.11	0.04	0.08	0.10	0.13	0.05	0.76		

Table 10-12.3 : Glass chemistry of possible correlatives of the Opotiki Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 01701
Reihana Road	76.91	12.75	0.23	1.22	0.23	1.17	3.78	3.50	0.20	5.41	3	0.93*
06216b	0.46	0.07	0.03	0.12	0.01	0.13	0.19	0.08	0.05	0.51		
Reihana Road	77.14	12.57	0.18	1.33	0.20	1.21	3.65	3.53	0.19	5.04	3	0.94*
06208b	0.60	0.10	0.02	0.12	0.06	0.02	0.11	0.28	0.05	0.40		

The Opotiki Tephra has its lower contact to the surface of a paleosol developed into loess. This contact is reasonably sharp, but in some places the basal beds of the tephra have been iron-stained (orange-brown) due to a perched water table flowing through them and there is little colour contrast to the firmer paleosol below (Photo-41).

Chemistry and mineralogy:

The middle (Op-2) and upper (Op-3) units of the Opotiki Tephra have near identical glass chemistries (Tables 10-12.1 & 10-12.2). A sample of the basal unit Op-1 was not analysed, but it is probably similar. The Opotiki Tephra contains glass which has moderately high FeO & CaO contents; both ≈ 1.2 wt.%. This chemistry is similar to that of the underlying Torere-G Tephra, suggesting that these two eruptives may have the same source.

The two samples from Reihana Road (06216b & 06208b; Table 10-12.3) represent a minor component in the mixed glass composition of the Reihana-F Tephra. The major chemical component of this tephra is significantly different to that of the Opotiki (see sect. 10-11) and is not recognised in the coastal Bay of Plenty. However, both these tephrae are believed to lie in the same stratigraphic position and are thought to be contemporaneous (coeval).

The Opotiki Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene

Distribution and size:

The Opotiki Tephra is recognised in sections across much of the coastal eastern Bay of Plenty. It has an unweathered thickness of ≈ 70 cm around the eastern edge of Ohiwa Harbour, and is also ≈ 70 cm thick at Torere West some 30 km further to the east (though many tephrae are thicker here than would be expected from data gathered elsewhere).

There is not enough evidence to determine the probable source area for the Opotiki eruption, but it was probably in the northern part of the T.V.Z., possibly in the Okataina V.C. If the tephra was erupted from the Reporoa V.C. or further to the south, it would almost certainly have formed a larger proportion of the Reihana-F Tephra.

10-13 Reihana-G Tephra

The Reihana-G Tephra has a very distinctive chemistry which has been recognised in deposits at several sites throughout the Bay of Plenty. It is thought to be the seventh tephra deposited in the Reihana subgroup, and is believed to be stratigraphically equivalent to the Torere-I Tephra. The probable correlative of the Reihana-G Tephra in the Tauranga area (western Bay of Plenty) has been designated the Welcome-A Tephra — in the Welcome Bay subgroup.

The type section for the Reihana-G Tephra is designated to be at Reihana Road. Chemical correlatives can be found around Tauranga Harbour as the Waimakariri Ignimbrite, and in the southern Mamaku Plateau (southwest of Rotorua) as the Chimp Ignimbrite.

The top of the Waimakariri Ignimbrite and the pisolitic ash above it has been studied in this work at the Welcome Bay and Omokoroa East sections. Harmsworth, (1983) lists further sites where these deposits crop out.

The Chimp Ignimbrite has been studied at the Downer Road section (east of Tokoroa), and is discussed in Chapter 13.

The Torere-I Tephra in the coastal eastern Bay of Plenty is believed to be a partial correlative of the Reihana-G Tephra, and is discussed in the following section (10-14).

Diagnostic features:

At Reihana Road: (Photo-37)

- The top 1 m consists of a fine grey ash with many accretionary lapilli (up to 1 cm across). A concentration of accretionary lapilli (pisolites) occurs at ~90 cm depth. This ash ("Reihana-G pisolitic ash") grades into:
- Basal 1.2 m consists of a grey, ash-rich, pyroclastic flow ("Reihana-G Ignimbrite"). This ignimbrite is generally fined grained with only rare pumice lapilli scattered throughout.

Around Tauranga Harbour:

- At Omokoroa East, the upper 1.5 m of the tephra consists of alternating beds of fine grey ash—that contain accretionary lapilli (up to 2 cm across)—and coarse sandy ash and lapilli. These beds overlie a 15 cm thick lapilli layer, and >2 m of well sorted, grey sandy ash that contains only occasional accretionary lapilli. This basal sandy ash is believed to overlie and/or be an airfall equivalent to the Waimakariri Ignimbrite, which is not observed in this section.
- At Welcome Bay, the top of the Waimakariri Ignimbrite can be seen; >1.5 m of unwelded pumice flow. The pisolitic ash is not seen here and may have been eroded out by the deposition of the overlying fluvial deposits.

At the Wairoa River section, near Ruahihi: [from Harmsworth, 1983]

- Columnar jointed, moderately welded ignimbrite (40 m thick); overlying poorly welded ignimbrite (3 m thick); overlying fluvial sediments and ash that contains accretionary lapilli up to 2 cm across.

East of Tokoroa (Chimp Ignimbrite):

- 20 cm of white pumice and ash; overlying ~10 m of grey-brown unwelded ignimbrite. The basal flow is a pumice poor, very fine, ash-rich 'veneer' ignimbrite. Keiller [1987] recognised a well sorted, coarse sandy ash/lapilli pre-ignimbrite airfall deposit (maximum of 45 cm thick), but this unit is not seen everywhere.

Table 10-13.1 : Glass chemistry of the Reihana-G Ignimbrite and probable correlatives.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 06218	S.C. 06219
Reihana Road **06219	75.99 0.23	13.20 0.13	0.19 0.05	1.63 0.10	0.18 0.02	1.14 0.05	3.87 0.11	3.56 0.14	0.24 0.04	5.43 0.47	10	0.97	1.00
Welcome Bay 08807	75.81 0.58	13.02 0.28	0.23 0.06	1.63 0.11	0.18 0.04	1.16 0.09	4.06 0.16	3.66 0.15	0.25 0.03	4.41 0.65	9	0.96	0.96
Downer Road 10303	75.74 0.32	13.06 0.23	0.19 0.04	1.56 0.11	0.18 0.04	1.19 0.07	4.00 0.16	3.84 0.14	0.24 0.05	4.25 1.01	12	0.95	0.97

Ignimbrite samples are as follows:- [06219] = Reihana-G; [08807] = Waimakariri; & [10303] = Chimp.

Table 10-13.2 : Glass chemistry of the Reihana-G pisolitic-ash and probable correlatives in the coastal Bay of Plenty.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	*Na ₂ O	K ₂ O	Cl	water	no.	S.C. 06218	S.C. 06219
Huntress Creek 01507b	77.55 0.24	12.67 0.29	0.17 0.02	1.44 0.17	0.15 0.04	1.14 0.05	*3.09 0.16	3.62 0.30	0.18 0.02	5.86 0.90	7	0.91*	0.92*
Torere West 02201b	77.42 0.33	12.74 0.18	0.17 0.03	1.46 0.12	0.16 0.02	1.14 0.05	*3.32 0.26	3.42 0.14	0.17 0.03	5.14 0.78	13	0.93*	0.93*
Hiwarau 02709b	77.24 0.22	12.99 0.03	0.17 0.03	1.51 0.11	0.15 0.01	1.18 0.03	*3.33 0.21	3.33 0.10	0.16 0.03	2.48 0.45	5	0.93*	0.92*
Ngatiawa lookout 04303b	77.50	12.56	n.d.	1.51	0.14	1.13	3.46	3.52	0.18	6.19	1	0.94	0.93
Reihana Road **06218	75.99 0.29	13.43 0.11	0.21 0.06	1.57 0.11	0.17 0.04	1.15 0.06	3.82 0.18	3.45 0.15	0.24 0.02	7.47 0.83	11	1.00	0.97
Omokoroa East 08701	76.57 0.38	12.86 0.34	0.28 0.08	1.55 0.11	0.20 0.04	1.16 0.07	3.79 0.20	3.40 0.19	0.21 0.07	6.41 1.17	9	0.94	0.93
Huntress Creek 01507a	78.64 0.19	12.08 0.18	0.15 0.03	1.05 0.09	0.14 0.03	0.89 0.07	*2.99 0.20	3.90 0.28	0.17 0.03	5.33 0.38	7	0.81	0.82
Torere West 02201a	78.88 0.33	11.95 0.09	0.14 0.03	0.98 0.05	0.10 0.02	0.90 0.06	*3.23 0.12	3.68 0.19	0.18 0.01	4.62 0.65	7	0.79	0.79
Hiwarau 02709a	78.70 0.22	12.20 0.14	0.12 0.04	1.00 0.07	0.13 0.03	0.88 0.07	*3.17 0.10	3.65 0.10	0.20 0.08	2.60 0.44	10	0.80	0.80

In the coastal eastern Bay of Plenty:

- see sect. 10-14 — Torere-I Tephra.

In general, the Reihana-G Tephra is recognised from its distinctive glass chemistry in conjunction with its stratigraphic position; the presence of accretionary lapilli in its ash being a supporting identification feature.

Stratigraphic relationships:

The top of Reihana-G pisolitic ash at Reihana Road has generally been eroded — occasionally totally eroded out. A paleosol has developed into this erosional surface and the Torere-K (Reihana-H) Tephra rests directly on this (see Photo-37). At Welcome Bay, a scoured erosional boundary cuts into the top of the pyroclastic flow, with >4 m of fluvially reworked pumice deposited above. At Omokoroa East, the upper alternating coarse and fine beds may possibly be water-lain (fluvial or lacustrine), and a paleosol has developed into the uppermost ash.

In the eastern coastal Bay of Plenty, the deposit that contains the mixture of Torere-I and Reihana-G chemistry is directly overlain by a unit showing only Torere-I chemistry. Both these units are often weathered (see sect. 10-14).

The base of the pyroclastic flow unit at Reihana Road has a sharp, erosional contact with the Reihana-F Tephra below (see Photo-37). The flow itself may be the cause of this erosion. At Downer Road (east of Tokoroa) the Chimp Ignimbrite rests on 5–10 cm of coarse pumice lapilli, which in turn overlies a very consolidated ash layer.

In the coastal eastern Bay of Plenty, the unit containing Reihana-G Tephra chemistry directly overlies the Opotiki Tephra without any noticeable time break. Nevertheless, the presumed boundary to the tephra below is still readily distinguished by the change from shower bedding to massive well sorted sandy ash (see sect. 10-14).

Chemistry and mineralogy:

The glass chemistry of the Reihana-G Tephra is very distinctive (Tables 10-13.1 & 10-13.2) compared with the other tephtras in this study. It has very high FeO; and moderately high CaO; with $\text{FeO} > \text{CaO}$, and $\text{Na}_2\text{O} > \text{K}_2\text{O}$. It also has a relatively low SiO_2 content, and concomitantly high Al_2O_3 . The CaO, TiO_2 & MgO values are only moderate compared with the high FeO content, which contrasts with the high values recorded for these three element-oxides in other tephtras that have a higher than average FeO content.

Three of the samples in Table 10-13.2 (01507b, 02201b & 02709b) occur as a significant component ($\approx 50\%$) of a deposit with a mixed chemistry. The other chemical component has been designated as belonging to the Torere-I Tephra (01507a, 02201a & 02709a). It is uncertain whether the mixture of glass from these two eruptions is due to coeval eruption, or to some other reason. This is discussed further in the section investigating the Torere-I Tephra (sect. 10-14).

The Reihana-G Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene

This tephra is poor in ferromagnesian minerals and relative proportions are difficult to determine from the limited sample that was separated.

Distribution and size:

The Reihana-G Tephra is believed to consist of a very widespread ignimbrite and a moderately widespread airfall ash. The ignimbrite has been found in a limited number of sections stretching from Tauranga Harbour in the north, through the river valleys draining into the harbour from the forests to the southwest of Rotorua (just east of Tokoroa), to the forests southeast of Rotorua near Waiotapu; 75 km from Tauranga. The Waimakariri Ignimbrite is 40 m thick at the Wairoa River section, and several localities near Ruahihi indicate that the ignimbrite had ponded in topographic depressions [Harmsworth, 1983]. The greatest (that this worker knows of) recorded thickness of the Chimp Ignimbrite is ≥ 15 m of moderately welded, columnar jointed ignimbrite, at the Jeff Road section northeast of Tokoroa, though it must almost certainly be thicker further to the east on the Mamaku Plateau. The wide dispersal of the Reihana-G flow deposits — including the Chimp and Waimakariri ignimbrites — requires that the flow be highly energetic. Gas escape pipes and segregation pods indicative of energetic flow have been found in the Chimp Ignimbrite [Keiller, 1987], supporting the correlation of these units. The distribution indicates a probable source in either the western part of the Rotorua V.C., or perhaps the northwest of the Kapenga V.C. Houghton et al. (1995) believes this latter area to be the source. There are not enough sections showing the airfall component of the Reihana-G Tephra for it to contribute much to the discussion on source.

Nevertheless, a probable correlative of the Reihana-G Tephra has been found in several sections in the coastal eastern Bay of Plenty. However, this deposit (Torere-I(1)) contains a mixture of glass compositions and there is still some question over its full relationship to the Reihana-G Tephra; and further study is required (sect. 10-14). The Reihana-G Tephra here (in the eastern Bay of Plenty) appears to consist of coarse pumice lapilli rather than the fine pisolitic ash found to the south (Reihana Road) and west. The pisolitic ash may have been dispersed to the west and south only, while the coarse pumice was distributed in a northeast direction. Alternatively the pisolitic ash may be a co-ignimbrite deposit found only in close association with the pyroclastic flow, and therefore not present in distal sites in the eastern Bay of Plenty.

The average thickness of the Reihana-G Ignimbrite is not known, especially as many of its thickest outcrops are some distance from its presumed source and have been interpreted as "valley ponded" ignimbrite. Previously, the Chimp Ignimbrite had been described as a "moderate volume ignimbrite" [Houghton et al., 1991], but if it is a correlative of the Waimakariri and Reihana-G Ignimbrites, then it is a much larger and stratigraphically more important unit.

Assuming the ignimbrite was deposited as a simple cone with its thickest deposits in the centre, an estimate of its volume can be made. In the case of a circular, conical sheet 75 km across and 40 m thick in the centre, the volume of erupted material would be $\approx 60 \text{ km}^3$. However, the true thickness at the centre is unknown and the ignimbrite distribution is not likely to be circular, but elliptical; and/or patchy — with the thickest deposits in paleo-valleys and much thinner on paleo-hills. Nevertheless, an estimate of $c. 50 \text{ km}^3$ is likely to be of the right order of magnitude.

Discussion:

The Reihana-G Tephra consists of a widespread ignimbrite and an associated pisolitic ash (possibly a co-ignimbrite ash), which was most likely erupted from either the Rotorua or the Kapenga Volcanic Centre at *c.* 0.29–0.30 Ma. The fine grained nature of the ash and the presence of accretionary lapilli within it suggests that the eruption was phreatomagmatic. Its glass chemistry is very distinctive and is the basis for this tephra's correlation over much of the Bay of Plenty region.

One shard from the Ngatiawa sample (04303) has Reihana-G chemistry, one other shard has Torere-I chemistry, while the rest have Opotiki Tephra chemistry (Table 10-12.1), tentatively suggesting that the Reihana-G eruption was contemporaneous with both the tail-end of the Opotiki eruption, and the beginning of the Torere-I eruption.

10-14 Torere-I Tephra

The Torere-I Tephra is often weathered and difficult to distinguish. Together with the immediately underlying tephra (the Opotiki) it is readily recognisable, making it one of the better marker horizons in the late Pleistocene stratigraphy of the Bay of Plenty. It is believed to be the ninth tephra deposited in the Torere subgroup, and is thought to be stratigraphically equivalent to the Reihana-G Tephra.

The type section for the Torere-I Tephra is designated to be at Torere West, where the tephra appears to have undergone the least weathering. The tephra can also be recognised in the Huntress Creek, Hiwarau, Hokianga Island, Ohiwa Hill, Reeves and Pukeruru Point sections, and is present, although highly weathered, at the Burchett and Ngatiawa lookout sections. The basal tephra in the Opape section may also be a correlative of the Torere-I Tephra (uncertain).

The Reihana-G Tephra (ignimbrite and ash)—which has been tentatively correlated with part of the Torere-I Tephra—can be recognised at Reihana Road, Downer Road, Omokoroa East, Welcome Bay, and many other sites in the Tauranga area (sect. 10-13).

Diagnostic features:

The Torere-I Tephra has tentatively been divided into two units; numbered in stratigraphic order of deposition as Torere-I(1) and Torere-I(2) (oldest to youngest), and described individually on the following page.

(see Photo-38; Photo-39; Photo-41)

Torere-I(1):

- Consists of white, shower bedded, coarse pumice lapilli; generally forming a layer *c.* 20 cm thick. The lapilli are up to 2.5 cm across at Pukeruru Point; 2 cm across at Hokianga Island; and ≥ 0.7 cm across at Ohiwa Hill, Huntress Creek and Torere West — though the pumice is plate-like at this latter distal site.
- The basal part of this unit is reverse graded.
- Contains a mixture of glass of two chemical types; with one of the two components being very distinctive.

Torere-I(2):

- Several well bedded layers of white fine ash and sandy ash forming a total thickness of *c.* 15–20 cm. This unit is generally very weathered and details are often difficult to pick out. A paleosol has often developed through this upper unit and into the Torere-I(1) unit below.

In general, the physical features of the Torere-I Tephra cannot be separated from those of the tephra immediately below (Opotiki Tephra). Together these deposit give an impression of shower bedded pumice; overlying a thicker layer ($\approx$ twice as thick — Opotiki) of very well sorted sandy ash (large glass shards), of which the lower 10 cm or so is an unusual dark yellowish grey colour (see sect. 10-12).

- The main differences between the Torere-I(2) and Torere-I(1) units, is that the upper unit is much finer grained than the lower, and also that the glass from the upper has a single "pure" chemistry, and glass from the lower shows a mixture of compositions.
- The distinctive glass chemistry of the Torere-I(1) Tephra is its major diagnostic feature.

Stratigraphic relationships:

The upper contact of the Torere-I Tephra is impossible to distinguish in all but the type section at Torere West (see Photo-41), and at Opape—if the tephra correlation to this site is correct. At both these sections, the tephra is directly overlain by a layer of organic-rich silts and lignite deposited in a subaqueous environment (probably lacustrine) which has preserved the Torere-I Tephra in its entirety. The top of the tephra may also be recognisable at Pukeruru Point, where the weak paleosol that has developed into it is overlain by a unit of weathered tephra/tephric loess. At all other sites, the upper part of the Torere-I Tephra has been weathered into by a weakly developed, yet quite thick paleosol (see Photo-39). Several eruptives have been incorporated within this paleosol—thought to represent several thousand years—with the Torere-I Tephra usually the lowermost weathered tephra preserved, though the upper parts of underlying Opotiki Tephra are also occasionally weathered. At the more weathered sites (e.g. Burchett, Ngatiawa lookout) the Torere-I Tephra cannot be distinguished at all.

Figure 10-10 : Glass chemistry of the Torere-I(1) Tephra from several sites (Huntress Creek, Torere West, & Hiwarau)

Figure 10-11 : Glass chemistry of the Torere-I Tephra; unit-1 (02201) & unit-2 (02216) [Torere West section]

The lower boundary of the Torere-I Tephra has not been precisely determined, as no weathering or time break can be recognised at the top of the Opotiki Tephra (Photo-38; Photo-41). Nevertheless, it is thought that the contact probably occurs where the shower bedded pumice lapilli unit (Torere-I(1)) rests on the massive well sorted sand unit (Opotiki-(3)). More detailed sampling and chemical analysis of this boundary region is required for precise determination of the contact, and it may yet be found that the contact is gradational.

At Rocky Cutting Road there is a tephra tentatively correlated to the Torere-I Tephra by its glass chemistry alone. This deposit is overlain by loess, and rests upon a brown paleosol developed into a thin white ash layer below.

The boundary between the two units making up the Torere-I Tephra is also not readily determined. The change from shower bedded pumice lapilli to sandy ash is gradational and further analyses are required on these beds to determine if the true boundary is gradational or sharp.

Chemistry and mineralogy:

The chemical difference between the coarse pumice of the lower unit (Torere-I(1)) and the fine grained upper unit (Torere-I(2)) is plainly obvious (Tables 10-14.1 & 10-14.2; Figures 10-10 & 10-11).

The glass in the lower unit is a mixture of two chemical types, whereas the upper unit is either "pure" or nearly so.

Of the two components in the lower unit, one type is identical to the upper unit, and the other to a widespread, chemically distinctive ignimbrite found in the western Bay of Plenty (Figure 10-12; see sect. 10-13).

Figure 10-12 : Comparison of the glass chemistry of the Torere-I and Reihana-G Tephras, and the Chimp/Waimakariri Ignimbrite

Table 10-14.1 : Glass chemistry of the Torere-I Tephra; unit-1.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	*Na ₂ O	K ₂ O	Cl	water	no.	S.C. 02201	S.C. 02201b
Huntress Creek 01507	78.64 0.19	12.08 0.18	0.15 0.03	1.05 0.09	0.14 0.03	0.89 0.07	*2.99 0.20	3.90 0.28	0.17 0.03	5.33 0.38	7	0.93	0.87
Torere West **02201	78.88 0.33	11.95 0.09	0.14 0.03	0.98 0.05	0.10 0.02	0.90 0.06	3.23 0.12	3.68 0.19	0.18 0.01	4.62 0.65	7	1.00	0.84
Hiwarau 02709	78.70 0.22	12.20 0.14	0.12 0.04	1.00 0.07	0.13 0.03	0.88 0.07	3.17 0.10	3.65 0.10	0.20 0.08	2.60 0.44	10	0.94	0.85
Huntress Creek 01507b	77.55 0.24	12.67 0.29	0.17 0.02	1.44 0.17	0.15 0.04	1.14 0.05	*3.09 0.16	3.62 0.30	0.18 0.02	5.86 0.90	7	0.85	0.97
Torere West **02201b	77.42 0.33	12.74 0.18	0.17 0.03	1.46 0.12	0.16 0.02	1.14 0.05	3.32 0.26	3.42 0.14	0.17 0.03	5.14 0.78	13	0.84	1.00
Hiwarau 02709b	77.24 0.22	12.99 0.03	0.17 0.03	1.51 0.11	0.15 0.01	1.18 0.03	3.33 0.21	3.33 0.10	0.16 0.03	2.48 0.45	5	0.84	0.98
Ngatiawa lookout 04303b	77.50	12.56	n.d.	1.51	0.14	1.13	3.46	3.52	0.18	6.19	1	0.85	0.96

Table 10-14.2 : Glass chemistry of the Torere-I Tephra; unit-2.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	*Na ₂ O	K ₂ O	Cl	water	no.	S.C. 02201
Opape 01401	78.05 0.55	12.31 0.20	0.14 0.03	1.03 0.05	0.12 0.03	0.86 0.09	3.57 0.32	3.73 0.09	0.21 0.07	5.95 0.83	12	0.95
Reeves 01904	79.10 0.19	12.05 0.07	0.12 0.03	0.96 0.10	0.12 0.04	0.86 0.04	*3.03 0.11	3.63 0.12	0.15 0.03	3.90 0.79	9	0.94
Torere West 02216	77.40 0.40	12.53 0.16	0.15 0.06	1.08 0.11	0.12 0.03	0.89 0.04	3.82 0.21	3.80 0.22	0.22 0.03	6.83 1.04	8	0.93
Pukeruru Point 02503	79.03 0.20	12.00 0.13	0.13 0.04	0.98 0.05	0.11 0.02	0.87 0.06	*3.04 0.18	3.72 0.09	0.17 0.02	5.23 0.90	10	0.97
Ngatiawa lookout 04303c	77.48	12.51	0.11	1.14	0.11	0.85	3.51	4.00	0.30	5.80	1	0.91

Table 10-14.3 : Glass chemistry of possible correlatives of the Torere-I Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 02201
Omokoroa East 08701b	78.19	12.24	0.18	1.11	0.12	0.92	3.27	3.76	0.20	7.27	1	0.93*
Rocky Cutting Rd. 09001	78.56 0.52	11.93 0.38	0.22 0.09	1.03 0.08	0.13 0.04	0.86 0.08	3.46 0.17	3.60 0.17	0.22 0.06	4.63 1.39	11	0.90*
Omokoroa East 08701	76.57 0.38	12.86 0.34	0.28 0.08	1.55 0.11	0.20 0.04	1.16 0.07	3.79 0.20	3.40 0.19	0.21 0.07	6.41 1.17	9	0.90*
Rocky Cutting Rd. 09001b	76.73 0.56	13.27 0.30	0.25 0.02	1.60 0.11	0.19 0.04	1.15 0.07	3.56 0.55	3.10 0.17	0.16 0.08	6.52 0.85	3	0.90*

The Torere-I(2) Tephra glass chemistry has moderate values for all of the element-oxides, whereas the other component has a very high FeO; moderately high CaO, TiO₂ & MgO; and relatively low K₂O contents (K₂O = 3.4 ≥ Na₂O).

The sample from Opape (01401) was taken from a thick deposit (>80 cm) of well sorted coarse sandy ash believed to have been deposited in a lacustrine environment. Its chemistry and general stratigraphic position suggests a correlation to either the Torere-I or Torere-L Tephra, but as its base is not observed and the stratigraphy of the tephra within the peats above is difficult to determine, its identification remains uncertain.

The sample from Ngatiawa lookout (04303) contains glass of predominantly Opotiki Tephra chemistry, and only one shard each of the Torere-I and Reihana-G Tephra chemistry. The glass chemistry of possible correlatives of the Torere-I/Reihana-G Tephra in the Tauranga region are presented in Table 10-14.3.

Based upon their chemical similarity, and the similarity in stratigraphic position, the Torere-I and Reihana-G Tephra eruptions are believed to be contemporaneous. However, the full relationship between these two tephra is uncertain. The Reihana-G Tephra is generally a very fine pisolitic ash, yet the correlated layer in the Torere-I Tephra consists of pumice lapilli. Of the three samples, 01507 was taken from the matrix, whereas samples 02201 and 02709 were taken from crushed selected pumices. The resultant chemical mixture obtained from the crushed pumices suggests that the deposit may be from one eruption and the mixture thus related to primary magmatic processes. Further analyses on individual pumice clasts is required to confirm this.

The Torere-I Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene ± augite (t)

Distribution and size:

Both units of the Torere-I Tephra are recognised in sections across the coastal Bay of Plenty, although the upper unit is usually weathered and not as obvious as the lower. The Torere-I(1) unit ranges in thickness from 10 cm — at Huntress Creek, to 35 cm — at Ohiwa Hill; and is generally ≈20 cm thick. The thickness of the Torere-I(2) unit is much harder to define, because if the upper boundary is taken as the base of the next visible tephra, many centimetres of weathering and/or paleosol development would be included in its total thickness. Also, at least one tephra (Torere-J) and occasionally more (e.g. Torere-K) are present but not usually distinguished within this weathered layer. Reliable estimates for the thickness of the Torere-I(2) unit can be gathered from only two sites — Pukeruru Point and Torere West — where it is 40 cm and 16 cm thick respectively. The thickness of the two Torere-I units together appears to be ≈60 cm around Ohiwa Harbour, and 30 cm at Torere West. Identification of the Torere-I Tephra is still uncertain in the Opape section, though it appears here to be substantially over-thickened due to deposition in a lacustrine environment.

There is not enough data to determine the source of eruption for the Torere-I Tephra, but as glass with this composition is not recorded at Reihana Road to the south (excluding the Reihana-G

component), its source is likely to be in the northern part of the T.V.Z. — probably the Okataina V.C. The Reihana-G Tephra is thought to have its source in either the western part of the Rotorua V.C., or in the Kapenga V.C.

Discussion

The Torere-I Tephra was at least a small to moderately sized eruption which was sourced from somewhere in the northern part of the T.V.Z. at c. 0.29–0.30 Ma. The tephra was contemporaneous with several other eruptions within the Bay of Plenty; the region undergoing one of its more intense volcanic episodes.

No time breaks can be seen between the Opotiki, Torere-I(1) and Torere-I(2) eruptions in the coastal eastern Bay of Plenty, and together the deposits form an easily recognisable and distinctive stratigraphic marker.

The Reihana-G Tephra (both ignimbrite and ash) has a "pure" glass chemistry and does not show any mixture, indicating that the Torere-I and Reihana-G Tephrae were not deposited from the same eruption. The chemically mixed deposit was formed from either the result of two coeval eruptions, or from the entrainment of country rock. In the latter case, the Torere-I Tephra could have had an initial, violent, vent enlarging, pumice producing phase which entrained some vent wall-rock of Reihana-G type chemistry; followed by a quieter, less erosive, finer and chemically homogeneous, ash producing phase.

10-15 Torere-J Tephra

The Torere-J Tephra has only been recognised at one site in the Bay of Plenty, near the base of the Opape section. It is believed to be the tenth tephra deposited in the Torere subgroup.

At Opape, the Torere-J Tephra has **diagnostic features** that consist of:

- 3 cm of coarse sandy ash within organic-rich silts.
- Has a distinctive glass chemistry.

Stratigraphic relationships:

The Torere-J Tephra lies near the base of an ~30 cm thick organic-rich peat bed that contains some wood. Only 2 cm of organic-rich sediment occurs below, to the top the well sorted pumice sand that is believed to be the Torere-I Tephra, whereas 25 cm of organic-rich sediment is found above, to the base of the next tephric deposit.

Table 10-15 : Glass chemistry of the Torere-J Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Opape	75.76	13.35	0.32	1.98	0.40	2.17	#2.84	3.02	0.16	5.10	6	1.00
**01404	0.42	0.19	0.08	0.19	0.07	0.07	0.39	0.11	0.05	0.82		
Opape	77.65	12.47	0.23	1.57	0.26	1.49	#2.77	3.50	0.13	4.59	3	0.82
01404b	0.14	0.15	0.02	0.08	0.01	0.15	0.10	0.17	0.03	0.71		

Chemistry and mineralogy:

The Torere-J Tephra contains a mixture of glass shards with two different chemistries (Table 10-15), probably the result of reworking of previously erupted material into the lacustrine environment during its eruption.

The major component of the Torere-J Tephra has a glass chemistry quite different from the most of the tephtras in this study. It has very high FeO, CaO, TiO₂ & MgO contents, and low K₂O & SiO₂. The glass chemistry of the minor component has much lower values of FeO, CaO, TiO₂ and MgO, although they are still higher than average for the tephtras in this study.

The Torere-J Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene

Discussion:

The Torere-J Tephra has been recognised at only one site — where its preservation has been enhanced by deposition of organic-rich sediment into a lacustrine environment immediately following the eruption. As the tephra is very thin, even in an environment which often causes over-thickening, it is thought to represent only a minor eruption. Its source is unknown.

Further detailed work at Reihana Road and other sites may discover shards from this eruption within the paleosol below the Torere-K tephra.

10-16 Torere-K Tephra

The Torere-K Tephra has been positively identified at only two sites in the Bay of Plenty, but it has a distinctive chemistry which is very useful for stratigraphic correlations. It is believed to be the eleventh tephra deposited in the Torere subgroup and is equivalent to the Reihana-H Tephra in the Kaingaroa forest area.

The type section for the Torere-K Tephra is designated to be at Reihana Road. It is also recognised at the Torere West section, and glass shards with a similar chemical composition has been found in lacustrine sediments at Opape.

Diagnostic features:

At Reihana Road: (Photo-37)

- ≈0.5 m of a yellowish-orange (stained), massive, well sorted coarse sandy ash.

At Torere West and Opape: (see Photo-41; Photo-42)

- ≈15 cm of a creamy-yellow fine ash, with only occasional thin sandy layers.

Generally:

- The distinctive glass chemistry of the Torere-K Tephra is its major diagnostic feature.
-

Table 10-16 : Glass chemistry of the Torere-K Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Opape	76.00	13.21	0.30	1.51	0.29	1.31	3.83	3.38	0.18	2.99	9	0.95
01405	0.41	0.30	0.07	0.10	0.03	0.10	0.14	0.12	0.04	2.32		
Torere West	77.04	12.80	0.31	1.35	0.28	1.37	#3.44	3.28	0.14	6.20	8	0.98*
02207	0.33	0.13	0.04	0.11	0.04	0.04	0.19	0.11	0.05	1.62		
Reihana Road	76.88	12.76	0.34	1.35	0.28	1.34	3.66	3.23	0.17	3.99	11	1.00
**06205	0.28	0.19	0.07	0.11	0.05	0.07	0.16	0.14	0.04	1.41		

Stratigraphic relationships:

The upper part of the Torere-K Tephra at Reihana Road is weathered and has a weak paleosol developed into it. This paleosol is directly overlain by the Torere-L Tephra. At Torere West, a lignite bed (5–8 cm thick) lies between these two tephras and is equivalent to this paleosol (Photo-42). The tephra at Opape which is tentatively correlated to the Torere-K Tephra also has organic-rich material (12 cm) resting directly on it.

At Reihana Road, the Torere-K Tephra rests on the paleosol developed into the Reihana-G pisolithic ash. In some places a significant amount of erosion has occurred into the top of this ash; the paleosol developing downwards from this erosional surface. At Torere West, the Torere-K Tephra rests directly on 7 cm of lignite, which separates it from the Torere-I Tephra below.

Immediately underlying the Torere-K correlative at Opape are 20 cm of organic-rich silts. Between these silts and the 25 cm thick organic-rich peat overlying the Torere-J Tephra, there are two, 7 cm thick, coarse sandy ash layers, separated by an 8 cm layer of organic-rich silt. These ash layers are not believed to represent primary airfall from any individual eruptions, but fluvially reworked tephra from the surrounding landscape. Both layers appear to contain a mixture of shards from two or more eruptions, although the parent tephras for some of the minor components are unknown.

Chemistry and mineralogy:

The glass from the Torere-K Tephra (Table 10-16) is chemically distinctive in that it has moderately high FeO & CaO contents (both ≈ 1.35 wt.%), but very high TiO₂ & MgO contents (both ≈ 0.3 wt.%) compared with other tephras with similar FeO & CaO values. Furthermore, K₂O is lower than average, with Na₂O > K₂O.

The Torere-K Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende

In general this tephra is very poor in ferromagnesian minerals, and the quoted assemblage may not be fully accurate as only small samples were studied.

Distribution and size:

The Torere-K Tephra is ≈ 15 cm thick in lacustrine sediments in the coastal eastern Bay of Plenty, but was not thick enough to be preserved as a separate layer in the terrestrial environment. It has not been recognised in the sections around Tauranga, but far to the south at Reihana Road it is ≈ 50 cm thick. From these sites it is impossible to accurately determine the source or size of this tephra, but its glass chemistry is sufficiently different from those of similar age to suggest that it may have come from a totally different source area than the surrounding eruptives. From the relatively small size of the pumice clasts at Reihana Road, it is thought that the tephra was not erupted from nearby. The tephra is even finer grained to the north, and a source in the southern T.V.Z.—perhaps the Taupo Volcanic Centre—is likely, though a source in the northwest T.V.Z. cannot yet be dismissed.

Table 10-17 : Glass chemistry of the Torere-L Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	[#] Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Opape	77.84	12.25	0.15	1.03	0.17	0.82	3.68	3.89	0.18	5.51	2	0.92
01406c	0.37	0.23	0.00	0.02	0.03	0.02	0.16	0.20	0.06	1.90		
Huntress Creek	77.89	12.42	0.15	0.98	0.14	0.88	3.68	3.67	0.21	4.97	21	0.94
01520	0.39	0.20	0.03	0.12	0.03	0.08	0.15	0.20	0.05	1.76		
Torere West	78.94	11.96	0.13	0.96	0.14	0.89	[#] 3.22	3.64	0.15	2.94	10	0.93*
02204	0.32	0.17	0.03	0.06	0.02	0.03	0.19	0.10	0.04	1.26		
Hiwarau	78.58	11.87	0.19	0.99	0.14	0.87	3.49	3.65	0.20	3.42	11	0.96
02713	0.46	0.23	0.05	0.08	0.03	0.06	0.17	0.12	0.04	2.13		
Reihana Road	78.83	11.75	0.17	0.98	0.12	0.84	3.41	3.76	0.17	2.56	11	1.00
**06203	0.36	0.07	0.05	0.08	0.05	0.10	0.09	0.21	0.03	0.92		

10-17 Torere-L Tephra

The Torere-L Tephra has been recognised at several sites in the eastern Bay of Plenty, and at Reihana Road on the Kaingaroa Plateau. It is believed to be the twelfth tephra deposited in the Torere subgroup, and is equivalent to the Reihana-I Tephra in the Kaingaroa Forest area.

The type section for the Torere-L Tephra is designated to be at Reihana Road. It is also well represented at the Torere West section, and although weathered has been identified at the Huntress Creek, Hiwarau, Ohiwa Loop Road and Ohiwa Hill sections, and also possibly at Pukeruru Point and Opape.

Diagnostic features:

At Reihana Road: (see Photo-40)

- An upper layer (≈ 0.5 m thick) that consists of coarse pumice lapilli (2–3 cm across) and contains many obsidian lithics (up to 1 cm across). This upper unit overlies a slight erosional boundary into the generally finer and better layered basal beds below.
- A middle layer (15 cm thick) of normally graded pumice lapilli to ash.
- A basal layer (30 cm thick) of predominantly normally graded pumice lapilli and obsidian lithics; grading upwards into thinner beds of coarse sandy ash and fine ash.

In the coastal eastern Bay of plenty: (Photo-39; Photo-42)

- An upper layer of normally graded coarse sandy ash to fine ash.
- A basal layer of normally graded coarse sandy ash to fine ash. At Torere West this unit shows thin alternating beds of coarse and fine ash.
- Generally found as intermittent sandy ash layers, ≈ 10 cm thick, within strongly weathered loess and tephra (weakly developed paleosol).

Stratigraphic relationships:

The Torere-L Tephra at Reihana Road rests on the weak paleosol developed into the Torere-K Tephra, and has a very weak (only 3 cm thick) paleosol developed into it; directly overlain by the Torere-M Tephra.

At Torere West the Torere-L Tephra is found within lignite (Photo-42). Throughout the remainder of the eastern Bay of Plenty sections the tephra occurs as an intermittent layer within the lower half of a weak—but thick—paleosol developed into weathered tephra/loess. Its basal contact at Ohiwa Loop Road is highly irregular due to bioturbation.

Chemistry and mineralogy:

The glass from the Torere-L Tephra (Table 10-17) has average element oxides values for the tephra in this study, with $\text{FeO} \approx 1.0 > \text{CaO}$. This chemistry is not particularly distinctive and is not a good basis for correlation without knowledge of the constraining stratigraphy. Nevertheless, its glass

The Torere-L Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene

Distribution and size:

The Torere-L Tephra is ~30 cm thick in the lacustrine sediments at Torere West, but was only just thick enough (10–20 cm) to be preserved as a separate layer in the weathered subaerial terrestrial sequence elsewhere in the eastern Bay of Plenty. It is over 1 m thick at Reihana Road, and contains large obsidian lithics that indicate that this section was near to source, or closer to the axis of dispersal than the coastal areas. A source in the northern T.V.Z. is postulated, either in the southern part of the Okataina V.C., or perhaps in the Reporoa V.C.

10-18 Torere-M Tephra

The Torere-M Tephra has been positively recognised at only two sites in the Bay of Plenty. It is believed to be the thirteenth tephra deposited in the Torere subgroup, and is equivalent to the Reihana-J Tephra in the Kaingaroa Forest area.

The type section for the Torere-M Tephra is designated to be at Reihana Road. It is also seen at the Torere West section, and possibly also as reworked ash deposits in the lacustrine sediments at Opape.

Diagnostic features:

At Reihana Road: (see Photo-40)

- An upper 10 cm thick layer of fine ash, overlying 55 cm of shower bedded granular pumice lapilli and coarse sandy ash.

At Torere: (see Photo-41)

- A 1 cm thick layer of white sandy ash within a 15 cm thick lignite bed.

Stratigraphic relationships:

The Torere-M Tephra at Reihana Road rests on the very thin paleosol developed into the Torere-L Tephra, and has a dark brown silty paleosol (10 cm thick) developed in its top which is directly overlain by the Torere-N Tephra.

At Torere West, the Torere-M Tephra lies approximately halfway through a 15 cm thick lignite bed; with the Torere-L Tephra below, and the Torere-N Tephra above.

Chemistry and mineralogy:

The glass from the Torere-M Tephra (Table 10-18) contains a slight mixture of two different chemical types. The minor component is only recognised as a single shard in three of the four deposits, and not at all in the other, and although the possibility of laboratory contamination cannot totally be dismissed, the similar chemistry at each site suggests that this minor component is of primary origin. The major component has a distinctive chemistry in that it has a very low CaO content (≈ 0.60 wt.%), high K₂O (≈ 4.3 wt.%), and MgO values that also are below average. This chemistry is noticeably different to most of the tephtras of this age; similar only to the Reihana-C Tephra, and to several tephtras in the very much older Tablelands subgroup.

The samples from Opape represent minor components (samples 01403b and 01406b & d) among shards from many other eruptives (though predominantly the Opotiki Tephra) in two fluvio-lacustrine deposited ash layers.

The Torere-M Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + biotite

Only small samples were taken from this tephra, and few ferromagnesian minerals were seen. The quoted assemblage therefore may not be fully accurate.

Distribution and size:

The Torere-M Tephra is 75 cm thick at Reihana Road, but <1 cm thick at the coast. Not enough data is available to determine this tephtras size or source, though on the basis of its glass chemistry similarity with the Reihana-C Tephra, these two eruptives may have originated from the same—as yet unknown—source area.

10-19 Torere-N Tephra

The Torere-N Tephra has been positively identified at only four sites in the Bay of Plenty. It is believed to be the fourteenth tephra deposited in the Torere subgroup and is equivalent to the Reihana-K Tephra in the Kaingaroa Forest area.

The type section for the Torere-N Tephra is designated to be at Reihana Road, but it is also seen in the coastal Bay of Plenty at the Torere West, Ohiwa Loop Road and Pukeruru Point sections, and as shards in reworked tephric-deposits in lacustrine sediments at Opape.

Table 10-19: Glass chemistry of the Torere-N Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	*Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Opape 01412b	77.62 0.49	12.41 0.22	0.17 0.07	1.14 0.11	0.13 0.06	0.97 0.09	3.61 0.18	3.75 0.27	0.21 0.02	5.93 0.87	4	0.96
Torere West 02206	78.41 0.25	12.36 0.12	0.17 0.03	1.20 0.07	0.13 0.02	0.95 0.05	*3.04 0.20	3.62 0.07	0.14 0.02	4.37 1.02	15	0.94*
Pukeruru Point 02507	78.37 0.22	12.33 0.06	0.16 0.03	1.20 0.08	0.12 0.02	0.93 0.03	*3.06 0.25	3.69 0.12	0.15 0.02	3.29 0.40	9	0.92*
Reihana Road **06217	77.36 0.30	12.52 0.15	0.19 0.04	1.21 0.13	0.15 0.03	0.97 0.08	3.62 0.10	3.79 0.10	0.20 0.04	4.86 1.16	19	1.00
Torere West 02206b	78.63	12.40	0.24	1.17	0.14	1.23	2.64	3.43	0.11	4.29	1	0.89
Pukeruru Point 02507b	77.80	12.61	0.10	1.11	0.18	1.16	3.22	3.62	0.20	3.00	1	0.87
Reihana Road 06217b	77.00	12.69	0.20	1.38	0.15	1.27	3.56	3.56	0.18	6.83	1	0.94

Diagnostic features:

At Reihana Road: (see Photo-40)

- An upper 20 cm thick layer of pale grey fine ash, overlying 60 cm of evenly bedded, alternating layers of medium sandy ash, pumice lapilli (up to 1 cm across) and medium sandy ash; with a basal coarse sandy ash.

In coastal Bay of Plenty sections: (Photo-43)

- Generally occurs as discrete lenses of fine white ash; up to 5 cm thick.

Stratigraphic relationships:

The Torere-N Tephra at Reihana Road shows only slight weathering in its upper ash layer, and is directly overlain by the Torere-O Tephra. In the coastal bay of Plenty sections, the Torere-N Tephra lies within a weathered loess/tephra paleosol (generally ≥ 40 cm thick), midway between the Torere-L and Torere-O Tephra. At Torere West, the Torere-N Tephra rests on a layer of brownish fine sand/silt, and 5 cm of a "dull brown" (7.5YR 5/3) organic-rich silt separates the tephra from the Torere-O Tephra above (see Photo-43).

At Reihana Road, the Torere-N Tephra rests on a 10 cm thick paleosol developed into the Torere-M Tephra.

Chemistry and mineralogy:

The glass from the Torere-N Tephra (Table 10-19) has moderate values for most element oxides, though FeO & CaO are slightly higher than other stratigraphically adjacent tephra; sufficiently different to be useful for correlation purposes.

The Torere-N Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene

Distribution and size:

The Torere-N Tephra is 60 cm thick at Reihana Road, but is only preserved as ≈ 5 cm thick lenses at the coast. That the thickness of these lenses remains constant throughout the coastal area suggests that either the source of this eruption was to the south of Reihana Road rather than to the west, or that its dispersal was towards the east/southeast from a source upwind of Reihana Road. The source and size of the Torere-N Tephra remain uncertain.

10-20 Torere-O Tephra

The Torere-O Tephra has been recognised at several sites in the coastal Bay of Plenty, and also at Reihana Road. It is believed to be the fifteenth tephra deposited in the Torere subgroup, and is equivalent to the Reihana-L Tephra in the Kaingaroa Forest area.

The type section for the Torere-O Tephra is designated to be at Reihana Road, and it is also seen in the coastal eastern Bay of Plenty, at the Torere West, Huntress Creek, Ohiwa Hill, Ohiwa Loop Road, Pukeruru Point and Hiwarau sections. It may also be represented as shards in a reworked—though almost pure—tephra deposit in lacustrine sediments at Opape, and possibly as creamcakes within a paleosol at the Burchett section.

Diagnostic features:

At Reihana Road: (see Photo-40)

- An upper 20 cm thick (including weathering) layer of greenish-yellow sandy ash; overlying:
- A 20 cm bed of coarse pumice lapilli that contains very large obsidian lithics. The pumices are generally 2–3 cm across, and the lithics, though commonly 0.5 cm reach a maximum of 3–4 cm across. This unit overlies:
- A firm, slightly sandy fine ash (7 cm thick); overlying an 11 cm thick bed of reverse graded ash to lapilli (maximum 1 cm across).
- The basal half (60 cm) of the tephra consists of coarse pumice lapilli and blocks. The maximum recorded pumice clast size was 8 cm across; most being 3–4 cm across.

In coastal eastern Bay of Plenty sections: (Photo-43)

- Generally found as an intermittent ash layer (c. 5–10 cm thick) with a slightly coarser layer at the base, occurring within a paleosol developed into weathered tephra/loess. Ash coarsens to granular pumice lapilli towards the west (at some sites only).

Stratigraphic relationships:

The Torere-O Tephra at Reihana Road has a thin (5 cm thick) paleosol weathered into its uppermost sandy ash layer; the Reihana-M Tephra directly overlying this (see Photo-44). In the coastal Bay of Plenty sections, the Reihana-M Tephra is generally not recognised and the Torere-O Tephra lies within the upper part of a weathered tephra/loess paleosol lying between the Kaingaroa and Torere-I Tephra. This paleosol is in total, c. 1–2 m thick. At Ohiwa Loop Road and Torere West the paleosol between the Torere-O and Kaingaroa eruptives has an irregular (erosional?) surface. At the latter site the paleosol is well developed and contains charcoal. At Opape, this period of time is represented by organic-rich sandy silts and peats; the Torere-O Tephra resting on a 6 cm thick layer of peat that contains some wood.

At Reihana Road, the Torere-O Tephra directly overlies the uppermost ash layer of the Torere-N Tephra with only a hint of weathering at the contact. This boundary is sometimes difficult to distinguish,

Table 10-20 : Glass chemistry of the Torere-O Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Opape 01403	78.75 0.26	12.09 0.14	0.12 0.03	1.03 0.08	0.13 0.03	0.91 0.05	#3.11 0.17	3.67 0.17	0.20 0.03	5.45 0.73	10	0.94
Huntress Creek 01521	77.81 0.49	12.36 0.22	0.16 0.06	0.96 0.07	0.12 0.02	0.83 0.07	3.71 0.18	3.84 0.17	0.21 0.04	5.99 1.19	12	0.91*
Torere West **02205	78.45 0.37	12.27 0.23	0.11 0.04	1.00 0.09	0.10 0.02	0.86 0.08	#3.21 0.21	3.91 0.10	0.16 0.06	5.58 1.47	10	1.00
Pukeruru Point 02501	78.99 0.25	11.93 0.16	0.12 0.04	0.99 0.11	0.10 0.02	0.79 0.05	#3.17 0.12	3.78 0.10	0.18 0.04	2.91 0.83	10	0.97
Hiwarau 02714	78.21 0.27	12.51 0.36	0.13 0.04	1.04 0.08	0.11 0.03	0.83 0.06	#3.28 0.09	3.72 0.15	0.17 0.03	4.73 0.97	12	0.95
Reihana Road 06214	78.01 0.41	12.32 0.22	0.14 0.05	1.02 0.06	0.16 0.07	0.81 0.07	3.50 0.13	3.90 0.13	0.20 0.06	5.35 1.58	21	0.90*
Ohiwa Loop Road 08501	78.04 0.39	12.45 0.39	0.16 0.05	1.07 0.13	0.12 0.03	0.86 0.09	3.29 0.17	3.87 0.08	0.15 0.05	4.84 1.74	12	0.93*

but was confirmed using glass chemistry. At Torere West, 5 cm of brownish stained ash separates these two eruptives (Photo-43).

Chemistry and mineralogy:

The glass from the Torere-O Tephra (Table 10-20) has moderate values for most element oxides; with FeO (≈ 1.0 wt.%) $>$ CaO , and $\text{Na}_2\text{O} < \text{K}_2\text{O}$ (≈ 3.8 wt.%). The chemistry of this tephra is identical to that of the Torere-L and Reihana-M Tephra and cannot be distinguished from them. It is likely that these three eruptives originated from the same source; possibly even the same magma batch.

The Torere-O Tephra has a ferromagnesian mineral assemblage consisting of:

- **hypersthene** + hornblende $\pm$ biotite

Distribution and size:

The Torere-O Tephra has identical glass chemistry to the Reihana-M Tephra which lies immediately above, and thus correlations made on chemical grounds alone cannot be 100% certain.

The Torere-O Tephra is 1.2 m thick at Reihana Road, and is generally ≈ 10 cm thick (ranges between 5 cm and 20 cm) at the coast. The very large pumice clasts at Reihana Road (8 cm across), indicate that the source of the tephra must have been nearby, most likely in the Reporoa V.C., or possibly in the southern part of the Okataina V.C.

10-21 Reihana-M Tephra

The Reihana-M Tephra has been positively identified at only one site, at Reihana Road — its type section. It is believed to be the thirteenth and final tephra to be deposited in the Reihana subgroup and lies stratigraphically between the Torere-O and Kaingaroa Tephra.

Diagnostic features: (Photo-44)

- An upper, brown stained sandy ash layer (6 cm thick) with occasional lapilli scattered within it; overlain by a finer grained paleosol 10 cm thick.
- A middle layer of white fine ash (12 cm thick).
- A basal layer containing shower bedded granular pumice lapilli and coarse ash (12 cm thick).

Stratigraphic relationships:

The Reihana-M Tephra at Reihana Road has an irregular upper contact with the Kaingaroa Tephra, with a moderately weathered paleosol (10 cm thick) developed into this erosional surface (see Photo-44; Photo-46). In some places the Reihana-M Tephra has been totally eroded out (see Photo-8).

Table 10-21 : Glass chemistry of the Reihana-M Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Reihana Road	78.65	11.89	0.16	1.05	0.14	0.84	3.39	3.72	0.16	3.69	17	1.00
**06204	0.34	0.28	0.05	0.08	0.03	0.06	0.12	0.13	0.04	1.47		

The Reihana-M Tephra is not seen at Torere West as it is incorporated within the thick, well developed paleosol that occurs here beneath the Kaingaroa Tephra. Burning may have aided paleosol development as small lumps of charcoal are found within it.

The Reihana-M Tephra at Reihana Road, rests on an only slightly weathered layer in the top of the immediately underlying tephra — the Torere-O.

Chemistry and mineralogy:

The glass from the Reihana-M Tephra (Table 10-21) has moderate values for most element oxides; with FeO (≈ 1.0 wt.%) $>$ CaO, and K₂O (≈ 3.8 wt.%) $>$ Na₂O. The chemistry of this tephra is virtually identical to that of the Torere-L and Torere-O Tephtras and cannot be distinguished from them. It is likely that these three tephtras originated from the same source and possibly the same magma batch.

The Reihana-M Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende + biotite

Biotite is not expected in tephtras that contain this little K₂O, but as the mineral is present in greater than trace amounts, and is also present in the Torere-O Tephtra immediately below, it is thought to be of primary origin.

Distribution and size:

The Reihana-M Tephra is only 40 cm thick at Reihana Road, and is not recognised at any other sites — except perhaps at Opape where at the same stratigraphic position there exist pockets of white ash within peats. As this tephra is only found at one section, no conclusions can be made about its size, source, or distribution. Nevertheless, it is believed to have originated from the same magma batch as the Torere-O and Torere-L Tephtras, most likely from the Reporoa or the southern Okataina Volcanic Centres.

Chapter Eleven : Huntress Creek and Welcome Bay subgroups

The Huntress Creek and the Welcome Bay subgroups are combined in this chapter for similar reasons to those used for the combining of the Torere and Reihana subgroups in the previous chapter. The Huntress Creek and the Welcome Bay subgroups are defined in separate areas — each with a slightly different tephrostratigraphy. Several tephtras in each of the subgroups are not found in the other, and the correlations that have been made between the two subgroups are not 100% certain. Rather than the unknown position of an unconformity as in the previous chapter, here there are too many possible correlations. The glass chemistries of the tephtras are too similar to one another for positive identifications using the chemistry alone, and the physical characteristics of the tephtras could not be used because the same tephtras would probably have quite different characteristics in the two widely separated areas.

The Huntress Creek subgroup takes its name from the Huntress Creek section [W15/833472], which is located ≈ 3 km west of Opotiki on Highway-2. This subgroup includes all the deposits that are found in the eastern Bay of Plenty that occur from the base of the Kaingaroa Tephtra (base), up to the base of the Kutarere Tephtra (top).

The Welcome Bay subgroup takes its name from the Welcome Bay section [U14/907820]; a coastal cliff at the base of a Maori pa site, together with a road cutting on the landward side of the pa, located within Tauranga City. This subgroup includes all the deposits found in the Tauranga region that occur between the base of the Waimakariri Ignimbrite eruptives (base), and the base of the Rotoiti Tephtra (top). In age, the Welcome Bay subgroup is believed to span the upper half of the Torere subgroup, and all of the Huntress Creek and Kukumoa subgroups. However, if the indicated correlations from the Torere, Huntress Creek and Kukumoa subgroups are correct, the Welcome Bay subgroup becomes redundant and the other subgroups can be used in the Tauranga region. The Welcome Bay subgroup is useful at present because the correlations to the Tauranga area are tentative, and that two of the units found here are not found in the eastern Bay of Plenty. The stratigraphic positions of the Welcome Bay subgroup tephtras—in relationship to the eastern Bay of Plenty stratigraphy—are still uncertain.

The naming of the tephra in this chapter has been simplified in that only the first word of the subgroup has been used, for example: the Welcome Bay-F becomes Welcome-F, and the Huntress Creek-B becomes Huntress-B.

At present it is believed that the Welcome-C and Welcome-F Tephra are not recognised in the eastern Bay of Plenty, and that the Kaingaroa, Huntress-C and Huntress-E Tephra are not recognised in the west (Tauranga area).

The ages of the Huntress Creek subgroup and the tephra within it have been estimated by fitting the paleoclimatic data gathered from the Bay of Plenty sections to the SPECMAP and the Bassinot LLS $\delta^{18}\text{O}$ records. In the coastal Bay of Plenty, all of the tephra are believed to have been deposited within loess, except the basal Kaingaroa Tephra which rests on a weathered paleosol. At the top of the subgroup, a well developed paleosol has weathered into the loess and incorporated several tephra within it, causing difficulties in distinguishing them. The paleoclimatic data indicates deposition of the Huntress Creek subgroup during a cold glacial climate, probably during $\delta^{18}\text{O}$ stage-8.

The best fit estimates (to the $\delta^{18}\text{O}$ record) give an age range for the Huntress Creek subgroup of 285 ka to 235 ka, with an average of one eruption recorded per 5000 years.

The tephra that occur in the Huntress Creek and Welcome Bay subgroups, and their estimated ages and volumes are: –

Welcome-F	c. 240 ka	0.5 km ³
Huntress-F	c. 245 ka	7 km ³
Huntress-E	c. 250 ka	< 1? km ³
Huntress-D	c. 260 ka	25 km ³
Welcome-C	c. 261 ka	≥ 0.5 km ³
Huntress-C	c. 265 ka	≥ 2 km ³
Huntress-B	c. 275 ka	≥ 5–15 km ³
Kaingaroa (ignimbrite)	c. 285 ka	≥ 100 km ³
Kaingaroa (airfall)	" "	> 20 km ³

A diagram showing the generalised stratigraphy of the Huntress Creek subgroup as found in the eastern Bay of Plenty is presented in Figure 11-1.

The Kaingaroa eruptives are very voluminous, with ≥100 km of flow and >20 km³ of airfall deposits. A possible correlation to the Pokai Ignimbrite could double this volume. The Huntress-D and Huntress-B Tephra are also thought to have moderate to large volumes. If its very tentative correlation to the "Upper Griffins Road Tephra" is correct, the Huntress-C Tephra too would have a large eruptive volume.

Figure 11-1 : Generalised stratigraphy of the Huntress Creek subgroup as found in the eastern Bay of Plenty (see appendix-(M) for key)

Table 11-0 : Similarity coefficients (S.C.'s) comparing representative glass chemistries of Huntress Creek and Welcome Bay subgroup tephra.

<i>oldest</i>		06209	06213	01509	01514	08806	01510	01512	08805a	08805b	08804a
Kaingaroa	06209	1.00									
Kaingaroa (igb)	06213	0.98	1.00								
Huntress-B	01509	0.91	0.92	1.00							
Huntress-C	01514	0.92	0.91	0.93	1.00						
Welcome-C	08806	0.92	0.92	0.89	0.85	1.00					
Huntress-D	01510	0.93	0.94	0.92	0.89	0.94	1.00				
Huntress-E	01512	0.94	0.93	0.93	0.89	0.95	0.96	1.00			
Huntress-F(a)	08805a	0.93	0.92	0.92	0.87	0.95	0.94	0.92	1.00		
Huntress-F(b)	08805b	0.82	0.82	0.85	0.85	0.77	0.80	0.81	0.79	1.00	
Welcome-F(a)	08804a	0.95	0.95	0.91	0.87	0.95	0.95	0.80	0.91	0.91	1.00
<i>youngest</i>

Figure 11-3 : Comparison between the Huntress Creek and Hiwarau sections of the means and standard deviations (1 s.d.) of glass analyses on the Huntress Creek subgroup tephra

The Kaingaroa Tephra was erupted from the Reporoa Volcanic Centre [Nairn *et al.*, 1994], but the Huntress-D, Huntress-E and Huntress-B Tephtras, although they have a similar glass chemistry, are thought more likely to have been erupted from the Okataina Volcanic Centre. This is based on their coarse clast-size and great thickness in the eastern Bay of Plenty, which suggests that they were erupted from a closer, more northerly source than Reporoa.

Because their glass chemistries are similar to that of the Mamaku Ignimbrite, the Welcome-F, Huntress-F and Welcome-C Tephtras are thought to have originated from the same source — the Rotorua Volcanic Centre.

The tephtras within both of the subgroups generally have quite similar glass chemistries, suggesting perhaps that they may have erupted from the same source. The Huntress-C and Welcome-C Tephtras are the only deposits able to be distinguished by their glass chemistries alone (see Figure 11-2).

Figure 11-2 : Plot of the means of glass analyses from the Huntress Creek and Welcome Bay subgroup tephtras — relative proportions of selected elemental-oxides

A secondary component present in three of these tephtras is believed to represent country-rock contamination from the Chimp Ignimbrite (Reihana-G Tephra).

Similarity coefficients that compare the glass chemistry of all the tephtras in the Huntress Creek and Welcome Bay subgroups are presented in Table 11-0.

Figure 11-4 : Stratigraphy of the Huntress Creek subgroup along the Bay of Plenty coast (see appendix-(M) for key)

The best sites to view the stratigraphy of the Huntress Creek subgroup is at the Huntress Creek and the Hiwarau sections (Photo-45; Photo-4 & 4(a)), where most of the units from both subgroups can be recognised. The physical characteristics are consistent at both these two sites for each tephra (in the Huntress Creek subgroup), allowing confident correlations despite the difficulty in distinguishing the eruptives via their glass chemistry (see Figure 11-3).

The best site to view the stratigraphy of the Welcome Bay subgroup is at Welcome Bay, where only the Kaingaroa, Huntress-C and Huntress-E Tephra are not recognised. The physical characteristics at this site are significantly different to those in the eastern Bay of Plenty.

Two other sites where the deposits in these two subgroups are well exposed are the Ohiwa Loop Road and Omokoroa East sections. The Huntress Creek subgroup is also believed to exist in its entirety at the Hillview section, but this site is very weathered and the tephra difficult to identify. The Hillview section was not studied in detail, but the nearby Ohiwa Hill section contains the basal two tephra in the Huntress Creek subgroup in their unweathered condition. The entire subgroup is also thought to be present at the Opape section, but here the deposits are generally extremely weathered, and some may also have been deposited in a subaqueous environment.

The Little Waihi section is also believed to contain deposits of this age, here deposited in a fluvial environment, but the correlations to this site are still tentative.

Figure 11-4 shows variations in the thickness and exposure of the Huntress Creek and Welcome Bay subgroup across the coastal Bay of Plenty. Correlations between sites are marked.

The eight tephra known to exist in the Huntress Creek and Welcome Bay subgroups (not including the Waimakariri Ignimbrite – Reihana-G Tephra; see sect. 10-14) are presented in the following pages in stratigraphic order of deposition (from oldest to youngest).

11-1 Kaingaroa Tephra

The Kaingaroa Tephra in the eastern Bay of Plenty represents the airfall component of the very large Kaingaroa Ignimbrite eruption. This eruption produced a welded ignimbrite that covered a large area of the Kaingaroa Plateau ($>500 \text{ km}^2$) — situated to the east of the T.V.Z. (see Figure 1-3) — and has an estimated volume of 100 km^3 [Nairn, 1989b]. As the ignimbrite is such an important and widespread deposit, the airfall tephra associated with it becomes an important stratigraphic marker wherever it is found.

The Kaingaroa Tephra is the basal unit in the Huntress Creek subgroup, and it is recognised at several sites in the eastern Bay of Plenty.

The type section for the Kaingaroa Tephra is at Reihana Road in the Waiotapu Forest, 35 km south of Rotorua. Here the tephra both underlies and is intercalated with surge deposits and basal Kaingaroa Ignimbrite flow.

Good reference sections for the Kaingaroa Tephra in the eastern Bay of Plenty can be found at Huntress Creek, Hiwarau, Ohiwa Loop Road and Ohiwa Hill. The tephra is also seen at the Torere West, Opape and Burchett sections east of Opotiki. The Welcome-B Tephra, found near Tauranga, is a possible correlative of the Kaingaroa Tephra (although more likely the Huntress-B Tephra); as also might be a weathered tephra near the base of the Rocky Cutting Road section.

Diagnostic features:

At the type section at Reihana: (see Photo-46)

- Generally well bedded, especially at base (decimetre-bedded); with ash being dominant throughout and occasional lines, lenses and/or layers of pumice lapilli intercalated within it.
- Near the base there are several fine ash beds containing abundant large (>2 cm) accretionary lapilli or pisolites (Photo-48).
- A pyroclastic flow (>3 m thick) is intercalated within the top half of airfall tephra sequence. On the basis of some slight pinching and swelling of the beds, surge deposits are thought to occur just above the flow unit.

In the eastern Bay of Plenty: (see Photo-47)

- Shower bedded ash at top — unless included within a paleosol.
- Three or four layers (each generally 30 cm thick) of generally reverse graded granular pumice lapilli (1 cm across maximum, 0.5 cm across common); separated by layers of fine ash (5-10 cm thick).
- Basal 20 cm consists of shower bedded (cm-bedding) ash.

The Kaingaroa Ignimbrite has previously been mapped as three separate flow sheets; from the base up they are — kg-1a, kg-1b and kg-2 [Nairn, 1981].

- kg-1a consists of a "non-welded grey-brown ash and pumice breccia containing abundant low-silica andesite xenoliths" [Nairn, 1981]. The kg-1a unit appears to be at least 50 m thick at the type locality for the lower members — "three miles south-east of Lake Rotowhero on the Rotorua-Murupara Road". The kg-1a breccia appears to have infilled valleys eroded into the underlying Onuku Pyroclastics [Nairn, 1989b] and is not present in areas where the Onuku Pyroclastics have not been eroded. Here, the kg-1b flow member directly overlies the Onuku Pyroclastics.
- kg-1b consists of "lightly welded, dark grey to black pumice tuff, containing light grey pumice fragments" [Martin, 1961]. This flow unit is commonly referred to as the "sandy black" member.

- kg-2 is a "fine-textured, pinkish welded vitric tuff containing sparse relict pumice lenticules" [Martin, 1961]. This upper flow member is lighter in colour and more strongly welded than the lower members.

A fourth flow unit may also be present at Reihana Road, where a pyroclastic flow (≥ 3 m thick) exists conformably within the top half of the airfall tephra sequence. This may be a fourth separate flow, or a correlative of kg-1a. If it is a previously unrecognised flow unit, its stratigraphic relationship to the kg-1a member is still unknown. The proper naming of this new member should therefore wait until its stratigraphic position is better ascertained, though an informal classification of kg-1c may be used.

The kg-1c flow member seems to be of limited thickness and therefore probably of limited distribution, and may not be recognised at many other sites.

- All of the Kaingaroa Ignimbrite flow members are quartz poor and phenocryst poor (<10%) [Nairn, 1981].
- The Kaingaroa Ignimbrites are characterised by the presence of "plagioclase–pyroxene andesite xenoliths which occur throughout the deposit, but most abundantly in the basal breccia" [Nairn, 1981].

Stratigraphic relationships:

The upper contact of airfall Kaingaroa Tephra at the type section is conformable with the unwelded base of the Kaingaroa Ignimbrite. In the eastern Bay of Plenty, the upper part of the Kaingaroa Tephra generally has weak paleosol development (Photo-47), and is overlain by loess that is occasionally also weathered.

The lower contact of the Kaingaroa Tephra at the type section is sharp, and in some places erosion of the underlying tephra beds has taken place. Where no erosion has occurred, the Kaingaroa Tephra rests directly upon a paleosol developed into the much thinner Reihana-M Tephra below. In the eastern Bay of Plenty the Kaingaroa Tephra overlies a paleosol developed into generally undifferentiated weathered tephra and coarse tephric loess. At some sites (e.g. Hiwarau) the boundary is irregular due to erosion of the soil surface and/or bioturbation in the upper part of the paleosol. At the Torere West section there exists a well developed paleosol into the tephra below. This paleosol has small pieces of charcoal scattered through it.

Near Tauranga, the Welcome-B Tephra (a possible correlative of the Kaingaroa) is overlain by weathered loess, and generally overlies fluvially reworked ash and lapilli from the Waimakariri Ignimbrite eruptives (see sect. 10-13).

Table 11-1.1 : Glass chemistry of the Kaingaroa Ignimbrite.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Old Waiotapu Rd 06101	78.42 0.15	11.98 0.08	0.14 0.03	1.15 0.10	0.10 0.02	0.84 0.05	#3.47 0.10	3.74 0.11	0.17 0.03	0.76 0.46	11	0.97
Old Waiotapu Rd 06103	78.38 0.13	12.10 0.05	0.14 0.03	1.19 0.07	0.09 0.02	0.81 0.06	#3.38 0.03	3.73 0.14	0.18 0.02	2.68 0.52	4	0.91*
Old Waiotapu Rd 06102	78.04 0.05	12.09 0.17	0.16 0.04	1.23 0.07	0.11 0.01	0.93 0.05	3.46 0.09	3.79 0.10	0.19 0.01	2.41 1.26	3	0.94
Reihana Road 06201	77.19 0.32	12.57 0.10	0.21 0.07	1.36 0.08	0.12 0.04	0.88 0.09	3.79 0.16	3.67 0.12	0.20 0.05	3.12 1.00	9	0.95
Onuku-(3) 09901	77.80 0.19	12.36 0.12	0.18 0.04	1.26 0.14	0.14 0.03	0.83 0.07	3.16 0.12	4.07 0.09	0.23 0.04	3.31 0.45	10	0.95
Reihana Road **06213	77.65 0.27	12.21 0.16	0.19 0.07	1.21 0.19	0.12 0.02	0.83 0.09	3.67 0.08	3.86 0.17	0.27 0.05	6.16 1.18	7	1.00
\$—\$ (Froggatt)	77.97 0.27	12.42 0.16	0.11 0.03	1.26 0.04	— -- 0.05	0.88 0.08	3.81 0.08	3.40 0.23	— -- 0.23	3.18 0.54	?	0.90*

\$—\$ = Kaingaroa Ignimbrite glass chemistry [pers.comm. Paul Froggatt in Sumosusastro, 1983]

Table 11-1.2 : Glass chemistry of the airfall Kaingaroa Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Opape 01402	78.76 0.28	12.01 0.19	0.10 0.02	1.14 0.05	0.10 0.02	0.89 0.07	3.30 0.16	3.57 0.12	0.17 0.03	3.30 0.75	14	0.89
Opape 01413	77.46 0.31	12.66 0.12	0.17 0.04	1.06 0.14	0.14 0.04	0.84 0.07	3.86 0.13	3.63 0.16	0.21 0.06	4.16 0.66	11	0.95
Huntress Creek 01519	77.87 0.47	12.39 0.27	0.18 0.04	1.19 0.07	0.13 0.04	0.92 0.08	3.50 0.15	3.62 0.20	0.20 0.05	5.40 0.89	9	0.96
Ohiwa Hill 01707	77.77 0.34	12.39 0.19	0.19 0.05	1.18 0.14	0.13 0.03	0.95 0.08	3.44 0.18	3.76 0.10	0.22 0.05	5.75 1.39	14	0.96
Torere 02214	77.98 0.30	12.62 0.12	0.19 0.06	1.17 0.08	0.14 0.02	0.83 0.07	3.36 0.14	3.53 0.14	0.18 0.04	4.35 1.33	11	0.95
Hiwarau 02716	78.18 0.44	12.36 0.39	0.16 0.05	1.24 0.09	0.11 0.03	0.88 0.06	3.26 0.20	3.64 0.11	0.17 0.04	5.07 0.80	13	0.94
Reihana Road† **06209	77.58 0.40	12.38 0.44	0.19 0.04	1.15 0.06	0.12 0.02	0.87 0.07	3.81 0.13	3.72 0.12	0.19 0.05	4.08 1.31	12	1.00
Ohiwa Loop Road 08506	77.41 0.37	12.50 0.23	0.17 0.05	1.22 0.10	0.11 0.03	0.85 0.05	3.73 0.18	3.79 0.13	0.22 0.05	6.17 1.12	13	0.96

† = pre-ignimbrite airfall (plinian – phreatoplinian)

Table 11-1.3 : Glass chemistry of possible correlatives of the Kaingaroa Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 06209
Ngatiawa lookout 04304	78.16 0.35	12.20 0.13	0.18 0.04	1.07 0.13	0.11 0.04	0.87 0.07	3.45 0.17	3.75 0.22	0.23 0.09	7.05 0.98	11	0.96
Welcome Bay 08802	77.60 0.23	12.44 0.16	0.20 0.09	1.20 0.08	0.16 0.04	0.92 0.07	3.72 0.11	3.54 0.12	0.24 0.04	6.96 0.95	10	0.94
Rocky Cutting Rd. **09003	78.20 0.28	12.12 0.16	0.21 0.04	1.18 0.13	0.13 0.02	0.92 0.08	3.47 0.18	3.52 0.14	0.25 0.06	7.03 0.92	12	0.95

Chemistry and mineralogy:

The glass chemistry of the Kaingaroa Ignimbrite and airfall tephra (Tables 11-1.1 & 11-1.2) is not particularly distinctive and shows only subtle differences from several other tephras in the Huntress Creek subgroup. It is similar also to several eruptives occurring near the top of the underlying Torere/Reihana subgroups (e.g. Torere-L, Torere-O, Reihana-M Tephras). It is likely that many of these tephras were erupted from the same source.

The glass chemistry of the Kaingaroa Ignimbrite (Table 11-1.1) shows quite a large variation in FeO wt.% values, which causes some problems with correlations based solely on chemical techniques.

The samples of Kaingaroa Ignimbrite from Old Waiotapu Road are of kg-1 (not certain if kg-1a or kg-1b). Sample 06103 is of a group of selected pumice clasts crushed together; 06102 is of the matrix only (63µm–250 µm); and 06101 is a crushed bulk sample. At Reihana Road, sample 06201 is probably of kg-1a, and 06213 is of kg-1c. Sample 09901 is of unwelded kg-1b ignimbrite, taken from about 5 m below the welded region.

The sample from Reihana Road (06209) is of phreatomagmatic pre-ignimbrite airfall, whereas the other samples in Table 11-1.2 are likely to also contain post- and co-ignimbrite airfall. The samples from Opape (01413 & 01402), taken from near the base and halfway up through the deposit respectively, are both reworked tephric-sediment deposited in a lacustrine paleoenvironment during flood events that probably immediately followed the Kaingaroa eruption. The relatively low FeO contents for the lower sample (01413) suggests a possible correlation to the Torere-O Tephra, but this tephra is more likely to correlate with another tephric deposit just below (sample 01403).

The samples in Table 11-1.3 (from Welcome Bay, Rocky Cutting Road and Ngatiawa lookout) are all thought to be possible correlatives to the Kaingaroa Tephra because of their similar glass chemistries in conjunction with their believed similar stratigraphic positions. However, they may instead be correlatives of the Huntress-B Tephra, or any one of a number of tephras which have a similar chemistry and stratigraphic position (see discussion).

The Kaingaroa Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende ± augite(t) ± biotite (t)

Pyroxene has previously been recorded as the dominant mafic mineral in the Kaingaroa Ignimbrites [Martin, 1961].

Distribution and size:

The Kaingaroa Tephra is voluminous and widespread. At the type section the airfall tephra is >13 m thick, not including 3 m of material which may be surge deposits and ≥3 m of an intercalated pyroclastic flow. The great thickness of airfall material and the presence of surge deposits indicates that the source of the eruption was nearby. The southern edge of the Okataina Volcanic Centre is only ≈10 km to the north, but the edge of the Reporoa caldera is directly to the west and southwest, and this latter

centre is now believed to be the source area [Nairn *et al.*, 1994]. The bulk of the Kaingaroa Ignimbrite is found to the southeast of the type section [Healy *et al.*, 1964], but outcrops are also seen within the Okataina Volcanic Centre (in the Puhipuhi Basin) and to the northeast near Kawerau [Nairn, 1981].

Much of the Kaingaroa airfall material consists of fine-grained ash which does not vary in particle size from site to site and is therefore not particularly useful in determining distribution patterns.

Not enough sections are available to construct detailed isopach maps, but if the ash was preferentially deposited in the coastal eastern Bay of Plenty (i.e. a southwesterly paleo-wind), a minimum eruptive volume of $\approx 20 \text{ km}^3$ can be estimated for the airfall Kaingaroa Tephra; its true volume though is likely to be significantly greater.

The Kaingaroa Tephra has been tentatively identified (via glass chemistry) in deep-sea cores RC12-215 and RC9-114, 1500 km east-northeast, and RC9-110, 1200 km east-southeast of New Zealand's Taupo Volcanic Zone (Table 2-5) [Froggatt, 1983; Watkins & Huang, 1977]. The "Upper Griffins Road Tephra" in the Wanganui Basin has been correlated to the Kaingaroa Tephra via its similar glass chemistry and stratigraphic position [Froggatt, 1983], though this worker believes that the "Middle Griffin Road Tephra" is a closer chemical match. If either of these correlations is correct, the Kaingaroa Tephra would have been much more widespread and voluminous than the estimate calculated above, and a volume in the order of 50 km^3 is more realistic.

The volume of the Kaingaroa Ignimbrite has been estimated at 100 km^3 [Nairn, 1989b], but if the Pokai Ignimbrite is a correlative of the Kaingaroa (see discussion), the size of the eruption is greatly increased. The Pokai Ignimbrite has an estimated volume of 100 km^3 [Houghton *et al.*, 1991] (Table 2-2) and therefore the Kaingaroa/Pokai Ignimbrite may have a volume of $>200 \text{ km}^3$ and the total volume of eruptives from the Kaingaroa eruption in the order of $250\text{--}300 \text{ km}^3$. However, there is not yet enough data to determine if there was one large eruption of this chemical composition, or if there were several smaller eruptions. The Huntress-D and Huntress-B Tephrae are also possible correlatives of the Pokai Ignimbrite, and more work is required — especially in the chemical and dating fields — to obtain a more complete understanding of the volcanic history of this period.

Discussion:

The Kaingaroa eruption, occurring in the Reporoa Volcanic Centre at *c.* 0.28–0.29 Ma (see Chapter 15), produced $>100 \text{ km}^3$ of ignimbrite and $30\text{--}60 \text{ km}^3$ of airfall tephra. The basal part of the Kaingaroa Tephra near source is very fine and contains large accretionary lapilli or pisolites (Photo-48). Pisolites were also seen in the Northern Boundary Road-1 stratigraphic drill-hole core, at a level just below the base of the Kaingaroa Ignimbrite [Nairn, 1984]. Accretionary lapilli are generally recognised as being the product of phreatomagmatic eruptions [Self & Sparks, 1978], as are base surges which are also present in the near-source Kaingaroa Tephra (at Reihana Road). The volume of the Kaingaroa Tephra places the style of eruption into the "phreato-plinian" category. The usual source of the water involved in phreato-plinian eruptions are caldera lakes, and hence the existence of a pre-Kaingaroa caldera is postulated here.

Several tephra in the underlying Reihana subgroup have similar glass chemistries to the Kaingaroa eruptives. These tephra — the Torere-L, Torere-O and Reihana-M — are possible progenitors of this caldera, although no ignimbrite deposits are known to be associated with them.

The Welcome-A Tephra near Tauranga (Waimakariri Ignimbrite) is believed to correlate to the Reihana-G Tephra which was probably erupted only 10–20 ka before the Kaingaroa. The Welcome-B Tephra overlies fluvial deposits that were almost certainly derived and reworked from the underlying Waimakariri Ignimbrite. It therefore has a similar stratigraphic position as the Kaingaroa Tephra. The Welcome-B and Kaingaroa Tephra are not believed to be correlatives though, chiefly because the grain-size of the Welcome-B Tephra appears to be too coarse. It is more likely that the Welcome-B is instead a correlative of the Huntress-B Tephra, although more detailed work is required to confirm this.

The Rocky Cutting Road section is extremely weathered and poorly understood. A tephra near the base of the section has a similar glass chemistry to the Kaingaroa eruptives, but is similar also to many other tephra within the Huntress Creek subgroup and therefore it cannot be positively identified.

A thick tephra at the Ngatiawa lookout section is found in a similar stratigraphic position as the Kaingaroa Tephra. However, the tephra here has suffered from severe, though patchy, weathering, and only vague physical characteristics can be recognised — not enough to positively identify the unit as Kaingaroa.

The Kaingaroa Tephra is widespread throughout the Bay of Plenty and is a useful stratigraphic marker bed. The well bedded basal ash layers of this tephra in the eastern Bay of Plenty, are similar in appearance to the basal layers of the Rotoiti Tephra where it is exposed in fresh sections, and so care must be taken to identify the stratigraphically adjacent tephra as well to avoid misidentification.

A plinian airfall deposit was reported to underlie the upper Kaingaroa Ignimbrite (kg-2) [Wilson *et al.*, 1984] and may explain why the upper half of the Kaingaroa Tephra contains larger clasts than expected from the fine grained nature of the phreatomagmatic deposits at the type section. Alternatively, this plinian airfall, and hence the kg-2 pyroclastic flow, may be represented in the coastal Bay of Plenty region by the Huntress-B Tephra — which has a similar glass chemistry.

The Pokai Ignimbrite, found in the southern Mamaku Plateau southwest of Rotorua, may possibly be a correlative of the Kaingaroa Ignimbrite. The Pokai Ignimbrite lies between the Mamaku and Whakamaru Ignimbrites, more specifically between the Mamaku and Chimp Ignimbrites [Keiller, 1987]. The stratigraphic position of the Pokai and Kaingaroa Ignimbrites are therefore very similar. Keiller [1987] also reports that the airfall tephra beneath the Pokai Ignimbrite generally consists of plinian pumice with many thin, fine ash beds interspersed within it. He concluded that the finer beds were "rain-flushed" ash. Accretionary lapilli were also seen immediately below the ignimbrite at one site (Waituna Road). The Pokai Ignimbrite consists of three flow units which cooled as one unit [Keiller, 1987], and the upper part has a dark grey ash matrix suggesting a possible correlation to the "sandy black" (kg-1b) flow member of the Kaingaroa Ignimbrite. The Pokai Ignimbrite is up to 60 m thick in the southern Mamaku Plateau area, though rapid thinning towards the west indicates that the western limit to its

Table 11-1.4 : Glass chemistry of the Pokai Ignimbrite.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 06213
Downer Road 10302	78.12 0.30	12.36 0.21	0.11 0.04	1.19 0.12	0.09 0.03	0.73 0.07	3.49 0.08	3.73 0.15	0.20 0.05	5.76 1.10	10	0.89
Tikorangi Road 10401	78.15 0.15	12.66 0.13	0.16 0.04	1.44 0.13	0.12 0.03	0.90 0.08	2.59 0.15	3.75 0.15	0.24 0.06	6.04 0.69	10	0.90

(see discussion in section 11-1)

distribution is in the Tokoroa area. A source to the northeast of this area was tentatively suggested for the Pokai Ignimbrite (Kapenga V.C. or Rotorua V.C.) [Keiller, 1987]; inferred from the thickening of the pre-ignimbrite airfall deposit in this direction. However, the possibility of erosion at the base of the ignimbrite was not discussed and a Reporoa source cannot, as yet, be dismissed.

The glass chemistry of a sample taken from the lower part of the Pokai Ignimbrite at Downer Road matches that of the Kaingaroa Tephra reasonably well (Table 11-1.4), but the chemistry of a sample of the upper part of the Pokai Ignimbrite taken from Tikorangi Road is somewhat different. Either, one of the two exposures is not of Pokai Ignimbrite, or there is a large variation in the FeO content up through the ignimbrite from base to top; or some form of chemical alteration has occurred in the ignimbrite exposed at the Tikorangi Road site. This latter scenario is the more likely as the sample from Tikorangi Road has unusually low wt.% values of Na₂O compared with the other tephras in this study; but the other factors may also have an effect. The Kaingaroa Ignimbrite at Reihana Road also shows some variability in its glass chemistry. In particular, sample 06201 (kg-1a?) has a much higher FeO wt.% than the underlying kg-1c unit (sample 06213).

If one of the ignimbrites analysed from the Mamaku Plateau is not the Pokai, it may be that either; there is another previously unknown ignimbrite—at Tikorangi; or that the Kaingaroa rather than the Pokai is exposed at Downer Road. This latter scenario would still greatly increase the range of the Kaingaroa Ignimbrite.

The ferromagnesian mineral assemblage of the Pokai Ignimbrite is also similar to that of the Kaingaroa, with hypersthene much more abundant than hornblende.

11-2 Huntress-B Tephra

The Huntress-B Tephra is believed to be the second eruptive deposited in the Huntress Creek subgroup. Its full distribution is unknown as it is only positively identified at a few sites in the eastern Bay of Plenty. The Huntress-B Tephra is the most likely—though not 100 % certain—correlative of the Welcome-B Tephra found in the western Bay of Plenty, and the two units are discussed below as if they were the same.

The type section for the Huntress-B Tephra is at Huntress Creek, though it is also well represented at the Hiwarau section. The tephra has also been recorded at the Ohiwa Loop Road, Ohiwa Hill and Opape sections, and may be present within fluvial sediments at Little Waihi. If the correlation to this latter site is correct, then it is at its thickest here.

The Welcome-B Tephra, which occurs in sections near Tauranga, is believed to be a correlative of the Huntress-B Tephra on the basis of its chemical and stratigraphic similarities. Correlations to this area from the eastern Bay of Plenty are still tentative, but as the Welcome-B Tephra consists of coarse sandy ash it is not thought to be a correlative of the Kaingaroa Tephra — which is generally much finer grained (ash-rich). A weathered tephra near the base of the Rocky Cutting Road section is another possible

correlative of the Welcome-B tephra, but this correlation (see Chapter 13) is even more tentative than that above.

Diagnostic features:

In the eastern Bay of Plenty: (see Photo-49)

- Top consists of ≈ 50 cm of white pumice lapilli (pumice up to 1 cm across); separated by a thin ash layer from the coarser grained middle layer below.
- Middle layer consists of ≈ 30 cm of coarse white pumice lapilli — up to 2 cm across.
- Basal layer consisting of ≈ 15 cm of reverse graded fine ash to coarse ash.
- Overall impression is of a slightly reverse graded blue-white pumice lapilli tephra.

At Little Waihi

- A 2 m thick layer of reverse graded, white pumice lapilli which appears to be of airfall origin — rather than the fluvial origin of the enclosing sediments.

In sections near Tauranga:

- The Welcome-B Tephra exists as 30 cm of a yellowish coarse sandy ash; and containing a paleosol in its upper half (at Welcome Bay).
- At Rocky Cutting Road, a tentative correlative occurs as a very weathered sandy tephra.

Stratigraphic relationships:

The top of the Huntress-B Tephra at Hiwarau is weakly weathered (Photo-49); and loess immediately overlies it. At Ohiwa Loop Road, the uppermost pumices of the Huntress-B Tephra are brown in colour (organic staining?), and the weathered Huntress-D Tephra directly overlies it; the Huntress-C Tephra not recognised here. The upper contact of the Huntress-B Tephra at Huntress Creek is relatively sharp; with loess directly overlying unweathered pumice.

Around Tauranga Harbour, the top half of the Welcome-B Tephra is weathered and grades into weathered loess above. The loess appears to lighten upwards becoming less weathered in the younging direction.

The lower contact of the Huntress-B Tephra is generally sharp. At Huntress Creek the tephra overlies a paleosol developed into loess (Photo-47); at Ohiwa Loop Road it overlies loess that contains flecks of pumice and weathered tephra; and at Hiwarau there is an irregular erosional boundary separating the Huntress-B Tephra from the paleosol developed into the Kaingaroa Tephra below. Loess may have been deposited here originally but was subsequently eroded before the emplacement of the Huntress-B Tephra.

The Welcome-B Tephra at both Omokoroa East and Welcome Bay overlies a paleosol developed into weathered tephra or tephric-sediment.

Table 11-2.1 : Glass chemistry of the Huntress-B Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Huntress Creek	78.08	12.18	0.16	1.28	0.14	0.99	3.65	3.34	0.18	2.92	12	1.00
**01509	0.48	0.23	0.04	0.08	0.04	0.08	0.20	0.16	0.04	1.71		
Hiwarau	77.76	12.72	0.20	1.27	0.12	1.02	3.29	3.43	0.20	4.80	11	0.93
02715	0.27	0.29	0.06	0.12	0.04	0.07	0.12	0.17	0.03	1.40		
Ohiwa Loop Road	77.69	12.49	0.13	1.27	0.12	0.92	3.66	3.54	0.21	5.58	16	0.94
08504	0.32	0.22	0.04	0.10	0.04	0.10	0.19	0.21	0.04	1.05		
Huntress Creek	78.32	12.03	0.11	1.02	0.11	0.79	3.62	3.82	0.18	3.56	2	0.86
01509b	0.04	0.11	0.01	0.01	0.04	0.01	0.10	0.06	0.04	0.33		

Table 11-2.2 : Glass chemistry of suspected correlatives of the Huntress-B Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Little Waihi	78.43	12.26	0.12	1.14	0.10	0.91	#3.27	3.63	0.15	3.45	19	0.88*
03102	0.29	0.19	0.03	0.09	0.03	0.08	0.16	0.12	0.04	0.70		
Welcome Bay	77.60	12.44	0.20	1.20	0.16	0.92	3.72	3.54	0.24	6.96	10	0.93
08802	0.23	0.16	0.09	0.08	0.04	0.07	0.11	0.12	0.04	0.95		
Rocky Cutting Rd.	78.20	12.12	0.21	1.18	0.13	0.92	3.47	3.52	0.25	7.03	12	0.93
09003	0.28	0.16	0.04	0.13	0.02	0.08	0.18	0.14	0.06	0.92		
Welcome Bay	77.78	12.30	0.17	1.03	0.16	0.75	3.74	3.86	0.21	8.81	4	0.90
08802b	0.32	0.20	0.04	0.08	0.05	0.06	0.20	0.13	0.03	1.11		

The reverse graded pumice layer at Little Waihi directly overlies bedded fluvial pumice blocks and tephric sand, and has an erosional boundary cut into its top.

The tentative correlative of the Huntress-B Tephra at Rocky Cutting Road is enclosed within loess.

Chemistry and mineralogy:

The glass chemistry of the Huntress-B Tephra (Table 11-2.1) shows only subtle differences from several other tephra in the Huntress Creek subgroup. It has a lower FeO content than the Huntress-C Tephra; higher FeO & CaO than the Welcome-C Tephra; and higher CaO than the Huntress-D, Huntress-E and Kaingaroa Tephra. In several samples there is a secondary glass chemistry, which has much lower values of FeO & CaO.

Table 11-2.2 shows the glass chemistry of possible correlatives of the Huntress-B Tephra. Samples 01407, 01509, 02715 and 08802 are from crushed total bulk-rock, while samples 03102 and 08504 are from crushed selected pumices. The latter two samples do not show any mixture of chemistry, suggesting that the secondary component consists of finer particles than those of the dominant component.

The Huntress-B Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende $\pm$ biotite(t)

Distribution and size:

Since there are only a few sites where the Huntress-B Tephra is recognised, detailed isopach maps cannot be constructed. The chemistry of the Huntress-B Tephra is similar to that of the majority of tephra in the Huntress Creek subgroup, indicating the likelihood that many of these eruptives originated from the same source area. The coarse grain-size and thickness of the tephra (generally >1 m in the eastern Bay of Plenty) indicate a northern T.V.Z. source.

The proportion of the secondary component in the Huntress-B Tephra appears to increase towards the west, possibly indicating a westwards dispersal and/or a more western source within the T.V.Z. for this component. On the basis of its glass chemistry, a Rotorua source is proposed for this minor component of the Huntress-B Tephra. It is likely that this component was only a small eruption but no volume estimates have been attempted. The volume listed (on page 213) is in that of the composite tephra.

Discussion:

The Huntress-B Tephra was erupted at c. 0.27–0.28 Ma and was of at least moderate size (see Chapter 15). Its physical characteristics are similar to the "recent" Mangaone Tephra, although with less pronounced reverse grading.

The Huntress-B Tephra may be a correlative of a plinian airfall deposit and associated ignimbrite (kg-2) from the Reporoa V.C., and if so represents a very large eruption. Much more work is required before this possible correlation could be confirmed.

Table 11-3 : Glass chemistry of the Huntress-C Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Huntress Creek	78.07	12.56	0.20	1.35	0.13	0.99	3.10	3.45	0.17	6.38	10	1.00
**01514	0.52	0.32	0.07	0.09	0.05	0.09	0.13	0.12	0.03	0.67		
Hiwarau	77.43	12.83	0.18	1.37	0.13	0.94	3.53	3.42	0.18	4.97	12	0.96
02711	0.49	0.25	0.08	0.14	0.04	0.14	0.13	0.18	0.03	0.80		

The secondary component within the Huntress-B Tephra deposit may be the first recognition of activity at the Rotorua Volcanic Centre.

11-3 Huntress-C Tephra

The Huntress-C Tephra is believed to be the third tephra deposited in the Huntress Creek subgroup, and probably has a limited distribution, with a moderate to small volume.

The type section for the Huntress-C Tephra is designated to be at Hiwarau, though it is also well represented at Huntress Creek. The tephra is not recognised at any other localities.

At both sites where it is recognised, the Huntress-C Tephra exists within loess and has sharp contacts with 25–30 cm of loess above, and 20–40 cm of loess below (see Photo-50).

Diagnostic features:

- Consists of a coarse ash layer, 7–10 cm thick, occurring near the middle of a 0.5–0.75 m thick unweathered loess unit. The tephra itself is not distinct, but in the coastal eastern Bay of Plenty there are relatively few unweathered loess layers enclosing entire tephra units (see Photo-51).
- The tephra has a moderately distinctive glass chemistry.

Chemistry and mineralogy:

The glass chemistry of the Huntress-C Tephra (Table 11-3) has a higher FeO content than the tephtras stratigraphically above and below; and above average for the tephtras in this study. Its wt.% FeO is distinctively much higher than its wt.% CaO ($1.4 \gg 1.0$), and the FeO/CaO ratio is one of the better guides for correlating the Huntress Creek subgroup from site to site.

The Huntress-C Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene

Distribution and size:

The Huntress-C Tephra has been positively identified at only two sites in the eastern Bay of Plenty, and it is not recognised in the Tauranga area. Therefore the paleo-wind direction during its eruption was probably from the west or the north.

The "Upper Griffins Road Tephra"—which is found in the Wanganui Basin far to the south—has a similar glass chemistry to the Huntress-C Tephra. The stratigraphic positions of these two tephra deposits are also believed to be similar. If this very tentative correlation is correct, then the thin Huntress-C Tephra in the coastal eastern Bay of Plenty is not representative of the true size of the eruption. A southerly dispersal of a moderately voluminous eruptive is possible.

Table 11-4 : Glass chemistry of the Welcome-C Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	#Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Little Waihi	78.89	11.94	0.12	1.05	0.09	0.67	#3.35	3.72	0.20	6.45	11	0.93*
03104	0.31	0.10	0.03	0.06	0.02	0.03	0.22	0.10	0.05	0.58		
Omokoroa East	77.71	12.22	0.15	1.13	0.09	0.72	3.82	3.92	0.23	4.74	12	0.97
08702	0.36	0.24	0.06	0.10	0.02	0.06	0.16	0.14	0.05	1.54		
Welcome Bay	77.93	12.34	0.15	1.09	0.10	0.74	3.71	3.76	0.20	5.87	24	1.00
**08806	0.31	0.22	0.05	0.07	0.04	0.05	0.17	0.15	0.03	1.72		

11-4 Welcome-C Tephra

The Welcome-C Tephra is believed to be the third eruptive deposited in the Welcome Bay subgroup and has not been recognised in the eastern Bay of Plenty. Stratigraphically it is thought to lie between the Huntress-C and Huntress-D Tephrae.

The type section for the Welcome-C Tephra is designated to be at Omokoroa East. It is also well represented at the Welcome Bay section, and is exposed as a fine ash layer deposited in a fluvial sequence at Little Waihi.

The physical characteristics of the Welcome-C Tephra in the Tauranga area are:

- Upper part consists of a light grey ash; 20–40 cm thick.
- Basal beds consist of pale fine ash; 10–15 cm thick.

Stratigraphic relationships:

The upper contact of the Welcome-C Tephra at Welcome Bay is sharp, with the weak paleosol developed into its top immediately overlain by the Welcome-D Tephra (Huntress-D). At Omokoroa East, the paleosol is not seen and it is difficult to distinguish the upper contact.

The lower contact of the Welcome-C Tephra is difficult to distinguish; the basal fine ash layer overlying loess. The studied sections are very dry and the boundary between the loess and tephra is most easily found by the change in consistence, as well as colour; the loess being somewhat harder than the ash above.

At Little Waihi, the tephra rests within organic-rich silt; that grades into fluvially deposited pumice below, and is truncated above by an erosional unconformity at the base of fluvially deposited tephric-sand.

Chemistry and mineralogy:

The glass chemistry of the Welcome-C Tephra (Table 11-4) is different to those of the tephrae lying stratigraphically above and below in that it has lower FeO & CaO contents. This chemistry is identical, however, to the secondary chemical component in the Huntress-B Tephra, which suggests that they may both have the same source.

The Welcome-C Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende

Distribution and size:

The Welcome-C Tephra has been positively identified at only two sites in the western Bay of Plenty — near Tauranga. It is probably also present in fluvial sediments at Little Waihi, although this section is not well understood and the identification is only tentative. The Welcome-C Tephra is not recognised at any of the sites in the eastern Bay of Plenty where it would be expected to be seen (e.g. Hiwarau, Huntress Creek), which suggests that the paleo-wind direction during its eruption was towards the west. This is confirmed by the tephra thickening towards the west, being ≥ 15 cm thick at Little Waihi, 40 cm

at Welcome Bay, and ≥ 50 cm thick at Omokoroa East. The Welcome-C Tephra is believed to have originated from the Rotorua Volcanic Centre, as the low CaO content of its glass is characteristic of tephtras believed to have originated from this centre (e.g. Mamaku Ignimbrite/Kutarere Tephra).

11-5 Huntress-D Tephra

The Huntress-D Tephra is believed to be the fourth eruptive deposited in the Huntress Creek subgroup and though it is only seen at a few sites, it is known to form thick deposits in both the eastern and western Bay of Plenty. The Huntress-D Tephra in the eastern Bay of Plenty is a probable—though not 100 % certain—correlative of the Welcome-D Tephra near Tauranga, and the two units are discussed below as if they were the same.

The type section for the Huntress-D Tephra is designated to be at Huntress Creek, though it is also well represented at the Hiwarau and Ohiwa Loop Road sections. It is present also at the Opape section, but here it is very weathered and no glass was analysed from this deposit.

The Welcome-D Tephra, although its physical characteristics are slightly different, is believed to be a correlative of the Huntress-D Tephra on the basis of its similar stratigraphic position and glass chemistry. The type section for the Welcome-D Tephra is at Welcome Bay, and it is also recognised at Omokoroa East.

The Welcome-D Tephra has also been very tentatively identified as a very weathered ash in the Rocky Cutting Road section; and the tephra is also suspected to be present within the upper part of the fluvial sequence at the Little Waihi section - the "banded pumice beds" (see Chapter 2).

Diagnostic features:

In the eastern Bay of Plenty: (see Photo-50)

- The bulk of deposit consists of massive white pumice lapilli; the clasts being very large — especially in middle part (maximum of 3 cm across near Opotiki, commonly to 2 cm across). The tephra is finer grained towards the top, and the matrix throughout consists of granular pumice generally 0.5 cm across.
- Crystal and lithic-rich layer at base of coarse pumice.
- A basal unit of well bedded coarse and fine ash layers (Photo-51).

In sections near Tauranga:

- The upper part of the tephra consists of alternating layers of coarse and fine ash, with occasional crystal-rich beds interspersed within it (crystals up to 2–3 mm across).
- The basal half of tephra consists of well bedded coarse and fine ash.

Table 11-5.1 : Glass chemistry of the Huntress-D Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Opape	77.55	12.41	0.17	1.18	0.11	0.91	3.79	3.68	0.21	5.16	13	0.96
01407	0.18	0.11	0.05	0.12	0.04	0.08	0.16	0.16	0.03	0.57		
Huntress Creek	77.70	12.53	0.14	1.23	0.11	0.84	3.68	3.59	0.18	5.86	12	1.00
**01510	0.30	0.19	0.03	0.09	0.03	0.06	0.10	0.14	0.04	0.69		
Huntress Creek	78.30	12.42	0.15	1.13	0.13	0.86	3.25	3.62	0.16	5.85	12	0.94
01515	0.43	0.33	0.04	0.13	0.03	0.06	0.11	0.09	0.04	0.63		
Hiwarau	78.37	11.94	0.15	1.22	0.12	0.87	3.54	3.62	0.18	2.85	12	0.96
02712	0.37	0.13	0.05	0.12	0.02	0.05	0.12	0.16	0.03	1.24		
Ohiwa Loop Road	77.91	12.34	0.14	1.23	0.10	0.89	3.52	3.70	0.20	4.79	10	0.97
08503	0.24	0.20	0.03	0.09	0.03	0.06	0.12	0.14	0.03	0.77		

Table 11-5.2 : Glass chemistry of probable correlatives of the Huntress-D Tephra in the western Bay of Plenty.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Omokoroa East	78.35	12.15	0.15	1.20	0.17	0.81	3.44	3.62	0.19	4.56	12	0.93
08705	0.23	0.09	0.06	0.11	0.06	0.09	0.10	0.14	0.03	0.82		
Welcome Bay	77.65	12.50	0.12	1.29	0.10	0.80	3.65	3.65	0.24	4.20	11	0.96
08803	0.39	0.29	0.03	0.05	0.03	0.06	0.18	0.11	0.05	1.19		
Rocky Cutting Rd.	77.44	12.79	0.15	1.18	0.09	0.77	3.69	3.69	0.23	7.89	17	0.95
09005	0.42	0.22	0.04	0.12	0.04	0.06	0.24	0.21	0.03	0.71		

At Rocky Cutting Road:

- A possible correlative of the Huntress-D Tephra exists as >50 cm of very weathered, white and multicoloured well bedded fine ash-clay.

Stratigraphic relationships:

In the eastern Bay of Plenty, the Huntress-D Tephra has sharp contacts both above and below to loess (Photo-50).

Near Tauranga, the upper part of the tephra has a paleosol weathered into it. At Welcome Bay, a thin paleosol has developed directly into the tephra and the Huntress-F Tephra immediately overlies this. At Omokoroa East, the paleosol below the Kutarere Tephra is so well developed that it has totally weathered through the Welcome-F and the Huntress-F Tephra, and into the top of the Huntress-D Tephra.

The lower contact of the tephra (in the Tauranga area) directly overlies the Welcome-C Tephra; , which at one site has a weak paleosol (5 cm thick) developed into it.

The possible Huntress-D Tephra correlative at Rocky Cutting Road overlies loess, and has a thick brown paleosol developed into its top.

Chemistry and mineralogy:

The chemistry of the Huntress-D Tephra (Table 11-5.1) is not particularly distinctive, but subtle differences in the amount of FeO & CaO, and the FeO/CaO ratio, can be used to distinguish it from some of the stratigraphically adjacent tephra. Sample 01515 is from the well bedded basal unit, and apart from having slightly less FeO it has a similar glass chemistry to the bulk of the deposit. More study is required on the chemistry of the different beds to establish whether the slight chemical difference is primary, or the result of slight variations in microprobe operation.

Table 11-5.2 shows the glass chemistry of possible correlatives of the Huntress-D Tephra. Simple comparisons of glass chemistry cannot readily distinguish between many of the tephra in the Huntress Creek subgroup and therefore the correlations between the eastern and western areas are not 100% certain.

The Huntress-D Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende

Hypersthene is the dominant ferromagnesian mineral in the coarse pumice unit of this tephra, but hornblende was slightly more common than hypersthene in the basal sandy ash unit.

Distribution and size:

Not enough sections are available for isopach maps to be constructed, but from the size of the clasts and the thickness of the deposits — up to 2 m thick in the Opotiki area — the Huntress-D Tephra is thought to have been erupted from the Okataina Volcanic Centre. It is comparable in thickness and grain size to the Mangaone Tephra—as seen in the same and nearby sections in the eastern Bay of Plenty—but

Table 11-6 : Glass chemistry of the Huntress-E Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Huntress Creek **01512	77.63 0.79	12.39 0.52	0.16 0.04	1.29 0.11	0.10 0.03	0.86 0.07	3.79 0.23	3.59 0.14	0.19 0.03	3.57 1.67	18	1.00
Huntress Creek 01512b	77.49 0.19	12.44 0.19	0.16 0.02	1.58 0.08	0.16 0.05	1.08 0.05	3.81 0.13	3.09 0.13	0.19 0.08	3.21 0.60	4	0.89

in addition it also occurs in sections around Tauranga where the Mangaone is not. Its eruptive volume is therefore likely to be somewhat greater than that calculated for the Mangaone Tephra; perhaps as much as 25 km³.

The basal, well bedded crystal-rich beds of the Huntress-D Tephra are much thicker towards the west (Tauranga), whereas the upper part is much coarser and thicker in the east. This suggests that the wind direction did not remain constant throughout the eruption. The abnormal easterly paleo-wind that is thought to have been present during the early phases of the eruption, was later replaced by the usual, predominant westerly wind direction.

11-6 Huntress-E Tephra

The Huntress-E Tephra is believed to be the fifth eruptive deposited in the Huntress Creek subgroup, though it is only recognised at one site in the Bay of Plenty — the Huntress Creek section (type section). The tephra is a possible, although unlikely, correlative of the Welcome-D Tephra found in the western Bay of Plenty.

At Huntress Creek, the Huntress-E Tephra exists only as 1 cm thick discontinuous lenses (creamcakes) of white fine ash within loess. A strong paleosol is developed into the loess above the tephra, and 20 cm of loess separates it from the unweathered top of the Huntress-D Tephra below.

Chemistry and mineralogy:

The Huntress-E Tephra contains a slightly mixed assemblage of glass shards with two different chemistries (Table 11-6). The dominant chemistry is virtually identical to that of the much thicker Huntress-D Tephra which immediately underlies it, and the secondary assemblage is a good chemical match with the secondary assemblage of the tephra thought to lie above it (i.e. the Huntress-F Tephra).

The Huntress-E Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende

No other ferromagnesian minerals were seen, but as only a small sample of tephra was studied, the listed assemblage may be in error.

Discussion:

It is likely, from the glass chemistry, that the Huntress-E and Huntress-D Tephtras have the same source, probably in the Okataina V.C., or possibly in the Rotorua V.C.

The secondary glass chemical component in the Huntress-E Tephra is believed to have the same source as that for the secondary component in Huntress-F. They are both thought to be the result of the entrainment of country-rock from the Chimp Ignimbrite, which is thought to have covered the vent sites of both these eruptions (& also the Welcome-F Tephra), perhaps to some depth (see sect. 11-7). The

Figure 11-5 : Glass chemistry of the Huntress-F Tephra

Huntress-E Tephra is only recognised as a very thin deposit, and probably represents an eruption which did not continue past the initial phases. Being of such limited volume, a significant portion of the tephra represents the vent-clearing phase of the eruption and the Chimp Ignimbrite chemistry is noticeable amongst the analyses. In comparison, the Huntress-D Tephra below is much thicker and any country-rock component, which would generally be concentrated in basal parts, would have been swamped by shards from the new magma. Furthermore, a thick tephra such as the Huntress-D is generally sampled a reasonable distance above its base, thus not recording the vent-clearing phase of the eruption.

11-7 Huntress-F Tephra

The Huntress-F Tephra is believed to be the sixth eruptive deposited in the Huntress Creek subgroup, but is recognised at only a few sites in the Bay of Plenty region. The Huntress-F Tephra is the most likely—though not 100 % certain—correlative of the Welcome-E Tephra found near Tauranga, and the two units are discussed below as if they were the same.

The type section for the Huntress-F Tephra is designated to be at Welcome Bay, and it is also seen at Ohiwa Loop Road.

Diagnostic features:

- At the type section the tephra consists of massive coarse sandy ash, ~20 cm thick. Elsewhere it is generally quite weathered and no distinctive physical characteristics can be recognised.
- The tephra has a distinctive glass chemistry (see Table 11-7) which is its principal method of correlation.

Stratigraphic relationships:

At Welcome Bay, either the top of the tephra, or the loess just above, contains a blocky paleosol. The tephra also overlies some paleosol development into weathered tephra below.

At Ohiwa Loop Road the Huntress-F Tephra rests directly on the Huntress-D Tephra, and consists of a very weathered fine ash with reasonable paleosol development in its top. The paleosol is immediately overlain by loess. At Huntress Creek, the tephra is believed to be incorporated as white weathered ash-clay layers within a paleosol developed into the loess above the Huntress-E Tephra.

Chemistry and mineralogy:

The glass chemistry of the Huntress-F Tephra (Table 11-7) is nearly identical to the overlying Welcome-F Tephra; both show a similar mixture of glass from two different eruptions. Both chemical components are present in roughly equal amounts; the more distinctive type-(b) chemistry comprising 55% of the total shards analysed at Welcome Bay, and 31% of the total at Ohiwa Loop Road (Figure 11-5).

Table 11-7 : Glass chemistry of the Huntress-F Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 08805a	S.C. 08805b
Ohiwa Loop Road 08502a	77.61 0.31	12.27 0.12	0.14 0.04	1.15 0.12	0.13 0.05	0.87 0.07	3.88 0.15	3.72 0.14	0.24 0.04	6.67 1.29	11	0.97	0.86
Welcome Bay **08805a	77.58 0.19	12.33 0.13	0.14 0.05	1.11 0.10	0.14 0.04	0.82 0.08	4.03 0.16	3.60 0.16	0.24 0.02	5.60 0.73	5	1.00	0.80
Ohiwa Loop Road 08502b	76.50 0.31	12.87 0.24	0.21 0.04	1.46 0.14	0.16 0.03	1.15 0.06	4.00 0.16	3.44 0.13	0.22 0.02	7.65 1.13	5	0.86	0.92
Welcome Bay **08805b	76.79 0.29	13.07 0.28	0.26 0.03	1.48 0.06	0.20 0.04	1.17 0.08	3.79 0.22	3.02 0.09	0.25 0.04	7.99 0.76	6	0.80	1.00

The type-(b) chemistry is distinctive due to its relatively high FeO content (compared to most of the tephra in this study) and a high FeO/CaO ratio, especially when compared with other tephra with high FeO values. It also has moderately high TiO₂, and low K₂O contents (Na₂O > K₂O ≈ 3.0 wt.%). The tephra which has the most chemical similarity to this is the Waimakariri Ignimbrite (Reihana-G Tephra) (see sect. 10-14).

The type-(a) chemistry is similar to many of the tephra erupted previously in the Huntress Creek subgroup, though it has slightly lower FeO values. It is similar also to the Mamaku Ignimbrite, which is only slightly younger, although this has slightly lower values of CaO.

The Huntress-F Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene ± biotite(t)

The ferromagnesian mineral assemblage of this tephra must reflect the fact that the deposit is probably a mixture from two separate eruptives and therefore should not be used in comparative or geochemical studies.

Distribution and size:

The glass chemistry of the Huntress-F Tephra may be the only useful method for correlation as the tephra lacks distinguishing physical characteristics and has different degrees of weathering at different sites. However, even the glass chemistry is not particularly diagnostic as it is virtually identical to the overlying Welcome-F Tephra. These two eruptions probably have the same source area, which on the basis of their glass chemistry is probably in the Rotorua Volcanic Centre.

Since the tephra is recognised at only two sites, no isopach maps can be constructed. However, as the sites are widely separated (90 km apart) occurring in the east and west of the Bay of Plenty, and are some distance from the inferred source (50 & 75 km northwest & northeast respectively), the tephra is likely to have a moderate volume of 7 km³; possibly much greater.

Discussion:

It is likely that material from two separate eruptions with different sources are recorded in the deposit that makes up the Huntress-F Tephra. The tephra is often weathered, and even where it is fresh (e.g. Welcome Bay) no bedding is observed. Therefore no physical features exist to indicate the presence of two different eruptives (unlike with the Paerata & Tablelands-D Tephra). Three separate eruptions — the Huntress-E, Huntress-F and Welcome-F Tephra — which are closely spaced in time, each contain shards of type "B" chemistry as part of a mixed glass chemistry assemblage (see Figure 11-6). It seems far too coincidental that three separate groups of coeval eruptions could occur in such a short space of time with no physical evidence for separate sources (e.g. differences in shower bedding), and with one of the chemical components remaining remarkably constant over time.

Contamination with country-rock during the eruption seems the most likely explanation for the mixed chemical assemblages.

The Chimp Ignimbrite, which has a similar chemistry to the Huntress-F(b) Tephra (see Figure 11-6), is thought to have been erupted from the Kapenga V.C., and would have presumably flowed over and covered the Rotorua area; perhaps to some depth if ponding occurred. It is here suggested that the Huntress-F Tephra was one of the first eruptions originating in the Rotorua Volcanic Centre and was forced to erupt through a significant thickness of Chimp Ignimbrite. During the process of eruption, large amounts of material from this ignimbrite were included (entrained) within the Huntress-F airfall deposit. Further eruptions from the Rotorua centre (i.e. the Welcome-F Tephra) also erupted through this ignimbrite, perhaps at a separate but nearby vent, and also entrained material from the ignimbrite.

Figure 11-6 : Comparison of the means and standard deviations (1 s.d.) of glass chemistry analyses from the Huntress-E (Huntress Creek), Huntress-F, and Welcome-F Tephtras (both Welcome Bay)

The Huntress-F Tephra is thought to be the result of one eruption, although including material from another older deposit, and hence it has been given just one name with the qualifier "(a)" or "(b)" to distinguish the different populations of glass shards. Both shard compositions are included in the tephra volume.

The variation in the relative concentrations of the two chemically distinct shard populations may be the result of the sampling of different beds within the eruptive deposit at the different sites. The majority of the xenolithic shards were probably entrained and deposited during the earlier part of the eruption (vent-clearing processes) and thus type "B" shards would be concentrated in the basal beds. The top of the tephra has a paleosol developed in it and so generally only the basal part of the unit has been available for sampling. Slight variations in which part of the tephra was sampled may have large implications in the relative proportions of the different chemical types within each sample.

Table 11-8 : Glass chemistry of the Welcome-F Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Welcome Bay	77.40	12.41	0.15	1.15	0.12	0.79	3.96	3.83	0.21	3.36	10	1.00
**08804a	0.42	0.13	0.03	0.10	0.04	0.07	0.17	0.26	0.02	1.80		
Welcome Bay	76.20	13.09	0.21	1.57	0.18	1.09	3.96	3.53	0.18	5.52	6	0.84
08804b	0.53	0.20	0.04	0.11	0.03	0.08	0.16	0.12	0.03	0.93		

11-8 Welcome-F Tephra

The Welcome-F Tephra is believed to be the sixth and uppermost eruptive deposited in the Welcome Bay subgroup. It is recognised at only one site in the western Bay of Plenty. Stratigraphically, the Welcome-F Tephra is thought to lie between the Huntress-F and the Kutarere Tephra, but it is also possible, though unlikely, that it is a correlative of the Huntress-F Tephra in the eastern Bay of Plenty.

The type section (only section) of the Welcome-F Tephra is at Welcome Bay.

At all other sites where the tephra was expected to have been deposited, a thick well developed paleosol has weathered totally through it; and it has been incorporated within the undifferentiated weathered material. A paleosol has developed into the tephra at Welcome Bay, but has not progressed entirely through it here. The basal pink ash of the Kutarere Tephra rests directly on this paleosol.

The Welcome-F Tephra rests on the blocky paleosol that exists between it and the underlying and chemically identical Huntress-F Tephra.

Although thin, the **diagnostic features** of the Welcome-F Tephra are:

- At the type section the tephra consists of a 5 cm thick layer of sandy ash; with a 10 cm thick paleosol developed into it.
- The tephra has a distinctive glass chemistry (Table 11-8).

Chemistry and mineralogy:

The glass chemistry of the Welcome-F Tephra (Table 11-8) is nearly identical to the underlying Huntress-F Tephra; both contain the same chemically distinctive mixture of glass shards. Both tephrae also have roughly equal amounts of both chemical components. However, the glass chemistry of the Welcome-F Tephra is slightly different in that it has a slightly higher K₂O content than that of the underlying Huntress-F deposit.

The Welcome-F Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende

Discussion:

The Welcome-F Tephra is thought to be the result of one eruption in the Rotorua V.C. at c. 0.24 Ma, and has been given just one name with the qualifier "(a)" or "(b)" to distinguish the different populations of glass shards. The origin of the two glass populations is believed to be through the same mechanisms as that presented in the discussion on the Huntress-F Tephra — entrainment of country-rock during eruption (see sect. 11-7).

Chapter Twelve : Kukumoa subgroup

The Kukumoa subgroup consists of all of the deposits which occur between the base of the Kutarere Tephra (base), up to the base of the Rotoiti Tephra (top). As all of the tephras in this subgroup are not found at any one site, the stratigraphic relationships between the units have been difficult to determine, and in some cases are not 100% certain.

The Kukumoa subgroup takes its name from Kukumoa cutting [W15/843469], a road cutting located ≈ 2 km west of Opotiki on Highway-2. Several of the younger tephras discussed in this chapter are not recognised at this section, nor at most of the other sections in the Ohiwa Harbour – Opotiki area, though they were likely to have been deposited here. There are two likely causes for these tephras not being recognised in this area:

- i) they have been incorporated within the very thick and very weathered paleosol that exists at the top of this subgroup; and/or
- ii) they have been removed during the period of erosion that caused a widespread regional unconformity that exists just below the Rotoiti Tephra.

The very thick paleosol at the top of the subgroup will sometimes be referred to (throughout this chapter) as the "last-interglacial paleosol", although the precise time at which this paleosol formed is not known for certain. As the stratigraphic relationships between sites are not 100% certain, the tephras at sites other than Kukumoa have been given distinct individual names, rather than letters representing their stratigraphic position within the Kukumoa subgroup.

The erosional unconformity near the top of the Kukumoa subgroup is well represented at the Ngatiawa lookout, Kukumoa, Reeves and Paerata Ridge Road sections (see Photo-63), where many metres of erosional relief can be seen. The unconformity is present at most sites in the Bay of Plenty, but a number of sections (e.g. Hawaii, Huntress Creek, Whitianga Orchard) contain a continuous record. A layer of unweathered loess exists between the Rotoiti Tephra and the "last-interglacial paleosol" at these sites (see Photo-61). The loess is believed to have been deposited just downwind of the large alluvial plains that existed in these areas during $\delta^{18}\text{O}$ stage-4. The loess represents the highest (youngest) deposit in the Kukumoa subgroup.

The age of the Kukumoa subgroup, and the tephras within it, have been estimated by fitting the paleoclimatic data gathered from the Bay of Plenty sections to the SPECMAP and Bassinot-LLS oxygen isotope ($\delta^{18}\text{O}$) records (see Chapter 15).

In the coastal Bay of Plenty the entire subgroup has generally suffered from severe weathering which has promoted the development of a very thick and weathered paleosol (see Photo-52). The primary nature of the tephra deposits is often difficult to determine. Only the basal unit of this subgroup, the Kutarere Tephra, is unweathered enough to still retain some glass — although only 1–5% of the original amount that was present. The other three tephras seen at Kukumoa cutting have been totally altered to clay, and no glass remains in them. The relative preservation of the Kutarere Tephra is probably due to its large thickness—in comparison to the other tephras—and its greater depth below the paleosol surface.

The tephra above the Kutarere (Kukumoa-B) rests on a paleosol developed into loess (tephric?) and weathered Kutarere Tephra. Above the Kukumoa-B Tephra is a thick unit of loess which contains two thin eruptives, the Kukumoa-C and Kukumoa-D Tephras. These three tephras, and the loess units between them, are extremely weathered.

The upper part of the Kukumoa subgroup is generally so weathered that no tephras can be recognised within it. The only sites where tephras have been preserved are those where the tephras were deposited in a subaqueous environment (e.g. at Torere School, Wairuru, Waiotuma).

The best fit estimates (to the $\delta^{18}\text{O}$ record/curve) give an age range for the Kukumoa subgroup of *c.* 230 ka to *c.* 50 ka, with an average of one eruption recorded per 22 000 years. Due to the lack of unweathered sections in the less distal regions the eruption record is obviously incomplete and further research may discover additional sections and many more eruptions.

The tephras known to occur in the Kukumoa subgroup and their estimated ages and volumes, are: –

Reid's Reserve	<i>unknown</i>	$\geq 10 \text{ km}^3$
Wairuru	<i>c. 90 ka</i>	$\geq 10 \text{ km}^3$
Copenhagen	<i>c. 105 ka</i>	$\geq 5 \text{ km}^3$
Torere	<i>c. 115 ka</i>	$\geq 10 \text{ km}^3$
Kukumoa-D	<i>c. 165 ka (?)</i>	$>> 0.5 \text{ km}^3$
Kukumoa-C	<i>c. 185 ka (?)</i>	$>> 0.5 \text{ km}^3$
Kukumoa-B	<i>c. 195 ka</i>	$>> 0.5 \text{ km}^3$
Mamaku (ignimbrite)	<i>c. 235 ka</i>	$> 300 \text{ km}^3$
Kutarere (airfall)	" "	$\geq 25 \text{ km}^3$

The Kutarere Tephra is thought to be a correlative of the very large Mamaku Ignimbrite eruption which originated in the Rotorua Volcanic Centre — forming the caldera in which the present day Lake Rotorua is found. New outcrops of this ignimbrite have been recognised in sections on the Maketu Peninsula and these extend its range slightly further than previously thought.

The glass chemistry of the Kutarere Tephra is nearly identical to the unwelded ignimbrite found at the Maketu headland (Newdicks Beach), but cannot readily be compared to the altered glass found at the base of welded Mamaku Ignimbrite at Tikorangi Road.

Figure 12-1 : Comparison of the means of glass analyses from some Kukumoa subgroup tephtras — relative proportions of selected element-oxides

Similarity coefficients that compare the glass chemistries of all of the tephtras that were analysed in the Kukumoa subgroup (i.e. those that contained glass) are presented in Table 12-0.

Table 12-0 : Similarity coefficients (S.C.'s) comparing representative chemistries of some Kukumoa subgroup tephtras.

<i>oldest</i>		03801	10402	01301	04803	05301	11201
Kutarere	03801	1.00					
Mamaku Igb.	10402	0.90	1.00				
Torere School	01301	0.83	0.81	1.00			
Copenhagen	04803	0.92	0.88	0.86	1.00		
Wairuru	05301	0.92	0.88	0.80	0.90	1.00	
Reid's Reserve	11201	0.91	0.86	0.84	0.94	0.87	1.00
Little Waihi	03105	0.90	0.87	0.81	0.88	0.88	0.91
<i>youngest</i>							

As no glass was found in the Kukumoa-B, Kukumoa-C, or Kukumoa-D Tephtras, Figure 12-1 is not complete. Some of the unknown Kukumoa tephtras may correlate with the Kutarere Tephtra, some with other lower Kukumoa subgroup tephtras, and some may be separate eruptives; only further work may tell.

The glass of the Torere School Tephtra is quite distinctive for the tephtras in this study, and especially so for the tephtras in the Kukumoa subgroup.

The Reid's Reserve Tephra has a distinctive chemistry not fully shown by the element—oxide ratio-plot in Figure 12-1, but the Copenhagen and Wairuru Tephra do have similar glass chemistries.

The titanomagnetite geochemistries of the Kutarere, Kukumoa-B, Kukumoa-C and Kukumoa-D Tephra are virtually identical (see Chapter 14) indicating that they may have originated from the same source. The tephra found at Copenhagen Road are not believed to be correlatives of the aforementioned Kukumoa eruptives because the titanomagnetite geochemistries of the two groups are significantly different.

Fluvial/lacustrine sediments at the Torere School, Wairuru, Waiotuma sections, and the possibly fluvial Waihapokopoko section, all contain tephra of younger Kukumoa subgroup age. Elsewhere, nearer to source, no tephra of this age can be distinguished within the weathered paleosol.

The Copenhagen Road section contains three tephra within an over-thickened colluvial toe-slope.

In the coastal western Bay of Plenty, the Little Waihi and the Rocky Cutting Road sections both contain tephra within the paleosol that exists directly beneath the Rotoiti Tephra. These tephra are likely correlatives of one of the lower Kukumoa subgroup tephra (Kutarere to Kukumoa-D). However, there is not enough data to determine specific tephra correlations and therefore the deposits at these two sections are not discussed in detail below, instead see Chapter Thirteen.

The Tapapa section on the Mamaku Plateau contains a tephra between the Mamaku Ignimbrite and the Rotoiti Tephra, and although the eruptive was not studied in this thesis, it is almost certainly a correlative of one of the Kukumoa subgroup tephra.

A tephra at Reid's Reserve, thought to have been deposited in a fluvial environment, may also be of this age.

There are many other sites (e.g. Awaawakino, Bookbinders) where tephra that probably belong to the Kukumoa subgroup are observed, but the lack of stratigraphic control, together with the difficulty of obtaining accurate correlations based solely on glass chemistry and a lack of time for thesis completion, has meant that glass from these various eruptives has not yet been analysed (see Chapter 13).

Many of the above sections contain deposits that are much less weathered than those at Kukumoa, and therefore were probably deposited after the strongest weathering had occurred. It is still uncertain whether this period of very strong weathering occurred during the entire duration of $\delta^{18}\text{O}$ stage-5, or only in the very warm $\delta^{18}\text{O}$ substage-5e, which is generally thought to have had a climate warmer than present [Burckle, 1993]. The less weathered sections do often contain a paleosol immediately beneath the Rotoiti Tephra, but it does not have the same extent of paleosol development as is found in the "last-interglacial paleosol". These weaker paleosols have developed into loess which is thought to represent the slightly cooler climates of $\delta^{18}\text{O}$ stages-5d & -5b. At Copenhagen Road, a mixture of colluvium, loess, and tephra is thought to represent these cooler periods, with the weak paleosols existing between the colluvial units representing the warmer $\delta^{18}\text{O}$ stages-5a & -5c (see Photo-1).

Figure 12-2: Stratigraphy of the Kukumoa subgroup along the Bay of Plenty coast
(see appendix-(M) for key)

Apart from some erosion at the very top, the entire subgroup can be best seen at the Kukumoa cutting section (see Photo-2). However, the tephra here are very weathered and little information for correlation purposes can be gathered from this site. Other good reference sites showing Kukumoa subgroup deposits can be found at Kutarere Wharf [W15/730435], Newdicks Beach [V14/159781], Tapapa [T15/635524], Copenhagen Road [X14/233737] and Torere School [X15/048517]. The "last-interglacial paleosol" is well exposed at many sites throughout the Bay of Plenty, but one is never sure of how much erosion has occurred at its top, or what the first recognisable tephra deposit at depth is.

Since little detail is observed within the deposits comprising the Kukumoa subgroup no diagram showing the generalised stratigraphy of the subgroup in the eastern Bay of Plenty is presented. Figure 12-2 shows instead the variation in thickness and exposure of the Kukumoa subgroup deposits across the coastal Bay of Plenty, with suspected correlations between the sites marked.

The seven tephra which have known stratigraphic positions within the Kukumoa subgroup are presented in the following pages in stratigraphic order of deposition (from oldest to youngest). The Reid's Reserve Tephra is also discussed in this chapter as it is believed to lie within the Kukumoa subgroup, but it does not correlate to any of the other tephra discussed here. Since the age and stratigraphic position of this tephra is not fully understood, it is discussed at the very end of the chapter as not to interfere with the discussion of the tephra for which the stratigraphic positions are known.

12-1 Kutarere Tephra

Although very weathered, the Kutarere Tephra is recognised throughout the northern Bay of Plenty. It had previously been given the name "Tephra-X" [Vucetich *et al.*, 1981], and from its glass chemistry and stratigraphic position it is thought to be a correlative of the Mamaku Ignimbrite eruption. It is also a likely correlative of the Welcome-G Tephra found in the western Bay of Plenty, and the two units are discussed below as if they were the same.

The Kutarere Tephra is the basal deposit in the Kukumoa subgroup and is therefore known also as the Kukumoa-A Tephra. This tephra was previously thought to be a correlative of the basal tephra in the "Hamilton Ashes" (i.e. the Ohinewai Tephra), but the correlation was subsequently proved incorrect (see sect. 2-3.2). The Kukumoa-A Tephra is instead the basal tephra in the "undifferentiated brown ashes" [Pullar *et al.*, 1973].

The type section for the Kutarere Tephra is at Kutarere Wharf. It is also recognised at the Huntress Creek, Waioeka River, Kukumoa cutting, Tablelands Road, Brown's driveway, Opape, Paerata, Hawaii and Omaio sections, and possibly at Ohiwa Beach. It is also thought to occur as the Welcome-G Tephra at the Welcome Bay and Omokoroa East sections.

The unwelded top of an ignimbrite is exposed at Newdicks Beach on the Maketu Peninsula. This deposit is thought to be a correlative of the Mamaku Ignimbrite, and is thus also the Kutarere Tephra.

Diagnostic features:

(see Photo-53; Photo-61)

- The tephra is extremely weathered has only a limited amount of glass remaining within it (1%–5% of that originally present). The glass consists of relatively large, non-pumiceous shards.
- Generally has a yellow-orange colour, or occasionally orange/ginger (i.e. 10YR 7/8 "yellow orange"), always with a very high chroma.
- Basal layer consists of a hard (cemented) white clay bed containing abundant black manganese concretions which give it a speckled appearance.
- Contains large, pale yellow-white, halloysite clay nodules scattered throughout; generally ≤ 5 cm across (i.e. not as large as those in the Tirohanga Tephra). The tephra also contains many manganese concretions scattered throughout, though concentrations of these are associated with the clay nodules
- The tephra appears to consist of coarse sand sized particles, but which are actually aggregates of clay. The clay "grains" probably retain the original shape and size of the glass-rich pumice grain from which—via in-situ weathering—they were formed. Some felsic crystals and rhyolitic lithics are also present.

The Welcome-G Tephra near Tauranga (Welcome Bay and Omokoroa East sections):

- A basal pink-red fine ash (≤ 5 cm thick), overlain by 5 cm of coarse sandy ash, which in turn is overlain by the bulk of the deposit.
- The bulk of tephra consists of ≥ 2 m of massive medium sandy ash.

Maketu Peninsula:

- ≈ 2 m of a massive white sandy ash, overlying > 5 m of a firm, fine grained pyroclastic flow that contains only scattered pumice lapilli.
- The base of ignimbrite has an erosional lower contact with > 20 cm of shower bedded coarse sandy ash.

Generally:

- The tephra is extremely weathered and the nature of the weathering products are the most useful characteristics for physical correlation. Although weathering often varies from site to site and therefore should not generally be used as a diagnostic tool for correlation, the tephra appears to have a consistent weathering pattern across much of the coastal Bay of Plenty, including the extremely weathered Rocky Cutting Road and Omokoroa Slump sections.

The Mamaku Ignimbrite has been studied previously by Martin [1961], Briggs [1973], and Murphy and Seward [1981] amongst others, and will not be discussed in detail here.

- The ignimbrite consists of "fairly distinctive, fine textured, light blue-grey to pink, soft vitric tuff, in which the original glass shards and pumice fragments have been devitrified to soft powdery aggregates" [Martin, 1961].
- The central portion of the ignimbrite is generally welded, often with columnar jointing.
- The crystal content of the ignimbrite is similar to that of the Matahina Ignimbrite in that it contains relatively abundant quartz and no sanidine, but differs in having a higher total phenocryst content, more biotite, and less hornblende [Briggs, 1973].

Stratigraphic relationships:

The Kutarere Tephra is very weathered and generally grades up into very weathered loess. At some sites (e.g. Opape; see Photo-53) a weak paleosol — 10YR 6/6 "bright yellowish brown" in colour — has developed into the top of the weathered tephra, and the loess above appears to be less weathered. At Kukumoa cutting, the Kukumoa-B Tephra rests on this paleosol – loess boundary, although here the paleosol appears to be developed into coarse tephric-loess rather than primary tephra (uncertain). At Newdicks Beach, the ignimbrite has a very well developed paleosol in its top, with up to 6 metres of æolian tephra-rich dune sands resting on this. The Welcome-G Tephra near Tauranga is overlain by fluvially reworked tephric material, almost certainly derived from the Mamaku Ignimbrite during flood events that immediately followed its eruption.

The Kutarere Tephra generally overlies a well developed paleosol in loess and tephra (7.5YR to 10YR 5/8 "bright brown" – "yellowish brown"), though the paleosol is not as well developed as that between the Rotoiti and Kutarere Tephra. The Kutarere Tephra at Tablelands Road overlies an erosional boundary with up to 40 cm relief. A moderately well developed paleosol exists below the tephra here and into the loess below, but it is uncertain whether the erosion took place before, during, or after paleosol formation.

The Welcome-G Tephra at Welcome Bay overlies a thin (5 cm) blocky paleosol in loess(?) that overlies unweathered Welcome-F Tephra. However, at Omokoroa East the paleosol beneath the Welcome-G Tephra is thick; having weathered through both the Welcome-F and Welcome-E Tephra, and into the Welcome-D (Huntress-D) Tephra below. At Little Waihi, the pre-ignimbrite airfall tephra rests on a paleosol developed into coarse sandy ash. This ash—the top of the banded pumice beds—appears to be airfall, but fluvial deposition cannot be dismissed.

A slightly less weathered, white ash-clay that occurs at Huntress Creek may represent either a separate, slightly older (than the Kutarere) eruptive, or a less weathered Kutarere correlative. Neither of these scenarios could be confirmed because the stratigraphic relationship of the ash-clay with typical weathered Kutarere Tephra was not seen and due to slumping and vegetation overgrowth the ash-clay deposit at Huntress Creek can no longer be found.

Table 12-1.1 : Glass chemistry of the Kutarere Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Opape	77.89	12.31	0.15	1.12	0.11	0.70	3.83	3.61	0.28	7.16	13	0.99
01410	0.39	0.18	0.04	0.12	0.05	0.10	0.19	0.27	0.06	1.21		
Huntress Creek	78.23	12.22	0.17	1.16	0.10	0.74	3.51	3.49	0.28	10.01	11	0.94
01518	0.28	0.16	0.06	0.10	0.04	0.09	0.25	0.19	0.03	1.35		
Huntress Creek	78.78	11.75	0.17	1.27	0.10	0.75	3.19	3.83	0.20	3.95	19	0.92
01511	0.47	0.20	0.05	0.11	0.03	0.07	0.24	0.31	0.05	1.37		
Kutarere Wharf	78.31	12.40	0.17	1.14	0.13	0.75	3.48	3.34	0.28	6.42	8	0.93
03401	0.28	0.16	0.04	0.05	0.03	0.04	0.18	0.15	0.03	0.92		
Kukumoa	77.87	12.33	0.15	1.13	0.11	0.68	3.80	3.65	0.28	7.92	6	1.00
**03801	0.24	0.16	0.05	0.13	0.04	0.06	0.15	0.16	0.03	0.52		

Table 12-1.2 : Glass chemistry of probable correlatives of the Kutarere Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 03801
Omokoroa East	77.71	12.10	0.14	1.18	0.10	0.69	3.95	3.89	0.24	3.28	10	0.96
08704	0.36	0.17	0.04	0.07	0.03	0.10	0.13	0.10	0.05	1.04		
Omokoroa East	77.66	12.31	0.15	1.16	0.12	0.70	3.79	3.86	0.26	5.77	11	0.98
08703	0.25	0.21	0.04	0.11	0.02	0.05	0.10	0.13	0.05	0.73		
Welcome Bay	77.64	12.23	0.20	1.18	0.09	0.67	3.90	3.90	0.24	4.23	11	0.93
08801	0.31	0.11	0.07	0.07	0.02	0.10	0.06	0.10	0.04	0.59		
Rocky Cutting Rd.	78.03	12.35	0.15	1.11	0.11	0.77	3.59	3.55	0.28	6.69	8	0.97
09004	0.28	0.19	0.04	0.06	0.05	0.12	0.20	0.30	0.05	1.25		
Rocky Cutting Rd.	78.27	12.39	0.21	1.24	0.09	0.68	3.33	3.61	0.18	6.86	10	0.91
09002	0.50	0.29	0.06	0.14	0.02	0.04	0.20	0.12	0.05	1.49		

Table 12-1.3 : Glass chemistry of the Mamaku Ignimbrite & probable correlatives.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 03801
Newdicks Beach	78.77	11.73	0.13	1.12	0.07	0.67	3.50	3.82	0.22	1.93	14	0.91
07901	0.23	0.15	0.03	0.09	0.01	0.04	0.16	0.11	0.04	0.37		
Tikorangi Road	78.10	12.34	0.16	1.05	0.09	0.53	3.28	4.12	0.35	5.96	10	0.90
10402	0.38	0.30	0.05	0.09	0.02	0.05	0.11	0.11	0.08	1.69		

Chemistry and mineralogy:

The glass chemistry of the Kutarere Tephra (Table 12-1.1) is similar to those of several tephra in the Huntress Creek subgroup, in that it has a moderate FeO content, but low in CaO & MgO.

The two samples from Huntress Creek are thought to represent slightly different weathering regimes. Sample 01518 represents the normal highly weathered yellow-orange tephra, whereas sample 01511 is from a slightly less weathered white ash-clay.

At Rocky Cutting Road there are two extremely weathered tephra with similar chemistries (Table 12-1.2) and it is uncertain which, if either, is a correlative of the Kutarere Tephra.

The upper sample from Omokoroa East (08704) is probably a fluvially reworked unit derived from the Mamaku Ignimbrite and Kutarere Tephra (08703) just after their eruption.

The Tikorangi Road sample (10401) was taken from the basal unwelded pumice of the Mamaku Ignimbrite. The glass chemistry of this sample does not closely match the chemistry of Kutarere Tephra glass. However, since welded ignimbrite (indicative of high temperature) exists <2 m above, it is likely that the glass at Tikorangi Road has been chemically altered, thus resulting in unusually low FeO and high K₂O values.

The Kutarere Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende

The Mamaku Ignimbrite contains mainly hypersthene in its ferromagnesian mineral assemblage, as well as some biotite, and only traces of hornblende [Briggs, 1973]

Distribution and size:

The Kutarere Tephra is recognised at many sites across the coastal Bay of Plenty but is highly weathered and its thickness is variable and often difficult to determine. The tephra is thickest in the eastern Bay of Plenty at the Kukumoa site; where the pure weathered tephra itself is 75 cm thick, and a further 100 cm of paleosol development into tephric material exists above. At Opape, east of Opotiki, the tephra is in total 80 cm thick, including its weathered top.

In the west, the Welcome-G Tephra is ≥ 2 m thick at Welcome Bay and 1.5 m thick at Omokoroa East. The tephra at the former site is totally unweathered due to the protection given to it by the >4 m thick sequence of fluvial sediments that directly overlies it.

The Kutarere Tephra is tentatively correlated to the Mamaku Ignimbrite eruption and is therefore believed to have the same source — the Rotorua Volcanic Centre.

On the basis of the quite large thicknesses recorded for the Kutarere Tephra throughout the Bay of Plenty, is likely to have had a circular distribution rather than strongly elliptical, leading to a relatively large minimum volume estimate of c. 25 km³.

The Mamaku Ignimbrite has an estimated volume of $>300 \text{ km}^3$ [Wilson *et al.*, 1984] (Table 2-2) and forms the bulk of the Mamaku Plateau — to the west of Lake Rotorua. The ignimbrite reaches almost as far as Te Puke to the north, Tauranga to the northwest, Putaruru to the west, and Tokoroa to the southwest [Healy *et al.*, 1964]; covering an area of $>3000 \text{ km}^2$. The ignimbrite had not previously been recognised as occurring on the Maketu Peninsula, but its presence here (this study) only slightly increases its range. The Mamaku Ignimbrite has only minor outcrops to the east of its source, which is believed to be the nearly circular caldera now occupied by Lake Rotorua.

Discussion:

The Kutarere Tephra is extremely weathered and the only physical characteristics which can be used to correlate the deposit from site to site are artefacts of this weathering. Problems can readily arise if the stratigraphy of the enclosing deposits is not well constrained as many tephrae having undergone a similar amount of weathering look similar. The "Te Uku" variant of the Ohinewai Tephra in the Waikato/King Country region, the Tirohanga Tephra in the older eastern Bay of Plenty deposits (see Photo-14), and several tephrae (both ancient and not so ancient) in the Tauranga region, all have characteristics caused by extreme weathering — yellow-orange colours, clay nodules, basal clay & manganese-rich layer — which could indicate correlation with the Kutarere Tephra.

In the Jackson Road section, the Tirohanga Tephra is found near the base of a very thick paleosol ($\geq 3 \text{ m}$) and the Rotoiti Tephra directly overlies the paleosol surface. The Tirohanga Tephra can be distinguished from the Kutarere (which isn't present here) only by the fact that:

- it is even more weathered and contains no glass whatsoever;
- it contains no pyroxenes — all having been weathered out;
- its hornblende grains are deeply etched and eroded, rather than smooth and shiny; and
- they have slightly different titanomagnetite geochemistries.

The hornblende geochemistry of the Tirohanga Tephra is distinctive, but as yet no hornblende grains from the Kutarere Tephra have been analysed.

The Kutarere Tephra is correlated to the Mamaku Ignimbrite eruption, though not with 100% certainty, but cannot be called the Mamaku Tephra because another tephra already has this name (Table 2-1). The "Mamaku Tephra" is a much more recent eruptive, only ≈ 7000 years old, and has no relationship to the Mamaku Ignimbrite. Several possibilities exist for resolving the nomenclature problem; either

- the Mamaku Tephra could be renamed,
- the Mamaku Ignimbrite could be renamed; or
- the Mamaku Ignimbrite could keep its name and become a member of the Kutarere Formation.

The first two solutions would cause a great deal of confusion, especially with published literature and are not recommended, although I believe that of the two deposits, less confusion would be engendered from the renaming the younger airfall tephra. The third solution is acceptable but the Kutarere Tephra,

because of its weathering, is not believed to be a good representative of the airfall component of the Mamaku eruptive episode. A more appropriate name may perhaps be found from a site where the airfall tephra is better preserved, possibly where the Mamaku Ignimbrite directly overlies it. The Kutarere Tephra itself could then be renamed. There are sections in the Tokoroa Forest, southwest of Rotorua, where the pre-ignimbrite airfall is preserved (*Neil Kennedy*, pers. comm. 1993), but these were outside the scope of this work.

The Kutarere Tephra represents a very widespread eruption at c. 0.21–0.24 Ma (see Chapter 15), which—if identified correctly—is a good marker horizon throughout the Bay of Plenty.

12-2 Kukumoa-B Tephra

The Kukumoa-B Tephra is believed to be the second eruptive deposited in the Kukumoa subgroup.

The tephra is extremely weathered and has only been positively recognised at one site — Kukumoa cutting. A tephra found near the top of the Omokoroa East section may be a correlative, but could also be one of several other tephtras, or more likely just reworked Kutarere Tephra. Thin patchy weathered tephra layers can be seen between the Kutarere tephra and the Rotoiti tephra at the Rocky Cutting Road, Little Waihi Road, Waioeka River and Opape sections, but there is not enough chemical and/or stratigraphic control to determine which of the several Kukumoa subgroup tephtras these individual layers could represent.

The Kukumoa-B Tephra is extremely weathered and contains no **diagnostic physical characteristics**. It exists only as discontinuous lenses (creamcakes) of white clay up to ~5 cm thick. No glass remains in the Kukumoa-B Tephra; it has all been altered to clay. The ferromagnesian mineral assemblage of the tephra was not studied.

Stratigraphic relationships:

The Kukumoa-B Tephra is overlain by up to 0.5 m of weathered loess to the base of Kukumoa-C Tephra, and directly overlies a paleosol developed into the Kutarere Tephra, or in some places developed into tephric-rich loess lying just above the Kutarere Tephra. Although the tephra and/or loess is extremely weathered, the paleosol appears to have only weak to moderate physical development.

Distribution and size:

The Kukumoa-B Tephra is recognised at only one site where it is very weathered, and since the original thickness of the tephra here cannot be determined, its source and volume remain unknown. The titanomagnetite geochemistry of the Kukumoa-B Tephra is nearly identical to that of the Kutarere (see Chapter 14), and therefore it is thought to have the same source — the Rotorua Volcanic Centre.

Discussion:

Due to its extremely weathered nature very little can be determined about the Kukumoa-B Tephra apart from that it does exist and shows that volcanism was occurring in the northern T.V.Z at this time, *c.* 0.2 Ma.

The alteration of the glass to clay may be the result of a perched water table providing a conduit for dissolution and hydration. The basal parts of several pumiceous tephra in the Huntress Creek and the Torere subgroups show this alteration and the subsequent compaction associated with the loss of pumice vesicles. For example; the Hiwarau Tephra in the eastern Bay of Plenty ranges in thickness from 1.5 m (pumice lapilli) to 0.3 m (white clay), depending solely upon how weathered it is (see sect. 10-6; Photo-33; Photo-34). The loess deposited within the Kukumoa subgroup would have been much less permeable to water than the tephra layers and could therefore provide a firm layer for the water-table to be perched on.

The major discussion point here is why should the tephra be weathered so much more in the Kukumoa subgroup than in the preceding Huntress Creek subgroup, or in the more recent post-Rotoiti tephra. Perhaps there was more water available, or less, or that the temperature was more conducive to weathering. It may have had something to do with the thickness of the tephra deposits and/or the rate of deposition and the associated length of time that it is exposed to the surface or to water table fluctuations. Perhaps the presence (unknown) of andesitic, or even per-alkaline ashes throughout the Kukumoa subgroup promoted soil development, and/or altered the pH of the soil and ground water so that it affected the glass to a much greater extent. Much further work is required to answer these questions.

12-3 Kukumoa-C Tephra

The Kukumoa-C Tephra is believed to be the third eruptive deposited in the Kukumoa subgroup. It also is extremely weathered and is positively recognised at only one site — Kukumoa cutting.

It is possible that a correlative of the Kukumoa-C Tephra exists at the Rocky Cutting Road, Little Waihi Road, Waioeka River, and/or Opape sections, but there is not enough information to correlate individual Kukumoa subgroup tephra (except for the Kutarere) across the coastal Bay of Plenty.

The Kukumoa-C Tephra is extremely weathered and contains no **diagnostic physical characteristics**. It exists only as discontinuous lenses (creamcakes) of white clay up to ≈ 5 cm thick. No glass remains in the Kukumoa-C Tephra; it has all been altered to clay. The ferromagnesian mineral assemblage of the tephra was not studied.

Stratigraphic relationships:

The Kukumoa-C Tephra exists as lenses of white clay in the centre of a 1 m thick loess unit — 0.5 m of loess above, and 0.5 m of loess below. The loess also is very weathered.

On the basis of its titanomagnetite geochemistry, which is near identical to that of the Kutarere Tephra found ≈ 1 m below (see Chapter 14), the Kukumoa-C Tephra is thought to have originated in the same source — the Rotorua Volcanic Centre.

12-4 Kukumoa-D Tephra

The Kukumoa-D Tephra is believed to be the fourth eruptive to have been deposited in the Kukumoa subgroup. It is extremely weathered and is positively recognised at only one site — Kukumoa cutting.

It is possible that a correlative of the Kukumoa-D Tephra exists at the Rocky Cutting Road, Little Waihi Road, Waioeka River, and/or Opape sections, but there is not enough information to correlate individual Kukumoa subgroup tephras (except for the Kutarere) across the coastal Bay of Plenty.

The Kukumoa-D Tephra is extremely weathered and contains no **diagnostic physical characteristics**. It exists only as discontinuous lenses (creamcakes) of white clay up to ≈ 5 cm thick. No glass remains in the Kukumoa-D Tephra; it has all been altered to clay. The ferromagnesian mineral assemblage of the tephra was not studied.

Stratigraphic relationships:

The Kukumoa-D Tephra exists as lenses of white clay within loess. The base of the Rotoiti Tephra is found ≈ 2.5 m above this white clay layer, and much of the material between consists of compact weathered loess.

There is a definite break in the stratigraphy at the base of the Kukumoa-D Tephra, although the nature of this contact is uncertain. The loess below it is less weathered and less consolidated than the loess above the tephra, as shown by the development of a hollow in the cliff face just below the tephra.

The geochemistry of its titanomagnetites suggests that the Kukumoa-D Tephra was erupted from the same source as the Kutarere Tephra — the Rotorua Volcanic Centre.

12-5 Torere School Tephra

The Torere School Tephra is recognised at several sites in the eastern Bay of Plenty and is believed to be the third to last tephra deposited in the Kukumoa subgroup (i.e. before the Rotoiti Tephra eruption).

The type section for the Torere School Tephra is at Torere School, and it is also recognised at the Waihapokopoko and Copenhagen Road sections.

Table 12-5 : Glass chemistry of the Torere School Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Torere School	78.80	11.96	0.17	1.10	0.18	1.37	2.89	3.39	0.18	3.99	10	1.00
**01301	0.27	0.07	0.03	0.11	0.02	0.05	0.14	0.11	0.04	0.95		
Copenhagen Road	77.24	12.72	0.27	1.20	0.22	1.16	3.65	3.31	0.24	4.72	10	0.86
04802	0.28	0.21	0.04	0.13	0.04	0.08	0.13	0.13	0.05	0.52		
Waihapokopoko	78.51	12.29	0.20	1.12	0.21	1.30	2.93	3.29	0.15	7.00	10	0.95
07701	0.28	0.23	0.06	0.09	0.02	0.05	0.09	0.18	0.06	0.68		

Diagnostic features:

- At its type section the tephra was subaqueously deposited. A basal, grey medium sandy ash layer that contains occasional pumice lapilli (up to 1 cm across) is overlain by thinner beds of pale yellow-white fine ash and sandy ash; total thickness is >1 m.
- At Copenhagen Road the tephra exists as a layer of colluvium that contains weathered tephra, sand, and occasional angular greywacke gravels.
- At Waihapokopoko the tephra consists of a fine white ash, though here it may also be a fluvially reworked deposit.

Stratigraphic relationships:

The colluvium containing the Torere School Tephra at Copenhagen Road has a weak paleosol developed in its top. At the other sites where this tephra is recognised it is overlain by weathered loess, which also has a paleosol developed in its top. The paleosol is directly overlain by the Rotoiti Tephra.

The Torere School Tephra at Copenhagen Road has a mixed lower boundary to a dark reddish paleosol which contains occasional gravel clasts (see Photo-62). The mixed zone is 5 cm thick. At Torere School the tephra directly overlies a black, organic-rich silt layer (>1 m thick) which contains buried and well preserved wood (trees). At Waihapokopoko the tephra overlies a weak paleosol developed into dark brown, well sorted and unconsolidated (loose) sand. This weathered sand overlies a bed of fine sand which rests on gravels. Gravels were also reported to be present at the base of the Torere School section [Paul Froggatt, pers. comm. 1990], but were not seen by this author.

Chemistry and mineralogy:

The glass chemistry of the Torere School Tephra (Table 12-5) is quite distinctive, with a CaO content that is noticeably higher than its FeO (1.3>1.1 wt.%). TiO₂ & MgO values are higher, and K₂O values lower than average for the tephra in this study.

The Torere School Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene

Distribution and size:

The Torere School Tephra is recognised at three sites, but only perhaps at the Waihapokopoko section is it likely to be of primary airfall origin. The tephra is very thick at Torere School because it was well preserved and probably over-thickened in a lacustrine or swamp environment. However, the catchment of the rivers which flow near here are not very large and therefore the size of the clasts found here may still represent the size and violence of the eruption. The probable source area of the Torere School Tephra is thus thought to be the northern T.V.Z.

Table 12-6 : Glass chemistry of the Copenhagen Road Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Copenhagen Road	77.69	12.39	0.16	1.01	0.13	0.90	3.70	3.82	0.20	4.95	14	1.00
**04803	0.31	0.13	0.05	0.07	0.03	0.08	0.08	0.16	0.03	0.82		

12-6 Copenhagen Road Tephra

The Copenhagen Road Tephra is recognised at only one site. It is believed to be the second to last tephra deposited in the Kukumoa subgroup (i.e. before the Rotoiti Tephra eruption).

Diagnostic features:

(see Photo-1; Photo-62)

- Exists as a pale, tephra-rich colluvium unit, that contains occasional large angular greywacke clasts, and rare very large pumice clasts (up to 6 cm across). Total thickness, including paleosol, is ≈ 0.75 m.

Stratigraphic relationships:

The colluvium containing the Copenhagen Road Tephra has a weak paleosol developed into its upper half; overlain by a pale weathered tephra (Wairuru Tephra).

The colluvium directly overlies a very weak paleosol developed into the top of another colluvium unit below, which contains the Torere School Tephra.

Chemistry and mineralogy:

The glass chemistry of the Copenhagen Road Tephra (Table 12-6) shows moderate values of most element oxides, and is similar—but not identical—to the Wairuru Tephra just above.

The Copenhagen Road Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene

Distribution and size:

The Copenhagen Road Tephra is recognised at only one site, and here it is not airfall but reworked in a colluvial toe-slope deposit and probably over-thickened (actual tephra thickness could not be determined). Elsewhere in the Bay of Plenty it was probably too thin to survive as a recognisable tephra layer within the intense soil forming regime that existed at this time.

12-7 Wairuru Tephra

The Wairuru Tephra is recognised at three sites in the very east of the Bay of Plenty. It is at present believed to be the last recognised tephra deposited in the Kukumoa subgroup, or alternatively the first tephra seen beneath the Rotoiti Tephra in the eastern Bay of Plenty.

The type section for the Wairuru Tephra is at Copenhagen Road. It is also seen at the Waiotuma and at Wairuru Cemetery sections, and possibly at the Torere School section.

Table 12-7 : Glass chemistry of the Wairuru Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Wairuru Cemetary 05101	78.52 0.31	12.36 0.11	0.09 0.02	0.95 0.07	0.09 0.04	0.70 0.10	3.44 0.24	3.83 0.09	0.12 0.04	2.87 0.72	9	0.93
Copenhagen Road 04801	77.90 0.17	12.34 0.13	0.14 0.03	1.03 0.14	0.11 0.04	0.82 0.12	3.61 0.11	3.85 0.21	0.19 0.03	4.07 1.12	15	0.94
Waiotuma **05301	78.28 0.39	12.15 0.21	0.11 0.02	1.05 0.09	0.10 0.02	0.76 0.06	3.67 0.17	3.73 0.23	0.18 0.03	2.86 1.49	9	1.00
Waiotuma 05301b	76.41 0.34	13.03 0.08	0.28 0.09	1.51 0.14	0.25 0.01	1.25 0.07	4.08 0.24	3.01 0.21	0.17 0.03	3.51 1.47	3	0.71

Diagnostic features:

(see Photo-1; Photo-62)

- At Copenhagen Road, the tephra exists as a pale, weathered sandy ash unit (35 cm thick) with no visible bedding. It is uncertain whether this deposit represents primary airfall, or has been reworked into a colluvial toe-slope, and thus over-thickened.
- At Wairuru and Waiotuma it exists as a white, subaqueously deposited sandy ash.
- At the Torere School section the tephra may (or may not) be a 10 cm thick weathered sandy ash layer found within weathered loess — no glass was analysed from this layer.

Stratigraphic relationships:

The Wairuru Tephra at Copenhagen Road has a well developed paleosol (25 cm thick) in its top, and is overlain by airfall Rotoiti Tephra (see Photo-1; Photo-62). The Wairuru Tephra at Wairuru is found within a fluvial sequence. The tephra is overlain by a unit of fluvially deposited very fine sand that contains some gravel, and a weak paleosol developed in its top. Above the paleosol there are many metres of fluvial gravels, which grade up and laterally into estuarine or lacustrine silts. At Waiotuma, the tephra exists as lenses of fine sandy ash within weathered mudstone gravels, sand, and organic-rich very fine sands and silts, that comprise a fluvial terrace cut into the Otamaroa marine terrace. A paleosol has developed into the top of these fluvial sediments, and the airfall Rotoiti Tephra rests on this.

At Copenhagen Road the Wairuru Tephra rests on a weak paleosol developed into tephra-rich colluvium below. At Wairuru the tephra directly overlies many metres of fluvially deposited cobbles and coarse gravels in a sandy matrix, which in turn rest on a cut-surface into basement. At Waiotuma, the tephra overlies weathered sand and mudstone gravels, above a less obvious cut-surface.

The possible correlative of the Wairuru Tephra at Torere School lies within a paleosol developed into weathered loess. The Rotoiti Tephra occurs <50 cm above (resting on the paleosol), and the top of Torere School Tephra is 70 cm below.

Chemistry and mineralogy:

The glass from the Wairuru Tephra (Table 12-7) has moderate values of most element oxides. This chemistry, apart from slightly lower CaO values, is similar to the Copenhagen Road Tephra which is found just below. The relatively high analytical totals before normalisation (i.e. 100% minus wt.% water) reflects the fact that the tephra is relatively young, and fell into a subaqueous environment which has preserved the glass well (Wairuru & Waiotuma sites especially).

The sample from Waiotuma shows a distinct secondary chemical component with a much higher FeO, CaO & Na₂O content, and lower SiO₂ & K₂O. The glass chemistry of this minor component is very distinctive, but is inexplicably absent from the samples taken from the other two sites.

The Wairuru has a ferromagnesian mineral assemblage consisting of:

hornblende + pyroxene (+ biotite?)

Hornblende is the dominant ferromagnesian mineral in this tephra at Copenhagen Road and it is also present in reasonable quantities at Wairuru. However, at Waiotuma it is only a trace mineral and pyroxene is more common. Biotite is the dominant ferromagnesian mineral at Wairuru, which is not expected from its glass chemistry. The assemblage at these two fluvially deposited sites (Wairuru & Waiotuma) is therefore believed to have been contaminated with eroding basement material during their deposition.

Distribution and size:

The Wairuru Tephra is recognised at three sites in the far eastern Bay of Plenty, but at two of these it is represented by deposits which are fluvially reworked, and the other is also probably over-thickened. The suspected correlative of the Wairuru Tephra at the Torere School site is almost certainly of airfall origin, but no sample was taken of it here for glass chemistry analysis to prove its identity. The Wairuru Tephra has not been recognised at any sites nearer its source. The tephra was probably incorporated into the very strong paleosol beneath the Rotoiti Tephra, or possibly removed by erosion as represented by the widespread unconformity often present at this stratigraphic position.

12-8 Reid's Reserve Tephra

The Reid's Reserve Tephra has been positively identified at only one site — opposite Reid's Reserve Memorial rest area between Whakatane and Taneatua. Its stratigraphic position has yet to be precisely determined.

Diagnostic features:

- Consists of a massive, 1.2 m thick layer of bright white, very fine sandy ash; composed predominantly of large glass shards, but contains some pumice up to 0.5 cm across.
- A basal layer (10 cm thick) of coarser sandy ash also exists.

Stratigraphic relationships:

The top of the Reid's Reserve Tephra is slightly weathered and is directly overlain by a 0.5 m thick bed of hard greywacke gravel, which is in turn overlain by several metres of a mixed unit that contains weathered gravel sized silt clasts, silt/loess beds, and weathered tephra and sand. A very well developed paleosol exists in the top few metres of this mixed unit, with the Rotoiti Tephra resting directly on this.

The Reid's Reserve Tephra overlies a paleosol developed into weathered greywacke gravels, of which only the uppermost 80 cm is observed.

Table 12-8 : Glass chemistry of the Reid's Reserve Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Reid's Reserve	76.56	12.66	0.17	1.25	0.12	0.91	3.74	4.24	0.35	6.21	17
11201	0.35	0.14	0.06	0.13	0.03	0.04	0.20	0.13	0.04	1.01	

Chemistry and mineralogy

The glass chemistry of the Reid's Reserve Tephra (Table 12-8) is distinctive, with moderately high FeO, lower CaO, and high K₂O contents. The high K₂O values do not allow a match to any other known tephra. The closest chemical match to the Reid's Reserve Tephra is the Kaingaroa Tephra, but this eruptive is generally much better bedded, coarser grained and contains highly vesicular pumice rather than the large glass shards of the Reid's Reserve Tephra.

The Reid's Reserve Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende + biotite

Discussion:

The Reid's Reserve Tephra is 1.3 m thick at Reid's Reserve, and is believed to be airfall at this site because it rests upon a paleosol which formed in a subaerial environment. It has an unknown source, but from its thickness it must have had at least a moderate eruptive volume, c. 10 km³.

The tephra is found just below the Rotoiti Tephra and bracketed by fluvial sediment. It is very well preserved and does not appear to be much older than the Rotoiti. The Reid's Reserve Tephra is most probably a member of the Kukumoa subgroup, but is not recognised elsewhere due to the extreme weathering that this subgroup has undergone. Alternatively, the widespread unconformity that exists just below the Rotoiti Tephra in the Bay of Plenty may have eroded and totally removed the Reid's Reserve Tephra at most other sites in the region.

Chapter Thirteen : Unidentified Tephra Deposits in the Bay of Plenty

This chapter describes and discusses sections and tephra which, for a number of reasons, have unknown or uncertain positions within the stratigraphic record.

The tephra within these sections may represent well preserved parts of the tephrostratigraphic record which elsewhere are not so well preserved (e.g. the Kukumoa, Ohiwa Harbour and/or Ohinekoao subgroups). The eruptives are discussed in this chapter to show that their presence has been recognised, but that further work is required to understand them fully.

Some of the sections and tephra have been studied in some detail and glass chemistry is available. Some of these sections may hold important information for the tephrostratigraphy of the eastern Bay of Plenty.

The failure to achieve positive correlations and identifications for the tephra presented in this chapter is due to many reasons, though it is often the differences in the physical characteristics of the tephra that has restricted correlations by "hand over hand" methods. Differences in the environment of deposition causes differences in appearance, for example, subaerial terrestrial deposition, versus subaqueous deposition within lignites and reworked deposits of a fluvial over-bank environment, versus deposition within a shallow marine sequence. In such cases, and where the sections are just much closer (e.g. Taneatua) or further away (e.g. Te Piki) from source, the distinctive physical features normally used to identify the individual tephra are often absent and correlation becomes difficult.

Several tephra (e.g. Burke, McCoy, Ngatiawa) occur by themselves without any other deposit or landform which could be used to estimate their age or stratigraphic position.

Glass chemistry was the only technique available in this work for the correlation of the "unidentified" tephra, but often the chemistries are not distinctive and match a number of different eruptives. Alternatively there are some eruptives (e.g. Ruatuna-D) which have highly distinctive glass chemistries that match no eruptives in the known eastern Bay of Plenty tephrostratigraphy.

Table 13-0.1 : Similarity coefficients (S.C.'s) that compare the glass chemistries of the major unidentified tephra found throughout the Bay of Plenty, with each other and with their possible correlatives in the known eastern BOP stratigraphy.

oldest?	O3902	O3902b	O2802a	O2802b	ALL	O2803	O3905	O6402	O0101	O0803a	O0803b	O9401	O9501	O4103	O6701	O6801	10201	O4301	O6801	O6804	O3002	O3001	O3103
Wainarara (plin.) 03902	1.00																						
Wainarara (plin-b) 03902b	0.87	1.00																					
Wainarara Igb. (a) 02802a	0.90	0.91	1.00																				
Wainarara Igb. (b) 02802b	0.79	0.86	0.86	1.00																			
All analyses	0.88	0.93	0.94	0.93	1.00																		
Ruatuna-D	0.91	0.86	0.88	0.78	0.86	1.00																	
McCoY	0.85	0.89	0.79	0.87	0.91	1.00																	
Wainana-C	0.84	0.86	0.91	0.92	0.91	0.85	0.84	1.00															
Herespuru	0.81	0.90	0.90	0.93	0.91	0.81	0.81	0.90	1.00														
Kohioawa Stream(a) 00803a	0.83	0.93	0.93	0.92	0.94	0.83	0.83	0.92	0.95	1.00													
Kohioawa Stream(b) 00803b	0.88	0.85	0.86	0.80	0.87	0.91	0.88	0.83	0.83	0.84	1.00												
Qtz-Biot. Igb.	0.87	0.79	0.81	0.72	0.79	0.83	0.87	0.77	0.73	0.76	0.86	1.00											
Qtz-Biot. Igb.	0.82	0.91	0.85	0.84	0.88	0.82	0.81	0.86	0.89	0.83	0.81	0.73	1.00										
Westend	0.87	0.87	0.90	0.78	0.87	0.89	0.87	0.84	0.81	0.85	0.83	0.81	0.83	1.00									
Te Piki West	0.89	0.90	0.96	0.87	0.96	0.86	0.89	0.89	0.90	0.93	0.86	0.80	0.85	0.88	1.00								
Te Piki	0.88	0.79	0.81	0.72	0.79	0.87	0.88	0.78	0.73	0.77	0.87	0.92	0.75	0.84	0.81	1.00							
Burke	0.82	0.87	0.91	0.83	0.91	0.82	0.82	0.94	0.95	0.94	0.81	0.76	0.86	0.83	0.89	0.76	1.00						
Ngatiawa	0.86	0.77	0.79	0.71	0.78	0.85	0.88	0.76	0.72	0.74	0.86	0.91	0.73	0.82	0.79	0.95	0.74	1.00					
T.P.farm. track-B	0.92	0.80	0.83	0.73	0.81	0.87	0.92	0.79	0.74	0.78	0.89	0.94	0.76	0.85	0.82	0.95	0.77	0.83	1.00				
T.P.farm. track-D	0.91	0.93	0.91	0.84	0.94	0.89	0.91	0.89	0.87	0.89	0.88	0.83	0.88	0.89	0.93	0.85	0.88	0.83	0.86	1.00			
Pikowai-1	0.88	0.77	0.80	0.72	0.78	0.87	0.89	0.78	0.74	0.76	0.89	0.93	0.73	0.81	0.79	0.94	0.75	0.93	0.86	0.83	1.00		
Pikowai-2	0.89	0.90	0.96	0.87	0.94	0.87	0.89	0.91	0.90	0.92	0.87	0.90	0.85	0.90	0.96	0.81	0.90	0.80	0.82	0.92	0.81	1.00	
Maketu-B	0.91	0.91	0.93	0.85	0.93	0.89	0.91	0.88	0.88	0.91	0.89	0.81	0.85	0.88	0.95	0.82	0.86	0.81	0.84	0.92	0.82	0.95	1.00
Reeves-A	0.90	0.90	0.91	0.85	0.94	0.90	0.90	0.88	0.88	0.91	0.91	0.81	0.86	0.85	0.98	0.82	0.86	0.81	0.83	0.90	0.81	0.92	0.96
Ohinekoao-A	0.88	0.89	0.90	0.85	0.94	0.89	0.88	0.90	0.87	0.91	0.91	0.82	0.86	0.85	0.92	0.83	0.88	0.81	0.85	0.90	0.82	0.90	0.93
Tablelands-A(a)	0.84	0.90	0.91	0.90	0.94	0.85	0.84	0.89	0.96	0.94	0.86	0.75	0.86	0.82	0.93	0.75	0.91	0.74	0.77	0.89	0.77	0.91	0.91
Tablelands-A(b)	0.88	0.84	0.88	0.79	0.86	0.92	0.89	0.84	0.82	0.83	0.83	0.87	0.79	0.87	0.88	0.88	0.82	0.86	0.89	0.90	0.88	0.90	0.90
Otarawaire	0.80	0.91	0.89	0.89	0.91	0.80	0.80	0.87	0.94	0.95	0.80	0.74	0.87	0.83	0.90	0.74	0.92	0.72	0.75	0.86	0.72	0.88	0.87
Kohioawa(a)	0.88	0.92	0.88	0.87	0.93	0.89	0.88	0.88	0.91	0.92	0.89	0.78	0.89	0.84	0.90	0.80	0.89	0.78	0.81	0.93	0.80	0.90	0.92
Kohioawa(b)	0.73	0.82	0.80	0.89	0.81	0.73	0.83	0.88	0.88	0.85	0.75	0.66	0.82	0.73	0.80	0.67	0.87	0.68	0.68	0.78	0.68	0.80	0.79
Whakamaru Igb.	0.87	0.83	0.90	0.89	0.95	0.86	0.87	0.90	0.91	0.94	0.87	0.78	0.89	0.86	0.92	0.79	0.91	0.78	0.80	0.94	0.78	0.92	0.92
Matahina	0.86	0.92	0.94	0.91	0.96	0.84	0.86	0.89	0.94	0.95	0.84	0.77	0.87	0.86	0.96	0.78	0.93	0.77	0.79	0.92	0.77	0.95	0.92
Hiwarau	0.89	0.81	0.83	0.74	0.81	0.88	0.91	0.80	0.76	0.79	0.90	0.93	0.77	0.84	0.82	0.97	0.78	0.94	0.97	0.87	0.85	0.83	0.85
Opotiki	0.91	0.81	0.84	0.76	0.82	0.90	0.92	0.82	0.78	0.80	0.94	0.92	0.79	0.84	0.84	0.92	0.79	0.91	0.95	0.87	0.84	0.85	0.86
Relhana-G Igb.	0.88	0.81	0.81	0.72	0.80	0.89	0.88	0.77	0.73	0.76	0.88	0.88	0.76	0.89	0.81	0.91	0.76	0.89	0.92	0.88	0.81	0.83	0.83
Kaingaaroa Igb.	0.95	0.89	0.87	0.79	0.88	0.89	0.94	0.85	0.81	0.84	0.84	0.85	0.83	0.87	0.88	0.86	0.83	0.84	0.89	0.91	0.85	0.87	0.89
youngest?																							

boxed shaded areas are believed to be possible correlatives of each other

Similarity coefficients have been used to compare the glass chemistries of the unidentified eruptives with each other, and with their suspected correlatives within the known eastern Bay of Plenty (BOP) stratigraphy. The similarity coefficients comparing all of the major (thickest) uncorrelated tephras are presented in Table 13-0.1, and those comparing the eruptives considered to be of lesser importance in Table 13-0.2. Tables showing the similarity coefficients that compare the tephras within any particular stratigraphic section are presented within the text discussing that section.

Table 13-0.2 : Similarity coefficients (S.C.'s) that compare the glass chemistries of the minor unidentified tephras found throughout the Bay of Plenty with each other, and with their possible correlatives in the known eastern BOP stratigraphy.

<i>oldest</i>		O3701	O3702a	O3702b	O3702c	O3702d	O6403	O6401	O6402	O2801	O2803
Waiopua-A	03701	1.00									
Waiopua-I(a)	03702a	0.78	1.00								
Waiopua-I(b)	03702b	0.61	0.75	1.00							
Waiopua-I(c)	03702c	0.95	0.80	0.63	1.00						
Waiopua-I(d)	03702d	0.87	0.77	0.61	0.86	1.00					
Waimana-A	06403	0.87	0.73	0.59	0.87	0.85	1.00				
Waimana-B	06401	0.86	0.71	0.58	0.85	0.87	0.89	1.00			
Waimana-C	06402	0.87	0.72	0.58	0.87	0.87	0.94	0.94	1.00		
Ruatuna-C	02801	0.83	0.90	0.72	0.85	0.76	0.76	0.74	0.75	1.00	
Ruatuna-D	02803	0.94	0.80	0.63	0.95	0.82	0.86	0.82	0.85	0.75	1.00
Waignarara(a)	02802a	0.91	0.74	0.60	0.91	0.87	0.93	0.88	0.91	0.79	0.88
Waignarara(a)	02802a	0.82	0.67	0.55	0.80	0.86	0.89	0.92	0.92	0.70	0.78
Waignarara (ALL)		0.90	0.73	0.59	0.89	0.89	0.89	0.91	0.91	0.77	0.86
McCoy	03905	0.93	0.82	0.65	0.93	0.87	0.86	0.82	0.84	0.85	0.91
Herepuru	00101	0.85	0.68	0.55	0.82	0.88	0.91	0.90	0.90	0.71	0.81
Ohinekoao-A	00913	0.92	0.76	0.60	0.93	0.86	0.87	0.91	0.90	0.81	0.89
Ohinekoao-D	00910	0.72	0.92	0.82	0.74	0.71	0.68	0.66	0.67	0.84	0.74
Ohinekoao-E	00904a	0.61	0.74	0.97	0.63	0.60	0.59	0.57	0.58	0.71	0.62
Ohinekoao-G	00903	0.91	0.73	0.59	0.90	0.88	0.87	0.92	0.90	0.77	0.87
Whakamaru Igb.		0.91	0.82	0.58	0.89	0.93	0.87	0.91	0.90	0.76	0.86
Matahina	01501	0.89	0.72	0.59	0.86	0.88	0.91	0.90	0.89	0.75	0.84
Hiwarau	02701	0.88	0.86	0.68	0.90	0.81	0.81	0.79	0.80	0.94	0.88
Opotiki	01701	0.90	0.84	0.65	0.91	0.83	0.82	0.79	0.82	0.89	0.90
Reihana-G	06218	0.85	0.87	0.70	0.88	0.79	0.79	0.75	0.77	0.91	0.88
Kaingaroa	06209	0.92	0.77	0.63	0.92	0.89	0.85	0.85	0.87	0.83	0.88
Kutarere	03801	0.90	0.73	0.61	0.89	0.88	0.85	0.87	0.87	0.78	0.86
<i>youngest</i>											

shaded areas represent tephras that are believed to be possible correlatives on stratigraphic grounds

Glass chemistry comparisons often give data that is good enough for tentative correlations to be made, and if these were supported by stratigraphic controls—for example, radiometric ages, fossil assemblages or paleoclimatic evidence—the correlations have been tentatively accepted and included within the discussions on the individual tephras in Chapters Six through Twelve. However, as the stratigraphic positions of the tephras in this chapter remain tentative, many sections have been discussed further in this chapter (e.g. Te Piki area, Pikowai Reserve, Maketu).

Table 13-1.0 : Similarity coefficients that compare the glass chemistries of tephtras found in the Te Piki area with each other and with their possible correlatives in the eastern BOP stratigraphy.

<i>oldest</i>		O6701	O6601	O6803	O6801	O6805a	O6805b	O6804
Te Piki West	06701	1.00						
Te Piki	06601	0.81	1.00					
Te Piki FT-A	06803	0.83	0.96	1.00				
Te Piki FT-B	06801	0.82	0.95	0.96	1.00			
Te Piki FT-C(a)	06805a	0.88	0.90	0.91	0.91	1.00		
Te Piki FT-C(b)	06805b	0.80	0.94	0.94	0.96	0.89	1.00	
Te Piki FT-D	06804	0.93	0.85	0.86	0.86	0.90	0.82	1.00
Matahina	01501	0.96	0.78	0.80	0.79	0.86	0.77	0.92
Hiwarau	02701	0.82	0.97	0.95	0.97	0.92	0.95	0.87
Opotiki	01701	0.84	0.92	0.92	0.95	0.93	0.92	0.87
Torere-N	06217	0.88	0.89	0.89	0.91	0.95	0.88	0.90
Torere-N(b)	06217b	0.84	0.93	0.94	0.95	0.93	0.94	0.87
Torere-O	06214	0.91	0.83	0.85	0.85	0.92	0.82	0.90
Kaingaroa	06209	0.90	0.85	0.85	0.87	0.92	0.84	0.93
Huntress-D	01509	0.94	0.83	0.85	0.84	0.88	0.82	0.96

youngest

shaded areas are tephtras that are believed to be likely correlatives

Other tephric deposits, and some entire sections (e.g. Taneatua, Motuhora Island) were not studied in detail. Some of these sections were discovered too late for inclusion within this thesis, while others were not believed to be essential for developing the tephrostratigraphic record. For example, although the Waiopua and McCoy Road-(2) sections would be useful for determining the local paleo-environmental history, they would probably not add as much to the complete tephrostratigraphic record as other sections that were chosen to be studied in detail.

Deposits and sections such as those above, along with others which have only undergone cursory inspection, are listed at the end of this chapter; primarily to locate areas for future research and follow-up studies.

The tephra and sections described below are presented in approximate order of their detail of study, though those whose stratigraphic positions are roughly known are presented first.

As their stratigraphic positions are uncertain, many of the units have been given individual tephra names. Further research may be able to identify the tephra and correlate them to the eastern Bay of Plenty stratigraphy. If, or when, this occurs, many of the individual tephra names may lapse.

13-1 Te Piki Area Tephra

Several tephra are found within marine sediments in the Te Piki area, near Cape Runaway at the very northeastern end of the Bay of Plenty region. These eruptives are thought to correlate with several of the larger tephra within the Murupara, Torere and Huntress Creek subgroups, but these correlations are based mainly upon glass chemistry and need further confirmation. Similarity coefficients that compare the glass chemistries of these tephra with those in the known eastern Bay of Plenty stratigraphy, are presented in Table 13-1.0.

There are four individual sections within the Te Piki area, two on Highway-(2) [Te Piki = Y14/562905, and Te Piki West = Y14/577903], and two on farm tracks nearby [Te Piki farm track = Y14/560904, airstrip road = Y14/560901]. Figure 13-1 is a sketch of the area, showing the four sections with their relative elevations and probable correlations.

The marine sediments found in this area contain fossils of topmost Castlecliffian age, namely *Pecten Novæzelandiæ Aotea* [Chapman-Smith & Grant-Mackie, 1971], which indicates that they are of similar age to the eastern Bay of Plenty stratigraphy that has been developed in this thesis.

The sediments in the Te Piki region represent a marine environment that has since been uplifted. The major terrace surface in this area has been traced to the coast and correlated with the $\delta^{18}\text{O}$ stage-5e Otamaroa marine terrace [Chapman-Smith & Grant-Mackie, 1971]. The cut surface of this terrace has been recognised in the Te Piki area at an elevation of c. 60–70 m above sea-level (a.s.l.); 13.5 m and 8 m above the TP/Farm-D Tephra, on the Te Piki farm track and the airstrip road respectively [Sumosusastro, 1983]. The variable height difference between the terrace surface and the TP/Farm-D Tephra is related to

the slight northwards dip of the marine sediments. The tephras also appear to thin towards the south, which suggests that they may have been over-thickened in the north. The presence of the Otamaroa Terrace so far inland in this area is the result of the relatively soft unconsolidated marine sediments that it has cut into. Where harder basement rock occurs, the Otamaroa Terrace parallels the coast only a few hundred metres inland.

Figure 13-1 : Stratigraphic sections in the Te Piki area

The tephras that occur in this region are presented below in stratigraphic order of deposition (oldest to youngest).

13-1.1 Te Piki West Tephra

The Te Piki West Tephra is seen at only one site in this area, where it rests within grey-brown marine mudstone; 4 m of which can be seen below (to the road), and 1 m above, to where it becomes weathered by the development of the 1 m thick present-day soil. This eruptive has previously been tentatively correlated with the Matahina Tephra [Sumosusastro, 1983], and this work concurs with this.

- The tephra is 70 cm thick and well bedded. It consists of cm-bedded, alternating white ash and slightly yellowish sandy ash beds; the coarsest layer (pumices up to 3 mm long) occurring at the base.

Table 13-1.1 : Glass chemistry of the Te Piki West Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Te Piki West	78.48	12.15	0.12	1.03	0.11	0.93	3.49	3.55	0.14	1.76	14	1.00
**06701	0.39	0.11	0.03	0.09	0.02	0.07	0.17	0.19	0.02	0.86		
Te Piki West	78.11	12.29	0.11	1.05	0.12	0.86	3.79	3.64		6.97	11	0.95
\$—\$	0.29	0.16	0.03	0.08	0.03	0.05	0.17	0.21		2.04		

\$—\$ = [Paul Froggatt pers. comm. in *Sumususastro*, 1983]

Table 13-1.2 : Glass chemistry of the Te Piki Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Te Piki	77.15	12.83	0.19	1.33	0.22	1.37	3.45	3.37	0.09	3.85	10	1.00
**06601	0.36	0.18	0.04	0.09	0.04	0.09	0.18	0.12	0.02	0.30		
Te Piki farm track	76.92	12.89	0.17	1.37	0.19	1.35	3.52	3.41	0.17	5.11	12	0.96
06803	0.38	0.14	0.05	0.10	0.05	0.12	0.10	0.13	0.05	1.47		
Te Piki	76.45	12.97	0.21	1.39	0.21	1.42	4.08	3.23		6.24	10	0.95*
\$—\$	0.46	0.33	0.03	0.16	0.05	0.13	0.30	0.17		1.10		

\$—\$ = [Paul Froggatt pers. comm. in *Sumususastro*, 1983]

The glass chemistry of the Te Piki West Tephra (Table 13-1.1) is not particularly distinctive, having moderate values for all major element oxides. This chemistry is quite a good match to that of the Matahina Tephra (see Table 9-8; Figure 13-2); having a similarity coefficient of "0.96" (Table 13-1.0).

The Te Piki West Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende ± *biotite(t)*

The coarse grain-size and great thickness of the tephra — for its distance away from source — limits the number of possible correlatives it can have. The Matahina Tephra is virtually the only large (thick) eruptive with this chemistry found in the eastern Bay of Plenty during the last 400 ka, and is hence the most likely correlative.

13-1.2 Te Piki Tephra

The Te Piki Tephra is recognised in at least one and up to possibly three sites in this area. It is best exposed along a 50 m stretch of Highway-35 (Te Piki site) where it rests within fossiliferous grey-brown marine mudstone; 4 m of which is seen below, to the road, and 2 m above, until obscured by vegetation. A white fine ash layer is visible near the base of the airstrip road section, and a white fine ash bed near the bottom gate of the farm track, are both believed to represent the Te Piki Tephra. The Te Piki eruptive has previously been tentatively correlated with the "Lower Griffin Road Tephra" [Froggatt, 1983]. From their distributions and physical features in this work, the Torere-A Tephra has been tentatively correlated with the Lower Griffin Road Tephra, and the Hiwarau Tephra (Torere-C), which is only very slightly younger than the Torere-A, is a much more likely correlative (than the Torere-A) of the Te Piki Tephra.

- The tephra is 60 cm thick and consists of a very white, massive fine ash. It has a sharp and irregular basal contact to the mudstone below, and a gradational mixing zone, 30 cm thick, with the mudstone above.

The glass chemistry of the Te Piki Tephra (Table 13-1.2) is distinctive in that it has relatively high wt.% values of FeO, CaO, TiO₂ & MgO. Few tephra in the eastern Bay of Plenty tephrostratigraphic record have this chemistry; the Hiwarau Tephra (S.C. = "0.97" in Table 13-1.0) one of the largest of these.

The Te Piki Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + biotite

The thickness of the Te Piki Tephra deposit in this area limits the number of possible correlatives it can have. The Hiwarau, Pikowai and Ngatiawa Tephrae are the only thick tephrae with this chemistry found in the north and eastern Bay of Plenty. However, the latter two eruptives have an unknown stratigraphic position, age or distribution, and hence cannot realistically be correlated to this area. They may even be correlatives of the Hiwarau Tephra themselves (see later this chapter). The Hiwarau Tephra is believed to have been dispersed in a northeasterly direction and is only slightly younger than the

Table 13-1.3 : Glass chemistry of the Te Piki farm track-B Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Te Piki farm track	77.33	12.64	0.21	1.28	0.19	1.28	3.54	3.40	0.14	2.79	13	1.00
**06801	0.26	0.09	0.03	0.10	0.04	0.08	0.12	0.12	0.01	1.09		
Farm Track	77.13	12.80	0.19	1.28	0.21	1.30	3.75	3.27		6.11	11	0.96*
\$—\$ (B)	0.36	0.16	0.04	0.10	0.02	0.04	0.09	0.31		0.82		

\$—\$ = [Paul Froggatt pers. comm. in *Sumususastro*, 1983]

Matahina Tephra — which fits well with the stratigraphic relationship of the Te Piki Tephra to the Te Piki West Tephra (a probable Matahina correlative).

Glass shards from the Te Piki Tephra have been fission-track dated at 0.21 ± 0.10 Ma, and 0.20 ± 0.08 Ma (± 2 s.d.) [Sumosusastro, 1983]. These ages are younger than that estimated for the Hiwarau Tephra from the paleoclimatic data (c. 0.31–0.32 Ma), but the fission-track ages have very large errors and may be significantly too young due to annealing of tracks in the glass (see Chapter 2, sect. 2-4). However, Uranium series dating on solitary corals found in the marine sediments at the Te Piki section give similar ages; 198 ± 4 ka, 186 ± 4 ka, 175 ± 3 ka, and 244 ± 13 ka [M. McCulloch, pers. comm. 1993]. If the Uranium series ages are correct, then either the tentative correlations made here—between the Te Piki tephras and the eastern Bay of Plenty tephras—are incorrect, or the estimated ages of many of the eastern Bay of Plenty eruptives are wrong.

13-1.3 Te Piki Farm Track-B Tephra

The Te Piki Farm Track-B Tephra (TP/Farm-B) is the Farm Track-B Tephra of Sumosusastro [1983], and is recognised at only one site in this area — on the Te Piki Farm Track. Here it rests on marine mudstone (>0.2 m thick), and is overlain by 2.4 m of reworked pumiceous sands, becoming less pumiceous upwards to the base of the next tephra. The upper contact to the pumiceous sand unit is erosional. The TP/Farm-B Tephra had previously been thought to be related to the Te Piki Tephra below, either a correlative of, or reworked from it [Sumosusastro, 1983], but this worker believes such reworking to be unlikely and that it is a primary tephra, though deposited in a subaqueous environment.

- The tephra consists of 15 cm of white medium sandy ash, above 15 cm of orange stained finer sandy ash.

The glass chemistry of the TP/Farm-B Tephra (Table 13-1.3) is similar to that of the Te Piki Tephra in that it has high wt.% values of FeO, CaO, TiO₂ & MgO, though the FeO & CaO contents are slightly lower than that of Te Piki Tephra. Few eruptives in the eastern Bay of Plenty tephrostratigraphy have this chemistry; the only thick deposit above the Hiwarau Tephra is the Opotiki Tephra (S.C. = "0.95" in Table 13-1.0).

The TP/Farm-B Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende

The thickness and medium sand sized clasts of TP/Farm-B Tephra limit the number of possible correlatives. The Opotiki Tephra is the most likely correlative of the TP/Farm-B Tephra and has similar physical characteristics — well sorted massive sandy ash (in the Opotiki area). The most distinctive characteristic of the Opotiki Tephra is the sharp colour change between the dark grey Opotiki-(2) unit and the lighter grey of the Opotiki-(3) unit, but the orange staining at the T.P. farm track site may have disguised this feature. Orange staining does occur at the base of the Opotiki Tephra, at both the Pukeruru

Table 13-1.4 : Glass chemistry of the Te Piki farm track-C Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Te Piki farm track	77.44	12.81	0.18	1.12	0.16	1.05	3.45	3.63	0.18	7.33	13
06805	0.39	0.20	0.06	0.09	0.04	0.11	0.13	0.21	0.03	2.01	
Te Piki farm track	76.40	13.25	0.22	1.47	0.20	1.30	3.50	3.51	0.14	6.31	2
06805b	0.39	0.16	0.03	0.01	0.04	0.12	0.03	0.37	0.01	2.50	

Point and Torere West sections. The Opotiki Tephra is immediately and directly overlain by the coarser pumice of the Torere-I Tephra which has a distinctive glass chemistry. The pumiceous sand unit immediately above the T.P.farm track-B Tephra contains large pumice lapilli which may correlate with the Torere-I Tephra, but the glass chemistry of the pumices in these pumices were not analysed.

13-1.4 Te Piki Farm Track-C Tephra

The Te Piki Farm Track-C Tephra (TP/Farm-C) is recognised at only one site in this area, where it occurs as 6 cm of white fine ash within firm greenish mudstone and fine sand, 6 cm above an irregular boundary to the unit of pumiceous sand below. The fine sand above the tephra is only 6 cm thick, also, and has an erosional upper boundary to ≈ 1 m of mudstone; the TP/Farm-D Tephra present above this. The TP/Farm-C Tephra has not previously been reported.

The glass chemistry of the TP/Farm-C Tephra (Table 13-1.4) is not particularly unusual, but none of the tephra within the Torere subgroup are a close chemical match — mainly due to a CaO content which is higher than other tephra with similar FeO contents. The closest chemical matches are the Torere-L, Torere-N and Torere-O Tephra. The presence of a secondary chemical component is also indicated, which is believed to correlate to the Reihana-G Tephra (probably reworked from below), though this latter eruptive has a slightly lower CaO content (see sect. 10-13).

Only a few minerals were found in the ferromagnesian separate of the TP/Farm-C Tephra; these are:

hornblende + hypersthene + augite

From the tentative correlations of the tephra which bracket it, the TP/Farm-C Tephra should correlate with one of the units between the Opotiki Tephra and the Huntress-D Tephra. On the basis of its thickness, the TP/Farm-C Tephra is most likely the Torere-O Tephra, although the Torere-N Tephra is a closer chemical match (see Table 13-1.0). If it is either of these tephra, then both the range and estimated volume—of whichever tephra it is—is greatly increased. The erosional boundaries that occur both above and below the tephra may have removed any other tephra that may have reached this distal area.

13-1.5 Te Piki Farm Track-D Tephra

The Te Piki Farm Track-D Tephra (TP/Farm-D) is the Farm Track-A Tephra of Sumosusastro [1983] and it is recognised at two sites in this area — where it rests within fine marine sandy mudstone. Little stratigraphy is visible above this tephra at the farm track section, but at the airstrip road section two tephra units are recognised; separated by 65 cm of sandy mudstone. The glass from these two units was not analysed in this work but they have previously been analysed by P.C. Froggatt [in Sumosusastro, 1983] and both are nearly identical to that of the TP/Farm-D Tephra. The two deposits on

Table 13-1.5 : Glass chemistry of the Te Piki farm track-D Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C.
Te Piki farm track **06804	78.48 0.28	12.24 0.18	0.16 0.07	1.20 0.13	0.11 0.05	0.83 0.14	3.43 0.18	3.40 0.18	0.18 0.02	4.34 0.72	10	1.00
Te Piki farm track \$-\$ (A)	78.48 0.23	11.88 0.25	0.12 0.04	1.20 0.18	0.10 0.04	0.82 0.15	3.68 0.13	3.67 0.19		6.31 1.33	10	0.93*
airstrip road \$-\$ (A)	77.67 0.56	12.38 0.29	0.11 0.02	1.26 0.17	0.07 0.03	0.80 0.12	3.97 0.27	3.65 0.25		8.31 1.87	14	0.88*
airstrip road \$-\$ (B)	78.19 0.46	12.09 0.29	0.12 0.04	1.24 0.20	0.08 0.03	0.83 0.17	3.89 0.21	3.57 0.21		5.63 1.01	13	0.91*

\$-\$ = [Paul Froggatt pers. comm. in *Sumususastro*, 1983]

Figure 13-2 : Comparison of glass chemical means and standard deviations (1 s.d.) between the Te Piki area tephtras and the eastern Bay of Plenty tephrostratigraphy

the airstrip road could represent one eruption, subsequently reworked, or two separate eruptions closely spaced in time.

- The tephra consists of a well sorted, yellow-green, medium sandy ash layer (60 cm thick). The lower tephra unit at the airstrip road section consists of 20 cm of fine sandy ash, and the upper tephra unit of 15 cm of stained and cemented medium sandy ash.

The glass chemistry of the TP/Farm-D Tephra (Table 13-1.5) is not particularly distinctive, with moderately high FeO, and average CaO contents.

The TP/Farm-D Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene

The thickness and medium sand sized clasts of the TP/Farm-D Tephra limit the number of possible correlatives. On the basis of the tentative correlations of the tephra below it, the TP/Farm-D Tephra should be a correlative of one of the tephra in the upper Torere, or lower Huntress Creek, subgroups. Two thick deposits in the eastern Bay of Plenty have near identical glass chemistries to the TP/Farm-D Tephra — the Kaingaroa Tephra and the Huntress-D Tephra (see Figure 13-2). The latter tephra is thicker and coarser than the former, but the Kaingaroa is also thought to be large enough to have reached this area. Both of these eruptives are likely correlatives, but the age difference between them makes it unlikely that the two tephra found on the airstrip road correlate to both the Kaingaroa Tephra (lower unit) and the Huntress-D Tephra (upper unit) respectively.

Summary:

The fact that three tephra in the eastern Bay of Plenty stratigraphy—the Matahina, Hiwarau and Opotiki—can be correlated to tephra found in the Te Piki area—the Te Piki West, Te Piki and Te Piki farm track-B respectively—reinforces all of the correlations and suggests that they are more than just tentative. However, as the correlations are based almost solely on glass chemistry (see Table 13-1.0; Figure 13-2) it would be unwise to consider them as positive correlations, especially as the radiometric ages conflict with the ages estimated from paleoclimatic data in the eastern Bay of Plenty.

13-2 Maketu Headland Tephra Deposits

(see also section 16-1.2)

The Maketu Headland is located on the western Bay of Plenty coast and contains a great thickness of tephric sediment and primary eruptive deposits. The most complete section through the headland can be seen on the road down to Little Waihi, and the cliff-face next to the estuary mouth [from V14/159765 to V14/166770]. The section here is almost continuous for its full ~50 m thickness.

Stratigraphy:

A stratigraphic section of the Maketu Headland is shown in Figure 13-3 and discussed below.

The lower third to half of the high-standing Maketu Headland is comprised of a very thick, single(?) event, torrential flood deposit. This flood deposit is possibly related to a caldera wall breach and the rapid draining of a caldera lake. The deposit has an erosional contact with much finer alternating beds of silt and cross-bedded pumiceous sand (Maketu-A) below; believed to be of marine origin. The basal few metres of the main flood deposit has incorporated large "rip-up clasts" of the underlying silts, and also contains large irregular boulders (up to 2 metres across) of hard welded ignimbrite (see Photo-54). The boulders are a mixture from several different ignimbrites—distinguished by colour, glassiness, phenocryst content, degree of welding, shapes of pumice lenticules—which indicates that these volcanics are not primary eruptives. The presence of dense ignimbrite clasts within the flow suggests that the flood was lahatic, or a hyper-concentrated stream flow.

The matrix of the flood deposit consists of pumice lapilli and coarse sandy ash (Maketu-B) with little bedding apparent, though it does appear to fine upwards; the boulders rapidly becoming smaller and much more sparse. The relatively well sorted nature and monotonous pale yellow-brown colour of the pumice sand is thought to mask any bedding features that are present. Bedding becomes apparent near the top of the unit, where it consists of thin, parallel bedded, greyish pumice sand and small lapilli, and occasional layers of coarser pumice (clasts ≤ 5 cm across). At the very top, 20–30 m up from the base, a coarse white pumice deposit is present. This consists of a 1 m thick bed of reworked pumice blocks (up to 10 cm across) and sand, overlain by 2 m of reverse graded white pumice lapilli (Maketu-D). This upper unit may be an airfall tephra deposit.

The top of the Maketu-D deposit has an erosion scoured boundary, with up to 2 m relief, overlain by a channel-fill deposit of cross-bedded pumice sand that contains coarse pumice blocks and hard ignimbrite boulders up to 15 cm across. This channel-fill unit is ≈ 5 m thick and has an erosional boundary at its top, and is overlain by more channel-fill deposits (1 m thick) that contains large scale cross-bedding of rounded pumice clasts and ignimbrite boulders—up to 30 cm across—at the base of the channel scour.

Above this second, thinner channel-fill, is a layer of organic-rich silt, which contains a 5–20 cm thick layer of white ash (Maketu-H) resting within it. This low energy paleoenvironment, which is bracketed by high energy sedimentation, has preserved the Maketu-H Tephra. This tephra deposit, although it may not be primary airfall, was almost certainly deposited synchronous with eruption.

The top of the Maketu-H Tephra has been eroded into by a 5 m thick unit of fluvial lapilli and pumice sand. This unit contains a concentration of coarse pumices (up to 10 cm across) in its uppermost 40 cm, and is believed to be fluvial in origin.

Above this fluvial unit are the "banded pumice beds" [Chappell, 1975], which are 4 m thick and consist of alternating beds of angular pumice and sandy ash containing no observable cross-bedding (see Photo-55). It is uncertain whether these beds represent primary airfall or fluvial deposition, but they are

Figure 13-3: Composite section through the Maketu headland

Table 13-2.0 : Similarity coefficients (S.C.'s) that compare the glass chemistries of tephtras found in the Maketu area, and with their possible eastern Bay of Plenty correlatives.

<i>oldest</i>		03101	03101	03102	03104	07901	03105
Maketu-A	03101	1.00					
Maketu-B	03103	0.93	1.00				
Maketu-D	03102	0.94	0.93	1.00			
Maketu-H	03104	0.88	0.89	0.93	1.00		
Newdicks Igb.	07901	0.85	0.86	0.90	0.94	1.00	
Little Waihi	03105	0.89	0.89	0.93	0.92	0.93	1.00
Matahina	01501	0.90	0.92	0.96	0.94	0.89	0.93
Torere-I	02201b	0.90	0.96	0.96	0.92	0.89	0.91
Kaingaroa	06209	0.89	0.91	0.90	0.86	0.85	0.89
Huntress-B	08504	0.93	0.94	0.94	0.88	0.88	0.93
Welcome-C	08806	0.87	0.91	0.93	0.93	0.91	0.91
Kutarere	03801	0.88	0.91	0.91	0.92	0.91	0.90
Mamaku Igb.	10402	0.83	0.87	0.88	0.92	0.89	0.87

youngest

shaded areas represent tephtras that are believed to be likely correlatives

Table 13-2.1 : Glass chemistry of the Maketu-A tephric deposit.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Little Waihi	78.21	12.29	0.12	1.19	0.14	1.04	3.17	3.69	0.20	5.70	9
03101	0.35	0.16	0.03	0.12	0.04	0.08	0.18	0.16	0.11	1.41	
Little Waihi	77.19	12.59	0.24	1.47	0.19	1.40	3.29	3.52	0.12	4.44	2
03101b	0.08	0.15	0.02	0.08	0.03	0.06	0.13	0.00	0.07	0.10	

Table 13-2.2 : Glass chemistry of the Maketu-B tephric deposit.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Little Waihi	78.41	12.36	0.14	0.98	0.12	0.99	3.32	3.60	0.10	8.52	12
03103	0.19	0.07	0.03	0.12	0.04	0.08	0.13	0.16	0.03	0.44	

capped by a weakly developed paleosol. This paleosol is overlain by a thin shower bedded airfall deposit which has been eroded by the emplacement of an unwelded pyroclastic flow.

This ignimbrite does not appear to be very thick (c. 5 m) and is visible near the top of the cliffs around much of the headland; capping the "banded pumice beds".

The top of the pyroclastic flow (Maketu-L or "Newdicks Ignimbrite") is observed above Newdicks Beach [V14/159781], where it has a thick, dark, well developed paleosol at its top. The paleosol is overlain here by 5 m of slightly tephric, cross-bedded æolian dune sands, which also have a well developed paleosol at their top. The Rotoiti Tephra rests on this upper paleosol.

The Rotoiti Tephra is also recognised along the road to Little Waihi, but dune sands are not present here, only a dark, very strong paleosol developed into loess. A 15 cm thick weathered tephra (Maketu-M) exists at ≈ 1 m below the base of the Rotoiti Tephra, and ≥ 1 m of weathered loess occurs below. Up to 10 m of post-Rotoiti tephra are present between the Rotoiti Tephra and the terrace surface.

The tephra found in the Maketu Headland section are presented below in stratigraphic order of deposition (oldest to youngest), together with tentative correlations to the eastern Bay of Plenty tephrostratigraphy. The correlations are tentative because they are based almost solely on glass chemistry; having little stratigraphic control or diagnostic primary airfall features. Similarity coefficients that compare the glass chemistries of the tephra in the Te Piki area with each other, and with their possible correlatives in the eastern Bay of Plenty stratigraphy, are shown in Table 13-2.0.

13-2.1 Maketu-A tephric deposit

The glass of the Maketu-A tephric deposit contains a mixture of two types of chemistry (Table 13-2.1), though one type is very dominant over the other. Neither chemistry can be positively correlated with any other tephra in the eastern Bay of Plenty stratigraphy.

The minerals found in the ferromagnesian separate of the Maketu-A deposit are:

hornblende + hypersthene $\pm$ biotite(t)

The unconformity at the base of the flood deposit may represent a great deal of missing time, or only a small amount. In either case the age of the Maketu-A pumice is unknown, and as the deposit is reworked, the original tephra that the rounded pumices were derived from may be much older still.

13-2.2 Maketu-B tephric deposit

The glass chemistry of the Maketu-B tephric deposit (Table 13-2.2) does not show a mixture of chemistries and therefore may be predominantly derived from one eruptive, though this may be somewhat older than the deposit itself. No other tephra in the eastern Bay of Plenty closely match the Maketu-B glass chemistry, with the Torere-I Tephra (especially at the Opape section) being the most similar (see Table 13-2.0). Other possible correlatives include the Torere-L and Torere-O Tephra. More samples are

Table 13-2.3 : Glass chemistry of the Maketu-D Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Little Waihi	78.43	12.26	0.12	1.14	0.10	0.91	3.27	3.63	0.15	3.45	19
03102	0.29	0.19	0.03	0.09	0.03	0.08	0.16	0.12	0.04	0.70	

Table 13-2.4 : Glass chemistry of the Maketu-H Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Little Waihi	78.89	11.94	0.12	1.05	0.09	0.67	3.35	3.72	0.20	6.45	11
03104	0.31	0.10	0.03	0.06	0.02	0.03	0.22	0.10	0.05	0.58	

required from different levels within the Maketu-B flood deposit to determine if all of it is derived from one tephra, or if several eruptives are present.

The minerals found in the ferromagnesian separate of the Maketu-B deposit are:

hornblende + hypersthene

13-2.3 Maketu-D Tephra

The glass chemistry of the Maketu-D Tephra (Table 13-2.3) is only slightly different to that of the Maketu-B deposit some distance below, and is similar—but not identical—to that of the Torere-N, Kaingaroa and Huntress-B Tephra. The thickness, reverse graded nature, and coarse pumice of the Maketu-D Tephra suggest a possible correlation to only the Huntress-B Tephra, out of those three, or it may be an as yet unknown eruptive. The chemistry and physical characteristics of the Maketu-B Tephra match well those of the Welcome-B Tephra seen in sections around Tauranga Harbour. This latter tephra has also been tentatively correlated with the Huntress-B Tephra, and less likely the Kaingaroa Tephra, in the eastern Bay of Plenty.

The Maketu-D Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende

The Huntress-B Tephra (see sect. 10-2) has an estimated age of *c.* 275 ka, and a probable, but as yet unspecified, source in the northern T.V.Z.

13-2.4 Maketu-H Tephra

The Maketu-H Tephra has a distinctive glass chemistry (Table 13-2.4) with moderate FeO, but very low CaO contents. This chemistry resembles that of the Welcome-C Tephra or the Kutarere Tephra, but as the ignimbrite at the top of the section is thought to be the Mamaku—a correlative of the Kutarere Tephra—the Welcome-C or another unknown tephra is thought to be the most likely correlative of the Maketu-H Tephra.

The sample Maketu-H Tephra contained virtually no ferromagnesian minerals; of the few seen only one type was recognised:

hypersthene

The physical characteristics of the Maketu-H Tephra are consistent with its correlation to the Welcome-C Tephra, which has not been recognised in the eastern Bay of Plenty, but is well preserved in sections around Tauranga Harbour. The Welcome-C Tephra (see Chapter 11) has an estimated age of *c.* 260 ka, and is suspected to have been erupted from the Rotorua Volcanic Centre.

Table 13-2.5 : Glass chemistry of the Newdicks Ignimbrite (Maketu-L Tephra).

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Newdicks Beach	78.77	11.73	0.13	1.12	0.07	0.67	3.50	3.82	0.22	1.93	14
07901	0.23	0.15	0.03	0.09	0.01	0.04	0.16	0.11	0.04	0.37	

Table 13-2.6 : Glass chemistry of the Little Waihi Tephra (Maketu-M).

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Little Waihi	78.34	12.20	0.13	1.25	0.08	0.83	3.47	3.61	0.11	3.80	11
03105	0.35	0.17	0.03	0.12	0.02	0.08	0.21	0.20	0.03	1.59	

13-2.5 Newdicks Ignimbrite (Maketu-L)

The glass of the Newdicks Ignimbrite has a low CaO content (Table 13-2.5), which is similar to that of the Kutarere Tephra and its probable correlative — the Mamaku Ignimbrite. This latter ignimbrite forms thick welded deposits in the hills <15 km to the southwest of the headland and hence the Newdicks Ignimbrite is a likely correlative; representing a distal unwelded phase of the Mamaku Ignimbrite.

Virtually no ferromagnesian minerals were observed in the sample of Newdicks Ignimbrite, only:

hornblende + hypersthene

The Mamaku Ignimbrite, and hence the Kutarere Tephra (see Chapter 12), is believed to have erupted from the Rotorua Volcanic Centre at c. 210–230 ka.

The Newdicks Ignimbrite provides a basis for determining the stratigraphy of the fluvial deposits lower in the sequence. The banded pumice beds below it are thought to probably represent the Welcome-F, Huntress-F, Huntress-E and Welcome-D (= Huntress-D) Tephra, even though no glass was analysed from these units.

13-2.6 Little Waihi Tephra (Maketu-M)

The glass chemistry of the Little Waihi Tephra (Table 13-2.6) also has a low CaO content, and is similar to that of the Kutarere Tephra. However, the Little Waihi Tephra lies just below the Rotoiti Tephra and presumably above the Newdicks Ignimbrite (= Kutarere Tephra). It is therefore not believed to correlate to the Kutarere Tephra and has been given its own name. It is also known as the Maketu-M Tephra.

The Little Waihi Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene

The age of this tephra is unknown, though it is believed to be younger than the Newdicks Ignimbrite (Mamaku). Alternatively, it may, though unlikely, be the airfall correlative of the Newdicks Ignimbrite that exists in a location where the ignimbrite, for some unknown reason, was not deposited.

Summary:

The deposits comprising the Maketu Headland have been studied previously by Chappell [1975], but were erroneously believed to represent a near source eruptive rather than a very large (caldera breach) flood deposit. All deposits from the erosional base of the section to the base of the paleosol beneath the Rotoiti Tephra (the pyroclastic flow deposit was not recognised) were given the name "Little Waihi Formation" (see Chapter 2). The top of this formation is here redefined as being the upper surface of the paleosol developed into the top of the banded pumice beds (or the base of the airfall tephra immediately below the ignimbrite).

The "Pikowai pyroclastics" (see sect. 13-3) [Bailey & Carr, 1994], which are found between Otamarakau and Matata 20 km to the east, also contain tephric-rich fluvial deposits, but are thought not to correlate with the Maketu deposits. The Pikowai pyroclastics are thought to conformably overlie the Matahina Ignimbrite and hence are slightly older than the deposits at Maketu.

The age of the Maketu flood deposit is not known, though several of the tephra found within the fluvial sediments immediately above are thought to correlate to tephra of the Huntress Creek subgroup which have estimated ages of *c.* 250 ka (see Table 13-2.0). The "large" eruption nearest in age to that suspected for the flood deposit is the Kaingaroa eruptive episode. Although this eruptive originated far to the south in the Reporoa Volcanic Centre, the Kaingaroa Ignimbrite could have caused considerable disruption if it happened to flow into a large caldera lake existing in the Kapenga – Okataina area. Alternatively, a caldera in the northern T.V.Z. may have been breached by non-volcanic means, such as an earthquake or normal erosional events.

Further work is needed on the tephric deposits found in the Maketu Headland section to better define their position within the Bay of Plenty stratigraphy.

13-3 Pikowai Pyroclastics

The Pikowai section is found in the coastal cliffs west of Matata, through the narrow fringe of bush opposite Pikowai Reserve camping-ground. The section lies topographically next to, and stratigraphically just above, the Matahina Ignimbrite. The deposits at this site probably represent tephra recorded elsewhere within the Torere subgroup.

The Pikowai pyroclastics consist of a thick sequence of fluvially deposited tephra and were recorded by Healy & Ewart [1965] as "<100 ft of well bedded white pumiceous sandstones with interbedded tuffs, mostly fine-bedded but with some current bedding indicating that they were laid down in shallow water. There are also pumice conglomerates, and the base of the unit is a 10 ft bed of airfall pumice lapilli".

The basal airfall deposit is here named the Pikowai Tephra. The deposits above this unit could not easily be reached and were not studied in this work. Bailey & Carr [1994] grouped together all of the tephric sediments at this site and named them the "Pikowai Pyroclastics".

The beds below the Pikowai Tephra were described by Healy & Ewart [1965] as "40 ft of loosely compacted current- & delta-bedded sands and conglomerates containing pebbles of rhyolite, obsidian and pumice. Occasional sandstone beds resemble the marine sandstones farther east".

Two samples were taken from these subaqueously deposited pumiceous beds; of Pikowai-B from a grey sandy ash layer $\approx$ 2 m below the base of the Pikowai Tephra, and of Pikowai-A a further 3.5 m below this — 20 cm below a 0.5 m thick orange layer that contains many large lithic fragments. The Pikowai-B sample may be a primary airfall tephra deposited within water and only slightly reworked, but the Pikowai-A sample is likely to be of pumice reworked from previous eruptions. This is generally

Table 13-3.0 : Similarity coefficients (S.C.'s) comparing the glass chemistries of tephras found at the Pikowai Reserve section, and with their possible eastern Bay of Plenty correlatives.

<i>oldest</i>		03006a	03006b	03007	03002	03001	03005a	03005b
Pikowai-A(a)	03006a	1.00						
Pikowai-A(b)	03006b	0.91	1.00					
Pikowai-B	03007	0.90	0.94	1.00				
Pikowai-(1)	03002	0.86	0.80	0.80	1.00			
Pikowai-(2)	03001	0.91	0.93	0.89	0.81	1.00		
Pikowai-(1/2)a	03005a	0.88	0.82	0.83	0.95	0.80	1.00	
Pikowai-(1/2)b	03005b	0.93	0.95	0.91	0.82	0.96	0.83	1.00
Hiwarau	02701	0.90	0.83	0.84	0.95	0.83	0.95	0.85
Opotiki	01701	0.91	0.84	0.85	0.94	0.85	0.92	0.86
Torere-I(a)	02201a	0.89	0.95	0.91	0.79	0.96	0.79	0.93
Torere-I(b)	02201b	0.93	0.85	0.87	0.89	0.86	0.99	0.87

youngest

shaded areas are tephras that are believed to be possible correlatives

Table 13-3.1 : Glass chemistry of the Pikowai-A tephric deposit.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Pikowai Reserve 03006a	77.84 0.32	12.32 0.19	0.17 0.03	1.18 0.10	0.13 0.03	1.08 0.05	3.54 0.19	3.61 0.17	0.16 0.04	5.29 0.62	5
Pikowai Reserve 03006b	78.04 0.50	12.41 0.34	0.15 0.03	0.99 0.06	0.11 0.02	0.85 0.05	3.59 0.12	3.66 0.12	0.19 0.05	5.21 0.81	4

Table 13-3.2 : Glass chemistry of the Pikowai-B Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Pikowai Reserve 03007	77.53 0.29	12.57 0.18	0.14 0.04	1.02 0.12	0.15 0.04	0.83 0.07	3.70 0.18	3.91 0.19	0.20 0.05	5.09 1.79	16
Pikowai Reserve 03007b	76.95 0.69	12.53 0.42	0.19 0.01	1.48 0.16	0.18 0.05	1.16 0.01	3.71 0.22	3.65 0.03	0.22 0.07	4.90 1.49	3

confirmed by analyses on their glass; with Pikowai-A contains a roughly equal mixture of two different chemistries, whereas the Pikowai-B consists of predominantly one chemical type, although a small secondary component is also present. These two samples were taken in an attempt to better constrain the stratigraphic position of the Pikowai Tephra, and so aid in its identification.

Similarity coefficients have been calculated that compare the glass chemistries of the tephtras found at the Pikowai Reserve section with possible correlatives in the eastern Bay of Plenty (Table 13-3.0).

13-3.1 Pikowai-A tephtric deposit

Neither of the two glass chemistries that comprise the Pikowai-A deposit is particularly distinctive (Table 13-3.1), and as the deposit is reworked little stratigraphic information has been gained from it.

The minerals found in the ferromagnesian separate of the Pikowai-A deposit are:

hornblende + biotite + hypersthene

13-3.2 Pikowai-B Tephra

The dominant glass chemistry in the Pikowai-B deposit is rather nondescript [Table 13-3.2], having moderate to low FeO & CaO, and moderately high K₂O contents. This chemistry matches that of a number of tephtras found throughout the Torere subgroup, but none in the Huntress Creek subgroup. The secondary chemical type is relatively distinctive, with a high FeO wt.%, and a high FeO/CaO ratio. The Torere-I Tephra (see sect. 10-14) has a glass chemistry containing a mixture of both these chemical types and is a possible correlative, or source tephra for the Pikowai-B deposit. However, as only three shards with this chemistry were recognised out of over twenty analyses, it would be unwise to correlate this deposits solely on the glass chemistry of this mixture.

The minerals found in the ferromagnesian separate of the Pikowai-B Tephra deposit are:

hornblende + hypersthene

13-3.3 Pikowai Tephra

The Pikowai Tephra is a thick airfall pumice deposit at Pikowai Reserve, and should therefore correlate with known a eruptive in the eastern Bay of Plenty stratigraphy.

Diagnostic features:

The Pikowai Tephra is divided into two units; an upper — Pikowai-(2), and a lower — Pikowai-(1) (see Photo-56).

- The upper unit (Pk-(2)) consists of an uppermost 25 cm thick layer of normally graded ash, sandy ash, and lapilli; grading down into a 63 cm thick bed of coarse pumice lapilli (maximum clast size = 5 cm across).

continued over...

Table 13-3.3 : Glass chemistry of the Pikowai-1 Tephra; unit-1.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Pikowai Reserve	77.87	12.64	0.22	1.28	0.21	1.30	2.92	3.42	0.17	4.91	8
**03002	0.27	0.06	0.06	0.07	0.03	0.09	0.25	0.11	0.02	0.72	

Table 13-3.4 : Glass chemistry of the Pikowai Tephra; unit-2.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Pikowai Reserve	78.69	12.04	0.13	1.10	0.10	0.97	3.28	3.56	0.17	5.44	10
03001	0.22	0.10	0.02	0.07	0.02	0.04	0.11	0.12	0.03	0.59	

Table 13-3.5 : Glass chemistry of the mixed Pikowai Tephra; unit 1/2.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Pikowai Reserve	76.56	12.94	0.22	1.35	0.20	1.31	3.56	3.69	0.17	7.02	9
03005a	0.18	0.14	0.04	0.10	0.03	0.07	0.11	0.16	0.02	1.48	
Pikowai Reserve	77.79	12.47	0.13	1.16	0.11	0.97	3.57	3.60	0.23	5.44	9
03005b	0.21	0.17	0.02	0.14	0.02	0.05	0.09	0.17	0.09	1.05	

- Between the Pk-(1) and Pk-(2) units is a 2 cm thick layer of coarse and very coarse sandy ash. This intermediary bed is designated the Pikowai-(1/2) unit and grades into the unit below.
- The basal bed (Pk-(1)) consists of ≈ 3.5 m of massive pumice lapilli (6 cm across maximum; 1–2 cm common). The unit fines slightly—at about 2.6 m below its top—in that very coarse pumice no longer occurs and the matrix is composed of lapilli that is generally only 1 cm across.

The total thickness of the Pikowai Tephra is 4 – 4.5 m.

Chemistry and mineralogy:

The glass from the Pikowai Tephra has some interesting chemical features. The Pikowai-(1) unit has a quite distinctive glass chemistry (Table 13-3.3), with high FeO & CaO, moderately high TiO_2 & MgO, and a lower than average K_2O content. The Pikowai-(2) unit, however, has a totally different glass chemistry (Table 13-3.4; Figure 13-4), having much lower (average for the tephra in this study) values of FeO, CaO, TiO_2 & MgO. The Pikowai-(1/2) boundary layer between the two units was also analysed (Table 13-3.5) and contains a mixture of glass from both units.

Figure 13-4 : Comparison of glass chemistry analyses from the different layers within the Pikowai Tephra

The most likely explanations for the chemical difference between unit-1 and unit-2, are that either the Pikowai Tephra deposit is the result of a single, mixed magma eruption, or there were two different tephra being erupted at the same time; unit-1 only slightly preceding unit-2.

The Pikowai-(1) Tephra unit is very poor in ferromagnesian minerals and none were able to be separated out from it.

The Pikowai-(2) Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene

Distribution and size:

Based upon the thickness of the Pikowai Tephra and size of the clasts within it, the tephra must have had a relatively nearby source in either the Okataina or Rotorua Volcanic Centres.

Assuming a preferential distribution towards the north from an Okataina source, a minimum eruptive volume of 15 km^3 can be estimated for the Pikowai Tephra, and possibly much greater if it correlates with one of the known tephra mentioned in the discussion below.

Discussion

The Pikowai-(1) chemistry is similar to those of several tephra, in particular the Anaputa, Torere-A, Hiwarau and Torere-K Tephra, and slightly similar to the Opotiki Tephra (see Table 13-3.0). The Hiwarau Tephra consists of $\geq 5 \text{ m}$ of massive pumice lapilli at Awakeri Springs and therefore fits the physical description as well as the chemical, whereas the Anaputa Tephra contains much more obsidian and does not match stratigraphically; being below the Matahina eruptives. The Torere-A and Torere-K Tephra consist of thin layers of fine ash in the eastern Bay of Plenty and are unlikely to be as thick and as coarse grained as the Pikowai Tephra is at Pikowai Reserve.

The Pikowai-(2) chemistry has fewer close matches with other tephra and is very similar to only the Torere-B Tephra, and possibly the Torere-I Tephra (see Table 13-3.0).

The Opotiki and Torere-I Tephra together have very similar physical features to the Pikowai Tephra, but their glass chemistry, although similar, is not a close enough match to be certain of correlation.

The Hiwarau Tephra generally only has one chemical component, but at most sections where it has been studied, only the base or middle of the tephra was sampled. The upper parts were either out of reach, or had experienced a significant amount of weathering and/or paleosol development. However, at the Torere West section the Hiwarau Tephra is present in its entirety and here the chemistry shows a mixture of two components which match both the Pikowai-(1) and the Pikowai-(2) Tephra units respectively. The Torere-A Tephra at the Torere West and Huntress Creek sites, also has a similar mixture of chemistries.

The Hiwarau Tephra is thus thought to be the most likely correlative of the Pikowai Tephra, though this correlation remains tentative until further work is carried out.

It is possible, although much less likely, that the Pikowai Tephra correlates with the Torere-A or Opotiki/Torere-I Tephra, or another unknown tephra not found in the tephrostratigraphy of the eastern Bay of Plenty. Thick tephra deposits are known to occur in the Matata-Maketu area (including the Pikowai) which are not found in the eastern Bay of Plenty. For example, the Hauparu Tephra (erupted at c. 35–40 ka) is $\approx 5 \text{ m}$ thick at Otamarakau (5 km to the west of Pikowai Reserve), but near Opotiki it is too thin to be distinguished.

Table 13-4.0 : Similarity coefficients (S.C.'s) comparing the glass chemistries of tephtras found at the Rocky Cutting Road section, with and their possible correlatives in the eastern BOP stratigraphy

<i>oldest</i>		09001	09001b	09003	09005	09002	09004
Rocky-A	09001	1.00					
Rocky-A(b)	09001b	0.83	1.00				
Rocky-B	09003	0.96	0.85	1.00			
Rocky-C	09005	0.87	0.78	0.88	1.00		
Rocky-D	09002	0.90	0.80	0.91	0.92	1.00	
Rocky-E	09004	0.91	0.79	0.91	0.96	0.90	1.00
Hiwarau	02701	0.86	0.90	0.89	0.82	0.85	0.84
Opotiki	01701	0.88	0.89	0.91	0.83	0.86	0.85
Torere-I	02201b	0.90	0.76	0.89	0.91	0.88	0.93
Reihana-G	02201a	0.86	0.90	0.89	0.84	0.84	0.86
Kaingaroa	06209	0.94	0.82	0.95	0.92	0.90	0.93
Huntress-B	01509	0.90	0.86	0.93	0.89	0.86	0.91
Huntress-D	01510	0.90	0.80	0.91	0.95	0.90	0.96
Kutarere	03801	0.89	0.77	0.89	0.95	0.91	0.97
Little Waihi	03105	0.87	0.77	0.88	0.94	0.91	0.92
<i>youngest</i>							

shaded areas represent tephtras that are believed to be likely correlatives

Table 13-4.1 : Glass chemistry of the Rocky-A Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Rocky Cutting Rd.	78.56	11.93	0.22	1.03	0.13	0.86	3.46	3.60	0.22	4.63	11
09001	0.52	0.38	0.09	0.08	0.04	0.08	0.17	0.17	0.06	1.39	
Rocky Cutting Rd.	76.73	13.27	0.25	1.60	0.19	1.15	3.56	3.10	0.16	6.52	3
09001b	0.56	0.30	0.02	0.11	0.04	0.07	0.55	0.17	0.08	0.85	

Table 13-4.2 : Glass chemistry of the Rocky-B Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Rocky Cutting Rd.	77.20	12.12	0.21	1.18	0.13	0.92	3.47	3.52	0.25	7.03	12
09003	0.28	0.16	0.04	0.13	0.02	0.08	0.18	0.14	0.06	0.92	

13-4 Rocky Cutting Road Tephra

The Rocky Cutting Road section is located between Tauranga and Te Puke [U14/965810], east of Welcome Bay, and consists of a sequence of very weathered tephra ranging in time from perhaps *c.* 300 ka to the present.

Five very weathered tephra units have been recognised below the well bedded and easily recognised Rotoiti Tephra, which is located in the middle of the sequence (see Photo-57). The tephra are separated by paleosols and weathered loess. The five eruptives below the Rotoiti have been designated in stratigraphic order of deposition; the Rocky-A Tephra (at the base) to the Rocky-E Tephra (top), and are presented below.

The glass from these five eruptives has been analysed, and similarity coefficients that compare these tephra to the eastern Bay of Plenty stratigraphy have been calculated (Table 13-4.0).

13-4.1 Rocky-A Tephra

The Rocky-A Tephra consists of <0.5 m of a white very weathered tephra that contains very coarse lithics and crystals. It rests on a brown paleosol (20 cm thick) developed into weathered white ash-clay, which overlies >20 cm of light grey-brown loess. 0.5 m of weathered loess separates the Rocky-A Tephra from the Rocky-B Tephra above.

The glass chemistry of the Rocky-A Tephra (Table 13-4-1) contains a mixture of two types of chemistry, though one is very dominant over the other. The mixture of chemistries is similar to that found in the Torere-I Tephra in that the secondary component similar to the Reihana-G Tephra/Waimakariri Ignimbrite. However, both the Torere-I and Reihana-G Tephra do not normally contain the coarse crystals and lithics that are observed at this site.

The Rocky-A Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene

13-4.2 Rocky-B Tephra

The Rocky-B Tephra exists as a weathered sandy ash unit within weathered loess. The glass chemistry of this tephra (Table 13-4.2) is of one type only, which is distinct from that of the Rocky-A Tephra below, and similar to those of the Kaingarua, Huntress-B and Huntress-D Tephra.

The Rocky-B Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende

Table 13-4.3 : Glass chemistry of the Rocky-C Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Rocky Cutting Rd.	77.44	12.79	0.15	1.18	0.09	0.77	3.69	3.69	0.23	7.89	12
09005	0.42	0.22	0.04	0.12	0.04	0.06	0.24	0.21	0.03	0.71	

Table 13-4.4 : Glass chemistry of the Rocky-D Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Rocky Cutting Rd.	78.27	12.39	0.21	1.24	0.09	0.68	3.33	3.61	0.18	6.86	10
09002	0.50	0.29	0.06	0.14	0.02	0.04	0.20	0.12	0.05	1.49	

Table 13-4.5 : Glass chemistry of the Rocky-E Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Rocky Cutting Rd.	78.03	12.35	0.15	1.11	0.11	0.77	3.59	3.55	0.28	6.69	10
09004	0.28	0.19	0.04	0.06	0.05	0.12	0.20	0.30	0.05	1.25	

13-4.3 Rocky-C Tephra

The Rocky-C Tephra is 50–75 cm thick, rests on loess (~50 cm), and has a thick (~50 cm) light brown paleosol developed into it. The tephra consists of very weathered, well bedded, white and multicoloured ash-clay. The glass chemistry of this tephra (Table 13-4.3) is only slightly different—having less CaO—from that of the Rocky-B tephra below, and is most similar to the Huntress-D Tephra. The well bedded nature is similar to that of the Welcome-D Tephra in the Tauranga region (a probable correlative of the Huntress-D Tephra), but is also similar to the Kaingaroa Tephra in the eastern Bay of Plenty.

No ferromagnesian minerals were able to be separated from the sample of the Rocky-C Tephra.

13-4.4 Rocky-D Tephra

The Rocky-D Tephra rests on a light brown paleosol, and has a light brown paleosol (~50 cm thick) at its top. It is unclear whether the paleosol has developed into the tephra itself, or into loess immediately overlying the tephra. The tephra consists of a pale, extremely weathered sandy ash-clay, that contains clay nodules up to 5 cm across, and many Mn concretions. The glass chemistry of the Rocky-D Tephra (Table 13-4.4) is similar to that of the Kutarere Tephra, as are its physical characteristics.

Very few minerals were found in the ferromagnesian separate of the Rocky-D Tephra; the only mineral identified was:

hornblende

13-4.5 Rocky-E Tephra

The Rocky-E Tephra rests on a light brown paleosol, and has a thick (~1.5 m) and very well developed red-brown paleosol in its top. It is overlain by the basal alternating pumice and ash layers of the Rotoiti Tephra. The Rocky-E Tephra consists of a very weathered, pale orange-yellow ash, having much fewer clay nodules than the Rocky-D Tephra below. The glass chemistry of the Rocky-E Tephra (Table 13-4.5) is similar to that of the Kutarere Tephra.

Only a few minerals were found in the ferromagnesian separate of the Rocky-E Tephra:

hypersthene + hornblende $\pm$ biotite(*t*)

Summary:

The physical characteristics of the deposits in the Rocky Cutting Road section have generally been masked by the intense weathering that the deposits have undergone and no definite correlations have been made. The glass chemistries and stratigraphic positions relative to the Rotoiti Tephra suggest the correlation of the Rocky Cutting Road tephra to several Kukumoa and Huntress Creek subgroup tephrae.

The surrounding hills are composed of an ignimbrite—often showing columnar jointing—which is believed to underlie the Rocky Cutting Road section. The 1:250 000 geological map [Healy *et al.*, 1964]

Table 13-5 : Glass chemistry of the Quartz-biotite Ignimbrites.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Whitely Road	77.21	12.79	0.26	1.19	0.21	1.22	3.65	3.23	0.23	6.09	10
09401	0.39	0.20	0.06	0.08	0.04	0.07	0.12	0.07	0.06	1.43	
Parapara Road	78.05	12.40	0.16	0.56*	0.09	0.83	3.48	4.23	0.21	6.26	12
09501	0.27	0.17	0.07	0.13	0.02	0.06	0.13	0.21	0.06	0.56	

shows the Papamoa Ignimbrite to be the underlying deposit, though other workers have suggested that the columnar jointed ignimbrite is the Mamaku Ignimbrite [Neil Kennedy, pers. comm. 1994]. The relationship of these two ignimbrites to each other was not studied here, but if the Papamoa is equivalent to the Mamaku, then the Rocky Cutting Road tephra must be younger than this eruptive (probably $\equiv$ Kutarere), and therefore not recognised in the eastern Bay of Plenty. If so, this would place some doubt on other correlations that have been made between the eastern and western areas of the Bay of Plenty region, namely between several of the Welcome Bay and Huntress Creek subgroup tephra.

13-5 Quartz-biotite Ignimbrites

The Quartz-biotite Ignimbrites can be seen at several localities within the Kaingaroa Forest, two of which were sampled and analysed in this work (sites by Ian Nairn, pers. comm. 1993). These ignimbrites have also been found below the Rangitaiki Ignimbrite in drill-holes located near Kawerau [Browne, 1978], and in the Kaingaroa Forest [Nairn, 1984]. The Quartz-biotite Ignimbrites are characterised by abundant books and flakes of biotite, and very large quartz crystals. Welding within these ignimbrites is generally weak, and often nonexistent.

An age of 380 ± 50 ka has been determined for the quartz-biotite ignimbrites [Kohn *et al.*, 1992], using the fission track method on zircons gathered from a site off Totara Road [V16/294249], ≈ 10 km to the north of the Parapara Road site. The glass chemistry of this site is not available.

The source of the Quartz-biotite Ignimbrites is uncertain, but has previously been assumed to be the Okataina Volcanic Centre [Wilson *et al.*, 1984].

On the basis of the glass chemistry analyses carried out in this work it is possible that the Quartz-biotite Ignimbrites may consist of two or more separate events. As yet no positive matches have been made for the Quartz-biotite Ignimbrites in the eastern Bay of Plenty tephrostratigraphy.

At Whitely Road [V16/350152], an unwelded pyroclastic flow composed of white pumice and containing many small biotite flakes (smaller than at Parapara Road) was sampled. The Matahina Ignimbrite is present not far up the road at a slightly higher elevation.

The glass chemistry (Table 13-5) of the Whitely Road ignimbrite is distinctive due to its moderately high FeO & CaO, and low K₂O contents, with Na₂O > K₂O (3.6 > 3.2 wt.%).

The Whitely Road ignimbrite has a ferromagnesian mineral assemblage consisting of:

biotite + hypersthene + hornblende

The glass chemistry has a much lower K₂O content than that expected relative to the amount of biotite in the ferromagnesian assemblage; for this much biotite a K₂O content of ≥ 3.9 % is expected. Re-sampling and further analyses are needed to confirm the glass chemistry of this deposit.

It is uncertain to what the Whitely Road ignimbrite correlates within the eastern Bay of Plenty stratigraphy, though one of the chemical components (type-b) of the Tablelands-A Tephra has a similar glass chemistry, and contains abundant biotite. The estimated age of the Tablelands-A Tephra and the quartz-biotite ignimbrites are similar, and thus they could well be the same eruptive.

At Parapara Road [V16/294147], a sample was taken from an outcrop of weathered, light grey-buff, unwelded, pumiceous pyroclastic flow, which contains abundant large biotite flakes.

The glass chemistry of the Parapara Road ignimbrite (Table 13-5) has undergone extensive alteration, with the preferential loss of FeO, and probable gain in K₂O content. Its CaO wt.% is higher than that of most of the Tablelands subgroup tephra that are known to contain biotite, but it may correlate with the Tablelands-A Tephra, or possibly the Kohioawa Stream Tephra (see sect. 13-5).

The Parapara Road ignimbrite has a ferromagnesian mineral assemblage consisting of:

biotite + hornblende

Hypersthene was not seen in this deposit, which may result from the high degree of alteration that the ignimbrite has undergone.

13-6 Kohioawa Stream Tephra

(see also section 5-2.7)

The Kohioawa Stream Tephra is a probable correlative of the Ohinekoao-N Tephra and/or the Ohiwa-G Tephra, or less likely the Herepuru Tephra. It is also a likely correlative of one of the Quartz-biotite Ignimbrites.

The Kohioawa Stream Tephra is found ~10 m up in the western cliff of a small stream canyon located just to the west of the Kohioawa cliffs section. It is overlain by several metres of pumiceous sand and gravel that contains some cross-bedding. At roughly 20 m above the tephra is a pumiceous sand layer occurring within much finer fossiliferous sands. This may be the Tablelands-A Tephra deposit.

Immediately below the Kohioawa Stream Tephra is a 1 m thick brown sand layer, then 20 cm of pebbles cemented in mud and 1 m of fine sand. Pumiceous sands are present ~12 m below the tephra.

Diagnostic features:

- The tephra consists of three units, each generally separated by a fine sandy ash layer.
- The uppermost unit consists of a 6 cm thick layer of normally graded coarse to fine sandy ash.
- The middle unit contains the bulk of the tephra, and consists of 95 cm of coarse white pumice lapilli (5 cm across maximum), lithics (2 cm across maximum) and crystals.
- The basal unit consists of white pumice lapilli (up to 0.5 cm across) and contains very large quartz crystals (also up to 0.5 cm long).
- The pumices contain much biotite.

continued over...

Table 13-6 : Glass chemistry of the Kohioawa Stream Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Kohioawa Stream	77.58	12.59	0.12	0.99	0.10	0.79	3.31	4.32	0.25	7.31	11
00803a	0.59	0.29	0.06	0.09	0.02	0.04	0.23	0.17	0.11	1.95	
Kohioawa Stream	78.23	12.16	0.17	1.05	0.17	1.17	3.01	3.95	0.10	5.28	7
00803b	0.38	0.19	0.04	0.03	0.03	0.04	0.14	0.16	0.05	1.26	

- Has a moderately distinctive glass chemistry.

Chemistry and mineralogy:

The Kohioawa Stream Tephra (Table 13-6) contains a mixture of glass with two different chemistries; both present in roughly equal amounts (Figure 13-5). Type-(a) has a relatively high K_2O content, and moderate values for the other major element oxides. Type-(b) chemistry is significantly different with higher FeO , TiO_2 & MgO , and a much higher CaO . This chemical component is distinctive in that it has $CaO \geq FeO$; an attribute shared by only a few other tephra in this study.

Figure 13-5 : Chemical analyses of glass from the Kohioawa Stream Tephra

The type-(a) chemistry is a good match to the Kohioawa type-(a), Rangitawa, Tablelands-A type-(a) and Herepuru Tephra. Apart from its high K_2O content, the Kohioawa Stream type-(b) component would be a good match for the Tablelands-A type-(b) chemistry.

The Kohioawa Stream Tephra has a ferromagnesian mineral assemblage consisting of:

biotite + hornblende + hypersthene

Discussion:

The Kohioawa Stream Tephra is 1.1 m thick at Kohioawa Stream and is probably a primary airfall deposit that fell in water. Its large lithics and pumices, and its very large crystals, suggest that its source was not too distant, almost certainly within the northern T.V.Z. Its chemistry suggests that it may have a similar source to that of the Tablelands-A Tephra.

The Kohioawa Stream Tephra and the shallow water sediments surrounding it are not visible in the the other (eastern) cliff side of the stream. It is thus thought that there is a fault with many metres of throw—up to the east—located in the stream bed, and that the sediments on the east side of the stream canyon are stratigraphically many metres higher than those on the west. Due to a lack of exposure the

existence of this fault could not be confirmed, but a discordance in height of the base of the Matahina Ignimbrite [Bailey & Carr, 1994] suggests that a fault, upthrown *c.* 20 m to the west, does indeed exist here. This fault creates a problem with deciding whether the tephra is stratigraphically above, or below, the Ohinekoao subgroup, and by how much.

The Kohioawa Stream Tephra has a similar stratigraphic position to the Ohinekoao-N Tephra, and they are thought to be likely correlatives. However, no chemical data was obtained from this latter deposit for direct comparisons. The Ohiwa-G Tephra, which is also thought to correlate to the Ohinekoao-N Tephra, has an identical ferromagnesian mineral assemblage to the Kohioawa Stream Tephra, but as no glass could be analysed from the Ohiwa-G Tephra either, these correlations remain tentative.

The Kohioawa Stream Tephra is also be a possible correlative of the Herepuru Tephra. These two tephrae have nearly identical physical characteristics; in particular the three bedding units, the ferromagnesian mineral assemblages; and the type-(a) glass component of the Kohioawa Stream Tephra has a nearly identical chemistry to the Herepuru Tephra. However, the Herepuru Tephra was deposited within a thick sequence of massive, fossiliferous, very fine marine sand. This moderately deep paleoenvironment of deposition contrasts greatly with the moderately shallow marine sediments that enclose the Kohioawa Stream Tephra. Furthermore, the Herepuru Tephra has a K/Ar age of 620 ka, which is much older than that suspected for the Kohioawa Stream Tephra; *c.* 420–430 ka.

Nevertheless, the presence of numerous faults makes stratigraphic relationships of the lower portions of the coastal cliffs west of Matata difficult to determine and the Herepuru and Kohioawa Stream Tephrae could be correlatives; the latter tephra much older than previously thought.

The glass chemistry, abundant biotite, and very large quartz crystals of the Kohioawa Stream Tephra suggests a possible correlation to the Quartz-biotite ignimbrite found at Parapara Road (see previous section). An age of *c.* 0.38 ± 0.05 Ma for the Quartz-biotite ignimbrites [Kohn *et al.*, 1992] is within errors of that estimated for the Kohioawa Stream Tephra.

13-7 Herepuru Tephra

(see also section 5-2.7)

The Herepuru Tephra cannot as yet be correlated with the eastern Bay of Plenty stratigraphy because of its uncertain placement within the stratigraphy of the marine sequence west of Matata. It is possible that the Herepuru Tephra correlates with the Kohioawa Stream Tephra and/or the Ohiwa-G and/or the Ohinekoao-N Tephrae, but it is very likely that it is much older. The Jackson Tephra is another possible correlative, but the Herepuru Tephra may be older still; beyond that of the known eastern Bay of Plenty stratigraphy.

The Herepuru Tephra has only been recognised at one site, within the marine sediments on Herepuru Road—where it runs parallel to the coast before turning sharply inland—just west of Matata.

Table 13-7 : Glass chemistry of the Herepuru Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Herepuru Road	78.44	12.02	0.11	0.94	0.09	0.80	3.09	4.31	0.21	2.95	10
00101	0.30	0.12	0.02	0.06	0.03	0.03	0.19	0.20	0.03	0.80	

The tephra is overlain by >15 m of very fine sandstone, which is pumiceous only within a few metres of the top of the tephra. There are also at least 10–20 m of non-pumiceous, fossiliferous (cockles, small gastropods, etc...) very fine sands below the tephra.

Diagnostic features:

- An upper, white, normally graded coarse to fine sandy ash layer (10 cm thick), separated by several thin, grey, white, and pink ash layers from a (10 cm thick) poorly sorted coarse sandy ash layer below, which contains occasional larger pumices and obsidian clasts.
- The middle and bulk of the deposit consists of a white, poorly sorted, coarse sandy ash and lapilli unit (90 cm thick), with pumice up to 4 cm across (2 cm common) and obsidian lithics up to 1 cm across. Pumice clasts generally coarsen upwards. A fine sandy ash layer separates this unit from the beds below.
- A finer basal layer (10 cm thick) which consists of poorly sorted pumice lapilli and obsidian lithics (both up to 1 cm across) in a coarse sandy ash matrix.
- Biotite is a very common mineral seen in this tephra.

Chemistry and mineralogy:

The glass chemistry of the Herepuru Tephra (Table 13-7) is moderately distinctive, with high K_2O , and moderately low FeO contents, and average CaO values (for the tephra in this study) similar to that of the Kohioawa type-(a) and Rangitawa chemistry, and also the Kohioawa Stream and Tablelands-A type-(a) chemistry (Figure 13-6).

Figure 13-6: Comparison of glass chemistry analyses from the Herepuru, Kohioawa Stream and Tablelands-A Tephra

The Herepuru Tephra has a ferromagnesian mineral assemblage consisting of:

biotite + hornblende + hypersthene

Discussion:

The Herepuru Tephra is ≈ 1 m thick in the coastal cliff marine sequence west of Matata. The large pumices and obsidian lithics within this tephra indicate that its source was not too distant, almost certainly within the northern T.V.Z. The bedding within the tephra is internally consistent and can be traced laterally for over 400 m, which indicates that the deposit is probably of airfall origin.

Placing the Herepuru Tephra into the known stratigraphy of the marine sequence west of Matata is not straight forward, let alone correlating it to any particular eastern Bay of Plenty tephra. The tephra is found alone with no other tephras to constrain the stratigraphy, and the outcrops that enclose the tephra appear to be bounded by faults. Chemical comparisons have been made with several other tephras with similar mineralogical characteristics, and shows that it is similar—but only in part—to the Kohioawa Stream Tephra (Figure 13-7).

Figure 13-7: Comparison of relative proportions of selected element-oxides analyses of glass from the Herepuru and Kohioawa Stream Tephras, and other possible correlatives

At Ohinekoao Stream, a previously unrecognised fault separates the Herepuru Tephra from the Ohinekoao-I and Ohinekoao-J Tephras, which are enclosed in sediments of much shallower deposition at approximately the same height across the other (west) side of the valley. The direction of throw on the "Ohinekoao Stream fault" is unclear, and therefore it is uncertain whether the Herepuru Tephra is older or younger than the Ohinekoao subgroup. From studying the cliffs through binoculars at both the Ohinekoao Reserve and Wilson's farm areas, the Herepuru Tephra must either correlate to the Ohinekoao-N Tephra, occurring ≈ 10 m above the Ohinekoao-I Tephra, or be ≥ 40 m below the Ohinekoao-I Tephra

Table 13-8 : Glass chemistry of the Westend Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Otarawairere	76.79	12.86	0.15	1.79	0.10	1.11	3.56	3.51	0.14	3.74	22
04103	0.46	0.17	0.04	0.11	0.03	0.06	0.22	0.17	0.02	1.62	
Otarawairere	74.65	13.73	0.22	2.35	0.17	1.43	3.83	3.45	0.17	5.78	2
04103b	0.28	0.14	0.03	0.05	0.00	0.03	0.36	0.22	0.01	1.79	

and not visible at either of these sites. No other tephra—that could be correlatives on mineralogical or chemical grounds—were seen in the cliffs for 30 m above, or below, the Ohinekoao-I Tephra.

The Jackson Tephra is considered, on the basis of its similar ferromagnesian mineral assemblage, and that it is significantly older than the Ohiwa-G Tephra (a probable correlative of the Ohinekoao-N Tephra), to be a possible correlative of the Herepuru Tephra.

The Herepuru Tephra has a radiometric (K-Ar) age of 0.62 ± 0.03 Ma, and planktonic index nannofossil assemblages also constrain its deposition to between 0.95 to 0.46 Ma (see sect. 15-4.8) [Nairn & Beanland, 1989]. The above ages suggest that the Herepuru Tephra is older than the Ohinekoao subgroup, which has an estimated age range of c. 0.47 to 0.42 Ma.

For further discussion see sect. 5-2.7.

13-8 Westend Tephra

(see also section 16-1.6)

The Westend Tephra has only been seen at one site — at the Otawairere–Westend section. The tephra probably lies within the Ohiwa Harbour subgroup, but its exact stratigraphic position is uncertain.

The tephra is found within a 4 m thick deposit of gravelly sand occurring just 2 m above a marine cut surface into greywacke. Many metres of marine sands and silts are found above it. A paleosol developed into the upper half of the Westend Tephra is difficult to reconcile with the surrounding subaqueous deposits.

Diagnostic features: (see Photo-58)

- The tephra exists as a very firm, consolidated bed (60 cm thick), grey at its base, but weathered to a dark brown colour in its upper half. It consists of very fine sandy ash and has occasional small pumices (up to 3 mm long) scattered throughout.
- The tephra has a very distinctive glass chemistry.

Chemistry and mineralogy:

The glass chemistry of the Westend Tephra (Table 13-8) is very distinctive, having a very high FeO content, but only average values of CaO. SiO₂ is lower than average (for the tephra in this study) and Na₂O $\approx$ K₂O. TiO₂ & MgO wt.% values are low in comparison with other tephra which have a similar FeO content.

There is also a very minor secondary glass component in the Westend Tephra, which has an even higher content of FeO, CaO & Al₂O₃, lower SiO₂, and with Na₂O > K₂O (3.8 > 3.5).

The Westend Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende

Distribution and size:

At Otarawairere–Westend the Westend Tephra is 60 cm thick, and although it is surrounded by marine sediments, it appears to be subaerial airfall. The source of the tephra is unknown, but its fine grained nature suggests that it may be a distal deposit. Assuming that the tephra was preferentially distributed towards the northeast from a northern T.V.Z. source, a minimum volume of c. 8 km³ can be estimated. The true volume may be very much larger if the source was further away.

The glass chemistry of the Westend Tephra does not match that of any other tephra in the eastern Bay of Plenty stratigraphy, though possible correlatives in the Ohiwa Harbour subgroup do not contain glass and cannot be correlated using this technique.

Age:

The Westend Tephra lies only 2 m above a surface cut into the basement greywacke rock (see Photo-5 & 5(a)). This erosional-cutting presumably occurred during a high sea-level stand; probably $\delta^{18}\text{O}$ stage-13. It is uncertain whether the sand and gravel deposits that enclose this tephra represent a shallow marine or fluvial paleoenvironment. If fluvial, then the tephra would have been erupted at some time during $\delta^{18}\text{O}$ stage-12, but if marine, it is likely to have been erupted near the beginning of $\delta^{18}\text{O}$ stage-11. The ≥ 20 m of marine sediment exposed above the Westend Tephra is topped by a 2 m thick unit of weathered beach gravels; the subaerial airfall Otarawairere Tephra (deposited at c. 380 ka) resting on these. The marine sediment is therefore thought to have been deposited during the $\delta^{18}\text{O}$ stage-11 sea-level high.

Comparing the paleoclimatic data to the oxygen isotope record, the Westend Tephra has a probable age of c. 420–430 ka, or less likely c. 450 ka. This older age requires the Ohinekoao subgroup to have been deposited at c. 530–570 ka; significantly older than what is believed to be the case.

Discussion:

The Westend Tephra has a distinctive chemistry and reasonable guesses can be made about its approximate age and stratigraphic position, but it is uncertain where the tephra fits within the tephrostratigraphy of the eastern Bay of Plenty.

The Ohiwa-G, Kohioawa Stream and Ohinekoao-N Tephrae are all believed to have been deposited near the $\delta^{18}\text{O}$ stage-11/stage-12 boundary, and are at present believed to be correlatives of each other. They therefore have similar stratigraphic positions to the Westend Tephra, but both the Kohioawa Stream and Ohiwa-G Tephrae contain biotite as their dominant ferromagnesian mineral — in contrast to no biotite in the Westend Tephra. The Kohioawa Stream Tephra also has a very different glass chemistry to that of the Westend Tephra; and thus neither the Ohiwa-G Tephra nor the Kohioawa Stream Tephra are considered to correlate with the Westend Tephra.

However, glass from the Ohinekoao-N Tephra has yet to be analysed, and it may yet prove to be a different eruptive than the Kohioawa Stream Tephra, and correlate instead with the Westend Tephra.

If the Ohinekoao-N Tephra and the Westend Tephra are correlatives, the other Ohinekoao subgroup tephras must have been eroded at Otawairere–Westend during $\delta^{18}\text{O}$ stage-12 or the beginning of $\delta^{18}\text{O}$ stage-11, as no other tephras are seen below the Westend Tephra.

The Westend Tephra in the eastern Bay of Plenty probably lies within the very thick paleosol at the top of the Ohiwa Harbour subgroup, where it almost certainly is unrecognisable as a tephra deposit due to the severe weathering that these deposits have experienced.

13-9 Tokoroa Forest Sections

The Tokoroa Forest area, located to the west and southwest of Rotorua, is outside the main area of study in this thesis. However, several sections in this area were recorded, although only the largest eruptives (ignimbrites) were analysed. It was hoped that the analyses could identify which of the many tephras found in the eastern Bay of Plenty were related to the major eruptives in the northwestern T.V.Z.

Three sections were studied, with the aid of Neil Kennedy, formally with the Forest Research Institute in Rotorua; at Downer Road, Tikorangi Road and Peach Road. Glass was analysed from five tephras from the first two sites, and some minerals were analysed from the third. Many more eruptives occur in these sections but have not been analysed (especially at Downer Road). Further work in this region may provide conclusive proof of the tentative correlations proposed in Chapters Ten, Eleven and Twelve.

The sections are briefly described below, but the deposits that have been analysed are presented alongside their probable correlatives in the previous chapters within this thesis.

13-9.1 Downer Road section

The Downer Road section has been discussed in detail in Chapter 5, and will only be summarised here. The section is located on Downer Road, ≈ 7.5 km northeast of Tokoroa [T16/646335] on the western side of the T.V.Z. It contains three ignimbrite deposits — the Whakamaru at the base, the Chimp in the middle, and the Pokai at the top — and many interbedded airfall tephras and paleosols. Only the ignimbrite units have had their glass analysed.

No loess was seen in this generally conformable section, except perhaps the hard silt/ash below the Chimp Ignimbrite. The lack of loess suggests that all tephras that occur here—above the Whakamaru—were deposited during a relatively warm climatic period. The erosion at the top of the Whakamaru Ignimbrite is believed to have occurred during the cold, harsh climate at the end of $\delta^{18}\text{O}$ stage-10. The tephras in the Downer Road section are therefore thought to have been erupted during $\delta^{18}\text{O}$ stage-9, though any erosion that may have occurred at the top of the Chimp Ignimbrite may have been masked by the paleosol developed into it. The deposits here therefore coincide in age with the Murupara and Torere subgroups.

13-9.2 Tikorangi Road section

The Tikorangi Road section contains two ignimbrite deposits — the Pokai at the base, and the Mamaku at the top — and several interbedded airfall tephras and paleosols. It is located just west of a sharp bend on Tikorangi Road [T16/646335], near the top of the dissected flat ignimbrite surface of the southern Mamaku Plateau, ≈20 km southwest of Rotorua.

The base of the Tikorangi Road section is composed of Pokai Ignimbrite [Neil Kennedy, pers. comm. 1993], although deposits below this can be seen further down the road.

This ignimbrite has only a small amount (5–10 cm) of weathering in its top, and is overlain by a 1.2 m thick bed of coarse conglomerate, composed exclusively of rhyolitic cobbles. No matrix is observed and the origin of the cobble bed is unknown, though it is probably of only local significance. A thin, 5 cm thick, paleosol can be seen at the top of the cobble bed.

A 30 cm thick grey-white fine grained deposit of unknown nature—may be primary tephra, or reworked ash, or loess, or even lacustrine sediment—overlies the cobble bed and has a grey-black paleosol developed into its top.

A white ash overlies this paleosol, and has a thin organic-rich paleosol at its top separating it from a 40 cm thick grey weathered tephra above. This upper tephra has a dark black paleosol in its top.

The basal unwelded part of the Mamaku Ignimbrite overlies this dark paleosol, though welding of the ignimbrite commences <2 m above. At other sites, a plinian airfall pumice has been recorded below the ignimbrite.

It is difficult to determine the paleo-climate that existed during the deposition of the beds in this section, although the lack of thick paleosols, except for near the top, suggests perhaps a cooler climate than that for the Downer Road section.

13-9.3 Peach Road section

At the base of the Peach Road section, the top of a very weathered ignimbrite is observed, and at the top of the section is the base of the Whakamaru Ignimbrite. The section is located on a road cut on the western side of Peach Road, ≈10 km southwest of Tokoroa [grid reference uncertain].

At least two very weathered tephras, separated by loess and paleosols are visible between the two ignimbrite deposits.

Both weathered tephras contain large quartz and feldspar crystals and abundant large biotite flakes. They also both have ginger-red paleosols, suggesting a possible correlation to the Tirohanga, Ohiwa-B and Jackson Tephras in the eastern Bay of Plenty.

The Whakamaru Ignimbrite directly overlies the ginger paleosol in the upper tephra.

The tephras were sampled to compare ferromagnesian mineral chemistries (no glass remains) with their possible correlatives in the eastern Bay of Plenty — for example, the Kohioawa and Otarawairere Tephras, or the Tirohanga and Jackson Tephras (see Chapter 14).

The results were inconclusive, but did indicate that the Tirohanga Tephra is not represented at Peach Road.

13-10 Waiotahi Tephra

The Waiotahi Tephra is observed in the coastal cliffs at Waiotahi Beach; reworked within the marine sediment just below the base of the 20–30 m thick unit of Waiotahi Gravels that underlies the Ohiwa Harbour subgroup (see Photo-70 & 70(a)). The tephra deposit is very weathered and no glass remains within, and its reworked nature precludes the use of its ferromagnesian mineral assemblage (predominantly hornblende & some biotite) for tephra characterisation.

On the basis of its stratigraphic position just below the base of the Waiotahi Gravels, the Waiotahi Tephra is thought to have been deposited at the end of an interglacial period, probably $\delta^{18}\text{O}$ stage-17, at *c.* 670 ka.

A similarly reworked tephra occurs within marine sediments immediately below gravels at Pukeruru Point. No glass remains in the weathered pumice here either, and this deposit may be a correlative of the Waiotahi Tephra. However, the age of the gravels at Pukeruru Point is not well understood; much erosion has occurred, and nowhere are the Ohiwa Harbour subgroup deposits seen. The oldest identified tephra at this site belong to the Tablelands subgroup, which lie above an eroded surface into the gravels above the Waiotahi Tephra correlative.

13-11 Ngatiawa Tephra

The Ngatiawa Tephra is found at the Ngatiawa west section, opposite the Ngatiawa lookout section [W15/636522] on the road between Whakatane and Ohope. The tephra is found alone with few other deposits to constrain the stratigraphy. The Rotoiti and younger tephra occur higher up in the section and therefore the Ngatiawa Tephra must be of at least last-interglacial age or older.

The Ngatiawa Tephra is important in that it directly overlies unweathered, unconsolidated marine sands. The lower contact is generally sharp and near horizontal, though on the left side of the section an erosional unconformity has eroded deep (>1.5 m) into the sand (see Photo-66). Hence the Ngatiawa Tephra records the first exposure of this marine sediment to the terrestrial environment. If the Ngatiawa Tephra could be identified, an age on this exposure could be obtained and uplift rates calculated.

Diagnostic features:

- Consists of a very thick (>3.5 m), reverse graded, finely bedded pumice lapilli. Pumice clasts range up to 4 cm across (0.5 cm at base), and dark grey lithics reach 1 cm across. Two finer ash layers occur in the lower metre.

continued over...

Table 13-11 : Glass chemistry of the Ngatiawa Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Ngatiawa-(2)	77.78	12.18	0.20	1.45	0.21	1.49	3.38	3.13	0.17	3.07	11
04301	0.20	0.06	0.02	0.07	0.02	0.07	0.12	0.10	0.03	0.85	

- The large size of the pumice clasts and the rhyolitic lithics is unusual.
- The tephra has a moderately distinctive glass chemistry.

Stratigraphic relationships:

The Ngatiawa Tephra directly overlies 20 cm of pumiceous sand, and 70 cm of grey, faintly cross-bedded, slightly pumiceous sand which has a concentration of mud clasts 15 cm from its base. Below the pumiceous sand is >6 m of light brown marine sand with rare 20 cm thick gravel beds throughout. At a much lower level down the road are very fine marine sands and muds.

The top of the tephra grades up into the very weathered paleosol below the Rotoiti Tephra, which at this site is up to 4 m thick. The Omataroa, Mangaone, and Rotoiti Tephra lie above an erosional unconformity at the top of this paleosol.

Chemistry and mineralogy:

The glass chemistry of the Ngatiawa Tephra (Table 13-11) is distinctive in that it has quite high values of both FeO & CaO, and $\text{Na}_2\text{O} > \text{K}_2\text{O}$ ($3.4 > 3.1$ wt.%).

The glass chemistry of the Torere-A and Hiwarau Tephra is similar to this, but both have considerably lower values of FeO & CaO. Furthermore, the physical characteristics of the Torere-A Tephra are completely different from the Ngatiawa Tephra, but those of the Hiwarau Tephra are remarkably similar. The Anaputa Tephra glass chemistry is a closer match, but this eruptive contains too many obsidian and not enough rhyolitic lithics for it to be a correlative of the Ngatiawa Tephra. The closest chemical matches to this tephra are the Ruatuna-C and the Pikowai-(1) Tephra. However, both these eruptives cannot be fitted into the known tephrostratigraphy, although the Pikowai-(1) Tephra is thought to be of Torere subgroup age and a possible correlative of the Hiwarau Tephra (see sect. 10-6). A match to the Ohinekoao-J, Ohinekoao-K, or Ohinekoao-M Tephra is also chemically possible, but these eruptives are thought to have erupted near the end of a glacial period, not at the start of a glaciation as the Ngatiawa Tephra is suspected to have done (see discussion below).

The Ngatiawa Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende

Discussion:

The source of the Ngatiawa Tephra is unknown, but the size of the pumice and lithic clasts suggest that it originated in the northern part of the T.V.Z. A preferential tephra dispersal to the Whakatane area from a source 40 km away (closest possible) results in a minimum volume estimate of 20 km^3 .

The age of the Ngatiawa Tephra is unknown, but was deposited on a newly emergent surface. It is unclear whether this emergence is due to glacio-eustatic sea-level fall, or tectonic uplift, or a combination of the two processes. Nevertheless, assuming sea-level fall to be the dominant process leads to the conclusion that the Ngatiawa Tephra was erupted at the start of a glacial period, although the actual oxygen isotope stage remains unknown. Tectonism is believed to be quite rapid in this area and cannot be dismissed, and even though the tephra occurs at an altitude of 120 m, it may still be quite young.

Based upon uplift rates and periods of marine bench cutting (see Chapter 15 & sect. 16-1.6), the Ngatiawa Tephra is believed to be a likely correlative of the Hiwarau Tephra. However, this correlation is tentative and it is possible that the Ngatiawa Tephra is a much older previously unrecognised eruptive.

13-12 Waingarara Tephra and Ignimbrite

The Waingarara Tephra consists of an ignimbrite and a pre-ignimbrite airfall unit (see Photo-59). The ignimbrite is recognised at several sites south of Ohiwa Harbour, but little is known about its age. This eruptive is also known as the Ruatuna-A Tephra at the Ruatuna Road section.

The type section for the Waingarara Ignimbrite is at the McCoy Road-(1) site [W15/676454], 300 m from its junction with the main road around Ohiwa Harbour (i.e. Wainui Road). The ignimbrite is also seen at the Ruatuna Road and Waingarara sections, and in several road cuttings along Highway-2 just east of Waimana Gorge — at Waiopua Stream, on Waimana Hill, and at the Maandonk section.

The pre-ignimbrite airfall tephra is seen at only two sites, McCoy Road-(1) and Waingarara [W15/677419],; the latter section being the more complete.

Diagnostic features:

- The upper part and bulk of the airfall deposit consists of granular pumice lapilli at its top; overlying >1.5 m of yellowish sandy ash which lightens downwards.
- A middle unit of grey ash 20 cm thick separates the uppermost and basal beds.
- The base of the tephra consists of a granular pumice unit, >20 cm thick, that contains large obsidian flakes (base of tephra not seen).
- The ignimbrite is unwelded, but generally still firm, and is matrix-rich with only occasional small pumices scattered through it. The matrix is pinkish in colour and consists of fine and very fine sandy ash. Generally both the pumices and the matrix contain biotite, but the matrix has a much higher concentration of this mineral.

Stratigraphic relationships:

The top of the ignimbrite is observed at several localities, but erosion has occurred before the emplacement of the deposits seen above it. At the Ruatuna Road and Maandonk sections, rip-up clasts of firm ignimbrite can be found just above the primary flow unit. At McCoy Road, 8–10 m of ignimbrite is present; overlain by reworked tephra consisting of well bedded, cross-bedded ash and pumice. The boundary between the primary ignimbrite and the reworked deposit is difficult to determine.

A slight erosional boundary exists between the airfall tephra and the overlying ignimbrite, and nowhere was the base of the airfall tephra recognised.

Table 13-12.1 : Glass chemistry of the Waingarara Ignimbrite.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 02802a	S.C. 02802b
Ruatuna Road **02802a	78.06 0.01	12.16 0.09	0.12 0.03	1.15 0.06	0.10 0.02	1.00 0.08	3.50 0.12	3.77 0.12	0.13 0.03	3.39 0.33	7	1.00	0.86
Ruatuna Road 02808a	78.25 0.21	12.10 0.09	0.12 0.03	1.05 0.06	0.11 0.03	0.84 0.04	3.61 0.13	3.75 0.13	0.20 0.05	7.86 0.67	17	0.95	0.88
Ruatuna Road 02809a	77.99 0.32	12.13 0.11	0.14 0.02	1.15 0.08	0.12 0.03	0.87 0.06	3.52 0.13	3.90 0.11	0.22 0.03	6.35 0.54	10	0.94	0.85
Maandonk 03601a	77.53 0.17	12.29 0.10	0.18 0.05	1.12 0.15	0.16 0.05	0.96 0.11	3.56 0.20	3.88 0.01	0.31 0.05	5.59 0.62	3	0.90	0.81
McCoy Road-(1) 03901a	77.92 0.30	12.28 0.05	0.13 0.04	1.21 0.10	0.11 0.03	1.00 0.04	3.42 0.11	3.72 0.05	0.21 0.04	1.05 0.62	6	0.97	0.84
Waingarara 06301a	77.48 0.35	12.30 0.25	0.19 0.03	1.18 0.11	0.13 0.04	0.98 0.06	3.68 0.18	3.83 0.19	0.24 0.05	4.29 1.15	12	0.91	0.80
Ruatuna Road **02802b	78.35 0.19	12.01 0.16	0.09 0.02	1.01 0.06	0.07 0.02	0.78 0.06	3.31 0.11	4.29 0.13	0.13 0.02	3.32 1.23	9	0.86	1.00
Ruatuna Road 02808b	78.32 0.14	12.11 0.06	0.09 0.02	0.84 0.06	0.09 0.02	0.70 0.03	3.56 0.12	4.10 0.12	0.21 0.01	7.31 0.66	5	0.87	0.92
Ruatuna Road 02809b	78.20 0.22	12.14 0.09	0.10 0.02	0.95 0.05	0.09 0.02	0.70 0.04	3.64 0.15	4.00 0.14	0.22 0.02	6.90 0.83	13	0.90	0.92
Maandonk 03601b	77.69 0.22	12.23 0.15	0.13 0.04	1.05 0.08	0.13 0.04	0.79 0.05	3.52 0.17	4.20 0.13	0.29 0.05	5.50 0.70	6	0.91	0.88
McCoy Road-(1) 03901b	78.23 0.27	12.23 0.25	0.10 0.04	0.92 0.05	0.10 0.03	0.76 0.04	3.46 0.03	4.04 0.20	0.21 0.01	1.38 0.33	4	0.91	0.92
Waingarara 06301b	77.00 0.01	13.08 0.22	0.14 0.03	0.97 0.05	0.09 0.03	0.73 0.02	3.61 0.12	4.16 0.00	0.22 0.04	2.14 0.39	2	0.89	0.89

Chemistry and mineralogy:

The glass from the Waingarara Ignimbrite (Table 13-12.1) appears to be a mixture of two different chemical types; both present in roughly equal amounts. The differences between the two chemical populations is slight and often difficult to distinguish using simple graphical plots (Figure 13-8).

Figure 13-8 : Glass analyses from the Waingarara Ignimbrite — three different sites

However, very few chemical compositions exist in the Waingarara Ignimbrite samples which are intermediary between the two "end-points" displayed here (Table 13-12.1), and the two groups can be readily distinguished by using the means of the analyses (see Figure 13-9). This suggests that the chemical differences within the tephra are real and not the result of a single, yet highly chemically variable glass population. Type-(a) chemistry has moderate values of most major element oxides, whereas type-(b) has lower FeO & CaO, and higher K_2O contents.

Figure 13-9 : Comparison of the analytical means of glass from the Waingarara Ignimbrite — relative proportions of selected element-oxides

Table 13-12.2 : Glass chemistry of single individual pumice lapilli from the Waingarara Ignimbrite.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 02802a	S.C. 02802b
Ruatuna Road 02806	78.00 0.27	12.20 0.13	0.15 0.02	1.19 0.07	0.14 0.02	1.01 0.06	3.49 0.22	3.64 0.14	0.22 0.04	5.58 1.08	10	0.93	0.81
Ruatuna Road 02807	77.80 0.22	12.35 0.14	0.14 0.03	1.06 0.05	0.11 0.02	0.86 0.11	3.72 0.11	3.73 0.08	0.22 0.04	7.49 1.97	3	0.93	0.86
Ruatuna Road 02804	78.10 0.20	12.19 0.10	0.11 0.02	0.94 0.09	0.10 0.02	0.71 0.05	3.51 0.14	4.19 0.16	0.19 0.03	5.99 0.66	17	0.92	0.91
Ruatuna Road 02805	78.17 0.22	12.15 0.07	0.11 0.02	0.96 0.11	0.11 0.02	0.75 0.11	3.43 0.16	4.14 0.11	0.23 0.06	6.35 1.20	8	0.91	0.91

Table 13-12.3 : Glass chemistry of reworked pumice from above the Waingarara Ignimbrite.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 02802a	S.C. 02802b
Ruatuna Road 02810a	78.22 0.27	12.05 0.01	0.10 0.02	1.09 0.08	0.13 0.04	0.87 0.06	3.51 0.02	3.79 0.21	0.25 0.04	5.77 0.65	2	0.93	0.89
Ruatuna Road 02810b	78.22 0.15	12.15 0.11	0.12 0.02	0.95 0.09	0.10 0.03	0.66 0.05	3.55 0.10	4.09 0.04	0.23 0.04	5.96 0.48	10	0.92	0.89

Table 13-12.5 : Glass chemistry of the Waingarara Tephra (pre-ignimbrite airfall).

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.	S.C. 02802a	S.C. 02802b
McCoy Road-(1) 03902	77.83 0.42	12.14 0.52	0.21 0.05	1.27 0.14	0.13 0.03	0.99 0.09	3.56 0.10	3.64 0.21	0.22 0.06	5.29 1.69	12	0.90	0.79
McCoy Road-(1) 03902b	77.91 0.60	12.34 0.33	0.16 0.02	0.91 0.01	0.10 0.00	0.79 0.02	3.75 0.26	3.80 0.00	0.24 0.03	3.62 1.74	2	0.91	0.86

The Waingarara Ignimbrite glass chemistry was then studied in greater detail; single pumice lapilli were individually crushed and analysed — samples 02804, 02805, 02806, 02807 (Table 13-12.2; Figure 13-10).

Figure 13-10: Glass chemistry analyses of individual pumices from the Waingarara Ignimbrite

The analyses from the individual pumice lapilli were compared with those of the ignimbrite matrix — sample 02809 (see Table 13-12.1), and to those of a group of many smaller pumices that were collectively crushed — sample 02808 (see Table 13-12.1).

Two of the individual pumices had chemistry type-(a), and the other two pumices had type-(b) chemistry, and no mixtures of glass were evident. However, the group of many pumices crushed together, and the sample of the matrix did show a mixture of two glass chemistries.

For further chemical data examination, all of the analyses on samples taken from the ignimbrite were collected together and averaged to produce a composite chemistry as if it were a single population (Table 13-12.4). The standard deviations of the FeO, CaO & K₂O wt.% values are high but not extremely so.

Table 13-12.4 : Composite glass chemistry of the Waingarara Ignimbrite (all analyses).

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
all analyses	78.03	12.18	0.13	1.05	0.11	0.83	3.54	3.94	0.21	5.54	135
	0.37	0.19	0.04	0.13	0.03	0.13	0.17	0.24	0.05	2.07	

The pre-ignimbrite airfall was sampled from the McCoy Road section only and analyses on its glass shows it to also contain a glass population that is slightly mixed (Table 13-12.5). However, both chemical types appear to be different to that of the ignimbrite above in that they have higher FeO & CaO, and lower K₂O contents. This suggests that the glass in the ignimbrite may have undergone some chemical alteration — lowering FeO and raising K₂O — and that the original magma chemistry may be

represented better by the pre-ignimbrite airfall glass than by the pumice sampled from the ignimbrite. Chemical alteration could possibly explain the mixture of pumices with different chemistries within the flow unit; some of the pumices perhaps less altered (type-a) than others (type-b).

However, the glass chemistry of the pre-ignimbrite airfall has only average values of K_2O , which conflicts with the presence of biotite in its ferromagnesian mineral assemblage. Biotite is normally associated with magma which contains >3.8–4.0 wt.% K_2O , suggesting that the analyses of the pre-ignimbrite airfall tephra may, for some unknown reason, have artificially low K_2O values. Further analyses of the airfall unit are required.

Using all samples, the Waingarara Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene + biotite

However, the individual washed pumices sampled from the ignimbrite have a different assemblage. Pumices of both type-(a) and type-(b) chemistries contain no biotite, though biotite was found in other combined pumice samples, and was the dominant ferromagnesian mineral found in the matrix of the ignimbrite.

Discussion:

The stratigraphic position of the Waingarara Tephra is uncertain as the ignimbrite is not recognised within any sequence that has stratigraphic control. The only site where other tephra are associated with it is at Ruatuna Road, but the tephra immediately above it here also cannot be correlated with the known tephrostratigraphy. The section also contains many significant erosional breaks and unknown durations of missing time. At least two unconformities are recognised between the deposition of the Ruatuna Road tephra and the eruption of the Rotoiti Tephra.

The Waingarara Ignimbrite occurs only as small outcrops scattered throughout the area; sometimes on topographic highs (at Waingarara & Waimana Hill) and sometimes in topographic lows (at Maandonk & Ruatuna Road). This distribution suggests that the ignimbrite was probably emplaced before the majority of uplift occurred. It is unclear, though, whether the ignimbrite formed a sheet of more consolidated material over the landscape, and has since been almost totally eroded away, or alternatively it was a very distal flow facies that was deposited in paleo-river valleys only. Nowhere is the ignimbrite observed to be >10 m thick. The deposits that underlie the ignimbrite are much less consolidated and readily eroded, and the present topography is the result of post-ignimbrite erosion.

On the basis of its thickness at both sites that it has been identified — >2.5 m thick at Waingarara and >1.5 m thick at McCoy Road — the airfall member of the Waingarara Tephra must have formed thick deposits in the Bay of Plenty, especially between Whakatane and Opotiki.

This thickness, at such a large distance from its source, indicates that it must have at least a moderate eruptive volume. Its source is unknown, but assuming that the tephra was preferentially distributed towards the northeast from northern T.V.Z. source, a minimum volume estimate in the order of c. 20 km³ is realistic.

It would be expected that a tephra of such thickness should be found as one of the thicker tephra layers elsewhere in the eastern Bay of Plenty. Possible correlatives are discussed below.

Only two thick deposits in the known tephrostratigraphy have a similar chemistry to the Waingarara Tephra.

One is the Kohioawa Tephra (see sect. 8-6), which also has a mixed chemistry. One of its two chemical components is similar to that of the Waingarara type-(b), but the other is even more K_2O rich, and FeO & CaO poor, and there is no match with the Waingarara type-(a) chemistry (see Figure 13-11). The glass chemistries of these two tephra could only be classed as a match if the glass in the Kohioawa Tephra had undergone even more alteration than the Waingarara Tephra. The physical characteristics of the Kohioawa Tephra deposits—especially at Kohioawa cliffs—makes this unlikely, as it is obviously an airfall deposit, and as such is unlikely to have undergone chemical alteration.

The combined chemistry of all of the samples from the Waingarara Tephra is similar to that of the Rangitawa Tephra in all aspects apart from its K_2O content, which is much lower (see Table 8-6.7). If these two tephra are the same, then the Waingarara Ignimbrite would be a correlative of the Rangitaiki Ignimbrite — part of the extremely large Whakamaru Ignimbrite eruption. The presence of the Rangitaiki Ignimbrite in the Ohiwa Harbour area, even if it is a distal valley confined flow, would significantly increase its range and size.

Figure 13-11 : Comparison of the analytical means of glass from many samples of the Waingarara Tephra, together with possible correlatives — relative proportions of selected element-oxides

The other possibly correlative of the Waingarara Tephra is the Ohinekoao-A Tephra (see sect. 7-2). This tephra is a thick deposit in the central coastal Bay of Plenty (Matata cliffs), but has not been

positively identified in the eastern Bay of Plenty. The tephra does not have a mixed chemistry, but its single glass population is similar to the Waingarara type-(b) chemistry. Again there is no match to the Waingarara type-(a) chemistry.

Tephra with similar chemical compositions to the Waingarara type-(a) do occur, but these are found in the Huntress Creek subgroup and do not contain biotite (e.g. Kaingaroa eruptives).

Other possible correlatives of the Waingarara Tephra include:

- the Quartz-biotite Ignimbrites (not too likely; see chemistry in sect. 13-5);
- several biotite rich tephra in the Ohiwa Harbour subgroup (e.g. Jackson, Ohiwa-B, or Ohiwa-F Tephra);
- the Herepuru Tephra, which has been dated at >600 ka has a glass chemistry very close to that of the combined Waingarara Ignimbrite.

The age of the Waingarara Ignimbrite is unknown, though the presence of cross-bedded, presumably intertidal, marine sediments just above it at Ruatuna Road suggests that the ignimbrite was emplaced during a period of glacial low sea-level. The rise in sea-level during the following interglacial then eroded the top of the ignimbrite and deposited the sediment. If, however, the cross-bedded sediments are fluvial, rather than marine, no age control can be gathered from their presence.

The next section to the north of the Ruatuna Road site contains many metres of intertidal cross-bedded sands overlain by deeper marine sands and silts, while the section to the south contains great thicknesses of pumice, that erosionally overlies brown marine sands. Much faulting has occurred in the Ruatuna Road area and correlations between sections have not yet been established.

13-13 Ruatuna Road Tephra

The Ruatuna Road section is a deep road-cutting on Ruatuna Road [W15/739441] at the eastern edge of Ohiwa Harbour (see Photo-60 & 60(a)).

The tephra observed here are believed to be airfall, but were not able to be correlated with the known tephrostratigraphy of the eastern Bay of Plenty.

Stratigraphy:

The base of the section contains the Waingarara Ignimbrite (discussed separately above) which has also been named the Ruatuna-A Tephra. The three unidentified tephra found higher in the sequence are named here as the "Ruatuna Road tephra"; and from oldest to youngest they have been designated the Ruatuna-B, Ruatuna-C and Ruatuna-D Tephra. Near the top of the section the Rotoiti, Mangaone and Omataroa Tephra are visible (see Photo 60 & 60(a)).

In the northern part of the section the tephtras are interbedded with pumiceous sands, but in the southern part, the tephtras occur between layers of lignite.

More than 2 m of Waingarara Ignimbrite is present at the base of the Ruatuna Road section, and lying directly above it are horizontally well bedded fine sands. These sands have been almost completely eroded out and only a few remnants remain. In the upper part of the sands occur many large rip-up clasts of firm ignimbrite.

Above the horizontally bedded sand are three cross-bedded pumiceous sand units—in total 3.5 m thick—separated by erosional contacts.

The Ruatuna-B Tephra varies in thickness, although it is usually ≈ 20 cm thick, and rests on an iron pan developed into the top of the cross-bedded sands. At the southern end of the section the uppermost white ash of the Ruatuna-B Tephra lies within the base of a 20 cm thick lignite layer, but in the northern part of the section the lignite is missing and the tephra (thicker here) is overlain by cross-bedded pumiceous sand.

These cross-bedded sands (0.75 m thick) fine upwards into a white silt, which has an erosional contact (only slightly) to the Ruatuna-C Tephra above.

The Ruatuna-C Tephra is ≈ 35 cm thick and has an erosional upper contact with cross-bedded pumiceous sands above. At the southern end of the section the tephra occurs within pumiceous sands between the lower and middle lignite units (see Photo-60).

Two pumiceous sand layers, totalling 1.5 m thick, occur above the Ruatuna-C Tephra. The top of these sands have been eroded off in the northern part of the section, and in the southern part they have an erosional upper contact to the 40 cm thick, middle lignite layer.

The Ruatuna-D Tephra is ≈ 1.1 m thick, and fills all of the space between the upper and middle lignite layers.

The upper lignite layer is overlain by 2 m of coarse silt which is purplish-black in colour and organic-rich at its base, but becomes green-orange and less organic-rich near the top. A fluvatile sand bed (1 m thick) above the silt has been eroded into by the subsequent deposition of ≈ 4 m of greywacke gravels. The full thickness of the gravels is unknown as the top of the unit has been severely eroded.

Above the gravels is a sandy-mud channel infill deposit (0.4 m thick), overlain by loess (0.7 m thick), and 2 m of slightly cemented fine and very fine sand which may also be loess.

The Rotoiti Tephra rests on an erosional boundary into this sand. This tephra was identified by its well bedded base and the occurrence of cummingtonite in its ferromagnesian mineral assemblage. Above the Rotoiti Tephra is a very well preserved sequence of loess, tephtras and paleosols — in total ≈ 10 m thick. Many of the tephtras observed in this upper sequence occur within thick loess layers that are generally not recognised at most other sites in the eastern Bay of Plenty. The post-Rotoiti deposits were not studied as part of this thesis, and abseiling is required to view them in detail here.

Table 13-13.2 : Glass chemistry of the Ruatuna-C Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Ruatuna Road	76.87	12.79	0.19	1.61	0.20	1.49	3.52	3.15	0.19	3.15	10
02801	0.39	0.21	0.03	0.07	0.02	0.07	0.16	0.08	0.02	0.80	

13-13.1 Ruatuna-B Tephra

The Ruatuna-B Tephra was not sampled and no glass chemistry or ferromagnesian mineral assemblages are presented. Its basal granular pumice layer is not seen everywhere, but generally varies from 15 to 20 cm thick. A white ash/silt layer can be found above the pumice, and this also has a variable thickness (0–10 cm).

13-13.2 Ruatuna-C Tephra

The Ruatuna-C Tephra was deposited in a subaqueous environment, but contains airfall rather than subaqueous bedding features. The physical characteristics of the tephra are internally consistent and can be traced laterally for >15 m.

Diagnostic features:

- The uppermost unit consists of 2 cm of granular pumice lapilli overlying 2 cm of grey fine sandy ash containing many dark grains.
- The middle unit consists of a 10 cm thick bed of shower bedded coarse/medium sandy ash.
- The basal unit (22 cm thick) consists of normally graded pumice lapilli (up to 1 cm across) and lithics (3 mm) at base to coarse sandy ash at top.
- The tephra has a very distinctive glass chemistry.

Chemistry and mineralogy:

The glass from the Ruatuna-C Tephra (Table 13-13.2) has a very high FeO & CaO content, and low K₂O, with Na₂O > K₂O (3.5 > 3.2). This chemistry is very distinctive and is similar to only two tephra within the known stratigraphy — the Ohinekoao-D and Ohinekoao-H Tephra in the Ohinekoao subgroup; the latter tephra a closer match. The Torere-A and Hiwarau Tephra, both within the Torere subgroup, have only slightly similar chemistries, with significantly lower FeO & CaO contents.

The Ruatuna-C Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene + hornblende ± augite(t)

The Ruatuna-C Tephra is 35 cm thick at Ruatuna Road suggesting a minimum eruptive volume in the order of c. 5 km³.

13-13.3 Ruatuna-D Tephra

The Ruatuna-D Tephra was originally thought to be a pyroclastic flow deposit because the sensation of resistance met when the surface of the tephra is cleaned off with a spade was similar to that gained when cleaning off the surface of an unwelded pyroclastic flow. However, the grain size distribution of this tephra shows that it is almost certainly an airfall deposit, not a flow.

Table 13-13.3 : Glass chemistry of the Ruatuna-D Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Ruatuna Road	77.47	12.80	0.16	1.41	0.14	1.07	2.98	3.78	0.21	6.57	12
02803	0.28	0.22	0.02	0.14	0.03	0.09	0.18	0.20	0.03	1.28	

Diagnostic features:

- The bulk of the tephra consists of poorly sorted, massive white sandy ash and pumice lapilli (pumice up to 0.5 cm across). This metre thick bed is overlain by 10 cm of coarse/medium sandy ash with occasional very coarse pumice clasts.
- The tephra has a distinctive glass chemistry.

Chemistry and mineralogy:

The glass from the Ruatuna-D Tephra (Table 13-13.3) has a high FeO content, but only an average value for CaO. This chemistry is very distinctive and similar to those of only two tephtras within the known stratigraphy. The Reihana-G (Torere-I) Tephra (see sect. 10-13) has the more similar chemistry, but the age of this eruptive is thought to be much younger than that of the Ruatuna Road tephtras. The other possible correlative is the Westend Tephra, though this has significantly higher values of FeO than the Ruatuna-D Tephra.

The Ruatuna-D Tephra has a ferromagnesian mineral assemblage consisting of:

hypersthene

Very few ferromagnesian minerals were seen in this tephra, but hypersthene was definitely present.

The Ruatuna-D Tephra is 1.1 m thick at Ruatuna Road, but it is possible that this deposit has been over-thickened. The source of the tephra is unknown.

Summary:

The bulk of the pre-Rotoiti deposits at the Ruatuna Road section are believed to represent shallow water deposition, either intertidal marine and estuarine, or fluvial channel and over-bank deposits. There are many metres of cross-bedded pumiceous sands which grade laterally into lignites over a distance of only 30 m.

Although the glass chemistries of the tephtras found here are quite distinctive, they do not match any sequence of those found in the eastern Bay of Plenty tephrostratigraphy. A possible correlation of the Waingarara Ignimbrite, Ruatuna-C and Ruatuna-D Tephtras with the Ohinekoao-A, Ohinekoao-H and Westend Tephtras respectively, is possible, though the ages of these eruptives are still uncertain, as is the stratigraphic position of the Westend Tephra. The glass chemistries of the Ruatuna Road tephtras have been compared to various other tephtras using similarity coefficients (Tables 13-0.1; 13-0.2)

13-14 Waimana Hill Tephtras

The Waimana Hill section [W16/663344] is located on Highway-2 between Taneatua and Opotiki, on the southeastern side of the first hill, "Waimana Hill", east of Waimana Gorge.

Table 13-14.1 : Glass chemistry of the Waimana-A Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Waimana Hill	77.39	12.86	0.11	1.25	0.08	0.96	3.26	3.99	0.14	5.42	13
06403	0.45	0.40	0.03	0.10	0.03	0.07	0.12	0.13	0.05	0.91	

Table 13-14.2 : Glass chemistry of the Waimana-B Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Waimana Hill	77.66	12.60	0.14	1.05	0.06	0.80	3.39	4.18	0.16	4.04	11
06401	0.39	0.46	0.05	0.07	0.01	0.07	0.13	0.17	0.06	0.90	

Three tephtras are found here, and from the oldest to youngest they have been named the Waimana-A, Waimana-B and Waimana-C Tephtras. These tephtras were not able to be correlated with any other deposits elsewhere in the Bay of Plenty.

The basal 3–4 m of the Waimana Hill section consists of weakly bedded mudstone (very fine sand/silt). Two pumiceous tephtras lie within these muds; respectively ≈ 1 m and 2.3 m up from the base of the section.

The lower tephtra (Waimana-A) is 30 cm thick with gradational upper and lower boundaries, and the upper tephtra (Waimana-B) is 15 cm thick.

The upper 30 cm of the muds contains either a well structured paleosol, or weathered desiccation cracks. Lying on this weathered surface is a ≥ 4 m thick pumice lapilli deposit — the Waimana-C Tephtra. Some wood was also found at this contact.

The Waimana Hill section is thought to represent the emergence from a subaqueous to a terrestrial environment, due to tectonic uplift, or sea-level change, or the rapid draining and/or infilling of a lake. The evidence for emergence is based upon the presence of a paleosol/desiccation cracks in the top of the subaqueous deposits, and the presence of wood immediately below the Waimana-C Tephtra. The top of this tephtra was not seen and hence the continuation of, or lack of subaqueous deposition could not be determined.

13-14.1 Waimana-A Tephtra

The Waimana-A Tephtra is 30 cm thick and contains pumice lapilli up to 1 cm across.

The glass chemistry of the Waimana-A Tephtra (Table 13-14.1) is not particularly distinctive, having moderate values for most major element oxides. Its FeO & K₂O contents are slightly higher, and its MgO slightly lower than average for the tephtras in this study.

Only a few minerals were found in the ferromagnesian separate of the Waimana-A Tephtra; these are:

hypersthene + biotite + hornblende

The source of this tephtra is unknown, but the size of the pumice suggests that it was in the mid to northern part of the T.V.Z.

13-14.2 Waimana-B Tephtra

The Waimana-B Tephtra has a variable thickness, but is on average ≈ 15 cm thick and contains pumice lapilli up to 0.5 cm across.

The glass chemistry of the Waimana-B Tephtra (Table 13-14.2) is not particularly distinctive, having moderate values of most major element oxides, except for K₂O which is higher than average, and MgO, which is very low. Its FeO & CaO contents are both significantly lower than in the underlying

Table 13-14.3 : Glass chemistry of the Waimana-C Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Waimana Hill	77.50	12.59	0.13	1.19	0.07	0.88	3.27	4.24	0.22	8.42	16
06402	0.31	0.18	0.06	0.11	0.03	0.07	0.13	0.13	0.08	0.54	

Waimana-A Tephra. This chemistry is relatively common, especially in the older Murupara and Tablelands subgroups, and also matches that of the type-(b), and combined analyses of the Waingarara Tephra.

Very few minerals were found in the ferromagnesian separate of the Waimana-B Tephra; only:
biotite

The source of the Waimana-B Tephra is unknown, and until proved otherwise it is believed to have only a small volume.

13-14.3 Waimana-C Tephra

The Waimana-C Tephra is a very thick deposit which appears to rest on a well structured paleosol that is 30 cm thick. The presence of lithics and the lack of sedimentary bedding in this tephra, indicate that it is probably an airfall deposit

The physical characteristics of the Waimana-C Tephra consist of a single massive yellowish pumice lapilli unit (pumice and lithics both up to 1 cm across) that is >4 m thick (top not observed).

The glass chemistry of the Waimana-C Tephra (Table 13-14.3) is not particularly distinctive and although similar to that of the Waimana-A Tephra, it has slightly lower values of FeO & CaO, and a higher K₂O content. Most major element oxides have moderate values, except for K₂O which is significantly higher than average. Like the Waimana-B Tephra, it also has a much lower than average MgO content.

The Waimana-C Tephra has a ferromagnesian mineral assemblage consisting of:

biotite

The Waimana-C glass chemistry is very similar to those of the Reid's Reserve Tephra, the Rangitawa Tephra, Ohinekoao-A Tephra, and the type-(a) Waingarara Tephra. However, these eruptives are all thought to have different physical characteristics to the Waimana-C Tephra; especially concerning its lack of internal bedding. The Burke Tephra also has a very similar chemistry, and similar physical characteristics, but the stratigraphic position of this tephra is unknown and hence provides no aid in identifying the Waimana-C Tephra. The Jackson Tephra, although lacking glass, contains abundant biotite and is also therefore a possible correlative.

The thickness of the Waimana-C Tephra suggests that this was a very large eruption, and the large lithics indicate that its source was probably not too distant. A preferential dispersal to this area from a source 50 km away in the northern part of the T.V.Z. results in a minimum volume estimate of c. 20 km³.

Summary:

None of the tephra at the Waimana Hill section can be correlated with the known eastern Bay of Plenty tephrostratigraphy. Their glass chemistries are not particularly distinctive except for a relatively high K_2O content. The presence of biotite in their ferromagnesian mineral separates precludes correlation to many of the Huntress Creek and Torere subgroup tephra which have similar chemistries. The glass chemistries of the Waimana Hill tephra have been compared to various other tephra using similarity coefficients (Tables 13-0.1; 13-0.2)

The age of the Waimana section is unknown, but if the sediments are marine in origin the emergence of the section would have most likely been due to glacio-eustatic sea-level fall at the start of a glacial period; though the actual oxygen isotope stage remains unknown.

A pyroclastic flow, probably the Waingarara Ignimbrite, occurs at about the same topographic height on the other (northwestern) side of Waimana Hill. As the Waimana Hill sediments are flat lying, the height concordance of the ignimbrite and Waimana-C Tephra suggests that they may be correlatives, or at least of similar age. The Waingarara Ignimbrite, however, has also been positively identified on the Waimana River flats to the east (Maandonk section) at a lower topographic height. The height difference between the ignimbrite deposits is probably due to faulting, with Waimana Hill being uplifted at a greater rate than adjacent areas.

The Burke, Ohinekoao-A and Jackson Tephra are all thought to have been erupted near the beginning of a glacial period, consistent with a correlation to the Waimana-C Tephra. These correlations are very tentative and much more work is required.

13-15 McCoy Tephra

The McCoy Tephra is observed at only one site, on McCoy Road [W15/676454], just 20–30 m down the road from the Waingarara Ignimbrite type section, and 300 m up from the junction with the main road around Ohiwa Harbour (i.e. Wainui Road).

The tephra has an erosional unconformity in its top which is overlain by Mangaone subgroup tephra of late Quaternary age. The age of the McCoy Tephra is thought to be much older.

The base of the McCoy Tephra rests on unconsolidated orange-brown marine sand. Marine sand is also seen above the tephra, but only ≈ 1 m of sand is seen before a significant erosional boundary is reached which has a relief of >5 m. A weathered late Quaternary tephra mantles this boundary, and has a paleosol developed into its top.

The physical characteristics of the McCoy Tephra consists of:

- A 5 m thick, well bedded (horizontal, slightly wavy decimetre bedding), weathered tephra, that contains pumice lapilli up to 2 cm across.

Table 13-15 : Glass chemistry of the McCoy Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
McCoy Road	78.16	12.10	0.21	1.27	0.13	1.01	3.39	3.51	0.21	3.53	9
03905	0.31	0.39	0.03	0.08	0.02	0.03	0.19	0.19	0.06	1.10	

The glass chemistry of the McCoy Tephra (Table 13-15) is not particularly distinctive, with moderate values of most major element oxides, except for FeO which is slightly higher than average. This chemistry is virtually identical to that of the airfall Waingarara Tephra found immediately beneath the ignimbrite just 20 m up the road, but has a significantly different ferromagnesian mineral assemblage. The glass chemistry is also virtually identical to that of the Huntress-B Tephra, and similar to other tephra of the Huntress Creek subgroup.

The McCoy Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene

The true thickness of this tephra is unknown as it has almost certainly been over-thickened here, and even only partly accurate volume estimates cannot be made. The source of the McCoy Tephra is unknown, but the size of the pumice suggests that it originated in the northern part of the T.V.Z.

Although the McCoy Tephra appears to have been deposited in a marine paleoenvironment, this tells us little about its age, which is unknown. The McCoy Tephra is likely to have a similar age to the Waingarara Ignimbrite, found just up the road, unless there is a fault lying between the two sections. This, however, is quite possible.

The most likely correlatives of the McCoy Tephra are thought to be the Waingarara Tephra, even though it has a different ferromagnesian mineral assemblage and its physical characteristics are quite different. The Huntress-B Tephra is also a possible correlative. The glass chemistry of the McCoy Tephra has been compared to various other tephra using similarity coefficients (Tables 13-0.1 & 13-0.2)

13-16 Burke Tephra

The Burke Tephra occurs by itself, with no other tephra to constrain the stratigraphy. It is found in a section [W15/698454] on the main road around Ohiwa Harbour (Wainui Road), directly opposite its intersection with Burke Road.

The tephra has few distinctive physical features and its glass chemistry matches that of be correlated with several different tephra, and therefore of little help in identification. Its stratigraphic position and "true" identity is unknown.

Its **physical characteristics** consists of:

- An upper reverse graded pumice lapilli layer (>1 m thick), which overlies a 40 cm thick bed of white, "dry", pumice lapilli and lithics.

The tephra directly overlies, with a generally smooth and near horizontal contact, 30–40 cm of weathered sand, which grades into >1.5 m of grey sand containing some cross-bedding.

The Burke Tephra is important in that it appears to overlie a weak paleosol or period of weathering developed in the top of a marine deposition sequence, therefore recording the first exposure of the marine

Table 13-16 : Glass chemistry of the Burke Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Burke	77.27	12.84	0.11	1.13	0.08	0.80	3.30	4.35	0.18	6.48	13
10201	0.26	0.16	0.04	0.13	0.04	0.07	0.16	0.17	0.05	1.64	

sediment to the terrestrial environment. If the Burke Tephra could be identified and its age discovered, a time for the first exposure of the sediment could be obtained and uplift rates calculated.

The glass chemistry of the Burke Tephra (Table 13-16) is not particularly distinctive, with moderate values of most major element oxides, except for K_2O which is much higher than average. This chemistry is similar to those of the Rangitawa, Kohioawa type-(a), Waimana-C, Ohinekoao-A, Herepuru, Murupara-C and Reid's Reserve Tephra, although the latter two tephra can be dismissed as possible correlatives due to their differing physical characteristics. The Burke Tephra is thought to be late Pleistocene in age as none of the post-Rotoiti tephra that have been recorded in the eastern bay of Plenty have a similar glass chemistry [P.C. Froggatt, pers. comm. 1995].

The glass chemistry of the Burke Tephra has been compared to various other tephra using similarity coefficients (Table 13-0.1)

The Burke Tephra has a ferromagnesian mineral assemblage consisting of:

biotite $\pm$ hornblende(t)

The source of the Burke Tephra is unknown, but on the basis of the size of its pumice clasts, it was probably erupted from the northern part of the T.V.Z., and from its thickness has a minimum eruptive volume estimate of *c.* 10 km³.

The age of the Burke Tephra is unknown, but it was deposited on a newly emergent surface which was probably the result of glacio-eustatic sea-level fall, though tectonic uplift cannot be dismissed. Assuming that sea-level fall was the dominant process leads to the conclusion that the Burke Tephra was erupted at the start of a glacial period, although the actual $\delta^{18}O$ stage remains unknown.

The Ohinekoao-A, Waimana-C and Jackson Tephra are also believed to have been erupted at the start of a glacial period, and have similar ferromagnesian mineral assemblages to the Burke Tephra. These three tephra are therefore its most likely correlatives, but this is very tentative and much more work is required.

13-17 Waiopua Tephra

The Waiopua section [W16/661354] is located at the base of the first hill ("Waimana Hill") to the east of Waimana Gorge, 750 m east of the Waiopua Stream bridge. The section contains many tephra, generally thin, that are enclosed by organic-rich sediment. The tephra have yet to be correlated with the known eastern Bay of Plenty tephrostratigraphy, though there is some indication that they may be similar in age to the Ohinekoao subgroup.

As most of the "tephra" in the Waiopua section are probably not primary airfall deposits, they will be referred to below as tephric deposits. The deposits are very well preserved as they fell into a subaqueous environment and have undergone little weathering. Many of the tephra recorded here are

Table 13-17.1 : Glass chemistry of the Waiopua-A Tephra.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Waiopua	78.42	12.10	0.16	1.11	0.14	0.98	3.26	3.66	0.22	6.80	17
03701	0.27	0.08	0.04	0.10	0.03	0.06	0.14	0.10	0.03	0.50	

unlikely to be found in subaerial sections elsewhere in the eastern Bay of Plenty because they were probably too thin to have survived bioturbation and other weathering processes intact. This situation is similar to the uppermost Torere subgroup tephra which are well preserved within lignites at the Torere West section, but only rarely recorded at other sites that are closer to source. As many of the Waiopua tephra would not be seen elsewhere, the stratigraphic position of this section would be difficult to establish even if it had been studied in more detail. Glass from only two deposits in the Waiopua section have been analysed — the basal layer and the third layer from the top.

Stratigraphy:

At the base of the Waiopua section is the Waiopua-A Tephra, which is >1 m thick (base not seen) and has a very thin paleosol developed in its top.

Above this paleosol is a unit of alternating thin sandy ash and lignite layers, in total 0.5 m thick. Four sandy ash layers are present, and the upper 15 cm consists of lignite and wood.

A light grey-brown weathered ash/silt layer (25 cm thick) rests on this lignite, but it is uncertain whether this unit is tephric, or represents loess that has been deposited in a subaqueous environment (sample has yet to be studied).

A dark lignitic paleosol has developed into the top of the ash/silt, and above this is a sandy ash bed (1 m thick) which contains some slightly wavy bedding. Above the sandy ash bed is a sequence of moderately thick tephric deposits—including the Waiopua-I—that lie within ≈4 m of hard, blocky, brownish-grey silt/clay. A few organic-rich silt and lignite layers are also present.

The grey silts are overlain by >2 m of white sediment which could not be reached and which may or may not be tephric.

Eleven tephric deposits have been recorded at the Waiopua site and are designated from oldest to youngest as the Waiopua-A to Waiopua-K.

13-17.1 Waiopua-A Tephra

The Waiopua-A Tephra contains glass that has only a single chemical component (Table 13-17.1), and is hence believed to represent a single eruption. This chemistry is not distinctive, having average values for all major element oxides. There are too many possible chemical correlatives of this tephra for it to be identified without greater stratigraphic control.

The physical characteristics of the Waiopua-A Tephric consist of:

- The tephra is >1 m thick, and has 12 cm of paleosol development at its top; the uppermost 2 cm very dark. The base of the tephra unit is not seen and there is no evidence for any reworking. The deposit is relatively poorly sorted, and shows no bedding. It may be a pyroclastic flow deposit, but more likely represents poorly sorted airfall sandy ash, possibly primary airfall.

Table 13-17.2 : Glass chemistry of the Waiopua-I tephric deposit.

sample no. & site	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	no.
Waiopua	75.92	13.14	0.26	1.64	0.27	1.63	3.45	3.50	0.19	6.44	5
03702a	0.78	0.37	0.05	0.22	0.07	0.16	0.25	0.19	0.04	1.18	
Waiopua	73.30	13.95	0.45	2.40	0.57	2.54	3.72	2.89	0.19	6.29	4
03702b	0.79	0.25	0.05	0.33	0.11	0.20	0.11	0.06	0.03	1.31	
Waiopua	77.20	12.70	0.17	1.18	0.14	1.05	3.49	3.88	0.19	6.18	4
03702c	0.09	0.16	0.02	0.04	0.01	0.07	0.05	0.08	0.05	0.14	
Waiopua	77.58	12.26	0.25	1.12	0.10	0.76	3.27	4.41	0.25	6.26	2
03702d	0.38	0.02	0.08	0.02	0.01	0.03	0.15	0.31	0.01	1.33	

The Waiopua-A Tephra has a ferromagnesian mineral assemblage consisting of:

hornblende + hypersthene

13-17.2 Waiopua-I deposit

The glass chemistry of the Waiopua tephric deposit shows it to be reworked, containing glass from at least four different tephra (Table 13-17.2). The chemistries represented here are quite distinctive and except for the Torere-J Tephra, have only been found in the Ohinekoao subgroup. The four different chemistries (03702a, b, c, d) are reasonable chemical matches to the Ohinekoao-D, Ohinekoao-E, Ohinekoao-A (or B) and Ohinekoao-G Tephra respectively.

The Waiopua-I tephric deposit is in total 65 cm thick and consists of:

- A basal white fine sandy ash, overlain by a grey medium sandy ash.
- An upper very well bedded (wavy beds) pale sandy ash, which has occasional organic-rich lenses throughout.

The upper pale unit makes up the bulk of the deposit but the middle grey layer was the unit sampled.

Since the deposit is reworked, its ferromagnesian mineral assemblage (**hornblende + pyroxene**) is not representative of single eruptive and is therefore no use in tephra characterisation studies.

Summary:

The organic-rich beds indicate that the deposits within the Waiopua section were deposited in a fluvial over-bank environment. Cross-bedding was not observed in the section, and only two units displayed any form of bedding. The upper part of the section—containing the thick unit of grey blocky clay—may represent deeper water deposition, or may alternatively represent weathered loess.

If the Waiopua-I tephric deposit contains material from Ohinekoao subgroup tephra, then its age is likely to be c. 450 ka. The correlations, however, are as yet only very tentative. The glass chemistries of the Waiopua tephra have been compared to various other tephra using similarity coefficients (Table 13-0.2)

A pyroclastic flow deposit, believed to be the Waingarara Ignimbrite, can be found nearby, both at the same level, Waiopua Stream to the west; and topographically higher, halfway up the hill to the southeast. The height difference between the several ignimbrite deposits is probably due to faulting and non-uniform uplift rates within this area.

The closeness of the Waingarara Ignimbrite suggests perhaps that the Waiopua section is of a roughly similar age, but this is still uncertain, as is the age of the ignimbrite.

13-18 Sections Requiring Further Study

This part of the chapter lists, with a brief location and description, many of the sections which are considered to be important, but as yet have been given only a cursory inspection. These deposits and sections are included within this thesis because many of the sections presented deserve to be studied in detail, either to enhance the tephrostratigraphic record, or to detail the local paleo-environmental and landform history.

The most common reason for the lack of detailed study on these sections is that of time constraints for the completion of this thesis. The overall tephrostratigraphy of the eastern Bay of Plenty had to be established first, before the detailed study of these sections was worthwhile. Generally there is no stratigraphic control in these sections, and correlations could only be achieved, if at all, by comparing the glass chemistries of sequences of tephras. However, not enough time remained, after the tephrostratigraphy was established, to study all tephras and sections that remained.

13-18.1 Taneatua section

The Taneatua section [W15/616400] is located just south of Taneatua, over the Waimana River bridge. It is a thick section (≥ 30 m) containing what are thought to be marine deposits at its base and terrestrial and fluvial deposits at higher levels. More than ten tephric layers are recorded here, mostly in the well bedded marine sequence, but no detailed studies were carried out on these deposits.

The subaqueous environment has preserved the tephras well and as the Taneatua section is closer to the T.V.Z. than most of the other sections in this thesis, any tephra thinner than perhaps 20 cm thick here, may not be recorded further to the east. The fact that these tephras may not be found elsewhere may make correlations to other areas difficult, but if several "tie" points could be established to the eastern Bay of Plenty stratigraphy, the Taneatua section would add greatly to the overall tephrostratigraphic record of the region.

The uppermost ≥ 10 m of the section consists of thick coarse pumice lapilli units, but these were not studied as they could only be reached by abseiling down from the top of the cliff section.

The age of the deposits in the Taneatua section are unknown. The top of the section contains a significant erosional unconformity with >20 m of relief. The unconformity lies just below the Rotoiti Tephra, with ≈ 2 m of colluvium between, and therefore is probably related to the same period of erosion observed at many other sites throughout the Bay of Plenty. The post-Rotoiti tephras mantle the paleo-landscape above the unconformity and rest on slopes of $\approx 30^\circ$, whereas the fluvial and marine deposits below are only slightly tilted.

13-18.2 Motuhora Island section (Whale Island)

The Motuhora Island section occurs at the western end of Motuhora (Whale) Island [W15/589648], ≈ 5 km off-shore from Whakatane. Here, marine and fluvial sediment has been thrust up from the sea floor during the emplacement and/or uplift of the "West Dome" dacite [Duncan, 1970]. The sediment has been tilted at progressively steeper angles closer to the contact with the dacite, from slightly tilted some distance away, to actually overturned at the baked contact.

The sediments consist of fine pumiceous marine sands and silts, alternating with thick units of fluvial conglomerates. At least four conglomerate units are present, consisting of a mixture of greywacke clasts and very large pumice block. The section appears to have complete record of several successive glacio-eustatic sea-level rises and falls.

Many pumice layers are present on the Motuhora Island, and although most are reworked, there are several layers which may be airfall deposits. Furthermore, the reworked deposits may also each consist of material from a single individual eruptive episode. The tephric layers found here have been named the "Motuhora tephra", and the deposits here are similar in nature to those found in the uplifted marine sequence exposed in the coastal cliffs west of Matata. Shallow water faunas of Putikian age (late Castlecliffian) [Edbrooke, 1978] have been collected from Motuhora Island, which suggests that the sediments here and at Matata are of similar age. Attempts should be made to correlate the Motuhora tephra across to the mainland, and hence to the eastern Bay of Plenty tephrostratigraphy, but as yet no glass from the Motuhora tephra has been analysed. The physical characteristics of the tephra on Motuhora Island did not match those of any sequence seen on the mainland, but this could be due to the fact that the Motuhora tephra are predominantly reworked.

The age of the Motuhora tephra is unknown, but on the basis of the number of conglomerate beds present, each presumably representing a glacial period, the oldest tephra may have been deposited at c. 0.5 Ma.

13-18.3 Boundary section

The "Boundary" section occurs at the northern end of Raukumara Peninsula and is the most easterly section looked at in this work. It is a road cutting on Highway-35, located [Y14/602903] near the boundary between the Opotiki and Gisborne districts.

Many road cuts showing great thicknesses of upper Tertiary, "Te Kahika Formation" [Chapman-Smith & Grant-Mackie, 1971] sediment is present along the road, but at the "Boundary section" the sediment is apparently unconformably overlain by 10 m of horizontally bedded deposits to the present-day soil surface. These cover-beds are thought to be terrestrial in nature and contain more than 10 tephra, interspersed with lignites, paleosols, fine sands and clay. Many of the tephra are weathered, especially near the top, but several have been well preserved due to subaqueous deposition in a swamp or fluvial over-bank environment. These terrestrial deposits rest on a sandy paleosol developed into the horizontally

bedded marine sands of the Te Kahika Formation below. This much older formation contains occasional layers of organic-rich sediment.

The Boundary section is important in that it is thought to contain a continuous record of tephras for at least the last 200 ka, probably 300 ka, or possibly longer. No ages are available, as yet, and glass from the tephras here has yet to be analysed. Further work is needed here to define the age of the coverbeds, and hence the age of the paleosol developed into the Te Kahika formation — which probably represents the age of the cut surface, or, less likely, the age of first exposure due to gradual uplift.

13-18.4 Omokoroa Slump section

The Omokoroa Slump section [U14/789922] is a very large slip scarp located on the western edge of the Omokoroa peninsula in Tauranga Harbour, about 1 km southwest of Omokoroa Point.

The section contains a very thick (>25 m) sequence of very weathered tephras, loess, and paleosols. The deposits here are considered to record eruptives ranging in age from the post-Rotoiti tephras at the top to an ignimbrite thought to be at least 0.5 Ma old, perhaps much older, at its base.

Glass is sparse in these tephras, but several units do contain enough shards to analyse [Paul Froggatt, pers. comm. 1993]. The Omokoroa Slump section may represent the oldest completely terrestrial tephra sequence in the Bay of Plenty region, but as it lies at the very western edge of the region, correlations to the well understood eastern Bay of Plenty tephrostratigraphy may be difficult. At least 16 tephras are represented in the Omokoroa Slump section.

Glass from a pyroclastic flow unit found as a stack 20 m out into the harbour from this section was analysed, but its stratigraphic position is unknown as it is believed to have flowed around the already formed peninsular landform. It is considered to be significantly younger than the ignimbrite found at the base of the Omokoroa Slump section.

13-18.5 Gault's Slip section

The "Gault's slip" section [W15/892447] is located just east of Opotiki, where the Otara River has eroded into the western edge of the Tablelands Terrace and caused a large slip. The deposits exposed in this slip scarp were not able to be correlated by their physical characteristics to the eastern Bay of Plenty tephrostratigraphy, and as yet no glass has been analysed from this site. The deposits here appear to be much less weathered than those of the Tablelands subgroup and therefore are likely to be much younger.

The most probable explanation is that the slip has exposed sediments deposited during the construction of a river terrace at a time much later than the formation of the high Tablelands terrace. The age of this river terrace is uncertain, but the Rotoiti and Mangaone Tephra occur at the top of the section overlying the fluvial deposits.

The Gault's slip section contains; from the top:

- Mangaone Tephra; then Rotoiti Tephra; then 4 m obscured; then 2–4 m of tephra, perhaps subaqueously deposited; then a well developed paleosol (0.5 m thick) developed into a stained tephra 1.5 m thick, grey at base; then a paleosol developed into 2 m of weathered silt (perhaps loess?), with a thin tephra present mid-way through this; then 1 m of soft weathered gravels (perhaps siltstone gravels); then more silt; and another gravel bed (harder, less weathered); then subaqueously deposited, cross-bedded tephra; overlying more silt and clay (probably not loess).

The tephra in the Gault's slip section may belong to the Kukumoa subgroup which elsewhere are extremely weathered. The Gault's slip section may therefore be very important for determining the stratigraphy of this little understood time period, and the section deserves some detailed study.

13-18.6 Bookbinders section

The "bookbinder" section [X15/050525] is located at the very eastern end of Torere Bay in a road-cut on a driveway (sign-posted as "Bookbinder") to a house sitting on a marine terrace. The sediments exposed as the driveway rises to the terrace surface are:

- Marine mudstones with occasional gravel beds and a compacted tephra layer at the base; overlain by –
- reworked, cross-bedded coarse sandy ash, coarsening upwards to rounded pumice clasts 2 cm across, then interbedded with beach gravels;
- then gravels;
- then loess/silt with reworked white weathered ash-clay and sandy ash.

The top of the sequence was not seen.

The bookbinder section is ≥ 15 m thick and represents the emergence of marine sediments to a terrestrial depositional environment. This section may be one of the better preserved sites for showing the deeper stratigraphy of the one of the major terraces in this area, but was only discovered near the very end of the thesis, and given a cursory examination only.

13-18.7 McCoy Road-(2) section

The McCoy Road-(2) section [W15/677455] is a slip scarp located on McCoy Road, just east of the hairpin bend of the Waingarara Ignimbrite type section — McCoy Road-(1).

Eight tephric beds are found here, lying within organic-rich deposits very similar to the Waiopua tephra, though generally slightly thicker. These deposits, also, have yet to be correlated with the known eastern Bay of Plenty tephrostratigraphy. Most of the tephra units are probably not primary tephra, but rather tephric deposits, though they have been named here as the "McCoy Road tephra". These "tephra"

are very well preserved as they fell into a subaqueous environment and have undergone little weathering. The good preservation at this site suggests that many of these tephras are not likely to be found in subaerial sections elsewhere in the eastern Bay of Plenty because they were probably too thin to have survived bioturbation and other terrestrial weathering processes as recognisable tephra layers. Most of the tephric deposits have probably been over-thickened here, and many probably reworked from older deposits. The stratigraphic position of the McCoy Road-(2) section may therefore be difficult to establish and the glass from the McCoy Road tephras has yet to be analysed.

The McCoy Road-(2) section is believed to record a marine transgression. The basal half of the section contains organic-rich deposits, either fluvial over-bank or estuarine in origin, while above this are less organic-rich and tephra-rich deposits, and more silt. The top 5–6 m of the section couldn't be reached, but appears to consist of brownish marine sands, silts, and pumiceous sands.

The Waingarara Ignimbrite can be found nearby at the same topographic level as the McCoy Road tephras, suggesting that may be of similar age.

13-18.8 McCoy Ridge tephras

The McCoy Ridge section occurs on western side of the southern portion of McCoy Road (McCoy Road-(3) [W15/682440]), ≈1 km north of its intersection with Stanley Road. To avoid confusion with the McCoy Road sections, the tephras here have been named the McCoy Ridge tephras; McCoy Road in this area travels along near the ridge-top between two catchments.

The McCoy Ridge section has no stratigraphic control whatsoever and contains two tephras which have physical characteristics that do not match those of any of the known tephras in the eastern Bay of Plenty stratigraphy. Neither of these two eruptives have had their glass analysed.

The basal McCoy Ridge-A Tephra rests on >0.5 m of grey fine sand which has an uncertain depositional history. The tephra is ≈2 m thick and well bedded, containing some beds with pumice lapilli up to 1 cm across, though most beds are finer grained.

A thin organic-rich layer separates the McCoy Ridge-A Tephra from the McCoy Ridge-B above.

The top of the McCoy Ridge-B Tephra is not seen. Some weathering in its upper part suggests a thickness of ≈2 m, though it may be thicker. This tephra is only weakly bedded, but angular coarse pumice lapilli (2 cm across) indicate that it is an airfall deposit. Its physical characteristics are not distinctive, though its pumice contains a dark material which can write on paper.

13-18.9 Waiotahi Back Road section

The Waiotahi Back Road section [W15/783460] is located just off the eastern side of Waiotahi Valley Back Road, a few kilometres east of Ohiwa Harbour. The section was possibly an old quarry site, or where the Waiotahi River in geologically recent times has eroded into the hill. The basal part of the section contains fluvial gravels composed predominantly of hard greywacke clasts. A near vertical cliff

face has been formed above and in this cliff are several tephra layers interbedded with lignites, loess, and more fluvial deposits. The Rotoiti Tephra is thought to be present at the top of the cliff some 15–20 m above. Abseiling from the top of the section is probably the easiest way to study these deposits.

The deposits here are of an unknown age, but are likely to be much younger than the Tablelands subgroup.

13-18.10 Hillview section

The Hillview section is located on the far side of the same hill as the Ohiwa Hill section. It contains tephra that are very weathered and originally it was not thought worthwhile to duplicate the work undertaken on the much less weathered section barely 100 m away (Ohiwa Hill). However, it is now thought that these two sections contain deposits of different ages; the Hillview section containing the younger deposits.

The Hillview section contains:

- The post-Rotoiti tephra, and the very well developed last-interglacial paleosol below the Rotoiti Tephra grading into a very weathered orange tephra 2–2.5 m below (Kutarere?).
- A further 4 m of clay paleosols, weathered loess and weathered tephra (at least 4 units) are present below the orange weathered tephra.

The deposits in the Hillview section are believed to overlie those in the Ohiwa Hill section, and therefore contain tephra that are not present there. There may be some overlap of the basal Hillview section tephra with the uppermost Ohiwa Hill section tephra, but this was not able to be confirmed from their physical characteristics alone.

13-18.11 Hawai section

The Hawai section [X15/061527] is a road-cut located on Highway-35 at the very western end of Hawai Bay. It exposes the cover-bed deposits on the highest terrace in this vicinity, which is now believed to be of at least penultimate interglacial age.

The Hawai section, although the very top is missing, has one of the best preserved exposures of distal post-Rotoiti tephra in the eastern Bay of Plenty. It also contains Kukumoa subgroup deposits.

The stratigraphy down from the Rotoiti Tephra is: (see Photo-61)

- Unweathered loess (1 m); then a very well developed paleosol (1.6 m thick into loess), with a very weathered tephra at its base (probably the Kutarere Tephra); over a well developed brown paleosol developed into wet sticky clay (2.3 m).

The Te Waiiti section is another road-cut only a few hundred metres along the road northeast of the Hawai section. The Te Waiiti section also exposes the cover-bed deposits on a terrace at the western end

of Hawai Bay, but it is uncertain whether this is the highest terrace in the area, or the next highest. No samples were taken from here, but it shows the Kutarere Tephra better than at the Hawai. section.

13-18.12 Ngawaikui Beach section

The Ngawaikui Beach section [X15/998496] is located in an actively eroding coastal cliff in a bay just south of Haurere Point, between Torere Bay and Opape. Here, a terrace with the Rotoiti Tephra resting on it unconformably overlies what appears to be marine sediment containing several consolidated tephra that are believed to be primary airfall deposits. The cut surface was not seen but the underlying marine sediments are tilted and dipping at an angle towards the northeast. The age of the marine deposits is uncertain.

At least one higher terrace can also be seen in this area, but no sections were found exposing the cover-beds through this.

13-18.13 Opape Beach section

The Opape Beach section [X15/986490] is located on a driveway heading up to the terrace surface behind Opape camping ground and Opape Beach access. Here, the terrace is lower than that seen at the Opape section on the main highway and is considered to be younger.

The Opape Beach section contains from the top:

- Mangaone Tephra; loess; Rotoiti Tephra; loess (>1 m); beach gravels interbedded with reworked tephra; then extremely weathered gravels.

The extremely weathered basal gravels here are very similar in appearance to the weathered Waiotahi Gravels found below the Ohiwa Harbour subgroup at the base of the high Tablelands Terrace. It is thought that the the top of the gravels here may represent marine cutting during either $\delta^{18}\text{O}$ stage-5a or stage-5e. The beach gravels represent emergence, and the loess above these was presumably deposited during $\delta^{18}\text{O}$ stage-4 (Porewan). No glass was analysed from the Opape Beach section.

13-18.14 Awaawakino section

The Awaawakino section [X15/005493] is road-cut located on the eastern side of Highway-35, opposite some lower swampy ground between Opape and Torere Bay. This section is one of the better sites in the eastern Bay of Plenty showing the distal post-Rotoiti tephra, especially the Tahuna/Ngamotu Tephra.

The Rotoiti Tephra here overlies leached, water saturated sandy mud, very weathered gravel layers, and further along the road (south), a water-logged reworked, white bedded tephra. More weathered gravels interbedded with tephra are present below. The white tephra near the base of the section is probably the

Torere Tephra, but this identification is very uncertain as no glass from the Awaawakino section has been analysed.

13-18.15 General areas requiring further study

Many sections exist that have not been discussed at all above. This is because they either contain only a few tephra with little stratigraphic control and are unlikely to be identified even after detailed study, or were located outside the main area of study. The areas listed below are where very little work was carried out in this study, but may contain as yet undiscovered sections that could greatly enhance the tephrostratigraphic record of the Bay of Plenty.

- around the coastal cliffs of Ohiwa Hill, just east of the Ohiwa Harbour mouth;
- road sections between Torere and Hawai, and between Opape and Torere;
- road sections in the Waimana area and further east towards the junction of Highway-2 with Wainui Road;
- the area south and southwest of Taneatua;
- the forestry roads in the pine plantations between Tokoroa and Rotorua, including the Downer Road, Galaxy Road and Tikorangi Road sections.

Chapter Fourteen : Mineral Geochemistry

The tephra in this study were identified and correlated using several different techniques, both physical and geochemical. The physical features and glass chemistry of the tephra have been discussed in the chapters detailing the individual eruptives (Chapters 6 to 13) while the geochemistry of the minerals found in the tephra is detailed in this chapter. Possible correlations of these tephra — based on mineral geochemistry — are also discussed here. Analyses of minerals has been carried out on only a small proportion of the tephra; generally from units which are highly weathered and no longer contain glass, and from their suspected correlatives — based on stratigraphic relationships.

The minerals were studied by microprobe analysis on individual grains; the methods of analysis and background information are discussed further in Chapter Three.

The types of minerals analysed include Fe-Ti oxides (titano-magnetite), amphiboles (hornblende & cummingtonite), pyroxenes (hypersthene) and biotites. The Fe-Ti oxides and amphibole minerals were found to be the most important minerals in distinguishing between eruptives.

In the data tables presented in this chapter the tephra are listed in their stratigraphic positions; the youngest deposits at top and the oldest at the bottom.

14-1 Titano-magnetite Analysis

For many of the tephra within the Reeves, Ohiwa Harbour and Kukumoa subgroups, titano-magnetite geochemistry is the most likely method of chemical correlation. The deposits in these three subgroups are extremely weathered, and generally no glass can be extracted for analysis and chemical characterisation purposes.

Using microprobe analyses of titano-magnetites, attempts have been made here to correlate a number of tephra found in the Ohiwa Harbour subgroup, to several tephra belonging to the Ohinekoao subgroup. The two subgroups are believed to be of the same age, but in the Ohinekoao subgroup the tephra have retained their glass, due to the preserving nature of the subaqueous environment that they were deposited in. If positive correlations could be made between the two subgroups via titano-magnetite geochemistry, the glass chemistry of the Ohiwa Harbour subgroup tephra would also, by proxy, be known. Possible correlations to other areas of the country could then be achieved using glass chemistry.

Table 14-1.1a : Titanomagnetite analyses from several Reeves and Ohiwa Harbour subgroup tephra.

tephra & samp.#	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	ZnO	Cr ₂ O ₃	total	Ulvösp.	no.
Ohiwa-F 02109	0.09 0.06	8.82 0.47	1.54 0.18	49.68 1.36	37.59 0.61	0.69 0.14	0.66 0.18	0.20 0.09	t	99.28 0.96	0.262 0.017	7
— 02109b	0.11 0.01	5.38 1.22	1.84 0.11	56.95 3.99	34.87 0.40	0.82 0.13	0.52 0.09	0.21 0.04		100.68 2.16	0.159 0.040	2
Tirohanga 02108	0.09 0.05	11.07 0.24	2.20 0.14	45.62 0.90	39.30 0.52	0.58 0.06	1.23 0.08	0.17 0.09	t	100.36 1.12	0.327 0.008	8
Tirohanga 04201	0.11 0.03	11.05 0.23	2.21 0.10	44.98 0.67	38.88 0.43	0.62 0.09	1.27 0.14	0.14 0.06		99.28 0.87	0.328 0.007	10
Ohiwa-D 04203	0.12 0.05	8.39 0.11	1.45 0.08	48.85 0.53	36.48 0.23	0.70 0.07	0.60 0.07	0.18 0.03	0.08 0.06	96.84 0.62	0.255 0.005	6
Ohiwa-C 04204	0.14 0.04	9.35 0.36	2.60 0.12	45.34 1.21	35.42 0.40	0.50 0.10	1.92 0.13	0.17 0.09	0.22 0.09	95.65 1.09	0.288 0.012	6
— 04204b	0.16 0.05	10.56 0.11	1.94 0.13	42.95 0.69	37.77 0.07	0.50 0.01	1.04 0.21	0.02 0.02	0.18 0.21	95.10 1.23	0.332 0.006	2
— 04204c	0.18 0.01	8.12 0.18	1.42 0.12	48.23 0.36	36.09 0.21	0.61 0.11	0.56 0.08	0.19 0.07	0.32 0.07	95.70 0.04	0.253 0.006	2
Ohiwa-B ? 01902	0.12 0.03	8.41 0.09	1.45 0.04	50.06 0.44	37.03 0.23	0.63 0.06	0.63 0.06	0.20 0.12	T	98.63 0.80	0.251 0.003	7
Ohiwa-B 03201	0.08 0.02	8.29 0.24	1.59 0.07	50.70 0.50	37.08 0.46	0.65 0.08	0.65 0.05	0.19 0.06	t	99.32 0.79	0.243 0.011	7
Ohiwa-B 09202	0.08 0.01	8.32 0.73	1.64 0.14	50.14 1.62	36.84 0.82	0.61 0.11	0.70 0.15	0.16 0.06	T	98.62 0.85	0.249 0.024	8
— 09202b	0.21 0.14	9.75 1.00	2.31 0.26	45.73 0.23	36.92 1.36	0.55 0.06	1.48 0.02	0.07 0.03		97.00 2.21	0.297 0.019	2
Jackson ? 01906	0.11 0.06	8.90 0.98	1.76 0.14	50.22 2.12	37.77 0.84	0.54 0.08	0.92 0.15	0.18 0.08	t	100.41 0.81	0.261 0.030	10
Jackson ? 02107	0.09 0.06	8.62 0.12	1.46 0.03	49.47 0.44	36.97 0.29	0.72 0.07	0.60 0.06	0.20 0.07	t	98.21 0.56	0.257 0.004	7
Jackson 03202	0.08 0.05	8.71 0.48	1.56 0.23	49.94 1.06	37.09 0.50	0.73 0.16	0.76 0.23	0.19 0.12		99.05 0.74	0.256 0.014	9
Jackson 04202	0.11 0.04	8.64 0.29	1.51 0.22	49.80 0.36	37.29 0.30	0.68 0.17	0.71 0.19	0.22 0.18	t	98.99 0.42	0.258 0.006	7
Jackson 09204	0.09 0.03	8.03 0.20	1.76 0.07	50.75 0.53	36.56 0.22	0.61 0.29	0.83 0.07	0.19 0.08	0.23 0.14	99.05 0.65	0.240 0.005	7
Reeves-C 01908a	0.12 0.05	11.26 0.65	2.51 0.23	42.27 1.38	37.86 1.37	0.43 0.09	1.90 0.71	0.20 0.09	1.36 0.37	97.66 0.67	0.351 0.025	5
— 01908b	0.12 0.04	8.23 0.36	1.50 0.18	49.86 0.51	36.37 0.87	0.59 0.15	0.86 0.14	0.20 0.07	0.20 0.16	97.93 0.98	0.246 0.012	5
— 01908c	0.08 0.04	5.77 0.72	1.47 0.15	54.89 1.39	34.59 0.82	0.88 0.29	0.46 0.17	T 0.15	0.19 0.15	98.39 0.47	0.173 0.023	2

Ilmenites are thought to be more diagnostic than titanomagnetites for the chemical characterisation (fingerprinting) of tephra, but only a very few ilmenites were analysed in this study. Therefore calculations using the compositions of titanomagnetite and ilmenite pairs to estimate the temperature of the crystallizing magma were not able to be carried out. All titanomagnetite and ilmenite analyses are presented in Appendix-(G).

For the following chemical data tables, all values are in oxide weight percentages (wt.%), with "Ulvösp." representing the mole proportion of Ulvöspinel in the cubic oxide. Iron was measured as Fe-total and recalculated to Fe₂O₃ and FeO via stoichiometry. "no." represents the number of analyses used for calculating the means (line-1), and 1σ standard deviations (line-2). The most reliable analyses are those with totals close to 100% (98–100%).

14-1.1 Reeves, Ohiwa Harbour and Ohinekoao subgroups

The titanomagnetite analyses for several of the tephra that occur in the Reeves and Ohiwa Harbour subgroups in the eastern Bay of Plenty are presented in Table 14-1.1a. Table 14-1.1b presents the titanomagnetite analyses for several tephra in the Ohinekoao subgroup, which are probably of similar age to those in Table 14-1.1a, but located in a different area — the central coastal Bay of Plenty.

Table 14-1.1b: Titanomagnetite analyses from Ohinekoao subgroup tephra.

tephra & samp.#	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	ZnO	Cr ₂ O ₃	total	Ulvösp.	no.
Ohinekoao-L 00909	0.12 0.06	9.23 0.74	1.49 0.09	48.43 1.58	37.83 0.77	0.68 0.15	0.63 0.12	0.16 0.08	0.14 0.08	98.71 1.08	0.276 0.022	11
Ohinekoao-I 00901	0.07 0.03	10.43 0.89	3.52 0.46	45.20 1.36	36.16 1.29	0.43 0.09	2.87 0.26	0.13 0.10	0.17 0.11	98.98 1.67	0.310 0.023	9
Ohinekoao-I 08302	0.12 0.04	10.22 0.56	3.36 0.57	45.93 0.58	36.34 1.06	0.50 0.09	2.73 0.38	0.17 0.06	0.18 0.10	99.53 0.53	0.302 0.014	8
— 00901b	0.06 0.01	11.24 0.05	2.24 0.05	43.24 0.56	38.41 0.01	0.59 0.01	1.33 0.13	0.11 0.01	0.20 0.06	97.40 0.80	0.344 0.005	2
Ohinekoao-H 00907	0.10 0.04	11.66 0.68	1.71 0.18	43.47 1.03	39.63 0.55	0.67 0.24	0.87 0.15	0.19 0.09	0.15 0.10	98.43 0.86	0.351 0.015	9
Ohinekoao-E + 00904	0.11 0.03	10.37 0.35	2.33 0.11	45.48 0.64	37.38 0.43	0.55 0.10	1.68 0.09	0.16 0.10	0.11 0.05	98.15 0.51	0.310 0.010	6
Ohinekoao-A 00913	0.08 0.04	8.29 0.17	1.52 0.08	51.08 1.07	37.05 0.32	0.74 0.12	0.65 0.09	0.25 0.08	0.11 0.08	99.75 1.38	0.243 0.007	7
Wilson 08401	0.10 0.03	10.00 0.21	2.06 0.07	47.23 0.52	38.03 0.38	0.55 0.06	1.18 0.04	0.22 0.07		99.36 0.89	0.296 0.005	6

In the eastern Bay of Plenty, the Tirohanga Tephra has the same moderately distinctive titanomagnetite chemistry from both sites that were analysed (see Figure 14-1); as does the Ohiwa-B Tephra, from three sites; and the Jackson tephra, from five sites. The Jackson, Ohiwa-B, Ohiwa-D and Ohiwa-F Tephra all have similar titanomagnetite chemistries, whereas the Reeves-C, Ohiwa-C and Tirohanga

Table 14-1.1c: Similarity coefficients (S.C.'s) comparing titanomagnetite analyses from tephra in the Reeves, Ohiwa Harbour and Ohinekoao subgroups, as well as several others.

oldest	O3901	O8401	O0913	O0604	O0907	O0801	O8302	O0809	O1908a	O1908b	O1906	O2107	O3202	O4202	O8204	O1902	O3201	O8202	O4204	O4203	O2108	O4201	O2109
Wainarara Igb. 03901	1.00																						
Wilson 08401	0.86	1.00																					
Ohinekoao-A 00913	0.88	0.79	1.00																				
Ohinekoao-E 00904	0.82	0.92	0.74	1.00																			
Ohinekoao-H 00907	0.88	0.88	0.82	0.84	1.00																		
Ohinekoao-I 00901	0.72	0.77	0.65	0.83	0.72	1.00																	
Ohinekoao-I 08302	0.75	0.81	0.68	0.86	0.74	0.95	1.00																
Ohinekoao-L 00909	0.93	0.83	0.95	0.77	0.85	0.67	0.70	1.00															
Reeves-C(a) 01908a	0.75	0.83	0.68	0.91	0.80	0.87	0.85	0.71	1.00														
Reeves-C(b) 01908b	0.88	0.85	0.91	0.79	0.89	0.69	0.72	0.90	0.72	1.00													
Jackson 01906	0.88	0.91	0.87	0.84	0.91	0.72	0.76	0.88	0.77	0.93	1.00												
Jackson 02107	0.91	0.79	0.96	0.75	0.82	0.66	0.68	0.96	0.68	0.90	0.86	1.00											
Jackson 03202	0.87	0.82	0.96	0.77	0.85	0.67	0.70	0.93	0.70	0.93	0.90	0.95	1.00										
Jackson 04202	0.89	0.82	0.96	0.77	0.85	0.67	0.70	0.96	0.70	0.94	0.90	0.96	0.97	1.00									
Jackson 09204	0.85	0.86	0.90	0.80	0.90	0.69	0.72	0.88	0.73	0.96	0.94	0.85	0.92	0.92	1.00								
Ohiwa-B 01902	0.91	0.81	0.96	0.76	0.84	0.67	0.70	0.96	0.69	0.93	0.88	0.96	0.93	0.96	0.91	1.00							
Ohiwa-B 03201	0.89	0.82	0.97	0.77	0.85	0.67	0.70	0.95	0.70	0.93	0.89	0.95	0.94	0.96	0.93	0.97	1.00						
Ohiwa-B 09202	0.89	0.84	0.94	0.79	0.87	0.68	0.71	0.92	0.71	0.94	0.91	0.92	0.94	0.96	0.95	0.96	0.97	1.00					
Ohiwa-C 04204	0.77	0.86	0.72	0.92	0.78	0.86	0.89	0.75	0.92	0.77	0.81	0.73	0.75	0.75	0.77	0.74	0.74	0.76	1.00				
Ohiwa-D 04203	0.91	0.79	0.96	0.75	0.82	0.66	0.69	0.96	0.68	0.91	0.85	0.99	0.93	0.95	0.89	0.97	0.95	0.93	0.73	1.00			
Tirohanga 02108	0.83	0.95	0.76	0.92	0.90	0.77	0.80	0.80	0.86	0.82	0.86	0.77	0.79	0.79	0.83	0.78	0.98	0.81	0.85	0.77	1.00		
Tirohanga 04201	0.82	0.93	0.77	0.91	0.89	0.77	0.79	0.80	0.86	0.81	0.84	0.77	0.80	0.80	0.83	0.79	0.80	0.81	0.84	0.77	0.98	1.00	
Ohiwa-F 02109	0.90	0.82	0.97	0.77	0.85	0.67	0.70	0.97	0.70	0.90	0.89	0.96	0.96	0.74	0.90	0.96	0.80	0.95	0.74	0.96	0.79	0.80	1.00
youngest																							

boxed shaded areas = believed to be correlatives on other criteria

shaded areas = possible correlatives

Tephra form a separate group with higher TiO_2 , Al_2O_3 & MgO , and lower Fe_2O_3 contents. The two chemical groups generally agree with groupings made on the basis of the ferromagnesian assemblages of these tephra.

Figure 14-1 : Titano-magnetite geochemistry of the Tirohanga and Jackson Tephra

The Ohinekoao subgroup tephra show more chemical variation between eruptives than within units. The Ohinekoao-I Tephra has a very similar titano-magnetite chemistry from both sites sampled, and contains the highest Al_2O_3 values for any tephra analysed in this study — beyond the scope of the diagram. A graphical comparison of the geochemistries of the various tephra found in the two areas is shown in Figure 14-2.

Figure 14-2 : Titanomagnetite analyses of some Ohinekoao and Ohiwa Harbour subgroup tephra

Table 14-1.2a : Titanomagnetite analyses from Kukumoa subgroup tephra.

tephra & samp.#	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	ZnO	Cr ₂ O ₃	total	Ulvösp.	no.
Wairuru 04801	0.08 0.04	9.85 1.12	1.46 0.10	47.17 1.87	38.10 1.28	0.69 0.03	0.65 0.08	0.23 0.15	0.03 0.03	98.27 0.74	0.293 0.032	6
— 04801b	0.13 0.09	9.22 0.74	2.93 0.61	47.46 1.64	34.47 1.07	0.69 0.16	2.83 0.48	0.16 0.08	0.12 0.05	98.00 1.06	0.267 0.025	4
Copenhagen 04803	0.03 0.03	9.17 0.45	1.38 0.13	48.73 1.44	37.33 0.02	0.69 0.12	0.76 0.16	0.15 0.13	0.11 0.02	98.35 0.90	0.271 0.014	3
— 04803b	0.18 0.06	7.13 1.78	4.76 1.91	50.13 2.88	32.94 1.69	0.56 0.15	3.13 0.79	0.13 0.12	0.10 0.07	99.05 0.70	0.214 0.047	5
Torere School 04802	0.06 0.02	7.37 0.57	1.79 0.13	53.56 1.60	35.34 0.55	0.81 0.13	1.35 0.10	0.22 0.10	0.03 0.04	100.53 1.21	0.209 0.018	6
Kukumoa-D 03802	0.08 0.04	11.39 0.41	1.07 0.09	43.70 0.85	39.20 0.49	0.86 0.03	0.50 0.05	0.18 0.11	0.05 0.07	97.02 0.73	0.341 0.012	6
Kukumoa-C 03803	0.10 0.03	11.97 0.73	1.15 0.14	44.23 1.43	40.43 0.74	0.95 0.22	0.51 0.13	0.25 0.06	0.07 0.06	99.66 0.74	0.349 0.021	6
— 03803b	0.08 0.02	11.27 2.82	3.28 0.97	43.00 4.54	37.85 3.32	0.40 0.13	2.10 0.60	0.22 0.11	0.16 0.10	98.35 0.90	0.344 0.084	4
Kukumoa-B 03804	0.04 0.04	11.89 0.44	1.11 0.12	44.21 0.72	40.26 0.55	0.77 0.14	0.54 0.08	0.23 0.11	0.08 0.09	99.24 0.74	0.348 0.012	8
— 03804b	0.07 0.10	8.39 0.73	2.08 0.11	51.36 1.70	34.80 2.24	0.83 0.05	2.28 0.81	0.18 0.13	0.10 0.02	100.06 0.37	0.233 0.030	2
Kutarere 03801	0.07 0.02	11.49 0.76	1.19 0.18	44.99 1.85	39.84 0.56	0.85 0.14	0.61 0.15	0.23 0.14	0.13 0.10	99.42 0.82	0.336 0.024	7

Figure 14-3 : Titanomagnetite geochemistry of Kukumoa subgroup tephra

The only tephra within the Ohinekoao subgroup that has a similar titano-magnetite chemistry to any eastern Bay of Plenty eruptive is the Ohinekoao-A Tephra (see Figure 14-2). However, this chemistry is relatively common and could represent one of many eruptives.

Based upon stratigraphic position and ferromagnesian assemblages, a tentative correlation between the Ohinekoao-A and Jackson Tephra is suggested. Also suggested are correlations between the Ohinekoao-B and Ohiwa-B Tephra, the Ohinekoao-D or -E and Ohiwa-C Tephra, the Ohinekoao-G and Ohiwa-D Tephra, the Ohinekoao-H or Ohinekoao-I with the Tirohanga Tephra, the Ohinekoao-J and Ohiwa-F Tephra, and the Ohinekoao-N with the Ohiwa-G Tephra. However, apart from the Ohinekoao-A – Jackson Tephra correlation, the titano-magnetite chemistries of these possible correlatives are not good matches.

Similarity coefficients comparing the titanomagnetite geochemistries of the tephra in these subgroups are presented in Table 14-1.1c.

The lack of close chemical matches between the two areas does not necessarily mean that the correlations are invalid, but that much further work is required on these deposits. It may be that the titano-magnetites from the eastern Bay of Plenty tephra have been altered — due to the intense weathering they have been subjected to — in a way that is not yet fully understood. Furthermore, as not all of the Ohinekoao subgroup tephra have been analysed, closer chemical matches may yet be found, and the thickest eruptives in the west may not necessarily correlate with the thickest eruptives in the east. Alternatively, the Ohinekoao and Ohiwa Harbour subgroups may be of different ages and not be correlatives.

14-1.2 Kukumoa subgroup

The titano-magnetite geochemistry of the tephra in the Kukumoa subgroup are presented in Table 14-1.2a. Unless the differing weathering conditions of the Kukumoa and Copenhagen Road sections has caused variations in the chemistries of the titano-magnetites, then it is clearly obvious that the tephra at the two sites are not correlatives (see Figure 14-3), and were erupted at different times. The Kukumoa subgroup is considered, therefore, to span a significant length of time, including two periods of warm climate weathering ($\delta^{18}\text{O}$ stages-5 & 7) and one of cold ($\delta^{18}\text{O}$ stage-6) (see Chapter 15).

All four of the tephra at Kukumoa cutting have similar titano-magnetite geochemistries, indicating that they were probably erupted from the same source area. Since the Kukumoa-B, Kukumoa-C and Kukumoa-D Tephra do not contain glass, this is a vital clue to their identity and origin. The Wairuru and Copenhagen Tephra also have very similar titano-magnetite geochemistries to each other, mirroring the closeness of their glass chemistry. Similarity coefficients that compare the titanomagnetite geochemistries of the tephra in the Kukumoa subgroup are presented in Table 14-1.2b.

Table 14-1.3a : Titanomagnetite analyses from miscellaneous tephra in this study.

tephra & samp.#	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	ZnO	Cr ₂ O ₃	total	Ulvösp.	no.
Reid's Reserve 11201	0.09 0.04	10.94 0.29	1.39 0.05	45.70 0.76	39.49 0.34	0.62 0.05	0.64 0.06	0.25 0.05	0.09 0.04	99.18 0.55	0.323 0.010	6
Kaingaroa Igb. 06201	0.08 0.02	12.11 0.19	1.41 0.06	43.19 0.63	40.16 0.26	0.81 0.05	0.68 0.06	0.23 0.12	T	98.78 0.69	0.359 0.006	7
Kaingaroa (?) 09301	0.03 0.04	11.04 1.10	1.06 0.23	45.01 1.86	39.15 1.05	0.62 0.12	0.59 0.26	0.16 0.02	0.09 0.12	97.74 0.54	0.327 0.031	7
— 09301b	0.00 0.00	7.89 1.22	1.43 0.08	50.37 2.34	35.10 1.55	0.69 0.40	1.12 0.03	0.14 0.06	0.12 0.11	96.84 0.02	0.233 0.039	2
Matahina Igb. 06202	0.10 0.05	10.98 0.82	1.51 0.07	46.11 1.70	39.91 0.78	0.62 0.13	0.61 0.09	0.17 0.09	T	100.10 1.08	0.324 0.024	7
Kohioawa 01601	0.19 0.02	8.23 0.58	1.42 0.15	49.87 1.52	36.67 0.64	0.66 0.13	0.72 0.12	0.19 0.06	0.16 0.05	98.06 1.07	0.247 0.019	6
pre-Whakamaru 11101	0.17 0.04	8.57 0.19	1.50 0.05	48.98 0.71	36.83 0.21	0.57 0.10	0.82 0.04	0.19 0.09	0.30 0.15	97.93 0.66	0.258 0.007	8
unknown? 11102	0.17 0.06	7.81 0.43	1.29 0.09	50.58 1.15	36.42 0.58	0.82 0.14	0.44 0.05	0.21 0.05	0.20 0.04	97.93 0.86	0.234 0.014	6
— 11102b	0.13	8.61	4.10	48.53	34.11	0.58	3.10	0.40	0.11	99.67	0.253	1
Qtz-biot. Igb. 09401	0.12 0.06	5.23 1.14	1.51 0.21	56.95 2.15	34.66 1.23	1.03 0.18	0.28 0.04	0.26 0.09	0.11 0.11	100.02 1.15	0.154 0.034	9
— 09401b	0.13 0.04	12.31 0.84	1.33 0.12	41.99 0.70	40.28 0.92	1.31 0.13	0.41 0.02	0.32 0.07	0.11 0.05	98.19 1.12	0.371 0.019	2
— 09401c	0.12 ---	9.83 0.18	1.30 0.23	47.54 0.98	38.15 0.49	1.35 1.11	0.35 0.08	0.12 0.08	0.13 ---	98.74 1.20	0.291 0.001	2
Qtz-biot. Igb. 09501	0.10 0.02	8.51 0.41	1.37 0.05	49.59 0.69	36.81 0.64	0.92 0.08	0.54 0.09	0.18 0.07	0.08 0.03	98.10 1.21	0.253 0.010	7

Table 14-1.3b : Analyses of titanomagnetites from the Waingarara Ignimbrite.

tephra & samp.#	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	ZnO	Cr ₂ O ₃	total	Ulvösp.	no.
Waingarara Igb. 03901	0.12 0.03	10.22 0.31	1.49 0.08	46.01 0.84	38.65 0.23	0.54 0.05	0.60 0.07	0.20 0.11	0.34 0.15	98.15 0.74	0.309 0.010	4
— 03901b	1.46 0.42	13.09 0.49	1.40 0.23	34.49 2.49	41.81 0.93	0.57 0.01	0.46 0.04	0.47 0.18	0.30 0.05	94.03 1.05	0.438 0.028	2
— 03901c	4.67 0.89	14.73 1.93	1.77 0.27	21.08 3.64	47.26 1.86	0.20 0.12	0.27 0.24	0.59 0.24	0.26 0.14	90.78 1.23	0.610 0.068	8
Waingarara Igb. 02802	4.99 1.07	13.46 0.40	1.91 0.10	22.07 3.46	46.81 1.72	0.21 0.04	0.16 0.01	0.09 0.09		89.68 0.51	0.580 0.052	3
— 03901d	6.72	17.77	2.82	8.53	52.95	0.13	0.14	0.69	0.12	89.87	0.863	1

An interesting feature of the titano-magnetite analyses are that there are often several components forming a mixed chemical assemblage. The high Al_2O_3 and MgO content for one of the components in the Wairuru, Copenhagen, Kukumoa-C and Kukumoa-B Tephra is quite distinctive. It is uncertain whether the high Al_2O_3 and MgO content is related to weathering of the titano-magnetite minerals, or due to pre- or syn-eruption mixing or entrainment of a separate magma, or xenoliths, within the magma chamber and/or vent.

Table 14-1.2b : Similarity coefficients (S.C.'s) comparing titanomagnetite analyses from tephra in the Kukumoa subgroup

<i>oldest</i>		03801	03804	03803	03802	11201	04802	04803	04801
Kutarere	03801	1.00							
Kukumoa-B	03804	0.94	1.00						
Kukumoa-C	03803	0.94	0.95	1.00					
Kukumoa-D	03802	0.94	0.95	0.95	1.00				
Reid's Res.	11201	0.91	0.89	0.86	0.86	1.00			
Torere School	04802	0.74	0.72	0.70	0.71	0.74	1.00		
Copenhagen	04803	0.86	0.84	0.80	0.81	0.91	0.81	1.00	
Wairuru	04801	0.89	0.87	0.83	0.84	0.94	0.78	0.95	1.00
<i>youngest</i>									

14-1.3 Other tephra

Several tephra other than those from the subgroups studied above have also had their titano-magnetites analysed. These are presented in Table 14-1.3a.

Several points of interest occur with these analyses, one being the good chemical match of the Kohioawa Tephra titano-magnetites with those from the weathered tephra found immediately below the Whakamaru Ignimbrite at the Peach Road site (sample 11101). However, it should be noted that the chemistry of the weathered tephra, and of the tephra immediately below (sample 11102), also quite closely matches those of the Jackson and Ohiwa-B Tephra which are believed to be much older. The Tirohanga Tephra, which has a similar ginger colour to sample 11101 (Peach Rd), has a very different titano-magnetite chemistry.

Another point to note is the difference between chemistries of the two Quartz-biotite Ignimbrite samples. This mirrors the difference seen between their glass chemistries and suggests that there are at least two Quartz-biotite Ignimbrites. However, hydrothermal alteration within different areas of the same ignimbrite may yet account for both the glass and the titano-magnetite chemical differences.

The Reid's Reserve Tephra has a similar titano-magnetite geochemistry to the Kaingaroa Tephra, which is consistent with the closeness of their glass chemistries. However, the physical characteristics of these two tephra are very different from one another and preclude correlation.

Table 14-1.3b presents analyses from the Waingarara Ignimbrite. Since it is a pyroclastic flow deposit, it might be expected that the glass and minerals in this unit may have suffered from some alteration. The glass shows a relatively consistent chemical mixture, though significantly different from

Table 14-2.1a : Hornblende analyses from tephtras in the Reeves and Ohiwa Harbour subgroups.

sample no. & site	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	total	no.
Tirohanga 04201	44.31 0.92	2.08 0.32	8.53 0.90	15.14 0.79	0.35 0.09	12.78 0.31	10.69 0.18	1.77 0.24	0.38 0.05	96.03 0.55	7
Ohiwa-B 01902	46.98 0.77	1.29 0.17	6.49 0.36	16.46 0.71	0.61 0.10	12.94 0.40	10.27 0.24	1.34 0.11	0.40 0.08	96.78 0.81	15
Ohiwa-B 09202	47.34 1.33	1.29 0.11	6.52 0.33	16.22 0.73	0.49 0.19	12.59 0.75	10.32 0.20	1.34 0.07	0.39 0.03	96.48 1.17	6
Jackson ? 01906	47.17 0.58	1.33 0.21	6.94 0.34	15.57 0.84	0.44 0.08	13.66 0.65	10.86 0.25	1.31 0.10	0.44 0.07	97.71 0.65	12
Jackson 03202	46.20 0.87	1.32 0.13	6.23 0.49	16.71 0.81	0.65 0.21	12.71 0.66	10.30 0.24	1.34 0.15	0.42 0.04	95.88 1.62	10
Jackson 04202	46.02 1.47	1.35 0.14	6.43 0.36	16.65 0.64	0.62 0.10	12.37 0.25	10.29 0.22	1.37 0.15	0.46 0.06	95.56 2.34	9
— 04202b	43.75	2.29	8.93	13.57	0.45	13.01	10.55	1.81	0.32	94.68	1
Reeves-B 01907	46.05 1.05	1.68 0.08	7.75 0.18	17.18 0.41	0.30 0.06	12.02 0.42	10.86 0.26	1.43 0.07	0.44 0.04	97.72 1.28	5
Reeves-A 01903	45.72 0.67	1.28 0.10	7.37 0.21	17.58 1.19	0.51 0.09	12.25 0.73	10.30 0.32	1.33 0.13	0.40 0.02	96.74 0.78	7

Table 14-2.1b : Hornblende analyses from tephtras found in the marine sequence west of Matata — below the Tablelands subgroup (i.e. mostly Ohinekoao subgroup tephtras).

tephra & samp.#	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	total	no.
unknown 07806	46.47 1.04	1.28 0.25	6.38 0.43	17.06 0.75	0.58 0.20	12.26 0.50	10.34 0.44	1.43 0.09	0.32 0.04	96.12 0.95	5
Ohinekoao-M/-N 08303	42.33 0.01	1.92 0.68	7.71 1.68	16.95 0.74	0.55 0.04	10.96 0.04	10.09 0.31	1.68 0.63	0.42 0.02	92.58 3.99	2
Ohinekoao-K 08301	46.45 0.80	1.30 0.18	6.42 0.39	16.95 0.80	0.59 0.10	12.82 0.44	10.31 0.20	1.37 0.10	0.40 0.07	96.60 1.17	9
Ohinekoao-I 00901	44.39 0.59	2.04 0.15	9.39 0.37	14.70 1.07	0.31 0.06	13.47 0.42	9.04 0.15	1.93 0.07	0.27 0.03	95.52 1.12	6
Ohinekoao-I 08302a	44.01 0.92	2.37 0.19	9.28 0.71	14.34 0.55	0.39 0.08	13.15 0.31	10.61 0.22	1.88 0.11	0.37 0.04	96.40 1.05	4
— 00901b	45.37	1.64	7.98	17.48	0.43	12.24	9.01	1.54	0.35	96.04	1
— 08302b	46.04 0.78	1.32 0.28	6.70 0.77	16.58 0.64	0.55 0.08	12.52 0.85	10.25 0.23	1.36 0.09	0.41 0.02	95.72 0.59	5
Wilson 08401	45.72 1.39	1.74 0.31	7.69 0.98	16.15 0.43	0.41 0.07	12.80 0.52	10.40 0.32	1.55 0.19	0.31 0.04	96.77 1.09	6

the airfall tephra immediately underlying the flow (see sect. 13-12), but the titano-magnetites show a significant and unusual chemical variation.

As the analytical totals — and hence the reliability of the analyses — decrease, the wt.% values of SiO_2 increase dramatically. TiO_2 , Al_2O_3 & FeO also increase, while Fe_2O_3 , MnO & MgO decrease, but all at slower rates than the increase in SiO_2 . Of the eighteen analyses conducted on the Waingarara Ignimbrite, only four (uppermost in the table) have acceptable totals and are believed to be reliable. However, if any alteration has occurred, perhaps none of the analyses accurately portray the original titano-magnetite geochemistry. This type of chemical variation is yet to be seen in any other eruptive, and its cause remains unknown.

Similarity coefficients comparing the titanomagnetite geochemistries of these various tephras are presented in Table 14-1.3c.

Table 14-1.3c : Similarity coefficients (S.C.'s) comparing titanomagnetite analyses from various tephras within this study.

<i>oldest</i>		O94O1	O95O1	111O2	111O1	O16O1	O62O2	O62O1	O93O1	O38O1	112O1
Qtz-biot. Igb. 09401		1.00									
Qtz-biot. Igb. 09501		0.79	1.00								
unknown 11102		0.72	0.92	1.00							
Whakamaru 11101		0.80	0.86	0.83	1.00						
Kohioawa 01601		0.74	0.90	0.88	0.94	1.00					
Matahina Igb. 06202		0.70	0.85	0.81	0.88	0.89	1.00				
Kaingaroa Igb. 06201		0.70	0.86	0.83	0.83	0.87	0.91	1.00			
Omaio 09301		0.65	0.83	0.81	0.83	0.85	0.94	0.87	1.00		
Kutarere 03801		0.70	0.87	0.85	0.80	0.83	0.91	0.93	0.92	1.00	
Reid's Res. 11201		0.69	0.86	0.82	0.88	0.90	0.98	0.92	0.94	0.91	1.00
Waingarara 02802		0.70	0.85	0.81	0.90	0.88	0.96	0.87	0.91	0.88	0.94
Jackson 04202		0.74	0.90	0.86	0.94	0.97	0.90	0.87	0.85	0.84	0.90
Tirohanga 04201		0.61	0.72	0.70	0.81	0.79	0.85	0.80	0.82	0.78	0.85
<i>youngest</i>											

shaded areas represent tephras that are believed to be likely correlatives

14-2 Hornblende Analysis

As with the titano-magnetites, the hornblendes are much more resistant to weathering than glass, but they are not ubiquitous like the Fe-Ti oxides and many tephras contain little or no hornblende. The use of hornblendes for correlation purposes is therefore limited.

14-2.1 Reeves, Ohiwa Harbour and Ohinekoao subgroups

Hornblendes were analysed from only eight tephras in the Reeves, Ohiwa Harbour and Ohinekoao subgroups (Table 14-2.1a). The Ohiwa-B and Jackson Tephras have consistent hornblende geochemistries which are very similar to each other, but are significantly different from the Tirohanga Tephra (see Figure

Table 14-2.1c: Similarity coefficients (S.C.'s) comparing hornblende analyses from tephra in the Reeves, Ohiwa Harbour and Ohinekoao subgroups, as well as others.

oldest	00101	02802	03902	04103	08401	08402	00801	08302a	08302b	08301	08303	07808	00803	01903	01907	01906	03202	04202	01902	09202	04201
Herepuru	1.00																				
Wainmarara Igb. 02802	0.85	1.00																			
Wainmarara plin. 03902	0.80	0.93	1.00																		
Westend	0.82	0.89	0.89	1.00																	
Wilson	0.84	0.92	0.91	0.96	1.00																
Ohinekoao-A	0.88	0.88	0.84	0.87	0.89	1.00															
Ohinekoao-I	0.76	0.82	0.87	0.88	0.87	0.78	1.00														
Ohinekoao-I	0.90	0.90	0.85	0.86	0.90	0.98	0.93	1.00													
Ohinekoao-I	0.76	0.84	0.89	0.89	0.89	0.80	0.78	0.81	1.00												
Ohinekoao-J	0.89	0.88	0.84	0.87	0.89	0.98	0.78	0.98	0.80	1.00											
Ohinekoao-K	0.83	0.96	0.94	0.88	0.91	0.87	0.84	0.89	0.85	0.88	1.00										
Wilson fm-(2)	0.90	0.89	0.85	0.87	0.88	0.98	0.77	0.97	0.79	0.98	0.88	1.00									
Kohioawa Stream 00803	0.87	0.86	0.82	0.85	0.86	0.96	0.76	0.95	0.78	0.96	0.85	0.95	1.00								
Reeves-A	0.90	0.91	0.87	0.88	0.90	0.95	0.79	0.96	0.81	0.95	0.89	0.95	0.93	1.00							
Reeves-B	0.82	0.89	0.88	0.94	0.93	0.87	0.86	0.88	0.84	0.87	0.88	0.88	0.86	0.89	1.00						
Jackson	0.86	0.86	0.85	0.90	0.91	0.93	0.81	0.94	0.84	0.92	0.84	0.91	0.90	0.93	0.88	1.00					
Jackson	0.87	0.87	0.82	0.86	0.88	0.98	0.77	0.97	0.79	0.98	0.86	0.96	0.97	0.94	0.86	0.92	1.00				
Jackson	0.88	0.88	0.84	0.87	0.88	0.98	0.78	0.97	0.79	0.98	0.88	0.97	0.96	0.94	0.87	0.98	0.98	1.00			
Ohiwa-B	0.89	0.87	0.83	0.87	0.88	0.98	0.78	0.97	0.79	0.98	0.86	0.97	0.96	0.94	0.86	0.93	0.98	0.98	1.00		
Ohiwa-B	0.89	0.88	0.85	0.89	0.90	0.96	0.79	0.97	0.81	0.96	0.86	0.96	0.94	0.96	0.87	0.95	0.95	0.95	0.97	1.00	
Tirohanga	0.78	0.87	0.91	0.93	0.92	0.82	0.93	0.83	0.94	0.82	0.88	0.82	0.80	0.83	0.89	0.85	0.81	0.82	0.82	0.83	1.00
youngest																					

boxed shaded areas are believed to be correlatives on other criteria
shaded areas are possible correlatives via hornblende geochemistry

14-4). The hornblendes from this latter eruptive have higher TiO_2 , Al_2O_3 & Na_2O , and lower SiO_2 values.

Table 14-2.1b shows hornblende analyses for several tephtras in the Ohinekoao subgroup which are thought to be possible correlatives of some Ohiwa Harbour subgroup tephtras. Hornblendes from the Ohinekoao-I Tephra have a similar chemistry to those from the Tirohanga Tephra (see Figure 14-4), which suggests that the tentative correlation between these two eruptives—based on stratigraphic relationships and estimated age—may be correct. However, the Ohinekoao-I Tephra appears to contain two populations of hornblende crystals, a mixture that is not seen in the Tirohanga Tephra.

Figure 14-4 : Hornblende geochemistry for some Reeves (Rv), Ohiwa Harbour (Oh) and Ohinekoao (Ok) subgroup tephtras.

Similarity coefficients comparing the hornblende geochemistries of the tephtras in the Reeves, Ohiwa Harbour and Ohinekoao subgroups are presented in Table 14-2.1c. Not enough tephra deposits were analysed in either area to positively correlate any units between the Ohiwa and Ohinekoao subgroups.

14-2.2 Hornblende analyses from a number of miscellaneous tephtras

A number of tephtras from subgroups other than the those discussed above have also had their hornblendes analysed. The analyses of hornblendes from eruptives whose stratigraphic positions are known are presented in Table 14-2.2a, and those of tephtras which have unconfirmed stratigraphic positions, in Table 14-2.2b. These analyses contain several points of interest.

The Hiwarau and Te Piki Tephtras have similar hornblende geochemistries (especially for TiO_2 & Na_2O), as do the Matahina and Te Piki West Tephtras. These similarities support the tentative correlation

Table 14-2.2c: Similarity coefficients (S.C.'s) comparing hornblende analyses from various tephra within this study.

oldest	11102	02106	02105	04105	00801a	00801b	08001	08201	11101	00502	00201	02301	01501	06701	02701	06601	01505
unknown	11102																
Otarawairere	0.87	1.00															
Paerata	0.75	0.69	1.00														
Paerata	0.73	0.66	0.90	1.00													
Kohioawa - (a)	0.91	0.84	0.81	0.76	1.00												
Kohioawa - (b)	0.79	0.72	0.91	0.90	0.84	1.00											
Rangitawa	0.87	0.77	0.85	0.84	0.91	0.89	1.00										
Te Whaiti Igb.	0.87	0.78	0.85	0.83	0.91	0.89	0.98	1.00									
Whakamaru	0.91	0.82	0.81	0.79	0.92	0.85	0.95	0.95	1.00								
Anaputa	0.89	0.80	0.82	0.80	0.91	0.86	0.96	0.95	0.96	1.00							
Matahina plin.	0.94	0.84	0.78	0.76	0.91	0.81	0.90	0.90	0.94	0.93	1.00						
Matahina plin.	0.94	0.83	0.79	0.77	0.92	0.83	0.92	0.92	0.96	0.95	0.97	1.00					
Matahina	0.76	0.69	0.91	0.94	0.80	0.91	0.87	0.87	0.83	0.84	0.79	0.81	1.00				
Te Piki West	0.80	0.71	0.92	0.89	0.84	0.90	0.92	0.92	0.87	0.89	0.83	0.85	0.94	1.00			
Hiwarau	0.83	0.75	0.85	0.87	0.85	0.91	0.89	0.88	0.87	0.90	0.87	0.88	0.91	0.89	1.00		
Te Piki	0.83	0.74	0.85	0.86	0.86	0.91	0.94	0.93	0.90	0.92	0.86	0.88	0.91	0.93	0.93	1.00	
Ohiwa Hill	0.78	0.70	0.88	0.93	0.82	0.90	0.89	0.88	0.85	0.86	0.81	0.82	0.96	0.91	0.93	0.93	1.00
Wainarara	0.89	0.80	0.81	0.78	0.87	0.85	0.90	0.89	0.92	0.93	0.94	0.92	0.82	0.86	0.89	0.80	0.83
Herepuru	0.89	0.89	0.73	0.70	0.90	0.77	0.93	0.83	0.88	0.85	0.89	0.88	0.73	0.76	0.79	0.89	0.75
Wilson	0.88	0.78	0.85	0.82	0.91	0.89	0.96	0.96	0.94	0.96	0.91	0.92	0.86	0.91	0.91	0.96	0.93
Jackson	0.97	0.88	0.76	0.74	0.90	0.80	0.74	0.88	0.88	0.90	0.93	0.93	0.77	0.81	0.83	0.84	0.79
Tirohanga	0.81	0.73	0.87	0.89	0.84	0.93	0.89	0.92	0.92	0.89	0.84	0.86	0.94	0.94	0.94	0.94	0.89
youngest																	

shaded and boxed areas are probable correlatives

and placements of the Te Piki area tephra within the eastern Bay of Plenty tephrostratigraphic record (discussed in Chapter 13). Similarity coefficients that compare the hornblende geochemistries of various tephra in this study are presented in Table 14-2.2c.

Table 14-2.2a : Hornblende analyses from miscellaneous tephra with known stratigraphic positions.

tephra & samp.#	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	total	no.
Torere School 01301	47.71 0.66	1.46 0.10	6.70 0.34	14.65 0.49	0.39 0.07	14.08 0.32	11.17 0.13	1.27 0.09	0.30 0.04	97.74 0.69	8
Torere-I ?? 01401	47.17 0.49	1.80 0.11	7.20 0.20	12.19 0.19	0.60 0.04	15.34 0.30	11.25 0.17	1.58 0.11	0.33 0.02	97.44 0.57	6
Reihana-F 06208	42.56 1.41	2.73 0.09	10.08 0.79	14.18 0.54	0.35 0.09	12.88 0.24	10.86 0.24	2.20 0.22	0.33 0.08	96.18 1.64	5
Ohiwa Hill 01505	44.18 1.71	2.35 0.60	9.06 1.13	13.52 1.02	0.40 0.12	13.72 0.88	10.69 0.16	1.91 0.29	0.29 0.05	96.12 0.68	7
Hiwarau 02701	44.09 2.40	2.14 0.40	9.10 1.04	16.85 2.32	0.43 0.01	11.97 1.82	10.50 0.04	1.85 0.47	0.32 0.13	97.24 0.16	2
Te Piki 06601	45.61 0.97	1.96 0.36	8.43 1.23	15.09 1.56	0.40 0.11	12.72 0.91	11.16 0.54	1.72 0.29	0.40 0.06	97.48 1.27	6
Matahina 01501	44.30 1.00	2.20 0.32	9.35 0.95	13.17 2.14	0.33 0.09	13.83 0.89	10.83 0.26	1.89 0.16	0.33 0.06	96.24 0.85	8
Te Piki West 06701	45.12 1.01	1.77 0.35	8.83 0.57	13.86 0.92	0.31 0.07	13.50 0.58	10.83 0.28	1.70 0.20	0.30 0.10	96.23 0.91	6
— 06701b	42.87 0.08	1.42 0.01	6.15 0.07	16.34 0.28	0.60 0.04	11.53 0.03	10.26 0.11	1.27 0.04	0.39 0.06	90.81 0.46	2
pre-Matahina Igb. 00201	45.70 0.36	1.43 0.17	7.04 0.39	18.19 1.11	0.53 0.08	11.73 0.54	10.55 0.28	1.51 0.08	0.35 0.07	97.03 0.65	6
pre-Matahina Igb. 02301	46.25 0.64	1.47 0.22	6.95 0.43	17.09 1.44	0.50 0.08	12.14 0.85	10.89 0.31	1.51 0.08	0.31 0.04	97.10 0.41	6
Anaputa 00502	46.18 1.09	1.68 0.31	7.21 0.84	16.35 0.87	0.47 0.07	12.50 0.63	10.94 0.20	1.61 0.22	0.34 0.03	97.28 0.54	7
Kohioawa 00801	47.29 0.43	1.22 0.12	6.99 0.59	16.37 1.16	0.44 0.07	13.20 0.40	9.08 0.22	1.50 0.07	0.40 0.02	96.49 0.32	4
Rangitawa 08001	45.94 1.32	1.70 0.19	7.07 0.84	15.36 0.73	0.39 0.08	13.25 0.47	10.72 0.38	1.60 0.16	0.54 0.08	96.59 0.97	6
pre-Rangitaiki 08201	46.30 0.48	1.68 0.04	7.06 0.25	15.55 0.17	0.37 0.06	13.01 0.25	10.76 0.17	1.56 0.13	0.50 0.05	96.80 0.71	5
pre-Whakamaru 11101	46.33 0.95	1.64 0.09	6.79 0.32	15.71 0.36	0.51 0.08	12.94 0.24	10.67 0.20	1.50 0.08	0.52 0.05	96.61 1.19	5
— 00801b	44.45 0.35	1.88 0.11	10.05 0.06	15.75 0.17	0.35 0.04	12.87 0.04	9.44 0.08	2.04 0.03	0.16 0.01	96.98 0.06	2
Paerata (02105)	43.14	1.71	11.16	12.78	0.30	14.06	9.19	1.84	0.24	94.42	1
Paerata (04105)	43.40	2.36	12.83	13.59	0.33	13.82	10.71	2.05	0.28	99.37	1
Otarawairere 02106	48.05 1.14	0.49 0.03	6.36 0.44	18.05 0.29	0.63 0.04	12.43 0.35	8.82 0.12	1.32 0.17	0.41 0.04	96.54 1.35	4

The Matahina Tephra appears to contain two populations of hornblendes. The pre-ignimbrite airfall has one composition, while the airfall recorded further east away from the ignimbrite cover has another composition, or a mixture of the two (pre-ignimbrite and syn-ignimbrite). The presence of this mixture supports the findings of Carr [1984], who suggested that the Matahina eruption originated from a zoned magma chamber with two different chemical and mineralogical magma types.

The Whakamaru Ignimbrite correlatives all have similar hornblende geochemistries, though the Kohioawa Tephra does have slightly lower TiO₂ and CaO values. The sample from Peach Road (11101) matches well with the Whakamaru eruptives, but has slightly higher TiO₂ and CaO values than the Jackson and Ohiwa-B Tephra, indicating that correlation to these two eruptives is less likely. The Tirohanga Tephra hornblendes have a very different chemistry from those of the upper or lower Peach Road samples.

The two analyses from the Paerata Tephra confirm that hornblende crystals are present within this eruptive, together with the dominant cummingtonite and rare hypersthene crystals.

The lower Peach Road sample (11102) has a very similar hornblende geochemistry to the Kohioawa Stream Tephra. The Tablelands-A Tephra has nearly identical glass chemistry to the Kohioawa Stream Tephra, and so probably has a nearly identical hornblende chemistry as well. As the stratigraphic positions of these two eruptives are also very similar, either eruptive could be a correlative to the lower Peach Road sample. The Otawairere Tephra has a much lower TiO₂ content, and therefore it, the Tablelands-C Tephra, and the Tablelands-D Tephra are unlikely correlatives to the lower Peach Road sample.

Table 14-2.2b : Hornblende analyses from miscellaneous tephra with unconfirmed stratigraphic positions.

tephra & samp.#	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	total	no.
Westend	46.35	1.63	8.04	15.76	0.36	12.96	10.60	1.55	0.39	97.64	7
04103	1.22	0.28	0.49	2.45	0.11	1.67	0.18	0.22	0.04	0.39	
unknown ?	46.50	1.31	6.81	17.24	0.66	11.92	10.21	1.43	0.46	96.55	7
11102	0.83	0.09	0.24	0.81	0.12	0.41	0.14	0.06	0.05	1.55	
Kohioawa	46.60	1.32	6.40	17.34	0.75	12.64	10.47	1.37	0.46	97.35	5
Stream	0.26	0.04	0.22	0.51	0.16	0.19	0.15	0.07	0.03	0.45	
00803											
— (00803b)	44.28	2.38	9.18	14.12	0.30	13.00	11.12	1.89	0.48	96.75	1
Herepuru	47.10	0.81	6.86	17.56	0.53	12.75	8.08	1.43	0.38	95.49	6
00101	1.00	0.28	0.85	0.72	0.13	0.62	0.87	0.22	0.08	0.94	
Waingarara Igb.	45.00	1.74	7.49	18.52	0.53	11.12	10.12	1.67	0.47	96.65	7
02802	1.33	0.48	0.99	0.28	0.08	0.65	0.35	0.20	0.08	2.35	
Waingarara airfall	44.43	1.98	7.91	17.83	0.45	10.70	10.49	1.87	0.51	96.16	7
03902	1.67	0.18	0.77	0.65	0.07	0.38	0.26	0.16	0.06	1.34	

Table 14-3.1 : Cummingtonite analyses of tephras studied in this thesis.

tephra & samp.#	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	Cl	total	no.
Rotoiti 01303	53.20 0.97	0.33 0.09	1.71 0.36	19.05 0.33	1.52 0.08	19.24 0.29	1.97 0.33	0.44 0.09	0.02 0.03	0.06 0.02	97.55 0.98	9
Rotoiti 06501	52.47 1.71	0.21 0.20	1.73 0.53	19.09 0.44	1.42 0.13	18.93 0.26	1.89 0.04	0.39 0.11	0.00 0.00	0.00 0.00	96.13 0.93	3
Rotoiti 07702	53.19 0.84	0.31 0.06	1.71 0.25	18.89 0.24	1.70 0.48	18.96 0.31	2.05 0.33	0.37 0.04	0.02 0.03	0.04 0.04	97.23 0.81	6
Rotoiti 09304	53.02 0.53	0.22 0.08	1.26 0.16	18.63 0.45	1.50 0.05	19.11 0.35	1.58 0.09	0.31 0.08	0.02 0.02	0.05 0.01	95.69 0.65	8
Paerata 00811	52.35 0.79	0.29 0.08	1.80 0.22	23.40 0.39	1.28 0.04	16.74 0.18	1.46 0.13	0.36 0.06	0.05 0.03	0.03 0.03	97.78 0.49	5
Paerata 01602	52.67 0.39	0.26 0.04	1.61 0.23	23.13 0.38	1.20 0.07	16.50 0.30	1.42 0.17	0.28 0.06	0.00 0.00	0.01 0.02	97.07 0.61	10
Paerata 02105	52.44 0.33	0.23 0.08	1.62 0.25	24.26 0.39	1.15 0.09	16.43 0.35	1.12 0.10	0.28 0.07	0.00 0.00	0.00 0.00	97.53 0.65	8
Paerata 02505	51.90 0.50	0.28 0.06	1.85 0.49	22.45 0.45	1.17 0.09	15.97 0.60	1.60 0.45	0.34 0.10	0.00 0.00	0.00 0.00	95.56 0.85	7
Paerata 02704	52.13 0.39	0.25 0.08	1.74 0.32	22.52 0.18	1.20 0.07	16.38 0.20	1.60 0.28	0.34 0.06	0.00 0.00	0.00 0.00	96.16 0.42	5
Paerata 04105	52.05 0.84	0.29 0.05	1.84 0.23	23.34 0.82	1.20 0.06	16.63 0.55	1.44 0.35	0.38 0.09	0.03 0.03	0.08 0.02	97.26 0.79	6
Ohiwa-B (01902)	51.60	0.19	1.62	23.01	0.95	17.29	1.50	0.26	0.00	0.07	96.49	1
Reeves-A 01903	51.83 0.70	0.26 0.05	1.68 0.34	24.25 0.67	1.08 0.13	15.58 0.19	1.63 0.43	0.33 0.08	0.03 0.04	0.06 0.02	96.73 0.96	6
Wilson (08401)	55.39	0.15	4.17	20.33	0.86	13.83	1.32	0.67	0.56	0.00	97.28	1

Table 14-3.2 : Similarity coefficients (S.C.'s) comparing cummingtonite analyses from various tephras in this study.

oldest	08401	01903	01902	00811	01602	02105	02505	02704	04105	01303	06501	07702	09304
Wilson 08401	1.00												
Reeves-A 01903	0.72	1.00											
Ohiwa-B 01902	0.75	0.89	1.00										
Paerata 00811	0.71	0.92	0.87	1.00									
Paerata 01602	0.71	0.93	0.92	0.93	1.00								
Paerata 02105	0.71	0.91	0.90	0.89	0.95	1.00							
Paerata 02505	0.72	0.95	0.87	0.95	0.93	0.89	1.00						
Paerata 02704	0.72	0.96	0.89	0.94	0.94	0.91	0.97	1.00					
Paerata 04105	0.73	0.92	0.86	0.93	0.93	0.89	0.96	0.94	1.00				
Rotoiti 01303	0.67	0.83	0.77	0.86	0.82	0.78	0.85	0.85	0.86	1.00			
Rotoiti 06501	0.70	0.86	0.84	0.87	0.84	0.83	0.86	0.89	0.87	0.92	1.00		
Rotoiti 07702	0.65	0.84	0.78	0.87	0.83	0.79	0.86	0.86	0.86	0.95	0.92	1.00	
Rotoiti 09304	0.68	0.85	0.84	0.84	0.86	0.84	0.85	0.87	0.83	0.86	0.90	0.86	1.00
youngest													

shaded areas are samples that are believed to be correlatives on other criteria

The Herepuru Tephra also has lower TiO_2 and CaO values than the Kohioawa Stream Tephra, which indicates that these are indeed two separate eruptives (see earlier discussion in Chapters 5 & 13).

The Waingarara Ignimbrite and its pre-ignimbrite airfall have, as expected, very similar hornblende geochemistries. This suggests that the difference in their glass chemistries may result from something other than primary magma differences; perhaps weathering or hydrothermal alteration.

14-3 Cummingtonite Analysis

Cummingtonites are rare in the eruptives studied in this work, with only five tephtras found to contain this mineral. Cummingtonite analyses from these tephtras are presented in Table 14-3.1.

The points to note here are the generally consistent chemistries between different sites within each of the Rotoiti and Paerata Tephtras. These two eruptives can be easily distinguished from each other by their cummingtonite geochemistry alone. Similarity coefficients that compare cummingtonite chemistries can readily distinguish between the different eruptives (see Table 14-3.2), as generally can graphical representations (Figure 14-5).

Figure 14-5 : Comparison of cummingtonite analyses from various tephtras found in the Bay of Plenty region — relative proportions of selected element-oxides

As only one cummingtonite crystal was analysed from each of the Ohiwa-B and Wilson Tephtras, it is possible—though unlikely—that the presence of cummingtonite is the result of post-sampling contamination. The Ohiwa-B cummingtonite chemistry is similar to that of the Paerata Tephra, but the cummingtonite from the Wilson Tephra is very different, especially with respect to its SiO_2 and Al_2O_3 contents, and is hence believed to be primary component of that eruption.

14-4 Biotite Analysis

Biotites from several tephras were analysed and the results are presented in Table 14-4. The biotite analyses generally have low totals (91–95%), although H₂O and F were not analysed for. Some of the tephras sampled contained very weathered 'gold' biotite flakes which appear to have suffered from vermiculisation, so only those analyses on apparently unweathered black biotite are presented here.

Table 14-4 : Biotite analyses from miscellaneous tephras within this study.

tephra & samp.#	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	Cl	total	no.
Tablelands-D 04101	35.05 1.16	4.32 0.19	13.35 0.52	21.01 1.13	0.36 0.06	9.10 0.92	0.09 0.07	0.39 0.08	8.54 0.38	0.38 0.05	92.59 1.59	5
Tablelands-C 00810	36.54 1.36	4.34 0.27	14.22 1.45	18.98 2.16	0.36 0.04	8.16 0.58	0.15 0.07	0.17 0.05	7.14 0.67	0.29 0.04	91.34 1.71	5
Otarawairere 02106	35.69 0.55	1.92 0.13	13.13 0.19	22.70 0.86	0.32 0.07	9.52 0.73	0.03 0.06	0.35 0.11	7.16 0.18	0.40 0.10	91.22 0.92	3
unknown (07806)	35.69	4.47	13.39	19.20	0.21	11.34	0.14	0.59	8.59	0.34	93.96	1
Kohioawa Stream 00803	35.53 0.45	4.61 0.14	13.37 0.12	19.98 0.23	0.31 0.05	11.19 0.14	0.06 0.09	0.52 0.05	8.89 0.15	0.40 0.05	94.86 0.41	4
Ohinekoao-K 08301	36.18 1.81	4.37 0.06	13.43 0.71	19.70 1.40	0.23 0.06	10.89 0.91	0.13 0.08	0.45 0.06	8.08 0.44	0.32 0.05	93.76 2.21	4
Ohiwa-B 01902	39.16 1.40	4.32 0.24	13.75 0.27	18.20 0.01	0.23 0.02	10.41 0.49	0.08 0.02	0.41 0.23	8.03 0.08	0.31 0.06	94.89 1.31	2
Ohiwa-B 09202	40.57 0.73	4.57 0.12	13.93 0.35	16.60 0.71	0.19 0.07	9.97 0.70	0.10 0.03	0.36 0.18	6.38 0.34	0.29 0.02	92.94 1.79	4
Jackson (01906)	40.03	3.17	20.20	13.24	0.00	7.10	0.21	0.12	5.55	0.35	89.97	1
Herepuru 00101	36.48 0.33	2.43 0.61	13.42 0.10	21.32 0.55	0.27 0.05	10.96 0.33	0.00 0.00	0.50 0.04	7.26 0.30	0.36 0.03	93.00 0.68	5

Points to note from these analyses are the relatively low TiO₂ content of the Otawairere and Herepuru Tephras, and the relatively high SiO₂ content of the Ohiwa-B and Jackson Tephras. This latter tephra, however, has a very high Al₂O₃ content and a low analytical total, indicating that it may have undergone some alteration.

On the basis of their biotite geochemistries, the Herepuru Tephra and the Kohioawa Stream Tephra are not believed to be correlatives, but the latter eruptive and the unknown eruptive from the Wilson's farm-(3) site (sample 07806) may well be. This correlation is also supported on stratigraphic grounds, as sample 07806 comes from a reworked pumice gravel bed at a similar stratigraphic position to the Ohinekoao-N Tephra.

Table 14-5.2 : Hypersthene analyses from miscellaneous tephra in this study.

tephra & samp.#	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	total	no.
Rotoiti 01303	51.88 0.49	0.13 0.04	0.51 0.07	23.07 1.02	2.06 0.45	21.15 0.80	0.81 0.19	0.05 0.03	0.00 0.00	99.65 0.48	4
Rotoiti 09304	52.70 0.10	0.16 0.03	0.47 0.04	23.36 0.04	2.08 0.04	20.58 0.03	0.63 0.02	0.04 0.05	0.04 0.05	100.04 0.26	2
Hiwarau 02701	50.96 0.46	0.15 0.03	0.57 0.15	26.18 2.40	1.44 0.34	18.68 1.50	0.90 0.18	0.04 0.05	0.02 0.02	98.94 1.05	5
Te Piki 06601	52.68 0.65	0.15 0.04	0.43 0.09	24.59 1.99	1.60 0.17	19.31 1.30	1.37 0.81	0.10 0.01	0.02 0.03	100.24 0.68	3
Kohioawa 00801	52.29 0.18	0.05 0.07	0.35 0.06	28.19 0.37	1.32 0.07	18.78 0.13	0.72 0.05	0.00 0.00	0.00 0.00	101.70 0.31	5
Rangitawa 08001	50.83 0.31	0.12 0.10	0.42 0.19	25.87 0.63	1.26 0.17	18.75 0.30	1.03 0.21	0.05 0.04	0.03 0.03	98.38 0.52	7
Paerata 00811	51.42 0.60	0.13 0.03	0.52 0.13	28.44 0.64	1.52 0.24	17.86 0.48	0.63 0.06	0.08 0.07	0.01 0.03	100.61 0.15	5
Paerata (01602)	51.25	0.00	0.39	28.30	1.74	17.37	0.62	0.00	0.00	99.67	1
Paerata 02505	51.21 0.08	0.00 0.00	0.45 0.12	27.53 0.35	1.74 0.07	17.44 0.25	0.61 0.05	0.00 0.00	0.00 0.00	98.98 0.23	5
Paerata 02704	50.51 0.26	0.00 0.00	0.45 0.13	27.59 0.33	1.76 0.06	16.94 0.34	0.60 0.02	0.00 0.00	0.00 0.00	97.85 0.52	3
Paerata 04105	51.60 0.39	0.07 0.09	0.33 0.06	28.20 0.21	1.28 0.76	17.44 0.06	0.62 0.04	0.03 0.04	0.00 0.00	99.56 0.41	2
Kohioawa Stream 00803	51.68 0.85	0.10 0.08	0.50 0.12	26.01 1.46	1.35 0.31	19.46 1.37	0.90 0.24	0.04 0.05	0.02 0.04	100.06 0.95	6
unknown 07806	51.08 1.09	0.13 0.06	0.46 0.13	28.42 1.19	1.63 0.44	16.82 0.66	0.84 0.21	0.01 0.03	0.00 0.00	0.62 1.15	7
unknown 11102	52.39 0.11	0.14 0.01	0.36 0.04	26.53 0.20	1.29 0.11	18.92 0.32	0.93 0.10	0.05 0.06	0.03 0.04	100.62 0.17	2
Ohinekoao-I 00901	51.50 0.38	0.03 0.07	0.51 0.10	28.48 1.51	1.15 0.19	18.22 1.32	0.91 0.04	0.00 0.00	0.00 0.00	100.80 0.44	5
Ohinekoao-I 08302	50.99 0.47	0.16 0.07	0.57 0.23	25.76 2.09	1.24 0.27	18.84 1.59	1.09 0.20	0.04 0.04	0.01 0.02	98.70 0.77	6
Wilson 08401	51.49 1.14	0.15 0.03	0.62 0.08	26.36 1.32	1.31 0.08	18.80 1.02	0.84 0.16	0.10 0.03	0.00 0.00	99.67 0.88	3
Westend 04103	49.06 0.53	0.14 0.03	0.38 0.11	33.91 2.22	1.44 0.18	13.07 1.81	1.18 0.21	0.02 0.05	0.01 0.02	99.21 0.73	10
— 04103b	52.45 0.84	0.31 0.10	1.17 0.35	21.62 2.45	0.62 0.19	22.50 1.59	1.45 0.34	0.02 0.04	0.02 0.04	100.14 0.59	6
Herepuru (00101)	52.24	0.00	0.50	26.67	0.95	19.85	0.62	0.00	0.00	100.83	1
Waingarara Igb. 02802	50.81 0.92	0.10 0.05	0.39 0.07	30.16 0.71	1.59 0.15	15.64 0.56	0.94 0.13	0.06 0.06	0.00 0.00	99.68 1.31	8
Waignarara 03902	50.47 0.82	0.17 0.04	0.35 0.10	29.45 1.16	1.39 0.19	15.85 1.03	0.92 0.12	0.04 0.04	0.02 0.03	98.65 1.04	4

14-5 Hypersthene Analysis

Little variation was seen between the hypersthene geochemistry from the different eruptives, and in most cases they are not useful for correlation purposes. However, there are several points to note from these analyses.

Hypersthene analyses of the Matahina Tephra from many sites are presented in Table 14-5.1. The Matahina Tephra appears to have a mixture of several different hypersthene types, and the mixture may be diagnostic of this unit. The Te Piki West Tephra does appear to be a likely correlative of the Matahina.

Table 14-5.1 : Hypersthene analyses from the Matahina Tephra.

tephra & samp.#	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	total	no.
pre-Matahina Igb. 00201	50.93 0.41	0.11 0.03	0.39 0.01	26.14 1.12	1.19 0.03	17.81 0.62	1.24 0.03	0.10 0.02	0.04 0.05	97.94 2.27	2
Matahina 01501a	52.37 0.48	0.16 0.01	0.63 0.29	25.04 0.47	0.96 0.23	19.31 0.60	1.22 0.01	0.02 0.03	0.02 0.03	99.71 0.35	2
Te Piki West 06701	50.89 0.89	0.16 0.07	0.51 0.25	28.15 2.00	1.16 0.21	17.03 1.71	1.08 0.15	0.03 0.06	0.00 0.00	99.00 0.97	4
— (00201b)	50.03	0.12	0.39	32.70	1.76	14.36	0.74	0.00	0.00	100.10	1
— 01501b	50.20 0.64	0.11 0.03	0.45 0.12	31.08 2.49	1.57 0.33	15.20 1.35	0.87 0.15	0.07 0.06	0.00 0.00	99.55 0.72	3
pre-Matahina Igb. 02301	50.71 0.35	0.10 0.06	0.32 0.09	30.52 1.40	1.70 0.10	15.23 0.94	0.81 0.07	0.00 0.00	0.00 0.00	99.39 0.47	5
— 01501c	53.11 1.34	0.28 0.06	1.40 0.51	17.80 0.43	0.67 0.04	25.13 0.84	1.46 0.05	0.00 0.00	0.01 0.02	99.87 1.55	3
— (02301b)	52.06	0.20	0.78	22.26	1.01	21.11	1.05	0.00	0.00	98.47	1
— (06701b)	52.34	0.29	1.63	22.63	0.75	21.66	1.29	0.00	0.00	100.59	1

Analyses of hypersthene from other tephras that were sampled at more than one site, and from several miscellaneous tephras, are presented in Table 14-5.2.

The Rotoiti Tephra has a higher MgO, and lower FeO content than most of the other eruptives analysed.

The Rotoiti, Paerata and Wilson Tephras all contain hypersthene, in addition to cummingtonite and hornblende.

The Ohinekoao-I Tephra hypersthene is not as chemically distinctive as other minerals in this eruptive, but are consistent in samples from different sites.

The Westend Tephra has a distinctive hypersthene geochemistry, but as yet no other eruptives can be correlated to it.

The Waingarara Ignimbrite and airfall tephra have nearly identical hypersthene chemistries, which are moderately distinctive.

Chapter Fifteen : Estimated Ages of Eastern Bay of Plenty Tephtras

Most of the eastern Bay of Plenty tephra deposits studied in this work have not previously been studied. Few radiometric age determinations have been conducted on any mid- to late Pleistocene T.V.Z. eruptives, and those chiefly on some of the larger ignimbrite flow sheets only; very few on the airfall units in the eastern Bay of Plenty.

The ages of the tephtras detailed in this work have been estimated by studying the paleoclimatic evidence from within the stratigraphy, and comparing it to the climatic record for the mid- to late Pleistocene inferred from variations in the oxygen isotope ratios in deep-sea cores.

The eastern Bay of Plenty paleoclimatic record is anchored in several places by the correlation of some tephtras to the large ignimbrite flow units which have radiometric ages (e.g. Mamaku, Kaingaroa, Matahina & Rangitaiki Ignimbrites).

This chapter will review the history of the oxygen isotope paleoclimatic record and the paleoclimatic indicators in the Bay of Plenty, and discuss the ages of the tephtras that have been inferred from the this record on an individual basis.

15-1 Pleistocene Climate Fluctuations: ice-ages

Fluctuations in the Pleistocene ice sheets caused concomitant fluctuations in the paleo-sealevel as varying amounts of water were "locked-up" as ice on the continental land surfaces. The colder the climatic period (glaciation), the more ice on the continents and the lower the sea-level. There is still much debate over whether parts of the Antarctic, or Greenland, were ever free of ice during this time period and therefore the continental ice sheets over North America and Europe are thought to be the major contributors to these water/ice reservoir fluctuations.

The origin and regulation of the Pleistocene glaciations has been much debated and many theories have been proposed.

A strong positive correlation has been demonstrated between the timing of the cold (glacial) and warm (interglacial) periods, and the seasonal and latitudinal distribution of incoming radiation caused by

changes in the Earth's orbital geometry [Hays *et al.*, 1976]. It is unclear whether the astronomical, or more specifically – "orbital" – variations, are responsible for initiating the period of climatic fluctuation in the Pleistocene, but they are almost certainly the controlling factor in the cyclical nature of these fluctuations. The "Milankovitch cycles", named after Milutin Milankovitch who developed this theory during the 1920's–40's, involve a combination of three separate cycles of differing length: the c. 105 ka cycle of the eccentricity of the Earth's orbit, the c. 41 ka cycle of the obliquity of the Earth's axis, and the c. 23 ka and c. 19 ka cycles of the precession of the Earth's axis. These cycles approximately match the cycles of climatic fluctuation inferred from oxygen isotopic records in deep sea cores.

Although there is a strong correlation between the Milankovitch cycles and the fluctuating climate, the physical mechanism that relates the two is not well understood. It appears to be related to the orbitally induced northern hemisphere summer insolation (incoming solar radiation) levels at mid- to high latitudes, but these vary by only a small percentage in comparison to the total temperature change.

Recent work indicates that the Earth may have two stable modes of ocean – atmosphere circulation; one existing during a relatively warm climate, and the other during a colder climate. In keeping with this, the glacial-to-interglacial transitions are thought to involve major reorganisations of the ocean – atmosphere system, causing jumps from one stable mode to the other [Broecker & Denton, 1990]. Milankovitch cycles are thought to trigger the switches between these stable modes; most likely through impacts of fresh water transport on the ocean's salinity distribution — generally the formation, or non-formation, of cold North Atlantic Deep Water. Climate change is enhanced by positive feed-back processes [Goudie, 1992], for example:

- increase/decrease of CO₂ and CH₄;
- rising sea-level causing increased carving of coastal ice sheets;
- clouds and polar ice resulting in higher albedo;
- fine glacially produced dust in the atmosphere blocking incoming solar radiation.

15-2 Oxygen Isotope Paleoclimatic Record

Emiliani [1955] determined the oxygen isotope ratios ($^{18}\text{O}/^{16}\text{O}$) in the tests of fossil foraminifera, and compared these with the oxygen isotope ratios in the sea-water from which the CaCO₃ tests precipitated. The $^{18}\text{O}/^{16}\text{O}$ ratio is related both to water temperature, and terrestrial ice volume [Shackleton & Opdyke, 1973]. Water molecules containing the heavier oxygen isotope are evaporated from the ocean less readily than those formed from the lighter isotope. Therefore if the lighter component is preferentially removed from the ocean system and bound in the vast continental ice sheets, the oceanic $^{18}\text{O}/^{16}\text{O}$ ratio will increase. The foraminiferal $^{18}\text{O}/^{16}\text{O}$ ratio is therefore strongly related to the paleo-sea-level. It is usually expressed either with respect to standard mean ocean water (SMOW) as $\delta^{18}\text{O}$ in parts per thousand (‰), or as standard deviation units around a zero mean.

A $\delta^{18}\text{O}$ record through time has been developed by the detailed sampling of foraminifera from deep sea cores (e.g. Shackleton & Opdyke, 1973; Imbrie *et al.*, 1984; Pisias *et al.*, 1984; Martinson *et al.*, 1987; Bassinot *et al.*, 1994; among others). Cores from around the world have very similar patterns of $\delta^{18}\text{O}$ fluctuation. The sediment near the base of the cores occasionally contains the Brunhes/Matuyama paleomagnetic boundary, which has been well dated and is the major age control. The ages of the sediments between this boundary and the top of the core have generally been estimated by assuming a constant sedimentation rate. Although the ages were not precisely determined, it is clear that despite some difference in inferred sedimentation rates, the $\delta^{18}\text{O}$ record (from the different cores) match quite well in age as well as in overall pattern. A climatic record of ice volume over time has thus been developed, which may be used to estimate the age of periods when the climate was warm (similar to present) or cold. Each warm or cold climatic period, was given a $\delta^{18}\text{O}$ stage number, from 1 (present) backwards through time. The warm stages have odd numbers, and cold stages even numbers.

However, it is unlikely that the sedimentation rates were truly constant over time, and therefore there is still debate concerning the exact timing of each glacial and interglacial event. Sequences of terraces along many tectonically active coastal regions are believed to represent uplifted marine erosion surfaces formed during the high sea-level stands of interglacial stages. Coral reefs formed just below sea-level near the high paleo-shorelines have been preserved in many areas — notably at Huon Peninsula in Papua New Guinea, and at Barbados. Individual corals from these reefs were dated by uranium series (U-series) methods and it was found that the high sea-levels occurred during the periods of maximum northern hemisphere summer insolation [Mesolella *et al.*, 1969; Bloom *et al.*, 1974]. The uranium series ages provided additional time control or "tie-points" for the deep-sea $\delta^{18}\text{O}$ record — in particular the 127 ka age for the $\delta^{18}\text{O}$ stage-5/stage-6 boundary.

The SPECMAP oxygen isotope curve [Imbrie *et al.*, 1984] was produced by using 18 ka, 21 ka, and 127 ka "tie-points", along with the Brunhes/Matuyama paleomagnetic boundary at 730 ka as time control in the development of an initial $\delta^{18}\text{O}$ vs time curve, based on an assumed constant sedimentation rate. This initial curve was subjected to a forcing function based upon the orbitally induced insolation cycles. The "forcing" shifted the peaks and troughs of the $\delta^{18}\text{O}$ curve slightly backwards or forwards in time so that they matched the times for peaks and troughs of the insolation record. A mathematically determined variable lag period was included. The technique of "orbitally tuning" the $\delta^{18}\text{O}$ record from the deep-sea cores alters the the presumed constant sedimentation rate to one that is variable. Most of the detailed $\delta^{18}\text{O}$ curves only span the last 300 ka, but the SPECMAP $\delta^{18}\text{O}$ curve is *c.* 800 ka in length and is of greater use in estimating the ages of the tephra in this study (Figure 15-1).

However, the SPECMAP $\delta^{18}\text{O}$ curve is problematic in that it uses an age of 730 ka for the Brunhes/Matuyama (B/M) paleomagnetic boundary, which is now believed to be at *c.* 780 ka [Baksi *et al.*, 1992; Spell & McDougall, 1992].

Figure 15-1 : Comparison between SPECMAP and LLS oxygen isotope curves

Bassinot et al. (1994) have provided an updated $\delta^{18}\text{O}$ curve. In this case, no age control points were used. The $\delta^{18}\text{O}$ record from the low-latitude deep-sea core MD900963 was directly compared to an ice-volume prediction model, and the result orbitally tuned. The ensuing curve produced an age for the B/M boundary of 775 ± 10 ka, which is very similar to recent radiometric ages. The MD900963 core was then stacked with the O.D.P. site 677 core to produce a "low-latitude" $\delta^{18}\text{O}$ curve, which is compared with the SPECMAP curve in Figure 15-1. The two curves are very similar, until beyond $\delta^{18}\text{O}$ stage-16 (c. 650 ka), where the low-latitude stack (LLS) has increased the ages of these stages. The only other differences between the two curves are that in the LLS curve several more very minor oscillations occur within $\delta^{18}\text{O}$ stages-10 & 11, $\delta^{18}\text{O}$ stage-14 is less cold, and $\delta^{18}\text{O}$ stage-8.5 (c. 285 ka) has a higher peak (warmer). The increased number of minor oscillations may be due to the added effect on the MD900963 $\delta^{18}\text{O}$ record of local salinity fluctuations, probably controlled by changes in monsoon intensity [Bassinot et al., 1994]. On the basis of its better core preservation, the SPECMAP curve is believed to provide a better estimate of stages-6 and 12 than the LLS curve [Bassinot et al., 1994].

As the stratigraphy in the eastern Bay of Plenty is not thought to extend beyond $\delta^{18}\text{O}$ stage-16, the SPECMAP and LLS $\delta^{18}\text{O}$ curves are both acceptable paleoclimate reference curves and give identical age estimates for the eastern Bay of Plenty stratigraphy. Nevertheless, the more recent LLS curve is used in this work (see Figures 15-2, 15-3, and 15-4).

However, there is a problem with using the deep-sea $\delta^{18}\text{O}$ curves to estimate the numerical ages of deposits, in that recent precise U-series ages on corals at Huon Peninsula and the Bahamas [Chen et al., 1991] suggest a possible conflict with the orbital theory of climate change [Stein et al., 1993]. Several U-series ages for the beginning of the high sea-level of $\delta^{18}\text{O}$ stage-5e ($\delta^{18}\text{O}$ stage-5/stage-6 boundary) have been found to precede that of the peak of northern hemisphere summer insolation, rather than lagging several thousand years behind. The major source of error in the time scale developed for the oxygen isotope record is the assumption that the climate response mimics the orbital forcing [Martinson et al., 1987], and therefore if the orbital theory of climate change is incorrect—or even only partially correct—all the orbitally tuned $\delta^{18}\text{O}$ curves have incorrect time scales.

Paleo-temperature curves have been developed for ice-cores both in Antarctica (Vostok) [Jouzel et al., 1987] and Greenland (GRIP) [GRIP members, 1993]. Using ice-sheet flow models, both the Vostok ice-core $\delta^{18}\text{O}$ and δD (deuterium), and the GRIP ice-core $\delta^{18}\text{O}$ records give ages for the warming at the $\delta^{18}\text{O}$ stage-5/stage-6 boundary preceding that of the peak of insolation.

A $\delta^{18}\text{O}$ curve independent of orbital tuning has also been developed using U-series dating of vein calcite from Devils Hole, Nevada [Winograd et al., 1992]. The $\delta^{18}\text{O}$ curve produced again shows conflict with the orbitally tuned record in that the terminations of the glacial $\delta^{18}\text{O}$ stage-6 and stage-8 pre-date those of the SPECMAP $\delta^{18}\text{O}$ curve. The Devils Hole $\delta^{18}\text{O}$ stage-5/stage-6 boundary matches reasonably well with the Vostok ice-core record. However, the mechanism of the relationship between the climate/ice volume and the continental aquifer Devils Hole $\delta^{18}\text{O}$ values is uncertain, and may be

different to that found in the deep marine environment [Johnson & Wright, 1989]. Therefore the $\delta^{18}\text{O}$ records for the two different locations and environmental systems may not be comparable.

Precise U-series dates on cave deposits in the Bahamas [Li *et al.*, 1989], and $^{40}\text{Ar}/^{39}\text{Ar}$ dating of tephras in European loess [van den Bogaard *et al.*, 1989], are in agreement with the high sea-level stand chronology of deep-sea foraminiferal $\delta^{18}\text{O}$ record, and disagree with the conclusions from Devils Hole.

The deep-sea $\delta^{18}\text{O}$ curves record ice-volume and relative sea-levels, and do not directly record paleo-temperatures. However, the polar ice-cores do record paleo-temperatures and show that there is a very close relationship between ice-volume and temperature. The two curves may be separated by a lag of several thousand years, but this is well within present radiometric dating errors.

15-3 Paleoclimatic Indicators in the Bay of Plenty

General indicators of cold paleoclimates, where such indicators occur outside their modern climate range include: glacial landforms and deposits; and periglacial landforms and deposits such as loess, outwash gravels and alluvial river terraces, and talus and solifluction deposits. Features related to climatically controlled changes in sea-level, such as uplifted marine cut surfaces (marine terraces), or marine sediment overlying terrestrial and fluvial deposits (and vice versa), can also be indicators of paleoclimate. The absence of cold paleoclimate indicators, and/or the presence of paleosols, provides evidence for a warmer climate. More direct evidence of paleoclimatic conditions can be obtained by identifying pollens and other fossil organisms which existed at the time and locality of deposition and are known to prefer a certain type of climate. Isotopic geochemistry such as $\delta^{18}\text{O}/^{16}\text{O}$, $\delta^{13}\text{C}/^{14}\text{C}$, and δ -deuterium can provide estimates of ice volume and paleo-temperature, depending in each case upon the environment of precipitation; marine or terrestrial.

The Bay of Plenty region of New Zealand was never cold enough in the Pleistocene to contain glacial or near glacial deposits, but increased deposition of fluvial gravels and river terraces, loess, paleosols, marine terraces and evidence for sea-level change are present. No isotopic determinations have been yet attempted.

15-3.1 Alluvial terraces

The alluvial river terraces of the southern half of the North Island, New Zealand, have been studied in some detail. The terraces are not related to glacial outwash as no major glaciers existed in this region, but are nevertheless believed to represent times of harsher—in this case colder—climate. The cooler climatic conditions would have resulted in a lower tree-line in the mountainous headwater regions of rivers, and a concomitant increase in the erosion rate, due mainly to frost action. The glacial periods, as well as being colder, are believed to have been much drier and windier than the warmer interglacial periods [Stewart & Neall, 1984]. Extensive aggradational surfaces were produced during the colder periods since the sediment load within the rivers was much greater than the carrying capacity that the decreased rainfall

could provide. During the interglacial periods river aggradation ceased and fluvial down-cutting of the terraces was dominant. It has been suggested that the bulk of the gravels making up the aggradational terraces were deposited in the latter part of the glacial periods, as the increasing precipitation would increase transportation of erosion detritus stored in the mountain ranges [Stewart & Neall, 1984]. However, other processes, such as tectonic uplift, that could also cause increased sediment load must also be considered in each case.

In the eastern Bay of Plenty many outcrops of fluvial gravels are observed, especially towards the far east on the Raukumara Peninsula where there are large rivers exiting from rapidly uplifting and eroding greywacke ranges. However, most deposits in area of study are relatively thin, do not form continuous surfaces, and are therefore difficult to correlate. Only a few large aggradational surfaces can be recognised, the most significant of which are the Waiotahi Gravels.

15-3.2 Loess

Loess may be simply defined as "a terrestrial wind-blown silt deposit consisting of quartz, feldspar, mica, clay minerals and carbonate grains in varying proportions. Heavy minerals, phytoliths, salts, and volcanic glass shards are also sometimes important constituents" [Pye, 1987]. Loess can generally be recognised by its uniform unstratified (i.e. massive) nature, its good sorting in the silt size-fraction, and its light yellow or buff colour.

In the Bay of Plenty region, and elsewhere within and near the central volcanic region, volcanic glass shards are an important component of wind-blown dust deposits, and in some areas loess consisting of almost 100% glass shards exists. For such deposits, the term "tephric-loess" has been used [Kennedy, 1988]. The physical characteristics of tephric-loess are generally quite different from primary airfall tephra, and it can be readily identified by its very good sorting, very fine sand grain-size, lack of bedding (usually massive), and uniform light grey colour.

The loess observed in the eastern Bay of Plenty region is recognised by characteristics that apply to both "normal loess" and "tephric-loess". It appears very different from the interbedded tephra, which generally show abundant bedding features and have a much greater range in grain size, colour and sorting. The loess in the eastern Bay of Plenty region is differentiated from tephric-loess by its poorer sorting, more weathered appearance, and light yellowish brown colour. The loess deposits in this study have not been analysed for their relative quartz-feldspar-glass composition and so it is unknown whether they are quartzo-feldspathic like that of loess elsewhere in New Zealand, or have a significant glass shard component. As the loess in the coastal Bay of Plenty differs significantly in appearance from the tephric-loess found on the edges of the ignimbrite plateau closer to, and on either side of, the T.V.Z., its source and composition is believed to be different — probably with a larger non-volcanic component.

Loess production is thought to occur where large areas of unconsolidated and friable sediment are exposed to wind action — that is in areas with little vegetation cover. However, loess can only accumulate where there is a "roughness boundary" resulting in turbulence and reduced wind velocities, as

occurs when moving from a barren to a vegetated environment, and from low grassland to forest [Pye, 1987]. Thus in very harsh climates erosion occurs, producing planed or "shaved" surfaces, rather than loess deposition. Erosional surfaces such as these are observed within the deposits on both the Kaingaroa and Mamaku Plateau.

Loess generation typically occurs in environments where there are high physical weathering rates, such as glacial outwash plains and braided fluvioglacial channels, alluvial flood-plains, alluvial fans, dry lake beds, and deserts. The devegetated landscape near the terminus of the great continental ice-sheets is thought to be the source area for the vast loess sheets found in Eurasia and North America. Loess deposition is thought to have been especially active near the end of glaciations, when the ice-sheets were retreating, exposing bare ground. The thickest Pleistocene loess deposits occur in China, where in some places they are >200 m thick. The loess here is believed to have come from the enlarged desert regions to the west. In New Zealand, especially in the lower North Island, loess is much thicker immediately to the east (downwind) of major rivers, indicating that it is sourced in the braided alluvial flood-plains which formed the widespread aggradational terraces [Cowie, 1964; Milne, 1973a]. There are several rivers in the eastern Bay of Plenty which are likely to have formed large aggradational surfaces; namely the Rangitaiki, Whakatane, Waimana and Waioeka Rivers. The Motu and Raukokore Rivers in the far north-east also have associated large terrace gravel deposits associated with them.

Another possible source of loess is the wide expanse of continental shelf, which is exposed to terrestrial weathering as sea-level falls at the start of glacial periods [Lowe & Walker, 1984]. Wind erosion may be significant before the advancing vegetation cover occupies and binds the surface. Whether, or not, loess was sourced from the exposed continental shelf regions depends upon the rate of sea-level fall and the rate of vegetation migration from coastal areas.

In areas, such as the Bay of Plenty, near active volcanic regions, a further cause of barren ground for loess production could be the devegetation following the occasional very large eruption. Very thick tephra deposits, and especially ignimbrites, can totally destroy all vegetation within a large area, and the vast areas of loose surface sediment would be an ideal site of loess production. Furthermore, rivers are often choked with material immediately after eruptions and can form broad flood-plains that are also good areas for loess production.

Loess is generally indicative of a cold climate; most of its sources present or active only during glacial or stadial periods. Magnetic susceptibility profiles through the thick loess and paleosol sequence in China show a remarkable similarity to the deep-sea $\delta^{18}\text{O}$ curves [Kukla *et al.*, 1988]; loess accumulation having been dominant in the cold glacial periods, and soil formation dominant in the warm interglacial periods. Ocean cores to the east of New Zealand show a much greater rate of detrital quartz sedimentation—that is, loess—during the last glaciation ($\delta^{18}\text{O}$ stage-2), especially in the latter part of the glaciation (22.6 ka – Kawakawa Tephra, to 14.7 ka – Rerewhakaaitu Tephra), rather than during post-glacial time (Holocene/post-Rerewhakaaitu Tephra) [Stewart & Neall, 1984].

However, in the coastal Bay of Plenty region it is possible that the beginning of the glacial periods, as sea-level was falling rapidly and the continental shelf was becoming exposed, may have been more

conductive to loess production than the latter part of the glacials. In the Bay of Plenty, loess of $\delta^{18}\text{O}$ stage-2 age is thought to have begun accumulation significantly before the eruption of the 22.6 ka Kawakawa Tephra, and ceased deposition synchronous with, or just following, the eruption of the Rerewhakaaitu Tephra at c. 15 ka [Neil Kennedy, pers. comm. 1987]. Elsewhere, for example in the southern part of the North Island, loess deposition is thought to have begun at a similar time, but ended slightly later, at c. 10–12 ka, when the deposition of the aggradational gravels which sourced this loess ceased [Pillans *et al.*, 1993]. Either a different process of loess production was operating in the Bay of Plenty (such as continental shelf exposure), or differing local geographic conditions were (strongly) influential. It may be that at the end of the "last glacial maximum" the wetter and warmer climate in the more northerly Bay of Plenty, combined with the lower elevation of the mountains here than those further south, promoted a more rapid vegetative recolonisation of mountain slopes in this region.

Loess can be deposited during brief cooler periods (not full glacials) within the warmer interglacials. All that is needed is for sediment supply to be significantly greater than the capacity for its removal. The loess that is recognised in the coastal Bay of Plenty stratigraphy could have been produced either by exposure of the continental shelf during brief sea-level falls during interglacial periods, or from increased aggradation following large eruptions.

Loess continues to be produced and deposited today in areas where barren ground is exposed to high winds — for example, braided rivers downstream of denuded slopes, cultivated flood-plains, and loessic soil areas.

Below are the names and ages of the loess units (if also gravels, then (G)) in the lower North Island, New Zealand [mostly from Alloway *et al.*, 1993; and Pillans, 1994].

Ohakea (G)	$\delta^{18}\text{O}$	stage-2	12–28 ka
Rata (G)	"	stage-3	c. 30–50 ka
Porewa (G)	"	stage-4	c. 70–80 ka
Cliff	"	stage-5b	c. 90–100 ka
Greatford	"	stage-5d	c. 110–120 ka
Marton (G)	"	stage-6	c. 140–170 ka
Burnand (G)	"	stage-8	c. 240–280 ka
Aldworth	"	stage-10	c. 340–350 ka
Waituna	"	stage-10	c. 360–370 ka

Loess is distributed throughout much of the Bay of Plenty, often interbedded with tephra and paleosols. At many sites, however, the loess is difficult to distinguish as strong paleosols have developed into it and pedogenic processes have altered it to clay. Here, the material can only be recognised as loess by its fine grained and massive nature.

15-3.3 Paleosols

The rate of paleosol development is dependent upon: the rate of deposition of extraneous material (loess and/or tephra); temperature; type of parent material (substrate); and the type and amount of vegetation, which is itself dependent on parent material and climate. Loess is produced and deposited in

both cold and warm climates, though more so in cold, but because of the different weathering regimes that exist, loess deposits are much better preserved during glacials, while the interglacials are represented by greater paleosol development. In warmer, wetter climates, the rate of weathering and soil formation is much higher due to increased vegetation, soil organism activity and temperature; and pedogenic processes incorporate the loess into the soil at a faster rate than it is deposited. Loess production and deposition is increased during glacial times (especially in Eurasia and North America), and pedogenic processes occur much more slowly due to the colder and drier climate, and generally poorer vegetation cover. As deposition during glacial times is much more rapid than incorporation into the soil, the loess is preserved with virtually no weathering.

In the eastern Bay of Plenty, several thick paleosols and many thinner paleosols, developed into both loess and tephra, can be recognised. However, the paleoclimatic record exhibited by the presence or absence of paleosols can be difficult to interpret. The thick tephra deposits in this region interrupt the steady rate of soil development with an instantaneous, thick deposit of glass shards and pumice. Pedogenic processes cannot easily incorporate deposits >0.25 m thick (many tephras are much thicker) and hence soil formation must begin anew following most eruptions; the (usually) totally unweathered tephric material becoming new parent material. Basalt is readily weathered, andesite less so, and rhyolite, due to its high silica, and low Fe, Mg and Ca content, is relatively resistant to weathering. Soil formation therefore proceeds at a much slower rate than if no tephras were deposited. If no new tephra is deposited for a significant period of time, the pedogenic processes may be able to totally weather and incorporate the tephra within the soil; merging with the previous underlying paleosol to form a pedo-complex.

Depending upon the rate of volcanic activity, a long period of warm climate may be represented by either a single very thick paleosol, or by a series of thin paleosols developed directly into the tops of individual tephras, or a mixture of the two scenarios. The diagnostic feature, therefore, of interglacial deposits in tephric regions, is a series of paleosols, thickness being relatively unimportant, developed directly into tephras with little or no loess present. A very thick paleosol is likely to have weathered deeply into the previously deposited loess, and although the paleosol surface and uppermost parts represent interglacial periods, the majority of the weathered material, or soil, represents deposition during glacial times. The thickness of the paleosol is related to the length of time during which weathering occurred, but the thickness of the parent material—if it can be determined—within the paleosol must also be recorded for paleoclimatic studies.

15-3.4 Evidence of sea-level change

Since the climate has had a large impact on paleo-sealevels, evidence of rapid sea-level change can be used as a proxy for that of climate change. The sea-level during glacial periods was often >100 m lower than that during interglacial times—the latter being similar to present relative sea-levels—causing the type of sediment deposited to be significantly different from one period to the next. Marine shelf sequences would thus show deep-water sediments associated with interglacials, alternating with shallow-

water (or even terrestrial) sediments associated with glacial periods. Unfortunately, the present relatively high interglacial sea-level prevents ready access to the marine shelf sequences, except where uplift has occurred. In the Bay of Plenty, a thick sequence of uplifted marine sediments is present in the coastal cliffs west of Matata. Several alternating cycles of deeper-water fine sands and silts, and shallow-water sands, gravels, terrestrial lignites and paleosols can be observed here. The tephra found within this sequence provide valuable stratigraphic controls for the terrestrial sequence found elsewhere.

Also useful for stratigraphic age control are uplifted wave-cut surfaces, or marine terraces, which are sub-horizontal erosional surfaces cut into the coastal terrain (older sediments or bed-rock) by wave action near the high-tide zone during the high sea-level stands of interglacials. The cut surfaces remain exposed during the low sea-level stands of glacial periods, and uplift preserves them at some height above the high sea-level of the following interglacial. As the cutting of the next terrace may completely erode the previously uplifted surface, the likelihood of preservation increases with uplift rate. Subsidence allows no preservation, or at least no visibility or access during the present high sea-level stand. The age of any wave-cut surface can be estimated by various means. These include: comparison of the $\delta^{18}\text{O}$ sea-level curve with the number of terraces existing between the surface in question and the coast; the relative heights of the wave-cut surfaces, together with estimated uplift rates; and dated "cover-bed" deposits — such as tephra, lignites and fossils — that overlie the cut surface. The age of the wave-cut surface can often be used to estimate the age of its cover-bed deposits, or vice versa.

Marine terraces are present at the eastern extreme of the Bay of Plenty region; along the west coast of the Raukumara Peninsula, but their preservation is patchy, and well exposed sections through them rare. The terraces are few in number and most are thought to be too young to be of much use in detailing the eastern Bay of Plenty tephrostratigraphy.

15-4 Estimated Ages for Eastern Bay of Plenty Tephra

The LLS deep-sea $\delta^{18}\text{O}$ curve is shown in detail in the following pages. The inferred stratigraphic ages of all the individual tephra and their relationship to the paleoclimatic conditions in the eastern Bay of Plenty are also shown. Periods of rapid loess deposition and little paleosol development (light hatch) alternate with periods of less rapid loess deposition and enhanced paleosol formation (darker hatch). Both processes of loess deposition and weathering occur simultaneously, but one or other process may be dominant according to the climatic conditions.

Some warm climate periods of loess deposition are recognised within the stratigraphic sequence. Loess deposition in warm climates often occur immediately following a very large eruption, or during the lowering of sea-level at the beginning of a glacial period. The large ignimbrite sheets associated with very large eruptions would have provided vast areas of loose sediment with little vegetation to stabilise the surface, and the lowering of sea-level may have exposed unconsolidated marine sediments; both are ideal environments for loess production.

The $\delta^{18}\text{O}$ curve is "anchored" to the tephrostratigraphy at several points where the ages of individual tephtras have been determined by radiometric dating. A significantly different but seemingly realistic stratigraphic fit to the $\delta^{18}\text{O}$ curve results if these ages are not used as control points (see Figure 15-6 at the end of the chapter).

The inferred ages of the tephtras are not precise, but whether they were deposited during warmer or cooler periods can usually be determined. Often the relative magnitude and length of the climatic periods can also be determined, and a given tephtra's approximate position within them — beginning, middle, or end. As more radiometric dates become available, the ages of the tephtras will become more accurately known.

15-4.1 Ages of the post-Rotoiti tephtras observed in the eastern Bay of Plenty

The ages of most of the post-Rotoiti tephtras are known from the ^{14}C dating of charcoal found within the tephtra deposits, and of the enclosing peats. These ages are presented in Table 2-1. The ages of the oldest post-Rotoiti tephtras are estimates only, determined by their stratigraphic positions relative to the Rotoiti Tephtra. The age of the Rotoiti Tephtra is discussed in detail in Chapter Four, but an age of *c.* 50–60 ka is considered likely on the basis of the paleoclimatic indicators in the surrounding stratigraphy (see Figure 15-2). The Rotoiti Tephtra has a weak paleosol in its top, and is separated from the underlying last-interglacial paleosol by loess that was probably deposited during $\delta^{18}\text{O}$ stage-4 (see Photo-61). Weathered loess exists between the Rotoiti and the overlying Mangaone Tephtra, which is thought to be much younger, *c.* 35 ka.

15-4.2 Ages of tephtras in the Kukumoa subgroup

The Kukumoa subgroup is thought to span ≈ 170 ka; from *c.* 50–60 ka at the base of the Rotoiti Tephtra, to *c.* 220 ka at the base of the Kutarere Tephtra (see Figure 15-2). Most of the deposits in this subgroup are extremely poorly preserved due to the effects of the very strong weathering regime that existed during the last-interglacial ($\delta^{18}\text{O}$ stage-5).

The Wairuru, Copenhagen and Torere School Tephtras are observed below the Rotoiti Tephtra at the Copenhagen Road section. The "last-interglacial paleosol", usually located immediately below the Rotoiti Tephtra, is not present in this section, and therefore these three tephtras are thought to be of last-interglacial age or younger. The Wairuru Tephtra has a moderate paleosol developed into it, and the lower two tephtras are found within colluvial units, each of which has a weak paleosol in its top. At the base of the section is a very weathered reddish paleosol (see Photo-62). This paleosol is thought to have formed only during the warmest period of the last-interglacial, $\delta^{18}\text{O}$ stage-5e, though it is possible that it represents all of $\delta^{18}\text{O}$ stage-5. If the former scenario is correct, all three pre-Rotoiti tephtras at Copenhagen Road would have been deposited between 70 ka and 120 ka; and if the latter scenario is correct, between 60 ka and 80 ka. The Wairuru Tephtra at Wairuru Cemetery is found within gravels above an erosional surface cut into basement rock. Depending upon whether the cut surface is of marine

Figure 15-2 : Low Latitude Stack – Oxygen isotope curve; post-Rotoiti and Kukumoa subgroups

(stage-5a), or fluvial origin (older), and whether the silts found higher in the sequence (Te Papa Terrace deposits) are of or fluvial overbank (stage-4 or younger), or estuarine deposition (stage-5); the age of the gravels enclosing the tephra is either $\delta^{18}\text{O}$ stage-4, or stage-5b/d respectively. Beach gravels are present at a higher level in this sequence at a nearby site [Sumosusastro, 1983], indicating that the silts are estuarine and that the older age is the more likely. This is consistent with the presence of the Wairuru Tephra within fluvial terrace deposits at Waitotuma. This terrace, named the "Waitotuma Terrace" [Sumosusastro, 1983] is believed to be younger than the Otamaroa marine terrace (c. 120 ka), and between the Wairuru and Rotoiti Tephra at Waitotuma there are many metres of cover-beds, including a moderately developed paleosol. The cover-bed sediments here represent deposition over many thousands of years and the Wairuru Tephra is therefore thought to have an age of c. 90 ka or older. The Copenhagen and Torere School Tephra were not seen in the cover-bed sequences, either because they were too thin to be preserved, or because they are older than the formation of the fluvial cut surfaces; probably the latter.

A weathered reddish layer found within the "last-interglacial paleosol" a few metres below its upper surface at Kukumoa, may represent the warmest part of the last-interglacial, $\delta^{18}\text{O}$ stage-5e, which is believed to have been warmer than present [Burke, 1993]. If (this is) so, and if the reddish paleosol at the base of the Copenhagen Road section also represents $\delta^{18}\text{O}$ stage-5e weathering, then the tephra above must lie within the remainder $\delta^{18}\text{O}$ stage-5. Assuming that the tephra were evenly distributed throughout the latter part of $\delta^{18}\text{O}$ stage-5, rough age estimates for the Wairuru, Copenhagen, and Torere School Tephra are c. 90 ka, c. 105 ka, and c. 115 ka respectively.

The age of the Kutarere Tephra is difficult to determine. Only 3–5 m of material, generally a paleosol developed into loess and tephra, lies between the Kutarere Tephra (c. 220 ka) and the Rotoiti Tephra (c. 50 ka) above (see Chapter 4). At the Tapapa section, at the edge of the Mamaku Plateau west of Lake Rotorua, the Rotoiti Tephra overlies the weathered top of the Mamaku Ignimbrite; separated from it by only three loess units and their associated weakly developed paleosols [Kennedy, 1988]. One sparsely preserved tephra is also present within the loess. It is therefore stratigraphically consistent for the Kutarere Tephra and the Mamaku Ignimbrite to be correlatives of each other, and the sparsity of deposits between them suggests a relatively short time span between these two eruptives. Working backwards in time (downwards) from the present day, the stratigraphy suggested to many workers an eruptive age near the end of $\delta^{18}\text{O}$ stage-6, c. 140–150 ka, for the base of the "undifferentiated brown ashes" [Pullar *et al.*, 1973], "tephra-X" [Vucetich *et al.*, 1981], and the Mamaku Ignimbrite [Kennedy, 1988]. A zircon fission-track age of 140 ± 80 ka (error = two standard deviations) was compatible with this conclusion [Murphy & Seward, 1981], but these early fission track ages are now thought to be significantly too young, due to annealing of the tracks (see sect. 2-4).

However, working from the older eruptives towards the present day gives a stratigraphic age of the Kutarere Tephra not considerably younger than the other large ignimbrite eruptions which have been dated (Kaingaroa = 0.24–0.33 Ma; Matahina = 0.28–0.34 Ma; Whakamaru = 0.33–0.35 Ma). Several workers embraced a c. 230 ka age determination on the Mt. Curl Tephra (a correlative of the Whakamaru Ignimbrite), because the age fitted well with the loess stratigraphy seen in the field for the Whakamaru

Ignimbrite in the Mamaku Plateau area. However, the 230 ka age was later found to be in error (see Table 2-4).

Furthermore, the thickness of the paleosol between the Rotoiti and Kutarere Tephra in the eastern Bay of Plenty suggests weathering over a significant length of time has occurred. Much of the weathered material is massive clay which was probably once loess. Owing to the thickness of these loess layers, it is unlikely that they were deposited during an interglacial, and more likely that they have been deposited during the much longer period of cold climate encompassing the entire $\delta^{18}\text{O}$ stage-6. The intense weathering that these deposits have experienced could have occurred during the entire length of the last-interglacial, $\delta^{18}\text{O}$ stage-5, which at some times was even warmer than the present.

At several other sites (e.g. Kutarere cutting) the strongly weathered paleosol beneath the Rotoiti Tephra has developed through several metres of loess and/or gravels and the Kutarere Tephra is not observed — presumably it is below the base of the section. The loess and gravel deposits are cold climate indicators and it is unlikely that this thickness of material could have been deposited, and then weathered to such an extent, during the period since the end of the last-interglacial. At Newdicks Beach, 6 m of dune sands lie between the top of the paleosol developed into the Kutarere Tephra and the paleosol beneath the Rotoiti Tephra. Dunes generally form in coastal environments, indicating a probable deposition during $\delta^{18}\text{O}$ stage-5, or possibly the latter part of $\delta^{18}\text{O}$ stage-7. These two time periods were the only occasions between the Mamaku and Rotoiti eruptions when sea-level was at a similar height to present-day and the coast was nearby, rather than many kilometres away. In the latter case, erosion immediately below the Rotoiti Tephra may have removed any loess deposited during $\delta^{18}\text{O}$ stage-6.

An erosional unconformity is recognised immediately below the Rotoiti Tephra at many sites throughout the Bay of Plenty region (e.g. see Photo-63 & 63(a)). This "missing time" must also be accounted for when estimating the length of time that has elapsed since the deposition of the Kutarere Tephra. At some sites (e.g. Ngatiawa lookout, Paerata Ridge Road & Kukumoa cutting) several metres of erosional relief are visible.

The Kutarere Tephra has undergone a great deal of weathering, with a thick paleosol developed into it causing much of its glass to be hydrated and altered to clay. It generally also overlies a thick paleosol developed into loess and tephra below, indicating that it was deposited during a warm interglacial climate — probably $\delta^{18}\text{O}$ stage-7. The precise time of deposition within this interglacial is uncertain, and therefore the eruption of the Kutarere Tephra has been placed approximately midway through $\delta^{18}\text{O}$ stage-7 in Figure 15-2. The age of c. 210–220 ka for the Kutarere Tephra is in only slight conflict with recent radiometric age determinations on the Mamaku Ignimbrite with which it is thought to correlate. Two recent ages: 230 ± 12 ka [Shane *et al.*, 1994] and 220 ± 10 ka [Houghton *et al.*, 1995], confirm that the Mamaku Ignimbrite—and thus the Kutarere Tephra—was erupted during $\delta^{18}\text{O}$ stage-7.

The Kukumoa-B Tephra rests on the paleosol developed into the Kutarere Tephra, and is overlain by weathered loess. It therefore is thought to have been erupted near the beginning of $\delta^{18}\text{O}$ stage-6, at c. 195 ka.

The Kukumoa-C and Kukumoa-D Tephra lie within the loess which is believed to have been deposited during most of $\delta^{18}\text{O}$ stage-6. There appears to be a stratigraphic break of some sort, at the contact of the loess with the base of the Kukumoa-D Tephra, which may result from a short period of warming near the beginning of $\delta^{18}\text{O}$ stage-6. The age of the Kukumoa-D Tephra is therefore tentatively estimated at c. 165 ka, and that of the Kukumoa-C Tephra at c. 180 ka.

15-4.3 Ages of tephras in the Huntress Creek subgroup

The Huntress Creek subgroup is thought to span ≈ 55 ka; from the Kutarere Tephra at c. 220 ka just above, to the Kaingaroa Tephra at c. 285 ka at its base (Figure 15-3). The subgroup contains tephras which are predominantly enclosed in loess, and has a thick paleosol developed into loess at its top, but few paleosols within it. Although individual tephra correlations remain tentative, the Welcome Bay subgroup is believed to be of equivalent age.

At the top of the subgroup is the Welcome-F Tephra, which has been strongly weathered after deposition. No loess is visible immediately above it, although loess is present not far below, suggesting that the tephra was erupted near the boundary between a warm and a cold climatic period; probably near the $\delta^{18}\text{O}$ stage-8/stage-7 boundary at c. 240 ka.

The white weathered ash-clay streaks that are mixed into the paleosol below the Kutarere Tephra at Huntress Creek probably represent the Huntress-F Tephra. Elsewhere the Huntress-F Tephra has a quite well developed paleosol in its top, and either directly overlies unweathered loess, or rests on a weak paleosol developed into loess. The loess below and paleosol above indicate that this tephra, also, was erupted near the end of a cooler glacial period; probably $\delta^{18}\text{O}$ stage-8.

At the base of the subgroup is the Kaingaroa Tephra. This tephra is a very widespread deposit and its age has been subject to study for some time. By means of glass chemistry, the Kaingaroa Tephra has been correlated to either the Upper Griffins Road, or Middle Griffins Road Tephra in the Wanganui region ([Froggatt, 1983], and this work respectively). Both these tephra lie within the "Burnand loess", the age of which was originally estimated to be c. 180 ka [Milne & Smalley, 1979; Wilde & Vucetich, 1988]. However, more recent work suggests that this loess has an older age of c. 300 ka [Bussell & Pillans, 1992]. Thermoluminescence dating proved inconclusive as three ages for the Burnand loess were produced: 176 ± 32 ka, 194 ± 22 ka and 328 ± 43 ka [Berger *et al.*, 1992].

In the Bay of Plenty region there is also paleoclimatic data to consider, such as:

- the presence of loess above the Kaingaroa Tephra in coastal sections (see Photo-50);
- the absence of loess beneath the Kaingaroa Tephra at the type section on the Kaingaroa Plateau, where presumably there would have been a harsh climate in glacial times;
- the presence of a moderately well developed paleosol immediately below the Kaingaroa Tephra on the Kaingaroa Plateau (see Photo-44);

continued over...

- the presence of weathered tephra and what appears to be very coarse loess below the Kaingaroa Tephra in sections near the coast; generally with limited paleosol development, except at Torere West. Here, there is a thick dark soil, the formation of which, as it contains charcoal, has possibly been enhanced by burning;
- the occasional presence of a paleosol developed into the top of the Kaingaroa Tephra, and into the tops of many of the tephra below.

The paleoclimatic evidence indicates that the Kaingaroa Tephra was deposited during a relatively warm climate, just before the beginning of a full glacial period.

Several fits of the paleoclimatic data to the oxygen isotope record (see Figure 15-3) are possible, which give the following ages for the Kaingaroa Tephra:

- at the end of oxygen isotope stage-7;
- at the end of oxygen isotope stage-9; or
- at the end of a minor, relatively short, warm period in the first half of $\delta^{18}\text{O}$ stage-8.

More loess is present within the Huntress Creek subgroup than in the two loess deposition periods of the Torere subgroup together, and therefore the Huntress Creek subgroup is thought to represent the bulk of the coldest part of $\delta^{18}\text{O}$ stage-8. On the basis of the estimated ages of the Matahina Tephra, and the number of tephra within the Torere subgroup, the latter of the above fits to the oxygen isotope record is believed to be the most likely (part-way through stage-8), resulting in an estimated age of the Kaingaroa Tephra of *c.* 285 ka.

Several radiometric age determinations on the Kaingaroa Ignimbrite have been produced in the last 20 years (see Table 2-2). Early fission-track dating on glass yielded ages of 145 ± 20 ka and 155 ± 30 ka [Kohn, 1973], but due to annealing and under-etching, most early glass fission-track ages have been found to be too young (see sect. 2-4) and are considered to be minimum ages only.

A more modern fission-track (zircon) age of 240 ka [Kohn, pers. comm. in Nairn, 1989b] has been produced, and recent $^{40}\text{Ar}/^{39}\text{Ar}$ laser fusion age determinations on plagioclase have yielded a similar value; 0.23 ± 0.01 Ma [Houghton *et al.*, 1995]. These two ages do not appear to be consistent with that estimated from paleoclimatic evidence in the Bay of Plenty. Nevertheless, the paleoclimatically derived age developed in this study of *c.* 285 ka for the Kaingaroa Tephra will be used here. $^{40}\text{Ar}/^{39}\text{Ar}$ age determinations on the Whakamaru Ignimbrite give slightly younger ages than other radiometric dating methods — such as ITPFT and fission-track on zircons (see Table 2-2) — and also conflict slightly with the paleoclimatic evidence.

Between the Huntress-F and Kaingaroa Tephra lie the Huntress-E, Huntress-D, Welcome-C and Huntress-C Tephra. These tephra were all deposited within loess and have not undergone paleosol development (see Photo-45). The top of the loess layer below the Welcome-C Tephra appears to be less weathered than its base which suggests a progressively cooling climate.

Figure 15-3 : Low Latitude Stack - Oxygen isotope curve; Huntress Creek, Torere, Murupara and Tablelands subgroups

The Huntress-B Tephra was also deposited within loess, but at the Huntress Creek site, the tephra rests on a thin paleosol developed into the loess. At the Hiwarau section the Huntress-B Tephra overlies an erosional boundary into weathered Kaingaroa Tephra; the weathering indicating that the climate may have been less harsh at this time than during the latter part of the subgroup's deposition. Generally ≈ 40 cm of loess separates the Kaingaroa and Huntress-B Tephra, thought to represent deposition over a likely time range of *c.* 10 ka, giving an eruption age of *c.* 275 ka for this latter tephra.

The radiometrically determined age of the Mamaku Ignimbrite, and the estimated age of the Kaingaroa Ignimbrite, constrain the beginning and end points of the Huntress Creek subgroup. The other tephra in the Huntress Creek subgroup have been assigned ages relative to their stratigraphic positions and the thickness of loess existing between the eruptives.

15-4.4 Ages of tephra in the Torere and Reihana subgroups

More tephra can be recognised in the Torere subgroup than in any other, though this is thought to be due more to better preservation of the smaller events, than to a larger number of eruptions. The Torere subgroup is believed to span ≈ 40 ka; from the Kaingaroa Tephra at *c.* 285 ka, to the base of the Torere-A Tephra at *c.* 325 ka (see Figure 15-3). The Torere subgroup and the Reihana subgroup are equivalent in time, but in each subgroup some eruptives are found that are not recognised in the other.

Loess is in general absent from the Torere subgroup. At the Reihana Road section, no loess is recorded between the eruptives below the Kaingaroa Ignimbrite, only moderately and weakly developed paleosols. Reihana Road lies within the Kaingaroa Plateau where, during full glacial periods, severe erosion or the deposition of tephric-loess has occurred at other sections (e.g. the Murupara sites). The paleoclimate is therefore thought to have been relatively mild during the deposition of the Torere subgroup, and the thin paleosols are probably due to a short period of soil development, rather than a harsh climate.

In the coastal region, two thin units of loess are observed within the Torere subgroup. Neither unit appears to contain anywhere near as much loess as that deposited within the Huntress Creek subgroup, indicating that the climate was generally milder than full glacial conditions, and/or that the time between eruptions was relatively short. The loess deposits may be attributable to a large eruption which caused large aggradational flood-plains (Hiwarau, Torere-A & Matahina eruptions being likely candidates); or to a rapid lowering in the sea-level, which exposed shelf sediments.

There is a relatively well developed paleosol immediately below the Kaingaroa Tephra at Reihana Road (see Photo-44), and at Torere West (see Photo-41). Therefore the Reihana-M Tephra is thought to be at least several thousand years older than the Kaingaroa. The top of the paleosol shows some relief, and at some places significant erosion is observed — for example, at the far right of the Reihana Road section. A very thin paleosol or period of weathering exists between the Reihana-M and Torere-O Tephra, indicating that little time separates these two eruptives. The boundary between the Torere-O and

Torere-N Tephra is also very difficult to distinguish, and hence the latter tephra is thought to have a similar age.

A thicker paleosol—and thus more time—exists between the Torere-N and Torere-M Tephra, but the Torere-L Tephra again has only a thin weathered layer at its top and is believed to be only slightly older than the Torere-M. In the coastal eastern Bay of Plenty, a moderate amount of weathering is apparent between the Torere-O and Torere-L Tephra.

At Reihana Road, the upper part of the Torere-K Tephra is weathered, with a weak paleosol separating it from the Torere-L Tephra above. A more significant paleosol separates the Torere-K and Reihana-G Tephra. In some places, the pisolitic ash of the Reihana-G Tephra has undergone substantial erosion, and a paleosol has developed into this erosional surface. The Reihana-G Ignimbrite directly overlies the Reihana-F Tephra, although the contact is erosional and it is possible, though unlikely, that the boundary represents a significant disconformity (time break). The Reihana-G Tephra is thought to correlate in part with the Torere-I Tephra in the coastal region. The Torere-I Tephra directly overlies the Opotiki Tephra with no noticeable time break, and therefore are considered to have the same age. The Opotiki Tephra rests on a moderately thick yellowish-brown paleosol developed into loess. The Reihana-F Tephra, which is also thought to be of similar age, rests upon a well developed paleosol.

The deposits between the Kaingaroa and the Opotiki Tephra in the coastal region contain paleosols and no loess, and are therefore thought to have been deposited during a period of relatively mild climate.

The deposits between the Torere-G and Torere-D Tephra are generally found within loess, with no paleosol development, and are thought to represent deposition in a relatively cool climate, or during a period associated with a rapidly falling sea-level. The cessation of loess deposition after the Torere-G eruption is interpreted to represent rising sea-level after a climatic minimum, which was, nevertheless, relatively warm in comparison to full glacial conditions. Fitting the paleoclimatic data to the oxygen isotope record gives an estimated age of *c.* 290 ka for the Opotiki Tephra, and *c.* 295 ka for the Torere-G Tephra.

The Ohiwa Hill Tephra is enclosed by loess which is generally unweathered, which indicates that it was erupted near a climatic minimum, at *c.* 300 ka. The loess below the Torere-E Tephra is quite sandy, suggesting strong winds and/or a nearby source of loose sediment — perhaps recent exposure of the continental shelf.

The Torere-D Tephra rests on a sandy paleosol developed into the Hiwarau Tephra. The Hiwarau Tephra is highly weathered at many sites, suggesting that it was erupted during a period of relatively warm and stable climate, possibly *c.* 310–320 ka ago. At some sites (Ohiwa Hill, Awakeri Springs) the Hiwarau Tephra overlies relatively unweathered loess, but at other sites (Huntress Creek, Pukeruru Point) it overlies a reasonably well structured paleosol developed into the loess.

The top of the loess below the Hiwarau Tephra contains discontinuous lenses of Torere-B Tephra, but this is often obscured by paleosol development. The Torere-A Tephra has loess above it but rests directly on the paleosol developed into the Matahina Tephra (see Photo-32; Photo-33). The coarse grained pumice that comprises the Matahina Tephra has an estimated age of *c.* 325–330 ka, and the

paleosol in its top is thought to represent several thousand years of weathering. The age of the base of the Torere subgroup is therefore thought to be *c.* 325 ka.

There are several tephra at the Reihana Road site which have not been recorded in the eastern Bay of Plenty, and vice versa. The Reihana-C Tephra rests on a very weak paleosol developed into the Torere-B Tephra, and there is no noticeable time break between the Reihana-C Tephra and Terrace Road Basalt above. An erosional contact, and no paleosol, exists between the basalt and the Reihana-E Tephra above, and it is uncertain how much time is represented by this disconformity.

A firm, well developed paleosol in the top of the Reihana-E Tephra separates it from the pumice of the overlying Reihana-F Tephra. The age of the Reihana-F Tephra is uncertain as there must be a significant time break, perhaps as much as 20 ka, occurring either immediately above, or below, the tephra.

This unconformity is believed to exist because many eruptives in the coastal areas at about this stratigraphic position are not recognised at Reihana Road, but the precise position of the unconformity remains uncertain. The erosion at the top of the Terrace Road Basalt may be significant, but alternatively may represent very little time. The same is true of the erosion at the top of the Reihana-F Tephra, which is its contact with the Reihana-G Ignimbrite. The other likely stratigraphic position of the unconformity is within the cemented paleosol between the Reihana-E and Reihana-F Tephra.

The Reihana-F Tephra is either marginally younger than the Torere-B Tephra, or has a similar age to the Reihana-G Ignimbrite; *c.* 315 ka, or *c.* 290 ka in age respectively.

The Te Piki Tephra, which is tentatively correlated to the Hiwarau Tephra (this work), has glass fission-track age determinations of 0.21 ± 0.10 , and 0.22 ± 0.08 Ma [Sumosusastro, 1983]. Given that these ages are probably too young due to under-etching and annealing, the estimated age of the Hiwarau Tephra is within the upper error bars of the fission-track ages, and the two tephras are likely correlatives. These age determinations, together with the estimated and radiometric ages from the underlying Murupara subgroup, confirm that the Torere subgroup was erupted during $\delta^{18}\text{O}$ stage-9 and stage-8.

15-4.5 Ages of tephras in the Murupara subgroup

The Murupara subgroup is believed to span only ≈ 15 ka; from the base of the Torere-A Tephra at *c.* 325 ka, to the base of the Murupara-A Tephra at *c.* 340 ka (see Figure 15-3).

Several radiometric ages have been determined for Matahina eruptives (see Table 2-2). A sample from the pre-ignimbrite airfall at the Murupara-(2) site produced a zircon fission-track age of 0.28 ± 0.04 Ma [Kohn, pers. comm. 1994]; and an ITPFT age of 0.34 ± 0.02 Ma on glass from the Matahina Ignimbrite at the same site [Tasha Black pers. comm. 1994] fixes this eruption to $\delta^{18}\text{O}$ stage-9. Recent $^{40}\text{Ar}/^{39}\text{Ar}$ determinations resulted in an age of 0.28 ± 0.01 Ma for the Matahina eruption [Houghton *et al.*, 1995].

In the terrestrial depositional environment, the Matahina Tephra at the top of this subgroup rests on a well developed paleosol weathered into the tephra below (see Photo-28; Photo-29). Its upper surface has also undergone weathering, which indicates that the Matahina Tephra was probably erupted during a period of warm climate; probably during $\delta^{18}\text{O}$ stage-9.

In sections near Matata, the Matahina eruptives directly overlie a marine sand (see Photo-64) which has an erosional unconformity at its base. As several tephra below the sand appear to have been deposited in a terrestrial environment, it is evident that the sea-level was higher during Matahina deposition, and equates to a warm, non-glaciated climate. The presence, at the Ngatiawa and Otawairere sections, of the estuarine "Otarawairere Mudstone" immediately overlying subaerially deposited airfall Matahina Tephra, indicates that the tephra was deposited just before the highest $\delta^{18}\text{O}$ stage-9 interglacial sea-level — represented here by estuarine mudstone deposition. The presence of loess not far above the paleosol in the top of Matahina Tephra, is thus most likely to have originated from the exposure of the continental shelf during a minor sea-level fall immediately following the sea-level high. The paleoclimatic data give an estimated age for the Matahina Tephra of *c.* 330 ka; this is within the 2σ uncertainty of the recent ITPFT radiometric ages, but is slightly older than the $^{40}\text{Ar}/^{39}\text{Ar}$ age.

At the base of the subgroup is the Murupara-A Tephra, which lies within tephric-loess at its type section, Murupara-(2) (see Photo-17), and directly overlies loess in the coastal sections. Hence the tephra is believed to have been erupted during a relatively cold period. Since a paleosol has developed into the top of the Murupara-A Tephra in the coastal sections, the climate after its eruption is thought to have been somewhat milder than before it. At the Murupara-(2) site, the tephric-loess below the Murupara-A Tephra rests upon the eroded or shaved surface of the Rangitaiki Ignimbrite. This erosion is presumed to have occurred during the harshest of climates and the tephric-loess therefore records an ameliorating climate. On the basis of the above features, the Murupara-A Tephra is thought to have been erupted during the transition from a very cold glacial climate to a warmer interglacial climate, probably very near the $\delta^{18}\text{O}$ stage-10/stage-9 boundary at *c.* 340 ka.

Using the 0.34–0.35 Ma age for the Rangitaiki Ignimbrite which lies below, and considering the likely time interval that is required for the erosion and loess deposition to have occurred, an age of *c.* 330–340 ka is estimated for the Murupara-A Tephra.

In the coastal eastern Bay of Plenty, paleosols are developed into all of the tephra in the Murupara subgroup and no loess is recognised. However, in the Kaingaroa Forest near Murupara, tephric-loess encloses the Murupara-A and Murupara-C Tephra (Murupara-B not seen), and the Bonisch Tephra rests on only a weak paleosol in tephric-loess. The data indicates that as with the Murupara-A Tephra, these eruptives were produced near the beginning of an interglacial, while the climate was steadily improving, but before full interglacial conditions were achieved.

The thickness of the tephric-loess between the Murupara-C and Murupara-A Tephra at the Murupara-(2) site, suggests a period of about 5 ka between the eruption of these two tephra. A zircon fission-track age has been obtained from near the base of the Murupara-C Tephra at this site. Duplicate

ages of 0.31 ± 0.04 Ma and 0.28 ± 0.04 Ma [Kohn, pers. comm. 1994] are slightly younger, but within the error margin of the c. 335 ka age estimated from the paleoclimatic record.

No loess was deposited between the Bonisch and Murupara-E Tephra, which indicates that full interglacial climatic conditions existed at this time. The paleosol developed into the Bonisch Tephra is generally very thin, except at Pahekeheke Road, indicating that little time separated these two eruptions.

The Murupara-E and Anaputa Tephra are separated only by a very thin weathering zone; not enough to be considered a true paleosol. This zone is barely recognisable on the Kaingaroa Plateau, and generally cannot be discerned at all in the coastal Bay of Plenty. The two eruptions are therefore considered to have the same age.

Again only a little weathering separates the Anaputa and Murupara-G Tephra, although more than that between the Anaputa and Murupara-E.

A quite well developed paleosol, which probably accumulated over a period of at least several thousand years, exists between the Murupara-G and Matahina Tephra.

The total length of time recorded by paleosols and tephric-loess between the Murupara-A and Matahina Tephra is not great; probably only 10–15 ka.

15-4.6 Ages of tephra in the Tablelands subgroup

The Tablelands subgroup is believed to span ≈ 65 ka; from the base of the Murupara-A Tephra at c. 340 ka, to the top of the very well developed paleosol immediately below the Tablelands-A Tephra at c. 400 ka (see Figure 15-3).

It is believed that the Tablelands subgroup was deposited during a glacial period, due to the presence of loess in the terrestrial sequence of the eastern Bay of Plenty, and because it consists of terrestrial and shallow marine sediments in the marine sequence near Matata. There are deeper marine sediments not far below, indicating that the shallower sediments are related to a relatively low glacio-eustatic sea-level.

The last tephra to be deposited in the Tablelands subgroup—the Kohioawa Tephra—is directly overlain by a massive and very thick loess unit. There is generally an erosional boundary between the top of the Kohioawa Tephra and the overlying loess, which may be a result of the very harsh climatic conditions that appear to have followed its eruption. The widespread erosion on the Kaingaroa Plateau was probably *æolian* in nature. At both the Murupara-(1) and Murupara-(2) sections, the top of the Rangitaiki Ignimbrite—which is thought to be a correlative of the Kohioawa Tephra—has also been eroded. This erosion has removed much of the softer top of the ignimbrite down to a harder, semi-welded or incipiently welded layer. An eroded ignimbrite surface such as this is sometimes called a shaved surface. Tephric-loess immediately overlies the shaved surface at the Murupara-(2) section.

In coastal areas the Kohioawa Tephra rests on weathered loess, although the weathering has little soil structure. The weathered loess is thought to represent a significant period of time during which loess

deposition occurred at a slower rate than in full glacial periods, but the climate was not warm enough for true soil structure to develop.

The presence of loess both above and below the Kohioawa Tephra indicates that the eruption occurred during a period of cold climate, probably during oxygen isotope stage-10. The loess overlying the tephra is the thickest (1.5–2.0 m) individual loess unit recorded in this study and is therefore thought to represent a significant length of time during which the climate was particularly cold.

In the generally marine sequence west of Matata (Kohioawa cliffs), the Kohioawa Tephra overlies organic-rich silts which are probably a weak paleosol, but possibly estuarine in origin. The upper part of the tephra has been eroded, and brown marine sands overlie the unconformity. The erosion is probably a consequence of the rise in sea-level at the $\delta^{18}\text{O}$ stage-10/stage-9 boundary.

From the comparison of this paleoclimatic data with the oxygen isotope record (see Figure 15-3), the Kohioawa Tephra is believed to have been erupted just before a glacial maximum, probably in $\delta^{18}\text{O}$ stage-10, and has an estimated age of *c.* 350 ka.

The Kohioawa Tephra has been tentatively correlated to the Rangitawa Tephra and the Whakamaru/Rangitaiki Ignimbrite. Paleoclimatic evidence from around the country (mainly loess stratigraphy) suggests that the Rangitawa Tephra was erupted during the latter part of oxygen isotope stage-10 [Pillans, 1991]. Pollen analyses from the Wanganui region confirm that the Rangitawa Tephra was erupted during a relatively cold climate [Bussell, 1986; Kohn *et al.*, 1992]. The Rangitawa Tephra, and Whakamaru and Rangitaiki Ignimbrites have been dated using several different techniques. The more reliable recent ages cluster around *c.* 330–350 ka (see Tables 2-2 & 2-4), in accordance with the paleoclimatic age estimate from the Bay of Plenty. The most recent $^{40}\text{Ar}/^{39}\text{Ar}$ ages cluster around 320–330 ka, in conflict with the paleoclimatic data fit to the orbitally tuned oxygen isotope record.

The Paerata Tephra is also found within estuarine/terrestrial sediments in the coastal cliffs west of Matata, indicating that it also was deposited during the period of low sea-level associated with $\delta^{18}\text{O}$ stage-10. No hiatus in deposition is recognised between the Paerata and Tablelands-D eruptives, and they are believed to have the same age, *c.* 370 ka.

At the Wilson's farm-(1) site, the Tablelands-C Tephra is separated from the Tablelands-D Tephra by 50 cm of sand and 2 cm of organic-rich silt. Little time is represented by these deposits; probably only a maximum of a few thousand years, though they do represent a slightly deeper environment of deposition than the tephras just above, and therefore probably a slightly warmer climate.

At sites where the Otarawairere Tephra was deposited in a terrestrial depositional environment, it rests on a paleosol with good structure which has developed into what is thought to be loess overlying the Tablelands-A Tephra. The presence of a paleosol indicates that the climate was relatively mild, but on the other hand the presence of loess suggests a relatively cold climate.

The Otarawairere Tephra overlies a change from marine to terrestrial deposition at the Otarawairere section, in the form of a paleosol developed into beach gravels overlying marine sands (see Photo-65). In

the cliffs west of Matata, the Otawairere Tephra fell and/or was washed into a shallowing-upwards marine sequence.

The paleoclimatic data indicates that the Otawairere Tephra was erupted during a period in which the sea-level was falling; probably during the early phase of a glacial period, most likely to be $\delta^{18}\text{O}$ stage-10. Non-pumiceous marine sands, 6 m thick, exist between the top of the reworked pumiceous sands representing the Otawairere tephra and the base of the Tablelands-C Tephra above. The non-pumiceous sand is likely to represent deposition over a period of ≈ 10 ka or more and indicates a slightly quieter or deeper environment of deposition than that of the Otawairere Tephra. The Otawairere Tephra is therefore thought to have been followed by a period of slightly warmer climate, prompting an age estimate for this eruption of *c.* 380–390 ka.

The Tablelands-A Tephra rests within deeper marine sediments near Matata, suggesting a much higher sea-level and warmer climate than for the tephra above. Where the paleoenvironment was terrestrial, the tephra rests on a thick, very weathered and well developed paleosol, which must have developed during a significant period of warm interglacial climate. The Tablelands-A Tephra is directly overlain by what appears to be loess—although this is uncertain and it may be weathered ash—which has a well structured paleosol developed into it. Since it has an extremely weathered paleosol below and only a moderately weathered paleosol above, with loess and few paleosols existing above this, the Tablelands-A Tephra is thought to have been erupted near the end of, or just following, an interglacial period; probably $\delta^{18}\text{O}$ stage-11 at *c.* 400 ka.

15-4.7 Ages of tephra in the Ohiwa Harbour and Reeves subgroups

The Ohiwa Harbour and Reeves subgroups are believed to span ≈ 150 ka in total; from the top of the very well developed paleosol immediately below the Tablelands-A Tephra at *c.* 400 ka, to the base of the Reeves-A Tephra at *c.* 550 ka (see Figure 15-4). However, as the deposits in these two subgroups are extremely weathered, tephra correlations are difficult and their ages remain poorly constrained. The age range may be slightly smaller or much greater — ≈ 220 ka — if the Reeves-A Tephra is as old as *c.* 625 ka.

The best stratigraphic information concerning the Ohiwa Harbour subgroup is obtained from the marine sequence in the coastal cliffs west of Matata, specifically at the Ohinekoao Reserve and Wilson's farm sections — that is, the Ohinekoao subgroup. The tephra exposed in this area were deposited in shallow water, estuarine and terrestrial paleoenvironments that are believed to have existed here during the $\delta^{18}\text{O}$ stage-12 low sea-level. However, there remains some doubt as to whether the Ohiwa Harbour subgroup tephra are actually correlatives of the Ohinekoao subgroup tephra; or, as is less likely, of an older sequence only partially seen here. The extreme weathering that the Ohiwa Harbour subgroup deposits have experienced has resulted in the alteration of all of their glass to clay, rendering correlation very difficult. The weathering is similar in intensity to that found within the Kukumoa subgroup, which is thought to have undergone weathering during $\delta^{18}\text{O}$ stage-5, stage-6 and also possibly stage-7.

However, as hypersthene still exist in the younger Kukumoa subgroup, and do not exist in the Ohiwa Harbour subgroup, the weathering that has affected the older subgroup may have been more intense or have had a longer duration, or both. The weathering could have entirely occurred during $\delta^{18}\text{O}$ stage-11 through to stage-13, possibly including stages-14 and 15 as well. It is now thought that $\delta^{18}\text{O}$ stage-11 was very warm; probably the warmest interglacial in the past *c.* 600 ka [Burke, 1993], and that it is therefore the most likely time of deposition of the Ohiwa Harbour subgroup — as shown in Figure 15-4.

Almost all of the tephra in the Ohiwa Harbour subgroup are enclosed within loess, with the uppermost several metres of loess being extremely weathered by the formation of the paleosol, which is thought to have occurred during $\delta^{18}\text{O}$ stage-11.

The Ohiwa-G Tephra lies within the upper part of this paleosol, about 1 m below the base of the Tablelands-A Tephra. Its likely correlative at Ohinekoao Reserve lies within marine sands $\approx$ 6 m above shallower estuarine-terrestrial sediments, and it is thus thought to have been deposited during the $\delta^{18}\text{O}$ stage-11 high sea-level.

The remaining tephra in the middle part of the Ohiwa Harbour subgroup lie within slightly less weathered loess with little paleosol development, except for the Tirohanga Tephra which has a dark paleosol developed into it. The SPECMAP $\delta^{18}\text{O}$ curve (see Figure 15-1)—which produces better results than the LLS curve in this case—shows a small peak which could correspond to this period of weathering.

The Jackson Tephra is overlain by loess, and rests on a paleosol which is well developed, usually into weathered gravels. At several sites the gravels are very weathered and the Jackson Tephra is absent. At these sites the Ohiwa-B Tephra or loess overlies the gravels.

In Figure 15-4, the Ohinekoao and Ohiwa Harbour subgroups are treated as equivalent, with several individual tephra correlations presented. The estimated ages of the tephra in each subgroup are generally similar, with only slight differences occurring between the two localities (Ohinekoao Reserve and eastern Bay of Plenty) respectively, and the ages indicated in this chapter/section are for the terrestrially deposited Ohiwa Harbour subgroup. The tephra in the marine sequence appear to have slightly younger ages, by $\approx$ 5 ka, than those deposited in the terrestrial environment (eastern B.O.P.). It is possible that the Ohinekoao-E Tephra has an age of *c.* 455 ka and correlates to the Tirohanga Tephra (see Chapter 7).

At only two sites in the eastern Bay of Plenty, the Reeves and Ohiwa Harbour Road West sections, — are tephra below the Jackson Tephra observed. At the latter section, the Jackson Tephra rests on a well developed paleosol into the Reeves-D Tephra, which in turn directly overlies $\approx$ 4 m of marine sands. These sands rest on $\approx$ 7 m of very weathered gravels, with more sand, silt and gravel below. The paleosol, tephra, and upper marine sand unit are thought to have been deposited during a warm interglacial climate and high sea-level, probably that of $\delta^{18}\text{O}$ stage-13, or perhaps stage-14. The gravels below are probably the uppermost weathered part of the Waitohi Gravels (see Figure 15-4).

At the Reeves section, the Jackson Tephra again overlies a well developed paleosol into what is believed to be the Reeves-D Tephra, although here it is not recognisable as a tephra layer but only as tephric material within the paleosol. Below the Reeves-D Tephra is loess, then the Reeves-C Tephra which rests on a well developed paleosol into more loess. This lower paleosol is likely to represent the warm period at the beginning of $\delta^{18}\text{O}$ stage-13; the loess above having been deposited during a brief cooler period of stage-13, and the loess below deposited during $\delta^{18}\text{O}$ stage-14. The Reeves-B Tephra is enclosed within this lower loess. The Reeves-A Tephra occurs below the loess, and appears to have been at least partially deposited in a subaqueous fluvial environment. The reworked base of the tephra rests on only slightly weathered gravels. These basal gravels appear to have undergone much less weathering than the Waiotahi Gravels and are possibly younger, or they could represent deeper unweathered gravels exposed through erosion, though there is strong no evidence for this. Figure 15-5 gives an alternate but slightly less likely, paleoclimatic fit to the $\delta^{18}\text{O}$ curve, which enables the correlation of the basal Reeves gravels with the Waiotahi Gravels.

The Wilson Tephra, in the marine sequence west of Matata, was deposited in deeper marine sediment than the tephra found above at Ohinekoao Reserve, and is very tentatively believed to correlate to the Reeves-D Tephra.

15-4.8 Age of the Waiotahi Gravels and other deposits

The marine sequence west of Matata contains the Herepuru Tephra within fossiliferous, relatively deep marine sediments, indicating that it was likely to have been deposited during an interglacial. Fitting the paleoclimatic data to the oxygen isotope curve shows that the Herepuru Tephra could have been deposited during $\delta^{18}\text{O}$ stage-11 (c. 410 ka) at its youngest, $\delta^{18}\text{O}$ stage-13 (c. 500 ka), or $\delta^{18}\text{O}$ stage-15 (c. 570–620 ka).

Biotite separated from the Herepuru Tephra has been K/Ar dated at 0.62 ± 0.03 Ma, and an age of between 0.46 and 0.95 Ma is indicated by the presence of the planktonic index nannofossil *Pseudoemiliania lacunosa*, and the absence of *Calcidiscus macintyre* and *Helicosphaera sellii* [Nairn & Beanland, 1989]. Furthermore, paleomagnetic investigation of the sediments immediately above and below the tephra shows them to be normally magnetised, indicating an age of <0.78 Ma [Phil Shane, pers. comm, 1992].

On the basis of this data, it is believed that the Herepuru Tephra was deposited during $\delta^{18}\text{O}$ stage-15, at c. 600 ka.

The Waiotahi Gravels are ≥ 20 m thick and consist of fluvially deposited gravels and cobbles that are composed of weathered siltstone, sandstone and greywacke. These fluvial deposits form the base of many of the terraces in the eastern Bay of Plenty region. The fluvial gravels must have been deposited during a low sea-level stand, as they exist at the present-day coast in great thickness. Many gravel deposits around Ohiwa Harbour may have been deposited during brief colder periods of $\delta^{18}\text{O}$ stage-13 and/or stage-14, but the bulk of the Waiotahi Gravels were almost certainly deposited during the much colder climate and more extensive glaciation of $\delta^{18}\text{O}$ stage-16. They were subsequently weathered and eroded during the generally warmer climate of stages-13 and stage-14.

The Waiotahi Tephra is found in marine sediment, just below the base of the Waiotahi Gravels. It is therefore believed to have been deposited near the end of the high sea-level stand of $\delta^{18}\text{O}$ stage-17.

If the radiometric ages of the tephras in the eastern Bay of Plenty are not used to "anchor" the stratigraphy to the oxygen isotope curve, a significantly different but seemingly realistic fit to the $\delta^{18}\text{O}$ curve is possible (Figure 15-6). This fit, which would be a valid interpretation of the paleoclimatic record in the Bay of Plenty solely on the basis of the stratigraphy, is not as plausible as the paleoclimatic fits accepted throughout this chapter. If the radiometric ages of the tephras studied in this work are accurate, the alternate fit is wrong. However, if the radiometric ages are inaccurate, then this alternate fit should be considered.

Figure 15-6 : Alternative oxygen isotope curve – tephra correlation; ignoring radiometric ages

Chapter Sixteen : Discussion of the Landform History of the Bay of Plenty Region

The Bay of Plenty region is roughly triangular in shape and extends from the base of the Coromandel Peninsula in the northwest, to Lake Taupo in the south, and northeastwards into the Raukumara Peninsula (Figure 16-1).

Figure 16-1 : Location map of the central North Island, showing features of the Bay of Plenty region

The major portion of the Bay of Plenty region consists of large ignimbrite plateau on either side of the Taupo Volcanic Zone (T.V.Z.): the Mamaku Plateau in the west, and the Kaingaroa Plateau in the east. The T.V.Z. is a faulted depression 20–40 km across running north-northeast from Lake Taupo to the Bay of Plenty coast. Within the depression are numerous normal faults, many of which have moved in the last 10 000 years. This zone of faulting is called the Taupo Fault Belt. Where the T.V.Z. intersects the coast is the Rangitaiki Plains; a sediment filled graben — the "Whakatane Graben" — that is widening at a rate of up to 7 mm a year [Sissons, 1979].

It is within the T.V.Z. that all major rhyolitic eruptions in New Zealand have occurred during the last half million years. The T.V.Z. contains many lakes, especially in the Rotorua area, most of which are water-filled calderas formed during the eruption of the large voluminous ignimbrites that comprise the volcanic plateau on either side.

The Kaingaroa Plateau to the east of the T.V.Z. abuts the uplifted Mesozoic greywacke ranges which form part of the North Island Shear Belt. The ranges extend north to the coast, and eastwards into the Raukumara Peninsula. Along the coast, outcrops of the more resistant greywacke often form rocky headlands separating sandy beaches.

The Mamaku Plateau to the west drops off into a series of lower, older ignimbrite surfaces which abut the greywacke basement comprising the Rangitoto Range, or grade into the aggradational surfaces created by the Waikato River. This river drains most of the south and west of the Bay of Plenty and has deposited the easily erodible and transportable volcanic sediment over a wide area.

16-1 Landforms in the Coastal Bay of Plenty

A number of landforms in the Bay of Plenty will be discussed in detail below, particularly those of mid-late Pleistocene age which can be dated by the tephrae studied in this thesis. The landforms presented generally occur in the coastal areas, and are typically marine and fluvial terraces. The order of discussion of landforms will be primarily by geographical location, moving from west to east, with a summary of the landforms by age at the end of the chapter.

16-1.1 Tauranga Harbour

Tauranga Harbour is a drowned valley estuary in a subsiding basin steadily being infilled with tephra, pyroclastic flows, and volcanogenic sediment. The bulk of the mid-late Pleistocene sediments found here have been called the "Matua Subgroup" [Harmsworth, 1983], and have been defined as "up to 240 m of terrestrial and estuarine sediments with interdigitating pyroclastic flows". The flow deposits are unwelded and generally of the valley ponded type, and are therefore readily eroded, with hick lobes of volcanoclastic fluvial sediment deposited in the period shortly following ignimbrite emplacement. These fluvial sediments can be traced back to their parent ignimbrites and have hence been called "post-ignimbrite units".

On the basis of their stratigraphy, the ignimbrites found in the Tauranga area are (from youngest to oldest): the Mamaku, Waimakariri, Te Ranga, Te Puna, Wairoa, Waiteariki, and the Aongatete; but there is limited age control on these units (see Table 2-2b). The Aongatete Ignimbrite shows apparent westward thickening, indicating that it may have been sourced in the southern part of the Coromandel Peninsula [Healy, 1967, in Harmsworth, 1983]. The other ignimbrites are all thought to have originated within the T.V.Z. The Mamaku Ignimbrite is not found within the Tauranga Harbour area itself, but forms hills not far to the south (Figure 16-2).

At many sites, the upper 40 m of the Matua Subgroup often contains up to 20 m of weathered airfall tephtras named the "Pahoia Tuffs" (here referred to as the Pahoia Tephtras) which are intercalated with several pyroclastic flows. The Pahoia Tephtras are overlain by what were thought to be the "Hamilton Ashes", with the Rotoiti Tephra and post-Rotoiti "Late Quaternary Tephtras" above. The "Hamilton Ashes" in the Tauranga area are now known not to equate with the Hamilton Ash in the Waikato region [Froggatt, pers. comm. 1993; and this work], and are thought to be equivalent to the Kukumoa subgroup in the eastern Bay of Plenty. The term "undifferentiated brown ashes", or "Kukumoa subgroup deposits", should be used instead of Hamilton Ash for these weathered tephtras in the Bay of Plenty region.

Two sections around Tauranga Harbour were studied in detail by this author; at Omokoroa East and at Welcome Bay (Figure 16-2). Both sections contain the upper part of the Matua Subgroup, and a large portion of the Pahoia Tuffs. The sections correlate well to each other and the deposits exposed here have been defined in this work as the "Welcome Bay subgroup"; generally equivalent to the Huntress Creek subgroup in the eastern Bay of Plenty. The base of the Pahoia Tephtras is not well defined, and the term has been used for all of the tephtras found below the "undifferentiated brown ashes" in the Tauranga Basin [Pullar *et al.*, 1973; Harmsworth, 1983]. The "Pahoia Tephtras" is therefore not a particularly useful term for detailed stratigraphic work, but is a good encompassing term for all airfall tephtras older than the Mamaku Ignimbrite throughout the Bay of Plenty, especially in the western area.

The Welcome Bay section was discussed in Chapter Five; its major features being the Waimakariri Ignimbrite at the base and the post-Mamaku Ignimbrite fluvial unit at the top. At Omokoroa East, the Rotoiti Tephra overlies a well developed paleosol in a similar fluvially reworked unit. The distinctive glass chemistry of the Waimakariri Ignimbrite suggests a possible correlation to the Chimp Ignimbrite, and consequently a likely age of *c.* 0.3 Ma. The Mamaku Ignimbrite, which has an age of *c.* 220–230 ka, is a likely correlative of the Kutarere Tephra.

The "Omokoroa slump" section was also studied, but not in as much detail. This section shows the Welcome Bay subgroup eruptives and much older deposits, but is very weathered and difficult to interpret.

The ignimbrites and the post-ignimbrite units control the physiography of the area, and the study of these deposits is fundamental to understanding the depositional and subsidence history of the Tauranga Basin. The area is believed to be a subsiding basin, as no fully marine sediments are exposed, even at depth; only a vast thickness of fluvial sediment.

Figure 16-2a: Key for geological maps - Figures 16-2, 16-3, 16-4 & 16-6

Figure 16-2 : Geological map of the western coastal Bay of Plenty [after Healy *et al.*, 1964] (see Fig. 16-2a for key)

The flat-topped headlands which protrude into Tauranga Harbour — Omokoroa Point, Otumotai/Matua, Te Puna and Maungatapu, for example — are not marine terraces related to glacio-eustatic sea-level fluctuations; rather they are surfaces related to the tops of buried ignimbrite sheets. The ignimbrites are covered by many metres (often >15 m) of airfall and fluvially reworked tephra deposits. Airfall deposits only slightly modify the landscape surfaces, and on flat-lying landscapes they are horizontally bedded. The differing heights of separate terrace surfaces are therefore due to variations in the number of ignimbrite units present in the sub-surface geology, which in turn may result from differing extents of erosion between each ignimbrite emplacement, or to different flow distributions — broad sheets versus valley-contained flows, and all variations between.

As shown in Figure 16-2, the mid-Pleistocene deposits (denoted as "Wf + hz" = cross-hatched) generally form higher surfaces than the younger mid-late Pleistocene deposits (denoted as "hl & ha" = dashed). The lower (younger) surfaces are believed to be related to the Waimakariri Ignimbrite and the overlying post-Waimakariri and post-Mamaku fluvial deposits; with the post-Waimakariri airfall tephras mantling this landscape. The higher surfaces may be related to the Te Puna Ignimbrite and/or other flow deposits, but these were not studied in detail in this work.

Glacial – interglacial cycles can only be recognised in a few places; by the presence of estuarine sediments interbedded with swamp and fluvial deposits beneath the Te Puna Ignimbrite at Omokoroa, and in two drill-cores [Harmsworth, 1983]. A low terrace, 0.2–0.5 m above present sea-level, is visible around much of Tauranga Harbour [Harmsworth, 1983], but it is uncertain whether this surface is the last-interglacial marine terrace that has since subsided several metres (sea-level is believed to have been several metres higher than present during the last-interglacial), or a more recent Holocene high sea-level surface. Marine sediments deposited during any previous interglacial sea-level highs would now, due to subsidence, be well below sea-level and only recorded within drill-cores where preservation is not always continuous. Distinguishing a thin marine silt or sand bed from the thick fluvial sequences is difficult, but possible beach and estuarine deposits have been recorded at ~30 m depths in several cores [Harmsworth, 1983].

Sedimentation rates may also be indicative of sea-level change. Variations in the rate of fluvial deposition — downcutting versus aggradation, for example — may be related to changes in the fluvial base level caused by sea-level change. Glacial – interglacial climatic changes may also have had an effect on erosion. These, however, must be balanced against periods of increased volcanic activity which may have caused devegetation and an increased sediment supply.

The formation of the Tauranga Basin is thought to post-date the eruption of the Waiteariki Ignimbrite at ≥ 0.84 Ma. The Kaimai Ranges to the south are an upthrust block of Mesozoic basement, ignimbrite, and older volcanics, with a significant amount of the uplift having occurred post-Waiteariki Ignimbrite deposition [Harmsworth, 1983].

16-1.2 Maketu Headland

The Maketu headland (Okurei Point) is a high, flat topped promontory, interrupting the smooth curve of the Bay of Plenty coast 30 km southeast of Mount Maunganui. It is bounded by the lowlands of the Kaituna and Pongakawa Rivers, and by the Maketu and Waihi Estuaries; standing like an island between them. A composite section through the Maketu headland is presented in Figure 13-2, and is discussed in greater detail in Chapter Thirteen.

The major features of this section are the very thick torrential flood deposit in the lower third to half, the tephric-rich fluvial deposits above this, the possibly airfall "banded pumice beds" near the top, and the relatively thin pyroclastic flow which caps the headland.

The flood deposit has an erosional basal contact and contains very large rip-up clasts of the underlying marine sediment, and very large clasts of several different types of welded ignimbrite (see Photo-54). It was probably laharic in nature; related to a caldera wall breach and the subsequent rapid draining of a caldera lake.

The matrix of the flood deposit consists of pumice lapilli and coarse sandy ash with little bedding apparent; though it does appear to fine upwards, the boulders rapidly becoming smaller and much more sparse. Bedding becomes discernable near the top of the unit.

Above the torrential flood unit lie many metres of fluvially reworked pumice beds, often with erosion scoured channel bases of several metres relief, and coarse channel fill deposits containing small boulders of ignimbrite. At the top of the fluvial sequence are 4 m of alternating beds of angular pumice and sand with no observable cross-bedding — the "banded pumice beds" [Chappell, 1975]. These beds are capped by a weak paleosol, followed by a thin shower bedded airfall deposit, and an unwelded pyroclastic flow deposit with a slightly erosional base.

The ignimbrite does not appear to be very thick (c. 5 m) and can be seen capping the "banded pumice beds" near the tops of the cliffs around much of the headland. The top of the pyroclastic flow can be seen in a section just above Newdicks Beach, and on the basis of its glass chemistry, it is thought to be a correlative of the Mamaku Ignimbrite and Kutarere Tephra. At this site it grades upwards into a white sandy ash tephra which has a dark, thick, well developed paleosol at its top, overlain here by 5 m of cross-bedded, slightly tephric, aeolian dune sands. These sands also have a well developed paleosol at their top on which the Rotoiti Tephra rests. The elevation of the Newdicks Beach section is much lower than that of the surrounding terrace, and either this particular area of the headland has been downfaulted, or the ignimbrite was deposited within a paleo-valley in the sediments below.

Immediately below the Rotoiti Tephra on Little Waihi Road, a paleosol has developed into loess that contains lenses of ash; the "Little Waihi Tephra". This tephra has yet to be recognised in the eastern Bay of Plenty stratigraphy. Up to 10 m of post-Rotoiti tephra are present between the Rotoiti Tephra and the terrace surface at this site.

The Maketu headland deposits were studied previously by Chappell [1975], and named the "Little Waihi Formation". This formation was redefined in Chapter Thirteen (of this work) to include only those deposits below and inclusive of the "banded pumice beds". As fluvial deposits do not normally have a

great extent, Chappell's correlations to the eastern Bay of Plenty are not supported here, and the Little Waihi Formation has yet to be correlated to any other area. The Little Waihi flood may have been a widespread event, but was most likely localised within a river valley, or perhaps several such valleys. There is no evidence of a widespread fluvial surface apart from a small area in the coastal cliffs opposite Pikowai Reserve camping ground, half-way between Otamarakau and Matata (Figure 16-3). Here there is a great thickness (>50 m) of fluvially deposited pumiceous sediment, containing both primary and reworked eruptives — the "Pikowai Pyroclastics" (see Chapter 13). These sediments overlie the Matahina Ignimbrite and possibly contain the Hiwarau Tephra near their base (see sect. 13-3). It is uncertain whether the Pikowai Pyroclastics are related to the Little Waihi formation, but it is thought that they are slightly older.

The flat top of the Maketu promontory does not represent an uplifted marine terrace, but most probably, an uplifted block of material which contains the moderately flat lying Mamaku Ignimbrite near its surface. The ignimbrite would thus also exist below the present day surface in the lowlands surrounding the headland. The Rotoiti Ignimbrite occurs in great thickness just 10 km to the south and east (Figures 16-2 & 16-3), and probably forms the bulk of surrounding plains. Its non-existence on the Maketu headland indicates that significant uplift had already occurred before the Rotoiti eruption at *c.* 50 ka; uplift occurring perhaps as early as 200 ka. Drill-holes in the surrounding plains may be able to confirm or refute this.

Another, less likely possibility, is that the headland is the last remnant of a more widespread surface, preserved here by the protection of the Mamaku Ignimbrite, which caps the older and much less consolidated fluvial sediments below, providing a barrier against erosion. Large thicknesses of welded Mamaku Ignimbrite crop out <15 km to the southwest (Figure 16-2), indicating that the ignimbrite did indeed reach areas close to the Maketu headland. It may be that the Mamaku Ignimbrite covered the entire area and has since been stripped from all but this small remnant, which is now the headland, or the ignimbrite may have been constrained by a paleo-valley and has protected the unconsolidated fluvial sediments within the valley, while the softer hills on either side of the valley were eroded away.

At Pikowai Reserve, a significant unconformity just below the Rotoiti Tephra has eroded away much of the Matahina Ignimbrite and all but one outcrop of the Pikowai Pyroclastics. This period may be that during which much of the material surrounding the Maketu headland was eroded, or alternatively, the erosion at Maketu may have occurred during the high sea-level stand of the last-interglacial.

The age of the Little Waihi flood deposit is uncertain, though several of the tephtras found within the fluvial sediments immediately overlying the deposit are thought to correlate with tephtras of the Huntress Creek subgroup, believed to have been erupted at *c.* 0.25 Ma.

Figure 16-3 : Geological map of the coastal central Bay of Plenty [after Healy *et al.*, 1964]; (see Fig. 16-2a for key)

16-1.3 The Matata Cliffs and Rotoiti Forest

The area between Otamarakau and Matata on the coast, and inland towards Lakes Rotoiti, Rotoehu and Rotoma (Figure 16-3), is an uplifted and tilted fault-block. It contacts the Whakatane Graben to the east with a prominent fault scarp (Matata Fault), and marine sediments have been found uplifted to the west of this fault to >300 m above sea-level [Nairn & Beanland, 1989]. The fault-block is gently tilted towards the northwest and hence the slightly dipping sediments are very well exposed within the coastal cliffs, from Otamarakau (youngest) to Matata (oldest) (see Chapter 5, sect. 5-2.7).

Stratigraphically, the highest marine sediments seen in the coastal cliffs directly underlie the basal Matahina eruptives (see Photo-64). This eruption is believed to have occurred at *c.* 0.33 Ma, during the high sea-level of $\delta^{18}\text{O}$ stage-9. It appears that the Matahina Ignimbrite flowed over and was deposited on the lagoonal sediments found here [Bailey & Carr, 1994], indicating that the paleo-shoreline was in a similar position to that of the present day. Ignimbrite more than 50 m thick would have had a significant impact on the position of the paleo-shoreline, and this, together with the uplift that was in progress, ensured that no further marine deposition has occurred here.

Sea-level during the peak of $\delta^{18}\text{O}$ stage-9 is believed to have been at a similar level to that of the present-day, and therefore the topographic height of the marine sediments equates approximately to the amount of uplift that has occurred in the past *c.* 0.33 Ma. The *c.* 300 m highest elevation thus gives a maximum uplift rate of 0.9 mm/year. Welded Matahina Ignimbrite has also been found at 250 m below sea-level in drill-cores from within the Whakatane Graben, giving a subsidence rate there of ≥ 0.8 mm/year [Nairn & Beanland, 1989]. The two rates together give a relative vertical displacement rate of ≈ 1.7 mm/year for the western margin of the Whakatane Graben.

A thick unit of fluvial gravel is found at the base of the exposed coastal cliff sequence just west of Matata, indicating that the area was above sea-level at that time; probably during $\delta^{18}\text{O}$ stage-16. Few gravels are observed above this stratigraphic level and the dominant paleoenvironment of deposition is marine. Only a few interludes of beach-estuarine and/or terrestrial sedimentation occur, in particular the Ohinekoao subgroup and the younger Tablelands subgroup deposits. The change from a terrestrial to a marine paleoenvironment suggests gradual subsidence, but this is overprinted by the glacio-eustatic sea-level changes.

From about 380 ka, however, rapid uplift is believed to have occurred. The Paerata Tephra (*c.* 370 ka) is thought to have been deposited subaerially at or just above sea-level, which at that time is believed to have been lower, perhaps significantly so (by >50 m) than that during the Matahina eruption, which is found only ≈ 8 m above. Up to 50 m of uplift and/or erosion is thus thought to have occurred within the 40 ka time period between the eruptions of these two tephtras. The precise time of the commencement of uplift is difficult to determine, but Nairn & Beanland (1989) believe it to be prior to 0.4 Ma, by which stage the Manawahe area had risen above sea-level.

The sediments exposed in the coastal cliffs west of Matata tend to thicken towards the east. The paleoenvironment of deposition also becomes deeper in this direction. This is expressed in the fewer

organic-rich silt layers (possibly paleosols) towards the east; and in the greater thickness of cross-bedded shallow-water deposits within the Ohinekoao subgroup at Wilson's farm than in similarly aged deposits at Ohinekoao Reserve 1.5 km to the west.

16-1.4 Whakatane Graben

The 20 km wide Whakatane Graben occurs where the T.V.Z. intersects the coast. It extends west to east from Matata to Whakatane, and south to Kawerau (Figure 16-3). The graben is widening at a rate of ≥ 7 mm a year [Sissons, 1979]; and has been filled with fluvial sediment from the Rangitaiki, Whakatane and Tarawera Rivers; and also by numerous thick ignimbrite deposits, many of which are welded. The Rangitaiki Plain that has been formed by this influx of sediment has steadily prograded seaward at a rate of c. 1–2 m/yr for the past 5 ka.

The information about the subsurface deposits comes from the many drill-holes bored around the Kawerau geothermal field and throughout the region. Subsidence in the Whakatane Graben is thought to have commenced long before the Matahina eruption, as fault offsets on the basement greywacke are four to six times greater than those on the Matahina Ignimbrite in the same drill-holes [Nairn & Beanland, 1989]. Gravity surveys indicate that the depth to basement within the graben axis is about 2 km [Vergara, 1987], and with an estimated subsidence rate of 2 mm/year for this area, subsidence is thought to have commenced at c. 1 Ma [Nairn & Beanland, 1989].

16-1.5 Motuhora Island, White Island and Rurima Rocks

Motuhora Island (Whale Island) is the eroded remnant of a dacite volcano located 5 km offshore to the north of Whakatane. A cliff section at the western end of the island shows a sequence of alternating marine and fluvial sediments, thrust up from the sea floor during the emplacement and/or uplift of the "West Dome" dacite [Duncan, 1970].

The alternating depositional environments are believed to be associated with the glacio-eustatic sea-level fluctuations. Within the sequence are several pumice layers which may be airfall tephra deposits similar in nature to those found in the coastal cliffs west of Matata, and probably of similar age (see Chapter 13, sect. 18.2). Detailed glass chemistry analysis has yet to be carried out on these deposits and therefore the position of the Motuhora tephra within the eastern Bay of Plenty tephrostratigraphy is yet to be confirmed.

The oldest mantling tephra found on the island is the Rotoiti Tephra [Duncan, 1970], giving a minimum time of the island's formation—by eruption or uplift—of >50 ka, though it may be very much older. The Motuhora volcano is thought to have been inactive for at least 36 ka [Duncan, 1970].

The Rurima Rocks are located ≈ 5 km offshore from the centre of the Rangitaiki Plain coastline. These generally low-lying islands contain tuffaceous marine and fluvial deposits of Castlecliffian age [Bruce Hayward, pers. comm. 1992], but have not been studied in this work.

White Island is an active dacite volcano, and together with Motuhora Island, Mount Edgecumbe, Maungakakamea and Tauhara volcanoes, forms a lineation of vents along the eastern margin of the T.V.Z. Duncan (1970) believed that White Island has been active for much of the Pleistocene, but there is little evidence to support this. No andesite, and very few rhyo-dacite, tephra have been found in this study of the late Pleistocene tephrostratigraphy — though it may be that the prevailing wind direction took the ash from White Island further out to sea, or the ash falls were too thin to be preserved on the mainland. A few rhyo-dacitic deposits found in the Ohinekoao subgroup are considered likely to have originated from the nearby, and now extinct, Manawahe volcano. The ≈ 295 ka Torere-J Tephra found within peats at the Opape section is the only other rhyo-dacite deposit recognised. This tephra is unlikely to be a White Island eruptive, though it is possible, as few dacitic volcanoes in New Zealand are known to have had active lives of >250 ka, and White Island is therefore relatively recent.

The submarine Rurima Ridge, which extends northeast from Matata, appears to "mark the offshore western boundary of the Whakatane Graben" [Nairn & Beanland, 1989]. The eastern margin of the graben is defined by the Motuhora Scarp and White Island Canyon [Lewis & Pantin, 1984], and the Motuhora and White Islands lie to the west within the offshore continuation of the T.V.Z.

16-1.6 Whakatane Heads and Ohope area

The hills immediately to the east of Whakatane consist of uplifted greywacke basement. The Whakatane Fault separates this uplifted block from the subsiding Whakatane Graben to the west. Further east, inland from Ohope, the greywacke is overlain by marine sands and silts of Castlecliffian age [Fleming, 1955], which extend eastwards into the Ohiwa Harbour region.

Paltridge (1958) named the marine sediments found here the "Ohope Formation", and described a lower non-pumiceous member and an upper non-fossiliferous pumiceous member. Edbrooke (1977) described several members; the Ohiwa Siltstone, Ohope Sandstone (equivalent to the Ohope Formation) and Otarawairere Mudstone; and further divided these members into many stratigraphic sub-units.

Around Ohope, the basal sedimentation is generally marked "by a conglomerate resting unconformably on a very irregular greywacke basement surface" [Edbrooke, 1977], which occurs at elevations of 10–50 m above sea-level. The conglomerate is overlain by the Lower Westend Sandstone, followed in sequence by the Westend Shellbed, Seacliff Sand, and Upper Westend Sandstone; the latter unit is >30 m thick, and comprises the major portion of sediment found in the cliffs behind Westend and Ohope Beaches, and on the Ohope–Whakatane road.

Two sections were studied in detail between Whakatane and Ohope; one on the coastal track between Otarawairere Bay and Westend-Ohope (Otarawairere), and the other at the top of the hill on the Ohope–Whakatane road near Ngatiawa lookout (Figures 16-3 & 16-4). These two sections give two slightly different interpretations of the tectonic history of the area.

The Otawairere section is discussed in detail in Chapter Five; the important features being the subhorizontal cut surface into the greywacke at ≈ 15 m above present sea-level, and the presence of ≈ 25 m of marine sand above this — to beach gravels and subaerially deposited tephra (see Photo-65). The Otawairere Tephra (so named in this work), immediately overlies the beach gravels, and has an estimated age of *c.* 390 ka. This indicates that the intervening marine sands were likely to have been deposited during the very high sea-level of $\delta^{18}\text{O}$ stage-11. The beach gravels were subsequently deposited while sea-level was falling at the $\delta^{18}\text{O}$ stage-11/stage-10 boundary (*c.* 390–400 ka).

These beach gravels are believed to be the "irregular conglomerate overlying a minor erosional break" [Paltridge, 1958] separating the lower and upper members of Paltridge's "Oho Formation", and they mark the upper boundary of the Lower Westend Sandstone.

From paleontological studies the Lower Westend Sandstone is thought to have been deposited at 20–30 m depth [Edbrooke, 1977], although no fossils were collected from the Otawairere–Westend section.

This depth is consistent with the formation of a wave-cut surface—observed in the greywacke cliffs from just west of Westend beach to Kohi Point—during the high sea-level stand of $\delta^{18}\text{O}$ stage-13. In this case, the cut surface would then have been exposed during the $\delta^{18}\text{O}$ stage-12 glacial period. The Westend Tephra, which occurs within gravelly sands only ≈ 2 m above the cut surface, appears to be weathered and to have a paleosol developed into it. The gravelly sands probably represent the transgressive marine cover beds of either $\delta^{18}\text{O}$ stage-13 or stage-11, but the paleosol developed into the Westend Tephra remains an anomaly not easily explained. This tephra may be the only representative of the terrestrial environment during $\delta^{18}\text{O}$ stage-12; terrestrial or marine erosion having removed any other deposits such as loess or tephra.

The sands deposited above the Westend Tephra show a shallow – deeper – shallow depositional profile consistent with a marine transgression and regression. Tectonic movement is not required for the transgression to have occurred as the sea-level during the $\delta^{18}\text{O}$ stage-11 interglacial is believed to have been significantly higher than that during $\delta^{18}\text{O}$ stage-13 [Burckle, 1993]; perhaps by as much as 40 m, though more likely by only 20 m (interpreted from "Bassinot et al. 1994" oxygen isotope curve).

This was followed by the deposition of up to 15 m of subaerially deposited tephras and loess during $\delta^{18}\text{O}$ stage-10. The well preserved shower-bedding and presence of paleosols indicates that these tephras were deposited subaerially, not water-lain as previously thought [Edbrooke, 1977].

Near the highest point on the Westend–Otatwairere Bay track (Otatwairere section), immediately above the Matahina Tephra, there occurs a weathered yellow-brown silt layer. This silt is likely to be the Otawairere Mudstone, which was defined at this site and this approximate elevation [Edbrooke, 1977]. The Otawairere Mudstone was reported to contain fossils of *Chione stutchburyi*, and is therefore thought to have been deposited in a shallow estuarine environment. This is consistent with an age of *c.* 330 ka for the Matahina eruption, at about the time of the highest sea-level of $\delta^{18}\text{O}$ stage-9.

The Otawairere Mudstone is thought to have been deposited at a depth of 0–4 m, which is approximately 15–25 m shallower than the depositional depth estimated for the Lower Westend

Sandstone. The sea-level during $\delta^{18}\text{O}$ stage-11 is thought to have been similar to or slightly higher than that of $\delta^{18}\text{O}$ stage-9, and that of present, and as only 20 m of sediment was deposited between stage-11 and stage-9, there is no reason to suppose that uplift occurred, but it may well have done so. Nevertheless, this area is thought to have remained relatively stable until after the deposition of the Matahina Tephra.

It is at this stage that uplift is thought to have begun, and over the last 0.3 Ma the Otarawairere Mudstone has been raised to an elevation of c. 55–60 m, giving an average uplift rate of ≈ 0.2 mm/year.

At this site, no cut surface is seen at the level of the Otarawairere Mudstone, which would suggest that the mudstone may have been emplaced by a tsunami event following the deposition of the hot Matahina Ignimbrite into the ocean near Matata [Bailey & Carr, 1994]. If this were the case, uplift might well have begun earlier. However, the presence of the mudstone unit above a paleosol developed into the Matahina Tephra at the Ngatiawa lookout section indicates that its deposition at this site occurred a considerable time after the Matahina eruption and was therefore not related to emplacement of the ignimbrite.

In the cliffs above the mudstone deposit at Otarawairere are observed many more airfall tephtras, and although these tephtras could not be reached, several members of the Torere subgroup were visually recognised. The Otarawairere section is at the currently eroding sea cliff edge of a terrace at c. 100 m elevation which presumably correlates with other terraces found nearby, also at ≈ 100 m elevation. However, there is a difficulty in correlating these terraces as the rate and history of uplift of the area to the southeast appears to be different from those at Otarawairere.

The section at Otarawairere is very different from the section observed while travelling uphill on the Ohope–Whakatane road. In the latter area, the basement greywacke is topographically much lower and is not seen. Nor are any airfall tephtras observed, until at ≈ 120 m elevation at the Ngatiawa west section, with the intervening sediment consisting of marine silts and sands of the Upper Westend Sandstone, and probably the Upper Stock Road Sandstone.

The Ngatiawa west section shows a coarse grained pumiceous tephra—named here the Ngatiawa Tephra (see sect. 13-11)—which directly overlies unweathered, unconsolidated marine sands (see Photo-66). The contact is generally sharp and near-horizontal, but at the left side of the section an erosional unconformity has eroded deep (>1.5 m) into the sand and the tephra overlying the unconformity is apparently over-thickened. Above and developed into the Ngatiawa Tephra is the very weathered "last-interglacial paleosol". This paleosol has developed into the regional erosional unconformity found immediately below the Rotoiti Tephra at many locations throughout the Bay of Plenty, and which is particularly evident here. No other tephtras are recognised between the Ngatiawa and the Rotoiti tephtras at this site.

The Ngatiawa Tephra is believed to be airfall, and so records the first exposure of the sediment here to the terrestrial environment. The tephra has a distinctive glass chemistry that is similar to that of the Hiwarau Tephra (c. 0.32 Ma), but with enough differences between the two to question any possible

correlation. The Ngatiawa Tephra has therefore been given its own name. If it is not a correlative of the Hiwarau Tephra, then the Ngatiawa Tephra is probably very much older.

On the opposite side of the road—the southeast side—is the Ngatiawa lookout section, which contains a significantly different sequence of deposits. This section has at its base a well sorted sandy ash which may be subaqueously deposited Matahina Tephra. The ash grades up into shower bedded airfall Matahina Tephra with a paleosol in its top. Above the paleosol is a correlative of the Otarawairere Mudstone, very similar in nature to that found at the Otarawairere section. The mudstone unit is at least 1 m thick; a further metre is obscured, above which are more airfall tephras, extending to the very weathered paleosol below the Rotoiti Tephra. As is the case with the Otarawairere section, the Ngatiawa lookout section can be incorporated into the eastern Bay of Plenty stratigraphy with little difficulty.

The Matahina Tephra is not recognised within the marine sediment exposed at the Ngatiawa west section, or in the sediment visible along the road below, although exposure in the upper part of the sequence is poor. The marine deposits here are therefore believed to be older than the Matahina, perhaps significantly so.

If the Ngatiawa Tephra is much older than the tephras found at the Ngatiawa lookout section, then one or both of the following applies:

- a major fault occurs between the Ngatiawa west and Ngatiawa lookout sections;
- extensive of erosion has occurred in the Ngatiawa lookout section at some time prior to the Matahina eruption; possibly during subaerial exposure coinciding with the low sea-level of $\delta^{18}\text{O}$ stage-10.

As the Otarawairere Mudstone at Ngatiawa lookout and the terrestrial–marine boundary at Ngatiawa west are at the same approximate elevation, it is quite likely that the high sea-level of $\delta^{18}\text{O}$ stage-9 was the cause of both; the deposition of the mudstone at the former site coinciding with the cutting of a surface into the soft unconsolidated sands at the latter site. The Ngatiawa Tephra, which was deposited directly on this cut surface, could then be a correlative of the Hiwarau Tephra, which is found just above the Otarawairere Mudstone at the Ngatiawa lookout section.

Since older marine sands were cut by the high sea-level that deposited the Otarawairere Mudstone, there must have been a substantial thickness of marine deposits already above this level. Significant uplift must therefore have commenced at some time before the eruption of the Matahina Tephra.

The Ohope basin is thought to have been a depositional area throughout the Castlecliffian, with the timing of the onset of uplift uncertain. Two terraces can be seen near the coast at Ohope, at elevations of ≈ 60 m and ≈ 100 m above sea-level. There are also indications of a much higher terrace further to the south at an elevation of *c.* 500 feet (150 m) [Paltridge, 1958], although this surface has been severely dissected.

The heights of all these terrace surfaces include the tephra cover-beds which mantle the landscape. In the eastern Bay of Plenty region the thickness of the cover-beds can be impressive, with estimated

thicknesses for the complete non-eroded cover-bed sequence of 40 m, 20 m, and 10 m for the 0.33 Ma, 0.22 Ma, and 0.12 Ma surfaces respectively.

The high elevation of the marine sands at the Ngatiawa west section, and of the Otarawairere Mudstone across the road (both at ≈ 120 m), indicate that uplift was occurring here at a greater rate than at Otarawairere only 1 km to the north. An average uplift rate of 0.35 mm/year for the last 0.3 Ma has been determined, compared with 0.2 mm/year at Otarawairere.

The top of the c. 150 m high terrace has been deeply eroded by the unconformity immediately below the Rotoiti Tephra and is often not recognisable as a terrace at this level. Nevertheless, it is likely that it corresponds to cutting, and/or final marine deposition at c. 0.33 Ma. The surface rises from a height of "500 to 800 feet" (150–240 m) 13 km to the south [Paltridge, 1958].

The lowermost terrace at ≈ 60 m elevation can be seen above and behind the Westend and Ohope townships. Applying the average uplift rate of 0.35 mm/year, the most likely period for the formation of the wave-cut base of this surface is during $\delta^{18}\text{O}$ stage-5, probably stage-5e, at c. 0.12 Ma.

Again on the basis of the average uplift rate of 0.35 mm/year, the ≈ 100 m high terrace inland from Ohope is thought to represent the formation of a wave-cut surface during $\delta^{18}\text{O}$ stage-7, at c. 0.20–0.22 Ma. This surface rises to ≈ 180 m elevation on Stanley Road, approximately 12 km to the south [Paltridge, 1958].

It is probable that an older, higher terrace was formed during $\delta^{18}\text{O}$ stage-11 (c. 0.40–0.42 Ma), but if so, this surface has been so severely dissected that it cannot be traced.

The differences in elevation between these wave cut surfaces show that the onset of uplift in the western part of Ohiwa Harbour pre-dates the eruption of the Matahina Tephra (at c. 0.33 Ma), but perhaps not to a considerable extent.

The Whakatane Heads area, including the Otarawairere section, must have existed as a basement high or up-standing ridge of exposed greywacke throughout much of the Castlecliffian period. This basement high was separate from the marine depo-basin just off-shore to the east in Ohiwa Harbour. In the latter area, sedimentation in deeper water continued and a much greater thickness of sediment was deposited. The sediments thicken towards the east within this basin, and have a deeper environment of deposition. Paleontological studies indicate a depth of 80–100 m for the Ohiwa Siltstone, as opposed to 10–40 m, with occasional periods of shallower deposition, for the deposits along the western margin of Ohiwa Harbour [Edbrooke, 1977].

The presence of the greywacke ridge at Whakatane Heads is consistent with the Ikawhenua Range having been present during the Matahina eruption. The ignimbrite ponded against the topographic high of the Ikawhenua Range and only topped it in a few of the lower saddles near its northernmost extent [Bailey & Carr, 1994].

At Otarawairere Bay, the Whakatane Heads basement ridge was cut by the $\delta^{18}\text{O}$ stage-13 high sea-level, but further to the east and southeast the basement was well below sea-level and was not cut.

The different rates of uplift at the Otarawairere and the Ngatiawa sites are probably best explained by the presence of a fault between these two areas (see points listed on page 364). This allows the possibility that uplift commenced at a similar time in both areas, but that the more eastern block was uplifted at a much faster rate. A continuation of block faulting down into the Whakatane Graben would explain the deposits that are observed and their various elevations.

A further possibility is that the area is being tilted up towards the south, with the 0.3 Ma surface having an $\approx 4^\circ$ dip to the north.

Tuffaceous marine and fluvial sediments can also be found far inland between Awakeri and Taneatua, and south of Ruatoki within the Whakatane River valley to the east of the Ikawhenua Range (Figure 16-3). The sediments found here, also, are thought to be of Caspian age or older, and record the glacio-eustatic cycles of high and low sea-level. However, sections showing these deposits were not studied in this work and therefore the precise ages of the sediments have not been determined (see Chapter 13, sect. 18.1).

16-1.7 Ohiwa Harbour

Ohiwa Harbour is a drowned river system, inundated by the rise in sea-level that followed the last glaciation (Figure 16-4). The presumed $\delta^{18}\text{O}$ stage-7, or perhaps stage-9, terrace extends across much of the western part of Ohiwa Harbour as a "broad, tilted dissected plateau" [Paltridge, 1958]. Most of the road cuttings around the shore of the harbour show Ohiwa Siltstone [Edbrooke, 1978]. This siltstone is non-pumiceous; indeed very few pumice layers are seen within it in the entire western Ohiwa Harbour region.

Several sections in this area were studied in detail, but with the exception of those in the lower part of McCoy Road, the tephra found could not be correlated to the eastern Bay of Plenty stratigraphy.

The lower part of the McCoy Road-(1) section contains an erosional surface cut into unconsolidated sands, with relatively recent Mangaone subgroup tephra above. The erosional surface exhibits great relief and is also visible ≈ 30 m higher at the top of the hill, where it has eroded into the thick, subaqueously deposited McCoy Tephra. The age of the McCoy Tephra is uncertain, but it is probably mid-Pleistocene. The Waingarara Ignimbrite (see sect. 13-12) is found nearby at a similar level.

The Waingarara Ignimbrite is recognised at several sites around and to the south of Ohiwa Harbour, and is the only pyroclastic flow unit recognised east of the Whakatane-Waimana basement ridge. It is seen at varying topographic heights, which indicates that there may be some differential uplift in this region. Its highest elevation, at c. 100 m above sea-level (a.s.l.), occurs near Waingarara. It is also thought to be present near the top of the hill just northwest of Waimana, at ≈ 80 m elevation. However, within a few hundred metres of this hilltop exposure the ignimbrite is recognised at about 40 m elevation, at the Waipua Stream and Maandonk sections; and it is also observed at 40–50 m at the top of McCoy Road, and at sea-level at Ruatuna Road.

Figure 16-4 : Geological map of the coastal eastern Bay of Plenty [after Healy *et al.*, 1964; Kingma, 1965] (see Fig. 16-2a for key)

The Raetoka Point area, in the southeast of Ohiwa Harbour, consists of an uplifted greywacke basement ridge which separates the western part of Ohiwa Harbour from the eastern part (Figure 16-4).

Several flat-topped islands can be seen within Ohiwa Harbour. Paltridge (1958) identified a surface *c.* 20 m a.s.l. on these islands, as well as a 3 m high coastal terrace. The lowermost surface has previously been attributed to cutting and deposition during the *c.* 6 ka. climatic optimum when sea-level was slightly higher than present, although this has not been confirmed as sections through this terrace were not studied in this work. The origin of the higher surface is not known.

This study has found that flat terraces in the eastern Bay of Plenty region need not be related to high sea-level events, but may instead be relic surfaces of ancient alluvial plains covered by many tens of metres of mantling cover-beds. An example of this is at the Hiwarau section, and another is further west near Opotiki.

At Hiwarau, on the eastern side of Raetoka Peninsula, a flat surface can be observed extending from the greywacke hills comprising the headland to the coastal cliffs. The surface is at about 20–30 m a.s.l. but no cut surface has been recognised. The Hiwarau section is described in detail in Chapter Four. The lowermost deposits here occur at the present sea-level high-tide mark and consist of subaerially deposited Tablelands subgroup tephra; the oldest observed being the Paerata Tephra. The uppermost tephra present at the main Hiwarau cliff section is the Huntress-D Tephra, which is overlain by very weathered colluvium above. The top of this section has been eroded; elsewhere, the terrace is higher and the post-Rotoiti tephra have been observed.

Hokianga Island, which lies 1 km to the northeast, has a flat terrace top of similar elevation (see Photo-67), though the base of this section consists of marine deposits. Airfall tephra of the Huntress Creek and Torere subgroups rest on reworked pumice overlying a poorly sorted mixture of weathered pumice, soil and gravel. Due to its stratigraphic position, this mixed unit is thought to represent the reworking of the Matahina Tephra in a shallow marine–estuarine environment during the $\delta^{18}\text{O}$ stage-9 interglacial sea-level high. Below the mixed unit are fine sands, sandy gravels, and well bedded pumiceous marine sand. The sandy gravels are probably the transgressive marine cover-beds deposited on a surface cut into the older marine sands below. As these marine deposits lie only 6–10 m above the present high tide mark, this area is thought to be relatively stable, with uplift of only 0.02–0.03 mm/year.

A similar mixture of Matahina pumice, soil, and gravel can be seen 0.75 km further east, at the western end of Pukeruru Point. Here, the basal Matahina "pink ash" rests on eroded fluvial gravels, and the reworked tephric-mixture lies immediately above with a strongly weathered paleosol developed into it. Torere subgroup tephra overlie this paleosol. However, only 50 m to the east, airfall Matahina Tephra is observed higher up in the cliffs, at >25 m a.s.l. The mixture at Pukeruru Point may be related to

colluvial deposition on a paleo-hillslope rather than to sea-level rise, and further work on these deposits is required.

The mixed Matahina deposit is found only a few metres above sea-level at Pukeruru Point, indicating that this area, also, has remained remarkably stable over the last 0.3 Ma.

Elsewhere in both the Pukeruru Point and Hokianga Island sections, there occur thick sequences of fluvially reworked pumice overlying an erosional boundary into gravels (see Photo-68). In a few places at the former site, the Paerata and Otawairere Tephra can be recognised between the pumice and the gravels, but generally these two tephras have been eroded out by the cutting of a fluvial channel. The fluvially deposited pumice was emplaced during one extreme flood event related to the eruption of the Kohioawa Tephra, which suggests that a paleo-river channel may have existed here, and at Hokianga Island, c. 350 ka ago.

The basal sequence at Pukeruru Point contains fluvial gravels overlying an erosional surface cut into well-bedded pumiceous sands.

On Ruatuna Road, 2 km south of Pukeruru Point, there occur many metres of unconsolidated, intertidal marine sands, believed to be of similar age to the underlying, but as yet undated, Waingarara Ignimbrite (see Photo-60). The intertidal sands grade laterally into lignites, indicative of an estuarine environment, which have remained only a few metres above present sea-level. The Ruatuna Road section is the only site in the eastern Ohiwa Harbour area at which the Waingarara Ignimbrite is recognised, and here, the ignimbrite and the overlying sands and lignites, underlie a fluvial gravel unit which may correlate with the gravels observed at Pukeruru Point.

If the ignimbrite was deposited during a glacial period, then a significant amount of uplift has occurred since, but if it was emplaced during an interglacial, then this area also has remained stable for some considerable time.

The Flax Hill section, 1 km northeast of Pukeruru Point, contains Ohiwa Harbour subgroup tephras that are observed to rest on what are probably Waiotahi Gravels cropping out at present day sea-level. The gravels here may correlate with those found at Pukeruru Point, and possibly hence to the gravels above the Waingarara Ignimbrite at Ruatuna Road.

The hill between Ohiwa Harbour and the Waiotahi River has a very different uplift history. A section along Ohiwa Harbour Road West shows ≥ 6 m of Ohiwa Siltstone overlain by coarser, bedded sandstone (10 m thick), followed by fluvial gravels (4 m thick; see Photo-69), estuarine silts (5 m thick), very weathered fluvial gravels (7 m thick), unconsolidated marine sands (4.5 m thick) and extremely weathered subaerially deposited tephras of the Reeves and Ohiwa Harbour subgroups (> 3 m thick; Figure 16-5).

Ohiwa Hill-Harbour

Figure 16-5 : Stratigraphic section through Ohiwa Hill (Ohiwa Harbour Road West)

The sequence along Ohiwa Harbour Road West displays well the alternating marine and terrestrial environments associated with glacio-eustatic sea-level changes. Edbrooke (1978) included within this sequence an outcrop of gravels found near the base of the section towards the harbour. This worker did not see any physical connection between these gravels and the sequence discussed above, and the gravels may therefore belong to a different, younger section which abuts against the marine sequence. However, the author did recognise basal gravels overlain by marine sediment along the road north to the Ohiwa Motor Camp, which suggests that the gravels recognised by Edbrooke may indeed be part of the sequence.

The highest marine deposits found on the hill occur at 40–50 m a.s.l. (exact height uncertain), immediately below the Reeves-D Tephra (see Photo-12). The Reeves-D Tephra has an estimated age of either c. 485 ka or 550 ka, giving rise to an average uplift rate of c. 0.1 mm/year over the last 0.5 Ma. However, if the uppermost marine sediments were deposited during $\delta^{18}\text{O}$ stage-13 or stage-15, both of which had peak sea-levels 10–20 m lower than that of present, an extra 10–20 m of uplift must be included. Furthermore, if uplift commenced only at c. 0.3 Ma, an uplift rate of 0.2 mm/year is obtained. The deposits higher up in the sequence are obscured until the Ohiwa Hill section at the very top of the hill at ≈ 70 –80 m a.s.l. (exact height uncertain), where Torere and Huntress Creek subgroup tephrae are recognised. Although no marine deposits corresponding to younger interglacial periods with higher sea-levels were observed (e.g. $\delta^{18}\text{O}$ stage-11), they may be present but obscured. In the absence of any further evidence, uplift of the "Ohiwa Hill" is considered to have commenced at c. 0.5 Ma.

A terrace parallel to the coast at Ohiwa Beach is likely to be of last-interglacial origin. The basal deposits here consist of white cross-bedded tephric sands, overlain by coarse gravels, followed by more tephric sand with a very weathered paleosol developed into its top. The Rotoiti Tephra rests on this paleosol and post-Rotoiti tephrae lie above.

Along the beach at a small headland to the west (Ohiwa Beach section), there are >4 m of hard indurated gravels, overlain by 2 m of dark, organic-rich silt beds interspersed with many thin white ashes. It is thought that the sea-level high of the last-interglacial ($\delta^{18}\text{O}$ stage-5e) cut a surface into the indurated gravels, and the organic-rich estuarine-swamp sediments were deposited onto the surface as the sea retreated. However, since the Rotoiti Tephra is not recognised here, there is still some doubt as to the true age of the sediment, and it may be much younger. The thin ash layers are yet to be studied in detail by glass chemistry. The entire sequence here has since been covered by a very large slump-block of older tephrae and paleosols, many of which are well preserved and in their correct stratigraphic sequence, enabling identification — the basal unit is the Paerata Tephra.

Other terrace surfaces can be seen around the eastern edge of Ohiwa Hill, and it is thought that these may have been cut into the side of the hill by interglacial high sea-levels. However, they may instead be river terraces associated with the nearby Waiotahi River, and further work is required to determine their origin.

The gravels found around the edges of this hill, and around the edges of Ohiwa Harbour, were given the name "Ohiwa Gravels" [Chappell, 1975]. Variable uplift rates have presented some difficulty in

correlating the gravel layers throughout the region, and it is also likely that there are many different gravel units of varying age. The Ohiwa Harbour Road West section contains two or three such units. These ancient gravels are often indurated enough to survive the incutting of marine benches, but elsewhere they are very soft and weathered. Where they are soft, it is thought that the gravels may have been exposed to terrestrial weathering for some considerable time, or that the silts and clays which comprise the matrix of the gravels may have undergone dissolution and deflocculation during marine submergence.

One place which contains very weathered, "soft" gravels is the Kutarere Wharf section (see Figure 16-4). Here, the Kutarere Tephra overlies reworked material whose base infills channels cut into very weathered gravels below. The erosion into the gravels may result from cutting during the high sea-level of $\delta^{18}\text{O}$ stage-7, but may instead be a result of fluvial erosion. Further work, perhaps paleontological, on the reworked sediment immediately above the gravels may provide proof of a marine origin. The top of the gravels is found <2 m above the present day high tide mark; therefore if this is a marine cut surface, the area has remained very stable over the last 0.2 Ma.

Near the coast, on the eastern side of the Waiotahi River, is a section where the basal gravels are cut by what appears to be a subhorizontal erosion surface. Several metres of subaqueously reworked tephra have been deposited on this surface, and airfall Matahina Tephra is present just above. It is not known whether the cut surface is marine or fluvial in origin, but as it is adjacent to a moderately large river, fluvial cutting is quite likely. The age of the surface is estimated at c. 330–350 ka.

16-1.8 Waiotahi Cliffs - Opotiki - Opape

The high terrace found behind Waiotahi Beach that can be traced eastwards to Opotiki, Tablelands and beyond, has been named here the "Tablelands Terrace". This terrace is believed to be a continuation of the uplifted Ohiwa Hill block (Figure 16-4). The coastal cliffs at Waiotahi Beach show a similar, though slightly different, sequence of deposits to that of Ohiwa Hill. The deposits could not be viewed at close range, but through binoculars the view was sufficiently detailed to enable identification of a few distinctive tephtras and thus correctly position the sequence within the eastern Bay of Plenty stratigraphy (Photo-70 & 70(a)).

The Kohioawa Tephra is near the top of the cliff, with the other tephtras of the Tablelands subgroup below. The Tablelands-A Tephra rests on the very weathered paleosol at the top of the Ohiwa Harbour subgroup, and the Tirohanga Tephra can be recognised below, overlying at least one further tephra. This lower tephra appears to have intermittent preservation, occurring in large lenses between the Tirohanga Tephra and the irregular top of a very thick weathered gravel unit below.

About halfway (≈ 10 m) down through these gravels there is a 2–3 m thick layer of sand, which could be of fluvial or marine origin. A further ≈ 10 m of gravels occur below, containing occasional lenses of sand. The base of the gravels is erosional and rests on slightly cross-bedded marine sand >10 m thick. The uppermost part of the sand unit contains the Waiotahi Tephra, which is of unknown age.

The uppermost marine sand unit on Ohiwa Hill — found just below the airfall tephra at Ohiwa Harbour Road West — is not recognised in the Waiotahi cliffs. However, some erosion, perhaps significant, has occurred at the base of the Ohiwa Harbour subgroup in this latter section; this could well have removed all the unconsolidated material—such as sand and tephra—down to the much firmer gravels. Alternatively, the uppermost Ohiwa Hill sand may correlate with the thin sand unit found midway through the gravels at Waiotahi, though a more likely correlative of this unit is the mudstone found between the upper two gravel layers at Ohiwa Hill.

The gravels that extend along within the Waiotahi cliffs have been named the Waiotahi Gravels, and this name is preferred over the Ohiwa Gravels of Chappell (1975) because their stratigraphic exposure is better here.

The Waiotahi Gravels directly overlie marine sands with an erosional contact. It is likely that they were deposited during a period of low sea-level; perhaps several kilometres seaward from the previous interglacial high sea-level shoreline.

The basal marine sediments in the coastal cliffs have been uplifted an unknown amount as the depth of deposition, extent of erosion, and relative sea-level height during deposition are not known with certainty. Nevertheless, uplift between the deposition of the gravels and the very high sea-level of $\delta^{18}\text{O}$ stage-11 (c. 400 ka) must have been ≥ 25 m; otherwise marine sediment would be present above the gravels, rather than the terrestrially deposited tephra and paleosols. Hence an estimated uplift rate of ≥ 0.1 mm/year has been determined.

The entire region from Ohiwa Hill to Opotiki is tilted, and the uplift at the eastern end of the Waiotahi cliffs is much less than to the western. The upper surface of the western Waiotahi gravels rises inland, cropping out on Verrall Road at c. 80 m a.s.l. about 5 km from the coast. The elevation of the terrace surface falls from 70 m in the west to 60 m in the east, and rises to >100 m, 5 km inland. The tilting continues towards Opotiki. The broad surface has undergone a greater amount of dissection in the east; a number of small streams forming long, narrow, low-lying flat floored valleys with remnants of the flat-topped terraces between. The terrace remnants form long promontories that would have extended outwards as headlands during the last-interglacial and perhaps also the climatic optimum of the Holocene (Figure 16-4).

The Huntress Creek section exposes the deposits within one of these promontories (see Photo-71). Continuous subaerial deposition occurred here since from at least the eruption of the Kohioawa Tephra. Coarse sandy ash from this eruptive was found at several metres depth when augered, not far above present day sea-level. The surface of the Tablelands Terrace here rises from ≈ 25 m a.s.l. at about 1 km from the coast, to ≈ 80 m a.s.l., 6 km inland.

Just to the east of Huntress Creek is the Kukumoa cutting section, which exposes the uppermost tephra in a topographically lower terrace/promontory. The basal tephra recognised here is the Kutarere Tephra. The terrace surface here extends inland and rises to a height of ≈ 40 m a.s.l., about 4 km from the coast.

On the eastern edge of this lower terrace, where the Waioeka River is cutting through it, is the Waioeka River section. This section shows the Kutarere Tephra resting on a paleosol developed into loess, which overlies gravels. The entire terrace may represent cover-beds mantling a relatively young fluvial aggradation surface, but it is much more likely that the Waioeka River section shows a limited area where either marine wave-cutting during $\delta^{18}\text{O}$ stage-7, or fluvial action during $\delta^{18}\text{O}$ stage-8, has cut into the basal gravels (Waiotahi Gravels) of the older Tablelands Terrace.

On the other side of the valley, at Gault's slip section, fluvial deposits of uncertain age rest against the western edge of another preserved area of the Tablelands Terrace. These sediments include silts, sands, gravels and tephra; both reworked and possibly also primary. The Rotoiti Tephra is recognised at the top of the section but the individual tephra units found below it at this site have yet to be studied in detail.

The Tablelands Terrace east of Opotiki is an obvious high, flat topped terrace stretching >5 km eastwards along the coast from Opotiki to Opape (Figure 16-4). In an earlier study by Iso et al. (1982), the cover-beds found on it were described. Post-Rotoiti tephra were found to overlie the "Hamilton Ash Formation" and the "Tablelands Tephra Formation". The latter formation was defined at the Tablelands Road section and was said to consist of an upper and a lower member. However, only a small portion of the complete stratigraphy is exposed at this site, and the descriptions given by these workers of the tephra which comprise the formation were not detailed enough to identify and correlate individual tephra units within it. Many of the tephra at Tablelands Road belong to the Tablelands subgroup defined in this thesis, and some also belong to the Ohiwa Harbour subgroup. Stratigraphically higher tephra belonging to the Murupara and Torere subgroups, together with several Tablelands subgroup tephra, are observed at the Burchett site ≈ 0.5 km to the north.

The base of the Tablelands Terrace consists of a thick sequence of fluvial gravels which can be correlated to the Waiotahi Gravels by the tephra cover-beds resting upon them. A similar tilt is found on the terrace here to that at the Waiotahi cliffs, with the height of the Tablelands Terrace ranging from ≈ 50 m to ≈ 40 m, west to east along the coast, and up to ≈ 80 m, at a distance of 4 km inland.

Inland, yet still surrounded and barely covered by the Tablelands Terrace deposits, can be found islands and promontories of greywacke basement.

The base of the Waiotahi Gravels is not seen anywhere east of Opotiki, and along the coastal cliffs further to the east near Tirohanga, the top of the gravels occurs at only a few metres above sea-level.

The Tablelands Terrace was previously, but incorrectly, correlated with the Matakaoa Terrace of penultimate interglacial age ($\delta^{18}\text{O}$ stage-7) located at the northeastern end of Raukumara Peninsula [Iso et al., 1982]. This correlation was based on several fission track dates on obsidian flakes collected from tephra in the lower Tablelands Formation. The ages ranged from 0.18 ± 0.02 Ma to 0.21 ± 0.02 Ma [Iso et al., 1982], but like many earlier fission track determinations, these are now thought to be significantly too young.

The Tablelands Terrace is not an uplifted marine cut surface; rather it consists of a thick (>30 m) accumulation of subaerially deposited cover-beds overlying a thick, ancient alluvial aggradation surface.

Along the coastal cliffs created during the highest Holocene sea-level, at *c.* 6 ka, are many small, lower terraces of varying heights. At least two terraces are visible below the Tablelands surface.

At the base is the post-glacial Te Araroa Terrace, which consists of aggradational silts, dunes and swamps. A section through the next lowest terrace, at Beach Road, shows the Rotoiti Tephra overlying weathered Waiotahi Gravels. The sea-level during $\delta^{18}\text{O}$ stage-5e is believed to have been up to 5 m higher than at present, and therefore terraces of stage-5e age could have been cut into the older Waiotahi Gravels and readily preserved in tectonically stable areas.

However, the great variation in height among these smaller terraces suggests that many are fluvial in origin; either aggradational or having eroded into the sides of the older higher Tablelands Terrace. Subaerial erosion and slumping of the unconsolidated cover-beds can also form relatively flat terraces perched on the more consolidated sub-surfaces at depth — gravels, clay, or even basement rock. One such surface is observed at Jackson Road, where the Rotoiti and post-Rotoiti tephtras directly overlie a thick, very well developed clay-rich paleosol (developed into loess) that contains the Tirohanga, Ohiwa-B and Jackson Tephtras at its base. All of the intermediary deposits — the Tablelands, Murupara, Torere and Huntress Creek subgroups; some 20 m of material — are not found at this site and must have been removed by erosion prior to the Rotoiti eruption. The thick paleosol may be the last-interglacial paleosol, but it is more likely the paleosol that exists at the top of the Ohiwa Harbour subgroup, and represents a consolidated clay-rich sub-surface that was not eroded. The highest terrace surface (at ≈ 60 m a.s.l.) probably contains the complete stratigraphy, whereas the intermediate surfaces were likely to have formed by erosion; probably subaerial.

Around the margins of the valleys within the greywacke basement hills (east of Tirohanga River, for example), the Rotoiti Tephra is observed to lie directly on basement rock. No older tephtras are seen below the Rotoiti, indicating that this tephra was the first eruptive deposited after a significant erosional episode. This is consistent with the erosional unconformity found just below the Rotoiti Tephra in other areas.

It is probable, but not certain, that the high terrace at Opape correlates with the Tablelands Terrace. The Opape terrace surface is possibly slightly lower, but this may be the result of a different deposition history of the cover-beds. The basal cover-bed deposits are not exposed here; the oldest tephtras recognised belong to the Torere subgroup. Therefore the tephrostratigraphy of the Opape site cannot be used to determine the terrace age.

There is evidence to suggest that the Opape area contained a fresh-water lake or pond of at least moderate size during $\delta^{18}\text{O}$ stage-9. Many metres of organic-rich silts, often containing wood, are interbedded with reworked tephtric sands and ashes (see Photo-72). The tephtric layers contain fresh-water diatoms which prefer a still-water environment [Margaret A. Harper, pers. comm. 1994]. A change to a subaerial terrestrial environment occurred following the deposition of up to 4 m of reworked Kaingaroa

Tephra, which appears to have filled the lake totally, and/or altered the course of, or blocked its water source.

Lacustrine deposits are not seen to the west, except at Brown's driveway where the upper half of the Paerata Tephra was water-lain and contains cross-bedding.

A lower terrace of last-interglacial age exists at Opape Beach, 0.5 km to the north (Figure 16-4). Here, the Rotoiti Tephra overlies ≥ 1 m of loess, which rests on beach gravels. The gravels overlie a reworked tephric sandy silt layer resting on very weathered gravels of uncertain age. These lower gravels may have been deposited during the cold climate of $\delta^{18}\text{O}$ stage-6, or possibly correlate with the older Waiotahi Gravels. Whatever their age, they appear to have been cut by the $\delta^{18}\text{O}$ stage-5e sea-level high, and subsequently overlain by marine and terrestrial cover-beds. Terraces at similar or slightly higher levels can be seen nearby, containing similar cover-beds, but without the beach gravels and reworked tephra. The presence of fluvial gravels in these possibly higher terraces suggests that the basal gravels at Opape Beach are younger than the Waiotahi Gravels, and are probably only a few metres thick, overlying greywacke basement.

Just to the east of Opape, the high terrace abuts against the uplifted greywacke basement of the Raukumara Peninsula and contains gravels and tephra overlying a greywacke surface. This is believed to mark the eastern boundary of the Waiotahi aggradation surface.

16-1.9 Opape to Motu River

The Bay of Plenty coast from east of Opape to near the mouth of the Motu River generally consists of long sandy beaches separated by headlands of greywacke basement. Inland from and paralleling the beaches are moderately narrow, but long and sometimes quite high, terraces (Figure 16-6).

Many terraces can also be seen in the hill country separating the individual bays. The terraces in these areas occur at varying heights and are believed to be fluvial in origin, or aggradational fans. Sections through these surfaces (e.g. Awaawakino, Torere East) generally show the Rotoiti Tephra overlying a very weathered paleosol into fluvially deposited gravels, sands, and reworked tephra. On the basis of the limited number of tephra observed in these sequences, the sediments within the terraces are thought most likely to have been deposited during $\delta^{18}\text{O}$ stage-6, but they may be of varying ages which are independent of height.

Behind a small bay located in the headland area between Opape Bay and Torere Bay are what are believed to be marine cut terraces (see Figure 16-4). The Rotoiti Tephra is the oldest tephra recognised within the cover-beds of the lowest terrace, indicating a last-interglacial age for this surface. There is at least one higher terrace further inland, but sections exposing its cover-beds were not found.

The deposits within the high coastal terrace in Torere Bay have been studied in two sections which cut through it; the Torere West and Torere School sections (Figures 16-4 & 16-5). The Torere West

section has reworked tephric sediment at its base, overlain by both terrestrial and "swamp" (lignite) deposits. The tephras belong to the Torere subgroup, with the basal unit most likely being reworked Torere-A Tephra, overlying a paleosol into firm pumiceous sand. The terrace is therefore thought to have been formed during $\delta^{18}\text{O}$ stage-9, at just over 0.3 Ma. The base of the Torere School section shows last-interglacial swamp deposits containing much wood. Uplift rates within Torere Bay are poorly known as the majority of terrace heights are derived from the tephra cover-beds, and the base of the terrace occurs not far above sea-level in the west, and probably below sea-level in the east. The western end has an estimated uplift rate of 0.02 mm/year, while the eastern end of the bay may be subsiding.

The "bookbinders" (BB) terrace is located at the coast at the very eastern end of Torere Bay. It has a section through it which shows marine deposits shallowing upwards, from a near-shore, through a beach, to a terrestrial paleoenvironment. Several subaqueously deposited tephras are also seen, but have yet to be identified, and the section unfortunately does not reach the top of the terrace. The age of this terrace is unknown, but the thickness of its cover-beds is not as great as those seen in sections through the main Torere Terrace, which is only slightly higher, suggesting therefore that the BB terrace is significantly younger. The higher elevation of the marine deposits in the BB terrace suggests an uplift rate of *c.* 0.15–0.25 mm/year; much faster than that of the main Torere Terrace. The BB terrace is nestled up against the greywacke basement that comprises the headland. The location of the headland may be due to the presence of a fault here, which is causing the basement, and also the BB terrace, to be uplifted at a relatively rapid rate (to the east of the fault). The only other possibility is that the BB terrace is older than the Torere terrace and has had most of its cover-beds eroded off. However, its location — slightly seaward of the Torere Terrace — suggests that it is younger.

The western part of Hawai Bay (Figure 16-6) contains a series of terraces. A section through the highest terrace shows the Rotoiti Tephra overlying loess, which rests on an extremely weathered and well developed paleosol. At the base of the paleosol is a very weathered orange tephra—probably the Kutarere—resting on a very weathered paleosol into grey sticky clay, possibly of marine origin. The terrace is therefore thought to have been created during $\delta^{18}\text{O}$ stage-7, or perhaps earlier. The next highest terrace has the same tephra cover-beds, and the extensive of slumping found here suggests that faulting may have caused the same terrace to be offset to different heights. The lower terraces also appear to be doublets. The Kutarere Tephra (*c.* 0.22 Ma) lies not far above what are believed to be the $\delta^{18}\text{O}$ stage-7 marine sediments at the Hawai section, and occurs at a height of ≈ 30 m a.s.l., indicating a likely uplift rate in the order of 0.15 mm/year. The lowermost raised terrace in the Hawai Bay area probably represents last-interglacial cutting or deposition, and the basal level lowlands thus representing post-glacial deposition.

In the eastern part of Hawai Bay there are several terraces which are thought to be fluvial in origin, but have unknown ages (penultimate glacial or younger).

Fluvial terraces of last glacial age are visible on the margins of the Motu River valley.

Figure 16-6: Geological and landform map of the coastal northeastern Bay of Plenty [after Kingma, 1965; Yoshikawa et al., 1980; Sumosusastro, 1983] (see Fig. 16-2a for key)

16-1.10 Motu River to Waihou Bay

North of the Motu River the coastal terraces become more continuous, particularly the last-interglacial terrace.

At Omaio Bay, this terrace—the Otamaroa Terrace—forms the bulk of the landscape, but at the very southwestern end a higher terrace can be observed (see Photo-75; Figure 16-6). The cover-beds within this higher "Omaio" terrace, consist of the Rotoiti Tephra and post-Rotoiti tephra overlying a paleosol developed into clay, that contains an orange weathered ash at its base — probably the Kutarere Tephra. The presumed Kutarere Tephra overlies reworked tephra and gravel layers which are probably fluvial in origin, but may be marine. The tephric sediment contains glass which has a similar chemistry to several Huntress Creek subgroup tephra. The age of the terrace depends on the position of the cut surface, which is unclear. The tephric sediment may be above or below the cut surface, and the age of the terrace is either $\delta^{18}\text{O}$ stage-9 or stage-7 respectively. There are no nearby large rivers from which to source the material and therefore fluvial aggradation during $\delta^{18}\text{O}$ stage-8 is an unlikely origin.

The surface of the Otamaroa Terrace below is at ≈ 35 m a.s.l., and it contains perhaps 3 m of cover-bed deposits. Taking into consideration that the sea-level during the last interglacial was ≈ 4 m higher than at present, this gives rise to an estimated uplift rate of $c. 0.25$ mm/year. The surface of the Omaio terrace is at ≈ 75 m a.s.l., which would be consistent with its formation any time between $\delta^{18}\text{O}$ stage-6 and stage-9, but $\delta^{18}\text{O}$ stage-7 is the most likely time of formation if the uplift rate was constant.

The Otamaroa Terrace becomes over 1 km broad around Te Kaha, where it is the only terrace recognised (Figure 16-6). Further north, on the north bank of the Raukokore River, several terraces are visible. Here there are two broad high terraces, with a smaller terrace between. Yoshikawa et al., (1980) traced the terraces throughout this region and identified the two most widespread as the Otamaroa Terrace (upper) and Te Papa Terrace (lower). The middle terrace was named the Raukokore Terrace [Sumosusastro, 1983]. All three terraces are thought to have been created during the last-interglacial; during $\delta^{18}\text{O}$ stage-5e, stage-5c and stage-5a, from highest to lowest. The excellent preservation of the three terraces here (elsewhere only the Otamaroa Terrace is seen) may be due to a change in the basement rock type from the very consolidated lower Cretaceous greywacke, to only moderately consolidated upper Cretaceous calcareous muddy siltstones, sandstones, and conglomerates [Kingma, 1965].

The elevation of the terrace surfaces are higher than expected and this is believed to be due more to the greater thickness of the cover beds than to a higher uplift rate, as terrace surface heights become lower to the north, away from the Raukokore River. A very good section through the Te Papa Terrace opposite the Wairuru cemetery exhibits a cut surface into basement at only ≈ 20 m a.s.l., which gives an uplift rate of 0.25 mm/year. There are 20–30 m of cover beds above this cut surface, consisting mainly of coarse fluvial gravels. However, at ≈ 40 m elevation, the gravels abut against or are overlain by a mudstone. This mudstone contains organic matter, including trees—possibly mangrove—still in growth position. If the mudstone is a fluvial overbank deposit then the uplift rate remains as that calculated above, but if it is an estuarine deposit, then the gravels must be older and the uplift rate much greater. Sumosusastro (1983) describes beach gravels (not observed in this work) occurring above the coarse fluvial gravels that

rest on the cut surface. This suggests that the last-interglacial marine wave-cut surface is much higher than the c. 20 m a.s.l. cut surface described above, in which case the surface was probably formed by fluvial cutting by the paleo-Raukokore River during the low sea-level of $\delta^{18}\text{O}$ stage-6. The many metres of fluvial gravels deposited on the cut surface would themselves have been cut by the high sea-levels of the last-interglacial. As the gravels are much less consolidated than the underlying basement rock, this could explain the high definition of the terraces here as opposed to elsewhere.

In this case, the uplift rate would be in the order of ≈ 0.5 mm/year, which fits well with the ≥ 20 m difference in terrace surface height between the Otamaroa and Te Papa Terraces. However, it does not explain the significant drop in elevation of the terrace surfaces towards the north, unless the rate of tectonic greatly decreases northwards away from the river. All three terraces are covered by the Rotoiti Tephra, which overlies a paleosol into a weathered silt/sand unit grading downwards into gravels.

The Te Papa Terrace is widest at Orete and Te Papa Points, which are at either end of Waihou Bay, and the Otamaroa Terrace is widest along Waihou and Whangaparaoa Bays. The Otamaroa Terrace extends inland for >5 km from the coast of Whangaparaoa Bay, chiefly because the unconsolidated Castlecliffian/Haweran basement sediment that exists here is more easily cut (Figure 16-6). The Otamaroa cut surface in this vicinity occurs at an elevation of 60–70 m [Sumosusastro, 1983], which indicates an uplift rate of ≈ 0.5 – 0.6 mm/year.

A few isolated areas of a higher terrace—the Matakaoa Terrace—are also observed, occurring at about twice the height of the Otamaroa Terrace. This higher terrace may have been formed by tectonic emergence rather than cutting, as the shallow marine sediments exposed near its top are thought to be of a similar age to that of the Castlecliffian/Haweran basement sediment, c. 0.3 Ma. This age has been obtained from the tentative correlations to the eastern Bay of Plenty stratigraphy of a sequence of reworked tephtras found within the sediments at Te Piki, and also from macrofossil age control from the Te Piki shellbed.

On the northern side of the valley, abutting against the Matakaoa Range, can be seen many terraces of varying heights. A section along the "Rereaurira track" through one of these terraces shows it to consist of fluvial fan deposits unconformably resting on much older, possibly Pliocene, well bedded coarse sands and gravels; probably the Whangaparaoa Pumiceous Sandstone of the Runaway Group [Chapman-Smith & Grant-Mackie, 1971].

Because the rate of uplift increases significantly from west to east, the terraces discussed here, including the Otamaroa Terrace, are at much higher elevations on the east coast of the Raukumara Peninsula — in the order of 300–500 m a.s.l.

16-2 Terraces in the Eastern Bay of Plenty

Numerous terraces are observed within the Bay of Plenty region, and have varying origins. Some are marine, some fluvial, and some are related to volcanic events, particularly ignimbrite sheets.

The coastal terraces in the eastern and far north-eastern Bay of Plenty have been studied in the most detail, both previously and in this work. The terraces are described below in chronological order.

16-2.1 Waiotahi – Tablelands Terrace

The Waiotahi Gravels form the base of the high Tablelands Terrace, which can be traced 20 km eastwards along the coast from Ohiwa Hill to Opape, and somewhat inland (see Photo-73 & 74). It often forms high cliffs paralleling the coast, showing where the terrace was cut by the highest Holocene sea-level at c. 6 ka. Believed to have originally been a continuous surface, it has been severely eroded by the Waiotahi, Waioeka, Otara and Waiaua Rivers, which have formed wide, flat-bottomed river valleys. Cliffs have formed where the rivers have cut into the edges of the terrace. Small streams have also cut away at the terrace, producing long promontories of high land which point towards the coast. Examples of these are at Huntress Creek and Kukumoa (Figure 16-4; Photo-71).

The basal gravels are overlain by up to 40 m of airfall tephra, loess and paleosols, and this is the major reason for the high elevation of the terrace surface.

Ohiwa Hill, which is the high hill between Ohiwa harbour and the Waiotahi River, is believed to be part of the same terrace. The Tablelands Terrace in this area has been uplifted along the western edge of the Ohiwa Hill. The Waikaremoana Fault may be a cause of this uplift, though the uplift may instead be regional in extent and a continuation of that observed at Whakatane–Ohope at the eastern margin of the Whakatane Graben. The Tablelands Terrace west of Opotiki has been uplifted by more in the west than in the east, and its surface slopes down towards Opotiki.

The Tablelands Terrace east of Opotiki has been studied previously by Yoshikawa et al. (1980), and Iso et al. (1982). An age of c. 0.2 Ma was suggested for the Tablelands Terrace, together with a correlation to the Matakaoa Terrace further north, but both this age and this correlation are both refuted in this study.

The height difference between the Tablelands Terrace surfaces on opposing sides of the combined Waioeka and Otara river valleys — the eastern side being higher than the western — may result from movement on the Koranga fault, or from differing thicknesses of fluvial deposition within the different parts of the paleo-river valley. The terrace to the east of Opotiki is tilted down towards the northeast, and consequently its surface is much lower near Opape. A complete section through the cover-beds is not seen at the latter site and therefore the possibility that the terrace at Opape may be slightly younger cannot be dismissed.

The Waiotahi Gravels form a fan of alluvial debris, from the uplifted greywacke ranges south of Opotiki, to the coast. At the Waiotahi cliffs the gravels have an erosional contact with marine sands, and

therefore probably extended for some distance seaward in the past. Since deposition, the gravels have been progressively eroded by wave action during the subsequent interglacial high sea-levels, and the presently existing cliffs were probably created during the highest Holocene sea-level, at c. 6 ka.

The gravels were almost certainly deposited during a period of glacial low sea-level, and as the mantling tephra cover-beds contain the Ohiwa Harbour subgroup, a probable age of c. 0.62–0.65 Ma ($\delta^{18}\text{O}$ stage-16) is indicated. The uppermost gravels in some areas, though, may have been deposited during $\delta^{18}\text{O}$ stage-14, at c. 0.55 Ma. The oxygen isotope record (see Chapter 15) indicates that the $\delta^{18}\text{O}$ stage-16 glacial was one of the harshest climatic periods during the Pleistocene, and erosion would have been at its most intense within the mountains to the south. The rivers draining these mountains, the ranges of the Urewera National Park, include the Waimana, Waiotahi, Waioeka, Otara and Waiaua, together with all of their tributaries. The Whakatane and Rangitaiki Rivers also flow through this area, and have deposited the great thicknesses of gravel found at depth below the Rangitaiki Plains [Nairn & Beanland, 1989], in the cliffs between Awakeri and Taneatua, and in the Matata coastal cliffs. The Matata gravels could well be of similar age to the Waiotahi Gravels; and if so, one extensive alluvial surface may have stretched from west of Matata to perhaps just east of Opape, with possibly a few islands of basement, such as the Whakatane Heads, showing through. The "Clifton Conglomerate", found in the Cape Kidnappers section in Hawke's Bay, is also thought to have been deposited at this time [Black, 1992].

The fact that no younger large-volume alluvial surfaces are recognised suggests that erosion was more intense during the deposition of the Waiotahi Gravels than at any time since. This may be due to the extremely harsh climate that existed at that time, or related to the initiation or increase in the rate of uplift of the Urewera Ranges; though most likely it results from a combination of the two. There may also have been increased fault movement along the numerous faults of the "North Island Shear Belt" which pass through the area.

16-2.2 Torere Terrace

The Torere Terrace is a high marine terrace which parallels the coast within Torere Bay. Its time of formation is believed to have been during the high sea-level of $\delta^{18}\text{O}$ stage-9, and hence it probably correlates with the Braemore and Brunswick marine terraces that exist within the Wanganui region [Pillans, 1988]. Yoshikawa et al. (1980) suggested that the Torere Terrace was formed during $\delta^{18}\text{O}$ stage-7, but the presence of Torere subgroup deposits within the terrace cover-beds are indicative of an older age; probably $\delta^{18}\text{O}$ stage-9.

Marine deposits of $\delta^{18}\text{O}$ stage-9 age are present at several localities throughout the coastal Bay of Plenty. They are generally thin and rest on terrestrial sediments deposited during $\delta^{18}\text{O}$ stage-10. Sea-level cutting of previously emergent deposits is generally not recognised, except in the vicinity of Ohope (at the Ngatiawa west section, for example), where a dissected terrace at ~150 m elevation at the coast, rising to 250 m 13 km inland, thought to have been formed at that time.

Other terraces that may have been formed at this time include the flat top of Hokianga Island (see Photo-67) and the western edge of Pukeruru Point, both of which are in the eastern Ohiwa Harbour; and several small terrace remnants of unknown age around the margins of the Ohiwa Hill-Tablelands Terrace. However, these remnants may instead be related to fluvial cutting during the peak of $\delta^{18}\text{O}$ stage-10.

16-2.3 Matakaoa Terrace

The Matakaoa Terrace is a marine terrace created during the high interglacial sea-level of $\delta^{18}\text{O}$ stage-7. It was first identified by Yoshikawa et al. (1980) and its type locality is at Matakaoa Point near the northern tip of the Raukumara Peninsula (Figure 16-6).

The Matakaoa Terrace is the highest terrace seen in the northern Raukumara Peninsula and has an elevation approximately twice that of the next highest — the Otamaroa Terrace. The Matakaoa Terrace is not widespread and is best preserved as scattered remnants along the northern coast and in the Te Piki area of the Whangaparaoa Valley.

Only a few localities to the south contain remnants of a high terrace believed to be the Matakaoa; just south of Te Kaha, and at the southwestern ends of both Omaio Bay (Omaio Terrace; see Photo-75) and Hawai Bay. Again, these terraces have surfaces at approximately twice the elevation of the next highest terrace, although the cover-beds within the Omaio Terrace suggest that it may be a fluvial terrace of slightly older age.

At least two terraces are visible behind Ngawaikui Beach, between Opape Bay and Torere Bay. The higher one is likely to be a correlative of the Matakaoa Terrace, though no sections through it were observed.

The cover-beds of a terrace at the southeastern end of Ohiwa Harbour near Kutarere (the Kutarere Wharf section) suggest that this surface, also, may correlate with the Matakaoa Terrace.

Other terraces located around the edges of Ohiwa Hill, Ohiwa Beach, and the Tablelands Terrace may be of $\delta^{18}\text{O}$ stage-7 age as well, but sections through these terraces are generally not available. The Waioeka River section, where the river is eroding into a lower surface at the edge of the Tablelands Terrace, shows the Kutarere Tephra overlying weathered gravels. The cover-bed deposits here suggest that the high sea-level of $\delta^{18}\text{O}$ stage-7 created a wave-cut surface into the Waiotahi Gravels at this site; or it is equally plausible that the paleo-Waioeka River may have cut a fluvial surface into the underlying Waiotahi Gravels, or deposited its own more recent gravels here during $\delta^{18}\text{O}$ stage-8.

On the western side of Ohiwa Harbour, behind Ohope Beach, occurs a terrace at ≈ 100 m a.s.l. The uplift rate here is greater than that further east and it is most likely that this surface represents mantling of loess and tephra over the $\delta^{18}\text{O}$ stage-7 wave-cut surface. The cutting of this surface would have been facilitated by the unconsolidated nature of the uplifted marine sands and silts. The extent of the $\delta^{18}\text{O}$ stage-7 surface was not studied in this work, and it has been mapped here together with older surfaces as undifferentiated mid-late Pleistocene marine sediment.

16-2.4 $\delta^{18}\text{O}$ stage-6 aggradational surface

On the headlands separating the sandy bays in the eastern Bay of Plenty occur many road cuttings, which show the Rotoiti Tephra resting on a very weathered paleosol developed into subaqueously deposited tephric sediment interbedded with greywacke gravels. The age of these deposits is not precisely known, but they are of last-interglacial age or older, probably emplaced during $\delta^{18}\text{O}$ stage-6 when there was increased erosion of the surrounding hills.

Terraces thought to be of similar age also exist adjacent to rivers in the Opotiki–Ohiwa Harbour area; for example, at the Kutarere section. It is often difficult, however, to determine whether the gravels observed in sections through such terraces are of relatively recent deposition (i.e. $\delta^{18}\text{O}$ stage-6) or are the much older Waiotahi Gravels, later cut by the high last-interglacial sea-level.

16-2.5 Last-interglacial Terraces

Three last-interglacial marine terraces have been identified in the eastern Bay of Plenty. They are, from oldest to youngest: the Otamaroa, Raukokore, and Te Papa Terraces. These terraces are discussed in detail on an individual basis, and then in combination as the "last-interglacial terrace".

Otamaroa Terrace

The Otamaroa Terrace is the most extensive terrace in the northeastern Bay of Plenty (see Photo-76). Its type locality is at Otamaroa, ≈ 6 km south of Cape Runaway [Chapman-Smith & Grant-Mackie, 1971]. The base of the terrace was cut during the high interglacial sea-level of $\delta^{18}\text{O}$ stage-5e at c. 0.12 Ma. The tephra cover-beds which overlie the cut surface are only a few metres thick and consist of the Rotoiti and post-Rotoiti tephra, together with the very weathered last-interglacial paleosol. A loess unit is occasionally observed between the Rotoiti Tephra and the last-interglacial paleosol. The paleosol at each site is developed either directly into the cut surface, or into material lying above just above it, such as shallow marine, beach or dune deposits.

The Otamaroa Terrace can be followed southwards, from Cape Runaway to the Motu River, as a virtually continuous surface along the northeastern Bay of Plenty coast. Only remnants of the Otamaroa Terrace are recognised south of the Motu River; Holocene coastal erosion having probably been the major cause of its removal.

Raukokore Terrace

The Raukokore Terrace is only seen at a few sites, and its best exposure is just north of the Raukokore River [Sumosusastro, 1983] in the far northeastern Bay of Plenty. Its surface lies just below the Otamaroa Terrace surface, and just above the Te Papa Terrace, and is therefore thought to represent cutting during $\delta^{18}\text{O}$ stage-5c, at c. 0.10 Ma.

Te Papa Terrace

The Te Papa Terrace is well displayed in the vicinity of Te Papa Point (see Photo-76), ≈ 6 km south of Cape Runaway [Chapman-Smith & Grant-Mackie, 1971], but is widespread only in this region and

southwards to the Raukokore River. The Te Papa Terrace has the same tephra cover-beds as the Otamaroa Terrace; that is, the Rotoiti and post-Rotoiti tephra; but the paleosol below the tephra is generally less weathered. The Te Papa Terrace surface lies not far below the Otamaroa Terrace surface, and it is therefore thought to represent a marine bench cut during $\delta^{18}\text{O}$ stage-5a, at c. 0.08 Ma.

All three terraces detailed above were formed during the last-interglacial, from 80–120 ka, and are only preserved separately where there was a high rate of uplift and/or relatively soft basement rock or sediment to cut into. South of the Raukokore River, the uplift rates are lower, the basement rock much more indurated, and only one last-interglacial terrace is seen. This single terrace may represent all three last-interglacial terraces, with the oldest part furthest inland. However, coastal erosion throughout the Holocene may have removed the younger components—the Te Papa and Raukokore—of this combined last-interglacial terrace, in which case the remaining surface would chiefly represent the Otamaroa Terrace. Therefore, in this region and in areas further south, the term "last-interglacial terrace" has been used synonymously with the Otamaroa Terrace.

Last-interglacial Terrace

A low terrace at the southwestern end of Hawaii Beach was probably formed during the last-interglacial period, as was the lower terrace at Ngawaikui Beach. The BB terrace at the very northeastern end of Torere Bay may also be of last-interglacial age, although it appears to have undergone rapid uplift in comparison to the nearby Torere Terrace. Further work is required here to positively determine the age of the BB terrace.

The last-interglacial terrace has been positively recognised at Opape Beach, where there is a cut surface into either $\delta^{18}\text{O}$ stage-6 fluvial gravels or the much older Waiotahi Gravels.

The relative sea-level during the early part of the last-interglacial period ($\delta^{18}\text{O}$ stage-5e) is believed to have been up to 6 m higher than that of present. Terraces, therefore, could have readily been cut into older terrace deposits such as the Waiotahi Gravels, and preserved in areas that are tectonically stable, with no requirement for active uplift. The relative sea-level difference between successive interglacials must also be considered when calculating uplift rates.

The numerous low-lying terraces developed into the edges of the Tablelands Terrace are therefore believed to be of last-interglacial age. A less likely scenario is that these terraces are fluvial in origin. Although this may well be the case in areas adjacent to major river systems, it is unlikely to be true for all of these surfaces. A section through one of these terraces, at Beach Road, shows the cover-bed sequence to be the same as that of the Otamaroa Terrace.

Behind Ohope, on the western side of Ohiwa Harbour, a terrace at ~60 m a.s.l. is thought to consist of loess and tephra which mantle the $\delta^{18}\text{O}$ stage-5 wave-cut surface. The uplift rate is relatively high here, and the substrate less consolidated than further east, thereby allowing better preservation.

A coastal terrace at Ohiwa Beach also has cover-beds which show it to be of last-interglacial age. There are several further terraces around the edges of Ohiwa Hill which may be marine cut terraces of the same age, but may be fluvial instead. Further work is required here.

16-2.6 $\delta^{18}\text{O}$ stage-5, stage-4 and stage-2 fluvial terraces

At a few sites, fluvial terraces formed during the cold climates of $\delta^{18}\text{O}$ stage-4 and $\delta^{18}\text{O}$ stage-2 have been observed. A fluvial terrace thought to have been deposited during stage-5d was named the Waiotuma Terrace [Sumosusastro, 1983]; and another, thought to have been deposited during stage-4, the Ngarue Terrace. The tephra cover-beds on these terraces are the same as those on the last-interglacial marine terraces, but the fluvial terraces are topographically lower and contain fluvial sediment.

Fluvial terraces of last-glacial age occur in the western Bay of Plenty, from Otamarakau to Te Puke [Healy *et al.*, 1964]. A large number of fluvial terraces also occur in the Motu River valley, but were not studied in this work.

16-2.7 Te Araroa Terrace

The Te Ararora Terrace was described by Yoshikawa *et al.* (1980) as the Holocene terrace related to the highest Holocene sea-level at c. 6 ka. This terrace is found throughout the Bay of Plenty and is often overlain by sand dunes and recent alluvial deposits.

The Te Araroa Terrace was divided into two smaller terraces in the Whangaparaoa area; the Orete and Urutana [Sumosusastro, 1983]; and contains more than 50 raised beach ridges at Te Araroa [Yoshikawa *et al.*, 1980]. In most areas only one terrace of Holocene age is recognised and it has been referred to as the Te Araroa, or Holocene, terrace.

Chapter Seventeen : Summary

This chapter gives a brief summary of the overall geological features and history of the Bay of Plenty derived from this work.

17-1 Tectonic Features

The tectonic outline of the Bay of Plenty coastal region during the mid-late Quaternary can be simply described as subsidence in the west and of uplift in the east (Figure 17-1). In the centre, between these two differing tectonic regimes, lies the Whakatane Graben which, through block down-faulting, is widening and subsiding at a rapid rate. On either side of the graben there are tilted blocks of sediment, and the onset of uplift of these blocks is believed to have been at *c.* 0.3–0.4 Ma.

The Matata – Otamarakau area is being uplifted in the east, at ≈ 0.9 mm/year, but is subsiding in the west, which suggests tilting about an axis somewhere near Pikowai. Several previously unknown faults are indicated here, just west of Matata. The area west of Otamarakau towards Tauranga is generally undergoing subsidence, except for the raised headland at Maketu which is thought to be an uplifted fault-block. Isolated inliers of basement greywacke occur in the Otamarakau area and these were considered by previous workers to have been "allocthonous block 'floating' in a medium of volcanic rocks" [Nairn & Beanland, 1989]. Unrecognised faulting similar to that at Maketu may also have a part to play in the existence of these inliers.

The raised greywacke basement on the eastern side of the Whakatane Graben—that is, the Whakatane Heads—appears to have been above or at sea-level since mid-Pleistocene times, and the Castlecliffian marine sediments in the Ohiwa basin are being uplifted, probably at an even greater rate than the headland.

East of the Whakatane Graben is a series of blocks that appear to be uplifted to a greater extent in the west than the east, which has caused the surfaces to be tilted, dipping towards the northeast. One block comprises the Whakatane Heads (≈ 0.2 mm/year uplift); another forms the area from the eastern side of the Heads (≈ 0.35 mm/year uplift) to the eastern margin of the Ohiwa Harbour (*c.* 0.02 mm/year uplift); a third extends from Ohiwa Hill (*c.* 0.1–0.2 mm/year uplift) to the Waioeka River area, which appears to be undergoing subsidence; and a fourth extends from Opotiki, where it is unclear whether uplift or subsidence is in progress, to Opape, where it is almost certainly undergoing subsidence (see Figure 17-1).

The general regional downward dipping slope towards the northeast can also be seen on terraces at Torere Bay, which ranges from *c.* 0.03 mm/year uplift in the west to subsidence in the east; and at Hawai Bay, which has ≈ 0.15 mm/year uplift in the west and less in the east. Terraces of similar age increase in height in each successive bay to the northeast, which indicates that more smaller uplifted and tilted blocks may also occur here, with the faults located at the western sides of the headlands which separate the bays.

The tilting of the landscape is also manifested in the fluvial patterns — the river mouths tend to be located at the northeastern ends of the bays; and in periods of lacustrine/swamp deposition which have taken place in these areas (e.g. at Opape and Torere School sections).

From the Hawai Bay area, the rate of uplift increases northeastwards to be ≈ 0.5 mm/year in the Raukokore, Whangaparaoa and Te Piki areas. This increase in the rate of uplift may be associated with the much greater uplift rate on the eastern side of the Raukumara Peninsula, in the order of 2.5 mm/year (Pillans, 1990). The east coast terraces are over twice the height of the Bay of Plenty terraces.

17-2 Basin Deposition History

Only a few areas in the Bay of Plenty region show Pleistocene marine sediments exposed above present sea-level. Subsidence is thought to have occurred over the central to western areas from probably the early Pleistocene onwards, and in some places has continued to the present day. Major areas of deposition were, and are, located around Tauranga and eastwards along the coast to Opoitiki. The western areas are still subsiding and have been filled by both primary pyroclastic flows and extensive thicknesses of alluvial volcanic sediment. Uplift in the central region on either side of the Whakatane Graben has exposed moderate thicknesses of Castlecliffian marine sediment, often interbedded with terrestrial sediment deposited during glacio-eustatic sea-level lows. The uplift is thought to have commenced only about 0.4 Ma ago. The chief exposures of marine sediment occur in the coastal cliffs west of Matata, and inland from these; on the margins of the Whakatane River valley from Awakeri to Ruatoki; on the Rurima Islands and on the western side of Motuhora Island; from Ohope to Waimana, and east across and inland from Ohiwa Harbour; Ohiwa Hill; and at the base of the Waiotahi cliffs.

The other major area of marine deposition occurred in the Whangaparaoa area in the far northeast near Cape Runaway. Here, deposition took place from the Miocene onwards; the youngest sediments being of Castlecliffian–Haweran age. The use of the tephra found in these deposits can enable the determination of the age of deposition with greater accuracy than by using the fossil assemblages alone.

Inland basins which contain extensive thicknesses of fluvial and lacustrine sediment (the Lukes Farm Formation) occur at Galatea, near Murupara, and at Waiohau, at the eastern edge of the Central Volcanic Region. These basins are fault bounded depressions which abut against the uplifted Ikawhenua Range. Further basins containing fluvial and lacustrine deposits (the Huka Group) occur within the T.V.Z. between Rotorua and Taupo where ancient caldera lakes once existed.

The remaining areas of the Bay of Plenty region are generally covered by the large rhyolitic ignimbrite sheets, with smaller areas of recent alluvium near rivers, and rhyolitic, dacitic, and rare basaltic lava.

The entire Bay of Plenty region, with the exception of the most recent alluvial deposits, is mantled by airfall rhyolitic tephra.

17-3 Volcanic history

The oldest volcanic deposits recorded in the eastern Bay of Plenty are thought to have an age of *c.* 0.6–0.7 Ma (the Waiotahi Tephra). Many eruptions occurred between that time and *c.* 0.4 Ma; found in the Reeves and Ohiwa Harbour subgroups; but these are generally extremely weathered and no glass, and few physical features, remain for correlation purposes. The Ohinekoao subgroup — found near Matata within estuarine and terrestrial deposits, and buried by many tens of metres of marine sedimentation — may be a time correlative of part of the Ohiwa Harbour subgroup. The glass within the Ohinekoao subgroup tephra has been well preserved, but as yet cannot be positively correlated with any other eruptives. The now extinct Manawahe volcano, found just to the south of the Matata area, is also thought to have been active at *c.* 0.4–0.5 Ma, and several rhyo-dacite tephra recorded in the Ohinekoao subgroup are believed to have originated from this source.

There is a good record of numerous eruptive episodes (about 40 episodes) from *c.* 0.4–0.25 Ma, especially in the latter half of this period. These eruptives include the airfall correlatives of the very large Rangitaiki/Whakamaru, Matahina and Kaingaroa Ignimbrites, and possibly the Quartz-biotite Ignimbrites. The Chimp, Pokai and Mamaku Ignimbrites may also be recorded; the latter is tentatively correlated to the airfall Kutarere Tephra.

The very weathered Kutarere Tephra marks the boundary to a volcanically less active time period. Extreme weathering during the last-interglacial has made identification of the few tephra that were erupted during this time period very difficult. Only six tephra are definitely known to have been deposited between *c.* 0.2–0.05 Ma, at the end of which period the Rotoiti Tephra was erupted.

At virtually every site where the Rotoiti Tephra is found, it almost immediately overlies a regional erosional unconformity. The unconformity is at the top of a thick very weathered paleosol, which appears to have a consistent thickness paralleling the high relief of the erosional surface. This indicates that paleosol development occurred near the end of, or immediately following, the period of erosion. The unconformity is therefore thought to have occurred either during $\delta^{18}\text{O}$ stage-6, or near the beginning of the last-interglacial (stage-5).

The Rotoiti Tephra marks the beginning of a period of increased volcanic activity (relative to that previous) which continues to the present day.

Initiation of activity at the Okataina Volcanic Centre (Okataina V.C.) is now thought to have occurred at *c.* 370 ka with the eruption of the Paerata Tephra, or earlier. The Paerata Tephra has a distribution pattern consistent with an Okataina source; and contains abundant cummingtonite, which is a signature mineral within tephrae from the Okataina V.C. during the late Quaternary. These two factors in conjunction justify pushing the time of initiation back to at least 370 ka, but the much older Reeves-A Tephra (estimated age of *c.* 0.5 Ma) also contains cummingtonite, as does the similarly aged Wilson Tephra. Either the onset of volcanism within the Okataina V.C. occurred even earlier, or cummingtonite—which previously has only been found in Okataina V.C. eruptives—was being produced from another source at *c.* 0.5 Ma. There is too little data from either the Reeves-A or Wilson Tephrae to confirm their eruptive source, and the presence of cummingtonite may, or may not, be indicative of an Okataina V.C. origin. Nairn (1981 & 1989a) suggested that the distribution of the Quartz-biotite Ignimbrites indicates that they may have been sourced in the Okataina V.C. This study does neither confirm or disputes this hypothesis, but does suggest a possible correlation of these ignimbrites with the Tablelands-A and/or Kohioawa Stream Tephrae; the latter eruptive having a distribution that suggests an origin in the Okataina V.C.

The first eruptive known with certainty to have originated in the Reporoa Volcanic Centre is the Kaingaroa Tephra and Ignimbrite, although members of the older Torere and Reihana subgroups may also have originated from here; especially any of the Reihana-F, Torere-L, or Torere-O Tephrae.

Activity in the Rotorua Volcanic Centre was previously thought to have initiated with the eruption of the Mamaku Ignimbrite. However, the Welcome-C and Welcome-F Tephrae, both of which pre-date the Mamaku Ignimbrite eruption, have very similar glass chemistries to the Mamaku eruptives and may instead be the first eruptives from the Rotorua V.C.

17-4 Conclusions

This thesis has produced the compilation of a complete tephrostratigraphic record of the eastern Bay of Plenty, including:

- Correlation of the Kohioawa Tephra to the Rangitawa Tephra/Whakamaru Ignimbrite eruption.
- Identification and correlation of the Matahina Tephra over much of the eastern Bay of Plenty.
- Identification and correlation of the Kaingaroa Tephra over much of the eastern Bay of Plenty.
- Recognition of the similarity in stratigraphic position and glass chemistry of the Pokai Ignimbrite with the Kaingaroa Ignimbrite and/or Huntress-D Tephra.
- Tentative identification of the Kutarere Tephra as the airfall correlative of the Mamaku Ignimbrite.

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- Tentative correlation of the Chimp Ignimbrite to the Waimakariri Ignimbrite, Reihana-G and Torere-I Tephra.
 - Recognition of a possible reduction in the eruptive frequency in the northern T.V.Z. during $\delta^{18}\text{O}$ stage-5 and stage-6.
 - Identification of the Waiotahi Gravel aggradational surface and inferred ages of the high terraces around Opotiki.
 - Identification of a $\delta^{18}\text{O}$ stage-13 or stage-15 wave-cut surface at Whakatane Heads.
 - Recognition of $\delta^{18}\text{O}$ stage-9 marine cutting and/or deposition at Torere (Torere Terrace), Ohope, and possibly in the eastern Ohiwa Harbour.
 - Tentative placement of the Te Piki marine strata within the eastern Bay of Plenty stratigraphy.
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- Tentative recognition and location of previously unknown faults in several places: in the Matata cliffs; Whakatane-Ohope; Ohiwa Hill; Opotiki; and the eastern ends of several bays east of Opape.
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- Recognition of glacio-eustatic cycles within the sediments exposed in several areas: the cliffs west of Matata; coastal deposits around Ohope; Ohiwa Hill; and in the terrestrial coverbeds throughout the Bay of Plenty region.
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**Late Pleistocene Tephrostratigraphy
of the
Eastern Bay of Plenty Region,
New Zealand**

**VOLUME II
APPENDICES**

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Photo 5a : Diagram of the Westend-Otarawairere section, showing the positions of the various features.

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Photo 6(a) : Diagram of the Tablelands Road section, showing the positions of various tephra.

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Photo 7a : Diagram of the Reeves section, showing the positions of the various tephra and other features.

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Photo 8a : Diagram of the Reihana Road section, showing the positions of various tephras.

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Photo 11 : Reeves-A Tephra; note well bedded (subaqueously deposited?) basal layers. [Reeves section]

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Photo 16 : Ohinekoao-J (upper) and Ohinekoao-I (lower) tephras. [Ohinekoao Reserve section]

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Photo 19: Paerata Tephra (massive yellow pumice) and Tablelands-D Tephra (grey bedded ash). [Otarawairere section]

Photo 20: Upper part of the Kohioawa Tephra, showing well bedded Koh-4 unit, and the rarely seen fine white ash above (Koh-5?).

Photo 21 : Kohioawa Tephra. Note 4 units; no.4 = well bedded, 3 = massive lapilli, 2 = fine grained (at spade handle), 1 = coarse pumice lapilli.
[Otarawairere section]

Photo 21a : Diagram of the Kohioawa Tephra. [Otarawairere section]

Photo 22 : Murupara-A Tephra, within tephric loess. [Murupara-(2) section]

Photo 23 : Tephric loess overlying the Murupara-C Tephra (note white ash at base), overlying more tephric loess. [Murupara-(2) section]

Photo 24 : Middle to upper part of the Bonisch Tephra in the Kaingaroa Forest [Pahekeheke section]. Note obsidian-rich speckled pumice above and below normally graded pink fine ash.

Photo 25 : Bonisch Tephra in the eastern Bay of Plenty [Burchett section]. Note pinkish ash at centre, between speckled sandy ash beds.

Photo 26 : Matabina (at top), Murupara-G, Anaputa (note pale grey ash layer in middle), and Murupara-E tephras. Note very thin paleosols between lower three tephras. [Pahekeheke section]

Photo 27 : Anaputa Tephra at its type section. Note speckled obsidian-rich pumice, overlying fine grey ash, with more obsidian-rich pumice below (base not shown). [Anaputa Point section - Lake Rotoma]

Photo 28: Matahina Ignimbrite (very top) with plinian airfall below, overlying Murupara-G, Anaputa, and Murupara-E tephra in the Kaingaroa forest. [Pahekeheke section]

Photo 29: Matahina Tephra, overlying paleosol in weathered Murupara-G and Anaputa tephra in the eastern Bay of Plenty. [Huntress Creek sect.]

Photo 30 : Matahina airfall at Ohiwa Harbour. Note pink ash near base separated from paleosol below by a coarse lithic-rich pumice lapilli bed.
[Hiwarau section]

Photo 31 : Matahina airfall below Ignimbrite near Matata. Note sandy ash separating fine pink ash from dark brown sand below. [Ohinekoao Stream cliff sect.]

Photo 32 : Hiwarau Tephra(at top),
Torere-B Tephra
(creamcakes within loess),
and Torere-A Tephra (note
white-pink-white ash layers
and bioturbated base).
[Ohiwa Hill section]

Photo 33 : Hiwarau Tephra (note small thickness) and Torere-A Tephra (at base)
[Huntress Creek section]

Photo 34 : Hiwarau Tephra, note thickness, shower bedded coarse pumice, and fine weathered base. [Hiwarau section]

Photo 35 : Opotiki Tephra (at top), Torere-G Tephra (creamcakes), and Ohiwa Hill Tephra (note highly bioturbated base). [Ohiwa Hill section]

Photo 36 : Opotiki (note grey base),
Ohiwa Hill, Torere-E, and
Hiwarau (at base) tephras.
[Ohiwa Hill section]

Photo 37 : Reihana-G Tephra (airfall & ignimbrite), below the Torere-K Tephra and above
the Reihana-F Tephra. [Reihana Road section]

Photo 38 : Torere-I / Opotiki Tephra; note Op-1 (at base), grey Op-2, Op-3, & Tor-1(1) layers. [Hiwarau section]

Photo 39 : Torere-L, Torere-I (weathered and not distinctive), and Opotiki tephra (note contrast of Op-1, Op-2 & Op-3). [Huntress Creek section]

Photo 40 : Kaingaroa Tephra at top (note bedding) to Torere-L Tephra at spade base (note bedding). [Reihana Road section]

Photo 41 : Kaingaroa Tephra at top (note well bedded nature) to Opotiki Tephra. Note bedding in Torere-L Tephra. [Torere West section]

Photo 42 : Close up of Torere-N (at top), Torere-M, Torere-L (main focus), and Torere-K tephra. [Torere West section]

Photo 43 : Close up of the Torere-O and Torere-N tephra, and the paleosol below the Kaingaroa Tephra. [Torere West section]

Photo 46 : Kaingaroa Tephra (note bedding), overlying paleosol developed into the Reihana-M Tephra, with further Torere subgroup eruptives below.
[Reihana Road section]

Photo 47 : Kaingaroa Tephra in the eastern Bay of Plenty (note bedding), with the base of the Huntress-B Tephra above.
[Huntress Creek section]

Photo 44 : The lower part of the Kaingaroa and the Reihana-M and Torere-O tephras, and the paleosols between them. [Reihana Road section]

Photo 45 : Huntress Creek subgroup;
Huntress-D (at top),
Huntress-C, Huntress-B and
Kaingaroa tephras.
[Huntress Creek section]

Photo 48 : Pisolites within the near source, fine grained phreatomagmatic Kaingaroa Tephra. [Reihana Road section]

Photo 49 : Huntress-B Tephra (note reverse grading).
[Hiwarau section]

Photo 50 : Huntress-D Tephra (at top),
Huntress-C Tephra, and top of
the Huntress-B tephra within
loess.
[Huntress Creek section]

Photo 51 : Basal beds of the Huntress-D Tephra (at top), loess, and the Huntress-C Tephra.
[Huntress Creek section]

Photo 52 : Post-Rotoiti tephra, overlying a very well developed paleosol with the orange Kutarere Tephra at base. [Opape section]

Photo 53 : Kutarere Tephra; note zone of greater weathering at top, clay nodules throughout, and Mn concretions & clay layer at base.
[Opape section]

Photo 54 : Little Waihi beach; showing torrential flood deposit (Maketu-B). Note faulting at right.

Photo 55 : "Banded pumice beds" and Maketu-L Ignimbrite at top. Dr Roy Bailey (of USGS) on ladder. [Little Waihi Road]

Photo 56 : Pikowai Tephra; note change
in bedding near top —
Pikowai-(2) unit (better
bedded).
[Pikowai Reserve section]

Photo 57 : Rocky Cutting Road section; note very well developed red-brown paleosol
below the Rotoiti Tephra (half way up). Spade handle is at base of
Rocky-E Tephra, while spade base is at Rocky-D Tephra.

Photo 58 : Westend Tephra; note paleosol developed into top.
[Westend-Otarawairere section]

Photo 59 : Waingarara Tephra, underlying the Waingarara Ignimbrite.
[McCoy Road-(1) section]

Photo 60 : Ruatuna Road section: viewed from the south showing post-Rotoiti tephra, gravels, subaqueously deposited sediment, and Waingarara Ignimbrite (road level). Note how the lignites and tephra grade into subaqueous deposits to the north.

Photo 60(a) : Diagram of the above photo of the Ruatuna Road section; note that the Mangaone Tephra is prominent whereas the bedded base of Rotoiti is only preserved in a small area above the gravels.

Photo 61 : Hawaii section; showing Mangai (top) and Rotoiti tephra overlying unweathered loess which rests on the very well developed "last interglacial paleosol".

Photo 62 : Copenhagen Road section; showing several tephra and paleosols between the Rotoiti Tephra and the well developed reddish paleosol just above greywacke basement.

Photo 63 : Paerata Ridge Road section; showing erosion below the Rotoiti Tephra. Also note erosion at base of loess below the yellow Paerata Tephra.

Photo 63(a) : Diagram of the above photo showing locations of the various tephra, loess, paleosols and erosional features.

Photo 64 : Matahina Ignimbrite and airfall, with basal pink ash resting on weathered brown estuarine sand. [Kohioawa cliff section]

Photo 65 : Terrestrially deposited airfall tephra — Paerata, Tablelands-D and Otawairere — overlying a paleosol developed into beach gravels. [Otarawairere section]

Photo 66 : Ngatiawa West section; showing Ngatiawa Tephra conformably resting on marine sands (on right), but with an erosional contact (at left), with the post-Ritoiti tephras occurring above the thick "last interglacial paleosol.

Photo 67 : Hokianga Island (located in Ohiwa Harbour), showing flat terrace surface and cliff section.

Photo 68 : Pukeruru Point section; showing erosional unconformity into gravels with fluvially deposited Kohioawa Tephra above.

Photo 69 : Ohiwa Harbour Road West section; base of lower gravels – contact with marine sands.

Photo 70 : Waiotahi cliffs section; showing terrestrially deposited airfall tephras and paleosols at top, overlying gravels, which overlie marine sand.

Photo 70a : Diagram of the above photo. Note the several interbedded layers of sand within the gravels.

Photo 71 : Promontory of Tablelands Terrace surface at the Huntress Creek section.

Photo 72 : Lower part of the Opape section showing the diatom-containing and organic-rich lake deposits.

Photos 73 & 74 : From right to left:— Ohiwa Harbour, with Ohiwa Hill behind; then along coast to Waiohahi cliffs and the Tablelands Terrace surface.

Photo 75 : High terrace (Omaio Terrace) at southwestern end of Omaio Bay, probably the Matakaoa Terrace.

Photo 76 : Last interglacial terraces at Te Papa Point, northern end of Waihou Bay; Te Papa (lower) and Otamaroa (higher).

APPENDIX - B:

Section Locations

Appendix (B) : List of Sections — with location directions

site no.	name	grid reference	notes
001	Herepuru Road	V15/376626	road-side cliff face at sharp corner inland
002	Herepuru Stream bridge	V15/344642	cliff face in bush on south side of road just east of bridge
003	—	—	—
004	Pahekeheke	V16/356186	north side of forestry track (overgrown?), just northeast of Pahekeheke Stream bridge (FORESTRY[1])
005	Anaputa Point	V15/243422	road-side cliff face (southwest)
006	Herepuru Road-(2)	V15/374604	small road cutting next to driveway on west side of road
007	—	—	—
008	Kohioawa cliffs	V15/366631	entire sea-cliff face in this region, sparse exposure but best around
009	Ohinekoao Reserve	V15/369629	cliff face on west side of valley, walk up side of slump
010	—	—	—
011	Lake Matahina	V16/448353	in cliff face on east side of track
012	—	—	—
013	Torere School	X15/048517	road cutting on southeast side of road as it rises to terrace surface
014	Opape	X15/984484	road cutting and slip scarp on south side of road as it rises to terrace surface
015	Huntress Creek	W15/833472	road-side cliff face (southern) and cliff paralleling the east bank of Huntress Creek — around through gate onto farm (PRIVATE LAND[1])
016	Paerata Ridge Road	W15/822479	road-side cliff (south) base of road as it rises to terrace surface
017	Ohiva Hill	W15/765468	road cutting on north side of road at the very top of the hill
018	Ohiva Beach	W15/761487	sea-cliff & slump, at slight headland
019	Reeves	W15/751463	road cutting (south) through seaward end of headland
020	Hillview orchard	W15/766469	cliff on south side of driveway, several hundred metres from main road (PRIVATE LAND[2])
021	Tablelands Road	W15/887462	road-side cliff face (north) near base of road as it rises to terrace surface
022	Torere West	X15/028507	road-side cliff face (south) near base of road as it rises to terrace surface
023	Murupara-(1)	V17/306992	road cutting (both sides but northeast better) part way down road as it descends from the Kaingaroa Plateau
024	Taneatua	W15/616400	cliff face next to driveway (PRIVATE LAND[3])
025	Pukeruru Point	W15/737459	sea-cliff and along to headland
026	Hokianga Island	W15/730456	sea-cliff, north side of island (PRIVATE LAND[4])
027	Hiwarau	W15/722450	sea-cliff, just south of where flatish clearing leads down to shore from farm track (PRIVATE LAND[5])
028	Ruatuna Road	W15/739441	road cutting (both sides but west better)
029	Waiotahi River	W15/788477	road-side cliff face (southeast) at end of ancient promontory
030	Pikowai Reserve	V15/326651	cliff face in bush on south side of road, opposite railway crossing
031	Little Waihi Road	V14/163766	road-side cliff face on left as road descends to camping ground and on west side of estuary entrance
032	Jackson Road	X15/955468	top of road cutting (west) part way up road as it rises to top of hill
033	Ohinekoao Stream cliff	V15/374614	slump cliff on east side of valley, visible from road (15 min. climb)
034	Kutarere Wharf	W15/730435	sea-cliff just west of jetty entrance
035	Waiotahi cliffs	W15/799482	sea-cliffs in this region, but especially near the westernmost end
036	Maandonk	W16/671333	small road-side cutting (north) adjacent to entrance to Maandonk's property

List of Sections (continued)

site no.	name	grid reference	notes
037	Waipua	W16/661354	road-side cutting (north) at base of hill
038	Kukumoa cutting	W15/843469	road cutting (south side best) especially the western end
039	McCoy Road-(1)	W15/675455 to 676454	road-side exposures and cuttings (both sides) from base of hill (intersection) to hairpin bend at top
040	McCoy Road-(2)	W15/677455	road-side slump cliff face (north)
041	Otarawaitere & Westend	W15/636531 to W15/637532	exposures on landward side of track, both at highest point and part-way down in either direction 15+ m up cliff face from beach level
042	Flax Hill	W15/748466	exposure at base of cliff at seaward end of headland (PRIVATE LAND?[6]). Can walk around headland at low tide.
043	Ngatiawa lookout & west	W15/636522	road cutting (both sides, east=lookout) just down from lookout at top of hill (Matahina off the side below road level).
044	Awakeri Springs	V15/488477	road-side cliff face (east) at bend south of camping ground
045	Waioeka River	W15/847416	cliff cut by river (west bank)
046	Burchett	W15/884468	farm track exposure on right (east) half-way down Tablelands Terrace (PRIVATE LAND[7])
047	Gault's slip	W15/892447	slumped cliff face in Tablelands Terrace on east side of Otara River, access by farm track (PRIVATE LAND[8])
048	Copenhagen Road	X14/233737	road cutting (south), opposite house
049	—	—	
050	—	—	
051	Wairuru cemetery	Y14/400828	all of road-side cliff face (east) through high last interglacial terrace, near cemetery entrance (west)
052	Raukokore	Y14/401822	road cutting (both sides?) near top of last interglacial terrace
053	Waioituma	Y14/478872	road cutting (north side best) near top of last interglacial terrace
054	Boundary	Y14/602903	road-side cliff face (south)
055	—	—	
056	—	—	
057	Torere east	X15/054520	road-side exposure (southwest) east of school
058	Awaawakino	X15/005493	road-side exposure (southeast)
059	Tirohanga	X15/911476	slip surface of old sea-cliff (very eastern edge of Tablelands Terrace)
060	—	—	
061	Old Waioitapu Road	U16/083110 to 100105	road-side exposures along the northern side of the road in this area (FORESTRY[1])
062	Reihana Road	U17/093098	south side of forestry track, large cutting/cliff face (FORESTRY[1])
063	Waingarara	W15/677419	road cutting (east) near highest part of road
064	Waimana Hill	W16/663344	road-side exposure (southwest) part way up southern side of hill
065	Waihora Road	T17/575881	road cutting (east)
066	Te Piki	Y14/562905	road-side exposure (west)
067	Te Piki west	Y14/577903	road-side exposure (north)
068	Te Piki farm track	Y14/560904	100 m up farm track (west) (PRIVATE LAND[9])
069	airstrip road	Y14/560901	road-side exposure (southeast) part way up road as it rises to terrace surface, and terrace surface
070	—	—	
071	—	—	
072	—	—	

List of Sections (continued)

site no.	name	grid reference	notes
073	airstrip farm	Y14/564896	farm track exposure (southwest) (PRIVATE LAND[10])
074	Rereaurira track	Y14/567917 to 565915	farm track exposures all the way up through terrace (PRIVATE LAND[11])
075	—	—	—
076	—	—	—
077	Waihapokopoko bridge	X15/155634	road-side exposure (south) adjacent to eastern end of bridge
078	Wilson's farm-(1)	V15/384618	farm track cutting (southwest), near top of main track (PRIVATE LAND[12])
	" -(2)	" /383618	farm track exposure (east), down a southern branch of main track (PRIVATE LAND[12])
	" -(3)	" /382619	farm track exposure (southeast) part way up main track (PRIVATE LAND[12])
	" -(4)	" /383619	farm track exposure (south) start of main track (PRIVATE LAND[12])
079	Newdicks Beach	V14/159781	parking area cliff exposure (south), just above main beach (PRIVATE ROAD with toll access)
080	Rangitawa Stream	S23/196165	stream-cut cliff section
081	Hawai	X15/061527	road cutting (both sides)
082	Waipunga	V19/147446	road cutting (west)
083	Wilson's farm-(5)	V15/384620	cliff section at eastern end of paddock (PRIVATE LAND[12])
084	Wilson's farm driveway	V15/386622	farm track cutting in coastal cliff (south) (PRIVATE LAND[12])
085	Ohiwa Loop Road	W15/739466	road cutting (east) near end of ancient promontory
086	Omokoroa slump	U14/789922	large coastal slump scarp on edge of promontory
087	Omokoroa east	U14/790899	sea-cliff near end of headland
088	Welcome Bay	U14/907820	coastal sea-cliff, and road cutting through headland (detailed work may require permission — Maori pa site)
089	—	—	—
090	Rocky Cutting Road	U14/965810	road cutting (west)
091	—	—	—
092	Ohiwa Harbour Rd West	W15/764468	road cuttings (south) down from top of hill to Ohiwa Harbour
093	Omaio	X15/181648	exposures as gravel farm(?) road rises to terrace surface
094	Whitely Road	V16/350152	forestry track exposure (east) just north of stream crossing (FORESTRY[1])
095	Parapara Road	V16/294147	forestry track exposure (east) (FORESTRY[1])
096	Ridgeway Road	V16/340135	forestry track cutting (north) (uncertain position) (FORESTRY[1])
097	Onuku-(2)	V16/104151	road cutting (both sides)
098	Onuku-(1)	V16/113141	road cutting (northeast)
099	Onuku-(3)	V16/121114	road cutting (northeast)
100	Murupara-(2)	V17/316991	road cutting (northeast), near base of hill down off the Kaingaroa plateau towards Murupara
101	Pikowai cliffs	V15/331648	coastal sea-cliff
102	Burke Road	W15/698454	road-side exposure opposite intersection of Burke Road with Wainui Road (main road around Ohiwa Harbour)
103	Downer Road	T16/646335	road cutting (northwest), near top of plateau as road descends to a stream (FORESTRY[2])
104	Tikorangi Road	U16/786205	road-side cliff exposure (southwest?) (FORESTRY[2])
105	—	—	—

List of Sections (continued)

site no.	name	grid reference	notes
106	—	—	road-side cliff exposure (east)
107	Ruahihi Road	U14/795761	
108	—	—	
109	—	—	
110	Bonisch Road	V16/300207	road cutting (east: - top & middle, west: - base)
111	Peach Road	—	road cutting (west) (FORESTRY ^[2])
112	Reid's Reserve	W15/611452	section off farm track (to south) (PRIVATE LAND ^[13])
113	Brown's driveway	X15/906476	driveway cutting (south) up through Tablelands Terrace (PRIVATE LAND ^[14])
114	Munupara-(3)	V17/282996	road cutting (southwest)
115	Whitianga orchard	X15/149633	road cutting (both sides)
116	Motuhora Island	W15/589648	very large sea-cliff on western side of island (PERMISSION REQUIRED from D.O.C. Whakatane)
117	Bookbinder's	X15/050525	driveway cutting as it rises to house on terrace surface (PRIVATE LAND ^[15])
118	Waiotahi Back Road	W15/783460	cliff section on east side of parking area (just off road)
119	McCoy ridge	W15/682440	roadside exposure (west)

Forestry^[1] = Kaingaroa Forest, entry permits from office on Highway 38

Forestry^[2] = Tokoroa Forest - N.Z. Forest Products, entry permits from Kinleith office off Highway 1

Private land^[1] = Gebert & Bachmann (Karl & John); RD2; Opotiki. ph (07) 315-7537 or 315-7536 (John's wife). Access readily given, may not be needed for small groups.

Private land^[2] = Go to house, unknown owners (changed hands).

Private land^[3] = Kevin & Carol Harper; Awahou Road.; PDC; Taneatua. ph (07) 312-9110

Private land^[4] = Owned by a Maori trust, uncertain of name - perhaps Roimata Marae.

Private land^[5] = Owned by a Maori trust, contact Charlie Aromoana at Kutarere Store (ph. (07) 315-46317), may be same as that above.

Private land^[6] = E. W. Hunt (Ted & Babs). ph (07) 315-4877. Can walk around headland at low tide and permission may not be needed.

Private land^[7] = Knock at managers house in front, or go and find him on property. Happily gives permission.

Private land^[8] = Unknown contact; Bill Wingate — (ph. (07) 315-7884, knows section and contacts.

Private land^[9] = Unknown contact; likely to be first house west of area (north side of road).

Private land^[10] = Unknown contact; ask anyone visible.

Private land^[11] = Contact people in house at front.

Private land^[12] = Roy Wilson; Box 105; Matata; Bay of Plenty ph. (07) 312-2146. Readily gives permission.

Private land^[13] = Contact people in house at end of track, or first driveway to the south (east side of road).

Private land^[14] = Contact Robin Brown? (may have changed ownership) or see people in house at top.

Private land^[15] = Contact people in house at top, or perhaps phone number available from advertising sign outside driveway.

List of Sections

1 = Otawairere	13 = Flax Hill
2 = Ngatiawa lookout	14 = Reeves
3 = Reid's Reserve	15 = Ohiwa Beach
4 = Taneatua	16 = Ohiwa harbour Rd. West
5 = McCoy Road-(1)	17 = Ohiwa Hill
6 = Waingarara	18 = Waiohahi River
7 = Hiwarau	19 = Paerata Ridge Road
8 = Kutarere Wharf	20 = Huntress Creek
9 = Ruatuna Road	21 = Kukumoa cutting
10 = Hokiangi Island	22 = Waioeka River
11 = Pukeruru Point	23 = Gault's slip
12 = Ohiwa Loop Road	24 = Tablelands Road
	25 = Burchett

Map of Ohiwa Harbour area (Whakatane-Opotiki) showing section locations

APPENDIX - C:

Fossils

Macrofossils

Fossil identifications carried out by A.G. Beu and P.P. Vella.

- 1) **Boundary section [Y14/602903]**
 - below tephra & lignite.
 - *Antisolarium*
 - *Dosinia*
 - *Austrovenus*

- 2) **Kohioawa cliffs section (Matata) [V15/365631]**
 - immediately below Tablelands-A Tephra (00804)
 - *Maoricolpus (Zeacolpus?)*
 - *Pellicaria vermis* (shallow?)
 - *Alcithoe arabica*
 - *Neilo australis*
 - *Austrofusus glans*

All fossils are shallow water species (generally inner shelf) existing on soft substrate (Neilo = siltstone), and all range in age from Nukumaruan/Castlecliffian to recent. *Austrofusus* and *Pellicaria* have also been found in the Te Piki shellbed.

Diatoms

List of main diatom species found in reworked tephra deposits at Opape (species for which more than one diatom seen) (Margaret A. Harper, personal communication, 1994).

diatom counts in brackets: tephra sample 01406 first, then tephra sample 01409 (01406, 01409).

habitats: P = planktonic, A = attached, S = on sediment, T = on soils.

salt tolerance: B = brackish water, F = freshwater, H = salt intolerant.

pH preferences: W = prefers hardwater, N = prefers neutral water, C = prefers humic water,
B = prefers salt water, ? = unknown.

[habitat information from Foged (1979), and Krammer & Lange-Bertalot (1986-1991)]

- Achnanthes conspicua* (A. Mayer) (2, 0) A, F, W.
Achnanthes lanceolata (de Brebisson) Grunow (1, 1) A, F, W.
Achnanthes spp. (4, 1) A, F, N.
Aulacoseira italica (Ehrenberg, Simonsen) (0, 2) P, F, W.
Cymbella species (5, 0) A, F, N.
Diploneis subovalis (Cleve) (7, 1) S, F, W.
Eunotia exigua (de Brebisson, Rabenhorst) (1, 1) A, F, W.
Eunotia lunaris (Ehrenberg, Grunow) (2, 0) A, F, N.
Eunotia pectinalis (Rabenhorst) (0, 3) A, H, C.
Frustulia vulgaris (Thwaites, De Toni) (1, 1) T, F, W.
Gomphonema species (4, 0) A, F, N.
Hantzschia amphioxys (Ehrenberg, Grunow) (2, 0) T, F, N.
Navicula arvensis (Hustedt?) (2, 0) S, F, C.
Navicula capitata (Ehrenberg) (3, 0) S, F, W.
Navicula contenta (Grunow) (3, 1) T, F, W.
Navicula cryptocephala (Kutzing) (4, 0) S, F, W.
Navicula helvetica (Brun) (1, 2) S, F, W.
Navicula maceria (Schimanski?) (2, 1) S, F, C.
Navicula pupula f. minuta (Grunow) (1, 5) S/T, F, N.
Navicula saxophila (Bock) (0, 2) T, F, B.
Navicula other species (5, 4) S, F/B, ?.
Neidium ampliutum (Ehrenberg, Krammer) (1, 1) S, F, W.
Nitzschia debilis (Arnott, Grunow) (2, 0) S, F, W.
Nitzschia filiformis var. *conferta* (Richter) (Lange-Bertalot) (1, 4) T, B, B.
Nitzschia pellucida (Grunow) (2, 1) S, B, B.
Pinnularia brauni (Grunow, Cleve) (1, 1) S, H, C.

continued over...

Diatoms – continued from previous page...

Pinnularia gibba (Ehrenberg) (2, 0) S, F, N.

Pinnularia microstauron (Ehrenberg, Cleve + varieties) (0, 2) S, F, N.

Pinnularia other species (2, 1) S, F/H, N/C.

Rhopalodia gibberula (Ehrenberg, O. Muller) (2, 1) S, F, W.

Stauroneis anceps (Ehrenberg) (2, 1) S/T, F, W.

Stauroneis obtusa (Lagerstedt) (2, 0) T, F, N.

Surirella angusta (Kutzing) (3, 3) S, F, N.

Surirella contorta (Kittoni) (0, 2) S, F, C.

Synedra parasitica (W. Smith, Hustedt) (4, 0) T, F, W.

other siliceous algal remains

Chrysophycean cysts (7, 4) P, F/H, N/C.

Discussion of the results:

The floras are both freshwater ones, tephra sample 01406 contains a fairly high proportion of species that grow attached to water weeds, this indicates a stable environment, several of the species prefer still water. In grab samples from South Island lakes, only lakes with a maximum depth of over 4 metres contained as high a proportion of epiphytes, but water weeds would be protected from waves in a smaller lake or pool, the small proportion of planktonic species indicates the latter. Tephra sample 01406 fell into a permanent rather than ephemeral water body. The flora in tephra sample 01409 from the bottom of the sequence appears more disturbed than sample 01406, fewer diatom remains were seen in a standard transect of sample 01409 (01406 – 86, 01409 – 47) and these belonged to fewer species. There are fewer algae which live attached to water weeds or rocks in sample 01409 and higher proportions from other habitats. Sediment ones are motile and can move onto the surface following burial, soil diatoms grow on bare damp soil and are often associated with erosion in the catchment. The flora in tephra sample 01409 contains both more diatoms which prefer brackish water and more intolerant of salt these would not grow together, therefore some of the diatoms were washed in. Tephra sample 01409 contains a higher proportion of diatoms which grow in humic waters, these could come from pools in the peat under the tephra. While a few of the species seen have not previously been recorded in New Zealand they all fairly common extant species.

References:

- Foged, N. (1979): Diatoms in New Zealand, the North Island. *Bibliotheca Phycologica* 47, 1–224
- Krammer, K; Lange-Bertalot, H. (1986, 1988, 1991, 1991): *Susswasserflora von Mitteleuropa*, 2, Bacillariophyceae parts 1 (876pp), 2 (596pp), 3 (576pp), 4 (438pp).

APPENDIX - D:

Elevations of terraces and sections

Date	Time	Meas.*	Elev.#	Site location
(1992)				
24/6	1409	200	70	set @ 200 m on flat area, van – Wilson Deer farm.
	1417	215	86	base of pumice gravel on main track.
	1431	270	142	top of marine sequence, just below white ash beneath base of Paerata.
	1440	225	99	pumice gravels on side track.
	1446	213	86	base of pumice gravel on main track, again.
	1450	206	80	sub.-aq. pum on flats near bottom of track.
	1458	213?	87 or	
			104	base of Ohinkoao Tuff (lower) – Wilson (83/3)
	1511	194	70	van (200 m).
	1514	185	61	white pumice on upper part of driveway.
	1521	175	51	top of gatepost half way down driveway, 1 m above large pumices, several m above lowermost pumices.
	1528	120	0	mean sea level – Kohioawa Beach. = 0.0
	1610	124	0	mean sea level – Westend Beach. = 0.0
	1623	161	39	top of beach gravels at Otawairere.
	1631	160	39	top of beach gravels at Otawairere.
	1701	158	39	top of gravels on Westend side.
	1705	117	0	mean sea level. = 0.0

HEIGHT OF GRAVELS = 39 – 40 m

25/6	0910	200	127	set @ 200 – Ngatiawa Lookout (at van).
	0951	190	120	top of marine overlain by pumice.
	1012	195	127	Ngatiawa lookout - van.
	1016	68	0	mean sea level. = 0.0
	1136	61	25?	cut surface – Jackson Road.
	1144	34	0	mean sea level – Opape Beach. = 0.0

(1992)				
26/6	1032	103	35.5	Te Piki tephra.
	1047	180	109	lowermost tephra – Boundary section.
	1220	197	109	lowermost tephra – Boundary section.
	1223	195	105	Benchmark – [GE 159] = 104.8
	1235	191	100	grey organic rich silts below "boundary section" - 50 m along road.
	1301	205	109	lowermost tephra – Boundary section.
	1319	207	109	lowermost tephra – Boundary section.
	1327	135	35.5	Te Piki tephra.
	1333	122	21	base of Rereauria track (at van).

continued over...

* Meas. = measured barometric height before calibration.

Elev. = calculated true elevation above mean sea-level.

Date	Time	Meas.	Elev.	Site location
(26/6) continued from previous page...				
	1343	142	40	lowermost gravels / contact onto silts/sands containing fossils.
	1346	149	47	tephra between gravels.
	1348	153	51	thin white tephra within sand.
	1349	159	57	organic layer between gravels.
	1354	177	75	top of sequence — grass.
	1400	144	40	lowermost gravels / contact onto silts/sands containing fossils.
	1405	126	21	van.
	1409	140	35.5	Te Piki tephra.
	1411	148	43.5	Benchmark - [GE 152A] = 43.5
	1413	163	58.5	top of 2 tephra up airstrip road.
	1414	183	78.5	top of section, base of weathered tephra — soil/top of sand/ash.
	1418	193	88.5	terrace surface, van next to airstrip shed.
	1426	204	98.5	exposed top of yellow weathered marine sand in next terrace up; not top of marine sequence though.
	1434	195	88.5	terrace surface, van next to airstrip shed.
	1439	165	58.5	top of 2 tephra up airstrip road.
	1546	165	58.5	top of 2 tephra up airstrip road.
	1548	172	64	upper fossil locality on airstrip road.
	1553	167	58.5	top of 2 tephra up airstrip road.
	1555	153	43.5	Benchmark – [GE 152A]. = 43.5
	1558	156	46	white tephra, just past gate; base of Te Piki farm track section.
	1602?	160	49.5	tephra at base of recorded section.
	1612	183	72	terrace surface.
	1615	179	68	Rotoehu.
	1630	157	43.5	Benchmark – [GE 152A]. = 43.5
	1632	147	35.5	Te Piki tephra.
	1634	146	34.5	Matahina? (dips towards the north - Te Piki Tephra) Therefore this tephra is below Te Piki.
	1659	136	25	base of gravels; Te Papa terrace — on road coming up hill.
	1702	168	59.5	base of Rotoehu; Otamaroa terrace — on road coming up hill.
	1704	171	57.5	cut surface?; Otamaroa terrace — on road coming up hill.
	1704	173	57.5	base of Rotoehu; Otamaroa terrace.
	1706	162	50	gravel on top – Waotuma section.
	1706	165	53	base of Rotoehu – Waiotuma section.
	1708	112	0	mean sea level. = 0.0

Date	Time	Meas.	Elev.	Site location
(1992) 28/6	0815	19	0	mean sea level. = 0.0
	0820	50	31	Waihou Bay-base of gravels on cut surface.
	0827	43	24	Te Papa tce; base of Rotoehu.
	0832	37	19	cut surface, Wairuru Cemetery
	0842	47	29.5	base of Fe stained marine gravels; top of marine silt with wood.
	0846	55	38.5	highest gravels.
	0851	64	46.5	top of weathered gravels — beneath Rotoehu – Raukokore section.
	0859	75	58	top of gravels beneath Rotoehu – Otamaroa Terrace.
	0900	76	59	highest gravels.
	1112	29	14	top of white ash containing gravels – Waihapokopoko Bridge section.
	1118	14	0	mean sea level. = 0.0
	1120?	25	11	loess paleosol beneath Rotoehu – Whitianga orchard section.
	1219	60	39	dark paleosol beneath weathered tephra, 2.5 m below Rotoehu – Hawai section.
	1227	22	0	mean sea level. = 0.0

APPENDIX - E:

Standards chemical data

- microprobe analyses of glass
and mineral standards

In the following chemical tables:

- (i) All element analyses calculated on a water free basis.
- (ii) All Fe calculated as FeO.
- (iii) Water (where listed) calculated by difference from 100%.
- (iv) Means of the analyses are presented at the bottom of the table below the basal underlined analysis. The number of analyses and the standard deviations of the means are presented on the next line below this.
- (v) The accepted chemistry of the standards are in brackets (bold & italicized) at the very end of each group.
- (vi) The glass analyses are split into two parts representing respectively; early microprobe work carried out with an operating system using peak searches and counts at the peak position, and later microprobe work using an operating system that integrated under the curve produced as the spectrometers scanned across the peak position.

Comenditic obsidian — KN18, Naivasha, Kenya.

analysed using the peak search method

SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
75.79	10.68	0.15	3.40	0.00	0.00	0.11	5.21	4.34	0.31	0.31
75.49	10.70	0.16	3.56	0.00	0.00	0.20	5.00	4.58	0.32	-0.32
75.90	10.56	0.21	3.46	0.00	0.00	0.12	5.11	4.29	0.35	-0.39
75.69	10.55	0.24	3.54	0.00	0.00	0.15	5.08	4.39	0.35	-1.28
76.05	10.74	0.20	3.60	0.00	0.00	0.14	4.48	4.47	0.32	-0.02
74.24	10.46	0.18	3.49	0.00	0.00	0.24	6.67	4.43	0.29	0.46
75.96	10.49	0.19	3.40	0.00	0.00	0.25	4.71	4.66	0.33	1.95
75.90	10.39	0.21	3.40	0.00	0.00	0.15	5.09	4.52	0.34	1.09
75.60	10.57	0.16	3.54	0.00	0.00	0.13	5.18	4.58	0.22	1.82
75.64	10.42	0.13	3.60	0.00	0.00	0.09	5.19	4.61	0.32	-0.99
76.21	10.60	0.13	3.32	0.00	0.00	0.23	4.47	4.75	0.28	3.65
75.26	10.52	0.18	3.74	0.00	0.00	0.12	5.67	4.42	0.09	1.34
75.83	10.49	0.18	3.51	0.00	0.00	0.23	4.86	4.57	0.32	1.38
75.65	10.56	0.21	3.61	0.00	0.00	0.09	5.29	4.36	0.22	-0.14
75.69	10.37	0.19	3.71	0.00	0.00	0.13	5.11	4.53	0.28	-0.31
75.66	10.70	0.16	3.36	0.00	0.00	0.14	5.07	4.58	0.31	1.26
76.95	10.48	0.14	3.28	0.00	0.00	0.12	4.86	4.05	0.12	0.32
75.54	10.53	0.16	3.39	0.00	0.06	0.13	5.26	4.50	0.43	0.58
75.42	10.59	0.20	3.45	0.00	0.00	0.10	5.69	4.38	0.18	-1.63
75.13	10.49	0.20	3.51	0.00	0.00	0.23	5.81	4.37	0.27	-0.76
76.02	10.61	0.20	3.72	0.00	0.00	0.11	4.93	4.19	0.21	1.17
75.57	10.63	0.09	3.45	0.00	0.00	0.19	5.34	4.42	0.30	0.60
75.83	10.45	0.13	3.66	0.00	0.00	0.10	4.97	4.60	0.28	-0.90
76.48	10.36	0.13	3.41	0.00	0.00	0.19	4.77	4.42	0.25	0.36
75.79	10.36	0.30	3.63	0.00	0.10	0.14	5.10	4.27	0.32	-1.55
75.87	10.39	0.17	3.45	0.00	0.00	0.11	5.23	4.48	0.29	0.32
76.31	10.11	0.14	3.32	0.00	0.00	0.09	5.31	4.41	0.32	-0.33
76.32	10.17	0.19	3.42	0.00	0.00	0.10	5.06	4.42	0.32	-1.71
75.64	10.69	0.07	3.41	0.00	0.06	0.18	5.04	4.61	0.30	-0.12
76.16	10.59	0.13	3.37	0.00	0.00	0.09	4.87	4.49	0.31	0.81
75.50	10.53	0.17	3.65	0.00	0.00	0.16	5.16	4.61	0.23	3.31
75.71	10.34	0.16	3.50	0.00	0.00	0.19	5.34	4.46	0.30	0.76
75.99	10.17	0.18	3.54	0.00	0.00	0.17	5.27	4.40	0.28	1.92
76.31	10.25	0.14	3.45	0.00	0.00	0.10	4.99	4.47	0.28	1.68
76.08	10.32	0.13	3.20	0.00	0.00	0.23	5.14	4.57	0.34	2.52
75.86	10.44	0.21	3.31	0.00	0.00	0.24	5.23	4.37	0.33	1.40
76.33	10.36	0.13	3.27	0.00	0.00	0.20	4.80	4.55	0.35	2.16
75.68	10.54	0.18	3.37	0.00	0.00	0.10	5.27	4.46	0.40	0.25
76.09	10.55	0.18	3.57	0.00	0.00	0.10	4.66	4.45	0.39	0.86
75.59	10.41	0.15	3.51	0.00	0.00	0.08	5.24	4.67	0.34	0.72
75.31	10.49	0.18	3.65	0.00	0.00	0.24	5.29	4.48	0.36	0.05
75.55	10.52	0.18	3.70	0.00	0.00	0.13	5.31	4.48	0.13	-0.70
75.80	10.48	0.17	3.49	n.d	0.01	0.15	5.15	4.47	0.29	0.52
42	0.43	0.15	0.04	0.13	—	0.02	0.05	0.13	0.07	1.25

standard

(74.60 10.53 0.18 3.45 0.06 0.01 0.15 5.68 4.39 0.37 <0.10 99.97)

(Analysts: S.A. Malik & D.A. Bungard)

Comenditic obsidian — KN18; continued...

analysed using the integration under the curve method

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
74.90	10.28	0.34	3.42	0.11	0.00	0.27	5.56	4.82	0.30	0.83	
75.08	10.41	0.54	3.58	0.00	0.00	0.27	5.66	4.23	0.24	-0.56	
74.23	10.34	0.32	4.11	0.00	0.00	0.22	5.95	4.50	0.33	-0.12	
74.59	10.29	0.19	3.60	0.00	0.07	0.21	6.33	4.33	0.38	0.82	
74.35	10.63	0.23	3.48	0.19	0.00	0.12	6.12	4.44	0.43	1.19	
75.57	10.54	0.39	3.58	0.00	0.00	0.11	5.09	4.39	0.33	2.34	
74.64	10.56	0.32	3.42	0.00	0.00	0.14	5.99	4.51	0.42	2.25	
73.84	10.49	0.29	3.94	0.19	0.08	0.18	6.00	4.60	0.38	0.96	
74.77	10.65	0.16	3.53	0.00	0.00	0.16	5.83	4.50	0.39	-0.80	
73.95	10.94	0.25	3.65	0.10	0.00	0.17	6.10	4.46	0.38	3.21	
74.87	10.96	0.22	3.78	0.00	0.00	0.14	5.02	4.68	0.33	1.75	
74.97	10.72	0.22	3.44	0.00	0.00	0.18	5.61	4.47	0.39	1.39	
75.16	10.58	0.19	3.35	0.18	0.08	0.20	5.48	4.41	0.36	1.07	
74.55	10.72	0.23	3.42	0.00	0.00	0.15	5.92	4.51	0.51	-0.96	
74.45	9.83	0.28	3.62	0.16	0.00	0.14	6.53	4.66	0.32	2.02	
75.95	11.04	0.16	3.60	0.00	0.05	0.15	4.18	4.45	0.42	-0.20	
74.73	10.39	0.20	3.72	0.00	0.00	0.19	5.70	4.61	0.46	3.01	
74.98	10.36	0.20	3.55	0.12	0.05	0.15	5.84	4.42	0.32	1.30	
74.78	10.28	0.16	3.51	0.00	0.00	0.18	6.36	4.43	0.29	0.68	
74.53	11.06	0.32	3.27	0.00	0.04	0.18	5.71	4.63	0.25	0.89	
74.79	10.88	0.25	3.64	0.00	0.00	0.10	5.38	4.74	0.20	1.74	
74.41	10.61	0.25	3.65	0.00	0.00	0.14	6.42	4.23	0.30	0.71	
75.05	10.16	0.26	3.35	0.00	0.06	0.15	6.19	4.58	0.19	2.40	
75.11	10.46	0.34	3.54	0.00	0.00	0.15	5.47	4.69	0.24	1.42	
74.76	10.55	0.26	3.57	0.04	0.02	0.17	5.77	4.51	0.34	1.14	
24 0.46	0.30	0.09	0.19	0.07	0.03	0.04	0.52	0.15	0.08	1.12	

standard

(74.60 10.53 0.18 3.45 0.06 0.01 0.15 5.68 4.39 0.37 <0.10 99.97)

(Analysts: S.A. Malik & D.A. Bungard)

combined comenditic glass analyses (both peak search & integration methods)

75.42	10.51	0.20	3.52	0.02	0.01	0.16	5.37	4.48	0.31	0.75
66 0.67	0.21	0.08	0.16	0.05	0.02	0.05	0.52	0.14	0.08	1.23

Amphibole — Engels.

analysed using the integration under the curve method

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	Cl	total
42.31	11.15	0.95	19.73	0.58	9.38	11.36	1.38	0.73	0.00	97.57	
42.17	11.51	0.86	19.48	0.77	8.81	11.34	1.43	0.90	0.00	97.27	
41.31	12.28	1.02	18.06	0.70	9.22	11.46	1.65	0.95	0.05	96.70	
42.30	12.17	0.89	18.00	0.71	9.25	11.45	1.54	0.87	0.00	97.18	
42.95	12.51	0.91	18.80	0.78	9.30	11.16	1.59	0.99	0.00	98.99	
42.93	12.27	0.82	18.82	0.67	9.32	11.41	1.42	0.93	0.06	98.65	
43.19	12.01	0.96	19.31	0.71	9.23	11.59	1.73	0.97	0.07	99.77	
41.99	11.86	0.96	19.26	0.53	8.42	11.31	1.55	0.87	0.05	96.80	
40.87	12.46	1.05	18.95	0.68	8.85	11.57	1.52	0.87	0.03	96.85	
41.40	11.90	0.80	19.15	0.75	9.20	11.32	1.39	0.88	0.04	96.83	
43.69	11.94	0.91	17.50	0.73	9.26	11.47	1.40	0.81	0.00	97.71	
41.13	12.12	0.73	19.18	0.69	9.24	11.48	1.50	0.87	0.00	96.94	
41.80	11.71	0.71	19.40	0.70	9.00	11.36	1.39	0.88	0.06	97.01	
40.38	12.30	1.02	18.57	0.76	8.74	11.26	1.76	0.98	0.00	95.77	
42.15	12.24	1.01	18.75	0.72	8.99	11.37	1.44	0.87	0.00	97.54	
42.04	12.03	0.91	18.86	0.70	9.08	11.39	1.51	0.89	0.02	97.44	
0.92	0.37	0.11	0.62	0.07	0.27	0.11	0.12	0.07	0.03	1.01	

standard

(42.14 12.09 0.94 19.05 0.63 8.67 11.56 1.63 0.91 --- 97.62)

(Analyst: C.O. Ingamells)

Basaltic glass — VG-A99, Makaopuhi, Hawaii (USNM 113498/1).

analysed using the peak search method

SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
51.84	12.64	3.99	13.22	0.30	5.34	9.31	2.62	0.74	0.00	1.44
50.93	12.74	4.32	13.83	0.20	9.44	4.93	2.85	0.76	0.00	1.66
51.77	12.34	4.31	13.52	0.00	5.15	9.43	2.66	0.82	0.00	2.14
51.51	12.32	4.19	13.83	0.00	5.03	9.41	2.86	0.83	0.00	2.26
51.48	12.48	4.18	13.95	0.00	5.01	9.22	2.74	0.80	0.14	2.85
51.72	12.33	4.38	13.61	0.00	5.04	9.38	2.70	0.85	0.00	2.42
52.38	12.67	4.12	13.10	0.00	4.97	9.39	2.39	0.94	0.04	1.76
51.48	12.31	4.17	13.97	0.00	5.08	9.32	2.79	0.87	0.00	2.68
51.67	12.45	4.20	13.62	0.00	5.26	9.16	2.74	0.89	0.00	2.52
51.71	12.47	4.59	13.35	0.00	5.04	9.24	2.76	0.83	0.00	1.15
51.56	12.42	4.27	13.82	0.00	5.09	9.03	2.81	0.93	0.06	1.15
51.57	12.91	4.13	13.02	0.00	5.01	9.68	2.84	0.75	0.08	2.89
51.15	12.31	4.35	13.47	0.00	5.13	9.69	2.93	0.87	0.09	2.40
51.40	12.51	4.42	13.44	0.00	5.12	9.56	2.69	0.87	0.00	2.47
51.53	12.47	4.33	13.89	0.00	5.22	9.07	2.59	0.90	0.00	2.44
51.80	12.53	4.16	13.32	0.00	5.20	9.24	2.90	0.85	0.00	3.26
51.96	12.18	4.15	13.47	0.00	5.27	9.35	2.79	0.82	0.00	2.47
51.46	12.43	4.42	13.46	0.00	5.22	9.25	2.92	0.85	0.00	0.69
51.84	12.40	4.31	13.56	0.00	5.18	9.22	2.64	0.85	0.00	2.52
51.52	12.42	4.37	13.30	0.00	5.18	9.27	3.10	0.80	0.04	0.06
51.77	12.43	4.02	13.32	0.00	5.19	9.46	2.93	0.84	0.04	2.42
52.46	12.34	4.15	13.00	0.00	4.91	9.52	2.79	0.82	0.00	0.35
51.93	12.52	4.14	13.46	0.00	5.06	9.29	2.69	0.92	0.00	0.60
52.21	12.54	4.15	13.12	0.00	5.04	9.25	2.81	0.88	0.00	3.44
51.87	12.48	4.06	13.31	0.00	5.06	9.52	2.77	0.80	0.12	1.61
51.68	12.76	3.85	13.55	0.00	5.18	9.45	2.69	0.83	0.00	2.90
52.40	12.40	4.12	13.19	0.00	5.17	9.20	2.73	0.80	0.00	2.02
51.56	12.43	4.43	13.33	0.00	5.29	9.39	2.74	0.82	0.00	0.56
51.84	12.24	4.26	13.68	0.00	5.05	9.37	2.71	0.84	0.00	3.38
51.54	12.44	4.22	13.49	0.00	5.30	9.35	2.83	0.84	0.00	-1.44
51.92	12.42	4.17	13.39	0.00	5.26	9.44	2.65	0.76	0.00	1.25
51.04	12.40	4.20	13.99	0.16	5.15	9.63	2.60	0.82	0.00	1.60
51.40	12.23	4.13	14.04	0.00	5.12	9.42	2.85	0.82	0.00	1.35
51.85	12.43	4.03	13.71	0.00	5.29	8.93	2.96	0.80	0.00	1.08
51.82	12.60	4.10	13.33	0.00	5.19	9.34	2.82	0.80	0.00	0.40
51.74	12.49	4.12	13.52	0.27	5.09	9.10	2.85	0.78	0.04	1.11
51.84	12.39	4.10	13.37	0.00	5.17	9.42	2.84	0.82	0.06	0.92
51.55	12.29	4.18	13.53	0.00	5.16	9.49	2.93	0.88	0.00	1.67
51.98	12.48	4.11	13.17	0.00	5.25	9.30	2.84	0.87	0.00	1.95
52.11	12.49	3.99	13.18	0.00	5.05	9.56	2.70	0.87	0.06	0.38
51.61	12.06	3.93	13.99	0.00	5.28	9.61	2.71	0.82	0.00	2.21
51.52	12.41	3.91	13.63	0.00	5.18	9.47	3.01	0.87	0.00	1.44
51.92	12.20	4.01	13.46	0.00	5.07	9.51	2.95	0.87	0.00	-0.13
51.90	12.29	4.07	13.32	0.00	5.13	9.65	2.83	0.82	0.00	0.63
52.06	12.33	4.13	13.15	0.00	5.21	9.43	2.73	0.88	0.07	2.37
51.30	12.40	4.42	13.86	0.00	4.97	9.57	2.69	0.78	0.00	4.20
52.20	12.29	4.04	13.11	0.00	5.08	9.49	2.93	0.87	0.00	3.26
51.52	12.44	4.12	13.61	0.00	5.24	9.58	2.67	0.82	0.00	3.09
51.38	12.44	4.14	13.80	0.00	5.12	9.48	2.81	0.83	0.00	1.59
51.78	12.30	4.39	13.14	0.00	5.37	9.31	2.88	0.82	0.00	4.14
51.54	12.64	4.08	13.32	0.00	5.18	9.44	2.95	0.84	0.00	1.51
51.93	12.33	4.23	13.28	0.00	5.17	9.43	2.70	0.86	0.07	0.96
51.56	12.28	4.26	13.53	0.00	5.11	9.50	2.89	0.86	0.00	0.57
51.86	12.34	3.95	13.69	0.00	5.22	9.42	2.67	0.86	0.00	2.17
51.24	12.50	5.04	13.34	0.00	5.08	9.01	2.89	0.89	0.00	0.86
51.57	12.55	4.14	13.55	0.00	5.12	9.63	2.70	0.73	0.00	1.80
51.71	12.43	4.19	13.49	0.02	5.22	9.31	2.79	0.84	0.02	1.77
56 0.31	0.15	0.19	0.27	0.06	0.58	0.62	0.12	0.04	0.03	1.10

standard

(50.94 12.49 4.06 13.3 0.15 5.08 9.30 2.66 0.82 --- 0.02 99.39)

(Analyst: J. Norberg)

Basaltic glass — VG-A99; continued...

analysed using the integration under the curve method

SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
50.89	13.38	3.90	13.23	0.79	4.99	9.02	2.85	0.89	0.06	-1.75
51.22	12.53	4.03	13.84	0.32	5.00	9.46	2.67	0.88	0.05	0.85
51.40	12.45	4.30	13.64	0.12	5.15	9.01	3.00	0.88	0.07	0.85
50.70	12.78	4.24	13.60	0.12	5.45	9.33	2.95	0.82	0.00	1.49
51.41	12.16	4.47	13.39	0.18	5.03	9.58	2.87	0.91	0.00	1.26
51.69	12.26	4.18	13.65	0.00	5.20	9.60	2.62	0.80	0.00	2.03
51.44	12.12	4.45	13.13	0.18	5.28	9.71	2.88	0.80	0.00	1.52
51.36	12.51	4.08	13.54	0.29	4.95	9.89	2.50	0.88	0.00	0.95
51.26	12.46	4.24	13.53	0.25	5.13	9.57	2.77	0.78	0.00	1.86
51.09	12.35	3.98	13.65	0.23	5.36	9.71	2.70	0.86	0.06	0.35
50.41	12.57	4.26	13.58	0.36	5.15	10.00	2.67	0.94	0.06	0.76
51.15	12.57	3.96	13.85	0.27	5.13	9.44	2.70	0.89	0.07	0.97
50.63	12.93	4.40	13.84	0.18	5.07	9.19	2.84	0.91	0.00	2.19
51.21	12.20	4.26	13.77	0.35	5.19	9.36	2.85	0.80	0.00	1.02
51.18	12.53	4.35	12.91	0.25	5.15	9.82	2.85	0.89	0.06	1.39
51.23	12.66	4.70	13.44	0.00	5.01	9.69	2.60	0.68	0.00	1.24
51.32	12.56	4.06	13.87	0.17	4.95	9.36	2.87	0.84	0.00	0.12
51.17	12.85	4.19	13.63	0.31	5.05	9.52	2.46	0.82	0.00	2.36
51.28	12.94	3.97	13.86	0.00	5.16	9.14	2.91	0.75	0.00	-0.08
51.36	12.52	4.25	13.40	0.25	5.33	9.38	2.66	0.85	0.00	1.86
51.77	12.47	4.13	13.15	0.28	5.18	9.27	2.88	0.88	0.00	0.90
50.63	13.07	4.08	13.23	0.34	5.23	9.62	2.96	0.84	0.00	2.69
50.95	13.06	4.17	13.10	0.18	5.20	9.73	2.73	0.86	0.00	2.00
50.69	12.87	4.09	13.11	0.36	5.55	9.52	2.89	0.86	0.06	2.58
51.22	12.63	4.24	13.27	0.12	5.28	9.54	2.92	0.78	0.00	0.14
52.07	12.79	4.16	13.05	0.11	4.86	9.29	2.90	0.77	0.00	1.14
51.54	12.69	3.88	13.48	0.17	5.34	9.35	2.76	0.74	0.05	0.98
51.03	12.70	4.20	13.30	0.36	5.34	9.54	2.74	0.74	0.06	-0.77
50.70	12.37	4.12	13.54	0.29	5.68	9.29	3.14	0.88	0.00	1.87
51.45	12.16	4.65	13.42	0.22	5.32	9.13	2.83	0.82	0.00	4.59
52.12	11.72	4.41	13.98	0.14	5.18	8.89	2.66	0.83	0.07	2.21
51.49	12.16	4.34	13.35	0.23	5.14	9.66	2.94	0.69	0.00	-0.70
51.24	13.27	4.09	13.22	0.12	5.50	8.89	2.85	0.81	0.00	0.77
52.13	12.31	4.28	13.25	0.10	5.22	9.31	2.59	0.74	0.07	1.30
51.14	12.67	4.44	13.54	0.22	5.17	9.18	2.73	0.89	0.00	1.22
52.14	12.64	4.10	12.47	0.12	5.61	9.23	2.86	0.79	0.05	0.21
52.11	12.38	3.97	13.48	0.10	5.15	9.31	2.62	0.80	0.08	0.26
51.77	12.51	4.01	13.20	0.14	5.19	9.40	2.81	0.90	0.07	1.04
50.90	12.60	4.34	13.41	0.19	5.42	9.41	2.88	0.78	0.06	0.50
51.65	12.18	4.18	13.29	0.14	5.48	9.32	2.84	0.92	0.00	2.18
50.86	12.63	4.16	13.86	0.16	5.23	9.42	2.74	0.88	0.06	0.84
51.10	12.68	4.10	13.96	0.29	5.06	9.02	2.89	0.90	0.00	0.72
51.41	12.83	4.50	13.28	0.00	5.31	9.02	2.86	0.80	0.00	3.17
50.89	12.62	4.10	14.02	0.00	5.07	9.64	2.86	0.80	0.00	1.14
51.20	12.96	3.91	13.37	0.28	5.21	9.34	2.87	0.86	0.00	4.79
50.80	12.28	4.16	13.76	0.26	5.39	9.54	2.84	0.98	0.00	2.06
51.33	12.76	4.01	13.39	0.31	5.25	9.34	2.72	0.78	0.10	5.59
51.27	12.58	4.19	13.46	0.21	5.22	9.40	2.80	0.83	0.02	1.38
47 0.42	0.32	0.19	0.31	0.13	0.18	0.25	0.13	0.06	0.03	1.34

standard

(50.94 12.49 4.06 13.3 0.15 5.08 9.30 2.66 0.82 -- 0.02 99.39)

(Analyst: J. Norberg)

combined basaltic glass analyses (both peak search & integration methods)

51.51	12.50	4.19	13.48	0.11	5.22	9.35	2.79	0.84	0.02	1.59
103 0.43	0.25	0.19	0.29	0.14	0.44	0.49	0.13	0.05	0.03	1.23

Hornblende P.S.U. — 4-190.

analysed using the integration under the curve method

SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	Cl	total
40.65	10.30	3.22	26.05	0.59	4.17	10.51	3.71	1.56	0.25	101.01

standard

(39.34 10.00 2.88 26.15 0.41 4.38 10.79 2.02 1.47 0.18 97.62)

(Analyst: C.O. Ingamells)

Rhyolitic glass — VG-568, Yellowstone National Park (USNM 72854).

analysed using the peak search method

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
	77.29	12.08	0.07	1.14	0.00	0.00	0.48	3.85	5.09	0.00	1.13
	78.05	11.87	0.07	1.05	0.00	0.08	0.47	3.28	5.01	0.12	0.06
	77.67	11.97	0.07	1.10	n.d	0.08	0.47	3.57	5.05	0.12	0.65
2	0.53	0.15	0.00	0.07	—	—	0.00	0.40	0.05	—	0.67

standard

(76.71 12.06 0.12 1.23 0.03 <0.10 0.50 3.75 4.89 0.12 99.57)

(Analyst: J. Norberg)

Rhyolitic glass — VG-568; continued...

analysed using the integration under the curve method

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
	76.35	11.88	0.13	1.32	0.55	0.09	0.43	4.00	5.03	0.25	-0.87
	77.23	11.89	0.07	1.08	0.12	0.05	0.45	4.04	4.91	0.14	2.89
	76.91	12.35	0.16	1.14	0.00	0.05	0.48	3.77	4.98	0.15	1.70
	76.98	12.09	0.12	1.09	0.00	0.11	0.47	3.87	5.12	0.13	1.85
	77.09	12.63	0.07	1.17	0.00	0.08	0.41	3.74	4.71	0.11	-0.73
	76.57	12.20	0.11	1.14	0.15	0.04	0.41	4.04	5.21	0.11	2.81
	77.50	11.88	0.08	1.06	0.00	0.05	0.43	4.00	4.82	0.18	-0.05
	76.82	11.91	0.11	1.18	0.00	0.06	0.52	4.05	5.19	0.16	-0.58
	76.83	12.27	0.12	1.16	0.00	0.07	0.37	4.18	4.92	0.07	1.90
	76.51	12.23	0.20	1.35	0.00	0.05	0.34	4.07	5.09	0.15	1.40
	76.53	12.78	0.12	1.19	0.00	0.04	0.52	3.83	4.85	0.14	1.15
	76.65	12.11	0.17	1.17	0.27	0.05	0.53	4.11	4.86	0.09	-1.24
	77.38	12.29	0.12	1.10	0.00	0.05	0.44	3.76	4.69	0.17	1.41
	76.97	12.28	0.13	1.15	0.00	0.08	0.42	4.15	4.68	0.14	-0.70
	76.39	12.00	0.21	1.24	0.00	0.07	0.44	4.39	5.11	0.14	2.32
	76.49	12.43	0.08	1.30	0.10	0.09	0.41	3.94	5.00	0.14	3.08
	77.19	12.16	0.22	1.04	0.00	0.13	0.43	3.96	4.81	0.07	2.52
	75.71	13.65	0.14	1.27	0.00	0.06	0.48	3.78	4.82	0.09	-1.42
	76.91	12.36	0.11	1.07	0.07	0.05	0.51	4.12	4.69	0.12	-0.44
	77.09	12.29	0.07	1.09	0.13	0.09	0.46	3.76	4.90	0.12	1.23
	76.95	12.07	0.16	1.02	0.00	0.06	0.46	4.14	5.02	0.13	1.13
	76.79	12.37	0.00	1.01	0.00	0.10	0.48	4.05	5.06	0.14	3.75
	76.22	12.53	0.11	1.32	0.00	0.10	0.41	4.21	5.01	0.09	2.77
	77.10	12.37	0.00	1.13	0.00	0.08	0.27	3.85	5.10	0.09	2.04
	77.05	12.47	0.14	1.06	0.00	0.08	0.50	3.56	5.03	0.11	5.75
	76.81	12.30	0.13	1.15	0.06	0.07	0.44	3.97	4.94	0.13	1.35
25	0.40	0.36	0.04	0.10	0.12	0.02	0.06	0.19	0.16	0.04	1.77

standard

(76.71 12.06 0.12 1.23 0.03 <0.10 0.50 3.75 4.89 0.12 99.57)

(Analyst: J. Norberg)

combined rhyolitic glass analyses (both peak search & integration methods)

	76.87	12.28	0.12	1.15	0.05	0.07	0.44	3.94	4.95	0.12	1.29
27	0.46	0.36	0.05	0.10	0.12	0.03	0.06	0.22	0.16	0.04	1.72

Albite — Amelia Ab-1.

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	Cl	total
	69.29	21.93	0.00	0.00	0.00	0.00	2.46	9.63	0.49	0.00	103.80
	69.16	21.89	0.00	0.00	0.00	0.00	2.38	9.67	0.18	0.00	103.28
	68.17	20.04	0.00	0.00	0.00	0.00	0.80	9.36	0.10	0.00	98.47
	68.87	21.29	0.00	0.00	0.00	0.00	1.88	9.55	0.26	0.00	101.85
	0.61	1.08	—	—	—	—	0.94	0.17	0.21	—	2.94

standard

(65.63 20.83 — 0.03 — — 1.93 9.06 2.39 99.87)

(Analyst: C.O. Ingamells)

Ilmenite, Ilmen Mountains, Miask, USSR (USNM 96189).

analysed using the integration under the curve method

SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	Cl	total
0.08	0.05	47.41	46.60	5.10	0.36	0.00	0.00	0.00	0.00	99.60
0.00	0.08	47.67	45.53	4.86	0.33	0.00	0.00	0.00	0.00	98.47
0.04	0.07	47.54	46.07	4.98	0.35	0.00	0.00	0.00	0.00	99.04
0.06	0.02	0.18	0.76	0.17	0.02	---	---	---	---	0.80

standard

(---	---	45.70	46.54	4.77	0.31	---	---	---	---	98.24)
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(Analyst: D. Mills, J. Nelen, J. Norberg)

Orthoclase — Or-1.

analysed using the integration under the curve method

SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	Cl	total
66.62	18.21	0.00	0.00	0.00	0.00	0.00	0.69	14.84	0.00	100.36
66.40	18.44	0.00	0.00	0.00	0.08	0.00	1.10	14.72	0.00	100.74
66.67	18.56	0.00	0.00	0.00	0.00	0.00	1.03	14.85	0.00	100.11
64.79	18.52	0.00	0.00	0.00	0.00	0.00	1.05	13.72	0.00	98.08
64.42	18.33	0.00	0.00	0.00	0.00	0.00	1.03	13.04	0.00	96.82
65.35	18.27	0.00	0.00	0.00	0.00	0.00	1.08	15.26	0.00	99.96
64.85	18.41	0.00	0.00	0.00	0.00	0.00	1.13	15.19	0.00	99.58
65.44	18.39	0.00	0.00	0.00	0.01	0.00	1.02	14.52	0.00	99.38
0.84	0.13	---	---	---	0.03	---	0.15	0.82	---	1.41

standard

(64.39	18.58	---	0.03	---	---	---	1.14	14.92	---	99.06)
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(Analyst: C.O. Ingamells)

Pyroxene P.S.U. — PX-1.

analysed using the integration under the curve method

SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	Cl	total
53.05	0.56	0.20	2.85	0.00	16.93	24.49	0.23	0.00	0.00	98.31
52.85	0.59	0.23	2.88	0.14	17.21	25.42	0.19	0.00	0.00	99.51
55.49	0.66	0.32	3.00	0.00	17.33	24.91	0.20	0.00	0.00	101.91
53.88	0.73	0.28	2.74	0.10	17.40	24.75	0.27	0.00	0.00	100.15
54.88	0.67	0.31	2.93	0.00	17.53	25.30	0.23	0.00	0.00	101.85
52.72	0.63	0.19	2.89	0.09	16.95	24.74	0.22	0.00	0.06	98.49
54.07	0.60	0.26	2.99	0.13	16.88	24.74	0.20	0.00	0.00	99.87
53.66	0.70	0.26	3.04	0.16	16.83	24.55	0.26	0.00	0.00	99.46
54.90	0.63	0.27	2.83	0.20	17.22	24.13	0.20	0.04	0.00	100.42
53.94	0.64	0.26	2.91	0.09	17.14	24.78	0.22	0.00	0.01	100.00
0.99	0.05	0.04	0.09	0.08	0.25	0.40	0.03	0.01	0.02	1.27

standard

(53.94	0.66	0.26	2.93	0.07	16.93	24.55	0.24	---	---	99.58)
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(Reference: Goldich et al. *Can. J. Earth Sci.* 4, 747, 1967)

APPENDIX - F:

Glass chemical data

- microprobe analyses of
Bay of Plenty tephras

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water

site 1 = Herepuru Rd (V15/376626)

00101 Herepuru: (pum) (pkrsch)											
78.29	11.97	n.d.	0.91	0.07	0.81	3.45	4.28	0.22	1.76		
78.58	11.94	0.16	0.93	0.08	0.81	2.99	4.31	0.19	2.80		
78.38	11.94	0.10	0.91	0.08	0.81	3.37	4.23	0.18	1.78		
78.54	12.05	0.10	0.88	0.07	0.81	2.86	4.47	0.22	3.21		
78.94	11.91	n.d.	0.92	0.11	0.76	3.12	4.08	0.17	3.84		
77.93	12.25	0.09	1.04	0.07	0.81	3.04	4.56	0.21	3.59		
78.40	11.96	0.11	0.95	0.08	0.84	2.99	4.42	0.25	2.69		
78.80	12.20	0.11	0.88	0.06	0.86	2.87	3.98	0.24	3.23		
78.43	12.00	0.08	1.02	0.13	0.76	3.17	4.21	0.21	2.52		
78.15	11.95	0.11	1.01	0.13	0.77	3.07	4.59	0.23	4.09		
78.44	12.02	0.11	0.94	0.09	0.80	3.09	4.31	0.21	2.95		
10	0.30	0.12	0.02	0.06	0.03	0.03	0.19	0.20	0.03	0.80	

site 2 = Herepuru Stream Bridge (V15/344642)

00201 Matahina pre-igb. airfall (near base): (pum) (pkrsch)											
78.44	12.25	0.09	0.96	n.d.	0.86	3.57	3.64	0.20	2.75		
79.07	12.07	n.d.	1.01	0.09	0.75	3.35	3.46	0.20	3.41		
77.62	12.57	0.15	1.02	0.10	0.89	3.65	3.80	0.21	7.98		
78.48	12.16	0.12	0.94	0.12	0.89	3.57	3.61	0.11	1.95		
78.99	12.02	n.d.	1.04	0.11	0.83	3.35	3.45	0.21	2.82		
78.35	12.11	0.10	0.96	0.11	0.82	3.65	3.71	0.18	3.88		
78.97	12.07	0.12	0.98	0.09	0.86	3.13	3.62	0.17	4.39		
78.94	12.03	0.09	1.03	0.09	0.91	3.28	3.47	0.16	5.06		
79.14	12.01	n.d.	1.05	n.d.	0.76	3.24	3.62	0.18	4.23		
78.90	11.94	0.11	1.05	0.09	0.82	3.32	3.62	0.14	2.02		
78.59	12.19	0.11	1.02	0.07	0.81	3.55	3.47	0.20	3.57		
78.68	12.13	0.11	1.01	0.10	0.84	3.42	3.59	0.18	3.81		
11	0.45	0.17	0.02	0.04	0.02	0.05	0.18	0.11	0.03	1.64	

00202 Matahina igb.-B: (pum) (integr)											
78.14	12.24	0.11	1.13	0.06	0.76	3.49	3.83	0.24	7.10		
78.19	12.05	n.d.	1.06	0.19	0.83	3.60	3.85	0.23	6.77		
78.02	12.34	0.15	1.00	0.14	0.87	3.56	3.62	0.30	6.90		
77.55	12.36	0.16	1.22	0.11	0.99	3.59	3.79	0.24	6.52		
77.68	12.16	0.16	1.12	0.13	0.82	3.63	3.99	0.31	6.98		
77.72	12.33	0.12	1.19	0.13	1.03	3.68	3.71	0.11	6.48		
77.64	12.32	0.14	1.01	0.13	0.85	3.77	3.86	0.27	7.54		
77.56	12.26	0.11	1.13	0.15	0.92	3.75	3.85	0.27	7.12		
77.81	12.26	0.14	1.11	0.13	0.88	3.63	3.81	0.24	6.93		
8	0.26	0.11	0.02	0.08	0.04	0.09	0.10	0.11	0.06	0.35	

site 4 = Pahekeheke Road (V16/356186)

00401 Bonisch: (pum) (pkrsch)											
78.76	12.35	0.12	0.92	0.09	0.85	3.03	3.77	0.10	9.02		
78.72	12.37	n.d.	0.92	n.d.	0.89	3.23	3.81	0.08	10.40		
78.12	12.46	0.09	0.95	0.15	0.83	3.45	3.85	0.09	8.69		
78.35	12.26	0.12	0.84	0.08	0.91	3.45	3.85	0.14	8.41		
78.31	12.34	n.d.	0.81	0.09	0.84	3.59	3.89	0.13	8.52		
78.13	12.34	0.14	0.94	0.11	0.83	3.45	3.95	0.12	7.51		
78.67	12.33	0.09	0.81	0.07	0.88	3.33	3.73	0.10	8.40		
78.09	12.39	0.09	0.97	0.07	0.78	3.47	4.00	0.14	9.21		
78.14	12.40	0.10	0.90	0.13	0.83	3.50	3.86	0.13	8.81		
78.48	12.29	0.12	0.83	0.11	0.80	3.48	3.78	0.11	8.30		
78.67	12.43	n.d.	0.92	0.10	0.81	3.14	3.76	0.17	9.64		
78.40	12.36	0.11	0.89	0.10	0.84	3.37	3.84	0.12	8.81		
11	0.27	0.06	0.02	0.06	0.03	0.04	0.17	0.08	0.03	0.76	

00402 Murupara-E: (pum) (pkrsch)											
78.33	12.10	0.07	0.99	0.09	0.77	3.66	3.82	0.15	4.47		
78.63	12.25	0.08	0.95	0.11	0.80	3.52	3.50	0.15	5.22		
78.63	12.07	0.10	1.01	0.10	0.78	3.25	3.86	0.20	6.96		
78.67	12.20	0.13	0.98	0.08	0.81	3.26	3.71	0.17	4.81		
78.82	12.18	0.08	1.06	n.d.	0.73	3.06	3.90	0.18	5.43		
78.54	12.27	0.08	1.03	0.10	0.77	3.22	3.81	0.18	5.37		
78.51	12.15	n.d.	0.94	0.11	0.76	3.42	3.96	0.17	6.01		
78.54	12.19	0.07	0.91	0.08	0.75	3.34	3.95	0.16	5.64		
78.94	11.98	0.12	0.91	0.10	0.72	3.27	3.78	0.17	5.63		
78.43	12.22	0.13	0.96	0.12	0.77	3.41	3.82	0.15	6.44		
78.27	12.29	0.10	1.14	0.08	0.88	3.73	3.36	0.15	4.14		
78.33	12.29	n.d.	0.82	0.07	0.73	3.67	3.89	0.20	5.34		
78.62	12.15	n.d.	0.91	n.d.	0.69	3.53	3.95	0.16	6.14		
78.09	12.23	0.07	1.06	0.05	0.69	3.67	3.94	0.19	4.75		
78.14	12.10	0.13	1.03	0.10	0.73	3.56	4.07	0.15	7.83		
78.77	12.24	n.d.	0.90	0.12	0.69	3.23	3.91	0.15	6.80		
78.77	12.24	n.d.	1.00	0.11	0.65	3.12	3.96	0.15	6.55		
78.53	12.18	0.10	0.98	0.09	0.75	3.41	3.83	0.17	5.74		
17	0.24	0.08	0.02	0.07	0.02	0.05	0.21	0.18	0.02	0.97	

00403 Murupara-G: (mix+pum) (pkrsch)											
78.18	12.21	0.13	1.14	0.15	1.04	3.41	3.53	0.21	4.53		
78.40	12.16	0.13	1.08	0.13	1.02	3.16	3.68	0.26	5.89		
78.19	12.22	0.17	1.17	0.15	1.08	3.31	3.52	0.19	4.63		
78.50	12.11	0.18	1.19	0.10	0.96	3.32	3.43	0.20	4.46		
78.79	11.98	0.15	1.00	0.10	0.94	3.26	3.58	0.19	4.70		
78.33	12.24	0.15	1.08	0.08	0.99	3.23	3.67	0.22	4.93		
78.55	12.09	0.12	1.18	0.12	1.01	3.17	3.50	0.28	5.54		
78.33	12.20	0.12	1.18	0.11	0.98	3.37	3.55	0.16	5.38		
78.31	12.21	0.17	1.17	0.15	1.00	3.22	3.59	0.18	4.78		
78.45	12.28	0.11	1.25	0.13	0.99	3.25	3.34	0.21	5.28		
78.54	12.18	0.19	1.11	0.12	0.90	3.26	3.53	0.18	6.21		
78.34	12.28	n.d.	1.16	0.15	0.93	3.33	3.63	0.18	7.10		
78.41	12.18	0.14	1.14	0.12	0.99	3.27	3.55	0.20	5.29		
12	0.17	0.09	0.03	0.07	0.02	0.05	0.08	0.10	0.03	0.80	

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water

00404 Anaputa: (pum) (pkrsch)

77.20	12.58	0.25	1.46	0.16	1.32	3.42	3.41	0.21	2.80		
77.28	12.83	0.18	1.52	0.14	1.24	3.13	3.39	0.30	6.08		
78.23	12.12	0.15	1.21	0.15	1.16	3.39	3.33	0.26	2.94		
76.85	12.95	0.12	1.49	0.15	1.41	3.51	3.37	0.14	3.15		
76.81	12.86	0.22	1.57	0.21	1.30	3.47	3.39	0.18	2.47		
77.37	12.74	0.20	1.29	0.16	1.30	3.37	3.38	0.20	3.43		
78.29	12.10	0.12	1.29	0.12	1.08	3.42	3.39	0.20	2.81		
78.08	12.45	0.09	1.20	0.13	1.02	3.38	3.43	0.22	2.93		
78.00	12.48	0.22	1.17	0.13	1.13	3.26	3.40	0.20	2.89		
78.17	12.41	0.11	1.32	0.11	1.00	3.24	3.46	0.17	2.57		
76.36	13.63	0.15	1.47	0.16	1.27	3.52	3.34	0.10	1.74		
77.77	12.43	0.17	1.37	0.20	1.21	3.31	3.38	0.16	2.71		
77.82	12.56	0.15	1.19	0.13	1.13	3.34	3.47	0.21	2.46		
77.56	12.63	0.16	1.35	0.15	1.20	3.37	3.39	0.20	3.00		
13	0.62	0.40	0.05	0.14	0.03	0.12	0.11	0.04	0.25	1.01	

00405 Matahina pre-igb. airfall (near top): (pum) (pkrsch)

77.76	12.27	0.21	1.20	0.12	0.95	3.68	3.60	0.22	4.81
77.81	12.28	n.d.	1.04	0.14	0.81	3.68	3.96	0.27	4.15
78.04	12.17	0.15	0.99	0.11	0.82	3.66	3.85	0.20	3.95
77.72	12.32	0.13	1.08	0.14	0.80	3.87	3.68	0.25	3.07
77.51	12.39	0.20	1.16	0.11	0.91	3.70	3.81	0.21	3.68
78.05	12.28	n.d.	1.14	0.16	0.80	3.71	3.62	0.25	3.27
77.85	12.26	0.13	1.10	0.09	0.91	3.70	3.72	0.24	2.45
77.52	12.46	0.12	1.07	0.18	0.85	3.72	3.88	0.20	3.07
77.31	12.32	0.17	1.05	0.19	0.82	3.85	3.98	0.31	4.05
77.73	12.31	0.16	1.09	0.14	0.85	3.73	3.79	0.24	3.61
9 0.25	0.08	0.03	0.06	0.03	0.06	0.07	0.14	0.04	0.72

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water

site 8 = Kohioawa Cliffs (V15/366631)

00801 Kohioawa-3; (pum) (pkrsch)

a	77.80	12.18	0.15	1.03	0.15	0.71	3.01	4.76	0.22	3.99
a	78.18	12.02	0.18	1.10	0.09	0.84	2.80	4.59	0.21	4.37
a	78.25	12.06	0.16	1.10	n.d.	0.79	2.94	4.49	0.20	3.84
a	78.41	11.94	0.11	1.06	0.14	0.77	2.95	4.38	0.23	4.06
a	77.94	12.17	0.13	1.18	0.07	0.81	3.04	4.47	0.19	4.24
a	78.15	12.04	0.11	0.95	0.16	0.78	3.04	4.56	0.21	4.22
a	77.87	12.10	0.16	0.97	0.09	0.83	2.98	4.79	0.21	3.91
7	78.09	12.07	0.14	1.06	0.12	0.79	2.97	4.58	0.21	4.09
7	0.22	0.08	0.02	0.08	0.03	0.04	0.08	0.15	0.01	0.19
b	78.17	12.28	0.08	0.87	n.d.	0.56	3.10	4.77	0.18	3.30
b	78.37	12.17	n.d.	0.78	n.d.	0.54	3.09	4.86	0.19	3.31
7	78.27	12.22	0.08	0.82	--	0.55	3.10	4.81	0.18	3.31
2	0.14	0.07	--	0.07	--	0.01	0.01	0.07	0.01	0.01
?	78.34	12.27	0.09	0.78	0.13	0.77	2.88	4.58	0.17	4.58

00802 Otawawire; (pum) (pkrsch)

78.12	12.29	n.d.	0.85	n.d.	0.66	3.35	4.61	0.12	2.44
77.98	12.32	n.d.	0.78	n.d.	0.71	3.22	4.85	0.15	3.58
78.60	12.32	n.d.	0.75	n.d.	0.64	3.08	4.48	0.13	4.55
78.33	12.16	n.d.	0.90	n.d.	0.69	3.11	4.64	0.17	3.40
78.37	12.35	0.10	0.75	n.d.	0.72	3.17	4.40	0.15	3.72
78.34	12.19	n.d.	0.71	0.08	0.69	3.12	4.72	0.13	3.47
78.32	12.19	n.d.	0.80	n.d.	0.69	2.99	4.88	0.14	3.75
78.05	12.28	0.10	0.72	0.10	0.70	3.25	4.66	0.13	2.76
78.35	12.15	0.07	0.83	0.08	0.72	3.27	4.43	0.10	3.30
78.08	12.32	0.14	0.76	n.d.	0.62	3.37	4.54	0.17	2.83
78.25	12.26	0.11	0.79	0.09	0.68	3.19	4.62	0.14	3.38
10	0.19	0.08	0.03	0.06	0.01	0.03	0.12	0.17	0.02

00803 Kohioawa Stream; (pum) (pkrsch)

a	77.90	12.27	0.13	0.93	0.14	0.80	3.06	4.69	0.09	5.08*
a	78.16	12.18	0.09	1.05	0.08	0.79	3.27	4.23	0.15	4.32*
a	78.40	12.31	0.08	0.94	0.09	0.82	2.99	4.21	0.15	5.13*
a	78.54	12.06	0.07	0.91	0.11	0.81	2.96	4.43	0.12	5.12*
a	77.08	12.66	0.17	0.96	0.09	0.83	3.54	4.34	0.34	8.19
a	77.53	12.52	0.07	1.05	0.11	0.72	3.37	4.32	0.31	8.82
a	77.27	12.91	0.11	0.84	0.09	0.75	3.62	4.07	0.34	8.53
a	77.07	12.88	0.25	0.90	0.11	0.84	3.29	4.31	0.35	8.11
a	77.27	12.63	0.21	1.09	0.12	0.72	3.28	4.40	0.27	8.50
a	77.41	12.68	0.08	1.04	0.06	0.81	3.54	4.09	0.31	9.53
a	76.75	12.81	0.09	1.14	0.12	0.81	3.48	4.41	0.38	9.07
77.58	12.59	0.12	0.99	0.10	0.79	3.31	4.32	0.25	7.31	
11	0.59	0.29	0.06	0.09	0.02	0.04	0.23	0.17	0.11	1.95
b	78.43	12.19	0.19	1.06	0.21	1.24	2.89	3.72	0.07	4.65*
b	78.44	12.07	0.20	1.03	0.13	1.15	3.02	3.90	0.07	4.81*
b	78.36	12.10	0.18	1.07	0.20	1.15	3.05	3.82	0.08	4.92*
b	78.33	12.13	0.19	1.04	0.18	1.17	2.81	4.16	n.d.	4.99*
b	78.35	12.04	0.12	1.03	0.15	1.17	3.03	4.07	0.06	4.81*
b	78.34	12.03	0.10	1.02	0.17	1.11	3.03	4.10	0.09	4.67*
b	77.37	12.56	0.21	1.10	0.17	1.22	3.27	3.92	0.19	8.13
78.23	12.16	0.17	1.05	0.17	1.17	3.01	3.95	0.10	5.28	
7	0.38	0.19	0.04	0.03	0.03	0.04	0.14	0.16	0.05	1.26
?	77.15	12.45	0.20	0.92	0.13	0.85	3.04	4.97	0.28	8.62

00804 Tablelands-A; (mtb) (pkrsch)

a	78.49	12.18	0.09	0.95	0.09	0.97	3.15	3.87	0.19	4.51
a	78.55	12.05	0.14	0.95	0.09	0.77	3.18	4.15	0.12	4.66
a	78.30	12.20	0.14	0.98	0.12	0.91	3.11	4.06	0.18	5.26
a	78.73	12.15	0.10	0.84	n.d.	0.87	3.10	4.03	0.17	4.55
a	78.09	12.26	0.11	0.99	0.11	0.85	3.28	4.15	0.15	4.32
a	78.57	12.30	n.d.	0.91	0.14	0.90	3.18	3.85	0.16	4.60
78.46	12.19	0.12	0.94	0.11	0.88	3.17	4.02	0.16	4.65	
6	0.23	0.09	0.02	0.06	0.02	0.07	0.06	0.13	0.03	0.32
b	78.25	12.32	0.11	1.23	0.17	1.33	3.09	3.35	0.15	3.71
b	78.76	12.17	0.16	1.01	0.08	1.08	3.15	3.38	0.21	4.31
b	78.48	12.09	0.14	1.17	0.17	1.21	3.25	3.33	0.16	4.63
b	78.65	12.09	0.19	1.08	0.18	1.17	3.17	3.32	0.16	5.03
b	78.46	12.21	0.12	1.09	0.19	1.06	3.25	3.47	0.14	3.84
78.52	12.18	0.14	1.12	0.16	1.17	3.18	3.37	0.16	4.30	
5	0.19	0.10	0.03	0.08	0.04	0.11	0.07	0.06	0.03	0.55
c	78.44	12.28	0.17	0.89	0.18	1.06	3.35	3.49	0.15	4.32

00805 Kohioawa-3 (II); (single pumice) (pkrsch)

78.79	12.13	n.d.	0.82	n.d.	0.58	2.98	4.68	n.d.	4.13	
78.71	12.04	n.d.	0.80	0.08	0.51	2.87	4.78	0.22	3.34	
78.53	12.09	0.09	0.83	0.06	0.53	3.07	4.63	0.17	3.31	
78.56	11.97	n.d.	0.78	0.08	0.47	2.79	5.09	0.25	3.13	
78.51	12.03	0.09	0.85	0.06	0.59	2.88	4.75	0.23	3.47	
78.97	11.94	n.d.	0.82	n.d.	0.60	2.93	4.52	0.21	4.04	
78.83	11.97	0.07	0.86	n.d.	0.51	3.01	4.54	0.21	3.59	
78.43	11.98	0.11	0.92	0.10	0.52	2.95	4.82	0.16	2.81	
78.67	12.02	0.09	0.84	0.08	0.54	2.93	4.73	0.21	3.48	
8	0.19	0.07	0.02	0.04	0.02	0.05	0.09	0.18	0.03	0.44

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water

00806 Kohioawa-3 (II); (single pumice) (Integr)

Source	Age	Sex	Height (m)	Weight (kg)	Age	Sex	Height (m)	Weight (kg)	Age	Sex	Height (m)	Weight (kg)
77.76	12.64	0.09	0.83	0.06	0.62	3.14	4.67	0.18	4.90			
77.31	12.69	0.16	0.87	0.12	0.66	3.34	4.64	0.21	5.92			
77.69	12.76	0.12	0.84	0.06	0.56	3.10	4.66	0.20	6.08			
77.40	12.58	0.15	0.77	0.10	0.54	3.30	4.93	0.24	3.62			
77.18	12.52	0.18	0.95	0.09	0.56	3.09	5.10	0.33	3.29			
77.78	12.58	0.11	0.90	0.12	0.62	3.31	4.37	0.21	4.84			
77.56	12.66	0.13	0.87	0.14	0.60	3.19	4.70	0.15	6.18			
77.51	12.77	n.d.	0.85	0.09	0.58	3.21	4.73	0.26	6.35			
77.37	12.63	0.10	0.93	0.14	0.65	3.41	4.61	0.17	5.56			
77.64	12.52	0.14	0.79	0.05	0.61	3.14	4.94	0.18	4.58			
77.59	12.65	0.19	0.99	0.07	0.61	3.19	4.46	0.24	5.23			
77.41	12.38	0.12	0.96	0.05	0.63	3.23	5.03	0.20	4.83			
77.52	12.62	0.13	0.88	0.09	0.60	3.22	4.74	0.21	5.12			
12	0.19	0.11	0.03	0.07	0.03	0.04	0.10	0.22	0.05	0.98		

00807 Kohioawa-3 (IV); (single pumice) (Integr)

77.73	12.46	0.17	0.97	0.16	0.84	3.03	4.39	0.25	5.49	
77.24	12.29	0.16	1.21	0.08	0.80	3.47	4.51	0.24	4.70	
77.42	12.48	0.16	1.15	0.14	0.77	3.22	4.44	0.23	4.98	
77.07	12.66	0.21	1.02	0.18	0.82	3.08	4.71	0.25	6.75	
77.18	12.50	0.27	1.01	0.14	0.81	3.35	4.53	0.20	5.14	
76.99	12.42	0.15	1.21	0.18	0.78	3.30	4.76	0.22	4.16	
76.91	12.56	0.17	1.31	0.17	0.84	3.27	4.59	0.20	4.52	
77.47	12.44	0.16	1.18	0.14	0.79	3.32	4.27	0.24	5.11	
77.57	12.45	0.17	1.09	0.12	0.77	3.23	4.34	0.26	4.36	
77.30	12.34	0.15	1.36	0.17	0.91	3.18	4.41	0.19	3.95	
78.02	12.19	0.13	1.11	0.18	0.69	3.21	4.28	0.20	3.29	
76.66	12.56	0.21	1.27	0.14	0.89	3.15	4.88	0.25	4.11	
77.62	12.66	0.20	0.91	0.09	0.77	3.15	4.40	0.20	5.12	
77.32	12.46	0.18	1.14	0.14	0.81	3.23	4.50	0.23	4.74	
13	0.37	0.14	0.04	0.14	0.03	0.05	0.12	0.19	0.03	0.85

00808 Kohioawa-3 (I); (mtb) (pkrsch)

a	77.95	11.86	0.17	1.11	0.14	0.88	3.18	4.45	0.26	2.43
a	78.60	11.94	0.14	1.05	0.12	0.80	2.83	4.30	0.24	4.45
a	78.19	11.99	0.17	0.97	0.15	0.79	3.07	4.47	0.21	3.66
a	78.34	11.89	0.13	1.07	0.10	0.86	2.82	4.52	0.26	2.95
a	78.08	11.93	0.18	1.09	0.10	0.80	3.22	4.34	0.25	2.18
a	78.24	12.22	0.18	1.04	0.13	0.79	3.05	4.11	0.24	4.23
a	78.23	12.04	0.16	1.21	0.10	0.80	2.78	4.43	0.25	3.77
a	77.96	11.85	0.17	1.09	0.15	0.80	3.27	4.49	0.22	4.03
a	77.90	12.04	0.16	0.92	0.12	0.85	3.33	4.36	0.24	2.49
	78.17	11.97	0.16	1.07	0.12	0.82	3.06	4.39	0.24	3.35
9	0.22	0.12	0.02	0.07	0.02	0.03	0.21	0.13	0.02	0.85
b	78.85	12.19	n.d	0.93	n.d	0.54	2.75	4.51	0.23	4.26
b	78.32	12.04	n.d	0.88	n.d	0.53	2.87	5.11	0.17	4.63
	78.58	12.11	--	0.91	--	0.54	2.81	4.81	0.20	4.44
2	0.38	0.11	--	0.03	--	0.01	0.09	0.42	0.04	0.26

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water

site 9 = Ohinekoao Reserve (V15/369629)

00901 Ohinekoao-I; (pum) (pkarch)

73.73	14.24	0.36	2.09	0.47	2.50	3.76	2.62	0.22	3.99
75.39	13.66	0.29	1.78	0.31	2.18	3.44	2.83	0.14	5.54
74.99	13.85	0.24	1.90	0.29	2.19	3.67	2.72	0.14	4.72
75.07	13.67	0.34	1.85	0.34	2.14	3.63	2.84	0.13	4.98
74.12	14.45	0.25	2.14	0.61	2.48	3.06	2.71	0.18	6.86
75.75	13.79	0.32	1.89	0.40	2.17	2.60	2.92	0.17	4.99
75.53	13.69	0.28	1.87	0.40	2.14	3.04	2.88	0.16	5.05
73.89	14.07	0.32	2.16	0.48	2.61	3.78	2.52	0.18	3.65
74.31	13.83	0.35	2.20	0.43	2.42	3.74	2.60	0.13	4.09
74.75	13.92	0.31	1.99	0.41	2.31	3.41	2.74	0.16	4.87
9 0.75	0.28	0.04	0.16	0.10	0.19	0.42	0.14	0.03	0.96

00902 Ohinekoao-J; (pum) (pkarch)

77.24	12.92	0.15	1.44	0.16	1.29	3.14	3.45	0.20	6.43
77.72	13.02	0.18	1.30	0.21	1.39	2.76	3.29	0.14	6.57
77.74	13.03	0.16	1.28	0.16	1.37	2.45	3.62	0.20	7.72
77.93	12.80	0.21	1.40	0.15	1.34	2.50	3.48	0.20	7.88
77.95	12.89	0.18	1.38	0.16	1.26	2.39	3.62	0.18	6.25
78.16	12.71	0.18	1.25	0.16	1.15	2.65	3.57	0.15	7.31
77.39	12.89	0.14	1.33	0.14	1.29	2.91	3.74	0.17	6.50
77.83	12.83	0.13	1.28	0.16	1.37	2.70	3.52	0.17	7.19
77.52	12.84	0.13	1.45	0.10	1.29	2.63	3.69	0.34	9.52
77.76	12.73	0.15	1.51	0.19	1.37	2.77	3.36	0.16	5.78
78.12	12.78	0.14	1.35	0.16	1.24	2.59	3.46	0.16	6.18
77.68	12.60	0.19	1.29	0.16	1.25	2.92	3.73	0.18	5.57
77.75	12.84	0.16	1.35	0.16	1.30	2.70	3.55	0.19	6.91
12 0.28	0.12	0.03	0.08	0.03	0.07	0.22	0.14	0.06	1.10

00903 Ohinekoao-G; (mtb) (integr)

77.34	12.89	0.10	1.04	0.11	0.87	3.26	4.25	0.16	6.41
77.84	12.40	0.18	0.88	0.11	0.90	3.55	4.14	n.d.	5.83
78.23	11.75	0.13	1.09	0.14	0.84	3.40	4.24	0.18	9.04
77.76	12.14	0.14	0.84	0.11	0.86	3.46	4.57	0.13	7.12
77.96	12.09	0.15	1.06	0.12	0.81	3.67	3.98	0.16	7.52
77.49	12.09	0.15	1.10	0.11	0.92	3.63	4.31	0.20	6.37
78.73	11.20	0.20	0.78	0.11	0.88	3.35	4.56	0.20	7.70
77.31	12.86	0.15	1.10	0.11	0.84	3.02	4.41	0.22	4.25
77.79	12.27	0.16	1.06	0.14	0.84	3.45	3.92	0.37	5.30
78.44	11.92	0.15	0.98	0.12	0.79	3.56	3.81	0.23	3.76
77.94	12.10	0.12	1.14	0.14	0.83	3.35	4.15	0.24	4.78
78.29	11.99	0.13	0.94	0.12	0.81	3.28	4.19	0.25	5.48
77.93	12.14	0.14	1.00	0.12	0.85	3.41	4.21	0.21	6.13
12 0.44	0.45	0.03	0.12	0.01	0.04	0.18	0.23	0.06	1.54
? 77.35	12.08	0.15	1.34	0.14	1.13	3.46	4.16	0.19	5.30

00904 Ohinekoao-E and reworked(?) -C; (mtb) (integr)

a 72.69	14.45	0.41	2.37	0.69	2.52	3.75	2.91	0.23	6.82
a 72.54	14.60	0.36	2.38	0.61	2.67	3.79	2.84	0.20	6.14
a 72.81	14.21	0.45	2.80	0.61	2.42	3.55	2.85	0.30	9.84
a 72.66	14.37	0.41	2.32	0.70	2.68	3.87	2.85	0.14	7.24
a 72.63	14.61	0.46	2.47	0.58	2.56	3.67	2.82	0.20	5.63
a 72.84	14.37	0.36	2.42	0.64	2.36	3.86	2.98	0.18	7.45
a 72.37	14.88	0.46	2.49	0.61	2.61	3.70	2.76	0.12	6.80
72.65	14.50	0.42	2.46	0.63	2.55	3.74	2.86	0.20	7.13
7 0.16	0.22	0.04	0.16	0.04	0.12	0.11	0.07	0.06	1.35
b 76.08	13.66	0.20	1.22	0.18	1.39	3.54	3.53	0.18	7.13
b 75.83	13.44	0.23	1.23	0.16	1.47	3.58	3.90	0.16	7.45
b 76.63	13.03	0.15	1.29	0.15	1.27	3.69	3.57	0.21	6.84
b 76.09	13.36	0.15	1.37	0.20	1.14	3.75	3.84	0.11	7.78
b 76.33	13.16	0.22	1.22	0.11	1.01	3.70	4.06	0.19	9.13
76.19	13.33	0.19	1.26	0.16	1.26	3.65	3.78	0.17	7.67
5 0.30	0.25	0.04	0.06	0.03	0.18	0.09	0.22	0.04	0.89
? 77.03	12.34	0.22	1.03	0.08	0.86	3.55	4.59	0.30	4.19
? 75.19	13.49	0.34	1.56	0.28	1.73	3.59	3.68	0.14	8.42

00905 reworked Ohinekoao-K, -?; (pum) (integr)

75.90	13.71	n.d.	1.24	0.24	1.19	3.38	4.15	0.20	4.50
76.61	12.95	0.23	1.16	0.16	1.27	3.72	3.80	0.09	5.20
75.72	13.50	0.12	1.37	0.24	1.25	3.53	4.09	0.19	3.02
75.60	13.38	0.27	1.82	0.29	1.38	3.58	3.59	0.09	4.17
76.39	12.78	0.21	1.44	0.25	1.52	3.81	3.50	0.09	4.24
75.74	13.67	0.31	1.29	0.17	1.22	3.20	4.21	0.18	2.25
75.99	12.98	0.27	1.63	0.20	1.19	3.32	4.19	0.23	3.34
76.33	13.16	0.21	1.22	0.11	1.48	3.82	3.59	0.07	2.60
76.56	12.97	0.18	1.21	0.22	1.24	3.08	4.43	0.11	3.96
76.00	12.99	0.19	1.71	0.23	1.24	3.36	4.09	0.20	4.07
75.91	13.45	0.39	1.32	0.24	1.19	3.60	3.81	0.08	4.48
76.01	13.05	0.17	1.35	0.17	1.32	3.58	4.15	0.20	3.17
76.18	13.07	0.30	1.47	0.29	1.16	3.71	3.66	0.16	4.11
76.51	13.62	0.08	1.10	0.19	1.35	3.31	3.67	0.18	4.30
75.34	13.85	0.23	1.02	0.15	1.53	4.06	3.67	0.16	3.86
75.64	13.66	0.26	1.22	0.09	1.35	3.51	4.05	0.22	4.61
75.15	14.07	0.20	1.40	0.25	1.48	4.21	3.16	0.09	3.07
75.01	13.65	0.23	1.85	0.33	1.57	3.66	3.46	0.23	4.11
75.75	13.30	0.31	1.42	0.25	1.42	3.76	3.58	0.20	9.32
76.35	12.90	0.22	1.38	0.31	1.44	3.59	3.54	0.26	8.87
76.45	12.89	0.22	1.77	0.20	1.28	3.64	3.29	0.26	8.59
76.17	13.11	0.23	1.61	0.24	1.54	3.50	3.34	0.26	9.06
76.08	13.15	0.23	1.62	0.22	1.55	3.59	3.38	0.19	8.15
75.99	12.84	0.28	1.92	0.16	1.39	3.63	3.56	0.23	7.37
76.45	13.12	0.22	1.42	0.22	1.40	3.50	3.47	0.21	8.59
75.99	13.27	0.23	1.44	0.22	1.36	3.59	3.74	0.18	5.16
25 0.43	0.36	0.06	0.25	0.06	0.13	0.25	0.34	0.06	2.28

continued next

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water

00905 continued

b 76.41	12.56	0.30	1.25	0.19	1.06	3.57	4.45	0.21	3.67
b 76.06	13.27	0.29	1.22	0.23	1.04	3.73	4.11	0.07	3.39
b 77.26	12.75	0.14	1.25	0.09	0.98	3.35	4.02	0.16	5.00
76.58	12.86	0.24	1.24	0.17	1.02	3.55	4.19	0.15	4.02
3 0.62	0.37	0.09	0.02	0.07	0.04	0.19	0.23	0.07	0.86
c 77.29	12.67	0.22	1.03	0.06	0.99	3.53	4.05	0.15	4.21
c 78.05	12.35	0.21	0.89	0.18	0.81	3.30	3.96	0.24	9.10
c 77.75	12.87	0.11	0.91	0.09	0.89	3.23	3.90	0.24	10.03
77.70	12.63	0.18	0.95	0.11	0.90	3.35	3.97	0.21	7.78
3 0.38	0.26	0.06	0.08	0.06	0.09	0.15	0.08	0.06	3.13

00906 reworked Ohinekoao-E, -G, -?; (pum) (integr)

a 72.82	14.61	0.44	2.29	0.55	2.43	3.68	3.01	0.18	6.52
a 73.60	14.02	0.39	2.66	0.48	2.33	3.40	2.94	0.18	3.01
a 71.83	14.89	0.51	2.53	0.60	2.59	3.81	2.99	0.26	4.22
a 72.75	14.49	0.43	2.58	0.63	2.40	3.88	2.64	0.21	4.47
a 71.73	15.05	0.59	2.54	0.60	2.55	4.02	2.73	0.20	6.55
a 72.72	14.20	0.44	2.48	0.74	2.31	4.02	2.93	0.15	7.21
72.57	14.54	0.47	2.51	0.60	2.43	3.80	2.87	0.20	5.33
6 0.70	0.39	0.07	0.12	0.09	0.11	0.24	0.15	0.04	1.66
b 77.13	12.63	0.19	1.29	0.14	0.86	3.37	4.14	0.27	3.77
b 77.45	12.57	0.24	0.89	0.09	0.89	3.18	4.31	0.38	4.38
b 77.16	12.61	0.19	1.07	0.07	0.90	3.52	4.17	0.31	4.09
b 77.76	12.40	0.12	0.89	0.10	0.81	3.50	4.15	0.28	-0.04
b 77.40	12.82	0.10	0.98	0.07	0.78	3.33	4.23	0.29	5.31
b 77.80	12.80	0.14	0.99	0.09	0.77	3.20	3.94	0.27	0.24
b 76.32	13.30	0.21	0.86	0.14	0.90	3.61	4.36	0.31	3.81
77.29	12.73	0.17	1.00	0.10	0.85	3.39	4.18	0.30	3.08
7 0.50	0.29	0.05	0.15	0.03	0.06	0.16	0.14	0.04	2.10

x	78.07	12.64	0.18	0.39	0.05	0.85	3.38	4.16	0.27	0.90
x	77.85	12.46	0.20	0.60	0.13	0.88	3.18	4.32	0.39	5.03
x	77.12	13.33	0.23	0.47	0.10	0.89	3.40	4.15	0.31	4.28
x	77.43	13.16	0.09	0.52	0.18	0.84	3.42	4.11	0.24	4.68
x	76.90	13.50	0.13	0.42	n.d.	0.77	3.67	4.37	0.24	4.31
x	77.58	12.59	0.10	0.61	0.08	0.90	3.18	4.58	0.38	7.88
	77.49	12.95	0.15	0.50	0.11	0.86	3.37	4.28	0.31	4.51
δ	0.44	0.44	0.06	0.09	0.05	0.05	0.18	0.18	0.07	2.23

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
00910 Ohinekoao-D: (mtx) (integr)										
76.20	12.82	0.19	1.67	0.37	1.46	3.46	3.67	0.16	5.47	
74.96	13.37	0.29	1.83	0.34	1.92	3.79	3.30	0.20	2.95	
75.82	13.10	0.29	1.75	0.36	1.54	3.66	3.31	0.17	3.88	
74.02	14.12	0.46	2.07	0.39	1.81	3.42	3.50	0.21	5.61	
75.03	13.76	0.20	1.74	0.30	1.58	3.77	3.47	0.15	6.79	
74.20	14.10	0.38	1.97	0.35	1.92	3.61	3.28	0.19	5.73	
75.07	13.54	0.23	1.84	0.35	1.74	3.57	3.41	0.25	6.97	
74.40	13.94	0.23	2.20	0.36	1.77	3.87	3.09	0.14	6.21	
74.56	13.84	0.34	1.90	0.34	1.84	3.74	3.19	0.23	7.02	
74.18	14.16	0.28	2.09	0.33	1.81	3.67	3.26	0.21	5.95	
75.10	13.49	0.30	1.70	0.34	1.70	3.69	3.51	0.18	5.86	
74.87	13.66	0.29	1.89	0.35	1.73	3.66	3.36	0.19	5.68	
11 0.69	0.44	0.08	0.18	0.02	0.15	0.14	0.16	0.03	1.26	
? 77.10 12.60 0.20 1.26 0.30 1.28 3.42 3.66 0.17 6.50										

00911 Ohinekoao-M: (pum) (integr)										
76.48	12.97	0.20	1.51	0.24	1.36	3.66	3.38	0.19	5.57	
77.02	12.86	0.20	1.28	0.22	1.33	3.48	3.41	0.19	5.40	
76.81	13.18	0.13	1.30	0.20	1.26	3.46	3.50	0.16	4.18	
76.13	13.16	0.20	1.36	0.18	1.37	3.70	3.75	0.15	4.62	
76.04	13.42	0.19	1.57	0.22	1.26	3.71	3.47	0.13	6.12	
76.17	12.98	0.37	1.53	0.35	1.50	3.50	3.39	0.20	8.04	
76.18	13.06	0.25	1.55	0.22	1.38	3.72	3.36	0.26	5.15	
76.30	13.01	0.39	1.54	0.20	1.35	3.50	3.56	0.12	6.08	
76.84	12.66	0.18	1.33	0.26	1.38	3.64	3.46	0.25	7.69	
76.16	13.20	0.33	1.26	0.27	1.33	3.69	3.57	0.20	8.28	
76.25	12.98	0.33	1.38	0.25	1.43	3.64	3.48	0.26	8.25	
76.40	13.05	0.25	1.42	0.24	1.36	3.61	3.49	0.19	6.31	
11 0.34	0.20	0.09	0.12	0.05	0.07	0.10	0.11	0.05	1.51	

00912 Ohinekoao-B: (pum) (integr)										
77.28	12.38	0.13	1.07	0.19	1.07	3.55	4.07	0.26	4.48	
77.43	12.34	0.15	1.20	0.17	1.02	3.83	3.68	0.18	5.06	
77.07	12.29	0.10	0.96	0.13	1.07	3.85	4.28	0.25	4.06	
77.84	12.23	0.27	1.01	0.14	1.09	3.52	3.71	0.20	6.15	
77.56	12.44	0.20	0.86	0.11	0.85	3.65	4.06	0.27	4.27	
77.77	12.29	0.21	0.91	0.08	1.02	3.63	3.90	0.19	2.87	
77.58	12.55	0.16	1.06	0.09	0.91	3.51	3.73	0.40	5.12	
77.51	12.41	0.16	0.90	0.15	0.81	3.54	4.23	0.29	5.96	
78.06	12.18	0.15	1.01	0.16	1.12	3.43	3.63	0.26	5.18	
77.59	12.40	0.17	1.14	0.17	0.88	3.41	3.99	0.26	4.28	
77.39	12.49	0.15	1.12	0.13	0.91	3.49	4.07	0.27	5.10	
77.55	12.52	0.24	0.95	0.12	0.84	3.24	4.25	0.30	7.32	
77.55	12.38	0.17	1.02	0.14	0.96	3.55	3.97	0.26	4.99	
12 0.26	0.11	0.05	0.11	0.03	0.11	0.17	0.24	0.06	1.15	
? 77.30 12.47 0.22 1.28 0.18 1.28 3.48 3.52 0.25 5.77										
? 77.07 12.43 0.08 1.08 0.07 0.78 3.32 4.94 0.23 5.60										

00913 Ohinekoao-A: (pum) (integr)										
76.90	12.72	0.19	1.05	0.15	0.95	3.63	4.19	0.23	5.17	
77.36	12.56	0.12	0.85	0.13	0.89	3.46	4.41	0.22	5.95	
77.63	12.58	0.12	1.13	0.17	0.80	3.30	4.03	0.25	5.05	
77.22	12.56	0.12	1.09	0.20	0.92	3.55	4.08	0.27	5.28	
77.31	12.69	0.19	1.03	0.14	0.87	3.40	4.11	0.26	6.12	
77.03	12.54	0.21	1.14	0.14	0.98	3.35	4.27	0.34	8.16	
77.23	12.55	0.13	1.21	0.12	0.87	3.50	4.04	0.35	7.54	
77.72	12.52	0.10	1.07	0.15	0.89	3.48	3.77	0.30	4.68	
77.76	12.61	0.09	1.05	0.11	0.82	3.32	3.98	0.26	6.59	
77.67	12.44	0.11	0.92	0.18	0.98	3.40	4.19	0.12	5.25	
77.81	12.30	0.16	1.05	0.13	0.86	3.51	3.98	0.21	4.54	
77.42	12.55	0.14	1.05	0.15	0.89	3.44	4.10	0.26	5.85	
0.31	0.11	0.04	0.10	0.03	0.06	0.10	0.17	0.06	1.17	
? 77.88 12.45 0.15 0.77 0.14 0.83 3.52 4.02 0.25 4.65										

site 13 = Torere School (X15/048517)

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
01301 Torere School: (pum) (pkrsch)										
79.15	12.02	n.d.	0.96	0.20	1.37	2.84	3.28	0.19	3.76	
78.92	11.90	0.17	1.19	0.22	1.36	2.76	3.34	0.14	3.39	
78.56	12.00	0.17	1.20	0.19	1.31	3.18	3.41	n.d.	3.38	
79.01	11.95	0.15	0.89	0.16	1.44	2.88	3.33	0.19	4.64	
78.44	12.03	0.12	1.18	0.19	1.37	3.00	3.50	0.18	3.63	
78.59	12.00	0.18	1.08	0.19	1.33	2.92	3.55	0.16	3.93	
79.00	11.79	0.24	1.09	0.16	1.34	3.00	3.24	0.13	2.60	
78.51	11.99	0.19	1.21	0.13	1.43	2.88	3.49	0.17	3.59	
78.69	12.00	0.20	1.17	0.20	1.43	2.79	3.26	0.25	5.82	
79.12	11.91	0.15	1.03	0.19	1.30	2.68	3.46	0.17	5.13	
78.80	11.96	0.17	1.10	0.18	1.37	2.89	3.39	0.18	3.99	
10 0.27	0.07	0.03	0.11	0.02	0.05	0.14	0.11	0.04	0.95	

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
01302 Mangaone: (total) (pkrsch)										
77.42	12.92	0.17	1.19	0.21	1.20	3.93	2.82	0.13	2.62	
77.52	12.74	0.15	1.25	0.22	1.20	4.07	2.67	0.16	2.04	
77.61	12.60	0.17	1.21	0.16	1.18	4.09	2.81	0.15	2.53	
77.81	12.78	0.16	1.13	0.15	1.07	4.14	2.76	n.d.	2.38	
77.50	12.81	0.28	1.15	0.13	1.38	3.95	2.81	n.d.	2.73	
76.30	13.29	0.16	1.36	0.23	1.39	4.32	2.80	0.17	4.86	
77.19	12.88	0.22	1.17	0.21	1.18	4.11	2.90	0.16	3.32	
77.11	12.95	0.18	1.21	0.20	1.35	3.91	2.88	0.22	3.23	
77.20	13.12	0.19	1.17	0.21	1.29	3.88	2.82	0.12	1.36	
77.72	12.89	0.19	1.12	0.23	1.21	3.71	2.75	0.17	2.11	
77.79	12.61	0.21	1.24	0.20	1.14	3.87	2.81	0.12	1.19	
77.59	12.85	0.20	1.21	0.22	1.22	3.66	2.88	0.16	1.01	
77.41	12.71	0.20	1.32	0.17	1.22	4.01	2.81	0.14	1.74	
76.86	13.09	0.18	1.42	0.26	1.25	4.04	2.75	0.14	1.04	
77.60	12.70	0.19	1.22	0.18	1.19	3.97	2.77	0.17	1.01	
76.80	13.14	0.19	1.16	0.27	1.36	4.26	2.64	0.18	1.11	
77.52	12.99	0.20	1.26	0.22	1.22	3.89	2.58	0.11	2.42	
77.87	12.83	0.22	1.12	0.18	1.24	3.67	2.69	0.17	1.48	
77.38	12.88	0.19	1.22	0.20	1.24	3.97	2.77	0.16	2.12	
18 0.41	0.19	0.03	0.08	0.04	0.09	0.18	0.08	0.03	1.02	

01303 Rotoliti: (mtx) (pkrsch)										
78.23	12.32	0.11	0.93	0.15	0.93	3.93	3.27	0.13	-0.15	
78.59	12.29	0.13	0.86	0.13	0.86	3.80	3.22	0.13	1.84	
78.81	12.24	0.17	0.82	0.14	0.94	3.43	3.36	0.10	3.16	
78.42	12.39	0.10	0.96	0.14	0.82	3.75	3.31	0.11	2.02	
78.52	12.27	0.13	0.92	0.17	0.87	3.70	3.35	0.08	3.18	
78.39	12.33	0.16	1.00	0.12	0.82	3.78	3.29	0.10	2.68	
78.84	12.08	0.11	0.97	0.16	0.91	3.53	3.22	0.17	3.51	
78.46	12.21	0.08	0.78	0.15	0.81	4.05	3.31	0.14	1.30	
78.73	12.17	n.d.	0.91	0.14	0.87	3.79	3.26	0.12	3.43	
78.68	12.20	n.d.	0.87	0.12	0.83	3.76	3.41	0.12	2.41	
78.39	12.20	0.15	0.87	0.11	0.84	3.87	3.44	0.11	2.44	
78.55	12.25	0.13	0.90	0.14	0.86	3.76	3.31	0.12	2.35	
11 0.19	0.09	0.03	0.07	0.02	0.05	0.17	0.07	0.02	1.08	

site 14 = Opape (X15/984484)

01401 Torere-17: below road level: (crs-ash) (pkrsch)										
78.82	12.05	0.13	1.03	0.09	0.87	3.10	3.72	0.19	4.59*	

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
01404 reworked Torere-J; (crs-ash) (pkscrh)										
75.42	13.47	0.33	1.91	0.32	2.21	3.33	2.92	0.08	4.31	
75.11	12.98	0.47	2.35	0.51	2.14	3.35	2.93	0.17	4.08	
75.97	13.46	0.31	1.98	0.38	2.18	2.46	3.07	0.19	5.94	
75.81	13.46	0.31	1.94	0.43	2.20	2.69	2.99	0.17	6.09	
76.20	13.33	0.26	1.77	0.33	2.16	2.62	3.22	0.11	5.08	
76.06	13.43	0.22	1.92	0.40	2.15	2.60	2.99	0.22	5.12	
75.76	13.35	0.32	1.98	0.40	2.17	2.84	3.02	0.16	5.10	
6 0.42	0.19	0.08	0.19	0.07	0.07	0.39	0.11	0.05	0.82	
b 77.79	12.63	0.22	1.50	0.26	1.65	2.76	3.30	0.09	3.86	
b 77.51	12.33	0.21	1.66	0.27	1.38	2.88	3.60	0.15	5.28	
b 77.64	12.45	0.25	1.56	0.25	1.43	2.68	3.60	0.14	4.64	
77.65	12.47	0.23	1.57	0.26	1.49	2.77	3.50	0.13	4.59	
3 0.14	0.15	0.02	0.08	0.01	0.15	0.10	0.17	0.03	0.71	
? 78.98	12.52	0.10	1.00	0.17	1.09	2.55	3.43	0.16	6.69	
? 74.32	13.45	0.55	2.84	n.d.	2.50	3.49	2.86	n.d.	4.22	
01405 reworked Torere-K; (mtb) (integr)										
75.92	13.39	0.29	1.57	0.32	1.37	3.66	3.36	0.13	4.33	
75.78	13.34	0.24	1.42	0.26	1.38	3.83	3.58	0.17	4.65	
75.97	13.20	0.36	1.56	0.25	1.42	3.73	3.30	0.21	0.80	
75.43	13.61	0.18	1.48	0.28	1.42	3.99	3.43	0.17	2.33	
75.55	13.52	0.32	1.35	0.34	1.32	3.88	3.51	0.21	4.29	
75.93	13.31	0.31	1.52	0.30	1.19	3.95	3.28	0.20	2.88	
76.73	12.70	0.23	1.66	0.26	1.17	3.94	3.21	0.09	0.41	
76.45	12.85	0.33	1.61	0.28	1.22	3.60	3.45	0.20	0.13	
76.22	13.01	0.41	1.41	0.31	1.28	3.89	3.27	0.20	7.08	
76.00	13.21	0.30	1.51	0.29	1.31	3.83	3.38	0.18	2.99	
9 0.41	0.30	0.07	0.10	0.03	0.10	0.14	0.12	0.04	2.32	
? 74.69	13.77	0.35	1.75	0.36	1.68	4.22	3.02	0.15	6.62	
? 77.12	12.43	0.33	1.08	0.22	1.19	3.90	3.57	0.16	2.19	
01406 reworked Torere-M, -L, -I; (mtb) (integr)										
a 76.44	13.01	0.13	1.37	0.18	1.29	3.83	3.43	0.32	6.31	
a 76.18	13.15	0.32	1.38	0.31	1.41	3.99	3.13	0.14	5.50	
a 76.66	12.75	0.18	1.36	0.26	1.26	4.02	3.26	0.25	4.63	
a 76.80	12.94	0.29	1.24	0.24	1.39	3.65	3.30	0.15	4.33	
a 77.59	12.81	0.11	1.01	0.19	1.30	3.77	3.07	0.14	6.20	
76.73	12.93	0.20	1.27	0.24	1.33	3.85	3.24	0.20	5.39	
5 0.53	0.16	0.10	0.15	0.05	0.07	0.15	0.14	0.08	0.90	
b 77.11	12.76	0.17	0.85	0.06	0.59	3.44	4.82	0.20	6.09	
b 77.26	12.66	0.10	0.85	0.13	0.55	3.64	4.69	0.13	5.94	
b 77.61	12.77	0.08	0.77	0.16	0.76	3.56	4.12	0.18	4.78	
77.32	12.73	0.12	0.82	0.12	0.63	3.55	4.54	0.17	5.60	
3 0.26	0.06	0.05	0.05	0.05	0.11	0.10	0.38	0.04	0.72	
c 77.58	12.41	0.15	1.04	0.19	0.81	3.56	4.03	0.23	6.86	
c 78.11	12.08	0.15	1.01	0.15	0.83	3.79	3.75	0.14	4.17	
77.84	12.25	0.15	1.03	0.17	0.82	3.68	3.89	0.18	5.51	
2 0.37	0.23	0.00	0.02	0.03	0.02	0.16	0.20	0.06	1.90	
? 78.10	12.41	0.20	1.20	0.12	0.82	3.37	3.64	0.15	4.93	
01407 Huntress-B; (mtb) (integr)										
77.58	12.56	0.11	1.03	0.07	0.81	3.82	3.83	0.18	6.27	
77.72	12.53	0.20	1.05	0.08	0.86	3.68	3.68	0.20	4.86	
77.45	12.23	0.19	1.21	0.13	0.91	4.13	3.60	0.16	4.88	
77.26	12.41	0.18	1.15	0.11	0.95	3.99	3.74	0.21	4.21	
77.69	12.38	0.18	1.13	0.18	0.84	3.71	3.68	0.21	4.80	
77.40	12.50	0.15	1.37	0.08	1.06	3.73	3.47	0.23	5.22	
77.58	12.44	0.07	1.44	0.16	0.81	3.77	3.51	0.22	4.81	
77.48	12.19	0.21	1.13	0.14	0.87	3.69	4.07	0.23	4.81	
77.87	12.43	0.12	1.06	0.06	0.92	3.82	3.52	0.20	4.70	
77.69	12.45	n.d.	1.30	0.08	0.97	3.55	3.73	0.24	5.80	
77.69	12.38	0.25	1.17	0.10	0.87	3.62	3.79	0.15	5.70	
77.44	12.44	0.17	1.20	0.17	0.94	3.83	3.59	0.22	5.65	
77.30	12.45	0.17	1.15	0.08	1.05	3.96	3.59	0.24	5.36	
77.55	12.41	0.17	1.18	0.11	0.91	3.79	3.68	0.21	5.16	
13 0.18	0.11	0.05	0.12	0.04	0.08	0.16	0.16	0.03	0.57	
? 77.96	12.45	0.17	0.92	0.11	0.78	3.77	3.64	0.21	5.20	
? 76.64	12.73	0.22	1.54	0.13	1.06	3.84	3.64	0.21	3.44	
01408 reworked Torere-L, -I; (mtb) (integr)										
77.26	13.04	0.17	1.32	0.19	1.16	3.28	3.38	0.21	9.98	
77.54	12.64	0.11	1.18	0.12	0.93	3.80	3.46	0.22	6.15	
77.52	12.66	0.13	1.16	0.20	1.08	3.59	3.49	0.17	8.37	
76.59	13.04	0.24	1.24	0.33	1.28	3.91	3.14	0.24	6.81	
77.62	12.59	0.14	1.31	0.24	1.35	3.36	3.24	0.15	7.41	
77.10	12.61	0.11	1.34	0.13	1.13	3.67	3.67	0.23	10.34	
77.27	12.76	0.15	1.26	0.20	1.15	3.60	3.40	0.21	8.18	
6 0.39	0.21	0.05	0.08	0.08	0.15	0.25	0.19	0.03	1.70	
b 77.93	12.28	0.22	0.99	0.15	1.15	3.57	3.55	0.16	6.10	
b 78.17	12.55	0.15	0.93	0.09	0.93	3.41	3.60	0.17	7.62	
b 77.72	12.42	0.11	0.96	0.19	1.10	3.59	3.70	0.22	7.13	
77.94	12.41	0.16	0.96	0.14	1.06	3.52	3.62	0.18	6.95	
3 0.22	0.13	0.06	0.03	0.05	0.11	0.10	0.08	0.03	0.78	
? 75.90	13.18	0.17	1.58	0.20	1.30	3.96	3.50	0.21	6.75	

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
01409 reworked Torere-L, Reihana-M: (mtb) (integr)										
	77.60	12.65	0.12	1.29	0.13	0.99	3.60	3.46	0.17	5.44
	76.33	13.21	0.30	1.35	0.36	1.25	4.00	3.06	0.15	4.89
	77.05	12.78	0.15	1.35	0.16	1.07	3.77	3.48	0.19	5.02
	76.22	12.94	0.14	1.50	0.19	1.11	4.13	3.58	0.18	6.52
	77.29	12.55	0.24	1.19	0.24	1.19	3.80	3.25	0.23	5.91
	76.71	12.72	0.27	1.53	0.22	1.27	3.82	3.20	0.26	4.69
	77.76	12.35	0.12	1.44	0.23	1.11	3.50	3.27	0.22	5.64
	76.47	12.94	0.29	1.39	0.32	1.21	4.03	3.16	0.18	6.70
	76.37	13.33	0.25	1.27	0.33	1.36	3.84	3.09	0.16	6.52
	76.87	12.83	0.21	1.37	0.24	1.17	3.83	3.29	0.19	5.70
9	0.58	0.31	0.08	0.11	0.08	0.11	0.20	0.18	0.04	0.76
b	78.03	12.13	0.13	0.79	0.10	0.73	3.63	4.31	0.16	6.43
b	78.28	12.19	0.17	0.74	0.08	0.71	3.24	4.37	0.20	7.17
b	77.33	12.48	n.d.	0.77	0.10	0.70	3.06	5.36	0.20	5.66
	77.88	12.27	0.15	0.77	0.09	0.71	3.31	4.68	0.19	6.42
3	0.50	0.18	0.03	0.02	0.01	0.01	0.29	0.59	0.02	0.76
c	77.87	12.56	n.d.	1.10	n.d.	0.93	3.61	3.78	0.15	5.27
c	78.07	12.21	0.21	1.14	0.10	0.81	3.67	3.55	0.23	4.76
	77.97	12.39	0.21	1.12	0.10	0.97	3.64	3.66	0.19	5.01
2	0.14	0.25	--	0.03	--	0.09	0.05	0.16	0.06	0.36
01410 Kutarere: (mtb) (integr)										
	77.76	12.58	0.20	1.22	0.11	0.72	3.67	3.44	0.31	8.24
	77.82	12.20	0.15	1.10	0.18	0.70	3.88	3.57	0.40	7.23
	78.44	12.20	0.11	1.10	0.12	0.78	3.68	3.26	0.33	5.40
	77.11	12.51	0.16	1.25	0.11	0.83	4.06	3.74	0.23	7.78
	78.25	12.29	0.09	1.08	0.09	0.75	3.70	3.46	0.29	9.28
	78.05	12.06	n.d.	1.00	0.08	0.56	4.04	3.94	0.26	5.06
	77.65	12.09	0.16	1.15	0.04	0.72	3.92	4.05	0.22	6.56
	77.58	12.63	0.24	1.17	0.14	0.80	3.83	3.41	0.20	7.09
	77.83	12.35	0.17	1.31	0.18	0.79	3.79	3.34	0.24	7.12
	77.53	12.47	0.17	0.88	0.06	0.52	4.04	4.01	0.33	5.22
	78.47	12.19	0.11	0.95	0.08	0.66	3.51	3.80	0.24	7.32
	77.84	12.29	0.11	1.18	0.18	0.59	4.08	3.35	0.38	6.40
	78.26	12.23	0.14	1.17	0.10	0.73	3.65	3.50	0.23	6.85
	77.89	12.31	0.15	1.12	0.11	0.70	3.83	3.61	0.28	7.16
13	0.39	0.18	0.04	0.12	0.05	0.10	0.19	0.27	0.06	1.21
?	76.26	12.92	0.13	1.50	0.14	0.90	4.24	3.68	0.23	6.81
01412 reworked Torere-N, -I: (mtb) (integr)										
	77.01	13.05	0.26	1.24	0.22	1.26	3.43	3.35	0.18	7.00
	76.90	12.78	0.25	1.47	0.16	1.19	3.92	3.15	0.18	4.79
	76.41	13.17	0.23	1.18	0.28	1.40	4.03	3.13	0.16	4.94
	76.58	12.95	0.12	1.23	0.20	1.17	3.81	3.66	0.28	6.75
	76.33	13.19	0.24	1.26	0.29	1.50	3.69	3.36	0.14	5.07
	76.64	12.92	0.21	1.27	0.28	1.38	3.84	3.25	0.21	6.47
	76.67	12.78	0.23	1.34	0.27	1.40	3.78	3.39	0.15	6.23
	76.66	13.02	0.33	1.11	0.28	1.20	3.71	3.49	0.20	6.37
	76.65	12.98	0.24	1.26	0.25	1.31	3.77	3.35	0.19	5.95
8	0.23	0.16	0.06	0.11	0.05	0.12	0.18	0.17	0.05	0.88
b	77.84	12.44	0.12	1.03	0.17	1.05	3.66	3.49	0.21	5.44
b	76.89	12.70	0.23	1.29	0.19	1.04	3.83	3.61	0.22	5.37
b	77.88	12.22	0.12	1.13	0.10	0.85	3.38	4.10	0.22	5.70
b	77.86	12.28	0.23	1.10	0.06	0.94	3.58	3.77	0.18	7.22
	77.62	12.41	0.17	1.14	0.13	0.97	3.61	3.75	0.21	5.93
4	0.49	0.22	0.07	0.11	0.06	0.09	0.18	0.27	0.02	0.87
01413 reworked Kaingaroa ?: (mtb) (integr)										
	77.12	12.71	0.22	0.97	0.09	0.83	4.11	3.62	0.32	4.46
	77.09	12.88	0.22	1.07	0.14	0.82	3.85	3.77	0.17	3.79
	77.40	12.75	0.11	0.91	0.13	0.71	3.91	3.83	0.23	3.70
	77.43	12.64	0.18	1.13	0.18	0.83	3.85	3.61	0.16	3.43
	77.38	12.76	0.16	1.15	0.20	0.93	3.68	3.52	0.21	4.63
	77.66	12.63	0.21	0.84	0.20	0.90	3.91	3.52	0.13	5.19
	77.47	12.54	0.19	1.31	0.18	0.78	3.98	3.39	0.17	4.94
	78.14	12.42	0.19	1.09	0.09	0.94	3.70	3.43	n.d.	4.56
	77.77	12.68	0.08	0.90	0.10	0.79	3.89	3.57	0.21	4.31
	77.38	12.67	0.20	1.10	0.15	0.84	3.79	3.71	0.18	3.46
	77.21	12.56	0.14	1.16	0.12	0.86	3.75	3.90	0.29	3.29
	77.46	12.66	0.17	1.06	0.14	0.84	3.86	3.63	0.21	4.16
11	0.31	0.12	0.04	0.14	0.04	0.07	0.13	0.16	0.06	0.66

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
01502 Murupara-E/Anaputa; (mtb) (pkrsch)										
78.34	12.22	n.d.	1.02	0.06	0.82	3.50	3.92	0.12	6.11	
78.36	12.11	0.10	1.08	0.09	0.81	3.31	4.03	0.12	5.96	
78.80	12.10	0.12	1.04	n.d.	0.80	3.09	3.91	0.14	6.74	
78.50	12.28	0.11	1.05	0.12	1.05	3.26	3.46	0.17	6.43	
78.51	12.10	0.11	1.08	0.11	0.98	3.19	3.78	0.15	5.36	
78.47	12.09	0.09	1.13	0.11	0.85	3.12	3.96	0.18	6.47	
78.99	12.07	0.08	0.98	0.08	0.86	3.04	3.76	0.14	5.68	
78.88	12.12	n.d.	0.90	0.15	0.81	3.30	3.67	0.17	5.25	
78.51	12.11	0.12	0.97	0.06	0.86	3.41	3.82	0.15	5.91	
79.03	12.06	0.06	1.06	0.11	0.99	3.14	3.43	0.12	5.66	
78.03	12.21	0.12	1.11	0.10	0.87	3.70	3.67	0.18	3.81	
77.94	12.55	0.10	0.94	0.12	0.81	3.64	3.70	0.20	4.41	
78.53	12.17	0.10	1.03	0.10	0.88	3.31	3.76	0.15	5.65	
12	0.35	0.14	0.02	0.07	0.03	0.08	0.22	0.19	0.03	0.85
b 79.14	11.73	0.21	1.37	0.19	1.42	3.29	2.54	0.11	3.49	
b 78.93	11.97	0.23	1.34	0.15	1.35	3.31	2.63	0.11	4.89	
b 78.97	11.89	0.18	1.27	0.15	1.45	3.31	2.69	0.08	5.70	
b 79.47	11.81	0.17	1.22	0.21	1.58	3.07	2.37	0.10	5.60	
b 78.57	12.33	0.15	1.29	0.12	1.15	3.26	2.96	0.16	7.09	
b 78.23	12.38	0.21	1.37	0.18	1.17	3.46	2.83	0.16	5.04	
b 78.54	12.09	0.14	1.44	0.25	1.37	3.49	2.54	0.14	4.08	
b 78.13	12.27	0.24	1.42	0.18	1.36	3.78	2.51	0.12	3.43	
b 79.01	12.13	n.d.	1.11	0.08	1.17	3.23	3.10	0.16	5.48	
78.78	12.07	0.19	1.31	0.17	1.33	3.36	2.69	0.13	4.98	
9	0.44	0.23	0.04	0.10	0.05	0.15	0.20	0.03	1.18	
01503 Bonisch; (cns-ash) (pkrsch)										
78.81	12.31	n.d.	1.05	0.11	0.89	2.91	3.76	0.15	6.93	
79.31	12.08	0.13	1.11	0.07	0.91	2.59	3.60	0.20	5.76	
78.97	12.07	0.08	1.10	0.12	0.89	2.86	3.72	0.19	5.86	
79.22	12.23	0.12	1.07	0.12	0.87	2.67	3.53	0.17	6.49	
79.26	12.14	n.d.	0.98	0.09	0.86	2.74	3.75	0.19	6.86	
79.19	12.02	0.13	0.87	0.12	0.95	2.89	3.66	0.18	6.12	
79.10	12.15	0.09	0.97	0.07	0.94	2.70	3.80	0.18	7.85	
79.33	12.19	0.09	0.97	0.12	0.97	2.51	3.69	0.14	6.82	
79.69	12.03	n.d.	0.93	0.10	0.86	2.60	3.62	0.18	5.72	
79.24	12.17	0.13	1.05	0.10	0.84	2.53	3.82	0.13	6.16	
79.21	12.14	0.11	1.01	0.10	0.90	2.70	3.69	0.17	6.46	
10	0.23	0.09	0.02	0.08	0.02	0.04	0.15	0.09	0.02	0.67
01504 Torere-A; (mtb) (pkrsch)										
76.75	13.09	0.18	1.19	0.17	1.37	3.50	3.53	0.23	6.77	
77.84	12.47	0.21	1.09	0.21	1.19	3.31	3.36	0.31	5.71	
76.55	13.17	0.21	1.21	0.18	1.27	3.67	3.46	0.28	6.01	
76.21	13.27	0.17	1.43	0.29	1.49	3.76	3.23	0.16	6.09	
77.00	12.93	0.20	1.42	0.20	1.16	3.49	3.34	0.27	4.79	
76.55	12.94	0.22	1.37	0.17	1.47	3.62	3.46	0.20	5.24	
76.32	13.56	n.d.	1.32	0.25	1.46	3.53	3.34	0.22	7.61	
77.01	12.73	0.12	1.42	0.19	1.26	3.69	3.37	0.20	6.53	
78.10	12.63	0.17	1.26	n.d.	1.19	3.26	3.20	0.18	5.65	
77.78	12.61	0.15	1.15	0.21	1.29	3.33	3.33	0.16	5.01	
77.84	12.57	0.20	1.20	0.14	1.21	3.25	3.42	0.17	5.63	
77.84	12.60	0.15	1.27	0.20	1.21	3.13	3.44	0.15	5.26	
77.95	12.71	0.20	1.31	0.17	1.23	2.97	3.30	0.16	5.48	
77.50	12.69	0.16	1.47	0.13	1.18	3.33	3.40	0.15	4.99	
77.19	12.88	0.22	1.35	0.22	1.40	3.19	3.39	0.15	5.14	
77.83	12.69	0.22	1.40	0.12	1.23	3.03	3.34	0.14	5.85	
77.56	12.85	0.16	1.38	0.22	1.30	2.95	3.48	0.09	4.14	
78.39	12.42	n.d.	1.28	0.16	1.14	3.20	3.26	0.14	6.52	
77.35	12.82	0.18	1.31	0.19	1.28	3.35	3.37	0.19	5.69	
18	0.66	0.30	0.03	0.11	0.04	0.11	0.25	0.09	0.06	0.82
b 77.75	12.42	0.22	1.06	0.20	1.06	3.46	3.55	0.28	5.48	
b 78.10	12.25	0.17	0.94	0.16	0.89	3.49	3.74	0.27	3.91	
b 77.40	12.56	0.19	0.96	0.10	0.99	3.51	4.09	0.19	6.68	
b 78.72	12.11	n.d.	0.93	0.07	0.89	3.27	3.85	0.16	4.61	
b 78.19	12.17	0.14	1.08	0.14	1.09	2.97	4.11	0.10	3.09	
b 78.76	12.05	0.22	1.06	0.13	0.92	3.17	3.54	0.15	5.47	
78.15	12.26	0.19	1.01	0.13	0.97	3.31	3.81	0.19	4.87	
6	0.53	0.19	0.03	0.07	0.05	0.09	0.21	0.25	0.07	1.28
? 77.69	12.52	0.23	1.24	0.17	1.04	3.42	3.47	0.22	5.74	
? 77.41	12.74	0.18	1.05	0.20	1.18	3.56	3.52	0.16	5.06	
? 78.34	12.23	0.22	1.03	0.20	1.26	3.30	3.31	0.10	0.09	
? 78.73	12.09	0.11	1.14	0.12	0.75	2.94	3.95	0.19	5.09	
? 78.42	12.09	0.10	0.92	0.09	0.69	3.16	4.37	0.15	4.15	
? 78.64	12.19	0.13	1.22	0.18	0.94	3.16	3.39	0.14	5.74	
? 79.04	11.99	0.15	1.00	0.15	0.89	3.34	3.32	0.13	5.98	
01505 Ohiwa Hill; (total) (pkrsch)										
77.81	12.60	0.11	1.29	0.15	1.01	3.33	3.52	0.18	3.73	
78.43	12.49	0.17	1.12	0.12	0.96	3.00	3.59	0.13	4.42	
77.95	12.59	0.16	1.10	0.16	1.05	3.24	3.62	0.15	3.58	
78.13	12.45	0.13	1.25	0.16	0.97	3.31	3.49	0.13	4.22	
77.98	12.65	0.19	1.18	0.15	1.09	3.19	3.45	0.13	4.09	
78.42	12.51	0.14	1.13	0.15	1.02	3.10	3.39	0.15	4.49	
78.36	12.45	0.20	1.26	0.15	1.02	2.82	3.58	0.16	5.32	
78.63	11.89	n.d.	1.19	0.10	0.91	3.13	3.95	0.19	4.29	
78.83	11.94	0.17	1.12	0.08	0.91	2.92	3.81	0.21	3.78	
78.35	12.40	0.14	1.19	0.15	1.06	2.92	3.63	0.17	4.48	
78.29	12.40	0.15	1.18	0.13	1.00	3.10	3.60	0.16	4.24	
10	0.32	0.27	0.03	0.07	0.02	0.06	0.18	0.17	0.03	0.50

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
01506 Murupara-C; (??) (pkrsch)										
78.81	12.28	0.07	0.82	0.06	0.71	3.07	4.01	0.17	6.44	
78.31	12.36	0.10	1.04	0.06	0.73	3.19	4.06	0.15	5.53	
78.80	12.14	0.11	1.00	0.05	0.83	3.18	3.82	0.07	5.75	
78.35	12.24	0.11	0.90	n.d.	0.82	3.47	3.96	0.16	4.80	
78.80	12.21	0.12	0.85	n.d.	0.78	3.10	3.97	0.17	5.88	
78.30	12.17	0.09	0.88	0.07	0.77	3.35	4.21	0.16	4.64	
77.99	12.27	0.11	1.07	0.06	0.85	3.41	4.07	0.18	4.31	
78.36	12.25	n.d.	0.94	0.13	0.74	3.43	4.01	0.16	4.88	
78.34	12.15	0.11	1.08	0.07	0.83	3.26	4.01	0.16	5.14	
78.57	12.33	n.d.	0.95	0.08	0.76	3.16	3.97	0.18	5.20	
78.46	12.24	0.10	0.95	0.08	0.78	3.26	4.01	0.16	5.25	
10	0.27	0.07	0.02	0.09	0.02	0.05	0.14	0.10	0.03	0.65
001507 Torere-I; (mtb) (pkrsch)										
a 78.68	11.89	0.16	1.01	n.d.	0.83	2.99	4.24	0.20	5.02	
a 78.80	12.36	0.13	0.97	0.11	0.94	2.97	3.60	0.13	5.57	
a 78.58	12.03	0.21	1.11	0.16	0.94	3.06	3.77	0.15	4.98	
a 78.74	11.94	0.16	1.20	0.16	0.84	2.63	4.13	0.20	4.88	
a 78.35	12.31	0.15	1.08	0.17	1.01	2.90	3.85	0.18	5.90	
a 78.87	12.06	0.13	0.97	0.11	0.86	3.27	3.55	0.18	5.61	
a 78.44	11.99	0.14	0.98	0.17	0.83	3.14	4.16	0.15	5.35	
78.64	12.08	0.15	1.05	0.14	0.89	2.99	3.90	0.17	5.33	
7	0.19	0.18	0.03	0.09	0.03	0.07	0.20	0.28	0.03	0.3

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	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
01520 — continued from previous page										
? 77.63	12.27	0.21	1.27	0.13	0.79		3.86	3.65	0.18	2.04
? 77.00	12.70	0.15	1.31	0.12	0.91		3.57	3.93	0.31	7.34
? 77.46	12.60	0.13	1.33	0.14	0.97		3.56	3.58	0.23	7.11
77.36	12.52	0.16	1.30	0.13	0.89		3.66	3.72	0.24	5.50
3 0.33	0.23	0.04	0.03	0.01	0.09		0.17	0.19	0.07	3.00

01521 Torere-O: (mb) (integr)

77.66	12.36	0.28	0.99	0.11	0.76		3.77	3.79	0.29	6.26
77.43	12.37	0.16	1.05	0.16	0.89		3.81	3.85	0.28	7.43
77.70	12.50	0.13	0.83	0.12	0.77		3.81	3.97	0.17	6.31
77.64	12.33	0.21	1.02	0.10	0.85		3.99	3.69	0.18	5.91
77.44	12.42	0.24	1.00	0.11	0.82		3.92	3.88	0.17	6.54
77.67	12.50	0.09	1.05	0.11	0.88		3.71	3.76	0.23	8.27
78.89	12.03	0.08	0.94	0.13	0.80		3.42	3.50	0.21	4.98
78.70	11.89	0.11	0.85	0.15	0.76		3.67	3.65	0.22	3.99
77.76	12.28	0.14	0.86	0.11	0.87		3.72	4.11	0.15	6.22
77.28	12.62	0.13	0.98	0.15	0.89		3.82	3.97	0.17	5.73
77.61	12.63	0.15	0.97	0.11	0.97		3.43	3.93	0.20	5.92
77.95	12.39	n.d.	0.98	0.16	0.75		3.51	4.03	0.22	4.38
77.81	12.36	0.16	0.96	0.12	0.83		3.71	3.84	0.21	5.99
12 0.49	0.22	0.06	0.07	0.02	0.07		0.18	0.17	0.04	1.19

? 77.91	12.64	0.28	0.68	0.14	0.87		3.42	3.83	0.23	6.91
? 78.52	11.83	0.17	1.02	0.16	1.02		3.73	3.39	0.17	4.59

01523 Anapuita: (mb) (integr)

76.46	13.06	0.18	1.31	0.22	1.29		3.81	3.41	0.24	5.70
76.68	13.06	0.17	1.42	0.19	1.19		3.88	3.20	0.20	5.74
76.52	13.16	0.15	1.37	0.22	1.30		3.83	3.20	0.24	5.32
76.51	12.86	0.17	1.62	0.18	1.28		4.00	3.16	0.24	3.54
76.47	13.21	0.21	1.52	0.14	1.23		3.68	3.26	0.28	3.37
76.51	13.09	0.17	1.57	0.22	1.18		3.70	3.36	0.20	4.43
76.45	12.91	0.23	1.56	0.24	1.19		3.90	3.32	0.20	3.98
76.29	13.04	0.27	1.44	0.15	1.25		3.99	3.31	0.25	4.34
76.20	13.12	0.17	1.48	0.28	1.31		3.95	3.29	0.21	6.07
76.10	13.38	0.12	1.34	0.11	1.29		4.08	3.32	0.26	5.18
76.66	13.04	0.16	1.26	0.18	1.31		3.89	3.19	0.31	6.27
75.96	13.14	0.19	1.52	0.18	1.15		4.12	3.50	0.25	5.76
76.21	12.97	0.17	1.60	0.18	1.30		3.86	3.44	0.29	5.39
76.39	13.08	0.18	1.46	0.19	1.25		3.90	3.31	0.24	5.01
13 0.22	0.13	0.04	0.11	0.05	0.06		0.13	0.10	0.04	0.97

site 16 = Paerata Ridge Rd. (W15/822479)

01601 Kohioawa-3: (pum) (pkrsch)

77.99	11.82	0.20	1.07	0.11	0.85		3.16	4.48	0.31	3.00
77.88	12.04	0.13	1.05	0.10	0.78		3.27	4.59	0.15	1.97
78.35	11.98	0.16	1.01	0.08	0.75		3.02	4.39	0.26	3.87
79.04	11.78	0.17	0.98	0.11	0.77		2.74	4.23	0.16	2.66
78.46	11.76	0.12	1.02	0.15	0.84		3.19	4.28	0.19	0.61
77.89	11.99	0.18	1.15	0.12	0.84		3.28	4.33	0.22	1.51
78.27	11.90	0.16	1.05	0.11	0.80		3.11	4.38	0.22	2.27
6 0.45	0.12	0.03	0.06	0.02	0.04		0.20	0.13	0.06	1.15
b 78.51	11.96	0.08	0.78	0.11	0.58		2.87	4.78	0.32	2.95
b 78.55	11.92	0.10	0.76	0.06	0.55		3.20	4.63	0.22	2.60
b 78.65	12.02	0.15	0.85	0.11	0.57		2.94	4.50	0.21	3.08
b 78.45	11.96	0.09	0.66	n.d.	0.54		3.15	4.97	0.18	1.57
78.54	11.97	0.11	0.76	0.10	0.56		3.04	4.72	0.23	2.55
4 0.09	0.04	0.03	0.08	0.03	0.02		0.16	0.20	0.06	0.68

01602 Paerata: (crs-ash) (pkrsch)

78.85	12.13	0.10	0.98	0.15	1.02		3.15	3.48	0.13	3.10
78.68	11.98	0.14	1.10	0.11	0.96		2.88	3.59	0.57	7.18
78.72	12.30	0.12	1.05	0.16	0.99		2.99	3.56	0.13	4.69
78.86	11.97	0.12	0.87	0.15	1.05		3.34	3.52	0.11	2.62
79.11	12.16	0.11	1.01	0.08	0.96		2.87	3.57	0.11	3.98
79.14	12.17	n.d.	0.94	0.17	1.01		3.06	3.40	0.12	3.99
78.39	12.25	0.08	1.04	0.13	0.99		3.09	3.85	0.19	4.59
78.86	12.19	0.18	0.92	0.12	1.07		3.09	3.45	0.13	4.36
78.64	12.27	0.10	1.13	0.11	1.04		3.04	3.51	0.15	3.94
78.50	12.53	0.13	0.96	0.15	1.10		2.87	3.58	0.18	4.26
78.30	12.41	0.11	0.93	0.14	1.10		3.36	3.52	0.13	5.19
78.73	12.22	0.12	0.99	0.13	1.02		3.07	3.55	0.18	4.35
11 0.27	0.17	0.03	0.08	0.03	0.05		0.17	0.12	0.13	1.18

01603 Kohioawa-3: (pum) (pkrsch)

78.84	11.53	0.16	1.05	0.09	0.75		2.90	4.47	0.21	0.86
78.56	11.76	0.19	0.95	0.14	0.78		3.20	4.27	0.14	1.22
78.00	11.87	0.18	1.09	0.11	0.82		3.30	4.39	0.23	1.79
78.05	11.92	0.17	0.99	0.09	0.89		3.15	4.52	0.21	1.44
77.23	12.63	0.10	1.09	n.d.	0.69		3.35	4.77	0.14	6.26
77.85	12.39	n.d.	0.93	0.18	0.82		2.97	4.47	0.38	7.22
77.40	12.23	0.12	1.09	0.09	0.92		3.32	4.63	0.19	3.39
78.47	12.10	0.17	1.04	n.d.	0.82		3.02	4.38	n.d.	4.87
77.64	12.16	0.17	1.09	0.13	0.87		3.28	4.43	0.23	4.82
78.01	12.07	0.16	1.04	0.12	0.82		3.17	4.48	0.22	3.54
9 0.54	0.34	0.03	0.06	0.03	0.07		0.16	0.15	0.07	2.36

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
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01603 continued

b 78.42	12.26	0.10	0.82	n.d.	0.57		3.06	4.62	0.17	3.15
b 78.59	11.99	0.07	0.70	n.d.	0.57		3.15	4.74	0.19	2.49
b 78.63	12.04	0.07	0.82	n.d.	0.51		3.15	4.56	0.23	2.12
b 78.73	11.98	n.d.	0.91	n.d.	0.55		3.03	4.64	0.16	2.27
b 78.31	12.17	n.d.	0.76	n.d.	0.60		3.21	4.76	0.19	3.26
b 78.32	11.96	n.d.	0.87	n.d.	0.58		3.31	4.75	0.19	2.38
b 78.62	11.89	n.d.	0.84	n.d.	0.54		3.17	4.78	0.16	2.86
b 77.66	12.39	0.09	0.81	0.07	0.57		3.43	4.80	0.17	5.06
b 78.21	12.31	n.d.	0.77	0.07	0.57		3.12	4.75	0.20	5.10
b 78.33	12.51	n.d.	0.67	0.08	0.61		3.06	4.53	0.21	5.32
b 78.23	12.21	0.07	0.83	0.07	0.62		2.93	4.84	0.19	3.57
78.37	12.15	0.08	0.80	0.08	0.57		3.15	4.71	0.19	3.42
11 0.29	0.20	0.02	0.07	0.01	0.03		0.14	0.10	0.02	1.20
? 77.46	12.31	0.10	1.26	0.06	0.60		3.25	4.77	0.19	5.33

01604 Kohioawa-3 (i): (mb) (pkrsch)

78.60	11.99	0.14	1.00	0.15	0.69		2.90	4.32	0.22	4.04
78.18	11.90	0.18	0.94	0.12	0.71		3.20	4.53	0.23	2.46
78.15	11.95	0.16	1.08	0.12	0.68		3.10	4.47	0.29	2.36
78.36	12.11	0.09	0.97	0.12	0.73		2.89	4.45	0.28	3.07
78.52	11.92	0.14	1.05	0.13	0.67		2.76	4.56	0.25	2.84
78.26	11.93	0.21	1.08	0.11	0.68		2.81	4.64	0.27	3.63
78.61	12.00	0.09	1.03	0.12	0.80		2.81	4.27	0.26	3.72
78.11	11.90	0.15	1.11	0.11	0.76		3.10	4.52	0.24	2.67
78.35	11.96	0.15	1.03	0.13	0.71		2.95	4.47	0.25	3.10
8 0.20	0.07	0.04	0.06	0.01	0.05		0.16	0.12	0.02	0.63
b 78.96	11.98	n.d.	0.90	0.10	0.61		2.70	4.60	0.15	4.37
b 78.63	11.99	n.d.	0.87	n.d.	0.46		2.96	4.86	0.23	3.14
b 78.53	12.07	n.d.	0.77	n.d.	0.49		3.32	4.63	0.19	2.80
b 78.22	12.07	n.d.	0.87	n.d.	0.53		3.39	4.71	0.20	1.78
78.59	12.03	--	0.85	0.10	0.52		3.09	4.70	0.19	3.02
4 0.30	0.05	--	0.06	--	0.06		0.32	0.19	0.03	1.07

01605 Kohioawa-3 (ii): (single pumice) (pkrsch)

77.91	12.15	n.d.	1.07	0.09	0.71	3.34	4.55	0.17	3.15
77.88	12.26	0.16	0.95	n.d.	0.57	3.05	5.03	0.10	2.92
77.99	12.18	n.d.	0.94	n.d.	0.64	3.25	4.84	0.16	3.62
77.94	12.41	n.d.	0.87	0.06	0.66	3.20	4.67	0.18	7.24
78.01	12.30	n.d.	0.79	0.07	0.71	3.20	4.79	0.13	3.68
78.08	12.24	n.d.	0.95	0.09	0.67	3.24	4.57	0.14	3.38
78.18	12.29	n.d.	0.86	0.06	0.61	3.19	4.65	0.16	3.68
78.30	12.24	0.06	0.94	n.d.	0.66	2.94	4.74	0.13	4.95
78.04	12.26	0.11	0.92	0.08	0.65	3.17	4.73	0.15	4.08
8	0.14	0.08	0.07	0.08	0.02	0.13	0.15	0.02	1.41
78.52	12.57	n.d.	0.90	n.d.	0.62	3.36	3.86	0.17	6.38
78.86	12.11	0.10	0.58	n.d.	0.69	2.83	4.75	0.08	5.65
78.53	12.25	0.08	0.62	0.09	0.66	2.95	4.64	0.18	3.60
78.29	12.05	0.11	0.67	0.07	0.76	3.16	4.72	0.16	3.59
77.88	12.24	n.d.	1.23	n.d.	0.67	3.03	4.79	0.15	2.77

SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
01703 Opoiki-3: (total) (pkrsch)										01801 continued									
78.53	12.45	0.27	1.01	0.19	1.21	2.91	3.27	0.15	5.16	b 77.92	12.53	0.09	0.80	n.d.	0.60	3.03	4.91	0.12	4.77
78.10	12.56	0.15	1.02	0.22	1.21	3.16	3.39	0.19	4.16	b 77.73	12.52	0.12	0.82	0.07	0.58	3.04	4.88	0.22	5.37
77.89	12.44	0.19	1.29	0.24	1.28	3.17	3.30	0.21	3.01	b 77.82	12.40	n.d.	0.88	n.d.	0.64	3.34	4.75	0.17	5.89
78.64	12.39	0.10	1.12	0.18	1.15	2.89	3.35	0.19	4.41	b 78.50	12.12	n.d.	0.67	n.d.	0.48	3.05	4.93	0.25	4.34
77.85	12.46	0.27	1.25	0.27	1.16	3.20	3.33	0.21	3.42	77.99	12.39	0.09	0.79	0.07	0.57	3.12	4.87	0.19	5.09
78.19	12.31	0.14	1.12	0.26	1.18	3.25	3.38	0.18	4.07	4 0.34	0.19	0.02	0.09	--	0.07	0.15	0.08	0.06	0.68
77.99	12.92	0.12	1.05	0.30	1.51	2.90	3.01	0.21	4.50	site 19 = Reeves Rd. (W15/751463)									
77.95	12.56	0.22	1.20	0.20	1.34	3.11	3.27	0.16	3.57	01901 Matahina: (pum) (pkrsch)									
78.27	12.55	0.20	1.26	0.17	1.39	2.83	3.16	0.18	4.02	79.00	11.95	0.12	1.25	n.d.	0.77	3.07	3.67	0.17	3.47
77.60	12.65	0.21	1.31	0.24	1.29	2.95	3.54	0.22	4.41	78.88	12.02	0.11	1.06	0.08	0.87	3.14	3.64	0.20	3.55
78.10	12.53	0.19	1.16	0.23	1.27	3.04	3.30	0.19	4.07	79.05	12.07	0.08	0.99	0.12	0.90	3.03	3.61	0.14	3.07
10 0.32	0.17	0.06	0.11	0.04	0.11	0.15	0.14	0.02	0.62	78.84	11.95	n.d.	1.22	0.12	0.84	3.07	3.83	0.14	5.12
? 78.99 12.13 n.d. 0.82 0.14 0.97 3.09 3.70 0.16 4.36										78.89	11.99	0.10	1.00	n.d.	0.83	3.40	3.66	0.12	2.84
01704 Ohiwa Hill: (total) (pkrsch)										79.26	11.98	0.08	1.02	0.13	0.81	2.98	3.61	0.12	3.34
78.60	11.93	0.11	1.20	0.10	0.91	3.15	3.83	0.17	4.33	79.04	11.89	0.08	1.00	0.09	0.85	3.16	3.70	0.18	2.70
78.93	11.88	0.12	1.22	n.d.	0.99	3.10	3.75	n.d.	2.39	79.30	12.11	0.09	1.09	0.12	0.80	2.84	3.44	0.21	3.69
78.44	11.96	0.16	1.19	0.10	1.04	3.12	3.83	0.16	4.02	79.03	12.00	0.10	1.08	0.11	0.83	3.09	3.64	0.16	3.47
78.82	11.76	0.19	1.26	0.12	0.96	2.98	3.74	0.18	3.71	8 0.17	0.07	0.02	0.10	0.02	0.04	0.16	0.11	0.03	0.75
78.85	11.93	0.28	1.25	0.11	1.00	2.85	3.54	0.19	3.67	? 79.12 12.12 0.16 0.79 0.11 0.89 3.00 3.58 0.23 3.41									
78.46	12.35	0.20	1.36	0.07	1.07	2.99	3.50	n.d.	5.61	01904 Opoiki-I (2) ? : (pum) (pkrsch)									
78.42	11.75	0.11	1.34	0.14	0.85	2.88	4.24	0.27	4.89	78.76	12.03	0.13	1.16	0.17	0.80	3.21	3.61	0.13	3.25
78.87	11.82	0.12	1.19	0.11	0.84	3.10	3.82	0.13	3.14	79.24	12.02	0.10	0.88	0.12	0.89	3.09	3.50	0.16	4.57
78.28	11.99	n.d.	1.36	0.07	0.90	3.21	4.03	0.16	4.48	79.12	12.19	0.09	1.01	0.09	0.90	2.88	3.60	0.12	5.24
78.18	12.01	0.17	1.30	0.14	1.03	3.11	3.82	0.24	2.52	79.36	12.06	n.d.	0.87	0.07	0.83	3.05	3.63	0.11	3.66
78.59	11.94	0.16	1.27	0.11	0.96	3.05	3.81	0.19	3.88	78.94	11.95	0.11	0.97	0.17	0.90	2.88	3.91	0.15	2.50
10 0.27	0.17	0.06	0.07	0.02	0.08	0.12	0.21	0.05	1.02	79.02	12.04	0.17	0.97	0.11	0.90	3.11	3.54	0.14	4.31
? 78.27 12.04 0.20 0.99 0.16 1.26 3.39 3.57 0.12 2.71										79.28	12.12	0.10	0.83	0.06	0.86	2.95	3.63	0.16	4.13
? 79.12 11.94 0.09 0.89 0.07 1.05 3.02 3.65 0.16 4.70										79.08	12.03	0.08	1.03	0.15	0.81	3.12	3.55	0.16	3.75
01705 Torere-E: (total) (pkrsch)										79.06	12.04	0.12	0.88	0.16	0.87	2.99	3.62	0.20	3.70
78.84	12.73	0.13	1.45	0.21	1.45	3.54	3.48	0.17	4.40	79.10	12.05	0.12	0.96	0.12	0.86	3.03	3.63	0.15	3.90
77.78	12.44	0.07	1.28	0.20	1.22	3.41	3.42	0.19	3.78	9 0.19	0.07	0.03	0.10	0.04	0.04	0.11	0.12	0.03	0.79
78.30	12.21	n.d.	1.23	0.08	1.27	3.15	3.57	0.18	5.81	01905 Reeves-A: fine ash near top: (total) (pkrsch)									
78.22	12.49	0.12	1.23	0.14	1.21	2.88	3.57	0.16	5.52	77.95	12.09	0.16	1.03	0.16	0.97	3.45	4.02	0.18	5.73
77.85	12.74	0.15	1.26	0.14	1.37	2.91	3.43	0.14	5.90	78.46	12.14	0.15	0.88	0.13	0.93	3.19	3.92	0.20	7.11
77.89	12.54	0.14	1.39	0.06	1.20	3.20	3.37	0.21	4.44	78.10	12.21	0.17	0.95	0.17	0.99	3.27	3.89	0.26	6.63
78.32	12.26	n.d.	1.16	0.13	1.08	3.31	3.59	0.16	5.76	77.92	12.29	0.10	0.91	0.13	0.96	3.41	4.04	0.25	6.14
77.89	12.49	0.12	1.29	0.14	1.26	3.20	3.49	0.17	5.09	77.93	12.21	0.17	1.00	0.08	0.85	3.50	4.05	0.21	5.65
7 0.51	0.21	0.03	0.10	0.05	0.12	0.24	0.09	0.02	0.86	78.38	12.16	0.10	1.01	0.15	0.97	3.26	3.74	0.23	7.16
b 78.63 12.17 0.22 0.99 0.18 1.04 3.42 3.17 0.18 5.74										78.21	12.28	0.16	0.91	0.16	0.90	3.32	3.81	0.24	5.97
b 78.80 12.08 0.18 0.95 0.17 1.00 3.25 3.34 0.22 5.37										78.04	12.19	0.13	0.99	0.14	0.94	3.41	3.91	0.25	5.81
b 78.88 12.29 n.d. 1.09 0.19 1.08 2.81 3.45 0.20 6.42										78.19	12.22	0.13	0.96	0.14	0.93	3.25	3.92	0.27	5.97
78.77 12.18 0.20 0.11 0.18 1.04 3.16 3.32 0.20 5.87										77.89	12.13	0.12	0.95	0.13	0.93	3.64	3.99	0.23	6.01
3 0.13	0.10	0.03	0.07	0.01	0.04	0.31	0.14	0.02	0.57	78.04	12.03	0.19	1.12	0.12	0.99	3.59	3.93	n.d.	6.30
01706 Torere-G: (mtx) (pkrsch)										78.24	12.17	n.d.	0.90	0.20	0.87	3.48	3.89	0.24	8.08
77.81	12.64	0.20	1.25	0.20	1.22	3.19	3.34	0.15	4.28	77.65	12.15	0.12	1.14	0.16	0.86	3.55	4.11	0.28	6.64
77.58	12.63	0.18	1.27	0.23	1.38	3.45	3.14	0.14	4.23	78.07	12.17	0.14	0.98	0.14	0.93	3.41	3.94	0.22	6.39
78.35	11.96	0.16	1.19	0.12	1.01	3.09	3.96	0.17	4.56	13 0.21	0.07	0.03	0.08	0.03	0.05	0.14	0.10	0.07	0.68
77.58	12.40	0.21	1.19	0.12	1.15	3.33	3.85	0.18	3.85	? 78.83 11.97 0.16 1.16 0.13 0.44 3.00 4.18 0.15 4.26									
78.04	12.37	0.17	1.18	0.12	1.18	3.42	3.40	0.10	3.59	01903 Reeves-A: near base: (mtx) (pkrsch)									
78.05	12.11	0.09	1.26	0.12	0.99	3.21	3.93	0.24	4.98	77.90	12.40	0.08	0.93	0.10	1.15	3.14	4.17	0.12	3.32
77.54	12.59	0.19	1.18	0.20	1.37	3.39	3.37	0.17	5.31	78.26	12.13	0.12	0.93	0.15	0.88	3.28	4.07	0.17	2.62
77.74	12.47	0.18	1.29	0.17	1.11	3.08	3.85	0.10	4.00	78.17	12.13	0.11	1.03	0.10	0.99	3.14	4.18	0.14	4.12
77.84	12.40	0.17	1.23	0.16	1.18	3.27	3.61	0.16	4.35	78.45	11.98	0.12	1.02	0.12	0.99	3.13	4.03	0.16	3.47
8 0.29	0.25	0.04	0.05	0.05	0.15	0.15	0.32	0.04	0.58	78.40	12.14	0.19	0.97	0.16	0.95	3.02	4.03	0.15	4.02
b 78.84 12.01 0.12 1.05 n.d. 0.85 3.37 3.62 0.12 3.92										78.46	12.01	0.15	0.96	0.13	0.99	3.08	4.07	0.17	4.14
b 78.83 12.01 0.09 1.02 n.d. 0.77 3.31 3.78 0.19 4.47										78.06	12.08	0.09	1.14	0.15	1.03	3.06	4.25	0.16	4.44
b 77.83 12.37 0.14 0.93 n.d. 0.88 3.47 4.20 0.18 6.12										78.38	12.17	0.13	0.93	0.10	0.99	3.04	4.13	0.13	4.62
78.50 12.13 0.12 1.00 0.12 0.84 3.38 3.87 0.16 4.84										78.26	12.13	0.12	0.99	0.13	1.00	3.11	4.12	0.15	3.84
3 0.58	0.21	0.02	0.06	0.03	0.06	0.08	0.30	0.03	1.14	8 0.20	0.13	0.03	0.07	0.02	0.07	0.08	0.08	0.02	0.66
01707 Kaingaroa: (mtx) (integr)										01909 Murupara-C: (mtx) (integr)									
77.95	12.38	0.21	0.98	0.11	0.95	3.34	3.88	0.20	8.35	77.43	12.86	0.11	0.93	0.09	0.81	3.65	3.97	0.15	8.71
77.84	12.35	0.21	1.30	0.13	0.93	3.20	3.76	0.27	4.64	77.76	12.59	0.16	0.85	0.13	0.82	3.42	4.08	0.19	8.31
77.63	12.64	n.d.	1.14	0.10	0.97	3.67	3.55	0.31	6.01	77.12	12.79	0.16	0.96	0.17	0.72	3.66	4.16	0.25	7.56
77.39	12.38	0.22	1.41	0.16	1.04	3.43	3.78	0.19	5.77	76.98	12.78	0.16	1.04	0.15	0.86	3.82	3.98	0.20	7.15
77.60	12.18	0.10	1.29	0.14	0.99	3.66	3.87	0.17	4.42	77.75	12.69	0.09	1.04	0.10	0.66	3.34	4.15	0.19	6.76
77.65	12.36	0.14	1.43	0.18	0.86	3.50	3.67	0.22	6.44	76.94	12.72	0.22	1.17	0.06	0.87	3.75	4.06	0.20	6.64
77.49	12.30	0.21	1.13	0.14	1.10	3.55	3.82	0.27	6.19	77.33	12.96	0.13	1.01	0.11	0.70	3.67	3.92	0.17	7.59
77.53	12.50	0.19	1.11	0.12	0.95	3.61	3.83	0.15	6.57	77.66	12.83	0.06	0.90	0.11	0.81	3.50	3.96	0.16	7.43
77.31	12.67	0.22	1.14	0.16	0.92	3.50	3.84	0.24	5.73	77.70	12.72	0.14	0.77	0.04	0.80	3.74	3.92	0.16	7.50
78.20	12.16	0.13	1.10	0.08	0.86	3.51	3.71	0.25	5.15	77.73	12.82	0.00	0.83	0.09					

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water

site 21 = Tablelands Rd (W15/887462)

02101 Kohioawa-1: (pum) (pkrsch)

78.32	11.94	n.d.	1.04	0.07	0.79	3.06	4.59	0.19	3.69
77.80	12.15	0.11	0.97	0.11	0.85	3.24	4.56	0.21	3.71
77.81	12.08	0.11	1.00	0.10	0.83	3.26	4.57	0.22	2.19
78.05	12.07	0.11	0.90	0.07	0.83	3.11	4.57	0.29	2.74
78.11	12.09	0.13	0.86	0.10	0.80	3.18	4.51	0.22	3.20
77.85	12.12	0.11	1.10	0.10	0.86	3.19	4.43	0.24	4.12
77.93	12.05	0.15	0.94	0.15	0.82	3.15	4.60	0.23	3.81
78.24	12.15	0.10	1.10	0.07	0.78	3.11	4.24	0.21	4.67
78.10	12.08	0.15	1.03	0.13	0.87	2.96	4.45	0.24	4.21
77.91	12.16	0.14	1.02	0.15	0.83	3.14	4.44	0.22	4.72
78.01	12.09	0.12	1.00	0.11	0.82	3.14	4.50	0.23	3.71
10	0.18	0.06	0.02	0.08	0.03	0.09	0.11	0.03	0.81

02103 Kohioawa-3: (pum) (pkrsch)

a 78.36	11.88	0.11	0.97	0.09	0.84	3.16	4.30	0.28	3.77
a 78.09	12.15	0.17	1.13	0.08	0.80	3.08	4.31	0.19	3.78
a 78.11	12.14	0.19	0.96	0.11	0.94	2.98	4.41	0.17	5.36
a 78.41	11.94	0.23	1.02	0.09	0.79	2.92	4.42	0.17	2.79
a 77.96	12.00	0.20	1.06	0.15	0.87	3.06	4.39	0.30	1.57
a 78.09	12.02	0.19	0.99	0.12	0.82	3.14	4.47	0.16	2.75
78.17	12.02	0.18	1.02	0.11	0.85	3.06	4.38	0.21	3.34
6	0.18	0.11	0.04	0.07	0.03	0.06	0.09	0.07	0.06
b 78.57	11.96	n.d.	0.80	0.06	0.58	3.27	4.55	0.22	3.56
b 78.49	12.22	n.d.	0.88	n.d.	0.55	3.06	4.80	n.d.	3.83
b 78.73	12.09	0.15	0.78	n.d.	0.58	2.91	4.59	0.16	2.93
b 78.58	11.92	n.d.	0.77	n.d.	0.66	3.17	4.68	0.22	3.88
78.59	12.05	0.08	0.81	0.06	0.59	3.10	4.66	0.20	3.55
4	0.10	0.14	--	0.05	--	0.04	0.16	0.11	0.03

02104 Tablelands-A: (crs-ash) (pkrsch)

78.75	11.99	n.d.	1.01	0.07	0.92	2.94	4.12	0.19	5.26
78.16	12.17	0.09	0.95	0.09	0.79	3.09	4.47	0.20	6.17
78.11	12.19	0.11	1.10	0.07	0.91	3.12	4.21	0.18	6.55
78.72	12.14	0.11	0.79	0.13	0.83	3.09	4.08	0.10	4.01
77.97	12.53	0.11	1.00	0.10	0.75	3.00	4.39	0.16	5.57
78.89	12.12	0.12	0.95	0.13	0.90	2.74	4.04	0.12	5.47
79.18	11.59	0.11	0.94	0.14	1.02	3.28	3.65	0.11	5.09
79.02	11.85	0.12	0.94	0.12	0.80	3.04	3.96	0.15	5.35
78.79	12.03	0.11	0.90	0.14	0.71	2.97	4.19	0.16	5.82
78.62	12.07	0.11	0.95	0.11	0.85	3.03	4.12	0.15	5.48
9	0.43	0.26	0.01	0.08	0.03	0.10	0.15	0.24	0.04
b 78.80	11.97	0.16	1.18	0.13	1.35	2.98	3.32	0.13	5.61
b 78.82	11.98	0.14	1.07	0.13	1.11	3.12	3.50	0.14	4.76
b 78.45	12.05	0.15	1.18	0.13	1.17	3.13	3.61	0.14	5.99
b 78.82	11.88	0.12	1.10	0.16	1.18	3.29	3.31	0.15	5.58
b 78.76	12.01	0.20	1.29	0.19	1.31	3.00	3.11	0.13	5.66
b 78.70	12.09	0.16	1.09	0.17	1.16	3.26	3.22	0.16	5.69
b 79.23	11.96	0.12	1.10	0.17	1.18	2.93	3.16	0.14	6.29
78.80	11.99	0.15	1.14	0.15	1.21	3.10	3.32	0.14	5.08
7	0.23	0.07	0.03	0.08	0.03	0.09	0.14	0.18	0.01

02105 Paerata: (crs-ash) (pkrsch)

78.33	12.54	0.13	0.84	0.13	1.23	3.12	3.56	0.14	4.72
78.50	12.53	0.19	1.09	0.16	1.01	2.77	3.61	0.14	5.21
78.34	12.46	n.d.	0.99	0.15	1.14	3.16	3.61	0.16	4.33
78.31	12.50	0.17	0.99	0.17	1.08	3.01	3.66	0.12	4.77
77.81	12.70	0.17	0.96	0.06	1.19	3.37	3.74	n.d.	5.89
78.64	12.46	0.07	0.81	0.21	1.15	2.94	3.54	0.18	5.76
78.09	12.61	0.11	0.98	0.11	1.23	3.15	3.57	0.15	5.96
78.40	12.88	0.13	1.01	0.16	1.06	2.90	3.35	0.11	6.96
78.44	12.52	0.11	0.86	0.18	1.05	3.22	3.43	0.19	5.73
78.32	12.58	0.13	0.95	0.15	1.13	3.07	3.56	0.15	5.48
9	0.24	0.14	0.04	0.09	0.04	0.08	0.18	0.12	0.03

02106 Otara-wairere: (crs-ash) (pkrsch)

78.16	12.32	0.08	0.86	0.09	0.78	2.86	4.71	0.13	3.48
78.48	12.34	n.d.	0.71	n.d.	0.66	3.09	4.58	0.13	3.48
78.43	12.05	0.11	0.88	0.08	0.75	2.94	4.55	0.20	3.75
78.32	12.31	n.d.	0.87	n.d.	0.67	3.21	4.46	0.16	3.00
78.58	12.28	n.d.	0.77	n.d.	0.70	3.08	4.45	0.15	5.07
78.26	12.08	0.10	0.85	0.10	0.70	3.06	4.67	0.18	3.82
78.37	12.21	0.11	0.77	0.06	0.66	3.03	4.67	0.12	3.57
78.77	11.95	n.d.	0.78	0.08	0.73	2.95	4.60	0.15	4.95
78.42	12.31	n.d.	0.87	n.d.	0.71	2.94	4.59	0.16	3.44
78.42	12.21	0.10	0.82	0.09	0.71	3.02	4.59	0.15	3.84
9	0.18	0.14	0.01	0.06	0.02	0.04	0.10	0.09	0.02
? 77.75	12.69	0.20	1.18	0.25	1.89	3.43	2.55	0.05	1.72

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water

site 22 = Torere West (X15/028507)

02201 Torere-I (1): (pum) (pkrsch)

a 77.04	12.64	0.18	1.62	0.17	1.20	3.68	3.31	0.18	3.80
a 77.17	12.74	0.14	1.43	0.15	1.18	3.59	3.41	0.20	4.15
a 77.56	12.87	0.17	1.58	0.11	1.17	3.23	3.13	0.19	6.69
a 77.31	12.82	0.12	1.48	0.12	1.17	3.37	3.45	0.17	5.04
a 77.64	12.38	0.18	1.30	0.16	1.11	3.38	3.66	0.20	5.16
a 77.27	12.81	0.17	1.42	0.16	1.13	3.59	3.30	0.15	5.49
a 77.12	12.73	0.21	1.51	0.18	1.19	3.59	3.31	0.17	4.11
a 77.22	12.82	0.16	1.50	0.16	1.17	3.34	3.46	0.18	5.14
a 78.20	12.38	0.17	1.22	0.18	1.11	3.04	3.59	0.11	5.66
a 77.63	12.98	0.20	1.34	0.16	1.09	2.96	3.44	0.20	5.82
a 77.15	12.90	0.14	1.54	0.20	1.08	2.46	3.37	0.17	5.12
a 77.78	12.79	0.20	1.43	0.15	1.06	2.98	3.48	0.13	5.58
a 77.33	12.82	0.19	1.56	0.15	1.16	3.01	3.54	0.23	5.10
77.42	12.74	0.17	1.46	0.16	1.14	3.32	3.42	0.17	5.14
13	0.33	0.18	0.03	0.12	0.02	0.05	0.26	0.14	0.03
b 79.14	11.91	0.12	0.94	0.11	0.91	3.20	3.46	0.20	3.88
b 78.40	11.97	0.17	1.01	0.09	0.88	3.34	3.96	0.18	3.90
b 78.58	12.14	0.08	0.91	0.08	0.96	3.41	3.66	0.18	5.76
b 79.26	11.94	n.d.	1.00	0.13	0.80	3.10	3.61	0.18	4.58
b 79.17	11.89	0.16	1.06	0.08	0.90	3.05	3.51	0.16	4.97
b 78.70	11.86	0.15	0.99	0.09	0.86	3.26	3.90	0.19	4.43
b 78.91	11.97	n.d.	0.97	0.08	0.98	3.23	3.68	0.18	4.72
78.88	11.95	0.14	0.98	0.10	0.90	3.23	3.68	0.18	4.62
7	0.33	0.09	0.03	0.05	0.02	0.06	0.12	0.19	0.01
? 77.92	12.78	0.25	1.20	0.23	1.30	3.45	2.67	0.19	4.92

02202 Hiwarau: (pum) (pkrsch & integr)

77.49	12.52	0.24	1.25	0.21	1.36	3.35	3.44	0.14	4.19
77.83	12.50	0.20	1.20	0.17	1.19	3.31	3.46	0.14	5.38
77.16	12.64	0.22	1.31	0.22	1.39	3.74	3.18	0.14	4.76
77.63	12.36	0.18	1.26	0.18	1.18	3.72	3.32	0.17	5.35
77.17	13.05	0.27	1.57	0.26	1.24	2.96	3.37	0.09	4.86
76.90	13.13	0.26	1.37	0.20	1.31	3.17	3.51	0.15	4.45
77.90	12.71	0.21	1.17	0.00	1.12	3.15	3.74	0.00	5.92
77.39	13.12	0.18	1.41	0.23	1.21	2.97	3.41	0.09	4.92
76.94	13.08	0.35	1.55	0.21	1.36	2.99	3.39	0.12	5.15
77.53	12.69	0.19	1.40	0.19	1.30	3.21	3.44	0.06	4.00
77.18	12.99	0.32	1.21	0.18	1.38	3.20	3.43	0.12	4.59
77.38	12.80	0.24	1.34	0.20	1.28	3.25	3.43	0.12	4.87
11	0.33	0.28	0.06	0.14	0.03	0.09	0.27	0.14	0.03
b 77.59	13.01	0.22	1.16	0.19	1.04	3.04	3.64	0.13	4.83
b 78.63	12.11	0.09	1.24	0.14	0.91	3.30	3.39	0.18	4.86
b 78.99	12.09	0.11	0.98	0.11	0.97	3.29	3.30	0.18	5.09
b 78.57	12.07	0.14	1.08	0.15	1.01	3.24	3.55	0.20	4.56
b 78.25	12.15	0.17	1.14	0.09	0.80	3.69	3.51	0.20	4.55
78.41	12.29	0.14	1.12	0.13	0.95	3.31	3.48	0.18	4.78
5	0.53	0.41	0.05	0.10	0.04	0.10	0.24	0.13	0.03
c 78.25	12.32	0.26	0.89	0.12	0.80	3.28	3.92	0.16	4.58
c 78.70	12.32	0.13	0.79	0.13	0.87	3.38	3.54	0.16	4.47
78.48	12.32	0.19	0.84	0.12	0.83	3.33	3.73	0.16	4.53
2	0.31	0.00	0.10	0.07	0.01	0.05	0.07	0.27	0.00

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
02205 Torere-O: (total) (pkrsch)										
77.90	12.79	n.d.	0.97	n.d.	0.88	3.48	3.98	n.d.	8.10	
78.91	12.36	n.d.	0.84	0.09	0.83	2.92	3.90	0.15	7.35	
78.36	12.32	0.10	0.97	0.11	0.89	3.26	3.87	0.14	6.62	
77.86	12.46	0.19	1.07	n.d.	0.95	3.34	3.97	0.15	6.53	
78.61	12.18	0.08	0.92	0.08	0.85	3.04	4.01	0.21	4.71	
78.56	12.16	0.14	1.00	0.08	0.76	3.24	4.02	0.05	4.67	
78.28	12.22	n.d.	1.06	0.07	0.75	3.47	4.01	0.15	3.51	
78.98	11.99	0.09	1.08	0.14	0.96	2.91	3.73	0.12	5.03	
78.63	12.07	0.10	0.94	n.d.	0.95	3.33	3.78	0.19	4.51	
78.40	12.15	0.09	1.17	0.10	0.83	3.15	3.86	0.25	4.74	
78.45	12.27	0.11	1.00	0.10	0.86	3.21	3.91	0.16	5.58	
10 0.37	0.23	0.04	0.09	0.02	0.08	0.21	0.10	0.06	1.47	
78.43	12.21	0.16	1.01	0.16	1.10	3.20	3.59	0.16	5.21	
02206 Torere-N: (total) (pkrsch)										
78.32	12.57	0.16	1.24	0.12	0.97	2.86	3.60	0.16	3.26	
78.52	12.38	0.14	1.14	0.10	1.07	2.79	3.72	0.15	4.23	
78.27	12.49	0.21	1.24	n.d.	0.94	3.20	3.65	n.d.	4.64	
78.40	12.38	0.16	1.27	0.17	0.94	3.02	3.52	0.15	3.70	
78.34	12.52	0.14	1.23	0.13	0.91	3.06	3.56	0.12	4.61	
77.99	12.43	0.18	1.19	0.11	0.93	3.27	3.73	0.17	3.65	
78.48	12.37	0.18	1.20	0.10	0.90	3.18	3.48	0.13	3.04	
78.46	12.24	0.18	1.11	0.12	0.94	3.20	3.62	0.13	3.22	
78.43	12.49	0.16	1.15	0.14	0.93	2.99	3.62	0.10	3.82	
77.93	12.40	0.12	1.32	0.14	0.97	3.32	3.65	0.16	3.87	
78.47	12.33	0.19	1.26	0.14	0.97	2.85	3.68	0.13	4.80	
78.79	12.24	0.20	1.11	0.11	1.01	2.76	3.65	0.14	5.66	
78.70	12.26	0.19	1.12	0.13	1.02	2.81	3.62	0.16	4.87	
78.79	12.17	0.12	1.17	0.14	0.92	2.97	3.56	0.17	6.63	
78.20	12.19	0.19	1.30	0.14	0.89	3.29	3.68	0.12	5.54	
78.41	12.36	0.17	1.20	0.13	0.95	3.04	3.62	0.14	4.37	
15 0.25	0.12	0.03	0.07	0.02	0.05	0.20	0.07	0.02	1.02	
78.63	12.40	0.24	1.17	0.14	1.23	2.64	3.43	0.11	4.29	
02207 Torere-K: (total) (pkrsch)										
76.72	12.91	0.34	1.55	0.30	1.40	3.40	3.26	0.14	5.56	
77.10	12.81	0.34	1.34	0.29	1.45	3.25	3.27	0.15	7.51	
77.21	12.86	0.32	1.30	0.31	1.34	3.33	3.08	0.25	7.67	
77.03	12.83	0.26	1.35	0.28	1.39	3.44	3.29	0.14	5.94	
76.76	12.92	0.31	1.26	0.24	1.33	3.69	3.36	0.12	6.07	
76.71	12.81	0.29	1.45	0.28	1.34	3.73	3.31	0.09	2.70	
77.71	12.52	0.25	1.21	0.20	1.33	3.20	3.46	0.13	7.24	
77.07	12.78	0.35	1.33	0.33	1.35	3.46	3.20	0.12	6.95	
77.04	12.80	0.31	1.35	0.28	1.37	3.44	3.28	0.14	6.20	
8 0.33	0.13	0.04	0.11	0.04	0.04	0.19	0.11	0.05	1.62	
02208 Ohiwa Hill: (total) (pkrsch)										
77.95	12.47	0.10	1.07	0.12	1.00	3.22	3.88	0.20	5.77	
78.24	12.15	0.12	1.14	0.13	0.97	3.15	3.93	0.17	5.37	
78.50	12.01	0.11	1.19	0.06	0.88	3.04	4.06	0.15	5.38	
78.84	12.41	0.14	1.06	0.13	1.14	3.35	3.77	0.18	4.44	
78.67	12.17	0.18	1.18	0.14	0.97	2.81	3.72	0.16	5.13	
77.72	12.51	0.17	1.17	0.16	1.03	3.25	3.81	0.19	4.24	
78.95	11.76	0.10	1.14	0.12	0.93	2.89	3.92	0.20	5.50	
77.45	12.52	0.15	1.25	0.13	1.14	3.33	3.87	0.17	4.43	
78.46	12.19	0.16	1.10	0.15	1.00	3.08	3.72	0.15	5.31	
77.57	12.69	0.24	1.18	0.13	1.14	3.00	3.55	0.51	9.28	
78.33	12.40	0.16	1.16	0.16	1.05	2.95	3.64	0.16	5.71	
77.96	12.55	0.15	1.29	0.23	1.20	3.01	3.41	0.19	5.97	
78.56	11.90	0.15	1.15	0.10	0.96	3.00	3.98	0.19	4.38	
77.69	12.61	0.12	1.24	0.15	1.18	3.01	3.86	0.15	5.07	
77.76	12.51	0.17	1.20	0.12	1.16	3.39	3.54	0.16	4.79	
78.29	12.46	0.14	1.11	0.14	1.13	3.10	3.50	0.14	5.38	
78.69	12.04	0.16	1.21	0.09	0.84	2.77	4.03	0.17	6.00	
78.51	12.01	0.20	1.18	n.d.	0.98	2.95	4.03	0.13	5.19	
78.86	12.14	0.16	1.12	0.08	1.15	3.44	3.92	0.13	4.88	
78.56	11.96	0.17	1.22	n.d.	0.86	3.11	3.92	0.20	5.29	
78.01	12.27	0.12	1.15	0.10	1.16	3.31	3.69	0.21	5.75	
77.97	12.50	0.15	1.21	0.16	1.14	3.06	3.63	0.17	5.31	
78.16	12.28	0.15	1.17	0.13	1.05	3.10	3.79	0.18	5.39	
22 0.42	0.26	0.03	0.06	0.04	0.11	0.18	0.19	0.08	1.01	

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
02209 Torere-B: (total) (pkrsch)										
	79.25	11.46	0.15	1.12	0.14	1.04	3.10	3.58	0.16	7.42
	78.70	12.06	0.16	1.01	0.10	0.92	3.18	3.70	0.17	4.32
	78.95	12.09	0.15	1.14	0.12	0.92	2.84	3.63	0.16	6.13
	78.59	12.10	0.14	1.03	0.09	1.00	3.15	3.74	0.17	4.72
	78.98	11.91	0.16	1.14	0.15	0.90	2.87	3.73	0.17	4.12
	78.87	12.14	0.18	1.02	n.d.	1.01	3.13	3.52	0.14	4.56
	78.96	11.98	0.08	1.15	0.17	0.90	2.83	3.77	0.16	4.28
	78.59	12.23	0.15	1.15	0.07	1.03	2.96	3.69	0.13	4.61
	78.86	12.00	0.14	1.10	0.12	0.96	3.01	3.67	0.16	5.02
8	0.23	0.24	0.03	0.06	0.03	0.06	0.15	0.09	0.02	1.15
b	77.71	12.58	0.28	1.15	0.21	1.34	3.28	3.29	0.17	4.91
b	77.87	12.44	0.28	1.33	0.12	1.23	3.45	3.15	0.12	2.35
	77.79	12.51	0.28	1.24	0.17	1.28	3.37	3.22	0.15	3.63
2	0.12	0.10	0.01	0.13	0.06	0.08	0.12	0.10	0.03	1.81
02210 Opoiki-2: (total) (pkrsch)										
	78.13	12.65	0.17	1.21	0.18	1.21	2.80	3.47	0.16	6.12
	78.20	12.49	0.19	1.27	0.16	1.17	2.74	3.59	0.19	5.70
	77.97	12.56	0.24	1.20	0.18	1.23	2.98	3.52	0.13	5.59
	77.97	12.39	0.23	1.20	0.18	1.17	3.06	3.68	0.14	3.87
	78.47	12.51	0.23	1.16	0.15	1.25	2.61	3.44	0.17	6.18
	78.35	12.51	0.17	1.25	0.19	1.21	2.69	3.44	0.19	7.18
	78.36	12.46	0.20	1.15	0.19	1.22	2.68	3.61	0.13	5.37
	78.24	12.58	0.19	1.16	0.16	1.14	2.96	3.41	0.15	5.56
	78.25	12.47	0.20	1.28	0.14	1.24	2.69	3.62	0.11	6.41
	78.21	12.51	0.20	1.21	0.17	1.20	2.80	3.53	0.15	5.78
9	0.17	0.08	0.03	0.05	0.02	0.04	0.16	0.10	0.03	0.90
02211 Opoiki-3: (total) (pkrsch)										
	77.72	12.77	0.23	1.19	0.25	1.16	3.23	3.30	0.15	3.54
	77.56	12.70	0.18	1.10	0.23	1.29	3.38	3.40	0.16	2.55
	77.87	12.95	0.25	1.16	0.24	1.19	3.04	3.16	0.15	3.84
	77.35	12.76	0.24	1.17	0.26	1.30	3.44	3.25	0.23	3.16
	78.37	12.90	0.23	1.07	0.14	1.21	2.80	3.28	n.d.	4.66
	78.02	12.71	0.13	1.18	0.21	1.23	3.03	3.34	0.15	3.05
	77.76	12.74	0.17	1.11	0.22	1.20	3.29	3.38	0.13	2.66
	77.89	12.70	0.28	1.19	0.25	1.26	3.09	3.22	0.12	3.73
	78.28	12.71	0.23	1.10	0.24	1.18	2.73	3.41	0.13	4.16
	77.87	12.77	0.22	1.14	0.22	1.22	3.11	3.30	0.15	3.48
9	0.32	0.09	0.04	0.05	0.04	0.05	0.24	0.09	0.03	0.70
02212 Torere-A: (total) (pkrsch)										
a	77.44	12.51	0.15	1.35	0.22	1.28	3.77	3.12	0.16	4.63
a	77.37	12.55	0.17	1.23	0.21	1.29	3.52	3.47	0.20	4.83
a	78.03	12.64	0.12	1.32	0.11	1.28	3.15	3.37	n.d.	6.53
a	77.54	12.73	0.16	1.58	0.19	1.33	3.00	3.30	0.17	4.98
a	77.57	12.86	n.d.	1.31	0.24	1.41	3.30	3.15	0.16	5.50
a	77.13	12.72	0.20	1.24	0.25	1.32	3.66	3.36	0.12	3.86
a	77.46	12.65	0.18	1.32	0.23	1.42	3.28	3.32	0.13	5.54
a	77.35	12.83	n.d.	1.30	0.27	1.37	3.41	3.32	0.15	4.59
	77.48	12.69	0.16	1.33	0.22	1.34	3.39	3.30	0.15	5.06
8	0.26	0.12	0.03	0.11	0.05	0.06	0.26	0.11	0.03	0.80
b	78.72	11.74	0.17	1.05	0.16	0.94	3.41	3.53	0.28	3.94
b	78.35	12.24	0.14	1.05	0.11	0.87	3.29	3.76	0.19	5.81
b	78.07	12.42	0.14	1.18	0.17	1.05	3.30	3.49	0.19	4.77
b	78.04	12.54	0.14	1.19	0.16	1.00	3.37	3.42	0.13	6.25
b	78.25	12.32	0.19	1.20	0.11	1.01	3.27	3.49	0.16	5.24
b	78.91	12.08	n.d.	0.91	0.13	0.85	3.15	3.77	0.20	5.74
b	78.30	12.27	0.10	1.08	0.10	0.93	3.51	3.52	0.19	4.53
	78.38	12.23	0.15	1.10	0.13	0.95	3.33	3.57	0.19	5.18
7	0.32	0.26	0.03	0.10	0.03	0.08	0.11	0.14	0.05	0.82
?	77.58	12.41	0.11	1.21	0.17	1.12	3.73	3.42	0.24	3.58
?	78.10	12.48	0.14	1.29	0.17	1.16	3.08	3.41	0.18	6.03
02213 Torere-M: (mtb) (pkrsch)										
	78.47	12.31	0.18	0.86	n.d.	0.68	3.17	4.20	0.13	4.55
	78.48	12.26	0.08	0.92	0.11	0.66	2.95	4.40	0.14	5.15
	78.32	12.18	0.07	0.84	0.09	0.71	3.26	4.41	0.13	4.48
	78.56	12.24	0.08	0.94	0.08	0.58	3.20	4.23	0.09	4.90
	78.52	12.26	n.d.	0.80	n.d.	0.63	3.35	4.31	0.13	4.96
	78.42	12.23	0.15	0.84	0.06	0.60	3.27	4.33	0.10	4.48
	78.92	12.20	0.07	0.77	n.d.	0.71	3.01	4.16	0.15	4.79
	78.31	12.39	0.08	0.76	n.d.	0.65	3.40	4.31	0.09	4.93
	78.61	12.18	0.07	0.82	n.d.	0.64	3.24	4.27	0.16	4.70
	78.61	12.10	0.07	0.93	n.d.	0.62	3.00	4.53	0.14	5.71
	78.52	12.11	n.d.	0.86	n.d.	0.66	3.59	4.15	0.11	5.64
	78.52	12.22	0.10	0.85	0.09	0.65	3.22	4.30	0.12	4.94
11	0.17	0.08	0.04	0.06	0.02	0.04	0.19	0.11	0.02	0.42
b	78.81	12.19	0.12	1.11	n.d.	0.97	3.31	3.51	n.d.	5.07
02214 Kaingaroa: (total) (integr)										
	78.01	12.63	0.10	1.29	0.14	0.82	3.33	3.46	0.21	4.62
	78.16	12.77	0.16	1.17	0.18	0.73	3.12	3.51	0.21	5.02
	77.93	12.68	0.17	1.11	0.11	0.83	3.38	3.60	0.19	5.12
	78.47	12.36	0.18	1.13	0.13	0.82	3.20	3.57	0.13	1.77
	77.81	12.63	0.22	1.08	0.15	0.70	3.45	3.70	0.25	4.70
	77.73	12.60	0.13	1.33	0.15	0.88	3.44	3.51	0.23	4.63
	77.49	12.70	0.26	1.25	0.18	0.91	3.55	3.47	0.19	4.71
	78.45	12.80	0.18	1.15	0.15	0.79	3.14	3.20	0.13	6.82
	77.86	12.53	0.32	1.08	0.14	0.86	3.42	3.61	0.18	2.96
	78.00	12.51	0.17	1.11	0.16	0.89	3.47	3.53	0.17	4.42
	77.82	12.59	0.19	1.17	0.11	0.88	3.42	3.69	0.14	3.13
	77.98	12.62	0.19	1.17	0.14	0.83	3.36	3.53	0.18	4.35
11	0.30	0.12	0.06	0.08	0.02	0.07	0.14	0.14	0.04	1.33

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
02215 Torere-G; (mtb) (integr)										
76.07	13.16	0.17	1.53	0.12	1.07	4.05	3.66	0.17	7.66	
76.01	13.22	0.30	1.27	0.33	1.40	4.09	3.28	0.11	6.30	
75.83	13.26	0.28	1.37	0.25	1.45	4.00	3.40	0.17	6.40	
76.16	13.18	0.29	1.31	0.13	1.07	3.85	3.80	0.21	7.49	
75.19	13.58	0.27	1.57	0.32	1.46	4.10	3.32	0.19	6.84	
75.51	13.14	0.29	1.50	0.34	1.40	4.12	3.51	0.19	6.25	
76.57	12.99	0.22	1.23	0.26	1.21	3.85	3.51	0.15	5.18	
76.46	13.16	0.28	1.16	0.21	1.12	3.83	3.54	0.25	6.15	
76.12	13.15	n.d.	1.23	0.30	1.28	3.92	3.37	0.23	5.42	
76.49	13.58	0.13	1.17	0.17	1.07	3.70	3.49	0.20	6.24	
76.14	13.01	0.12	1.41	0.17	1.24	4.16	3.53	0.23	5.30	
76.18	13.25	0.22	1.50	0.27	1.35	3.47	3.55	0.20	6.07	
76.59	13.00	0.28	1.41	0.15	1.16	3.58	3.67	0.16	5.79	
76.55	12.98	0.20	1.39	0.10	1.26	3.69	3.62	0.21	5.71	
76.16	13.19	0.23	1.36	0.23	1.25	3.89	3.52	0.19	6.23	
14 0.42	0.19	0.06	0.13	0.08	0.14	0.22	0.14	0.04	0.72	
b 77.45 12.46 0.18 1.17 0.15 0.79 3.79 3.73 0.29 4.23										
b 77.39 12.69 0.19 1.02 0.11 0.80 3.79 3.78 0.22 6.09										
77.42 12.57 0.18 1.10 0.13 0.80 3.79 3.75 0.26 5.16										
2 0.04 0.17 0.01 0.10 0.03 0.00 0.00 0.04 0.05 1.32										
02216 Torere-I (2); (mtb) (integr)										
77.38	12.43	0.16	1.17	0.14	0.89	3.75	3.87	0.21	5.44	
77.46	12.54	0.09	1.04	0.14	0.84	3.96	3.70	0.23	6.88	
76.79	12.55	0.26	1.00	0.13	0.94	4.21	3.94	0.19	7.54	
77.13	12.72	0.10	1.14	0.17	0.85	3.77	3.83	0.28	8.17	
77.13	12.79	0.17	1.10	0.14	0.91	3.83	3.73	0.20	7.26	
77.83	12.29	0.00	0.99	0.09	0.85	3.49	4.20	0.25	7.47	
77.44	12.51	0.11	1.26	0.08	0.89	3.89	3.64	0.19	5.19	
78.04	12.45	0.19	0.90	0.11	0.92	3.69	3.47	0.23	6.68	
77.40	12.53	0.15	1.08	0.12	0.89	3.82	3.80	0.22	6.83	
8 0.40	0.16	0.06	0.11	0.03	0.04	0.21	0.22	0.03	1.04	
? 77.49 12.41 0.20 0.84 0.14 0.83 3.41 4.44 0.24 7.20										
? 77.09 12.52 0.19 1.21 0.14 1.13 3.52 3.94 0.25 7.14										

site 23 = Murupara-(1) (V17/306992)

02301 Matahina; pre-igb. airfall; (pum) (pkarch)										
78.46	12.13	0.11	1.16	0.08	0.89	3.24	3.73	0.19	3.54	
78.23	12.47	0.10	0.87	0.11	0.83	3.50	3.70	0.19	3.25	
78.01	12.37	0.14	0.88	0.15	0.88	3.47	3.88	0.24	4.33	
78.57	12.11	n.d.	1.00	n.d.	0.90	3.35	3.93	0.15	3.54	
78.52	12.13	n.d.	0.94	n.d.	0.94	3.50	3.76	0.21	4.50	
78.37	12.21	n.d.	1.05	0.07	0.83	3.58	3.72	0.16	2.77	
78.60	11.93	0.12	1.02	0.11	0.87	3.37	3.81	0.17	3.18	
78.13	12.27	0.11	1.01	0.13	0.92	3.43	3.79	0.21	3.13	
78.36	12.20	0.12	0.99	0.11	0.88	3.43	3.79	0.19	3.53	
8 0.22	0.17	0.01	0.10	0.03	0.04	0.11	0.08	0.03	0.60	
b 78.11 12.32 0.10 1.02 0.15 1.22 3.73 3.18 0.17 4.73										
b 78.24 12.06 0.18 1.09 0.16 1.12 3.45 3.54 0.17 3.61										
78.18 12.19 0.14 1.05 0.15 1.17 3.59 3.36 0.17 4.17										
2 0.09 0.19 0.05 0.05 0.01 0.07 0.19 0.25 n.d. 0.79										
02302 Anaputa; (pum) (pkarch)										
77.58	12.71	0.15	1.35	0.12	1.35	3.28	3.28	0.17	3.06	
76.61	13.20	0.18	1.44	0.15	1.48	3.48	3.28	0.17	2.53	
76.83	12.81	0.16	1.32	0.14	1.30	3.51	3.72	0.20	1.63	
77.62	12.49	0.20	1.28	0.20	1.22	3.51	3.32	0.17	3.31	
76.65	13.21	0.19	1.43	0.18	1.52	3.37	3.31	0.15	3.77	
77.63	12.57	0.17	1.32	0.13	1.20	3.58	3.21	0.19	1.00	
77.10	12.68	0.13	1.18	0.18	1.19	3.83	3.54	0.17	1.70	
77.15	12.81	0.17	1.33	0.16	1.32	3.51	3.38	0.17	2.43	
7 0.46	0.29	0.02	0.09	0.03	0.13	0.17	0.18	0.02	1.02	
b 77.85 12.43 0.13 1.05 0.13 1.11 3.56 3.57 0.16 2.59										
b 78.71 11.89 0.15 1.17 0.14 0.97 3.12 3.64 0.19 2.52										
b 77.78 12.66 0.10 1.06 0.13 1.07 3.62 3.43 0.14 3.43										
77.11 12.33 0.13 1.09 0.13 1.05 3.43 3.55 0.16 3.85										
3 0.52 0.40 0.03 0.07 0.01 0.07 0.27 0.11 0.03 0.51										
02303 Murupara-C; (pum) (pkarch)										
77.98	12.41	0.09	0.90	0.12	0.81	3.48	4.05	0.17	4.42	
77.96	12.36	0.11	1.02	0.08	0.73	3.35	4.23	0.16	3.70	
78.41	12.13	0.08	1.10	0.10	0.72	3.53	3.82	0.11	2.46	
78.63	12.31	0.10	0.83	0.08	0.84	3.05	3.98	0.18	3.30	
78.18	12.27	0.09	0.85	n.d.	0.69	3.36	4.36	0.20	3.57	
78.27	12.17	n.d.	0.94	0.10	0.74	3.36	4.23	0.18	3.31	
78.53	12.33	0.11	0.89	0.09	0.80	3.10	4.00	0.15	5.01	
78.57	12.28	n.d.	0.96	0.09	0.82	2.96	4.15	0.18	3.30	
78.61	12.41	0.10	0.93	n.d.	0.76	2.86	4.17	0.15	4.33	
78.35	12.29	0.10	0.94	0.10	0.77	3.23	4.11	0.16	3.71	
9 0.26	0.10	0.01	0.08	0.01	0.05	0.24	0.16	0.02	0.76	
? 78.45 12.17 0.15 1.22 0.08 0.69 2.97 4.12 0.17 3.77										

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
02304 Bonisch-2; (pum) (pkrsch)										
	78.94	12.04	n.d.	1.00	0.12	0.85	3.06	3.81	0.17	2.47
	78.83	12.00	0.13	1.11	0.15	0.87	2.95	3.86	0.11	4.17
	79.06	11.91	0.12	0.90	0.09	0.78	3.00	4.02	0.11	2.96
	78.69	11.93	0.08	0.99	n.d.	0.88	3.40	3.87	0.15	2.48
	78.74	12.00	0.12	1.01	0.10	0.89	3.13	3.85	0.15	3.65
	78.94	11.91	0.14	0.92	n.d.	0.88	3.18	3.89	0.13	2.53
	78.61	11.95	0.09	1.07	0.11	0.89	3.25	3.87	0.14	2.60
	79.01	12.03	0.08	0.98	n.d.	0.83	2.99	3.93	0.14	3.38
	78.51	12.21	0.13	1.01	0.10	0.87	3.16	3.84	0.17	4.76
	78.83	11.95	n.d.	1.06	0.12	0.90	3.18	3.80	0.15	3.01
	78.82	11.99	0.11	1.01	0.12	0.86	3.13	3.87	0.14	3.20
10	0.18	0.09	0.02	0.06	0.02	0.04	0.14	0.06	0.02	0.79
02305 Bonisch-1; (pum) (pkrsch)										
	78.76	12.36	n.d.	0.98	0.12	0.78	2.98	3.88	0.13	3.67
	78.90	12.28	0.13	0.83	n.d.	0.84	3.01	4.00	0.02	4.39
	78.34	12.51	0.13	1.01	0.06	0.86	3.08	3.83	0.17	3.21
	78.85	12.24	0.11	0.99	n.d.	0.80	2.97	3.89	0.15	4.04
	78.52	12.20	0.07	1.10	0.17	0.88	3.11	3.80	0.16	3.34
	78.81	12.31	0.12	0.96	0.10	0.67	2.96	3.89	0.18	3.93
	78.75	12.36	0.07	1.00	0.08	0.84	2.99	3.77	0.13	3.66
	78.91	12.49	n.d.	0.77	0.07	0.82	2.99	3.76	0.19	4.41
	78.72	12.22	0.11	1.15	0.09	0.83	3.07	3.71	0.10	3.24
	78.58	12.31	n.d.	1.07	0.10	0.83	3.11	3.88	0.11	3.82
	78.71	12.33	0.11	0.98	0.10	0.81	3.03	3.84	0.13	3.77
10	0.18	0.11	0.03	0.11	0.03	0.06	0.16	0.08	0.05	0.43
site 25 = Pukeruru Point (W15/737459)										
02501 Torere-O; (cra-cash) (pkrsch)										
	78.42	12.23	0.08	1.14	0.07	0.84	3.12	3.91	0.18	4.66
	78.83	12.03	n.d.	0.82	0.12	0.82	3.34	3.89	0.16	3.75
	78.76	12.04	n.d.	1.05	0.11	0.82	3.18	3.95	0.09	3.36
	79.02	12.07	n.d.	0.85	0.11	0.82	3.18	3.78	0.16	3.03
	79.21	11.86	0.18	0.89	0.11	0.84	2.94	3.74	0.24	2.93
	79.09	11.77	0.14	0.94	0.08	0.81	3.23	3.73	0.20	2.62
	79.00	11.85	0.12	0.98	0.11	0.73	3.24	3.79	0.17	2.40
	79.15	11.94	0.09	1.13	0.08	0.76	3.04	3.62	0.18	2.29
	79.18	11.82	n.d.	1.03	0.11	0.72	3.25	3.73	0.15	2.15
	79.19	11.73	n.d.	1.04	0.11	0.77	3.23	3.70	0.22	1.92
	78.99	11.93	0.12	0.99	0.10	0.79	3.17	3.78	0.18	2.91
10	0.25	0.16	0.04	0.11	0.02	0.05	0.12	0.10	0.04	0.83
02502 Kohleawa-1; base of fluvial deposit; (pum) (pkrsch)										
a	78.14	12.10	0.11	1.18	0.09	1.02	3.11	4.01	0.24	3.27
a	78.31	11.93	0.17	1.04	0.07	0.84	3.09	4.39	0.15	2.63
a	78.14	11.98	0.16	1.00	0.13	0.78	3.12	4.47	0.21	1.79
a	77.94	12.02	0.16	1.01	n.d.	0.96	3.08	4.61	0.20	1.43
a	78.15	12.19	n.d.	0.96	0.12	0.84	3.22	4.35	0.16	1.58
a	78.09	11.89	0.11	1.10	0.08	0.82	3.14	4.50	0.27	1.46
	78.13	12.02	0.15	1.05	0.10	0.88	3.13	4.39	0.21	2.03
6	0.12	0.11	0.03	0.08	0.03	0.09	0.05	0.20	0.05	0.75
b	77.85	12.19	n.d.	0.88	0.10	0.65	3.17	4.92	0.24	1.74
b	78.22	12.20	n.d.	0.87	0.07	0.58	3.16	4.72	0.18	1.88
b	78.35	12.17	n.d.	0.72	n.d.	0.51	3.46	4.68	0.11	1.77
b	78.56	12.05	n.d.	0.93	n.d.	0.64	2.94	4.70	0.18	1.37
	78.24	12.15	0.07	0.85	0.09	0.60	3.18	4.76	0.18	1.69
4	0.29	0.07	-	0.09	0.02	0.07	0.21	0.11	0.05	0.22
02503 Torere-I (2); (total) (pkrsch)										
	79.15	12.14	0.13	0.98	n.d.	0.81	2.76	3.85	0.19	6.39
	78.89	12.09	0.16	1.00	0.10	0.85	3.10	3.64	0.18	6.03
	79.31	11.80	0.11	1.03	0.14	0.84	2.78	3.86	0.14	6.41
	78.88	12.20	0.23	0.91	0.13	0.83	3.01	3.64	0.17	5.67
	79.20	11.89	0.10	1.07	n.d.	0.77	3.28	3.69	n.d.	5.46
	78.96	12.07	0.15	0.92	0.11	0.99	3.01	3.66	0.14	4.80
	79.32	11.89	0.08	0.93	n.d.	0.86	2.96	3.78	0.18	5.04
	78.91	12.03	0.09	0.97	0.08	0.85	3.22	3.67	0.16	4.44
	78.87	11.89	0.15	1.00	0.11	0.93	3.20	3.67	0.18	4.14
	78.80	12.02	0.12	0.96	0.10	0.93	3.10	3.79	0.17	5.94
	79.03	12.00	0.13	0.98	0.11	0.87	3.04	3.72	0.17	5.23
10	0.20	0.13	0.04	0.05	0.02	0.06	0.18	0.09	0.02	0.90
?	79.37	11.69	0.16	1.10	0.15	0.53	3.36	3.49	0.16	6.17
02504 Otaraaware; (total) (pkrsch)										
	78.36	12.36	n.d.	0.81	n.d.	0.55	3.30	4.51	0.12	5.93
	78.11	12.39	0.12	0.80	0.09	0.59	3.18	4.52	0.21	5.22
	78.15	12.45	0.12	0.76	0.07	0.61	2.96	4.72	0.16	5.08
	78.09	12.23	0.06	0.71	0.15	0.58	3.12	4.84	0.21	4.78
	78.64	12.35	0.05	0.60	n.d.	0.52	3.12	4.62	0.10	5.41
	78.49	12.13	0.08	0.83	0.05	0.64	3.24	4.38	0.16	4.84
	78.09	12.10	0.08	0.91	0.07	0.72	3.22	4.67	0.15	3.98
	78.47	12.12	0.07	0.87	0.07	0.71	3.07	4.45	0.17	4.44
	78.32	12.15	0.07	0.87	n.d.	0.72	3.19	4.53	0.15	4.14
	78.30	12.25	0.08	0.80	0.09	0.63	3.15	4.58	0.16	4.87
9	0.20	0.14	0.02	0.09	0.03	0.08	0.10	0.14	0.04	0.62
?	77.50	12.63	0.18	1.10	0.19	0.79	3.00	4.53	0.09	6.22

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
02505 Paerata: (total) (pkrsch)										
78.88	12.27	0.15	0.97	0.14	0.99	2.95	3.48	0.17	6.93	
78.80	12.29	0.13	0.91	0.07	1.11	3.03	3.51	0.15	5.89	
78.20	12.46	0.17	1.08	0.18	1.12	3.05	3.61	0.15	5.15	
78.39	12.20	0.11	0.94	0.18	1.04	3.30	3.71	0.13	5.17	
78.70	12.19	0.14	1.00	0.12	1.04	3.05	3.63	0.15	5.46	
78.15	12.26	0.09	1.07	0.09	1.02	3.36	3.86	0.09	4.67	
78.88	12.28	n.d.	1.10	0.12	1.08	2.97	3.40	0.18	5.51	
78.81	12.25	0.13	0.97	0.17	0.99	3.01	3.52	0.16	3.63	
78.60	12.28	0.13	1.00	0.13	1.05	3.09	3.59	0.15	5.30	
8	0.31	0.08	0.03	0.07	0.04	0.05	0.15	0.15	0.03	0.95
b 78.28 12.23 n.d. 0.77 n.d. 0.63 2.95 4.97 0.17 5.70										
b 78.32 12.12 0.08 0.77 n.d. 0.60 3.08 4.88 0.15 4.31										
78.30	12.17	0.08	0.77	0.06	0.61	3.02	4.93	0.16	5.01	
2	0.02	0.07	–	0.00	–	0.10	0.07	0.02	0.98	

02506 Hiwarau: (pum) (pkrsch)										
77.80	12.96	0.25	1.26	0.18	1.30	2.70	3.46	0.09	3.55	
77.47	12.81	0.29	1.38	0.22	1.36	2.71	3.58	0.20	2.86	
77.24	12.64	0.28	1.24	0.30	1.18	2.89	3.28	0.95	2.51	
78.11	12.78	n.d.	1.44	0.12	1.50	2.56	3.48	n.d.	3.52	
77.18	12.71	0.27	1.49	0.24	1.23	3.32	3.43	0.14	2.29	
77.55	12.80	0.19	1.23	0.26	1.41	2.95	3.33	0.27	2.45	
77.86	12.58	0.21	1.17	0.21	1.20	2.98	3.62	0.16	2.74	
77.86	12.73	0.29	1.28	0.21	1.42	2.52	3.44	0.26	2.24	
77.63	12.75	0.25	1.31	0.22	1.33	2.83*	3.45	0.30	2.77	
8	0.33	0.12	0.04	0.11	0.05	0.12	0.26	0.11	0.30	0.52
? 78.47 13.02 0.14 1.20 0.24 0.96 2.53 3.32 0.13 4.04										
? 78.38 12.79 0.17 0.89 0.22 1.26 2.77 3.36 0.17 3.30										

02507 Torere-N: (mtx) (pkrsch)										
78.39	12.40	0.19	1.16	0.13	0.90	2.99	3.69	0.17	4.01	
78.54	12.28	0.18	1.10	0.09	0.94	2.92	3.79	0.16	3.66	
77.94	12.40	0.15	1.27	0.11	0.94	3.51	3.54	0.13	2.90	
78.24	12.34	0.19	1.30	0.14	0.98	2.80	3.90	0.11	3.22	
78.14	12.32	0.11	1.05	0.14	0.93	3.35	3.81	0.14	3.03	
78.63	12.31	0.16	1.21	0.10	0.91	2.83	3.67	0.18	3.62	
78.42	12.33	0.11	1.16	0.09	0.92	3.22	3.59	0.15	3.14	
78.49	12.38	0.17	1.26	0.10	0.92	2.91	3.61	0.17	3.22	
78.51	12.23	0.17	1.26	0.14	0.89	3.02	3.59	0.17	2.79	
78.37	12.33	0.16	1.20	0.12	0.93	3.06	3.69	0.15	3.29	
9	0.22	0.06	0.03	0.08	0.02	0.03	0.25	0.12	0.02	0.40
? 77.80 12.61 0.10 1.11 0.18 1.16 3.22 3.62 0.20 3.00										

site 26 = Hokianga Island (W15/730456)

02601 Torere-E: (crs-ash) (pkrsch)										
78.23	12.20	0.23	1.18	0.12	1.15	3.24	3.50	0.15	5.08	
79.05	12.22	0.13	1.07	n.d.	1.13	2.81	3.60	n.d.	6.37	
79.06	12.01	0.10	1.36	n.d.	1.13	2.72	3.62	n.d.	6.01	
79.26	11.93	n.d.	0.99	0.13	1.10	2.73	3.62	0.24	5.44	
79.10	12.08	0.12	1.03	0.07	1.21	2.72	3.56	0.11	6.40	
78.26	12.44	0.13	1.22	0.15	1.17	3.18	3.34	0.13	5.03	
78.56	12.14	n.d.	1.30	0.12	1.16	3.06	3.43	0.24	5.14	
78.55	12.03	0.13	1.25	0.08	1.19	3.14	3.63	n.d.	5.52	
78.51	12.05	0.16	1.25	0.12	1.03	3.18	3.63	0.08	4.43	
78.34	12.02	0.10	1.22	0.16	1.11	3.07	3.79	0.19	5.75	
78.69	12.11	0.13	1.19	0.12	1.14	2.99	3.57	0.16	5.52	
10	0.39	0.14	0.04	0.12	0.03	0.05	0.21	0.12	0.06	0.63

02602 Torere-D: (total) (pkrsch)										
78.46	12.18	0.12	1.03	0.09	0.78	3.32	3.88	0.14	3.92	
78.02	12.20	0.10	1.02	0.15	1.06	3.50	3.81	0.14	0.83	
78.49	12.24	0.14	0.95	n.d.	0.77	3.08	4.18	0.16	4.85	
78.46	12.10	0.07	1.09	0.11	0.98	3.27	3.82	0.10	3.35	
78.24	12.31	n.d.	0.93	0.07	0.71	3.49	4.05	0.20	3.71	
78.72	11.73	0.20	1.16	0.09	0.92	3.19	3.79	0.19	4.47	
78.27	12.12	0.15	1.12	0.12	0.87	3.41	3.84	0.12	5.44	
78.24	12.28	0.13	1.06	0.14	1.02	3.24	3.72	0.17	5.15	
78.76	12.09	0.12	0.89	0.09	0.74	3.01	4.21	0.11	6.56	
78.65	12.26	0.13	1.16	0.15	0.89	3.04	3.55	0.18	5.36	
78.43	12.15	0.13	1.04	0.11	0.87	3.25	3.89	0.15	4.36	
10	0.24	0.17	0.03	0.10	0.03	0.12	0.18	0.21	0.03	1.56
? 78.42 12.37 0.08 0.73 n.d. 0.75 3.32 4.19 0.14 5.09										
? 78.23 12.38 0.22 1.29 0.14 1.15 2.99 3.41 0.19 5.74										

02603 Ohiwa Hill: (mtx) (pkrsch)										
78.07	12.55	0.20	1.14	0.09	1.07	3.41	3.33	0.13	2.98	
78.26	12.32	0.17	1.18	0.17	1.05	3.00	3.67	0.19	3.40	
78.67	12.16	0.13	1.21	0.14	0.97	3.03	3.55	0.15	4.38	
78.65	11.96	0.15	1.28	n.d.	0.95	3.00	3.90	0.13	4.33	
78.89	11.83	0.09	1.20	0.08	0.95	2.90	3.95	0.09	3.63	
78.68	12.31	n.d.	1.15	n.d.	1.03	3.37	3.45	n.d.	5.48	
78.54	12.19	0.15	1.19	0.12	1.00	3.12	3.64	0.14	4.03	
6	0.31	0.26	0.04	0.05	0.04	0.05	0.22	0.25	0.03	0.89
? 78.01 11.93 0.16 1.71 0.07 0.97 3.11 3.91 0.13 2.78										

site 27 = Hiwarau (W15/722450)

02701 Hiwarau: (pum) (pkrsch)										
77.47	12.53	0.19	1.28	0.22	1.30	3.45	3.42	0.16	3.69	
77.80	12.53	0.20	1.16	0.18	1.19	3.41	3.40	0.13	3.28	
77.57	12.55	0.20	1.27	0.19	1.29	3.38	3.40	0.18	3.72	
77.02	13.05	0.18	1.36	0.23	1.45	3.30	3.27	0.14	4.08	
77.93	12.35	0.20	1.18	0.22	1.28	3.21	3.46	0.15	1.87	
77.37	12.51	0.22	1.29	0.21	1.35	3.47	3.39	0.20	2.64	
77.98	12.52	0.22	1.13	0.23	1.28	3.33	3.16	0.17	3.56	
77.81	12.37	0.13	1.30	0.17	1.31	3.32	3.43	0.15	2.49	
77.50	12.44	0.17	1.33	0.23	1.26	3.51	3.40	0.16	2.26	
77.69	12.33	0.21	1.29	0.17	1.24	3.34	3.50	0.23	2.52	
77.61	12.52	0.19	1.26	0.20	1.29	3.37	3.38	0.17	3.01	
10	0.29	0.21	0.02	0.08	0.02	0.07	0.09	0.10	0.03	0.75
? 78.95 12.05 n.d. 0.73 0.06 0.81 3.30 3.94 0.15 2.03										

02702 Murupara-C: (crs-ash) (pkrsch)										
78.68	11.92	0.08	1.02	0.12	0.80	3.26	3.97	0.17	4.52	
79.03	12.03	n.d.	0.80	n.d.	0.72	3.11	4.17	0.14	4.94	
78.45	12.04	n.d.	1.05	0.09	0.79	3.37	4.06	0.16	4.65	
78.93	12.17	0.12	1.02	n.d.	0.77	3.02	3.78	0.19	4.88	
79.06	12.13	0.10	0.87	0.08	0.76	2.94	3.89	0.17	5.69	
79.29	11.95	n.d.	0.98	0.08	0.77	2.86	3.87	0.18	5.29	
78.66	12.18	n.d.	0.87	0.11	0.85	3.04	4.12	0.17	5.02	
79.18	12.01	0.07	0.91	0.06	0.80	2.87	3.95	0.14	5.85	
79.03	12.13	0.07	0.86	0.07	0.80	2.89	3.99	0.15	6.26	
78.90	12.07	0.09	1.00	0.08	0.76	2.86	4.08	0.16	8.17	
78.34	12.12	n.d.	0.95	0.09	0.81	3.45	4.07	0.18	4.82	
78.22	12.33	0.09	0.95	0.08	0.78	3.32	4.05	0.18	5.02	
78.74	12.05	0.13	0.94	0.12	0.84	3.12	3.91	0.16	5.44	
78.81	12.09	0.09	0.94	0.09	0.79	3.08	3.99	0.16	5.43	
13	0.33	0.11	0.02	0.07	0.02	0.03	0.21	0.11	0.02	0.96

02703 Murupara-A: (crs-ash) (pkrsch)										
78.54	11.91	0.15	1.14	0.17	1.30	3.10	3.54	0.16	5.52	
78.73	12.03	0.18	1.08	0.19	1.27	2.99	3.38	0.14	5.82	
78.72	11.98	0.18	1.14	0.14	1.35	2.89	3.46	0.13	6.71	
78.92	11.82	0.18	1.11	0.16	1.26	3.05	3.38	0.13	5.57	
78.85	11.89	0.20	1.20	n.d.	1.27	3.27	3.33	n.d.	5.45	
78.49	12.10	0.14	1.07	0.16	1.27	3.09	3.50	0.17	6.94	
79.04	11.76	0.12	1.05	0.14	1.24	3.21	3.29	0.15	5.56	
78.70	11.80	0.16	1.33	0.23	1.17	2.88	3.57	0.15	5.33	
78.75	11.91	0.16	1.14	0.17	1.27	3.06	3.43	0.15	5.86	
8	0.19	0.12	0.03	0.09	0.03	0.05	0.14	0.10	0.02	0.61

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
02707 Bonisch; (crs-ash) (pkrsch)										
78.27	12.35	0.12	1.04	0.06	0.92	3.36	3.74	0.14	3.77	
78.67	12.40	n.d.	1.05	0.07	0.87	3.06	3.72	0.17	6.44	
79.05	12.13	0.11	0.98	0.12	0.95	2.82	3.67	0.17	6.59	
78.79	12.14	0.10	0.93	0.06	0.94	2.93	3.93	0.17	6.68	
78.37	12.33	0.13	1.02	0.12	0.92	3.12	3.81	0.18	6.34	
78.84	12.21	0.10	1.05	0.08	0.83	2.99	3.77	0.15	5.55	
78.91	12.31	0.11	0.93	0.07	0.82	2.97	3.70	0.18	6.15	
78.53	12.09	0.11	1.04	0.08	0.90	3.12	3.98	0.15	5.53	
78.50	12.41	0.09	1.09	0.11	0.93	3.23	3.45	0.21	6.11	
78.87	12.18	0.13	0.91	0.06	0.91	3.01	3.74	0.19	6.26	
78.70	12.26	0.10	1.04	0.12	0.84	3.16	3.61	0.18	6.29	
78.73	12.25	0.10	0.88	0.08	0.84	3.17	3.76	0.19	5.74	
78.80	12.21	0.13	0.96	0.08	0.90	3.13	3.63	0.15	5.51	
78.75	12.19	0.12	1.02	0.11	0.81	3.11	3.71	0.19	5.74	
78.58	12.21	0.09	0.98	0.11	0.85	3.15	3.85	0.19	5.92	
78.69	12.24	0.11	0.99	0.09	0.88	3.09	3.74	0.17	5.91	
15	0.21	0.10	0.02	0.06	0.02	0.05	0.13	0.13	0.02	0.70

02708 Malahina; (pum) (pkrsch)										
79.11	12.24	n.d.	1.05	0.08	0.86	3.02	3.46	0.18	3.25	
79.14	12.03	n.d.	1.17	0.07	0.80	3.14	3.45	0.21	3.39	
78.94	12.19	0.12	1.01	0.12	0.89	2.97	3.55	0.21	5.02	
79.00	12.13	0.14	1.13	0.12	0.88	2.88	3.56	0.15	3.93	
78.79	12.14	0.12	1.05	0.08	0.89	2.91	3.84	0.17	3.17	
79.20	12.15	0.17	1.07	0.15	0.87	2.70	3.50	0.20	3.96	
79.17	12.12	0.11	0.95	0.12	0.94	2.80	3.57	0.21	3.54	
78.96	12.28	n.d.	1.03	0.12	0.96	3.02	3.50	0.14	4.51	
78.74	12.22	0.21	1.10	0.09	0.86	2.76	3.83	0.19	4.64	
79.11	12.25	0.09	0.98	0.08	0.92	2.71	3.66	0.19	4.41	
78.73	12.17	0.12	0.88	0.10	0.97	2.99	3.87	0.17	3.68	
79.11	12.26	0.07	1.01	0.12	0.81	2.98	3.47	0.17	3.69	
79.36	11.77	0.14	1.02	0.13	0.92	2.67	3.86	0.15	5.59	
79.45	12.02	0.15	1.11	0.09	0.89	2.74	3.99	0.17	5.17	
79.06	12.14	0.13	1.04	0.11	0.89	2.88	3.61	0.18	4.14	
14	0.21	0.13	0.04	0.08	0.02	0.05	0.15	0.17	0.02	0.76
b	78.81	12.32	0.08	1.11	0.13	1.17	3.18	3.02	0.18	3.07
b	79.31	12.32	0.09	1.00	0.09	1.16	2.77	3.09	0.17	4.60
79.06	12.32	0.09	1.06	0.11	1.16	2.97	3.06	0.17	3.84	
2	0.35	0.00	0.01	0.08	0.03	0.00	0.29	0.05	0.01	1.08

02709 Torere-I (1); (pum) (pkrsch)										
a	78.60	12.22	0.15	1.06	0.11	0.86	3.11	3.52	0.36	2.37
a	78.39	12.12	0.09	1.11	0.13	0.86	3.23	3.77	0.30	2.39
a	78.46	12.56	n.d.	0.96	0.19	1.01	3.18	3.51	0.14	3.02
a	78.93	12.16	0.07	1.06	n.d.	0.83	3.08	3.74	0.13	2.20
a	79.14	12.09	n.d.	0.98	0.10	0.83	3.03	3.69	0.24	3.37
a	78.66	12.11	0.15	0.96	0.10	0.90	3.36	3.53	0.22	2.35
a	78.56	12.23	0.17	1.08	0.14	0.85	3.11	3.72	0.14	2.11
a	78.80	12.21	0.09	0.95	n.d.	0.97	3.17	3.68	0.13	3.18
a	78.77	12.09	0.11	0.93	0.10	0.78	3.28	3.76	0.17	2.41
a	78.75	12.25	n.d.	0.94	0.12	0.92	3.18	3.65	0.17	2.55
78.70	12.20	0.12	1.00	0.13	0.88	3.17	3.65	0.20	2.60	
10	0.22	0.14	0.04	0.07	0.03	0.07	0.10	0.10	0.08	0.44
b	77.18	13.00	n.d.	1.70	0.15	1.17	3.47	3.16	0.17	2.17
b	77.27	13.01	0.20	1.42	0.17	1.20	3.26	3.33	0.13	2.72
b	76.96	13.02	0.18	1.49	0.15	1.20	3.46	3.36	0.17	2.54
b	77.56	12.96	0.14	1.52	0.13	1.13	2.99	3.45	0.11	3.06
b	77.20	12.98	n.d.	1.43	0.15	1.21	3.50	3.34	0.18	1.92
77.24	12.99	0.17	1.51	0.15	1.18	3.33	3.33	0.16	2.48	
5	0.22	0.03	0.03	0.11	0.01	0.03	0.21	0.10	0.03	0.45
?	79.03	11.99	0.15	1.25	n.d.	0.76	3.07	3.75	n.d.	2.03

02710 Torere-A; (mbx) (pkrsch)										
77.56	12.71	0.18	1.22	0.18	1.28	3.50	3.19	0.16	2.00	
77.71	12.94	n.d.	1.19	0.17	1.35	3.26	3.24	0.13	3.66	
77.77	12.76	0.17	1.28	0.15	1.27	3.18	3.27	0.17	3.69	
77.31	13.04	0.19	1.39	0.25	1.46	2.92	3.34	0.11	3.35	
77.86	12.65	0.23	1.20	0.18	1.29	3.05	3.38	0.16	3.64	
77.88	12.82	0.16	1.27	0.23	1.27	2.99	3.20	0.18	3.42	
77.73	12.77	0.14	1.14	0.21	1.21	3.35	3.30	0.14	3.32	
78.08	12.66	0.13	1.19	0.21	1.22	3.05	3.30	0.17	3.25	
77.02	13.06	0.21	1.39	0.27	1.45	3.24	3.21	0.15	2.79	
77.66	12.82	0.18	1.25	0.20	1.31	3.17	3.27	0.15	3.24	
9	0.32	0.16	0.03	0.09	0.04	0.09	0.19	0.07	0.02	0.54
b	79.00	12.27	0.12	0.79	n.d.	0.90	3.24	3.67	n.d.	3.38
b	78.80	12.24	n.d.	0.97	0.12	0.98	3.12	3.62	0.14	3.13
b	78.90	12.14	0.12	0.94	0.10	0.91	3.01	3.72	0.15	2.44
b	78.32	12.17	0.14	1.04	0.08	1.03	3.16	3.92	0.12	2.16
78.75	12.21	0.13	0.94	0.10	0.96	3.13	3.74	0.14	2.78	
4	0.30	0.06	0.01	0.11	0.02	0.06	0.09	0.13	0.02	0.57

02711 Huntress-C; (mbx) (integr)										
77.13	12.86	0.15	1.49	0.21	1.11	3.57	3.34	0.14	5.36	
78.03	12.72	0.12	1.12	0.14	0.83	3.50	3.37	0.18	4.41	
77.32	12.83	0.08	1.32	0.14	0.94	3.47	3.70	0.20	4.90	
77.87	12.50	0.20	1.17	0.08	0.88	3.60	3.49	0.21	4.40	
77.28	12.80	0.09	1.43	0.08	1.00	3.66	3.48	0.18	4.80	
77.28	13.14	0.28	1.41	0.11	0.96	3.41	3.26	0.15	6.26	
78.09	12.63	n.d.	1.44	0.14	0.82	3.51	3.23	0.14	5.19	
77.81	12.56	0.12	1.29	0.10	0.71	3.50	3.72	0.19	3.80	
77.37	13.13	0.21	1.48	0.12	0.97	3.30	3.27	0.15	6.14	
76.88	13.18	0.31	1.46	0.14	1.13	3.47	3.22	0.20	5.57	
76.42	13.08	0.17	1.60	0.18	1.16	3.82	3.37	0.21	3.81	
77.66	12.57	0.26	1.25	0.09	0.83	3.53	3.62	0.19	4.98	
77.43	12.83	0.18	1.37	0.13	0.94	3.53	3.42	0.18	4.97	
12	0.49	0.25	0.08	0.14	0.04	0.13	0.18	0.03	0.80	

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
02712 Huntress-D; (pum) (integr)										
78.49	11.86	0.23	1.32	0.11	0.80	3.58	3.49	0.12	2.00	
77.54	12.07	0.18	1.42	0.15	0.90	3.77	3.79	0.18	5.73	
77.99	12.14	0.25	1.05	0.10	0.88	3.63	3.78	0.18	3.07	
78.81	11.86	0.13	1.19	0.11	0.92	3.40	3.39	0.19	2.28	
78.94	11.83	0.17	1.02	0.12	0.92	3.47	3.37	0.16	1.05	
78.28	12.15	0.14	1.13	0.10	0.85	3.42	3.75	0.18	4.07	
78.45	11.78	0.08	1.16	0.12	0.78	3.61	3.87	0.13	1.79	
78.28	11.90	0.12	1.34	0.07	0.96	3.50	3.63	0.20	1.92	
78.65	11.89	0.10	1.19	0.15	0.87	3.39	3.58	0.18	3.09	
78.14	12.07	0.11	1.38	0.09	0.81	3.46	3.72	0.22	3.64	
78.41	11.89	0.11	1.22	0.09	0.89	3.65	3.53	0.21	2.51	
78.49	11.82	0.10	1.20	0.14	0.86	3.56	3.60	0.23	3.00	
78.37	11.94	0.15	1.22	0.12	0.87	3.54	3.62	0.18	2.85	
12	0.37	0.13	0.05	0.12	0.02	0.05	0.12	0.16	0.03	1.24

02713 Torere-L: (crs-ash) (integr)										
	77.73	12.15	0.20	1.07	0.18	0.98	3.84	3.64	0.21	4.39
	78.63	11.85	0.24	1.02	0.11	0.86	3.56	3.45	0.28	3.54
	78.71	11.87	0.25	1.01	0.11	0.81	3.45	3.62	0.17	1.57
	79.11	11.62	0.11	1.10	0.12	0.78	3.39	3.61	0.15	2.73
	79.16	11.60	0.16	0.93	0.16	0.80	3.34	3.66	0.19	1.36
	78.63	11.76	0.14	1.01	0.09	0.94	3.62	3.62	0.20	2.77
	78.58	12.10	0.19	0.86	0.18	0.83	3.41	3.71	0.15	4.78
	77.73	12.31	0.19	0.99	0.13	0.86	3.67	3.93	0.19	9.01
	78.78	11.66	0.13	1.05	0.14	0.92	3.47	3.65	0.19	2.18
	78.62	11.90	0.15	1.03	0.17	0.89	3.36	3.60	0.28	2.68
	78.76	11.80	0.27	0.86	0.18	0.93	3.26	3.72	0.22	2.56
	78.58	11.87	0.19	0.99	0.14	0.87	3.49	3.65	0.20	3.42
11	0.46	0.23	0.05	0.08	0.03	0.06	0.17	0.12	0.04	2.13
?	77.61	12.27	0.10	1.27	0.16	0.86	3.45	3.99	0.28	7.29

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
site 28 = Ruatuna Road (W15/739441)										
02801 Ruatuna-C; unknownll; (pum) (pkscrh)										
77.42	12.79	0.13	1.64	0.19	1.37	3.20	3.06	0.18	2.06	
77.06	12.76	0.19	1.51	0.22	1.52	3.36	3.18	0.20	2.78	
76.25	13.05	0.17	1.63	0.19	1.58	3.72	3.20	0.21	4.36	
76.62	12.99	0.21	1.71	0.22	1.55	3.44	3.09	0.18	3.60	
76.83	12.74	0.18	1.64	0.17	1.49	3.63	3.16	0.18	3.47	
76.36	13.16	0.22	1.63	0.21	1.49	3.64	3.08	0.21	3.35	
77.42	12.55	0.18	1.54	0.22	1.41	3.45	3.04	0.17	2.42	
76.85	12.61	0.19	1.62	0.22	1.48	3.65	3.18	0.21	2.87	
76.95	12.56	0.22	1.69	0.19	1.42	3.49	3.28	0.20	4.29	
76.89	12.67	0.18	1.50	0.15	1.55	3.64	3.24	0.16	2.28	
76.87	12.79	0.19	1.61	0.20	1.49	3.52	3.15	0.19	3.15	
10	0.39	0.21	0.03	0.07	0.02	0.07	0.16	0.08	0.02	0.80

02802 Waingarara Ignimbrite; (pum) (pkscrh)										
a 78.06	12.17	0.08	1.13	0.08	0.96	3.57	3.84	0.10	3.18	
a 78.20	12.14	0.17	1.22	0.13	0.98	3.23	3.80	0.13	3.61	
a 78.17	12.09	0.12	1.18	0.09	0.97	3.56	3.70	0.10	3.42	
a 78.04	12.13	0.12	1.05	0.07	0.94	3.55	3.98	0.11	3.98	
a 77.95	12.29	0.13	1.09	0.09	1.14	3.51	3.69	0.10	3.18	
a 77.94	12.25	0.10	1.19	0.10	1.10	3.55	3.61	0.14	3.38	
a 78.07	12.03	0.12	1.19	0.13	0.93	3.53	3.80	0.20	2.96	
78.06	12.16	0.12	1.15	0.10	1.00	3.50	3.77	0.13	3.39	
7	0.01	0.09	0.03	0.06	0.02	0.08	0.12	0.12	0.03	0.33
b 78.29	12.10	0.11	0.90	n.d.	0.85	3.17	4.46	0.10	3.85	
b 78.37	12.12	0.07	1.03	0.09	0.81	3.24	4.15	0.11	3.81	
b 78.19	12.08	0.08	1.07	0.07	0.86	3.23	4.28	0.14	3.72	
b 78.80	11.66	0.10	1.02	0.07	0.81	3.38	4.02	0.14	4.06	
b 78.35	12.18	n.d.	1.03	0.06	0.70	3.24	4.32	0.11	4.02	
b 78.42	12.07	n.d.	0.96	n.d.	0.76	3.29	4.37	0.14	3.79	
b 78.21	11.92	0.10	1.06	n.d.	0.74	3.47	4.34	0.17	3.49	
b 78.33	12.05	0.06	0.96	0.05	0.76	3.29	4.36	0.13	3.68	
b 78.17	11.91	0.10	1.06	0.05	0.74	3.47	4.34	0.17	3.44	
78.35	12.01	0.09	1.01	0.07	0.78	3.31	4.29	0.13	3.32	
9	0.19	0.16	0.02	0.06	0.02	0.11	0.13	0.02	1.23	
? 75.16	13.52	0.20	1.89	0.18	1.44	3.99	3.55	0.07	3.76	

02803 Ruatuna-D; unknownll; (pum) (pkscrh)										
77.18	12.92	0.15	1.55	0.13	1.23	3.00	3.60	0.22	8.46	
77.63	12.56	0.15	1.30	0.12	1.02	3.21	3.83	0.19	5.64	
77.42	12.93	0.14	1.46	0.09	1.16	2.93	3.65	0.24	7.37	
77.32	12.89	0.18	1.53	0.16	1.08	2.97	3.69	0.17	6.61	
77.52	12.96	0.16	1.33	0.16	1.15	2.84	3.61	0.27	6.84	
77.50	12.68	0.14	1.20	0.10	1.03	3.08	4.11	0.18	6.36	
77.83	12.67	0.20	1.43	n.d.	0.96	2.81	3.88	0.22	5.81	
77.07	13.13	0.16	1.69	0.16	1.12	2.86	3.60	0.20	6.77	
77.77	12.84	0.21	1.49	n.d.	1.16	2.78	3.53	0.22	5.08	
77.60	12.37	0.16	1.28	0.14	0.97	3.37	3.92	0.21	5.24	
77.02	13.00	0.17	1.26	0.19	1.04	3.04	4.09	0.21	9.21	
77.80	12.67	0.16	1.39	0.12	0.96	2.84	3.89	0.18	5.51	
77.47	12.80	0.16	1.41	0.14	1.07	2.98	3.78	0.21	6.57	
12	0.28	0.22	0.02	0.14	0.03	0.09	0.18	0.20	0.03	1.28

02804 Waingarara Ignimbrite; (single pumice) (pkscrh)										
77.91	12.29	0.09	1.03	0.10	0.73	3.48	4.18	0.20	6.22	
77.93	12.29	0.13	0.97	0.09	0.71	3.47	4.26	0.16	5.18	
78.16	12.15	n.d.	0.77	0.07	0.77	3.51	4.36	0.19	5.78	
78.27	12.18	n.d.	0.94	0.12	0.74	3.24	4.27	0.23	5.78	
78.38	12.03	0.09	0.82	0.14	0.70	3.37	4.29	0.18	4.79	
78.29	11.95	n.d.	1.14	0.10	0.60	3.51	4.21	0.19	5.51	
78.19	12.23	0.09	0.83	0.07	0.73	3.47	4.18	0.21	5.97	
77.97	12.25	n.d.	0.94	0.12	0.79	3.62	4.14	0.17	5.49	
78.43	12.16	0.07	1.01	0.10	0.68	3.40	3.97	0.19	5.77	
78.04	12.22	0.12	0.92	0.10	0.75	3.52	4.12	0.21	5.87	
78.19	12.35	n.d.	0.96	0.13	0.69	3.49	4.05	0.15	5.39	
78.10	12.25	n.d.	0.96	0.11	0.61	3.58	4.15	0.24	7.22	
78.01	12.12	0.11	0.93	0.07	0.70	3.67	4.20	0.18	6.12	
77.80	12.26	0.12	0.90	0.14	0.73	3.36	4.53	0.17	6.34	
77.75	12.18	0.11	1.05	0.11	0.67	3.57	4.39	0.18	6.40	
77.99	12.19	0.09	0.99	0.09	0.62	3.79	4.00	0.25	6.94	
78.28	12.07	0.16	0.84	0.12	0.75	3.70	3.87	0.19	7.07	
78.10	12.19	0.11	0.94	0.10	0.71	3.51	4.19	0.19	5.99	
17	0.20	0.10	0.02	0.09	0.02	0.05	0.14	0.16	0.03	0.66

02805 Waingarara Ignimbrite; (single pumice) (pkscrh)										
78.48	12.04	0.08	0.91	0.08	0.75	3.22	4.06	0.39	9.22	
78.23	12.12	n.d.	1.06	0.10	0.71	3.27	4.31	0.19	6.09	
78.08	12.28	n.d.	0.96	0.10	0.70	3.66	3.99	0.22	6.30	
78.32	12.13	0.13	0.83	0.12	0.65	3.45	4.16	0.21	6.09	
78.28	12.15	n.d.	0.85	0.10	0.73	3.39	4.29	0.20	6.12	
78.17	12.18	0.10	0.93	0.11	0.70	3.48	4.11	0.22	5.66	
77.77	12.18	0.12	1.16	0.14	1.02	3.36	4.07	0.18	5.34	
77.99	12.11	0.14	0.97	0.12	0.72	3.62	4.11	0.22	5.98	
78.17	12.15	0.11	0.96	0.11	0.75	3.43	4.14	0.23	6.35	
8	0.22	0.07	0.02	0.11	0.02	0.11	0.16	0.11	0.06	1.20

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
02806 Waingarara Ignimbrite; (single pumice) (pkscrh)										
77.91	12.16	0.15	1.22	0.13	1.11	3.46	3.65	0.21	4.89	
77.98	12.05	0.15	1.20	0.14	1.01	3.68	3.58	0.22	5.87	
77.93	12.27	0.14	1.16	0.12	1.02	3.45	3.74	0.18	5.23	
77.73	12.48	n.d.	1.04	0.13	1.03	3.63	3.74	0.22	5.69	
78.44	12.13	n.d.	1.27	0.13	1.00	3.44	3.27	0.32	8.17	
77.90	12.19	0.19	1.18	0.15	1.03	3.51	3.68	0.17	4.97	
78.39	12.17	0.16	1.17	0.12	1.00	3.13	3.67	0.20	5.89	
78.16	12.29	0.14	1.24	0.17	1.02	3.14	3.64	0.20	6.08	
78.00	12.06	0.15	1.18	0.17	0.87	3.69	3.69	0.19	4.63	
77.57	12.18	0.10	1.25	0.16	0.96	3.81	3.72	0.24	4.36	
78.00	12.20	0.15	1.19	0.14	1.01	3.49	3.64	0.22	5.58	
10	0.27	0.13	0.02	0.07	0.02	0.06	0.22	0.14	0.04	1.08
? 77.28	12.22	0.18	1.55	0.18	0.99	3.64	3.70	0.26	6.03	

02807 Waingarara Ignimbrite; (single pumice) (pkscrh)										
77.92	12.30	0.15	1.01	0.12	0.94	3.66	3.64	0.27	7.07	
77.93	12.25	0.11	1.06	0.08	0.73	3.85	3.78	0.21	5.76	
77.55	12.51	0.17	1.12	0.12	0.92	3.66	3.77	0.19	6.64	
77.80	12.35	0.14	1.06	0.11	0.86	3.72	3.73	0.22	7.49	
3	0.22	0.14	0.03	0.06	0.02	0.11	0.11	0.08	0.04	1.97

02808 Waingarara Ignimbrite; (pum) (pkscrh)										
a	78.13	12.32	0.12	1.04	0.15	0.75	3.55	3.74	0.21	7.84
a	78.41	12.17	0.08	1.04	n.d.	0.89	3.48	3.72	0.22	8.57
a	78.38	12.04	0.09	1.04	0.09	0.87	3.51	3.75	0.24	8.25
a	78.33	12.20	0.15	1.06	0.13	0.88	3.44	3.63	0.17	8.15
a	78.43	12.06	0.13	0.98	0.08	0.81	3.62	3.87	0.02	8.31
a	78.12	12.16	0.14	0.97	0.09	0.85	3.72	3.73	0.23	7.23
a	77.86	12.17	0.15	1.01	0.13	0.85	3.76	3.85	0.22	7.37
a	78.71	12.06	n.d.	1.07	0.11	0.82	3.40	3.65	0.18	7.22
a	78.36	11.98	0.13	1.04	0.12	0.85	3.55	3.78	0.20	7.77
a	78.36	12.12	0.15	1.08	0.09	0.84	3.45	3.66	0.25	7.43
a	78.21	12.05	0.17	1.08	0.10	0.88	3.60	3.69	0.22	8.14
a	78.43	12.15	n.d.	1.17	0.14	0.84	3.64	3.42	0.21	7.64
a	78.01	12.05	0.13	1.14	0.11	0.79	3.59	3.95	0.24	6.05
a	78.28	12.07	0.09	1.00	0.11	0.86	3.77	3.65	0.18	7.88
a	78.02	11.94	0.13	0.98	0.16	0.82	3.81	3.93	0.21	8.83
a	78.05	12.05	0.08	1.12	0.08	0.79	3.74	3.92	0.19	8.58
a	78.10	12.08	0.08	1.09	n.d.	0.82	3.80	3.85	0.19	8.34
	78.25	12.10	0.12	1.05	0.11	0.84	3.61	3.75	0.20	7.86
17	0.21	0.09	0.03	0.06	0.03	0.04	0.13	0.13	0.05	0.67
b	78.25	12.01	0.10	0.90	0.09	0.73	3.73	3.99	0.22	7.92
b	78.17	12.12	0.08	0.90	0.12	0.65	3.65	4.11	0.21	7.76
b	78.35	12.17	0.09	0.76	n.d.	0.69	3.49	4.26	0.19	7.65
b	78.54	12.15	0.09	0.80	0.09	0.71	3.44	3.98	0.20	6.82
b	78.30	12.11	0.13	0.82	0.09	0.72	3.49	4.15	0.20	6.41
	78.32	12.11	0.09	0.84	0.09	0.70	3.56	4.10	0.21	7.31
5	0.14	0.06	0.02	0.06	0.02	0.03	0.12	0.12	0.01	0.66
?	78.86	11.85	n.d.	0.92	0.11	0.74	3.53	3.75	0.24	9.04
?	78.40	12.01	0.10	0.88	0.14	0.78	3.69	3.77	0.23	8.14

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
02810 reworked Waingara Ignimbrite; (pum) (pkrsch)										
a 78.42	12.05	0.09	1.03	0.10	0.91	3.50	3.64		0.28	6.23
a 78.03	12.04	0.12	1.14	0.16	0.82	3.53	3.94		0.22	5.31
78.22	12.05	0.10	1.09	0.13	0.87	3.51	3.79		0.25	5.77
2 0.27	0.01	0.02	0.08	0.04	0.06	0.02	0.21		0.04	0.65
b 77.86	12.38	0.14	0.98	0.13	0.65	3.66	4.01		0.21	5.71
b 78.38	12.17	0.12	0.76	n.d.	0.67	3.54	4.12		0.25	6.40
b 78.12	11.98	0.13	1.02	0.13	0.68	3.63	4.12		0.20	5.99
b 78.42	12.09	n.d.	0.92	0.10	0.54	3.54	4.09		0.30	5.64
b 78.31	12.14	0.11	0.94	0.06	0.72	3.44	4.14		0.15	5.16
b 78.00	12.17	0.12	1.00	0.12	0.65	3.67	4.08		0.20	5.79
b 78.19	12.24	n.d.	0.88	0.06	0.72	3.60	4.07		0.25	6.54
b 78.16	12.17	0.09	0.88	0.10	0.69	3.62	4.05		0.24	6.01
b 78.41	12.11	n.d.	1.03	0.11	0.60	3.43	4.06		0.24	5.64
b 78.38	12.05	n.d.	1.05	0.08	0.65	3.40	4.15		0.24	6.76
78.22	12.15	0.12	0.95	0.10	0.66	3.65	4.09		0.23	5.96
10 0.15	0.11	0.02	0.09	0.03	0.05	0.10	0.04		0.04	0.48

site 29 = Waiotahi River (W15/788477)

02901 Matahina; (pum) (pkrsch)										
78.72	12.11	0.12	1.05	0.13	0.88	3.01	3.78		0.20	5.02
78.73	12.18	0.09	1.01	0.09	0.90	3.04	3.67		0.30	6.63
78.84	12.12	0.10	0.96	n.d.	0.82	3.16	3.74		0.26	8.27
79.12	12.21	n.d.	0.94	0.11	0.80	3.17	3.51		0.14	5.18
78.76	12.13	0.11	1.01	0.10	0.87	3.19	3.65		0.18	4.30
78.88	11.98	0.12	1.15	0.07	0.84	3.10	3.62		0.23	6.10
78.91	12.21	0.12	1.09	0.13	0.76	3.07	3.58		0.14	6.69
78.57	12.41	0.09	1.03	0.09	0.81	3.27	3.58		0.14	2.79
78.97	12.11	n.d.	1.12	0.09	0.78	3.20	3.61		0.12	3.32
78.90	12.41	0.11	0.99	0.08	0.83	3.13	3.40		0.15	3.47
78.99	12.25	0.07	0.95	0.11	0.86	3.29	3.35		0.12	3.56
78.72	12.29	n.d.	1.24	0.10	0.86	3.06	3.56		0.16	3.75
78.72	12.27	0.11	1.12	0.10	0.82	3.15	3.54		0.16	3.92
78.53	12.21	0.08	0.99	0.06	0.84	3.50	3.65		0.14	2.16
78.71	12.17	0.12	0.92	0.09	0.86	3.38	3.59		0.16	3.33
78.58	12.27	n.d.	1.16	0.09	0.82	3.21	3.70		0.17	2.37
78.57	12.25	0.12	1.02	0.12	0.84	3.47	3.48		0.14	1.60
78.78	12.21	0.10	1.04	0.10	0.83	3.20	3.59		0.17	4.26
17 0.17	0.11	0.02	0.09	0.02	0.04	0.14	0.11		0.05	1.82
b 78.30	12.34	0.09	1.21	0.15	1.25	3.21	3.29		0.16	4.06
b 78.59	12.12	0.11	1.18	0.15	1.21	3.34	3.14		0.15	2.54
78.44	12.23	0.10	1.19	0.15	1.23	3.28	3.22		0.16	3.30
2 0.20	0.16	0.01	0.02	0.01	0.03	0.10	0.11		0.00	1.07
? 79.13	12.08	0.12	0.75	0.07	0.84	3.13	3.67		0.21	4.99

site 30 = Pikowai Reserve (V15/326651)

03001 Pikowai-2; unknown; (pum) (pkrsch)										
79.11	11.98	0.13	1.01	0.07	0.97	3.29	3.33		0.10	6.12
78.93	12.06	0.11	1.01	0.12	0.92	3.28	3.40		0.18	6.08
78.54	12.22	0.13	1.09	0.13	0.94	3.19	3.59		0.18	4.37
78.57	12.02	0.14	1.04	0.10	0.93	3.21	3.78		0.21	5.75
78.64	11.96	0.12	1.17	0.08	0.96	3.26	3.62		0.18	5.32
78.73	11.94	0.12	1.08	0.09	1.01	3.32	3.52		0.19	4.66
78.38	12.17	0.12	1.21	n.d.	1.00	3.39	3.57		0.16	5.94
78.53	12.00	n.d.	1.09	0.09	1.02	3.50	3.57		0.19	5.25
78.81	12.09	n.d.	1.11	0.12	0.98	3.12	3.62		0.16	5.21
78.62	11.95	0.16	1.18	0.12	1.02	3.20	3.58		0.18	5.66
78.69	12.04	0.13	1.10	0.10	0.97	3.28	3.56		0.17	5.44
10 0.22	0.10	0.02	0.07	0.02	0.04	0.11	0.12		0.03	0.59

03002 Pikowai-1; unknown; (pum) (pkrsch)										
77.91	12.66	0.19	1.37	0.21	1.32	2.68	3.49		0.18	4.81
77.79	12.71	0.31	1.33	0.21	1.33	2.74	3.39		0.19	4.40
77.48	12.53	0.28	1.26	0.21	1.45	3.04	3.56		0.20	4.68
78.16	12.62	n.d.	1.18	0.21	1.30	3.00	3.35		0.18	4.80
77.68	12.62	0.20	1.36	0.26	1.32	2.89	3.52		0.16	4.25
77.91	12.70	0.17	1.29	0.20	1.37	2.82	3.39		0.16	4.49
78.32	12.61	0.17	1.22	0.16	1.16	2.75	3.42		0.19	5.35
77.69	12.64	0.20	1.25	0.20	1.19	3.45	3.22		0.15	6.48
77.87	12.64	0.22	1.28	0.21	1.30	2.92	3.42		0.17	4.91
8 0.27	0.06	0.06	0.07	0.03	0.09	0.25	0.11		0.02	0.72

03005 Pikowai-1/2; (B) unknown; (total) (pkrsch)										
a 76.84	12.72	0.25	1.31	0.18	1.22	3.58	3.72		0.18	6.63
a 76.58	13.02	0.29	1.26	0.23	1.40	3.54	3.49		0.20	5.61
a 76.53	13.03	0.23	1.32	0.19	1.39	3.47	3.64		0.19	6.07
a 76.56	13.08	0.18	1.23	0.19	1.22	3.43	3.94		0.18	9.05
a 76.46	13.05	0.15	1.48	0.20	1.29	3.59	3.63		0.15	8.30
a 76.70	12.69	0.21	1.35	0.16	1.26	3.63	3.82		0.16	9.00
a 76.31	13.01	0.24	1.44	0.23	1.33	3.71	3.55		0.18	4.91
a 76.72	12.90	0.20	1.28	0.19	1.25	3.39	3.88		0.18	7.14
a 76.34	12.99	0.21	1.49	0.24	1.39	3.69	3.52		0.14	6.45
76.56	12.94	0.22	1.35	0.20	1.31	3.56	3.69		0.17	7.02
9 0.18	0.14	0.04	0.10	0.03	0.07	0.11	0.16		0.02	1.48
b 78.01	12.29	0.17	1.30	0.09	0.93	3.49	3.47		0.25	4.27
b 77.99	12.58	0.09	1.00	n.d.	0.90	3.54	3.73		0.17	4.17
b 77.62	12.39	0.13	1.33	0.12	1.04	3.59	3.37		0.41	6.78
b 77.81	12.69	0.12	1.04	0.13	0.98	3.52	3.47		0.23	6.16
b 77.94	12.26	0.14	1.20	0.07	1.00	3.53	3.74		0.12	4.89
b 77.45	12.44	0.16	1.24	0.13	0.99	3.75	3.61		0.22	5.99
b 77.66	12.63	0.13	1.02	0.10	0.92	3.55	3.82		0.18	6.44
77.79	12.47	0.13	1.16	0.11	0.97	3.57	3.60		0.23	5.44
7 0.21	0.17	0.02	0.14	0.02	0.05	0.09	0.17		0.09	1.05

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
03006 Pikowai-A; reworked (unknown?); (mbd) (integr)										
a 77.64	12.37	0.13	1.30	0.10	1.08	3.52	3.73		0.14	4.48
a 77.45	12.42	0.20	1.15	n.d.	1.16	3.84	3.40		0.13	5.90
a 77.93	12.20	0.15	1.08	0.11	1.02	3.44	3.83		0.23	5.02
a 78.36	12.04	0.18	1.11	0.17	1.07	3.34	3.60		0.14	5.25
a 77.61	12.50	0.19	1.27	0.14	1.07	3.54	3.50		0.18	5.55
77.84	12.32	0.17	1.18	0.13	1.08	3.54	3.61		0.16	5.29
5 0.32	0.19	0.03	0.10	0.03	0.05	0.19	0.17		0.04	0.62
b 77.37	12.85	0.12	1.08	0.11	0.91	3.68	3.71		0.18	6.24
b 77.97	12.48	0.19	0.99	0.13	0.84	3.69	3.49		0.22	4.41
b 78.46	12.11	0.15	0.93	0.12	0.85	3.44	3.70		0.24	4.74
b 78.37	12.18	0.16	0.97	0.08	0.79	3.55	3.75		0.13	5.44
78.04	12.41	0.15	0.99	0.11	0.85	3.59	3.66		0.19	5.21
4 0.50	0.34	0.03	0.06	0.02	0.05	0.12	0.12		0.05	0.81
? 77.41	12.55	0.24	1.04	0.23	1.27	3.80	3.28		0.18	5.32

03007 Pikowai-B; reworked (unknown?); (mtx) (integr)										
	78.07	12.59	0.10	0.95	0.13	0.70	3.56	3.68	0.22	4.39
	77.87	12.29	0.09	1.19	n.d.	0.93	3.78	3.67	0.19	3.90
	77.07	12.43	0.18	1.00	0.20	0.87	4.13	3.93	0.20	2.91
	77.56	12.21	0.18	1.20	n.d.	0.93	3.82	3.89	0.22	3.14
	77.77	12.43	0.14	0.99	0.18	0.78	3.53	4.01	0.16	2.95
	77.55	12.74	0.11	1.03	0.22	0.85	3.56	3.77	0.17	4.97
	77.34	12.88	0.07	1.10	0.15	0.75	3.84	3.66	0.21	4.74
	78.82	12.56	n.d.	1.16	0.15	0.81	3.75	3.75	0.23	2.50
	77.49	12.66	0.13	1.03	0.17	0.78	3.74	3.90	0.10	3.57
	77.71	12.51	0.11	0.88	0.11	0.75	3.31	4.35	0.27	5.77
	77.01	12.63	0.14	1.14	0.17	0.96	3.76	3.91	0.27	8.53
	77.70	12.45	0.16	0.96	0.05	0.78	3.57	4.19	0.13	6.45
	77.38	12.75	0.13	0.85	0.11	0.82	3.71	4.02	0.23	7.72
	77.49	12.58	0.19	0.88	0.13	0.90	3.77	4.05	n.d.	7.09
	77.78	12.64	0.09	0.90	0.14	0.83	3.61	3.84	0.18	6.31
	77.21	12.72	0.22	1.08	0.14	0.84	3.72	3.83	0.23	5.76
	77.53	12.57	0.14	1.02	0.15	0.83	3.70	3.91	0.20	5.09
16	0.29	0.18	0.04	0.12	0.04	0.07	0.18	0.19	0.05	1.79
b	77.73	12.13	0.20	1.35	0.13	1.16	3.51	3.63	0.16	3.23
b	76.71	12.49	0.18	1.42	0.19	1.17	3.94	3.68	0.21	5.39
b	76.42	12.97	n.d.	1.66	0.22	1.15	3.66	3.63	0.29	6.08
	76.95	12.53	0.19	1.48	0.18	1.16	3.71	3.65	0.22	4.90
3	0.69	0.42	0.01	0.16	0.05	0.01	0.22	0.03	0.07	1.49
?	78.37	12.25	0.19	1.05	n.d.	1.41	3.72	2.86	0.16	3.24
?	78.27	12.29	0.12	1.11	0.19	1.05	3.59	3.26	0.13	4.40
?	77.65	12.73	0.20	1.03	0.32	1.07	3.59	3.26	0.16	3.31
?	77.06	12.81	0.16	1.42	0.39	1.00	2.95	4.02	0.20	4.94
?	78.04	12.40	0.15	1.15	0.07	1.23	3.91	2.88	0.17	5.93

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
03103 unknown; flood deposit; (pum) (pkscrh)										
78.43	12.39	0.10	0.84	0.11	0.96	3.49	3.59	0.09	8.80	
78.36	12.34	n.d.	1.08	0.12	1.02	3.34	3.69	0.07	8.89	
78.70	12.30	0.13	0.83	0.07	1.10	3.05	3.72	0.10	9.24	
78.41	12.41	0.10	0.77	0.09	0.92	3.31	3.82	0.17	8.08	
78.28	12.49	0.14	0.93	0.16	1.14	3.26	3.52	0.08	8.70	
78.63	12.47	0.14	0.93	0.11	0.93	3.30	3.42	0.08	8.44	
78.40	12.33	0.19	1.03	0.10	0.89	3.30	3.67	0.10	9.00	
78.59	12.37	0.11	1.09	0.17	0.95	3.40	3.23	0.09	8.55	
78.07	12.36	0.19	1.03	0.16	1.03	3.35	3.68	0.11	8.19	
78.21	12.28	0.09	1.08	0.12	0.92	3.55	3.66	0.10	7.63	
78.56	12.32	0.15	1.06	0.15	0.90	3.15	3.62	0.09	8.26	
78.28	12.24	0.15	1.10	0.09	1.08	3.33	3.60	0.12	8.41	
78.41	12.36	0.14	0.98	0.12	0.99	3.32	3.60	0.10	8.52	
12	0.19	0.07	0.03	0.12	0.04	0.08	0.13	0.16	0.03	0.44

03104 Welcome-C; (mbx) (pkscrh)										
78.50	12.07	0.17	1.09	0.10	0.73	3.50	3.68	0.16	6.56	
78.52	11.93	0.07	1.08	0.11	0.69	3.67	3.67	0.26	5.64	
78.60	11.92	0.15	1.06	0.12	0.66	3.64	3.53	0.33	5.56	
78.55	12.04	0.13	1.15	n.d.	0.67	3.47	3.79	0.19	6.16	
79.01	12.10	n.d.	1.08	0.09	0.67	3.24	3.60	0.20	6.62	
79.14	11.91	0.10	1.01	0.10	0.69	3.08	3.78	0.20	6.60	
78.71	11.96	0.12	1.08	0.07	0.60	3.50	3.82	0.14	5.75	
79.34	11.86	n.d.	0.96	0.10	0.63	3.21	3.75	0.15	6.91	
79.13	11.88	0.11	0.95	0.06	0.68	3.13	3.85	0.22	7.04	
79.12	11.78	0.11	1.02	n.d.	0.71	3.35	3.71	0.19	7.17	
79.13	11.90	0.10	1.06	0.09	0.67	3.09	3.77	0.19	6.91	
78.89	11.94	0.12	1.05	0.09	0.67	3.35	3.72	0.20	6.45	
11	0.31	0.10	0.03	0.06	0.02	0.03	0.22	0.10	0.05	0.58

03105 Little Waihi; (mbx) (pkscrh)										
77.65	12.31	0.14	1.19	0.08	0.90	3.82	3.83	0.07	0.33	
78.12	12.37	0.12	1.23	0.09	0.80	3.43	3.76	0.07	3.33	
78.64	12.27	n.d.	1.35	0.09	0.85	3.11	3.55	0.14	5.26	
78.42	11.94	0.15	1.30	0.08	0.76	3.34	3.85	0.14	3.11	
78.16	12.32	0.12	1.42	0.06	0.87	3.66	3.30	0.08	3.98	
78.65	12.21	0.08	1.17	0.10	0.84	3.42	3.42	0.11	4.26	
78.55	12.09	0.12	1.14	0.07	0.74	3.72	3.48	0.09	2.48	
78.93	11.96	0.10	1.13	0.05	0.68	3.33	3.73	0.08	4.57	
78.38	12.03	0.13	1.14	0.10	0.83	3.44	3.85	0.10	3.13	
78.05	12.27	0.18	1.28	0.09	0.94	3.62	3.45	0.13	6.09	
78.15	12.43	n.d.	1.46	0.06	0.91	3.31	3.56	0.13	5.21	
78.34	12.20	0.13	1.25	0.08	0.83	3.47	3.61	0.11	3.80	
11	0.35	0.17	0.03	0.12	0.02	0.08	0.21	0.20	0.03	1.59

site 33 = Ohinekoao Stream slip (V15/374614)

03301 Malahina; airfall ash beneath ignimbrite; (total) (pkscrh)										
78.50	12.39	n.d.	0.92	n.d.	0.77	3.74	3.56	0.12	8.97	
78.13	12.30	0.08	0.89	0.08	0.78	3.85	3.71	0.20	8.02	
78.20	12.44	n.d.	1.01	0.10	0.74	3.65	3.74	0.12	8.10	
78.42	12.38	0.13	1.02	0.10	0.75	3.45	3.61	0.13	5.92	
78.66	12.35	0.10	0.93	n.d.	0.76	3.48	3.61	0.12	7.63	
78.38	12.25	n.d.	0.87	0.08	0.77	3.65	3.84	0.17	7.65	
78.63	12.20	0.14	0.94	0.15	0.70	3.37	3.74	0.12	7.76	
78.30	12.36	0.11	0.87	0.14	0.79	3.58	3.72	0.13	8.06	
78.44	12.32	0.09	0.89	0.10	0.77	3.49	3.79	0.12	7.41	
78.46	12.40	0.12	0.91	0.10	0.74	3.58	3.54	0.15	8.08	
78.51	12.23	0.12	0.98	0.09	0.68	3.60	3.68	0.11	7.54	
78.15	12.21	0.09	0.93	0.09	0.75	3.91	3.72	0.15	8.14	
78.02	12.25	0.10	1.00	0.10	0.72	4.06	3.62	0.13	8.39	
78.37	12.31	0.11	0.94	0.10	0.75	3.65	3.68	0.14	7.82	
13	0.20	0.08	0.02	0.05	0.02	0.03	0.20	0.09	0.03	0.70

03302 Malahina ignimbrite; base; (total) (pkscrh)										
78.36	12.18	0.07	0.94	0.12	0.78	3.63	3.71	0.20	3.87	
78.60	12.11	0.19	0.93	0.14	0.77	3.44	3.62	0.21	5.12	
78.59	12.11	0.09	0.95	0.08	0.83	3.59	3.61	0.14	4.82	
78.60	12.10	n.d.	1.00	0.10	0.81	3.49	3.76	0.15	4.59	
78.59	12.16	0.09	0.96	0.09	0.79	3.42	3.72	0.18	4.58	
78.44	12.10	0.07	1.12	0.11	0.81	3.31	3.80	0.17	5.68	
78.56	12.09	0.11	1.05	0.11	0.85	3.78	3.22	0.24	5.61	
78.92	12.04	n.d.	1.03	0.13	0.86	3.24	3.61	0.18	4.28	
78.65	12.10	0.12	0.89	0.11	0.82	3.64	3.49	0.20	5.17	
78.57	11.94	0.10	1.12	n.d.	0.79	3.61	3.68	0.19	5.62	
78.55	12.24	0.12	0.81	0.10	0.81	3.49	3.71	0.18	5.82	
78.87	12.06	0.12	0.92	0.10	0.77	3.58	3.44	0.15	5.53	
78.53	12.06	n.d.	0.95	0.12	0.82	3.62	3.79	0.11	5.37	
78.60	12.10	0.11	0.97	0.11	0.81	3.53	3.63	0.18	5.08	
13	0.15	0.08	0.03	0.09	0.03	0.03	0.15	0.16	0.04	0.61

? 78.58	12.25	0.08	1.17	0.19	1.02	3.61	2.90	0.19	5.22	
? 78.79	12.24	0.14	1.06	0.06	0.59	3.62	3.34	0.15	7.25	
? 78.62	12.17	0.12	1.08	0.17	1.16	3.45	3.09	0.15	5.19	

site 34 = Kutarere Wharf (W15/730436)

03401 Kutarere; (mbx+) (integr)										
78.08	12.27	0.17	1.15	0.14	0.74	3.59	3.61	0.25	5.48	
78.68	12.23	0.18	1.11	0.10	0.75	3.31	3.37	0.27	5.72	
78.13	12.44	0.15	1.22	0.11	0.78	3.65	3.27	0.25	6.53	
78.71	12.22	0.11	1.17	0.17	0.77	3.20	3.30	0.34	7.01	
78.55	12.33	0.16	1.07	0.11	0.65	3.49	3.34	0.30	6.12	
78.02	12.58	0.19	1.14	0.17	0.77	3.60	3.28	0.25	7.22	
78.14	12.46	0.23	1.12	0.17	0.78	3.70	3.11	0.30	5.34	
78.19	12.66	0.13	1.10	0.11	0.77	3.30	3.48	0.26	7.92	
78.31	12.40	0.17	1.14	0.13	0.75	3.48	3.34	0.28	6.42	
8	0.28	0.16	0.04	0.05	0.04	0.18	0.15	0.03	0.92	

continued next

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
03401 continued										
? 78.24	12.42	0.16	1.01	0.13	0.65	3.02	4.11	0.26	6.67	
? 77.89	12.26	0.19	1.25	0.12	0.72	3.08	4.16	0.33	6.92	

site 36 = Maandonk (W16/671333)

03601 Waingarara Ignimbrite; (pum) (integr)										
a 77.69	12.19	0.12	1.00	0.13	0.85	3.79	3.90	0.34	5.33	
a 77.36	12.39	0.21	1.29	0.14	1.07	3.41	3.88	0.25	6.29	
a 77.55	12.30	0.20	1.08	0.22	0.97	3.48	3.87	0.34	5.14	
77.53	12.29	0.18	1.12	0.16	0.96	3.56	3.88	0.31	5.59	
3	0.17	0.10	0.05	0.15	0.05	0.11	0.20	0.01	0.05	0.62
b 77.55	12.14	0.14	1.01	0.10	0.86	3.55	4.39	0.27	5.71	
b 78.10	12.04	n.d.	0.93	0.14	0.75	3.48	4.19	0.37	4.44	
b 77.54	12.45	n.d.	1.05	0.12	0.74	3.66	4.20	0.23	5.73	
b 77.79	12.34	0.11	1.09	0.18	0.76	3.21	4.27	0.24	5.86	
b 77.51	12.17	0.10	1.14	0.09	0.82	3.67	4.16	0.33	6.36	
b 77.65	12.23	0.19	1.09	0.16	0.81	3.55	4.01	0.30	4.91	
77.69	12.23	0.13	1.05	0.13	0.79	3.52	4.20	0.29	5.50	
6	0.22	0.15	0.04	0.08	0.04	0.05	0.17	0.13	0.05	0.70
? 78.38	12.16	0.24	1.02	0.11	0.66	3.51	3.64	0.27	5.02	

site 37 = Waiopua (W16/661354)

03701 "Waiopua-A" (unknown?); (total) (pkscrh)										
78.64	12.13	0.10	0.97	n.d.	0.96	3.38	3.65	0.18	5.99	
78.34	12.18	0.12	1.02	0.12	0.91	3.31	3.78	0.20	7.00	
78.59	12.04	0.14	1.11	0.14	0.90	3.20	3.68	0.20	6.84	
78.74	12.12	0.13	1.01	0.09	0.88	3.35	3.70	n.d.	6.65	
78.31	11.98	0.13	1.26	0.16	1.08	3.27	3.60	0.21	6.40	
78.94	12.05	n.d.	1.02	0.17	0.97	3.08	3.56	0.21	6.78	
78.33	11.98	0.15	1.23	0.18	0.95	3.36	3.66	0.17	5.91	
78.08	12.19	0.19	1.22	0.13	1.11	3.37	3.53	0.18	7.36	
78.43	12.06	0.16	1.12	0.14	1.07	3.07	3.73	0.22	7.40	
78.56	12.05	0.16	1.09	0.15	0.97	3.25	3.52	0.26	6.36	
77.93	12.20	0.20	1.16	0.12	0.98	3.52	3.67	0.22	7.12	
78.36	12.13	0.18	1.00	0.10	1.03	3.34	3.63	0.24	6.84	
77.97	12.04	0.14	1.22	0.13	0.94	3.39	3.94	0.23	6.12	
78.25	12.19	0.24	1.20	0.14	1.03	3.15	3.53	0.27	7.20	
78.50	12.25	0.12	1.12	0.15	0.96	2.99	3.65	0.26	7.40	
78.72	11.99	0.19	0.98	0.14	0.98	3.17	3.62	0.19	7.36	
78.47	12.08	0.16	1.06	0.12	1.01	3.17	3.72	0.21	6.84	
78.42	12.10	0.16	1.11	0.14	0.98	3.26	3.66	0.22	6.80	
17	0.27	0.08	0.04	0.10	0.03	0.06	0.14	0.10	0.03	0.50
? 78.26	12.40	n.d.	0.75	n.d.	0.64	3.23	4.51	0.20	6.90	

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water

site 39 = McCoy Road-(1a & b) (W15/676454)

03901 Waingarara Ignimbrite: (pum) (pkrsch)

a	77.77	12.32	0.13	1.26	0.15	0.99	3.54	3.70	0.14	0.87
a	77.91	12.31	0.19	1.23	0.11	1.01	3.38	3.67	0.19	1.27
a	78.21	12.21	0.13	1.15	0.07	1.03	3.27	3.68	0.24	1.59
a	78.13	12.24	0.12	1.15	0.09	0.96	3.36	3.72	0.23	0.81
a	78.08	12.25	0.07	1.11	0.13	0.96	3.44	3.76	0.20	1.74
a	77.40	12.35	0.15	1.38	0.10	1.04	3.54	3.80	0.24	0.05
	77.92	12.28	0.13	1.21	0.11	1.00	3.42	3.72	0.21	1.05
6	0.30	0.05	0.04	0.10	0.03	0.04	0.11	0.05	0.04	0.62
b	78.03	12.45	n.d.	0.96	0.13	0.74	3.43	4.05	0.21	1.13
b	78.61	12.10	0.14	0.94	n.d.	0.79	3.43	3.79	0.20	1.21
b	78.06	12.44	0.10	0.86	0.08	0.71	3.47	4.08	0.19	1.86
b	78.22	11.95	0.07	0.92	0.08	0.78	3.49	4.27	0.22	1.32
	78.23	12.23	0.10	0.92	0.10	0.76	3.46	4.04	0.21	1.38
4	0.27	0.25	0.04	0.05	0.03	0.04	0.03	0.20	0.01	0.33

03902 Waingarara: pre-ignimbrite ardal; (mtx+) (integr)

78.37	11.48	0.26	1.23	0.15	1.02	3.73	3.53	0.24	6.69	
77.14	12.77	0.19	1.37	0.12	1.08	3.54	3.67	0.13	6.99	
78.08	12.02	0.19	1.09	0.11	1.07	3.43	3.76	0.25	5.51	
77.92	12.13	0.19	1.32	0.13	1.06	3.52	3.45	0.29	4.45	
77.95	11.67	0.23	1.44	0.12	1.07	3.68	3.65	0.19	3.57	
78.26	11.88	0.21	1.20	0.16	0.99	3.52	3.59	0.19	5.18	
77.17	12.68	0.19	1.39	0.08	0.80	3.53	4.01	0.16	2.73	
77.49	13.21	0.19	1.02	0.15	0.86	3.39	3.43	0.26	4.22	
77.98	12.09	0.35	1.13	0.17	1.02	3.62	3.44	0.19	3.84	
78.04	11.59	0.17	1.47	0.17	1.06	3.68	3.63	0.17	6.91	
77.40	12.22	0.20	1.26	0.11	0.99	3.51	4.09	0.23	8.49	
78.15	11.89	0.19	1.34	0.16	0.88	3.57	3.49	0.33	4.88	
77.83	12.14	0.21	1.27	0.13	0.99	3.56	3.64	0.22	5.29	
12	0.42	0.52	0.05	0.14	0.03	0.09	0.10	0.21	0.66	
b	78.33	12.11	0.15	0.90	0.11	0.78	3.57	3.79	0.26	4.85
b	77.48	12.57	0.17	0.92	0.10	0.80	3.93	3.80	0.22	2.39
	77.91	12.34	0.16	0.91	0.10	0.79	3.75	3.80	0.24	3.62
2	0.60	0.33	0.02	0.01	0.00	0.02	0.26	0.00	0.03	1.74

03903 Omataroa: (pum) (integr)

77.27	12.82	0.26	1.26	0.21	1.15	4.06	2.76	0.21	4.83
76.80	13.39	0.17	1.20	0.17	1.07	3.98	2.91	0.31	2.73
76.85	13.28	0.19	1.16	0.19	1.08	3.87	3.17	0.22	4.35
77.22	13.31	0.22	1.06	0.16	1.06	3.87	2.89	0.21	6.25
77.37	12.78	0.29	1.01	0.17	1.14	4.10	2.95	0.18	6.35
77.39	13.33	0.19	1.02	0.17	1.20	3.79	2.80	0.10	7.19
77.66	12.07	0.40	1.12	0.18	1.08	4.51	2.79	0.20	5.28
77.62	13.01	0.17	1.13	0.16	1.04	3.85	2.76	0.25	7.10
77.40	12.43	0.32	1.25	0.18	1.11	4.36	2.79	0.17	4.53
77.77	12.10	0.18	1.08	0.22	1.07	4.12	3.14	0.31	7.55
77.49	12.77	0.20	1.31	0.25	0.99	3.73	3.14	0.13	8.06
77.27	12.72	0.16	1.33	0.19	1.07	4.06	3.05	0.16	5.82
77.45	12.70	0.18	1.32	0.22	1.09	4.06	2.71	0.26	6.02
77.48	13.09	0.27	1.22	0.15	1.00	3.88	2.79	0.13	5.83
77.58	13.04	0.24	1.12	0.20	0.94	3.99	2.80	0.10	3.76
77.31	13.09	0.27	1.13	0.16	1.09	3.90	2.87	0.19	6.23
77.23	12.94	0.22	1.28	0.15	0.98	4.08	2.82	0.31	5.53
77.36	12.87	0.23	1.18	0.18	1.07	4.01	2.89	0.20	5.73
17 0.26	0.39	0.06	0.10	0.03	0.06	0.20	0.15	0.07	1.39
? 77.43	12.77	0.23	0.91	0.17	1.01	4.27	3.01	0.21	3.59
? 75.12	13.26	0.14	1.45	0.40	1.43	4.91	3.01	0.29	9.18

03904 uncertain? (Tahuna or Ngamohu): (mtx) (integr)

78.71	12.12	0.21	0.93	0.14	0.96	3.28	3.48	0.18	4.10
77.92	11.97	0.17	1.21	0.17	1.05	3.51	3.83	0.18	4.75
77.79	12.10	0.24	1.12	0.09	0.74	3.64	3.95	0.33	2.32
77.65	12.25	0.14	1.11	0.15	0.94	3.76	3.74	0.26	2.06
77.83	12.32	0.26	0.95	0.09	0.85	3.85	3.67	0.17	1.46
77.83	11.79	0.21	1.17	0.12	1.14	3.62	3.89	0.24	3.10
77.44	12.44	0.26	0.98	0.19	1.06	3.40	4.00	0.24	3.82
78.10	12.00	0.21	0.93	0.13	0.99	3.48	3.99	0.17	1.93
78.73	11.82	0.29	0.95	0.12	0.79	3.29	3.89	0.12	3.81
78.08	11.84	0.16	0.96	0.11	1.02	3.60	4.05	0.18	3.37
77.82	12.16	0.19	1.12	0.20	0.82	4.09	3.50	0.10	0.96
78.34	12.23	0.19	0.90	0.16	0.81	3.68	3.37	0.30	1.33
77.51	12.62	0.21	1.04	0.18	1.05	3.11	4.01	0.28	3.14
77.98	12.13	0.21	1.03	0.14	0.94	3.56	3.80	0.21	2.78
13	0.41	0.25	0.04	0.10	0.03	0.13	0.26	0.23	0.07
b	77.54	12.35	0.29	1.39	0.19	1.26	4.03	2.73	0.22
b	76.67	12.67	0.28	1.35	0.26	1.46	4.23	2.89	0.17
b	76.01	13.16	0.27	1.36	0.34	1.51	4.51	2.68	0.15
b	77.30	12.84	n.d.	1.13	0.26	1.39	4.15	2.79	0.14
76.88	12.76	0.28	1.31	0.27	1.41	4.23	2.77	0.17	
4	0.69	0.34	0.01	0.12	0.06	0.11	0.21	0.09	
?	78.54	12.51	0.28	0.87	0.13	0.77	3.82	2.85	0.23

03905 McCoy: (pum) (integr)

78.42	11.59	0.27	1.27	0.14	0.99	3.56	3.44	0.31	3.44
78.00	12.21	0.23	1.18	0.12	1.06	3.31	3.72	0.17	2.70
77.87	12.54	0.19	1.34	0.13	0.96	3.41	3.39	0.18	3.44
78.35	12.03	0.19	1.23	0.17	1.02	3.46	3.30	0.26	3.52
77.57	12.78	0.22	1.38	0.12	1.02	3.36	3.27	0.27	1.45
78.52	11.83	0.16	1.20	0.15	1.02	3.15	3.73	0.25	4.99
78.15	12.13	0.24	1.39	0.12	0.99	3.07	3.72	0.20	5.10
78.48	11.65	0.21	1.17	0.12	1.00	3.60	3.62	0.14	3.40
78.11	12.12	0.22	1.26	0.12	1.03	3.56	3.45	0.13	3.69
78.16	12.10	0.21	1.27	0.13	1.01	3.39	3.51	0.21	3.53
9	0.31	0.39	0.03	0.08	0.02	0.03	0.19	0.06	1.10

continued next

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water

03905 continued

? 78.04	12.40	0.15	0.93	0.11	1.00	3.43	3.75	0.18	2.15
? 77.23	12.21	0.28	1.62	0.27	1.29	3.70	3.22	0.17	5.11

03906 Mangaone: (pum) (integr)

77.74	12.69	0.29	1.04	0.23	1.11	4.07	2.70	0.13	2.97	
77.24	12.99	0.31	1.24	0.23	1.25	3.86	2.65	0.23	3.20	
76.33	13.66	0.28	1.21	0.24	1.34	4.38	2.44	0.13	2.20	
76.85	13.20	0.27	1.27	0.28	1.17	4.00	2.82	0.14	3.18	
77.36	12.75	0.28	1.14	0.21	1.21	4.11	2.79	0.15	4.78	
77.20	12.80	0.26	1.11	0.26	1.06	4.29	2.82	0.20	4.28	
77.03	13.16	0.31	1.08	0.24	1.17	4.08	2.79	0.16	2.35	
77.34	13.23	0.28	1.16	0.22	1.21	3.85	2.62	0.09	3.54	
77.58	12.66	0.17	1.09	0.20	1.21	4.01	2.93	0.17	3.76	
77.26	12.60	0.25	1.09	0.24	1.31	4.27	2.81	0.18	4.23	
77.25	12.94	0.22	1.20	0.24	1.02	4.22	2.78	0.14	3.86	
76.90	12.97	0.33	1.12	0.29	1.18	4.23	2.89	0.10	2.98	
76.43	13.68	0.37	1.02	0.26	1.14	4.13	2.76	0.23	2.55	
77.37	13.14	0.31	1.07	0.23	1.15	3.92	2.68	0.13	2.81	
77.13	13.03	0.28	1.13	0.24	1.18	4.10	2.75	0.16	3.33	
14	0.40	0.34	0.05	0.08	0.03	0.09	0.16	0.12	0.04	0.77

site 41 = Otawairere/Westend Ohope (W15/637531)

04101 Tablelands-D: (total) (pkrsch)

78.39	12.30	0.15	0.87	0.05	0.72	3.22	4.15	0.14	8.37
78.30	12.31	n.d.	0.88	n.d.	0.64	3.20	4.51	0.16	7.99
78.11	12.20	0.13	0.76	n.d.	0.44	3.27	4.96	0.13	7.41
77.94	12.38	0.06	0.86	n.d.	0.46	3.36	4.76	0.17	7.13
78.37	12.39	0.07	0.73	0.05	0.42	3.16	4.64	0.16	8.00
78.22	12.36	n.d.	0.75	0.05	0.48	3.27	4.72	0.15	7.43
78.07	12.36	0.09	0.75	0.08	0.45	3.34	4.75	0.12	7.17
78.42	12.31	n.d.	0.84	0.07	0.54	3.12	4.55	0.15	8.71
78.41	12.37	0.07	0.71	n.d.	0.44	3.13	4.74	0.14	8.18
78.47	12.42	n.d.	0.65	n.d.	0.47	3.19	4.68	0.12	7.90
78.12	12.25	n.d.	0.88	0.07	0.43	3.34	4.72	0.18	7.90
78.16	12.39	n.d.	0.83	0.05	0.46	3.40	4.56	0.14	7.33
78.36	12.33	0.06	0.83	n.d.	0.55	3.14	4.55	0.17	7.62
78.42	12.23	0.06	0.74	0.09	0.50	3.07	4.75	0.14	6.30
78.58	12.15	n.d.	0.74	0.06	0.52	3.16	4.62	0.17	7.17
78.16	11.80	n.d.	0.91	0.09	0.57	3.59	4.75	0.13	8.13
78.18	11.82	0.11	0.94	0.11	0.50	3.46	4.73	0.14	6.86
78.62	11.81	0.08	0.75	0.07	0.52	3.53	4.46	0.16	8.23
78.27	12.27	n.d.	0.94	0.06	0.49	3.38	4.52	0.08	7.32
78.32	12.33	n.d.	0.83	0.11	0.57	3.40	4.44	n.d.	7.17
77.62	12.06	0.17	1.04	0.09	0.70	3.66	4.47	0.18	7.66
77.61	12.47	n.d.	0.81	n.d.	0.52	3.61	4.81	0.17	8.73
77.74	12.30	0.12	1.09	0.09	0.73	3.45	4.26	0.22	9.84
77.84	12.15	n.d.	0.66	0.07	0.56	3.52	5.05	0.15	9.12
77.79	12.33	n.d.	0.85	n.d.	0.53	3.53	4.82	0.15	9.15
77.80	12.24	0.07	0.86	0.08	0.55	3.49	4.79	0.13	9.13
77.60	12.26	0.12	0.83	0.05	0.58	3.51	4.80	0.15	8.03
77.55	12.42	0.08	0.81	0.07	0.51	3.54	4.90	0.12	8.56
77.99	12.25	0.09	0.87	0.07	0.71	3.51	4.32	0.20	8.38
77.62	12.20	n.d.	1.01	0.05	0.61	3.62	4.73	0.16	8.50
77.60	12.32	n.d.	0.79	n.d.	0.60	3.60	4.94	0.15	7.78
77.63	12.32	0.09	0.64	n.d.	0.51	3.69	4.98	0.14	7.64
77.84	12.26	n.d.	0.77	n.d.	0.52	3.47	4.95	0.18	7.25
78.06	12.25	0.09	0.82	0.07	0.54	3.39	4.68	0.15	7.93
33 0.33	0.17	0.03	0.10	0.02	0.08	0.18	0.21	0.03	0.74

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water		SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
04103 Westland; (total) (pkscrch) & (integr)											04111 Munupara-A; (mtx) (integr)										
77.09	12.89	0.11	1.67	0.11	1.17	3.36	3.48	0.11	2.89		77.38	12.62	0.21	1.14	0.27	1.06	3.73	3.34	0.25	7.54	
76.79	12.80	0.21	1.77	0.08	1.15	3.41	3.66	0.13	3.48		77.50	12.33	0.24	1.30	0.24	1.23	3.64	3.34	0.18	7.62	
76.90	12.88	0.16	1.73	0.08	1.05	3.79	3.27	0.13	2.73		77.45	12.79	0.36	1.14	0.26	1.23	3.35	3.25	0.16	6.83	
76.77	12.84	0.16	1.59	0.06	1.15	3.99	3.31	0.12	1.85		76.56	12.72	0.30	1.50	0.17	1.36	3.70	3.55	0.12	7.64	
76.99	12.72	0.16	1.73	0.12	1.08	3.74	3.33	0.12	2.90		77.36	12.51	0.23	1.30	0.15	1.21	3.58	3.43	0.23	7.78	
77.07	12.91	0.16	1.72	0.12	1.06	3.52	3.31	0.12	3.71		77.50	12.38	0.35	1.18	0.28	1.28	3.50	3.38	0.16	7.35	
76.96	12.75	0.17	1.92	0.08	1.06	3.62	3.28	0.16	1.69		77.32	12.58	0.25	1.13	0.21	1.40	3.44	3.44	0.23	7.33	
77.27	12.69	0.09	1.80	0.06	1.04	3.17	3.75	0.12	3.21		77.10	12.89	0.29	1.30	0.19	1.44	3.35	3.28	0.16	7.66	
77.08	12.77	0.12	1.74	0.09	1.17	3.42	3.48	0.13	2.26		76.65	13.13	0.21	1.06	0.22	1.44	3.56	3.34	0.40	7.41	
76.95	12.92	0.11	1.77	0.13	1.05	3.26	3.68	0.14	4.89		77.64	12.58	0.24	1.03	0.16	1.18	3.52	3.47	0.18	7.60	
76.86	12.62	0.17	2.00	0.11	1.07	3.69	3.37	0.11	3.33		77.24	12.65	0.27	1.21	0.22	1.29	3.54	3.38	0.21	7.48	
76.81	12.87	0.12	1.82	0.06	1.17	3.30	3.72	0.12	3.37		10 0.37	0.24	0.06	0.14	0.05	0.12	0.13	0.09	0.08	0.27	
77.40	12.85	0.14	1.73	0.10	1.04	3.25	3.37	0.14	4.35		04112 Munupara-B; (mtx) (integr)										
76.30	13.06	0.19	1.77	0.06	1.16	3.84	3.51	0.12	5.02		77.85	12.48	0.18	1.10	0.14	0.80	3.45	3.80	0.20	7.79	
76.42	12.77	0.18	1.85	0.12	1.14	3.66	3.71	0.14	2.51		77.40	12.72	0.13	0.98	0.12	0.74	3.72	3.94	0.25	7.20	
77.19	12.71	0.17	1.70	0.08	1.11	3.64	3.28	0.11	3.12		77.68	12.61	0.17	1.15	0.00	0.78	3.61	3.73	0.25	7.87	
77.04	12.80	0.13	1.91	0.11	1.04	3.40	3.42	0.15	3.58		77.61	12.42	0.22	1.03	0.13	0.78	3.48	4.18	0.16	7.35	
76.88	12.89	0.11	1.72	0.09	1.04	3.46	3.66	0.13	3.31		77.50	12.71	0.12	1.04	0.10	0.84	3.64	3.76	0.29	7.66	
77.09	12.62	0.12	1.75	0.08	1.02	3.55	3.62	0.13	2.56		77.24	12.57	0.12	1.15	0.09	0.91	3.36	4.30	0.27	6.59	
75.78	13.14	0.25	1.97	0.16	1.23	3.66	3.63	0.18	6.83		77.42	12.63	0.11	1.19	0.17	0.89	3.41	3.95	0.23	9.11	
76.19	13.10	0.13	1.65	0.17	1.17	3.85	3.57	0.16	7.65		77.61	12.60	0.00	1.10	0.18	0.88	3.39	4.01	0.23	9.15	
75.62	13.28	0.16	2.00	0.12	1.20	3.66	3.76	0.19	6.94		77.53	12.79	0.18	0.92	0.14	0.79	3.46	4.01	0.15	8.08	
76.79	12.86	0.15	1.79	0.10	1.11	3.56	3.51	0.14	3.74		77.54	12.62	0.15	1.07	0.13	0.83	3.50	3.96	0.23	7.87	
22 0.46	0.17	0.04	0.11	0.03	0.06	0.22	0.17	0.02	1.62		9 0.18	0.12	0.04	0.09	0.03	0.06	0.12	0.19	0.05	0.84	
b 74.46 13.82 0.20 2.39 0.17 1.40 4.08 3.30 0.18 4.51											04113 Munupara-C; (mtx) (integr)										
b 74.85 13.63 0.25 2.31 0.17 1.45 3.57 3.60 0.16 7.04											77.48	12.60	0.21	0.79	0.11	0.74	3.67	4.17	0.23	7.99	
74.65 13.73 0.22 2.35 0.17 1.43 3.83 3.45 0.17 5.78											76.99	12.54	0.25	1.06	0.08	0.84	3.81	4.24	0.20	6.99	
2 0.28 0.14 0.03 0.05 0.00 0.03 0.36 0.22 0.01 1.79											77.50	12.84	0.13	0.92	0.13	0.81	3.45	4.04	0.19	8.38	
? 78.22 11.80 0.11 1.35 n.d. 0.58 3.54 4.20 0.19 0.95											77.32	12.64	0.13	1.06	0.12	0.88	3.78	3.88	0.20	6.41	
? 76.92 12.23 0.23 1.22 0.09 1.13 3.60 4.25 0.33 5.04											77.93	12.49	0.23	0.73	0.12	0.87	3.58	3.89	0.15	7.06	
? 75.40 13.18 0.24 2.20 0.12 1.12 3.91 3.61 0.23 6.90											77.59	12.59	0.10	0.79	0.08	0.77	3.68	4.08	0.33	8.08	
04105 Paerata; near base; (total) (pkscrch)											77.25	12.84	0.14	0.84	0.11	0.80	3.74	4.08	0.19	6.71	
77.37	12.52	0.08	0.93	0.07	0.55	3.24	5.10	0.15	4.87		77.77	12.61	0.00	0.96	0.10	0.71	3.63	4.05	0.16	8.59	
77.00	12.67	0.07	0.87	0.06	0.58	3.30	5.27	0.18	4.58		77.65	12.64	0.23	1.13	0.09	0.83	3.38	3.90	0.14	7.78	
77.77	12.21	n.d.	0.88	0.10	0.53	3.28	5.03	0.19	2.77		77.26	12.88	0.09	0.99	0.16	0.83	3.48	4.10	0.22	8.22	
77.39	12.38	0.10	0.94	n.d.	0.72	3.28	5.02	0.17	6.00		77.43	12.62	0.14	1.10	0.10	0.72	3.61	4.04	0.24	7.03	
77.65	12.42	n.d.	0.81	n.d.	0.56	3.33	5.04	0.19	3.72		77.47	12.66	0.16	0.94	0.11	0.80	3.62	4.04	0.20	7.57	
77.58	12.43	0.10	0.86	0.09	0.65	3.33	4.79	0.17	3.35		11 0.26	0.13	0.06	0.14	0.03	0.06	0.14	0.11	0.05	0.75	
76.78	12.72	0.11	0.96	n.d.	0.72	3.27	5.28	0.15	7.56		site 43-(2) = Ngatiawa west (W15/636523)										
77.04	12.63	0.12	0.83	0.07	0.59	3.30	5.24	0.17	6.13		04301 Ngatiawa; (unknown); (mtx+) (pkscrch)										
77.32	12.50	0.10	0.88	0.08	0.61	3.29	5.10	0.17	4.87		78.07	12.24	0.21	1.35	0.21	1.53	3.23	3.00	0.16	2.80	
8 0.35	0.17	0.02	0.05	0.02	0.08	0.03	0.17	0.01	1.61		77.80	12.09	0.17	1.51	0.24	1.50	3.23	3.32	0.15	4.10	
b 78.35 12.28 0.14 1.01 0.16 1.09 3.10 3.70 0.18 4.76											77.75	12.21	0.19	1.49	0.22	1.46	3.34	3.17	0.18	2.93	
b 77.71 12.65 0.12 1.12 0.14 1.04 3.36 3.67 0.19 9.25											77.94	12.19	0.18	1.39	0.21	1.34	3.48	3.09	0.17	4.61	
b 77.38 12.81 0.12 1.11 0.10 1.17 3.47 3.71 0.13 8.84											77.75	12.11	0.19	1.51	0.19	1.46	3.46	3.14	0.17	2.23	
77.81 12.58 0.13 1.08 0.13 1.10 3.31 3.69 0.17 7.62											77.62	12.21	0.22	1.41	0.18	1.48	3.60	3.07	0.20	1.60	
3 0.49 0.27 0.01 0.06 0.03 0.07 0.19 0.02 0.03 2.48											77.74	12.14	0.23	1.43	0.23	1.51	3.46	3.14	0.13	2.75	
04108 reworked Kohiawa +; pumices in loess; (total) (pkscrch)											77.62	12.13	0.17	1.55	0.21	1.61	3.37	3.21	0.13	2.70	
a 78.17	12.09	0.12	1.13	0.10	0.76	2.86	4.59	0.18	0.90		77.79	12.27	0.21	1.54	0.23	1.43	3.28	3.05	0.21	3.00	
a 78.38	12.10	0.19	1.02	0.11	0.77	2.80	4.42	0.21	3.20		77.45	12.18	0.22	1.42	0.25	1.55	3.43	3.25	0.24	3.84	
a 78.05	12.15	0.16	1.07	0.12	0.82	2.88	4.57	0.17	1.14		78.06	12.20	0.18	1.36	0.21	1.54	3.26	3.04	0.17	3.25	
a 77.98	12.09	0.15	1.10	0.11	0.81	2.73	4.81	0.21	1.23		77.78	12.18	0.20	1.45	0.21	1.49	3.38	3.13	0.17	3.07	
78.15	12.11	0.16	1.08	0.11	0.79	2.82	4.60	0.19	1.62		11 0.20	0.06	0.02	0.07	0.02	0.07	0.12	0.10	0.03	0.85	
4 0.17	0.03	0.03	0.05	0.01	0.03	0.07	0.16	0.02	1.06		? 78.10 12.04 0.17 1.07 0.10 0.97 3.72 3.59 0.24 2.15										
b 78.11 12.11 0.14 0.98 0.10 0.65 2.81 4.93 0.17 1.57											? 77.99 11.95 0.13 0.98 0.15 0.79 3.58 4.18 0.25 2.40										
b 78.19 12.22 n.d. 0.88 n.d. 0.62 3.05 4.91 0.13 1.48											site 43-(1) = Ngatiawa lookout (W15/636522)										
b 77.94 12.24 0.11 0.84 0.07 0.64 3.08 4.90 0.18 1.11											04302 Ohia Hill; (mtx) (integr)										
b 78.03 12.42 n.d. 0.76 n.d. 0.61 3.17 4.84 0.16 2.04											a 77.66	12.46	0.18	1.15	0.14	0.93	3.58	3.73	0.19	5.02	
78.07 12.25 0.13 0.86 0.09 0.63 3.03 4.90 0.16 1.55											a 77.76	12.60	0.17	1.19	0.14	0.93	3.49	3.55	0.17	5.82	
4 0.11 0.13 0.02 0.09 0.02 0.02 0.15 0.04 0.02 0.38											a 77.33	12.45	0.16	1.35	0.18	1.04	3.76	3.52	0.21	5.51	
c 78.76 12.50 0.16 0.92 0.13 1.08 2.76 3.57 0.12 4.50											a 77.38	12.80	0.21	1.16	0.18	1.19	3.49	3.48	0.11	6.02	
c 78.83 12.51 0.17 0.98 0.17 1.03 2.63 3.56 0.12 3.54											a 77.53	12.55	0.07	1.16	0.12	1.04	3.64	3.69	0.21	4.77	
78.80 12.51 0.16 0.95 0.15 1.05 2.70 3.56 0.12 4.02											a 77.65	12.95	0.12	1.15	0.12	1.17	3.30	3.45	0.10	5.40	
2 0.05 0.01 0.01 0.04 0.03 0.04 0.09 0.01 0.01 0.68											a 77.49	12.40	0.23	1.30	0.11	0.86	3.69	3.74	0.18	4.17	
d 78.61 12.19 0.21 1.43 0.16 1.30 2.84 3.18 0.09 3.00											a 77.92	12.29	0.24	1.28	0.15	0.89	3.55	3.50	0.18	5.93	
04107 Tablelands-D; near top; (total) (pkscrch)											a 77.47	12.74	0.17	1.01	0.15	1.02	3.64	3.69	0.11	3.89	
77.89	12.27	0.11	0.89	n.d.	0.65	3.22	4.83	0.13	2.47		a 77.57	12.68	0.14	1.30	0.13	0.84	3.59	3.59	0.17	4.91	
77.32	12.47	0.11	0.89	0.08	0.71	3.37	4.86	0.19	7.45		a 77.82	12.24	0.11	1.22	0.17	0.91	3.67	3.70	0.17	5.08	
77.19	12.49	n.d.	1.01	0.06	0.68	3.39	5.02	0.17	5.51		a 77.86	12.20	0.19	1.28	0.17	1.09	3.59	3.41	0.22	3.28	
77.12	12.50	n.d.	0.86	0.07	0.56	3.41	5.32	0.16	7.71		a 78.23	12.01	0.14	1.28	0.11	0.84	3.69	3.58			

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
04302 continued from previous page										
b 78.27	11.99	0.07	0.96	0.19	0.78	3.46	4.08	0.19	4.95	
b 78.37	11.99	0.17	0.93	0.07	0.82	3.53	3.94	0.18	4.51	
b 77.95	12.39	0.11	0.86	0.12	0.76	3.53	4.06	0.23	4.89	
b 78.20	12.49	0.11	1.09	0.13	0.76	3.23	3.78	0.20	5.87	
b 78.22	12.18	0.15	0.89	0.20	0.87	3.62	3.74	0.13	5.68	
b 78.22	11.92	0.08	0.93	0.13	0.83	3.57	4.12	0.20	4.78	
b 78.22	12.18	0.09	0.90	0.13	0.73	3.47	4.07	0.21	6.42	
b 77.99	12.47	0.18	1.00	0.15	0.70	3.51	3.79	0.21	4.08	
b 77.95	12.48	0.16	1.03	0.11	0.81	3.42	3.85	0.19	3.35	
b 78.02	12.11	0.16	1.01	0.12	0.74	3.26	4.35	0.25	4.77	
b 77.51	12.96	0.10	0.86	0.10	0.77	3.55	4.03	0.12	4.44	
b 77.81	12.42	0.16	0.93	0.15	0.71	3.61	4.00	0.20	6.21	
b 78.06	12.39	n.d.	1.08	0.10	0.78	3.67	3.71	0.19	2.26	
b 78.36	12.12	0.14	0.96	0.10	0.75	3.68	3.69	0.21	3.74	
78.08	12.29	0.12	0.96	0.13	0.77	3.51	3.94	0.19	4.71	
14 0.23	0.28	0.05	0.08	0.03	0.05	0.14	0.19	0.04	1.14	
c 77.03	12.98	0.17	1.46	0.16	1.30	3.56	3.17	0.19	3.13	
? 77.70	12.64	0.08	1.44	0.14	0.95	3.51	3.41	0.13	5.19	
? 78.40	12.43	0.17	0.92	0.21	0.91	3.31	3.46	0.20	4.13	
04303 Opoliki-3: (mtb) (integr)										
77.99	12.24	0.12	1.13	0.13	1.20	3.24	3.74	0.22	5.13	
77.96	12.12	0.19	1.07	0.17	1.20	3.51	3.54	0.24	4.30	
77.53	12.45	0.22	1.16	0.12	1.24	3.37	3.72	0.19	4.92	
77.67	12.11	0.22	1.31	0.14	1.16	3.51	3.67	0.22	5.34	
77.41	12.36	0.27	1.37	0.15	1.20	3.50	3.51	0.23	6.88	
77.33	12.51	0.21	1.18	0.14	1.11	3.44	3.84	0.23	5.76	
77.29	12.23	0.16	1.37	0.17	1.15	3.56	3.72	0.35	5.50	
77.47	12.48	0.21	1.15	0.19	1.02	3.54	3.73	0.20	6.15	
77.26	12.36	0.20	1.36	0.24	1.31	3.54	3.50	0.21	6.06	
77.86	12.34	0.13	1.16	0.13	1.23	3.34	3.51	0.31	5.68	
77.50	12.39	0.11	1.30	0.17	1.09	3.38	3.85	0.21	6.70	
77.57	12.33	0.18	1.23	0.16	1.17	3.45	3.67	0.24	5.67	
11 0.26	0.14	0.05	0.11	0.04	0.08	0.10	0.13	0.05	0.76	
? 77.50	12.56	n.d.	1.51	0.14	1.13	3.46	3.52	0.18	6.19	
? 77.48	12.51	0.11	1.14	0.11	0.85	3.51	4.00	0.30	5.80	
04304 unknown?? (Kaingaroa?): (mtb) (integr)										
78.38	12.24	0.14	1.10	0.09	0.74	3.41	3.71	0.20	9.12	
77.77	12.24	0.18	1.16	0.07	0.88	3.48	4.02	0.20	8.10	
78.07	11.98	0.25	1.19	0.14	1.01	3.42	3.77	0.17	6.26	
77.99	12.40	0.18	1.03	0.13	0.88	3.68	3.56	0.15	6.78	
78.20	12.35	0.20	1.15	n.d.	0.84	3.12	4.13	n.d.	6.83	
77.90	12.27	0.14	1.01	0.18	0.90	3.62	3.66	0.32	6.28	
78.95	12.24	0.11	0.92	0.07	0.87	3.27	3.32	0.25	8.03	
78.26	12.18	0.19	0.83	0.13	0.81	3.29	3.91	0.41	6.55	
77.68	12.14	0.19	1.30	0.14	0.97	3.57	3.71	0.29	6.51	
78.37	12.04	0.26	1.02	0.12	0.85	3.54	3.67	0.13	7.24	
78.15	12.11	0.18	1.05	0.10	0.85	3.52	3.85	0.19	5.90	
78.16	12.20	0.18	1.07	0.11	0.87	3.45	3.75	0.23	7.05	
11 0.35	0.13	0.04	0.13	0.04	0.07	0.17	0.22	0.09	0.98	
? 76.83	12.65	0.14	1.56	0.12	1.25	3.89	3.35	0.21	8.47	
04305 Hiwarau: (pum) (integr)										
77.23	12.73	0.25	1.15	0.19	1.20	3.43	3.64	0.19	3.84	
77.16	12.76	0.34	1.13	0.22	1.11	3.84	3.31	0.15	5.09	
77.35	12.57	0.22	1.13	0.26	1.20	3.78	3.31	0.17	6.18	
77.02	12.71	0.17	1.28	0.23	1.17	3.79	3.43	0.20	4.61	
76.94	12.67	0.13	1.53	0.23	1.19	3.79	3.32	0.21	4.13	
77.62	12.67	0.25	1.15	0.17	1.03	3.40	3.53	0.18	4.24	
77.18	12.83	0.24	1.14	0.16	1.18	3.70	3.33	0.23	4.55	
77.09	12.75	0.22	1.17	0.22	1.41	3.71	3.24	0.18	4.44	
77.45	12.67	0.15	1.16	0.26	1.29	3.59	3.28	0.17	3.54	
77.20	12.77	0.23	1.30	0.20	1.19	3.71	3.22	0.18	4.73	
77.11	12.78	0.12	1.37	0.22	1.13	3.84	3.19	0.24	5.54	
76.89	12.61	0.22	1.53	0.25	1.34	3.62	3.37	0.17	4.05	
77.29	12.51	0.16	1.41	0.20	1.16	3.66	3.42	0.19	4.35	
76.97	12.87	0.28	1.40	0.23	1.17	3.66	3.24	0.17	4.98	
77.18	12.71	0.21	1.28	0.22	1.20	3.68	3.34	0.19	4.59	
14 0.20	0.10	0.06	0.15	0.03	0.10	0.14	0.12	0.03	0.69	
b 77.73	12.29	0.13	1.13	0.12	0.80	3.51	3.96	0.34	5.58	
b 77.70	12.32	0.19	1.28	0.15	0.79	3.65	3.75	0.17	4.38	
77.72	12.30	0.16	1.20	0.13	0.80	3.58	3.86	0.25	4.98	
2 0.02	0.02	0.04	0.10	0.02	0.01	0.10	0.15	0.12	0.85	
? 78.08	12.22	0.06	1.45	0.08	0.99	3.47	3.46	0.19	4.01	
04306 Matahina: (pum) (integr)										
78.05	12.00	0.34	1.11	0.15	0.84	3.66	3.71	0.14	5.32	
77.64	12.31	0.21	1.26	0.14	1.07	3.73	3.43	0.21	5.38	
78.08	12.22	0.14	1.13	0.07	0.83	3.52	3.81	0.20	5.87	
77.36	12.42	0.25	1.00	0.22	1.01	3.67	3.80	0.26	4.86	
78.13	12.47	0.17	0.88	0.16	0.80	3.44	3.70	0.25	5.70	
77.58	12.20	0.21	1.17	0.19	1.03	3.76	3.63	0.22	5.17	
77.90	12.37	0.18	1.01	0.15	0.83	3.63	3.67	0.25	5.82	
77.81	12.48	0.13	1.02	0.08	0.87	3.86	3.54	0.21	5.02	
77.71	12.51	0.12	1.09	0.15	0.95	3.53	3.70	0.24	5.42	
77.44	12.58	0.17	1.10	0.09	0.86	3.77	3.71	0.28	7.10	
77.77	12.36	0.19	1.08	0.14	0.91	3.66	3.67	0.23	5.57	
10 0.27	0.18	0.07	0.10	0.05	0.10	0.13	0.11	0.04	0.63	
b 78.44	12.15	0.25	1.14	0.17	1.15	3.61	2.96	0.14	6.69	
b 78.16	12.32	0.21	1.10	0.12	1.08	3.68	3.10	0.22	5.54	
78.30	12.24	0.23	1.12	0.15	1.12	3.65	3.03	0.18	6.12	
2 0.20	0.12	0.03	0.03	0.04	0.05	0.05	0.10	0.06	0.81	

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
04307 Rotoliti: (mtb) (integr)										
	78.08	12.31	0.19	1.01	0.18	0.85	3.84	3.27	0.26	5.22
	78.14	12.48	0.13	1.12	0.17	0.78	3.70	3.19	0.29	6.31
	77.80	12.58	0.16	0.88	0.14	0.95	3.71	3.47	0.31	6.44
	77.76	12.44	0.20	0.80	0.17	0.80	3.95	3.54	0.35	5.01
	78.03	12.64	0.07	1.03	0.14	0.93	3.82	3.11	0.24	6.61
	78.12	12.47	0.17	0.85	0.14	0.92	3.81	3.32	0.20	7.15
	78.95	11.88	0.20	0.80	0.13	0.87	3.74	3.19	0.24	3.53
	78.63	12.07	0.15	1.08	0.18	0.90	3.62	3.09	0.27	2.57
	78.08	12.50	0.17	1.03	0.17	0.79	3.92	3.13	0.22	4.51
	78.78	11.77	0.14	1.08	0.16	0.81	3.78	3.24	0.23	1.74
	78.24	12.31	0.16	0.97	0.16	0.86	3.79	3.25	0.26	4.91
10	0.41	0.30	0.04	0.12	0.02	0.06	0.10	0.15	0.04	1.82
04308 Manganese: (pum) (integr)										
	76.95	13.15	0.32	0.91	0.19	1.27	4.07	2.87	0.27	5.95
	76.79	13.21	0.17	1.14	0.23	1.22	4.20	2.87	0.17	6.25
	77.06	13.28	0.18	1.01	0.14	1.18	4.10	2.92	0.14	6.73
	76.66	13.12	0.20	1.26	0.23	1.20	4.30	2.88	0.14	5.81
	77.02	13.40	0.20	1.07	0.16	1.28	3.93	2.73	0.21	5.39
	76.90	13.23	0.21	1.08	0.19	1.23	4.12	2.85	0.19	6.03
5	0.17	0.11	0.06	0.13	0.04	0.04	0.14	0.07	0.05	0.50
site 44 = Awakeri Springs (V15/488477)										
04401 Hiwarau: (pum) (integr)										
	77.02	12.67	0.24	1.33	0.19	1.34	3.59	3.39	0.23	3.99
	76.90	12.70	0.29	1.39	0.23	1.27	3.70	3.34	0.18	4.01
	77.54	12.57	0.10	1.20	0.18	1.46	3.43	3.36	0.16	4.01
	77.59	12.56	0.21	1.43	0.25	1.20	3.28	3.28	0.21	3.57
	77.08	12.71	0.25	1.42	0.26	1.27	3.50	3.31	0.20	3.69
	76.85	13.14	0.13	1.34	0.25	1.33	3.48	3.34	0.15	6.58
	76.80	12.93	0.24	1.36	0.24	1.32	3.50	3.43	0.17	5.27
	76.66	12.90	0.25	1.49	0.25	1.46	3.55	3.28	0.17	4.13
	76.48	12.97	0.31	1.27	0.24	1.29	3.84	3.41	0.19	5.30
	76.13	13.22	0.32	1.36	0.25	1.49	3.80	3.23	0.19	5.63
	76.90	12.84	0.23	1.36	0.23	1.34	3.57	3.34	0.18	4.62
10	0.44	0.23	0.07	0.08	0.03	0.10	0.17	0.06	0.02	1.01
?	77.56	12.41	0.13	1.01	0.24	0.89	3.60	3.90	0.25	3.68
04402 Torere-B: (mtb) (integr)										
	76.96	12.74	0.14	1.29	0.14	0.90	3.91	3.67	0.25	7.70
	76.98	12.55	0.15	1.00	0.18	0.99	4.20	3.80	0.16	7.79
	77.37	12.62	0.22	0.93	0.15	0.95	3.84	3.69	0.22	9.06
	77.02	12.83	0.14	1.09	0.10	0.97	3.78	3.87	0.21	9.24
	76.87	12.67	0.22	1.13	0.14	1.04	3.89	3.82	0.21	8.94
	77.73	12.51	0.16	1.13	0.08	0.94	3.78	3.53	0.14	8.49
	77.32	12.78	0.19	1.11	0.12	0.91	3.66	3.78	0.14	8.13
	77.25	12.79	0.15	1.04	0.15	1.03	3.64	3.79	0.15	8.74
	77.39	12.57	0.20	1.09	0.11	1.06	3.53	3.79	0.27	8.12
	77.87	12.33	0.00	1.13	0.17	0.95	3.77	3.61	0.16	6.68
	77.28	12.64	0.17	1.09	0.14	0.97	3.80	3.73	0.19	8.29
10	0.33	0.15	0.03	0.09	0.03	0.05	0.18	0.11	0.05	0.77
b	76.16	13.19	0.38	1.35	0.27	1.43	3.78	3.24	0.21	8.11
b	76.83	12.84	0.14	1.16	0.18	1.22	3.64	3.74	0.25	8.00
	76.50	13.02	0.26	1.26	0.23	1.33	3.71	3.49	0.23	8.06
2	0.47	0.25	0.17	0.13	0.06	0.15	0.10	0.35	0.03	0.08
SiO ₂ Al ₂ O ₃ TiO ₂ FeO MgO CaO Na ₂ O K ₂ O Cl water										
04403 Torere-A: (mtb) (integr)										
	76.45	13.26	0.18	1.35	0.16	1.20	3.73	3.47	0.20	7.21
	75.78	13.59	0.24	1.53	0.22	1.37	3.67	3.39	0.22	7.18
	76.07	13.49	0.23	1.50	0.24	1.48	3.37	3.42	0.19	6.85
	76.15	13.63	0.21	1.33	0.25	1.55	3.37	3.30	0.21	6.72
	76.58	13.24	0.19	1.25	0.24	1.41	3.36	3.56	0.18	7.02
	76.95	13.29	0.14	1.30	0.14	1.37	3.10	3.51	0.19	7.52
	76.53	13.41	0.22	1.46	0.19	1.27	3.41	3.30	0.20	6.28
	76.31	13.63	0.29	1.25	0.23	1.46	3.29	3.36	0.19	6.94
	77.14	12.76	0.24	1.40	0.16	1.44	3.06	3.58	0.22	6.12
	77.39	12.77	0.21	1.33	0.27	1.33	3.15	3.37	0.18	4.45
	77.19	12.95	0.26	1.18	0.30	1.41	3.27	3.28	0.17	3.93
	76.59	13.27	0.22	1.35	0.22	1.39	3.34	3.41	0.20	6.38
11	0.52	0.32	0.04	0.11	0.05	0.10	0.21	0.11	0.02	1.16
04404 Matahina: paleosol into ignimbrite: (mtb) (integr)										
	76.90	12.64	0.11	1.26	0.11	0.89	3.80	4.02	0.27	3.09
	77.47	12.46	0.20	1.16	0.16	0.98	3.67	3.68	0.22	7.29
	77.46	12.41	0.17	1.02	0.05	1.01	3.90	3.67	0.30	4.35
	77.35	12.51	0.17	1.01	0.09	0.93	3.98	3.68	0.28	4.53
	77.96	12.28	0.11	1.08	0.10	0.83	3.95	3.43	0.26	5.30
	77.43	12.41	0.07	1.09	0.14	0.82	3.91	3.87	0.26	3.81
	77.45	12.67	0.13	0.92	0.09	0.86	3.85	3.74	0.29	4.35
	76.89	12.77	0.16	1.23	0.13	0.76	3.96	3.79	0.33	4.98
	76.75	12.91	0.20	1.26	0.06	1.00	3.64	3.97	0.21	4.75
	77.51	12.48	0.11	1.06	0.16	0.92	3.78	3.64	0.35	5.12
	77.32	12.55	0.14	1.11	0.11	0.90	3.84	3.75	0.28	4.76
10	0.37	0.19	0.04	0.12	0.04	0.08	0.12	0.17	0.04	1.10
?	76.47	12.69	0.29	1.57	0.24	1.62	3.63	3.48	0.00	6.02
?	77.23	12.72	0.00	0.97	0.07	0.57	3.59	4.67	0.19	4.76
?	76.80	12.80	0.21	1.16	0.19	1.15	3.84	3.63	0.22	5.76

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water

site 46 = Burchett (W15/884468)

04601 Murupara-C: (total) (pkrsch)

78.40	12.21	n.d.	0.95	n.d.	0.89	3.25	4.11	0.20	3.33
78.72	12.12	0.12	0.96	0.11	0.80	3.05	3.95	0.17	3.79
78.83	12.17	0.11	0.88	0.12	0.76	3.00	3.93	0.19	3.08
78.65	12.12	0.15	0.97	n.d.	0.72	3.28	3.95	0.17	3.91
78.62	12.18	n.d.	1.06	0.11	0.70	3.07	4.02	0.24	3.91
78.45	12.17	0.11	0.93	0.07	0.79	3.38	3.93	0.16	2.46
78.87	12.24	n.d.	1.02	0.06	0.72	3.14	3.79	0.17	3.64
78.95	12.24	n.d.	0.97	0.09	0.73	3.10	3.74	0.19	3.82
78.60	12.11	0.08	1.03	0.08	0.75	3.12	4.07	0.17	3.71
78.67	12.21	n.d.	1.15	0.09	0.78	3.12	3.81	0.18	3.09
78.69	12.21	n.d.	0.95	0.06	0.76	3.02	4.16	0.15	4.33
78.59	12.17	0.13	1.06	0.09	0.81	2.94	4.00	0.20	2.82
78.66	12.10	0.08	1.09	0.11	0.74	3.14	3.89	0.20	3.44
78.67	12.17	0.11	1.00	0.09	0.77	3.12	3.95	0.18	3.49
13	0.15	0.05	0.02	0.07	0.02	0.05	0.12	0.02	0.52

04602 Murupara-A: (total) (pkrsch)

78.74	12.04	0.19	1.23	0.12	1.02	3.10	3.43	0.13	1.80
78.35	12.11	0.13	1.29	0.17	1.14	3.15	3.51	0.13	2.57
78.83	11.79	0.21	1.17	0.18	1.13	3.17	3.40	0.10	2.67
78.78	11.85	0.11	1.27	0.18	1.03	3.17	3.45	0.15	3.20
78.39	11.99	0.16	1.24	0.16	1.00	3.37	3.55	0.13	1.86
78.76	12.01	0.20	1.19	0.14	1.00	3.16	3.37	0.16	3.28
78.61	12.02	0.14	1.06	0.17	1.08	3.28	3.46	0.18	3.07
78.65	12.02	0.17	1.17	0.17	0.95	3.35	3.35	0.17	2.31
78.48	12.18	0.26	1.23	0.18	1.05	3.21	3.32	0.09	3.51
78.62	12.00	0.18	1.21	0.16	1.04	3.22	3.43	0.14	2.70
9	0.18	0.12	0.04	0.07	0.02	0.06	0.09	0.03	0.62

? 79.01 11.85 0.15 0.93 0.14 0.73 3.17 4.01 n.d. 2.66

04603 Bonisch: (total) (pkrsch)

78.64	12.24	0.10	1.10	n.d.	0.70	3.42	3.61	0.19	5.86
78.97	12.25	0.13	0.98	0.11	0.71	3.11	3.55	0.20	5.72
78.82	11.99	0.14	1.01	0.10	0.72	3.29	3.77	0.15	2.88
78.57	12.20	0.19	1.09	0.16	0.80	3.23	3.61	0.15	2.72
78.92	12.02	0.12	1.10	0.06	0.68	3.17	3.73	0.20	3.34
78.67	12.21	0.09	0.95	0.09	0.77	3.30	3.75	0.15	3.17
78.80	12.12	n.d.	1.10	0.06	0.72	3.18	3.84	0.18	3.12
78.80	12.18	0.11	1.07	0.07	0.62	3.36	3.58	0.20	2.91
79.22	12.14	0.13	1.05	0.13	0.78	3.20	3.16	0.19	4.14
78.94	12.10	n.d.	1.06	0.09	0.85	3.01	3.76	0.19	3.00
78.83	12.15	0.13	1.05	0.10	0.74	3.23	3.64	0.18	3.69
10	0.19	0.09	0.03	0.06	0.03	0.07	0.12	0.19	1.18

04604 Kohioawa: (mb) (integr)

77.40	12.22	0.17	1.19	0.15	0.76	3.25	4.53	0.34	4.86
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04605 Otarawairere: (mb) (integr)

77.40	12.43	0.07	0.98	0.08	0.76	3.45	4.62	0.20	4.32
77.38	12.83	n.d.	0.91	0.07	0.61	3.43	4.57	0.19	5.61
77.18	12.50	n.d.	0.96	0.12	0.71	3.54	4.71	0.27	5.37
77.07	12.53	0.06	1.02	0.09	0.68	3.62	4.71	0.21	4.79
77.12	12.91	n.d.	0.89	0.05	0.69	3.57	4.50	0.26	4.27
77.32	12.38	0.16	0.97	0.11	0.67	3.51	4.66	0.23	4.81
77.25	12.60	0.10	0.95	0.09	0.69	3.52	4.63	0.23	4.86
6	0.14	0.22	0.05	0.05	0.02	0.05	0.07	0.08	0.54

04606 Paerata: (mb) (integr)

77.62	12.53	0.17	1.08	0.12	1.16	3.23	3.90	0.18	5.70
77.73	12.50	0.08	0.96	0.26	1.11	3.49	3.67	0.20	4.33
77.81	12.46	0.14	1.01	0.21	1.03	3.57	3.57	0.21	4.09
78.02	12.73	0.11	0.94	0.15	1.03	3.43	3.48	0.10	4.09
77.10	12.85	0.18	1.00	0.17	1.03	3.61	3.82	0.24	6.65
76.95	12.91	0.20	1.16	0.20	0.97	3.47	3.84	0.30	6.95
77.74	12.96	0.14	0.90	0.13	0.94	3.39	3.58	0.22	7.92
77.57	12.71	0.15	1.01	0.18	1.04	3.46	3.69	0.21	5.68
7	0.39	0.21	0.04	0.09	0.05	0.07	0.12	0.16	0.66

? 77.08 12.83 0.11 1.32 0.15 1.03 3.61 3.71 0.17 6.55

site 48 = Copenhagen Rd. (X14/233737)

04801 Wairuru: (mb) (integr)

77.43	12.47	0.23	1.29	0.15	1.06	3.62	3.58	0.17	4.90
78.10	12.17	0.11	0.99	0.15	0.80	3.41	4.12	0.16	3.70
78.08	12.39	0.17	0.77	0.07	0.60	3.48	4.26	0.18	4.08
77.96	12.32	0.12	1.03	0.17	0.73	3.61	3.83	0.23	2.58
77.95	12.26	0.17	1.05	0.08	0.82	3.68	3.79	0.21	3.07
77.66	12.51	0.17	0.81	0.08	0.62	3.74	4.22	0.19	3.05
77.84	12.30	0.10	0.90	0.14	0.90	3.82	3.78	0.22	2.35
77.91	12.44	0.15	1.09	0.14	0.91	3.48	3.65	0.23	5.77
77.98	12.07	0.16	1.14	0.10	0.84	3.76	3.76	0.19	4.36
77.81	12.38	0.13	1.18	0.09	0.97	3.65	3.66	0.15	4.84
77.80	12.36	0.17	1.02	0.08	0.79	3.65	3.92	0.21	3.07
77.89	12.25	0.14	1.15	0.04	0.84	3.55	3.92	0.22	5.30
78.01	12.58	0.10	0.97	0.11	0.82	3.61	3.62	0.16	3.98
78.04	12.26	0.14	0.98	0.11	0.79	3.57	3.88	0.23	4.13
78.01	12.43	0.11	1.04	0.14	0.81	3.54	3.76	0.17	5.93
77.90	12.34	0.14	1.03	0.11	0.82	3.61	3.85	0.19	4.07
15	0.17	0.13	0.03	0.14	0.04	0.12	0.11	0.21	0.03

? 77.40 12.30 0.12 1.47 0.19 0.92 3.70 3.71 0.19 3.77

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water

04802 Torere School: (mb) (integr)

77.20	13.02	0.22	1.27	0.21	1.11	3.61	3.16	0.19	4.76
77.59	12.62	0.20	1.14	0.21	1.14	3.68	3.21	0.22	4.56
77.00	12.76	0.31	1.20	0.20	1.17	3.75	3.42	0.19	5.09
77.22	12.68	0.26	1.10	0.29	1.14	3.68	3.37	0.26	5.36
76.97	13.14	0.25	1.09	0.21	1.16	3.74	3.12	0.32	4.81
76.98	12.76	0.26	1.10	0.27	1.25	3.81	3.32	0.25	3.86
77.23	12.63	0.26	1.44	0.21	1.15	3.38	3.54	0.16	4.82
77.58	12.58	0.32	1.05	0.18	1.01	3.74	3.26	0.26	4.09
77.67	12.45	0.26	1.24	0.18	1.18	3.47	3.34	0.20	5.47
76.91	12.60	0.33	1.38	0.20	1.30	3.60	3.38	0.30	4.38
77.24	12.72	0.27	1.20	0.22	1.16	3.65	3.31	0.24	4.72
10	0.28	0.21	0.04	0.13	0.04	0.08	0.13	0.13	0.05

? 76.05 13.13 0.19 1.75 0.17 1.06 4.14 3.29 0.21 4.21
? 77.16 12.84 0.21 1.51 0.19 1.14 3.51 3.27 0.17 4.90
? 76.27 13.07 0.15 1.64 0.22 1.20 3.70 3.47 0.28 4.67

04803 Copenhagen: (mb) (integr)

77.72	12.49	0.11	1.03	0.13	0.93	3.64	3.78	0.17	5.06
77.42	12.54	0.08	1.01	0.17	0.80	3.64	4.13	0.20	5.33
77.46	12.46	0.13	1.10	0.17	0.87	3.59	4.05	0.17	5.54
78.46	12.27	0.13	0.87	0.08	0.80	3.64	3.59	0.17	5.68
77.40	12.51	0.20	1.01	0.22	0.82	3.75	3.91	0.19	4.31
77.82	12.27	0.18	0.94	0.16	0.81	3.86	3.72	0.24	4.99
78.02	12.15	0.19	1.06	0.10	0.93	3.74	3.60	0.20	4.72
77.83	12.35	0.12	0.89	0.13	0.93	3.71	3.87	0.18	5.27
77.90	12.27	0.21	1.08	0.12	0.89	3.76	3.61	0.17	5.23
77.72	12.34	0.13	1.02	0.14	0.94	3.59	3.94	0.19	4.03
77.43	12.25	0.23	1.11	0.11	1.03	3.73	3.84	0.27	3.33
77.48	12.50	0.12	1.02	0.10	0.93	3.69	3.90	0.26	3.79
77.59	12.45	0.25	0.97	0.12	0.91	3.75	3.75	0.20	5.87
77.35	12.57	0.13	1.00	0.14	1.02	3.76	3.84	0.19	6.14
77.69	12.39	0.16	1.01	0.13	0.90	3.70	3.82	0.20	4.95
14	0.31	0.13	0.05	0.07	0.03	0.08	0.08	0.16	0.03

? 76.81 12.67 0.14 1.08 0.14 1.13 4.14 3.61 0.28 5.85
? 77.70 12.29 0.21 1.22 0.10 0.94 3.72 3.57 0.25 3.89
? 74.89 13.67 0.38 1.69 0.41 1.59 4.11 3.05 0.23 4.14

site 51 = Wairuru (Y14/400828)

05101 Wairuru: (mb) (pkrsch)

78.90	12.38	0.10	0.80	0.07	0.66	3.19	3.77	0.14	4.00
78.59	12.23	0.08	1.02	n.d.	0.67	3.66	3.75	n.d.	2.51
78.86	12.25	n.d.	0.94	0.06	0.60	3.25	3.98	0.06	2.62
78.74	12.27	n.d.	0.98	0.13	0.52	3.27	3.93	0.17	3.06
77.94	12.44	n.d.	1.06	n.d.	0.82	3.84	3.89	n.d.	2.84
78.44	12.47	0.07	0.94	n.d.	0.78	3.46	3.74	0.09	2.72
78.15	12.51	n.d.	0.93	0.15	0.75	3.65	3.74	0.12	1.51
78.57	12.46	0.11	0.91	0.06	0.80	3.17	3.81	0.11	2.81
78.48	12.25	n.d.	0.99	0.07	0.74	3.44	3.87	0.17	3.77

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
06102 Kaingaroa lgb. (kg1); (mbx) (pkscrh)										
78.07	11.90	0.13	1.31	0.12	0.87		3.56	3.84	0.20	3.66
78.07	12.18	0.20	1.21	0.10	0.96		3.42	3.67	0.18	2.43
77.98	12.20	0.13	1.18	0.11	0.95		3.40	3.85	0.19	1.14
78.04	12.09	0.16	1.23	0.11	0.93		3.46	3.79	0.19	2.41
3 0.05	0.17	0.04	0.07	0.01	0.05		0.09	0.10	0.01	1.26
? 78.44	12.22	0.15	0.99	0.10	0.97		3.15	3.80	0.17	2.29
06103 Kaingaroa lgb. (kg1); (pum) (pkscrh)										
78.37	12.06	0.15	1.19	0.07	0.72		3.39	3.88	0.16	3.00
78.30	12.17	0.12	1.10	0.07	0.84		3.42	3.81	0.17	3.23
78.28	12.11	0.18	1.25	0.11	0.83		3.35	3.68	0.22	2.36
78.56	12.06	0.11	1.23	0.11	0.84		3.35	3.56	0.18	2.14
78.38	12.10	0.14	1.19	0.09	0.81		3.38	3.73	0.18	2.68
4 0.13	0.05	0.03	0.07	0.02	0.06		0.03	0.14	0.02	0.52
? 78.15	12.13	0.12	1.09	0.12	1.00		3.38	3.82	0.20	3.54

site 62 = Reihana Rd. (U17/093098)

06201 Kaingaroa lgb (kg1); unwelded; (pum) (integr)										
77.80	12.41	0.20	1.38	0.08	0.84		3.46	3.56	0.27	1.35
77.14	12.60	0.20	1.26	0.17	0.95		3.75	3.75	0.21	3.08
76.89	12.52	0.28	1.45	0.19	0.77		3.94	3.79	0.18	4.04
76.76	12.74	0.27	1.23	0.12	0.91		3.90	3.85	0.23	2.88
77.24	12.63	0.15	1.41	0.07	0.99		3.80	3.59	0.12	3.66
77.00	12.62	0.13	1.31	0.12	0.97		4.00	3.65	0.19	3.25
77.55	12.48	0.12	1.42	0.12	0.71		3.65	3.74	0.22	4.78
77.16	12.64	0.30	1.41	0.12	0.92		3.79	3.50	0.15	2.87
77.18	12.52	0.28	1.38	0.12	0.84		3.85	3.59	0.24	2.17
77.19	12.57	0.21	1.36	0.12	0.88		3.79	3.67	0.20	3.12
9 0.32	0.10	0.07	0.08	0.04	0.09		0.16	0.12	0.05	1.00
? 77.65	12.55	0.10	1.05	0.11	0.90		3.70	3.74	0.19	3.31

06202 Matahina lgb; semi-welded, sheet III; (total) (integr)										
78.17	12.27	0.16	1.03	0.14	0.80		3.54	3.70	0.20	4.12
77.87	12.34	0.22	1.07	0.10	0.82		3.63	3.79	0.17	3.18
77.78	12.20	0.22	1.24	0.12	0.94		3.81	3.52	0.17	4.54
77.90	12.45	0.17	1.08	0.05	0.76		3.71	3.67	0.20	5.51
77.63	12.60	0.19	1.12	0.14	0.73		3.56	3.84	0.20	5.01
77.74	12.54	0.17	1.25	0.07	0.80		3.54	3.71	0.17	4.90
77.75	12.59	0.14	1.15	0.09	0.97		3.49	3.60	0.23	4.91
77.40	12.47	0.08	1.14	0.23	0.86		3.69	3.87	0.25	4.43
77.73	12.61	0.24	0.98	0.10	0.87		3.62	3.57	0.27	4.22
77.79	12.45	0.15	1.15	0.08	0.73		3.89	3.58	0.18	4.27
78.00	12.35	0.29	0.98	0.14	0.96		3.57	3.63	0.09	4.74
77.80	12.44	0.18	1.11	0.12	0.84		3.64	3.68	0.19	4.53
11 0.20	0.14	0.06	0.09	0.05	0.09		0.12	0.12	0.05	0.61

06203 Torere-L; (pum) (integr)										
79.21	11.69	0.12	0.89	0.13	0.74		3.36	3.70	0.16	2.08
78.32	11.77	0.15	1.06	0.09	0.92		3.37	4.11	0.21	0.93
79.48	11.77	0.20	0.89	0.07	0.82		3.42	3.36	n.d.	3.53
78.86	11.70	0.15	0.95	0.15	0.90		3.53	3.57	0.19	2.82
78.47	11.85	0.10	0.98	0.21	0.86		3.47	3.92	0.14	2.80
78.47	11.71	0.26	1.03	0.19	0.72		3.47	4.01	0.13	1.36
79.21	11.59	0.13	0.86	0.07	0.69		3.44	3.85	0.15	2.62
78.97	11.76	0.17	0.99	0.06	0.81		3.25	3.79	0.20	3.18
78.81	11.73	0.17	0.99	0.08	0.86		3.56	3.63	0.18	3.65
78.61	11.80	0.25	1.13	0.09	1.02		3.34	3.62	0.14	1.74
78.69	11.84	0.11	0.96	0.13	0.91		3.32	3.82	0.21	3.47
78.83	11.75	0.17	0.98	0.12	0.84		3.41	3.76	0.17	2.56
11 0.36	0.07	0.05	0.08	0.05	0.10		0.09	0.21	0.03	0.92
? 77.90	12.32	0.14	1.19	0.11	0.88		3.46	3.81	0.19	2.76
? 79.72	11.58	0.14	1.18	0.09	0.76		3.26	3.15	0.11	2.26
? 78.38	11.88	0.14	1.24	0.11	0.92		3.81	3.30	0.23	1.73
? 79.35	11.93	0.11	0.68	n.d.	0.83		3.54	3.37	0.19	1.64

06204 Reihana-M; (total) (integr)										
78.75	11.77	0.10	0.99	0.09	0.93		3.37	3.82	0.17	3.42
78.44	12.12	0.16	1.19	0.16	0.86		3.32	3.51	0.25	6.52
78.95	11.48	0.14	1.06	0.14	0.91		3.50	3.66	0.14	3.09
78.89	11.71	0.19	1.03	0.15	0.84		3.28	3.77	0.13	2.34
78.81	11.83	0.09	1.05	n.d.	0.89		3.39	3.78	0.16	3.27
78.64	11.64	0.19	1.12	0.19	0.85		3.40	3.80	0.18	3.47
79.01	11.75	0.13	0.92	0.21	0.91		3.33	3.65	0.09	3.54
78.48	11.94	0.25	1.03	0.17	0.80		3.34	3.80	0.19	6.21
79.10	11.55	0.13	1.13	0.07	0.84		3.42	3.59	0.15	2.88
79.08	11.85	0.12	1.09	0.13	0.86		3.24	3.48	0.13	2.89
78.44	11.92	0.20	1.18	0.13	0.82		3.46	3.65	0.21	3.22
78.48	11.82	0.24	1.04	0.12	0.76		3.40	3.97	0.16	3.24
77.86	12.55	0.25	1.01	0.12	0.89		3.49	3.67	0.17	3.98
78.22	12.49	0.11	1.10	0.13	0.78		3.14	3.90	0.12	3.09
78.34	12.00	0.11	0.99	0.12	0.75		3.69	3.86	0.15	0.69
78.84	11.76	0.13	0.88	0.17	0.90		3.51	3.61	0.20	5.76
78.78	11.93	0.11	1.01	0.14	0.76		3.44	3.74	0.09	5.13
78.65	11.89	0.16	1.05	0.14	0.84		3.39	3.72	0.16	3.69
17 0.34	0.28	0.05	0.08	0.03	0.06		0.12	0.13	0.04	1.47

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
06205 Torere-K; (total) (integr)										
76.94	12.67	0.45	1.23	0.22	1.38		3.60	3.34	0.17	4.80
76.62	13.01	0.28	1.28	0.26	1.30		3.79	3.36	0.12	6.00
77.13	12.54	0.40	1.32	0.32	1.35		3.57	3.17	0.19	2.26
76.22	12.88	0.27	1.43	0.23	1.46		4.01	3.34	0.13	1.58
77.14	12.56	0.26	1.32	0.31	1.45		3.72	3.02	0.24	2.60
77.10	12.55	0.37	1.53	0.33	1.28		3.43	3.18	0.23	3.20
77.02	12.87	0.28	1.25	0.30	1.38		3.65	3.11	0.13	4.22
76.99	12.90	0.38	1.23	0.21	1.27		3.69	3.32	n.d.	5.07
76.83	12.74	0.26	1.38	0.35	1.28		3.57	3.47	0.13	4.55
77.06	12.58	0.32	1.52	0.30	1.25		3.75	3.06	0.16	4.03
76.69	13.02	0.42	1.38	0.28	1.38		3.48	3.19	0.17	5.55
76.88	12.76	0.34	1.35	0.28	1.34		3.66	3.23	0.17	3.99
11 0.28	0.19	0.07	0.11	0.05	0.07		0.16	0.14	0.04	1.41

06206 Torere-M; (mbx) (integr)										
78.08	12.34	0.08	1.07	0.05	0.57		3.00	4.66	0.14	3.91
78.51	12.19	0.08	1.03	0.09	0.63		3.15	4.19	0.12	3.48
78.73	11.69	0.13	1.00	n.d.	0.57		3.29	4.45	0.14	5.16
78.00	12.35	0.10	0.86	0.15	0.77		3.41	4.19	0.16	1.82
79.03	11.75	0.12	0.75	0.10	0.64		3.35	4.07	0.19	6.33
78.98	11.52	0.15	0.87	0.12	0.59		3.48	4.06	0.23	6.20
78.81	11.94	0.09	0.94	0.08	0.64		3.26	4.13	0.13	7.25
78.94	12.03	0.13	0.93	0.07	0.59		3.16	4.02	0.13	5.33
78.68	11.73	0.09	0.83	0.10	0.62		3.52	4.26	0.17	7.76
78.64	12.40	0.07	0.76	0.07	0.54		3.13	4.21	0.18	4.41
78.16	12.38	0.18	0.85	0.09	0.67		3.15	4.40	0.12	6.09
78.48	11.77	0.17	0.90	0.10	0.70		3.46	4.26	0.16	5.81
78.78	12.21	n.d.	0.85	n.d.	0.62		3.26	4.13	0.15	4.60
78.60	12.03	0.12	0.90	0.09	0.63		3.28	4.23	0.16	5.24
13 0.34	0.31	0.04	0.10	0.03	0.06		0.16	0.18	0.03	1.61
b 79.26	11.47	0.21	1.14	0.14	0.83		3.22	3.58	0.15	5.37

06207 Reihana-C; (mbx) (integr)										
78.75	12.24	0.12	0.96	n.d.	0.59		3.25	3.98	0.11	0.13
79.14	11.39	0.16	1.12	0.08	0.52		3.02	4.47	0.11	3.28
78.91	11.73	0.17	0.89	0.13	0.74		3.37	3.83	0.23	5.39
78.59	11.81	0.09	0.92	0.11	0.69		3.39	4.22	0.18	4.08
78.15	12.16	0.11	0.94	n.d.	0.77		3.48	4.24	0.16	3.31
78.05	12.11	0.17	1.14	0.14	0.77		2.98	4.44	0.19	7.52
78.53	11.67	0.18	0.85	0.08	0.77		3.24	4.50	0.16	2.54
78.13	12.55	0.18	0.96	0.10	0.73		2.97	4.23	0.15	6.06
78.80	11.89	0.17	0.84	0.13	0.70		2.94	4.35	0.18	3.45
77.61	12.06	0.18	1.02	0.17	0.78		3.68	4.33	0.18	4.65
78.28	11.67	0.19	1.10	0.09	0.67		3.19	4.68	0.12	5.09
79.35	11.27	0.08	0.90	0.06	0.65		2.97	4.56	0.16	5.20
78.80	11.45	0.11	1.00	0.12	0.75		3.40	4.17	0.19	3.27
78.65	11.51	0.18	1.07	0.08	0.76		3.40	4.20	0.15	3.89
78.55	11.82	0.15	0.98	0.11	0.71		3.24	4.30	0.16	4.13
14 0.47	0.37	0.04	0.10	0.03	0.08		0.23	0.23	0.03	1.76

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
06210 Torere-A: (pum) (integr)										
77.05	13.00	0.15	1.26	0.18	1.26	3.42	3.52	0.17	5.32	
77.82	12.32	0.13	1.51	0.18	1.13	3.41	3.34	0.16	6.03	
77.61	12.49	0.15	1.23	0.16	1.19	3.55	3.47	0.16	6.94	
77.71	12.31	0.17	1.33	0.23	1.31	3.42	3.41	0.11	6.76	
77.45	12.22	0.19	1.47	0.21	1.25	3.50	3.51	0.22	9.32	
77.94	12.02	0.23	1.30	0.17	1.21	3.51	3.49	0.13	9.34	
77.10	12.80	0.22	1.35	0.22	1.27	3.51	3.40	0.13	7.36	
76.67	12.97	0.27	1.55	0.20	1.28	3.26	3.69	0.11	6.43	
77.31	12.39	0.27	1.26	0.19	1.16	3.79	3.43	0.21	5.78	
76.76	13.11	n.d.	1.39	0.20	1.40	3.59	3.42	0.14	6.38	
77.34	12.56	0.20	1.36	0.19	1.25	3.49	3.47	0.15	6.97	
10 0.44	0.38	0.05	0.11	0.02	0.08	0.14	0.09	0.04	1.37	
b 77.72	12.25	0.27	1.04	0.16	0.70	3.67	3.96	0.22	6.63	
? 77.29	12.06	0.24	1.43	0.28	1.56	3.65	3.40	0.08	4.09	
06211 Torere-B: (pum) (integr)										
77.27	13.24	0.21	1.07	0.11	0.83	3.45	3.69	0.12	2.07	
78.14	11.62	0.15	1.15	0.09	0.78	3.97	3.92	0.18	3.73	
77.71	12.43	0.23	1.26	0.19	0.99	3.32	3.78	0.09	1.68	
78.21	12.35	0.18	1.01	0.16	0.86	3.25	3.88	0.11	3.53	
78.22	11.81	0.17	1.22	0.14	0.91	3.69	3.64	0.19	1.59	
78.09	12.19	0.20	0.99	0.14	0.88	3.70	3.65	0.14	2.31	
78.56	12.09	n.d.	1.01	0.07	0.79	3.59	3.78	0.10	2.83	
77.89	12.72	0.20	0.99	0.15	0.88	3.71	3.46	n.d.	1.63	
78.18	12.07	0.22	0.93	0.18	0.99	3.63	3.64	0.16	2.67	
78.62	11.49	0.13	0.98	0.10	0.80	3.91	3.81	0.15	1.42	
78.05	12.43	0.15	1.10	0.11	0.98	3.39	3.58	0.21	2.87	
78.27	12.06	0.18	0.93	0.09	0.85	3.68	3.71	0.11	2.29	
78.10	12.21	0.19	1.05	0.13	0.89	3.61	3.71	0.14	2.38	
12 0.36	0.48	0.03	0.11	0.04	0.08	0.22	0.13	0.04	0.76	
b 77.24	12.51	0.28	1.18	0.27	1.16	3.75	3.43	0.18	1.64	
b 77.24	12.44	0.47	1.30	0.26	1.16	3.83	3.11	0.18	1.70	
b 76.74	12.69	0.38	1.35	0.20	1.17	4.12	3.21	0.12	1.05	
77.07	12.55	0.38	1.28	0.25	1.16	3.90	3.25	0.16	1.46	
3 0.29	0.13	0.09	0.09	0.04	0.01	0.20	0.16	0.04	0.36	
? 77.53	12.65	0.16	0.96	0.09	1.09	3.57	3.75	0.19	1.44	
06212 Reihana-E: (mtb+) (integr)										
77.63	12.45	0.11	0.85	0.09	1.12	3.53	4.06	0.16	6.33	
77.99	12.25	n.d.	1.15	0.11	0.88	3.64	3.75	0.23	2.62	
77.74	12.09	0.23	0.86	0.12	1.02	3.21	4.30	0.43	2.52	
78.04	12.32	0.06	1.04	0.12	0.87	3.51	3.79	0.25	4.49	
77.22	12.28	0.17	1.15	0.13	0.84	3.30	4.61	0.31	4.32	
77.08	12.85	0.17	0.80	0.11	0.86	3.50	4.28	0.35	7.25	
76.99	12.69	0.15	0.97	0.18	0.79	3.44	4.49	0.30	5.42	
77.15	12.83	0.11	1.00	0.08	0.78	3.81	3.99	0.26	7.56	
77.11	12.73	0.13	0.99	0.12	0.81	3.81	4.08	0.21	6.47	
77.37	12.63	0.10	0.81	0.05	0.80	3.70	4.31	0.23	7.38	
76.65	12.95	0.20	1.15	0.14	0.84	3.83	3.98	0.26	6.47	
77.17	12.73	0.11	1.18	0.06	1.01	3.80	3.69	0.24	7.16	
77.20	12.84	0.09	1.00	0.15	0.90	3.56	4.04	0.22	7.90	
76.98	13.10	0.09	1.15	0.19	1.06	3.44	3.76	0.23	9.03	
77.92	12.14	0.13	0.92	0.13	0.96	3.40	4.16	0.23	3.44	
77.61	12.63	0.15	0.98	0.12	0.89	3.74	3.69	0.19	5.80	
77.37	12.60	0.13	1.00	0.12	0.90	3.58	4.06	0.26	5.88	
16 0.41	0.30	0.05	0.13	0.04	0.10	0.19	0.28	0.07	1.93	
? 78.50	11.84	0.21	0.97	0.14	0.66	3.32	4.16	0.20	4.96	
? 77.87	12.32	0.12	1.23	0.10	0.84	3.88	3.40	0.24	2.54	
06213 Kaingaroa Igls. (kglc): unwelded; (pum) (integr)										
77.62	12.25	0.17	1.42	0.12	0.92	3.64	3.56	0.29	8.35	
77.82	12.07	0.32	1.07	0.11	0.72	3.60	3.97	0.33	5.33	
77.43	12.33	0.23	1.28	0.12	0.79	3.67	3.83	0.32	5.45	
77.28	12.44	0.13	1.26	0.14	0.97	3.81	3.73	0.24	6.59	
77.74	12.26	0.15	1.04	0.13	0.78	3.59	4.04	0.27	5.37	
77.52	12.15	0.20	1.44	0.10	0.76	3.64	3.94	0.25	6.89	
78.11	11.98	0.14	0.98	0.14	0.83	3.72	3.93	0.17	5.16	
77.65	12.21	0.19	1.21	0.12	0.83	3.67	3.86	0.27	6.16	
7 0.27	0.16	0.07	0.19	0.02	0.09	0.08	0.17	0.05	1.18	
06214 Torere-O: (pum) (integr)										
78.34	12.16	0.17	0.98	0.20	0.76	3.30	3.97	0.13	4.00	
78.21	12.05	0.18	1.02	0.17	0.72	3.47	4.04	0.15	4.09	
78.41	12.17	n.d.	1.12	0.18	0.76	3.41	3.69	0.27	4.09	
78.77	12.26	n.d.	1.04	n.d.	0.70	3.40	3.82	n.d.	3.94	
78.24	12.15	0.26	0.94	0.14	0.77	3.38	3.97	0.15	4.15	
78.53	11.91	0.12	0.97	0.12	0.71	3.72	3.75	0.17	3.37	
78.52	11.86	0.12	1.00	0.30	0.89	3.42	3.74	0.15	3.54	
78.02	12.28	n.d.	0.92	0.29	0.81	3.48	4.02	0.19	3.87	
78.64	12.28	n.d.	0.94	0.15	0.80	3.46	3.72	n.d.	4.16	
78.21	12.20	0.16	1.00	0.29	0.87	3.30	3.76	0.21	3.44	
77.55	12.46	0.18	1.07	0.20	0.78	3.57	4.00	0.18	5.69	
77.59	12.50	0.12	1.03	0.05	0.84	3.68	4.01	0.17	6.23	
77.77	12.28	0.17	1.08	0.16	0.76	3.65	3.88	0.25	7.42	
77.76	12.49	0.14	1.01	0.16	0.95	3.48	3.83	0.17	7.13	
77.79	12.49	0.09	1.01	0.08	0.85	3.56	3.90	0.24	7.07	
77.61	12.62	0.11	1.08	0.16	0.74	3.60	3.93	0.16	6.28	
77.63	12.50	0.07	0.99	0.11	0.89	3.52	4.10	0.19	6.25	
77.77	12.56	0.09	0.98	0.09	0.85	3.55	3.86	0.26	6.51	
77.59	12.57	0.17	1.18	0.17	0.83	3.22	4.06	0.21	5.94	
77.75	12.57	0.13	1.05	0.12	0.84	3.64	3.71	0.19	6.42	
77.47	12.42	0.18	0.96	0.10	0.81	3.58	4.08	0.41	8.74	
78.01	12.32	0.14	1.02	0.16	0.81	3.50	3.90	0.20	5.35	
21 0.41	0.22	0.05	0.06	0.07	0.07	0.13	0.13	0.06	1.58	

continued next

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
06214 continued										
? 78.07	12.29	0.18	0.92	0.25	0.99	3.66	3.46	0.18	4.37	
? 78.71	11.72	0.09	0.97	0.17	0.59	3.73	3.84	0.18	3.84	
? 78.16	12.28	0.23	0.85	0.11	0.77	3.46	3.94	0.20	6.91	
06215 Torere-A: (pum) (integr)										
76.69	12.77	0.23	1.52	0.19	1.24	3.62	3.53	0.21	5.45	
76.69	12.96	0.21	1.39	0.22	1.25	3.58	3.44	0.26	3.76	
76.93	12.92	0.17	1.47	0.17	1.24	3.55	3.36	0.19	5.41	
76.60	13.37	0.21	1.30	0.29	1.34	3.38	3.32	0.19	7.34	
77.23	12.75	0.19	1.29	0.16	1.12	3.53	3.53	0.21	4.76	
77.14	12.83	0.19	1.22	0.17	1.15	3.65	3.47	0.18	5.27	
76.99	12.79	0.12	1.40	0.23	1.14	3.57	3.50	0.26	5.61	
76.31	13.04	0.22	1.53	0.22	1.34	3.85	3.23	0.26	5.08	
76.82	12.93	0.19	1.39	0.21	1.23	3.59	3.42	0.22	5.33	
8 0.30	0.21	0.04	0.11	0.04	0.08	0.13	0.11	0.04	1.00	
06216 Reihana-F(2): (pum) (integr)										
77.80	12.21	0.17	1.07	0.09	0.80	3.33	4.27	0.25	5.07	
77.87	12.00	0.13	1.05	0.08	0.93	3.53	4.21	0.19	4.59	
78.22	12.01	0.20	0.99	0.07	0.77	3.36	4.18	0.21	3.82	
77.40	12.32	0.14	1.10	0.12	1.01	3.66	3.98	0.27	6.67	
77.48	12.03	0.21	1.27	0.11	0.85	3.45	4.39	0.22	4.22	
77.77	12.23	0.14	1.11	0.13	0.79	3.27	4.39	0.18	5.28	
77.86	12.23	0.16	1.05	0.11	0.87	3.36	4.15	0.20	5.14	
77.83	12.46	0.14	0.94	0.11	0.85	3.36	4.10	0.22	5.11	
76.92	12.58	0.21	1.31	0.17	1.07	3.44	4.10	0.20	4.40	
77.78	12.01	0.17	1.14	0.13	0.88	3.32	4.36	0.22	5.17	
77.69	12.21	0.17	1.10	0.11	0.88	3.41	4.21	0.22	4.95	
76.50	0.20	0.03	0.12	0.03	0.10	0.12	0.14	0.03	0.78	
b 76.49	12.75	0.24	1.36	0.23	1.32	3.92	3.41	0.26	5.98	
b 77.40	12.69	0.20	1.16	0.22	1.12	3.56	3.50	0.17	5.01	
b 76.84	12.82	0.25	1.15	0.23	1.08	3.85	3.58	0.19	5.25	
76.91	12.75	0.23	1.22	0.23	1.17	3.78	3.50	0.20	5.41	
3 0.46	0.07	0.03	0.12	0.01	0.13	0.19	0.08	0.05	0.51	
? 76.56	12.65	0.33	1.36	0.17	1.20	3.55	3.99	0.19	5.94	
? 77.55	12.37	0.17	1.25	0.08	0.65	3.43	4.25	0.25	4.63	
? 76.96	12.54	0.13	1.48	0.27	1.01	3.38	4.02	0.22	7.18	
06217 Torere-N: (mtb) (integr)										
77.51	12.32	0.16	1.31	0.11	1.07	3.56	3.74	0.21	4.05	
76.98	12.36	0.23	1.45	0.17	1.03	3.79	3.80	0.20	4.63	
77.67	12.68	0.25	0.97	0.15	0.95	3.40	3.73	0.21	5.01	
77.12	12.61	0.13	1.20	0.15	1.05	3.70	3.76	0.28	7.33	
77.79	12.36	0.23	1.28	0.11	0.83	3.47	3.73	0.21	6.72	
76.89	12.77	0.18	1.27	0.13	1.06	3.65	3.88	0.17	3.46	
77.52	12.30	0.28	1.03	0.17	0.98	3.66	3.79	0.26	3.29	
77.44	12.58	0.18	1.13	0.17	0.99	3.65	3.68	0.19	4.35	
77.38	12.56	0.15	1.29	0.16	0.86	3.46	3.96	0.20	3.69	
77.45	12.48	0.15	1.12	0.16	0.93	3.65	3.89	0.18	5.37	
77.26	12.56	0.16	1.18	0.12	1.03	3.59	3.95	0.15	6.63	
77.30	12.42	0.19	1.18	0.17	0.89	3.69	3.98	0.19	5.13	
77.13	12.54	0.21	1.27	0.11	1.14	3.60	3.69	0.30	5.67	
77.25	12.69	0.22	1.06	0.18	0.95	3.70	3.79	0.17	5.03	
76.85	12.76	0.25	1.41	0.14	0.96	3.76	3.70	0.16	5.67	
78.11	12.29	0.14	0.99	0.10	0.88	3.66	3.71	0.13	4.08	
77.33	12.61	0.20	1.30	0.18	0.95	3.47	3.80	0.17	4.80	
77.36	12.59	0.19	1.24	0.15	1.00	3.67	3.61	0.20	3.94	
77.44	12.42	0.16	1.22	0.18	0.90	3.65	3.79	0.24	3.54	
77.36	12.52	0.19	1.21	0.15	0.97	3.62	3.79	0.20	4.86	
19 0.30	0.15	0.04	0.13	0.03	0.08	0.10	0.10	0.04	1.16	
? 77.00	12.69	0.20	1.38	0.15	1.27	3.56	3.56	0.18	6.83	
06218 Reihana-G(2): pisolitic ash: (mtb) (integr)										
76.38	13.29	0.14	1.56	0.10	1.15	3.60	3.51	0.27	8.22	
76.08	13.55	0.17	1.48	0.13	1.01	4.15	3.21	0.22	5.99	
76.38	13.50	0.14	1.56	0.16	1.19	3.81	3.24	0.00	8.47	
75.99	13.41	0.24	1.65	0.19	1.22	3.61	3.44	0.26	8.26	
75.41	13.48	0.33	1.67	0.23	1.16	3.84	3.65	0.23	7.79	
75.70	13.45	0.20	1.56	0.14	1.13	4.08	3.50	0.24	6.55	
76.02	13.51	0.19	1.36	0.22	1.18	3.79	3.50	0.23	7.68	
76.08	13.48	0.21	1.62	0.14	1.14	3.64	3.50	0.20	7.78	
75.80	13.56	0.00	1.48	0.22	1.13	3.86	3.68	0.27	7.89	
75.85	13.33	0.18	1.80	0.17	1.18	3.95	3.27	0.25	7.15	
76.17	13.21	0.28	1.58	0.16	1.19	3.70	3.48	0.24	6.42	
75.99	13.43	0.21	1.57	0.17	1.15	3.82	3.45	0.24	7.47	
11 0.29	0.11	0.06	0.11	0.04	0.06	0.18	0.15	0.02	0.83	
06219 Reihana-G(1): Ignimbrite: (mtb) (integr)										
75.97	13.31	0.20	1.61	0.19	1.09	3.95	3.41	0.27	5.24	
76.39	12.92	0.17	1.61	0.16	1.22	3.73	3.64	0.15	5.83	
76.18	13.15	0.09	1.62	0.18	1.18	3.74	3.61	0.25	4.99	
76.11	13.20	0.22	1.65	0.18	1.06	3.87	3.43	0.28	5.62	
76.08	13.27	0.16	1.53	0.16	1.11	3.97	3.49	0.23	4.39	
75.93	13.13	0.18	1.47	0.19	1.17	3.85	3.88	0.19	5.73	
76.02	13.14	0.30	1.52	0.18	1.15	3.83	3.59	0.28	5.98	
75.89	13.27	0.17	1.70	0.20	1.14	3.78	3.57	0.29	5.27	
75.69	13.37	0.18	1.78	0.16	1.17	3.89	3.51	0.24	5.70	
75.61	13.25	0.23	1.78	0.21	1.13	4.07	3.49	0.22	5.56	
75.99	13.20	0.19	1.63	0.18	1.14	3.87	3.56	0.24	5.43	
10 0.23	0.13	0.05	0.10	0.02	0.05	0.11	0.14	0.04	0.47	
b 77.89	12.64	0.10	0.93	0.11	0.89	3.16	4.06	0.22	5.75	

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water

site 63 = Waingarara (W15/677419)

06301 Waingarara Ignimbrite: (mtb) (integr)

a	77.93	11.86	0.17	1.22	0.12	1.04	3.65	3.77	0.25	6.18
a	77.07	12.51	0.17	1.03	0.10	0.94	3.81	4.09	0.26	4.26
a	77.33	12.13	0.13	1.19	0.12	0.98	3.97	4.00	0.14	1.97
a	77.75	12.27	0.18	1.10	0.20	0.96	3.42	3.82	0.30	4.31
a	78.02	12.24	0.18	1.05	0.07	0.95	3.39	3.88	0.22	4.16
a	77.96	12.10	0.22	1.13	0.16	0.95	3.54	3.69	0.24	5.67
a	77.34	12.35	0.17	1.23	0.13	0.95	3.84	3.75	0.24	4.57
a	76.99	12.68	0.19	1.40	0.18	1.08	3.77	3.55	0.16	2.87
a	77.33	12.39	0.26	1.32	0.13	0.96	3.76	3.61	0.24	4.51
a	77.45	12.74	0.16	1.20	0.10	0.88	3.54	3.68	0.25	4.52
a	77.35	12.18	0.21	1.11	0.22	1.01	3.69	3.93	0.30	3.35
a	77.21	12.12	0.20	1.12	0.08	1.05	3.79	4.16	0.26	5.10
12	77.48	12.30	0.19	1.18	0.13	0.98	3.68	3.83	0.24	4.29
12	0.35	0.25	0.03	0.11	0.04	0.06	0.18	0.19	0.05	1.15

b	77.00	12.92	0.16	1.00	0.11	0.74	3.70	4.16	0.19	2.42
b	76.99	13.24	0.12	0.94	0.07	0.71	3.53	4.16	0.24	1.87

2	77.00	13.08	0.14	0.97	0.09	0.73	3.61	4.16	0.22	2.14
2	0.01	0.22	0.03	0.05	0.03	0.02	0.12	0.00	0.04	0.39

?	77.03	12.58	n.d.	1.51	0.11	0.98	3.76	3.89	0.15	3.72
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site 64 = Waimana Hill (W16/662344)

06401 Waimana-B: (unknown): (pum) (pkscrh)

77.44	12.93	0.08	1.04	0.05	0.80	3.33	4.08	0.24	3.28
77.35	13.12	n.d.	0.91	n.d.	0.78	3.27	4.44	0.12	3.74
77.66	12.43	0.24	1.01	0.06	0.72	3.63	4.15	0.10	2.74
78.32	11.85	0.14	1.03	0.06	0.92	3.33	4.25	0.10	5.51
77.25	12.81	0.10	1.12	0.04	0.69	3.53	4.19	0.26	3.85
77.77	12.68	0.13	1.00	0.06	0.78	3.28	4.09	0.21	3.31
77.42	12.57	0.14	1.14	0.06	0.75	3.27	4.52	0.14	4.86
77.05	13.41	0.08	1.07	0.07	0.84	3.37	4.00	0.10	3.30
77.89	12.39	n.d.	1.09	0.07	0.80	3.50	4.07	0.20	5.30
77.93	12.37	0.21	0.98	0.05	0.87	3.24	4.20	0.15	4.37
78.12	12.00	0.16	1.11	0.05	0.87	3.50	4.01	0.19	4.19
77.66	12.60	0.14	1.05	0.06	0.80	3.39	4.18	0.16	4.04
11	0.39	0.46	0.05	0.07	0.01	0.07	0.13	0.17	0.06

06402 Waimana-C: (unknown): (pum) (pkscrh)

77.60	12.42	0.09	1.26	0.04	0.86	3.53	4.19	n.d.	8.87	
77.98	12.40	n.d.	1.21	0.05	0.78	3.23	4.14	0.21	7.74	
77.62	12.33	0.08	1.19	n.d.	0.88	3.35	4.30	0.26	8.32	
77.18	12.33	0.10	1.37	0.09	0.96	3.46	4.29	0.21	8.22	
77.59	12.54	n.d.	1.24	0.08	0.97	3.34	4.02	0.22	8.30	
77.50	12.57	0.09	1.28	0.05	0.87	3.16	4.23	0.26	7.22	
77.14	12.50	0.22	1.25	0.04	0.84	3.23	4.41	0.38	8.55	
77.73	12.61	n.d.	1.14	0.04	0.86	3.13	4.38	0.11	8.83	
77.18	12.66	n.d.	1.31	0.09	0.89	3.28	4.27	0.32	8.28	
77.48	12.63	n.d.	1.23	0.11	0.85	3.32	4.19	0.20	8.76	
77.61	12.86	n.d.	1.19	0.10	0.92	3.23	3.96	0.13	8.48	
77.28	12.79	0.21	1.14	0.04	0.80	3.35	4.29	0.10	7.75	
76.99	12.94	0.13	1.03	0.13	0.90	3.30	4.36	0.22	8.87	
77.86	12.74	n.d.	0.95	n.d.	0.86	3.30	4.28	n.d.	9.53	
78.04	12.44	n.d.	1.06	0.05	0.83	3.13	4.22	0.22	8.39	
77.30	12.67	0.18	1.20	n.d.	1.04	3.00	4.39	0.22	8.62	
77.50	12.59	0.13	1.19	0.07	0.88	3.27	4.24	0.22	8.42	
16	0.31	0.18	0.06	0.11	0.03	0.07	0.13	0.13	0.08	0.54

06403 Waimana-A: (unknown): (pum) (pkscrh)

77.33	13.04	0.17	1.16	0.12	0.91	3.21	3.94	0.13	4.86	
77.01	12.84	0.09	1.42	0.06	1.02	3.26	4.07	0.21	5.94	
77.91	12.21	0.11	1.24	0.06	0.97	3.41	3.89	0.19	6.57	
76.44	13.55	0.15	1.23	0.16	0.96	3.31	4.09	0.10	4.65	
77.39	12.91	0.11	1.13	0.11	0.92	3.37	3.85	0.22	5.27	
78.17	12.38	0.11	1.25	n.d.	0.80	3.26	3.92	0.11	5.53	
77.42	13.04	0.10	1.20	n.d.	1.01	3.27	3.79	0.10	4.15	
77.22	13.11	n.d.	1.30	n.d.	0.94	3.39	3.97	0.06	5.35	
77.64	12.77	0.15	1.18	0.04	1.09	3.00	4.13	n.d.	5.87	
77.02	12.88	0.09	1.35	0.07	0.92	3.35	4.20	0.12	4.66	
77.53	12.42	0.13	1.43	0.06	1.02	3.21	4.00	0.19	7.16	
77.12	13.46	0.10	1.18	n.d.	0.94	3.27	3.85	0.07	4.24	
77.85	12.53	0.07	1.19	0.07	0.92	3.10	4.12	0.13	6.17	
77.39	12.86	0.11	1.25	0.08	0.96	3.26	3.99	0.14	5.42	
13	0.45	0.40	0.03	0.10	0.03	0.07	0.12	0.13	0.05	0.91

?	76.36	13.21	0.10	1.46	0.05	0.95	3.12	4.63	0.13	7.33
?	77.14	12.69	0.14	1.03	0.13	0.97	3.04	4.67	0.19	6.90

site 65 = Waihora Rd. (T17/575881)

06501 Rotoiti: (mtb) (pkscrh)

79.03	12.10	n.d.	0.84	0.12	0.83	3.69	3.25	0.14	1.05	
78.84	11.87	0.12	0.93	0.13	0.80	3.79	3.34	0.17	0.44	
78.96	11.92	0.12	0.87	0.09	0.78	3.72	3.34	0.19	1.50	
79.16	12.03	0.15	0.82	0.11	0.82	3.57	3.19	0.13	1.53	
79.28	11.79	0.17	0.83	0.15	0.82	3.43	3.36	0.15	1.73	
78.87	11.95	0.21	0.95	0.12	0.85	3.54	3.36	0.15	2.48	
78.53	12.05	0.14	0.92	0.18	0.88	3.81	3.38	0.11	0.24	
78.87	11.95	0.20	0.93	n.d.	0.81	3.77	3.45	n.d.	1.59	
79.01	11.88	0.12	0.89	0.13	0.83	3.74	3.22	0.17	2.19	
79.11	12.06	0.12	0.87	0.15	0.79	3.48	3.26	0.16	3.51	
78.97	11.96	0.15	0.89	0.13	0.82	3.65	3.32	0.15	1.63	
10	0.21	0.10	0.03	0.05	0.03	0.03	0.14	0.08	0.02	0.96

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water

06502 unknown?: chemically altered: (pum) (pkscrh)

78.31	12.43	0.10	0.37	0.06	0.56	3.37	4.74	0.04	2.20
78.33	12.38	0.07	0.38	0.07	0.63	3.36	4.69	0.08	2.85
78.16	12.28	0.10	0.62	0.07	0.62	3.27	4.81	0.07	2.08
78.44	12.17	0.10	0.31	n.d.	0.60	3.42	4.96	n.d.	3.12
78.47	12.46	n.d.	0.31	n.d.	0.61	3.16	4.99	n.d.	3.66
78.58	12.29	0.11	0.57	n.d.	0.73	3.00	4.72	n.d.	3.19
78.36	12.35	0.10	0.43	n.d.	0.57	3.31	4.88	n.d.	2.89
78.08	12.44	0.13	0.50	n.d.	0.71	3.28	4.79	0.10	5.35
78.27	12.37	0.08	0.50	n.d.	0.65	3.21	4.92	n.d.	3.32
78.47	12.37	n.d.	0.50	0.05	0.61	3.20	4.72	0.08	3.06
78.15	12.32	n.d.	0.49	n.d.	0.57	3.27	5.09	0.12	5.16
78.43	12.20	n.d.	0.51	n.d.	0.61	3.27	4.92	0.05	2.11
78.34	12.34	0.10	0.46	0.06	0.62	3.26	4.85	0.08	3.25
12	0.15	0.09	0.02	0.10	0.01	0.05	0.11	0.13	0.03

site 66 = Te Piki (Y14/562905)

06601 Te Piki (Hiwarau?): (mtb) (pkscrh)

76.44	13.12	0.22	1.33	0.26	1.42	3.82	3.34	0.05	4.01	
77.22	12.85	0.19	1.48	0.25	1.36	3.36	3.19	0.09	3.89	
77.62	12.58	0.18	1.27	0.16	1.29	3.43	3.40	0.07	3.44	
77.04	12.88	0.13	1.35	0.26	1.47	3.41	3.34	0.13	4.02	
77.03	12.70	0.24	1.23	0.18	1.25	3.74	3.55	0.08	4.00	
77.01	12.99	0.24	1.31	0.21	1.42	3.40	3.33	0.09	3.70	
77.76	12.52	0.15	1.17	0.16	1.21	3.36	3.57	0.10	3.94	
77.03	12.87	0.23	1.41	0.20	1.43	3.38	3.36	0.09	4.20	
77.21	12.96	0.20	1.32	0.26	1.46	3.24	3.23	0.11	4.03	
77.18	12.88	0.17	1.41	0.24	1.37	3.36	3.33	0.07	3.24	
77.15	12.83	0.19	1.33	0.22	1.37	3.45	3.37	0.09	3.85	
10	0.36	0.18	0.04	0.09	0.04	0.09	0.18	0.12	0.02	0.30

site 67 = Te Piki West (Y14/577903)

06701 Te Piki West (Matahina?): (mtb+) (pkscrh)

78.45	12.18	0.12	1.05	0.11	0.82	3.47	3.66	0.14	0.47
78.81	12.06	0.15	1.03	0.12	0.93	3.20	3.53	0.16	1.50
78.45	12.19	n.d.	0.97	0.09	0.86	3.70	3.60	0.14	1.00
78.83	12.12	0.12	0.87	0.13	0.89	3.43	3.43	0.17	1.43
79.01	12.03	0.13	1.08	0.07	1.00	3.42	3.14	0.11	3.42
78.61	12.18	0.13	0.96	0.10	0.91	3.58	3.35	0.16	2.58
79.00	12.02	0.08	1.02	0.12	0.93	3.46	3.22	0.15	2.54
78.47	12.20	0.08	1.03	n.d.	0.92	3.51	3.65	0.13	0.94
78.75	11.94	0.19	1.18	0.06	0.92	3.16	3.64	0.15	1.86
78.14	12.16	0.08	0.99	0.10	0.89	3.79	3.70	0.15	0.67
78.38	12.19	0.13	0.95	0.11	0.96	3.55	3.63	0.10	2.73
77.69	12.27	0.14	1.17	0.14	1.08	3.64	3.75	0.12	1.84
78.20	12.27	0.12	1.06	0.08	0.93	3.50	3.68	0.14	2.28
77.98	12.31	0.12	1.11	0.13	1.01	3.47	3.72	0.15	1.36
78.48	12.15	0.12	1.03	0.11	0.93	3.49	3.55	0.14	1.76
14	0.39	0.11	0.03	0.09	0.02	0.07	0.17	0.19	0.02

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
06804 T.P.farm track-D (unknown/Kaingaroa ?): (mtb) (pkrsch)										
78.63	12.13	0.13	1.22	0.07	0.81	3.38	3.46	0.17	4.22	
78.45	12.30	0.08	1.29	0.07	0.68	3.39	3.58	0.16	5.23	
78.96	12.09	n.d.	1.23	0.07	0.71	3.34	3.42	0.18	4.77	
78.77	12.08	0.11	1.20	0.08	0.82	3.26	3.49	0.20	4.79	
78.56	12.04	0.11	1.09	n.d.	0.72	3.64	3.70	0.15	3.72	
78.04	12.46	0.17	1.01	0.08	0.80	3.80	3.45	0.19	3.73	
78.12	12.36	0.24	1.18	0.19	1.09	3.48	3.19	0.15	2.89	
78.34	12.50	0.25	1.44	0.20	0.77	3.19	3.10	0.21	4.66	
78.60	12.03	0.27	1.05	0.15	1.02	3.36	3.33	0.19	5.06	
78.31	12.36	0.13	1.31	0.07	0.93	3.45	3.27	0.17	4.38	
78.48	12.24	0.16	1.20	0.11	0.83	3.43	3.40	0.18	4.34	
10 0.28	0.18	0.07	0.13	0.05	0.14	0.18	0.18	0.02	0.72	
? 76.95	13.05	0.21	1.23	0.18	1.25	3.82	3.12	0.19	8.99	
? 76.67	12.63	0.13	1.52	0.09	0.99	4.08	3.66	0.24	7.07	

06805 T.P.farm track-C (unknown/Torere-O ?): (total) (pkrsch)										
77.74	12.63	0.12	1.13	0.14	0.88	3.27	3.96	0.14	4.78	
76.86	13.21	0.10	1.09	0.11	0.99	3.69	3.76	0.18	9.32	
76.89	12.90	0.29	1.16	0.21	1.18	3.47	3.76	0.15	9.27	
77.29	12.89	0.20	1.08	0.15	1.18	3.53	3.49	0.18	9.67	
77.27	12.87	0.19	1.26	0.16	1.09	3.58	3.38	0.19	6.78	
77.87	12.56	0.21	1.11	0.21	1.07	3.50	3.34	0.14	4.75	
77.10	13.01	0.18	1.13	0.19	1.11	3.39	3.70	0.18	6.23	
77.48	12.98	0.11	1.04	0.13	0.87	3.33	3.89	0.17	9.53	
77.38	12.81	0.19	1.28	0.17	1.08	3.54	3.34	0.21	9.32	
77.81	12.55	0.19	1.10	0.16	1.13	3.44	3.46	0.17	4.07	
77.21	12.88	0.26	1.18	0.18	1.07	3.44	3.54	0.23	7.69	
77.67	12.63	0.15	0.95	0.15	1.09	3.32	3.84	0.20	6.39	
78.16	12.62	0.11	0.99	0.09	0.85	3.28	3.68	0.21	7.45	
77.44	12.81	0.18	1.12	0.16	1.05	3.45	3.63	0.18	7.33	
13 0.39	0.20	0.06	0.09	0.04	0.11	0.13	0.21	0.03	2.01	
b 76.68	13.14	0.24	1.47	0.23	1.38	3.48	3.25	0.14	4.55	
b 76.12	13.36	0.20	1.48	0.17	1.22	3.52	3.78	0.15	8.08	
76.40	13.25	0.22	1.47	0.20	1.30	3.50	3.51	0.14	6.31	
2 0.39	0.16	0.03	0.01	0.04	0.12	0.03	0.37	0.01	2.50	

site 77 = Waihapokopoko Bridge (X15/155634)

07701 Torere School: (mtb) (pkrsch)										
78.65	12.17	0.20	1.22	0.17	1.38	2.92	3.02	0.28	6.25	
78.73	12.31	0.19	1.10	0.26	1.33	2.84	3.08	0.16	5.95	
78.44	12.22	0.13	1.18	0.21	1.34	2.84	3.48	0.16	7.48	
78.17	12.56	0.32	1.23	0.18	1.33	3.02	3.03	0.17	6.50	
78.92	11.84	0.13	1.15	0.22	1.29	2.85	3.38	0.22	7.17	
78.75	12.10	0.21	0.98	0.22	1.33	2.99	3.35	0.09	7.97	
78.30	12.42	0.20	1.06	0.19	1.29	3.09	3.33	0.12	6.42	
78.61	12.20	0.16	1.00	0.20	1.26	2.97	3.48	0.11	7.28	
78.50	12.41	0.23	1.13	0.22	1.24	2.90	3.31	0.08	7.73	
78.04	12.62	0.26	1.16	0.20	1.24	2.85	3.45	0.17	7.24	
78.51	12.29	0.20	1.12	0.21	1.30	2.93	3.29	0.15	7.00	
10 0.28	0.23	0.06	0.09	0.02	0.05	0.09	0.18	0.06	0.68	

07702 Rotoliti: (mtb) (pkrsch)										
78.88	12.09	0.09	0.95	0.18	0.88	3.62	3.18	0.13	3.31	
79.09	12.14	0.16	0.90	0.11	0.88	3.24	3.35	0.14	2.02	
78.55	12.32	0.18	0.99	0.15	0.88	3.55	3.21	0.18	3.07	
79.05	12.32	0.11	0.91	0.13	0.84	3.25	3.25	0.14	3.00	
78.58	12.36	0.17	0.92	0.14	0.88	3.47	3.32	0.14	2.50	
78.69	12.16	0.13	0.80	0.15	0.84	3.78	3.32	0.13	1.36	
78.88	12.19	0.17	0.90	0.17	0.87	3.42	3.23	0.18	4.12	
78.79	12.30	0.15	0.94	0.14	0.93	3.29	3.31	0.12	2.55	
78.95	12.18	0.15	0.92	0.13	0.90	3.31	3.31	0.14	3.22	
78.79	12.18	0.16	0.89	0.14	0.81	3.54	3.37	0.11	2.92	
78.62	12.33	0.13	0.82	0.18	0.84	3.58	3.35	0.16	3.32	
78.49	12.16	0.09	0.90	0.12	0.90	3.83	3.35	0.16	3.36	
78.78	12.23	0.14	0.90	0.14	0.90	3.49	3.30	0.15	2.90	
12 0.20	0.09	0.03	0.05	0.03	0.05	0.20	0.06	0.02	0.71	

site 78(A) = Wilson's farm-(1) (V15/384618)

07801 Matahina Ignimbrite: unwelded: (mtb) (integr)										
78.60	11.66	0.25	0.98	0.11	0.84	3.70	3.67	0.18	4.13	
78.65	12.11	0.17	0.94	0.11	0.96	3.48	3.42	0.17	3.89	
78.31	11.90	0.11	1.07	0.10	0.88	3.73	3.64	0.27	2.35	
77.98	12.11	0.22	1.07	0.12	0.85	3.75	3.62	0.27	1.74	
78.38	11.77	0.20	0.93	0.14	0.79	3.97	3.70	0.12	2.98	
77.49	12.40	0.09	1.08	0.10	0.88	3.83	3.83	0.30	2.90	
77.28	12.74	0.27	1.12	0.12	1.04	3.68	3.63	0.11	2.81	
77.75	12.46	0.19	0.95	0.08	0.93	3.72	3.69	0.22	3.60	
77.97	12.20	0.19	1.10	0.15	0.92	3.67	3.56	0.23	2.53	
77.47	12.62	0.20	1.06	0.11	0.91	3.66	3.66	0.23	1.38	
77.93	12.20	0.19	1.03	0.12	0.90	3.72	3.64	0.21	2.83	
10 0.49	0.37	0.05	0.07	0.02	0.07	0.13	0.10	0.06	0.88	
? 78.51	11.79	0.25	1.12	0.13	0.86	3.86	3.19	0.29	2.94	

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
07802 Kohiaawa-3: (mtb) (integr)										
a 77.32	12.70	n.d.	1.06	0.11	0.83	3.25	4.47	0.28	5.56	
a 77.79	12.18	0.20	0.97	0.12	0.88	3.17	4.33	0.35	6.09	
a 77.68	12.04	0.17	1.11	0.19	0.81	3.00	4.76	0.24	4.76	
a 77.80	12.41	0.15	1.14	0.09	0.73	2.86	4.59	0.21	4.63	
a 77.26	12.49	0.12	1.17	0.12	0.88	3.23	4.43	0.30	5.48	
a 77.40	12.36	0.17	1.13	0.12	0.79	3.27	4.46	0.31	5.41	
a 77.53	12.39	0.18	1.03	0.16	0.91	2.89	4.68	0.22	5.60	
a 77.92	12.00	0.17	1.09	0.21	0.87	2.93	4.49	0.32	3.11	
a 77.40	12.33	0.18	1.12	0.15	1.01	2.89	4.56	0.35	6.19	
77.57	12.32	0.17	1.09	0.14	0.86	3.05	4.53	0.29	5.20	
9 0.24	0.22	0.03	0.06	0.04	0.08	0.17	0.13	0.05	0.94	
b 77.62	12.42	n.d.	0.82	0.06	0.62	3.16	4.93	0.36	6.45	
b 77.61	12.50	0.13	0.87	0.11	0.59	3.23	4.65	0.32	5.21	
b 77.86	12.39	n.d.	0.84	0.11	0.51	3.27	4.69	0.33	6.15	
b 77.66	12.46	0.07	0.87	0.06	0.64	2.87	5.03	0.33	5.39	
b 77.76	12.22	0.16	0.84	n.d.	0.65	3.06	4.95	0.36	5.13	
b 77.79	12.36	0.13	0.99	0.06	0.62	2.99	4.81	0.25	4.72	
b 77.50	12.46	0.15	0.88	0.08	0.71	2.98	4.90	0.35	6.68	
77.68	12.40	0.13	0.87	0.08	0.62	3.08	4.85	0.33	5.68	
7 0.12	0.09	0.03	0.05	0.02	0.06	0.15	0.14	0.04	0.75	
? 78.14	12.29	0.13	0.49	0.10	0.92	2.95	4.69	0.29	5.79	
? 77.27	12.45	0.13	1.00	0.09	0.73	3.31	4.67	0.36	7.13	
? 77.95	12.53	0.08	0.59	0.08	0.72	3.24	4.57	0.23	5.43	

07803 Tablelands-C: (mtb) (integr)										
78.39	12.06	0.13	0.76	0.11	0.60	3.16	4.67	0.13	6.07	
77.42	12.56	0.22	0.82	0.08	0.64	3.35	4.75	0.16	2.56	
77.44	12.41	0.16	0.89	0.05	0.57	3.29	5.01	0.19	3.28	
77.91	11.95	0.14	0.87	0.06	0.54	3.41	4.94	0.18	4.33	
77.13	12.97	0.14	0.73	n.d.	0.63	3.49	4.64	0.25	3.27	
77.96	12.12	n.d.	0.88	0.04	0.56	3.39	4.81	0.23	3.82	
77.92	12.14	0.09	0.69	0.05	0.62	3.58	4.66	0.24	3.76	
77.46	12.48	0.24	0.60	0.12	0.57	3.47	4.81	0.25	2.98	
77.46	12.57	0.17	0.77	0.08	0.55	3.34	4.96	0.10	3.86	
78.19	11.83	0.27	0.73	0.05	0.60	3.64	4.54	0.14	5.13	
77.94	12.81	0.10	0.88	0.07	0.65	3.45	4.93	0.17	5.79	
77.75	12.26	0.16	0.78	0.08	0.59	3.42	4.79	0.18	4.08	
11 0.39	0.36	0.06	0.09	0.02	0.04	0.13	0.15	0.05	1.14	

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water

site 79 = Newdicks Beach (V14/159781)

07901 Mamaku Ignimbrite (?): unwelded top: (mtx) (pkrsch)										
78.65	11.89	n.d.	1.13	n.d.	0.73	3.62	3.75	0.22	1.93	
79.09	11.65	0.13	1.01	0.07	0.67	3.28	3.88	0.22	2.02	
78.58	11.52	0.13	1.17	0.06	0.72	3.62	3.97	0.22	1.75	
78.57	11.66	0.09	1.28	0.07	0.63	3.56	3.89	0.25	1.31	
78.91	11.56	0.10	1.13	0.09	0.61	3.56	3.82	0.21	1.68	
78.91	11.71	0.16	1.05	0.06	0.68	3.51	3.73	0.18	2.41	
78.73	11.70	0.17	1.17	0.06	0.65	3.45	3.85	0.21	1.74	
78.68	11.73	0.17	1.00	0.08	0.73	3.31	3.97	0.32	1.91	
78.96	11.79	0.12	1.11	n.d.	0.67	3.44	3.69	0.21	1.86	
78.87	11.79	0.11	1.09	0.10	0.63	3.36	3.83	0.22	2.00	
78.74	11.79	0.11	1.07	n.d.	0.66	3.47	3.98	0.18	1.52	
78.84	11.70	0.13	1.30	n.d.	0.64	3.51	3.64	0.23	1.76	
78.21	12.13	0.14	1.04	0.07	0.66	3.90	3.67	0.17	2.66	
79.10	11.63	0.09	1.10	n.d.	0.65	3.47	3.80	0.17	2.46	
78.77	11.73	0.13	1.12	0.07	0.67	3.50	3.82	0.22	1.93	
14	0.23	0.15	0.03	0.09	0.01	0.04	0.16	0.11	0.04	0.37
? 80.61 11.79 0.13 0.78 0.07 0.64 3.35 2.43 0.20 5.25										

site 80 = Rangitawa Stream (Wanganui basin) (O6/636365)

08001 Rangitawa: (mtx+) (pkrsch)										
77.96	12.08	0.13	1.08	0.10	0.84	3.28	4.27	0.25	3.43	
77.82	12.23	0.18	1.01	0.14	0.73	3.22	4.40	0.27	3.11	
77.69	12.36	0.12	1.16	0.09	0.83	3.10	4.38	0.27	3.19	
78.11	12.10	0.14	1.12	0.12	0.89	3.23	3.99	0.30	2.06	
77.87	12.25	0.18	1.00	0.12	0.80	3.20	4.30	0.28	2.94	
77.78	12.35	0.17	0.97	0.13	0.86	3.24	4.26	0.24	3.48	
77.96	12.19	0.12	1.09	0.12	0.78	3.20	4.24	0.28	2.89	
78.19	12.06	0.14	1.11	0.16	0.84	3.13	4.10	0.27	2.36	
78.02	12.15	0.16	1.02	0.16	0.80	3.23	4.22	0.25	3.38	
78.08	12.39	0.15	1.11	0.11	0.85	3.02	4.07	0.23	4.34	
77.91	12.41	0.15	1.02	0.08	0.86	3.21	4.14	0.22	3.49	
78.15	12.21	0.14	1.01	0.11	0.81	3.13	4.21	0.23	2.62	
77.87	12.30	0.08	1.06	0.13	0.76	3.24	4.36	0.20	1.78	
77.95	12.24	0.14	1.06	0.12	0.82	3.19	4.23	0.25	3.01	
13	0.15	0.12	0.02	0.06	0.02	0.04	0.07	0.12	0.03	0.68

site 82 = Waipunga (V19/147446)

08201 Te Whaiti Ignimbrite: unwelded base: (mtx) (pkrsch)										
76.90	12.85	n.d.	1.04	0.13	0.88	3.40	4.55	0.25	6.79	
76.37	13.10	0.10	1.06	0.11	0.88	3.53	4.59	0.26	8.24	
75.90	13.09	0.17	1.21	0.14	0.89	3.57	4.77	0.27	9.79	
76.55	12.60	0.16	1.27	0.17	0.94	3.48	4.41	0.42	4.31	
76.02	12.86	0.13	1.15	0.11	0.92	3.62	4.92	0.26	8.80	
76.73	12.69	0.14	1.19	0.16	0.86	3.31	4.69	0.24	5.73	
76.25	12.96	0.14	1.10	0.15	0.93	3.38	4.94	0.28	9.60	
77.84	12.09	0.09	1.18	0.12	0.80	3.17	4.50	0.21	0.54	
77.48	12.32	0.13	1.03	0.15	0.80	3.21	4.65	0.23	2.55	
76.67	12.73	0.13	1.14	0.14	0.88	3.41	4.67	0.27	6.26	
9	0.65	0.35	0.03	0.09	0.02	0.05	0.16	0.18	0.06	3.26

site 83 = Wilson's farm-(5) (V15/384620)

08301 Ohinekoao-J: (crs-ash) (pkrsch)										
76.92	12.97	0.14	1.43	0.16	1.28	3.50	3.50	0.11	5.11	
77.41	13.06	0.12	1.48	0.08	1.25	2.88	3.73	n.d.	5.28	
77.03	13.02	0.19	1.46	0.15	1.24	3.12	3.67	0.14	3.75	
77.52	12.99	0.18	1.27	0.15	1.27	2.85	3.67	0.09	4.71	
77.72	12.89	0.17	1.51	0.17	1.29	2.91	3.21	0.13	4.89	
75.98	13.40	0.13	1.48	0.15	1.32	3.74	3.67	0.13	7.99	
77.24	12.90	0.15	1.51	0.16	1.28	2.91	3.67	0.18	4.17	
77.21	13.08	0.16	1.52	0.19	1.24	2.95	3.50	0.16	4.79	
76.79	13.20	0.20	1.40	0.17	1.32	3.28	3.48	0.16	3.87	
77.38	12.95	0.10	1.46	0.17	1.31	3.02	3.47	0.13	4.12	
76.92	12.86	0.10	1.43	0.18	1.32	3.58	3.50	0.12	4.44	
77.45	12.95	0.15	1.48	0.14	1.26	3.03	3.42	0.13	4.71	
77.04	12.65	0.13	1.61	0.14	1.30	3.55	3.50	0.08	2.27	
78.08	12.62	0.10	1.26	0.12	1.19	2.98	3.50	0.14	3.20	
77.19	12.97	0.14	1.45	0.15	1.28	3.16	3.54	0.13	4.52	
14	0.49	0.20	0.03	0.09	0.03	0.04	0.30	0.14	0.03	1.28
? 76.69 13.17 0.17 1.70 0.20 1.35 3.10 3.46 0.15 2.58										

08302 reworked(?) Ohinekoao-I: (pum) (integr)										
74.51	13.97	0.38	2.34	0.40	2.17	3.44	2.65	0.15	5.00	
73.88	14.06	0.43	2.11	0.51	2.45	3.85	2.52	0.19	4.72	
75.50	12.73	0.30	2.16	0.40	2.16	3.54	2.96	0.26	6.83	
75.45	12.90	0.30	2.06	0.39	2.34	3.87	2.70	n.d.	4.09	
74.87	13.73	0.34	1.88	0.45	2.22	3.45	2.90	0.17	6.25	
74.83	14.15	0.29	2.16	0.38	2.04	3.36	2.64	0.15	6.47	
74.95	13.44	0.34	2.00	0.37	2.00	3.77	2.91	0.23	8.12	
74.75	14.02	0.34	1.94	0.39	1.74	3.62	3.10	0.10	2.55	
74.93	13.81	0.28	1.84	0.43	2.08	3.66	2.84	0.13	4.65	
74.21	13.96	0.23	2.09	0.40	2.14	3.87	2.86	0.24	8.01	
74.72	14.11	0.26	2.04	0.53	1.91	3.53	2.73	0.17	9.94	
74.21	14.09	0.35	2.08	0.40	2.06	3.74	2.85	0.21	8.32	
74.18	13.73	0.41	1.93	0.32	2.15	4.11	2.92	0.25	9.64	
74.69	13.75	0.33	2.05	0.41	2.11	3.68	2.81	0.19	6.51	
13	0.48	0.46	0.06	0.13	0.06	0.18	0.21	0.16	0.05	2.24
? 72.67 14.40 0.39 2.35 0.60 2.79 3.72 2.88 0.21 8.32										
? 75.19 13.48 0.30 1.66 0.36 2.23 3.71 2.99 0.07 6.56										
? 71.72 15.18 0.49 2.35 0.73 2.83 3.99 2.52 0.19 6.98										

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water

08303 Ohinekoao-K: (pum) (integr)

76.17	13.19	0.21	1.43	0.27	1.30	3.57	3.56	0.30	10.62	
75.69	13.50	0.21	1.50	0.23	1.40	3.67	3.57	0.23	9.79	
76.66	12.96	0.15	1.41	0.11	1.33	3.54	3.58	0.25	8.75	
75.75	13.34	0.24	1.68	0.19	1.40	3.64	3.55	0.21	8.54	
76.41	13.11	0.21	1.38	0.18	1.29	3.50	3.69	0.23	10.06	
76.25	13.17	0.22	1.53	0.20	1.34	3.45	3.59	0.25	8.95	
76.06	13.26	0.17	1.44	0.15	1.46	3.66	3.51	0.29	9.20	
76.43	13.30	0.14	1.29	0.18	1.32	3.68	3.52	0.14	9.17	
76.20	13.30	0.20	1.42	0.24	1.45	3.36	3.58	0.23	9.88	
75.49	13.47	0.19	1.67	0.20	1.34	3.67	3.69	0.27	10.92	
76.51	12.94	0.15	1.48	0.24	1.46	3.58	3.44	0.22	8.01	
76.22	13.24	0.11	1.26	0.22	1.41	3.51	3.78	0.25	9.00	
76.17	13.26	0.10	1.54	0.17	1.33	3.57	3.65	0.21	8.40	
76.15	13.23	0.18	1.46	0.20	1.37	3.57	3.59	0.24	9.33	
13	0.34	0.17	0.04	0.12	0.04	0.06	0.09	0.04	0.87	
? 76.38 13.35 0.23 1.45 0.20 1.14 3.60 3.43 0.22 9.66										

08304 Ohinekoao-I (mtx+pum) (integr)

74.58	13.68	0.36	1.75	0.31	2.13	3.99	2.94	0.26	4.26	
74.65	13.71	0.37	1.94	0.38	2.19	3.93	2.69	0.15	4.41	
75.10	13.80	0.23	1.88	0.25	2.36	3.60	2.68	0.10	3.69	
74.17	14.05	0.35	2.03	0.38	2.18	3.77	2.86	0.22	3.33	
74.68	13.76	0.28	1.99	0.38	2.16	3.77	2.82	0.15	4.37	
74.76	13.96	0.26	1.90	0.40	2.02	3.63	2.86	0.22	4.29	
74.39	13.87	0.38	2.11	0.32	2.28	3.61	2.83	0.21	3.59	
74.23	13.85	0.29	2.11	0.41	2.23	3.69	3.00	0.20	2.94	
74.57	14.03	0.20	2.01	0.40	2.21	3.63	2.74	0.23	3.86	
74.27	14.07	0.28	2.22	0.39	2.22	3.68	2.63	0.24	3.12	</

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water

site 85 = Ohiwa Loop Road (W15/739466)

08501 Torere-C: (mtb) (integr)

78.72	11.96	0.15	1.01	0.15	0.82	3.23	3.79	0.17	5.22
78.00	12.92	0.10	0.88	0.10	0.83	3.13	3.93	0.10	3.33
77.53	12.63	0.11	1.29	0.15	0.93	3.23	3.98	0.14	2.80
78.08	12.25	0.20	1.04	0.11	0.94	3.45	3.85	0.07	5.01
77.85	12.34	0.15	1.24	0.10	0.83	3.51	3.83	0.15	3.47
77.58	13.24	0.15	1.00	0.10	0.73	3.28	3.71	0.21	4.00
77.97	12.30	0.26	0.89	0.11	0.84	3.50	3.95	0.17	3.89
78.67	11.99	0.12	0.96	0.18	0.77	3.15	3.92	0.23	5.45
77.75	12.73	0.09	1.09	0.13	0.95	3.29	3.77	0.21	9.32
78.04	12.22	0.19	1.11	0.06	0.83	3.52	3.95	0.09	4.25
78.41	12.10	0.22	1.12	0.11	1.04	3.02	3.91	0.07	6.33
77.84	12.69	0.18	1.19	0.09	0.79	3.14	3.90	0.19	5.01
78.04	12.45	0.16	1.07	0.12	0.86	3.29	3.87	0.15	4.84
12	0.39	0.39	0.05	0.13	0.03	0.09	0.17	0.08	0.05

08502 Huntress-F: (mtb) (integr)

77.07	12.33	0.13	1.19	0.21	0.82	4.15	3.89	0.21	6.47
77.74	12.22	0.14	1.11	0.11	0.90	3.81	3.66	0.31	8.51
77.44	12.49	0.19	1.19	0.05	0.94	3.92	3.57	0.21	8.42
77.18	12.42	0.22	1.28	0.17	0.98	3.77	3.72	0.25	7.28
77.65	12.23	0.12	1.11	0.10	0.83	3.96	3.76	0.24	8.17
77.79	12.18	0.07	1.15	0.09	0.81	4.08	3.68	0.14	4.94
78.05	12.14	0.13	1.17	0.09	0.94	3.72	3.50	0.27	6.74
77.70	12.34	0.17	0.94	0.11	0.84	3.89	3.78	0.23	5.20
77.90	12.15	0.08	0.98	0.18	0.91	3.92	3.65	0.22	5.37
77.35	12.16	0.18	1.38	0.07	0.78	3.83	3.99	0.26	6.44
77.86	12.30	0.16	1.09	0.19	0.81	3.62	3.72	0.25	5.84
77.61	12.27	0.14	1.15	0.13	0.87	3.88	3.72	0.24	6.67
11	0.31	0.12	0.04	0.12	0.06	0.07	0.15	0.14	0.04

b	76.16	13.09	0.27	1.52	0.15	1.09	4.17	3.31	0.23	8.19
b	76.24	13.17	0.15	1.37	0.18	1.20	4.16	3.32	0.21	8.95
b	76.91	12.68	0.20	1.26	0.13	1.13	3.90	3.61	0.18	7.80
b	76.64	12.68	0.21	1.59	0.13	1.23	3.88	3.43	0.22	7.39
b	76.55	12.75	0.23	1.54	0.20	1.09	3.87	3.52	0.24	5.90
	76.50	12.87	0.21	1.46	0.16	1.15	4.00	3.44	0.22	7.65
s	0.31	0.24	0.04	0.14	0.03	0.06	0.16	0.13	0.02	1.13

08503 Huntress-D: (mtb) (integr)

78.31	12.26	n.d.	1.09	0.11	0.88	3.59	3.58	0.18	4.26	
78.17	12.08	0.18	1.28	0.05	0.89	3.56	3.59	0.20	3.88	
77.92	12.30	0.18	1.30	0.08	0.85	3.44	3.73	0.20	4.49	
77.98	12.18	0.14	1.23	0.12	0.84	3.58	3.69	0.24	4.87	
77.46	12.26	0.14	1.41	0.10	0.84	3.65	3.94	0.20	3.82	
77.75	12.64	0.09	1.19	0.08	0.85	3.65	3.52	0.22	5.11	
78.04	12.12	0.17	1.14	0.14	0.98	3.33	3.88	0.19	5.53	
77.76	12.48	0.14	1.27	0.07	0.86	3.53	3.70	0.19	4.80	
77.94	12.39	0.09	1.21	0.07	0.86	3.51	3.80	0.13	4.77	
77.73	12.67	0.14	1.19	0.15	0.99	3.33	3.59	0.21	6.38	
77.91	12.34	0.14	1.23	0.10	0.89	3.52	3.70	0.20	4.79	
10	0.24	0.20	0.03	0.09	0.03	0.06	0.12	0.14	0.03	0.77
?	78.16	12.16	0.16	1.09	0.17	1.19	3.45	3.48	0.15	4.79

08504 Huntress-B: (pum) (integr)

77.86	12.19	0.18	1.42	0.18	0.94	3.68	3.39	0.17	3.68	
77.82	12.43	0.07	1.43	0.13	1.06	3.67	3.19	0.20	4.82	
78.12	12.47	0.19	1.14	n.d.	0.76	3.54	3.61	0.17	5.76	
77.69	12.80	0.11	1.12	0.16	0.89	3.50	3.51	0.22	7.16	
77.60	12.36	0.16	1.32	0.14	0.85	3.62	3.65	0.31	4.44	
77.60	12.43	0.20	1.28	0.10	1.06	3.91	3.22	0.19	4.20	
77.96	12.04	0.10	1.26	0.14	0.83	3.61	3.81	0.26	4.40	
77.43	12.64	0.18	1.24	0.05	1.08	3.85	3.36	0.16	5.95	
77.71	12.35	0.08	1.22	0.11	0.81	3.77	3.71	0.23	5.43	
77.74	12.60	0.10	1.26	0.13	0.82	3.32	3.83	0.19	6.37	
77.50	12.69	0.08	1.13	0.17	0.94	3.74	3.53	0.23	7.16	
77.31	12.78	0.14	1.23	0.11	1.00	3.81	3.40	0.21	6.68	
78.36	12.36	n.d.	1.29	0.05	0.83	3.48	3.46	0.17	5.75	
77.86	12.39	n.d.	1.25	0.13	0.92	3.34	3.92	0.19	6.36	
77.20	12.53	0.15	1.27	0.14	1.00	3.95	3.56	0.21	5.32	
77.23	12.78	0.10	1.42	0.13	0.93	3.73	3.48	0.20	5.78	
77.69	12.49	0.13	1.27	0.12	0.92	3.66	3.54	0.21	5.58	
16	0.32	0.22	0.04	0.10	0.04	0.10	0.19	0.21	0.04	1.05
?	77.12	12.64	0.16	1.57	0.14	1.01	3.55	3.61	0.19	5.39

08505 Rotoli: (mtb) (integr)

78.26	12.52	0.10	0.73	0.13	0.78	3.95	3.36	0.17	1.21	
77.81	12.38	0.13	1.06	0.17	0.96	3.91	3.43	0.14	3.24	
77.95	12.33	0.08	1.13	0.17	0.88	3.93	3.39	0.15	0.78	
77.75	12.67	0.13	0.99	0.14	0.87	3.71	3.45	0.29	4.68	
77.79	12.75	0.19	0.93	0.16	0.81	3.95	3.28	0.14	4.10	
77.91	12.53	0.13	0.97	0.15	0.86	3.89	3.38	0.18	2.80	
5	0.21	0.18	0.04	0.15	0.02	0.07	0.10	0.07	0.07	1.73

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water

08506 Kaingaroa: (mtb) (integr)

77.42	12.45	0.16	1.37	0.13	0.86	3.53	3.82	0.27	7.06	
77.61	12.49	0.14	1.10	0.11	0.87	3.73	3.78	0.18	7.03	
77.32	12.60	0.16	1.25	0.08	0.89	3.78	3.65	0.26	7.24	
77.37	12.56	0.20	1.03	0.14	0.80	3.83	3.90	0.17	5.83	
77.49	12.48	0.09	1.33	0.07	0.87	3.91	3.51	0.25	4.49	
77.26	12.56	0.22	1.10	0.13	0.89	3.81	3.82	0.22	5.23	
76.91	12.73	0.17	1.27	0.16	0.87	4.02	3.64	0.22	6.16	
78.39	11.86	0.15	1.34	0.09	0.82	3.46	3.75	0.15	3.69	
77.12	12.29	0.24	1.28	0.16	0.89	3.93	3.80	0.29	7.09	
77.54	12.62	0.15	1.15	0.12	0.73	3.55	3.96	0.18	6.36	
77.31	12.64	0.10	1.18	0.10	0.93	3.54	3.93	0.28	7.07	
77.59	12.42	0.25	1.25	0.11	0.82	3.58	3.78	0.20	6.99	
76.99	12.74	0.20	1.19	0.10	0.85	3.77	3.95	0.21	6.03	
77.41	12.50	0.17	1.22	0.11	0.85	3.73	3.79	0.22	6.17	
13	0.37	0.23	0.05	0.10	0.03	0.05	0.18	0.13	0.05	1.12
?	75.59	13.30	0.20	1.62	0.12	1.12	4.04	3.76	0.25	4.98
?	77.20	12.42	0.19	1.22	0.23	1.27	3.76	3.45	0.26	3.56

site 86 = Omokoroa slump (U14/789922)

08601 unknown ignimbrite II: (mtb+) (integr)

a	77.46	12.38	0.16	1.29	0.17	1.03	3.63	3.62	0.25	6.74
a	77.23	12.52	0.12	1.41	0.12	0.85	3.62	3.77	0.37	5.58
a	77.31	12.55	0.15	1.22	0.17	0.83	3.85	3.54	0.36	6.56
a	77.45	12.49	0.14	1.13	0.17	1.02	3.64	3.70	0.26	6.81
a	76.82	12.44	0.19	1.32	0.17	1.17	3.90	3.70	0.28	6.30
a	77.48	12.44	0.16	1.11	0.14	0.93	3.96	3.52	0.27	6.05
a	77.51	12.34	0.11	1.33	0.15	1.15	3.58	3.58	0.26	7.20
a	77.39	12.30	0.26	1.41	0.15	0.96	3.65	3.60	0.27	5.11
	77.33	12.43	0.16	1.28	0.15	0.99	3.73	3.63	0.29	6.29
8	0.23	0.09	0.05	0.12	0.02	0.13	0.15	0.09	0.05	0.69
b	77.36	12.65	0.14	1.05	0.07	0.75	3.64	3.99	0.33	6.12
b	77.07	12.40	0.24	1.11	0.17	0.70	3.66	4.34	0.31	5.92
b	77.23	12.67	0.09	0.91	0.11	0.68	3.76	4.18	0.38	6.72
b	77.65	12.50	n.d.	1.03	0.10	0.70	3.71	3.99	0.31	4.27
b	77.47	12.20	0.23	1.14	0.16	0.80	3.49	4.24	0.26	5.35
	77.36	12.49	0.18	1.05	0.12	0.73	3.65	4.15	0.32	5.68
5	0.22	0.19	0.08	0.09	0.04	0.05	0.10	0.15	0.04	0.93
?	77.55	12.71	0.07	1.02	0.13	0.82	3.77	3.66	0.27	6.58

site 87 = Omokoroa East (U14/790899)

08701 Waimakariri: (above or instead of igb.): (mtb) (integr)

76.35	13.04	0.25	1.46	0.22	1.01	3.96	3.60	0.11	4.81
77.22	12.53	0.27	1.35	0.21	1.16	3.98	3.13	0.15	6.75
76.27	13.07	0.31	1.53	0.18	1.21	3.87	3.26	0.29	5.97
76.61	12.66	0.31	1.59	0.15	1.21	3.71	3.62	0.13	7.61
76.31	12.73	0.18	1.58	0.26	1.11	4.06	3.46	0.32	5.94
76.11	13.34	0.20	1.71	0.22	1.19	3.73	3.21	0.26	5.43
76.40	13.31	0.31	1.54	0.13	1.20	3.60	3.30	0.21	7.77
77.10	12.52	0.20	1.48	0.20	1.19	3.74	3.36	0.20	5.41
76.70	12.53	0.46	1.70	0.18	1.15	3.45	3.64	0.18	8.01
76.57	12.86	0.28	1.55	0.20	1.16	3.79	3.40	0.21	6.41
9	0.38	0.34	0.08	0.11	0.04	0.07	0.20	0.19	0.07
?	75.47	13.27	0.25	1.98	0.14	1.17	4.06	3.44	0.21
?	78.19	12.24	0.18	1.11	0.12	0.92	3.27	3.76	0.20

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
08704 Kutarere (?): (mtb) (integr)										
77.20	12.23	0.15	1.17	0.09	0.74	4.13	4.01	0.27	5.16	
77.14	12.20	0.11	1.25	0.12	0.84	4.10	3.96	0.27	2.90	
77.57	12.12	0.21	1.19	0.10	0.77	3.97	3.78	0.29	2.58	
77.85	11.93	0.18	1.24	0.13	0.65	3.87	3.89	0.25	3.37	
78.16	11.91	0.15	1.11	0.07	0.62	3.90	3.86	0.21	1.68	
77.60	11.92	0.19	1.27	0.09	0.62	4.08	4.06	0.18	3.84	
77.63	12.07	0.15	1.25	0.12	0.86	3.77	3.88	0.27	2.39	
78.16	12.07	0.11	1.07	0.08	0.55	3.99	3.70	0.27	3.47	
77.95	12.08	0.08	1.16	0.06	0.65	3.87	3.87	0.28	2.86	
77.87	12.45	0.08	1.08	0.09	0.63	3.78	3.86	0.16	4.58	
77.71	12.10	0.14	1.18	0.10	0.69	3.95	3.89	0.24	3.28	
10	0.36	0.17	0.04	0.07	0.03	0.10	0.13	0.10	0.05	1.04

08705 Huntress-D (?): (mtb) (integr)										
78.24	12.08	0.09	1.24	0.12	0.68	3.67	3.68	0.20	5.05	
78.44	12.18	0.22	1.04	n.d.	0.72	3.37	3.82	0.21	4.67	
78.32	12.11	n.d.	1.34	0.18	0.82	3.39	3.60	0.24	3.86	
78.21	12.17	n.d.	1.22	0.14	0.94	3.40	3.74	0.18	5.26	
78.51	12.10	0.19	1.22	0.14	0.80	3.43	3.45	0.16	5.47	
78.15	12.07	0.15	1.33	0.24	0.75	3.39	3.71	0.22	4.46	
78.40	11.99	n.d.	1.33	0.29	0.75	3.52	3.72	n.d.	3.86	
78.14	12.14	0.14	1.11	0.26	0.84	3.47	3.67	0.23	3.12	
78.74	12.26	0.09	1.08	0.16	0.73	3.38	3.41	0.16	4.33	
78.11	12.30	0.24	1.07	0.12	0.84	3.51	3.65	0.17	4.84	
78.13	12.11	0.08	1.24	0.17	1.00	3.49	3.58	0.20	3.83	
78.75	12.28	0.12	1.14	0.12	0.79	3.25	3.37	0.18	5.98	
78.35	12.15	0.15	1.20	0.17	0.81	3.44	3.62	0.19	4.56	
12	0.23	0.09	0.06	0.11	0.06	0.09	0.10	0.14	0.03	0.82
? 78.47	11.86	0.15	0.88	0.27	0.67	3.33	4.20	0.18	3.79	

site 88 = Welcome Bay (U14/907820)

08801 Kutarere (?): airfall below fluvial; (mtb) (integr)										
77.69	12.14	0.15	1.30	0.07	0.63	3.81	3.98	0.22	5.11	
77.82	12.38	n.d.	1.10	0.10	0.65	3.86	3.89	0.20	4.18	
77.34	12.41	0.27	1.17	0.15	0.63	3.95	3.84	0.24	3.50	
77.49	12.20	0.31	1.13	0.09	0.66	3.89	4.04	0.20	4.15	
77.82	12.19	0.17	1.10	0.07	0.66	3.84	3.88	0.28	4.33	
77.10	12.37	0.21	1.23	0.09	0.78	3.94	4.03	0.25	3.80	
77.78	12.09	0.14	1.17	0.09	0.80	3.92	3.78	0.23	3.78	
78.14	12.13	n.d.	1.24	0.07	0.50	3.89	3.80	0.22	5.15	
77.80	12.17	n.d.	1.17	0.09	0.72	3.83	3.90	0.30	4.63	
77.81	12.16	0.13	1.10	0.09	0.56	3.93	4.02	0.20	4.54	
77.24	12.24	0.22	1.29	0.10	0.79	4.04	3.78	0.31	3.40	
77.64	12.23	0.20	1.18	0.09	0.67	3.90	3.90	0.24	4.23	
11	0.31	0.11	0.07	0.07	0.02	0.10	0.06	0.10	0.04	0.59
? 78.06	12.19	0.17	0.91	0.14	0.70	3.65	3.94	0.24	4.82	

08802 Huntress-B (?) or Kaingaroa (?): (mtb) (integr)										
77.57	12.40	0.30	1.36	0.17	0.84	3.67	3.41	0.27	5.27	
77.64	12.52	n.d.	1.18	0.27	0.85	3.64	3.63	0.27	5.86	
77.49	12.60	0.08	1.10	0.17	0.95	3.91	3.43	0.27	7.56	
77.70	12.36	0.23	1.19	0.12	1.02	3.60	3.56	0.23	7.77	
77.68	12.70	0.11	1.13	0.14	1.00	3.54	3.48	0.22	7.83	
77.29	12.51	0.25	1.14	0.12	0.84	3.85	3.72	0.28	7.51	
77.70	12.46	0.09	1.18	0.16	0.91	3.73	3.57	0.18	7.89	
77.24	12.44	0.28	1.29	0.15	1.00	3.80	3.61	0.18	6.95	
77.60	12.26	0.16	1.22	0.19	0.98	3.74	3.60	0.24	5.92	
78.04	12.15	0.30	1.22	0.14	0.84	3.73	3.33	0.25	7.02	
77.60	12.44	0.20	1.20	0.16	0.92	3.72	3.54	0.24	6.96	
10	0.23	0.16	0.09	0.08	0.04	0.07	0.11	0.12	0.04	0.95
b 77.91	12.20	0.22	0.99	0.18	0.73	3.82	3.76	0.19	5.74	
b 77.51	12.59	0.18	1.02	0.21	0.82	3.66	3.76	0.25	6.84	
b 77.54	12.16	0.13	1.15	0.11	0.68	3.98	4.02	0.22	6.32	
b 78.17	12.24	0.15	0.97	0.13	0.76	3.51	3.88	0.17	8.34	
77.78	12.30	0.17	1.03	0.16	0.75	3.74	3.86	0.21	8.81	
4	0.32	0.20	0.04	0.08	0.05	0.06	0.20	0.13	0.03	1.11
? 78.21	12.31	0.09	1.34	0.17	0.69	3.66	3.29	0.24	4.88	

08803 Huntress-D: (mtb) (integr)										
78.47	12.13	0.14	1.21	0.09	0.90	3.39	3.47	0.20	4.07	
77.82	12.37	0.09	1.32	0.09	0.71	3.53	3.79	0.27	3.46	
77.40	12.92	n.d.	1.37	0.10	0.81	3.58	3.56	0.26	6.55	
78.22	12.00	0.10	1.25	0.17	0.83	3.49	3.62	0.32	3.82	
77.59	12.56	0.12	1.29	0.09	0.81	3.74	3.49	0.32	6.21	
77.17	12.77	0.09	1.29	0.05	0.81	3.93	3.70	0.18	4.24	
77.28	12.44	0.20	1.34	0.09	0.84	3.88	3.75	0.18	2.65	
77.45	12.58	0.09	1.33	0.09	0.69	3.76	3.80	0.21	4.22	
77.70	12.46	0.15	1.30	0.09	0.87	3.57	3.65	0.21	3.77	
77.46	12.90	0.14	1.21	0.10	0.79	3.47	3.71	0.22	4.21	
77.63	12.35	0.11	1.25	0.14	0.76	3.83	3.65	0.27	3.02	
77.65	12.50	0.12	1.29	0.10	0.80	3.65	3.65	0.24	4.20	
11	0.39	0.29	0.03	0.05	0.03	0.06	0.18	0.11	0.05	1.19
? 77.75	12.91	0.12	1.00	0.11	0.72	3.37	3.83	0.20	5.14	

	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	Cl	water
08804 Welcome-F: (mtb) (integr)										
77.35	12.34	0.17	1.13	0.06	0.90	4.08	3.76	0.22	0.45	
76.67	12.46	0.19	1.27	0.12	0.81	4.25	4.02	0.21	3.40	
76.83	12.60	0.18	1.19	0.13	0.72	4.10	4.09	0.21	4.11	
77.30	12.29	0.16	1.21	0.13	0.72	4.13	3.85	0.21	3.60	
77.94	12.23	0.15	1.22	0.12	0.76	3.72	3.63	0.22	0.09	
77.73	12.50	0.17	0.96	0.07	0.87	3.83	3.66	0.21	3.98	
77.72	12.29	0.10	1.04	0.14	0.73	3.83	3.99	0.17	3.95	
77.56	12.46	0.12	1.25	0.19	0.86	3.86	3.49	0.22	4.86	
77.18	12.36	0.14	1.17	0.13	0.72	3.79	4.27	0.23	3.29	
77.71	12.58	n.d.	1.05	0.15	0.81	3.95	3.52	0.23	5.87	
77.40	12.41	0.15	1.15	0.12	0.79	3.96	3.83	0.21	3.36	
10	0.42	0.13	0.03	0.10	0.04	0.07	0.17	0.26	0.02	1.80

b 75.86	12.99	0.21	1.77	0.19	1.14	4.21	3.42	0.21	5.06	
b 75.84	13.14	0.24	1.60	0.19	1.18	4.07	3.58	0.16	6.03	
b 75.93	13.32	0.24	1.47	0.13	1.14	3.94	3.65	0.18	5.04	
b 76.60	12.88	0.21	1.54	0.19	1.03	3.88	3.48	0.18	4.13	
b 77.10	12.88	0.14	1.50	0.17	0.96	3.76	3.37	0.13	6.39	
b 75.86	13.30	0.19	1.55	0.22	1.11	3.90	3.67	0.19	6.48	
76.20	13.09	0.21	1.57	0.18	1.09	3.96	3.53	0.18	5.52	
6	0.53	0.20	0.04	0.11	0.03	0.08	0.16	0.12	0.03	0.93
? 76.72	12.77	0.15	1.27	0.17	1.01	3.98	3.81	0.13	5.72	
? 77.24	12.32	0.10	1.45	0.12	0.82	3.89	3.78	0.27	9.84	
? 76.99	12.65	0.16	1.54	0.12	0.90	3.58	3.85	0.20	4.85	
? 78.00	12.33	n.d.	0.83	0.17	0.76	3.94	3.76	0.20	4.08	
? 77.37	12.38	0.27	1.43	0.14	0.82	3.64	3.79	0.17	4.01	

08805 Huntress-F: (mtb) (integr)										
a 77.77	12.39	0.13	0.97	0.16	0.78	4.20	3.35	0.25	5.03	
a 77.77	12.15	0.12	1.09	0.13	0.75	4.08	3.65	0.27	5.68	
a 77.53	12.32	0.07	1.22	0.18	0.78	4.13	3.54	0.22	6.34	
a 77.33	12.31	0.20	1.19	0.15	0.95	3.93	3.71	0.23	4.68	
a 77.50	12.49	0.17	1.10	0.09	0.85	3.82	3.75	0.22	6.25	
77.58	12.33	0.14	1.11	0.14	0.82	4.03	3.60	0.24	5.60	
5	0.19	0.13	0.05	0.10	0.04	0.08	0.16	0.16	0.02	0.73

b	76.46	13.21	0.21	1.50	0.20	1.18	3.82	3.16	0.27	7.74
b	77.04	12.51	0.28	1.58	0.14	1.06	4.13	3.05	0.27	7.74
b	77.08	13.15	0.24	1.47	0.25	1.11	3.54	2.95	0.20	6.87
b	76.42	13.07	0.28	1.52	0.25	1.29	3.83	3.08	0.28	7.73
b	76.96	13.17	n.d.	1.44	0.19	1.17	3.88	2.92	0.27	8.29
b	76.80	13.30	0.28	1.40	0.20	1.19	3.55	2.98	0.31	9.10
	76.79	13.07	0.26	1.48	0.20	1.17	3.79	3.02	0.25	7.99
6	0.29	0.28	0.03	0.06	0.04	0.08	0.22	0.09	0.04	0.76
?	74.75	12.47	0.20	1.46	0.10	0.85	3.46	3.83	0.18	6.84

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water

site 90 = Rocky Cutting Rd (U14/965810)

09001 ? unknown (Torere-I ??): (mtx) (integr)											
78.72	11.81	0.20	1.01	0.11	0.88	3.41	3.57	0.30	5.82		
78.55	11.76	0.26	1.04	0.08	0.83	3.48	3.74	0.27	7.42		
77.96	12.20	0.09	1.05	0.09	0.87	3.70	3.78	0.24	4.98		
78.13	12.36	0.17	1.05	0.16	0.98	3.49	3.50	0.16	5.12		
78.89	11.52	0.18	1.14	0.17	1.02	3.13	3.83	0.12	2.49		
78.47	12.20	0.36	0.93	0.08	0.83	3.49	3.43	0.21	4.53		
77.69	12.65	0.40	1.10	0.16	0.74	3.43	3.67	0.17	4.79		
79.44	11.38	0.19	1.04	0.13	0.83	3.52	3.29	0.19	4.36		
78.29	11.86	0.22	1.10	0.20	0.90	3.73	3.43	0.27	2.39		
78.84	11.77	0.21	1.01	0.14	0.84	3.28	3.62	0.29	4.76		
79.14	11.70	0.18	0.85	0.10	0.77	3.35	3.74	0.18	4.24		
78.56	11.93	0.22	1.03	0.13	0.86	3.46	3.60	0.22	4.63		
11	0.52	0.38	0.09	0.08	0.04	0.08	0.17	0.06	1.39		

b	76.46	13.56	0.24	1.62	0.24	1.22	3.37	3.21	0.09	6.62	
b	77.36	13.29	0.24	1.70	0.15	1.08	3.12	2.90	0.15	7.32	
b	76.35	12.96	0.26	1.48	0.19	1.14	4.17	3.19	0.24	5.62	
3	76.73	13.27	0.25	1.60	0.19	1.15	3.56	3.10	0.16	6.52	
3	0.56	0.30	0.02	0.11	0.04	0.07	0.55	0.17	0.08	0.85	
?	77.37	11.74	0.28	1.07	0.14	1.06	3.56	4.59	0.20	3.85	
?	77.23	12.95	0.27	1.09	0.22	1.28	3.62	3.12	0.21	3.94	

09002 ? unknown (Kutarere ??): (mtx+) (integr)											
78.91	12.24	0.12	1.02	n.d.	0.67	3.30	3.60	0.13	8.09		
77.24	12.67	0.21	1.25	0.10	0.66	3.77	3.85	0.25	3.68		
78.47	12.48	0.19	1.07	0.12	0.72	3.20	3.59	0.16	7.06		
77.99	12.45	0.26	1.36	0.07	0.65	3.45	3.62	0.15	6.40		
78.17	12.59	0.27	1.41	0.09	0.71	3.10	3.50	0.15	8.50		
77.83	12.49	0.22	1.30	0.10	0.72	3.46	3.70	0.17	6.44		
78.50	12.02	0.30	1.44	0.10	0.67	3.38	3.39	0.20	6.00		
78.92	11.78	0.21	1.23	0.08	0.70	3.26	3.58	0.25	8.37		
78.40	12.56	0.16	1.16	0.12	0.72	3.06	3.68	0.14	5.97		
78.28	12.58	0.16	1.21	0.07	0.59	3.27	3.61	0.23	8.09		
78.27	12.39	0.21	1.24	0.09	0.68	3.33	3.61	0.18	6.86		
10	0.50	0.29	0.06	0.14	0.02	0.04	0.20	0.12	0.05	1.49	

09003 ? unknown (Huntress-B/Kaingaroa): (mtx+) (integr)											
78.52	12.23	0.20	1.27	0.13	0.98	3.20	3.27	0.20	8.13		
78.25	12.01	0.17	1.24	0.15	0.97	3.39	3.67	0.14	7.41		
78.64	11.80	0.23	1.10	0.16	0.90	3.43	3.51	0.23	7.57		
78.04	12.09	0.22	1.20	0.12	0.83	3.64	3.60	0.26	7.04		
77.93	12.23	0.16	1.34	0.15	0.93	3.35	3.56	0.35	7.47		
77.91	12.26	0.22	1.03	0.14	1.05	3.70	3.47	0.22	7.00		
78.03	12.12	0.24	1.07	0.15	0.91	3.50	3.73	0.24	5.71		
77.95	11.96	0.26	1.20	0.14	0.92	3.86	3.47	0.24	5.15		
78.59	11.99	0.20	1.01	0.14	0.78	3.35	3.71	0.24	7.70		
78.08	12.12	0.26	1.35	0.11	0.99	3.41	3.42	0.26	6.85		
78.01	12.36	0.22	1.32	0.11	0.87	3.43	3.42	0.26	6.25		
78.45	12.20	0.13	1.03	0.12	0.85	3.42	3.43	0.38	8.09		
78.20	12.12	0.21	1.18	0.13	0.92	3.47	3.52	0.25	7.03		
12	0.28	0.16	0.04	0.13	0.02	0.08	0.18	0.14	0.06	0.92	

09004 ? (Kutarere ??): (mtx+) (integr)											
77.71	12.34	0.12	1.08	0.11	0.78	3.83	3.87	0.16	6.87		
77.69	12.59	0.13	1.19	0.14	0.87	3.72	3.35	0.31	7.84		
78.24	12.26	0.20	1.16	0.09	0.82	3.65	3.28	0.30	6.53		
78.30	12.01	0.15	1.04	0.05	0.61	3.66	3.86	0.31	4.01		
78.21	12.25	0.20	1.14	0.14	0.74	3.48	3.50	0.33	6.92		
77.87	12.56	0.14	1.02	0.21	0.98	3.74	3.24	0.26	6.03		
78.21	12.35	0.11	1.16	0.08	0.66	3.19	3.98	0.27	7.46		
78.42	12.43	0.18	1.10	0.09	0.68	3.47	3.32	0.30	7.84		
78.03	12.35	0.15	1.11	0.11	0.77	3.59	3.55	0.28	6.69		
8	0.28	0.19	0.04	0.06	0.05	0.12	0.20	0.30	0.05	1.25	

09005 ? unknown (Huntress-D ??): (mtx) (integr)											
77.66	12.79	0.13	1.27	0.05	0.78	3.44	3.63	0.24	7.98		
76.92	13.16	0.21	1.24	0.09	0.81	3.91	3.41	0.26	6.94		
77.37	12.72	0.17	1.10	0.06	0.70	3.91	3.76	0.21	7.33		
77.64	12.85	0.11	1.07	0.07	0.75	3.75	3.57	0.20	8.08		
77.02	12.69	0.12	1.16	0.11	0.79	3.72	4.16	0.25	8.32		
77.10	12.77	0.14	1.31	0.18	0.72	3.95	3.63	0.20	7.90		
76.70	13.23	n.d.	1.41	0.11	0.89	3.82	3.57	0.28	7.78		
77.61	12.83	0.13	1.09	0.09	0.69	3.84	4.00	0.22	8.78		
78.08	12.57	0.10	1.11	0.07	0.72	3.38	3.77	0.21	8.48		
77.75	12.69	0.20	1.21	0.09	0.87	3.41	3.56	0.23	7.91		
77.52	12.68	0.12	1.19	0.11	0.79	3.64	3.75	0.20	8.77		
77.86	12.45	0.17	0.99	0.04	0.73	3.98	3.53	0.26	6.43		
77.44	12.79	0.15	1.18	0.09	0.77	3.69	3.69	0.23	7.89		
12	0.42	0.22	0.04	0.12	0.04	0.06	0.24	0.21	0.03	0.71	

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water

site 93 = Omaio (X15/181648)

09301 reworked Kaingaroa (?): (mtx) (integr)											
78.82	11.79	0.09	1.26	0.12	0.88	3.56	3.49	n.d.	5.24		
78.30	11.97	0.16	1.25	0.10	0.78	3.75	3.56	0.15	5.81		
78.27	11.97	0.20	1.31	0.13	0.80	3.60	3.65	0.07	4.74		
77.49	12.19	0.20	1.14	0.13	0.94	3.72	3.99	0.19	3.61		
78.42	12.08	0.08	1.22	0.13	0.77	3.57	3.52	0.22	4.64		
77.91	12.16	0.17	1.22	0.06	0.98	3.61	3.63	0.26	4.99		
77.60	12.46	0.11	1.32	0.11	0.92	3.38	3.86	0.24	5.76		
77.41	12.16	0.22	1.34	0.12	1.05	3.77	3.66	0.26	3.93		
77.63	12.16	0.29	1.27	0.16	1.00	3.81	3.52	0.16	4.84		
77.79	12.22	0.17	1.21	0.19	0.79	3.57	3.82	0.22	5.34		
77.71	12.32	0.16	1.07	0.13	0.75	3.63	3.99	0.24	5.69		
77.92	12.18	0.20	1.10	0.11	0.87	3.55	3.84	0.23	5.97		
77.21	12.42	0.16	1.34	0.10	1.05	3.74	3.78	0.20	6.27		
77.88	12.16	0.17	1.23	0.12	0.89	3.64	3.72	0.20	5.14		
13	0.46	0.18	0.06	0.09	0.03	0.11	0.12	0.20	0.06	0.79	

09302 reworked Torere-I/Opotiki (?): (mtx) (integr)											
77.85	12.35	0.13	1.26	0.14	1.23	3.25	3.62	0.18	5.75		
77.95	12.45	n.d.	1.18	0.10	1.15	3.23	3.64	0.29	7.81		
78.30	12.30	0.14	1.12	0.17	1.06	2.77	3.88	0.26	6.97		
78.54	12.10	0.21	1.10	0.12	1.14	2.96	3.62	0.21	6.09		
78.29	12.51	0.07	1.10	0.12	1.25	2.88	3.56	0.21	6.29		
77.83	12.26	0.13	1.30	0.22	1.07	3.29	3.68	0.22	5.87		
77.68	12.46	0.17	1.20	0.22	0.99	3.26	3.64	0.39	4.70		
77.98	12.58	0.20	1.16	0.16	1.01	3.05	3.60	0.25	6.99		
79.04	11.95	0.21	0.96	0.16	1.14	3.02	3.32	0.19	4.61		
78.20	12.26	0.11	1.08	0.11	1.16	3.26	3.60	0.21	6.77		
78.02	12.36	0.23	1.00	0.11	1.01	3.43	3.65	0.19	5.90		
78.35	12.44	n.d.	0.91	0.19	1.23	3.12	3.53	0.24	6.99		
78.17	12.33	0.16	1.11	0.15	1.12	3.13	3.61	0.24	6.23		
12	0.37	0.18	0.05	0.12	0.04	0.09	0.19	0.13	0.06	0.95	

12	76.17 0.37	12.53 0.18	0.16 0.05	1.11 0.12	0.15 0.04	1.12 0.09	0.13 0.19	3.61 0.13	0.24 0.06	6.25 0.93
b	77.71	12.48	0.15	1.49	0.11	1.23	3.35	3.20	0.29	6.55
b	77.43	12.56	n.d.	1.48	0.11	1.23	3.48	3.50	0.22	5.37
	77.57	12.52	0.15	1.48	0.11	1.23	3.41	3.35	0.26	5.96
2	0.20	0.06	--	0.01	0.00	0.00	0.09	0.21	0.05	0.83

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water

site 96 = Ridgeway Rd. (V16/340135)??

09601 unknown lgb = Matahina ?; (mtb) (integr)											
78.86	12.06	0.13	1.19	0.07	0.78	2.99	3.66	0.25	2.85		
78.79	12.17	0.13	0.85	0.08	0.85	3.20	3.70	0.22	3.47		
78.88	11.58	0.12	1.01	0.11	0.84	3.26	4.04	0.16	5.02		
78.61	12.09	0.11	0.92	0.10	0.79	3.26	3.87	0.24	3.41		
78.04	12.49	0.18	0.98	0.11	0.84	3.44	3.74	0.17	1.77		
78.72	12.27	0.09	1.05	0.11	0.87	3.09	3.64	0.16	3.39		
79.04	11.61	n.d.	1.01	0.10	0.84	3.22	3.96	0.22	3.96		
78.32	12.61	0.10	1.07	0.11	0.93	3.22	3.49	0.15	1.48		
78.65	12.49	0.12	1.01	0.14	0.84	3.16	3.39	0.18	2.36		
78.76	11.92	0.21	1.05	0.10	0.87	3.18	3.75	0.17	3.64		
78.31	12.37	0.22	1.02	0.17	0.95	3.19	3.66	0.11	3.49		
78.51	12.16	0.11	1.01	0.14	0.82	3.28	3.72	0.24	2.45		
78.62	12.15	0.14	1.01	0.11	0.85	3.21	3.72	0.19	3.11		
12	0.28	0.33	0.04	0.08	0.03	0.05	0.11	0.04	0.98		

site 97A = Onuku-2 (V16/104151)

09701 unknown ?? (Bonisch/Murpara-E ?); (pum) (integr)											
77.36	12.82	0.10	1.22	0.06	0.94	3.50	3.79	0.20	6.63		
78.30	12.33	0.12	0.99	0.16	0.83	3.53	3.56	0.20	3.29		
78.40	12.37	n.d.	1.11	0.08	0.79	3.45	3.57	0.22	3.74		
78.06	12.44	0.12	1.04	0.15	0.90	3.47	3.62	0.19	1.85		
78.19	12.46	0.12	1.04	0.09	0.86	3.38	3.63	0.22	1.51		
78.04	12.56	0.11	1.00	0.16	0.85	3.37	3.66	0.25	2.08		
78.15	12.29	0.10	1.00	0.11	0.90	3.48	3.68	0.29	0.66		
78.04	12.54	0.15	0.98	0.05	0.94	3.55	3.57	0.16	2.03		
78.18	12.44	0.23	0.93	0.14	0.77	3.44	3.64	0.22	1.36		
77.82	12.75	0.12	0.81	0.19	0.79	3.46	3.82	0.24	1.08		
78.33	12.51	0.08	1.04	0.11	0.79	3.28	3.63	0.23	2.04		
77.56	12.86	0.15	1.26	0.08	0.90	3.55	3.45	0.20	3.00		
77.06	13.33	0.09	1.07	0.17	0.88	3.39	3.79	0.22	3.88		
77.96	12.59	0.13	1.04	0.12	0.86	3.45	3.65	0.22	2.55		
13	0.40	0.28	0.04	0.12	0.04	0.06	0.08	0.10	0.03	1.58	

site 97B = Onuku-2 (V16/102152)

09702 unknown ?? (Murpara-C ?); (mtb) (integr)											
77.78	12.66	0.19	0.92	0.10	0.86	3.34	3.94	0.21	0.94		
77.68	11.99	0.16	0.89	0.15	0.86	3.32	4.59	0.35	4.96		
78.47	12.18	0.09	0.76	0.11	0.76	3.41	3.98	0.24	4.96		
77.76	12.56	0.07	0.95	0.11	0.75	3.52	4.06	0.24	4.83		
77.76	12.49	0.09	0.91	0.10	0.83	3.66	3.93	0.22	4.66		
77.07	12.74	0.16	1.00	0.10	0.87	3.69	4.13	0.24	2.13		
77.79	12.44	0.10	0.95	0.19	0.80	3.06	4.40	0.28	3.20		
77.09	12.50	0.15	0.96	0.11	0.79	3.57	4.67	0.16	3.49		
77.11	12.49	0.14	1.07	0.07	0.94	3.16	4.69	0.33	3.90		
77.61	12.45	0.13	0.94	0.12	0.83	3.42	4.27	0.25	3.67		
9	0.46	0.23	0.04	0.09	0.03	0.06	0.22	0.32	0.06	1.40	
? 77.49	12.28	0.08	0.92	0.10	0.56	3.44	4.89	0.23	1.26		
? 78.34	11.93	0.23	0.61	0.19	0.80	3.12	4.62	0.17	3.26		

site 98 = Onuku-1 (V16/113141)

09801 Matahina Ignimbrite; (pum) (integr)											
77.38	12.48	0.14	1.07	0.11	0.93	3.80	3.86	0.23	5.04		
77.31	12.61	0.18	1.09	0.13	0.98	3.66	3.76	0.28	5.49		
77.69	12.52	0.11	1.06	0.19	0.84	3.58	3.81	0.20	4.99		
77.61	12.62	0.11	0.89	0.11	0.84	3.65	3.88	0.28	4.99		
77.94	12.58	0.07	1.04	0.10	0.84	3.68	3.58	0.17	4.46		
78.16	12.00	0.11	0.94	0.10	0.83	3.68	3.94	0.24	2.44		
77.75	12.43	n.d.	1.14	0.13	0.86	3.56	3.95	0.19	2.94		
78.17	12.00	0.15	1.11	0.17	0.84	3.47	3.76	0.32	1.51		
77.62	12.52	0.12	1.09	0.11	0.78	3.67	3.85	0.23	3.66		
77.57	12.44	0.13	1.11	0.09	0.90	3.74	3.81	0.21	3.17		
77.48	12.34	0.23	0.98	0.24	0.93	3.71	3.91	0.20	3.21		
77.70	12.41	0.14	1.05	0.13	0.87	3.66	3.83	0.23	3.81		
11	0.29	0.22	0.04	0.08	0.05	0.06	0.09	0.11	0.05	1.28	

site 99 = Onuku-3 (V16/121114)

09901 Kaingaroa Ignimbrite; (mtb) (integr)											
78.03	12.32	0.25	1.15	0.11	0.77	3.07	4.08	0.22	3.52		
77.55	12.38	0.21	1.47	0.17	0.68	3.42	3.94	0.20	3.78		
77.64	12.31	0.12	1.40	0.16	0.87	3.15	4.09	0.25	3.00		
78.06	12.17	0.19	1.12	0.09	0.91	3.14	4.04	0.28	3.93		
77.84	12.29	0.18	1.22	0.17	0.83	3.06	4.16	0.26	3.84		
77.88	12.46	n.d.	1.21	0.13	0.82	3.30	3.91	0.28	2.87		
77.68	12.45	0.18	1.35	0.16	0.80	3.11	4.09	0.16	3.01		
77.96	12.21	0.15	1.16	0.10	0.91	3.05	4.22	0.24	2.91		
77.55	12.46	0.16	1.42	0.16	0.83	3.16	4.08	0.19	3.53		
77.86	12.52	0.19	1.08	0.10	0.84	3.11	4.07	0.24	2.76		
77.80	12.36	0.18	1.26	0.14	0.83	3.16	4.07	0.23	3.31		
10	0.19	0.12	0.04	0.14	0.03	0.07	0.12	0.09	0.04	0.45	

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water

site 100 = Murupara-2 (V17/316991)

10001 Rangitiki lgb; unwelded top (altered); (pum) (integr)											
77.37	12.53	0.11	0.64	0.11	0.96	3.28	4.73	0.27	5.11		
77.19	12.45	0.23	0.59	0.11	1.00	3.25	4.87	0.31	4.01		
77.43	12.46	0.18	0.53	0.07	0.87	3.19	5.02	0.25	4.79		
77.12	12.29	0.16	0.66	0.14	1.01	3.36	4.89	0.37	4.99		
77.52	12.42	0.12	0.62	0.14	0.90	3.18	4.82	0.28	3.97		
77.34	12.70	0.19	0.43	0.05	0.83	3.06	5.10	0.29	6.87		
76.95	12.75	0.19	0.45	0.05	0.90	3.31	5.08	0.30	4.81		
77.54	12.18	0.13	0.66	0.05	0.97	3.35	4.84	0.28	3.67		
77.40	12.51	0.27	0.84	0.16	0.95	3.11	4.40	0.35	3.93		
76.97	12.53	0.23	0.65	0.11	0.89	3.45	4.90	0.27	3.66		
77.35	12.48	0.21	0.48	n.d.	0.81	3.07	5.37	0.23	4.85		
77.29	12.48	0.18	0.60	0.10	0.92	3.24	4.91	0.29	4.61		
11	0.20	0.16	0.05	0.12	0.04	0.07	0.13	0.24	0.04	0.93	

10002 Murupara-A; (pum) (integr)											
77.23	12.83	0.20	1.28	0.15	1.15	3.56	3.41	0.19	6.09		
77.05	12.75	0.17	1.28	0.20	1.21	3.53	3.57	0.22	6.57		
76.44	12.75	0.27	1.41	0.27	1.39	3.55	3.62	0.29	7.37		
77.44	12.67	0.13	1.05	0.16	1.21	3.78	3.36	0.20	6.46		
77.15	12.77	0.16	1.26	0.19	1.23	3.58	3.42	0.24	5.55		
77.34	12.82	0.23	1.38	0.15	1.19	3.53	3.22	0.15	4.06		
78.03	12.43	n.d.	1.08	0.17	1.18	3.43	3.49	0.19	4.45		
76.82	12.76	0.19	1.41	0.27	1.19	3.45	3.67	0.24	6.51		
76.61	12.97	0.18	1.41	0.19	1.07	3.53	3.75	0.28	7.05		
77.10	12.93	0.20	1.09	0.17	1.22	3.60	3.52	0.16	7.06		
76.64	13.07	0.21	1.28	0.16	1.30	3.47	3.68	0.18	6.91		
76.92	12.87	0.24	1.20	0.22	1.34	3.53	3.51	0.17	7.41		
76.90	12.44	0.19	1.33	0.12	1.34	3.83	3.63	0.22	6.64		
77.26	12.45	0.38	1.31	0.22	1.34	3.50	3.39	0.15	5.09		
77.96	12.32	0.18	1.21	0.21	1.26	3.36	3.35	0.14	3.12		
77.13	12.72	0.21	1.26	0.19	1.24	3.55	3.51	0.20	6.02		
15	0.45	0.22	0.06	0.12	0.04	0.09	0.12	0.15	0.05	1.30	
? 75.64	13.36	0.21	1.34	0.16	1.68	3.93	3.42	0.25	6.20		

10003 Murupara-E & Anaputa; (mtb) (integr)										
	78.20	12.57	n.d.	1.06	0.11	0.73	3.60	3.58	0.15	4.13
	77.79	12.52	n.d.	1.08	0.11	0.80	3.55	3.98	0.16	4.13
	77.91	12.62	n.d.	0.95	n.d.	0.80	3.66	3.86	0.21	5.13
	77.55	12.68	0.11	1.02	0.12	0.80	3.74	3.76	0.22	5.13
	77.68	12.63	0.16	0.99	0.10	1.00	3.61	3.63	0.19	6.42
	77.68	12.51	0.08	1.14	0.09	0.67	3.78	3.89	0.16	4.39
	77.77	12.54	n.d.	1.14	0.08	0.74	3.85	3.66	0.23	4.91
	77.84	12.62	0.07	1.04	0.07	0.80	3.73	3.61	0.22	5.70
	77.55	12.69	0.16	1.20	0.12	0.94	3.46	3.70	0.19	3.45
	77.53	12.19	0.17	1.07	0.08	0.87	3.84	4.07	0.20	3.58
	77.81	12.44	0.09	1.06	0.04	0.77	3.74	3.84	0.22	3.43
	77.75	12.54	0.12	1.07	0.09	0.81	3.69	3.78	0.19	4.58
11	0.20	0.14	0.04	0.07	0.03	0.10	0.12	0.16	0.03	0.97
b	77.85	12.50	0.22	1.46	0.21	1.31	3.33	3.03	0.09	5.03
b	77.23	12.56	0.30	1.51	0.25	1.31	3.38	3.16	0.30	7.07
b	77.38	12.67	0.27	1.30	0.20	1.57	3.49	2.95	0.18	6.78
b	78.06	12.13	0.15	1.49	0.31	1.38	3.28	2.97	0.23	4.45
b	78.28	12.26	0.20	1.32	0.18	1.30	3.40	2.88	0.18	5.26
	77.76	12.42	0.23	1.42	0.23	1.37	3.37	3.30	0.20	5.74
5	0.45	0.22	0.06	0.10	0.05	0.11	0.08	0.11	0.08	1.12

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water
 site 103 = Downer Rd. (T16/646335)

10301 Whakamaru Ig. weathered altered top; (mtx) (integr)

77.72	12.84	n.d.	0.69	0.07	0.83	3.13	4.44	0.29	5.54
78.02	12.61	n.d.	0.54	n.d.	0.68	3.28	4.66	0.22	5.29
77.58	12.63	0.17	0.67	n.d.	0.74	3.40	4.49	0.30	4.53
78.09	12.75	0.09	0.54	0.09	0.73	3.08	4.50	0.13	5.01
78.06	12.50	0.13	0.38	0.08	0.68	3.20	4.77	0.20	5.36
77.89	12.67	0.13	0.56	0.08	0.73	3.22	4.57	0.23	5.15
5	0.23	0.13	0.04	0.12	0.01	0.06	0.13	0.07	0.39

10302 Pokai Ignimbrite; near base, unwelded; (pum) (integr)

78.30	12.25	0.10	1.02	0.10	0.71	3.40	3.88	0.25	5.36
78.00	12.47	0.14	1.18	0.10	0.72	3.51	3.68	0.21	5.86
78.21	12.37	0.06	1.20	0.07	0.62	3.48	3.81	0.17	5.57
78.17	12.14	0.07	1.34	0.07	0.73	3.48	3.77	0.22	4.08
78.16	12.23	0.13	1.15	0.07	0.77	3.61	3.59	0.30	5.47
78.26	12.25	0.11	0.98	0.12	0.72	3.42	3.91	0.24	5.78
77.46	12.81	0.12	1.34	0.11	0.87	3.53	3.59	0.17	7.02
78.62	12.10	n.d.	1.26	0.05	0.69	3.36	3.75	0.17	4.74
77.99	12.56	0.17	1.22	0.13	0.81	3.54	3.45	0.14	5.74
78.01	12.38	0.07	1.23	0.05	0.65	3.55	3.88	0.17	8.01
78.12	12.36	0.11	1.19	0.09	0.73	3.49	3.73	0.20	5.76
10	0.30	0.21	0.04	0.12	0.03	0.07	0.08	0.15	1.10
? 78.65	12.37	0.18	0.80	0.10	0.71	3.37	3.64	0.17	7.22
? 77.02	12.64	0.12	1.60	0.11	0.91	3.60	3.84	0.16	6.77

10303 Chimp Ignimbrite; weathered; (pum) (integr)

75.64	13.11	0.15	1.58	0.21	1.13	4.10	3.86	0.21	6.06
75.49	13.12	0.14	1.62	0.20	1.12	4.13	3.91	0.28	5.48
75.16	13.27	0.26	1.60	0.21	1.14	3.95	4.15	0.26	5.20
75.33	13.18	0.23	1.58	0.13	1.32	4.24	3.89	0.11	4.22
75.69	13.33	0.20	1.65	0.19	1.09	3.79	3.80	0.26	4.79
75.69	13.22	0.16	1.40	0.18	1.15	3.97	3.93	0.30	4.33
76.00	12.96	0.14	1.61	0.18	1.29	3.84	3.76	0.22	4.01
75.63	12.87	0.22	1.65	0.23	1.29	4.27	3.57	0.28	3.04
75.92	13.24	0.21	1.38	0.14	1.22	3.97	3.70	0.22	4.14
76.00	13.07	0.22	1.42	0.17	1.19	3.80	3.85	0.28	3.44
76.23	12.56	0.19	1.69	0.17	1.18	4.03	3.74	0.21	3.69
76.12	12.75	0.15	1.60	0.11	1.17	3.90	3.91	0.28	2.63
75.74	13.06	0.19	1.56	0.18	1.19	4.00	3.84	0.24	4.25
12	0.32	0.23	0.04	0.11	0.04	0.07	0.16	0.14	1.01

site 104 = Tikorangi Rd. (U16/786206)

10401 Pokai Ignimbrite; top; (mtx) (integr)

78.03	12.74	0.18	1.54	0.07	0.89	2.62	3.74	0.19	5.78
77.95	12.61	0.19	1.53	0.18	0.86	2.68	3.73	0.26	7.07
78.32	12.40	0.10	1.27	0.10	0.77	2.79	4.04	0.22	5.29
78.25	12.70	0.17	1.45	0.11	0.90	2.44	3.74	0.26	6.59
77.98	12.61	0.15	1.30	0.11	0.90	2.83	3.90	0.22	7.07
78.03	12.70	0.17	1.52	0.13	1.04	2.38	3.65	0.37	5.23
78.09	12.83	0.16	1.31	0.09	0.82	2.67	3.87	0.17	6.36
78.17	12.75	0.19	1.64	0.12	0.87	2.46	3.62	0.19	5.47
78.34	12.78	0.08	1.34	0.15	0.96	2.45	3.61	0.30	5.79
78.33	12.50	0.22	1.51	0.15	0.97	2.53	3.57	0.21	5.71
78.15	12.66	0.16	1.44	0.12	0.90	2.59	3.75	0.24	6.04
10	0.15	0.13	0.04	0.13	0.03	0.08	0.15	0.15	0.69

10402 Kutarere (Mamaku); pre-ignimbrite airfall; (pum) (integr)

77.71	12.26	0.24	1.24	0.12	0.52	3.38	4.24	0.30	5.32
78.09	12.19	0.15	0.96	0.06	0.55	3.43	4.24	0.35	5.79
78.26	12.30	0.14	1.04	0.07	0.52	3.32	4.01	0.33	6.03
78.60	12.15	n.d.	1.08	0.08	0.51	3.07	4.10	0.43	9.03
78.26	12.24	0.14	1.10	0.07	0.52	3.22	4.09	0.35	3.94
78.41	12.27	0.13	0.93	0.12	0.50	3.16	4.21	0.27	5.31
77.28	13.18	0.22	1.13	n.d.	0.44	3.26	3.94	0.55	8.92
78.05	12.23	0.11	1.02	0.06	0.60	3.35	4.25	0.33	5.04
77.96	12.38	0.20	1.07	0.11	0.63	3.27	4.11	0.28	5.46
78.34	12.22	0.16	0.97	0.10	0.51	3.33	4.01	0.36	4.76
78.10	12.34	0.16	1.05	0.09	0.53	3.28	4.12	0.35	5.96
10	0.38	0.30	0.05	0.09	0.02	0.05	0.11	0.11	1.69
? 78.05	12.16	0.16	1.33	0.10	0.68	3.35	3.81	0.35	4.56
? 78.25	12.60	n.d.	0.79	0.11	0.51	3.39	4.11	0.24	5.44

SiO₂ Al₂O₃ TiO₂ FeO MgO CaO Na₂O K₂O Cl water
 site 112 = Reid's Reserve (W15/611452)

11201 Reid's Reserve; (mtx) (integr)

76.92	12.52	0.16	1.10	0.07	1.02	3.51	4.35	0.36	7.85
76.51	12.65	0.31	1.19	0.16	0.92	3.62	4.20	0.45	4.65
76.30	12.86	0.15	1.30	0.10	0.95	3.90	4.08	0.36	6.63
76.13	12.60	0.19	1.41	0.09	0.88	4.00	4.38	0.31	5.06
76.98	12.49	0.19	1.11	0.13	0.90	3.69	4.18	0.34	5.13
76.32	12.65	0.17	1.33	0.16	0.93	3.79	4.31	0.35	6.05
76.47	12.74	0.15	1.19	0.15	0.93	3.80	4.22	0.35	6.20
76.79	12.59	0.10	1.23	0.10	0.92	3.72	4.24	0.31	7.36
76.68	12.44	0.10	1.34	0.11	0.94	3.79	4.25	0.37	6.96
76.43	12.55	0.16	1.52	0.11	0.91	3.74	4.24	0.34	7.01
75.86	12.83	0.14	1.48	0.12	0.92	3.81	4.55	0.30	6.22
76.21	12.58	0.21	1.18	0.13	0.90	4.16	4.32	0.31	7.49
76.30	12.76	0.12	1.21	0.13	0.88	3.96	4.28	0.37	7.22
77.06	12.53	0.17	1.21	0.07	0.89	3.65	4.07	0.34	4.96
76.96	12.80	0.28	1.06	0.00	0.86	3.38	4.30	0.34	5.15
76.87	12.91	0.11	1.14	0.15	0.93	3.47	4.08	0.34	6.14
76.80	12.79	0.11	1.33	0.14	0.83	3.55	4.09	0.38	5.52
76.56	12.66	0.17	1.25	0.12	0.91	3.74	4.24	0.35	6.21
17	0.35	0.14	0.06	0.13	0.03	0.04	0.20	0.13	1.01

APPENDIX - G:

Titano-magnetite chemical data

- microprobe analyses of
Bay of Plenty tephtras

SiO₂ TiO₂ Al₂O₃ Fe₂O₃ FeO MnO MgO ZnO Cr₂O₃ total ulvöspin.
site 32 = Jackson Rd (X15/955468)

03201 Ohlwa Harbour-B: (mbx) [integr]												
0.09	8.09	1.63	50.76	36.67	0.61	0.67	0.30	n.d.	98.82	0.241		
0.08	8.01	1.56	50.99	36.52	0.67	0.69	0.22	n.d.	98.74	0.237		
0.12	8.35	1.68	51.04	37.43	0.55	0.75	0.14	n.d.	100.06	0.246		
0.08	8.07	1.49	50.37	36.65	0.59	0.63	0.16	0.19	98.23	0.243		
0.04	8.35	1.66	51.33	37.44	0.68	0.61	0.18	0.03	100.32	0.245		
0.06	8.62	1.51	50.60	37.64	0.65	0.61	0.15	0.09	99.93	0.254		
0.07	8.55	1.57	49.82	37.20	0.80	0.60	0.17	0.35	99.13	0.256		
0.08	8.29	1.59	50.70	37.08	0.65	0.65	0.19	†	99.32	0.243		
7	0.02	0.24	0.07	0.50	0.46	0.08	0.05	0.06	0.79	0.011		
7	0.14	13.07	3.27	40.19	39.05	0.58	2.57	0.13	0.21	99.21	0.393	
03202 Jackson Rd: (mbx) [integr]												
0.05	8.71	1.13	49.26	36.63	0.97	0.54	0.19	n.d.	97.48	0.257		
0.14	9.72	1.80	47.95	37.85	0.76	1.01	0.28	n.d.	99.51	0.285		
0.08	8.80	1.42	49.98	37.46	0.79	0.47	0.38	n.d.	99.38	0.259		
0.10	8.28	1.67	50.45	36.86	0.57	0.79	0.05	n.d.	98.77	0.246		
0.07	8.45	1.85	50.76	36.64	0.74	0.99	0.26	n.d.	99.76	0.246		
0.12	8.73	1.40	49.91	37.14	0.89	0.54	0.12	n.d.	98.85	0.259		
0.01	8.52	1.65	50.02	36.97	0.52	0.84	0.01	n.d.	98.54	0.253		
0.04	8.09	1.70	51.74	36.47	0.54	1.07	0.18	n.d.	99.83	0.235		
0.15	9.08	1.39	49.39	37.76	0.83	0.56	0.21	n.d.	99.37	0.266		
0.08	8.71	1.56	49.94	37.09	0.73	0.76	0.19		99.05	0.256		
9	0.05	0.48	0.23	1.06	0.50	0.16	0.23	0.12	0.74	0.014		
7	0.15	10.45	1.77	46.50	38.53	0.62	0.95	0.43	n.d.	99.40	0.307	

site 38 = Kukumoa (W15/843469)

03801 Kutarere: (mbx+) [integr]												
0.08	10.85	1.38	45.80	39.13	0.63	0.76	0.24	0.10	98.97	0.320		
0.06	11.02	0.96	46.48	39.81	0.93	0.40	0.16	0.12	99.94	0.319		
0.06	11.57	1.07	45.93	40.19	0.86	0.53	0.44	0.06	100.71	0.331		
0.07	11.70	1.12	44.65	39.79	1.09	0.57	0.39	0.36	99.74	0.341		
0.08	12.90	1.39	41.32	40.76	0.79	0.78	0.16	0.14	98.32	0.384		
0.06	11.76	1.05	44.16	40.00	0.86	0.51	0.19	0.09	98.68	0.345		
0.11	10.66	1.35	46.58	39.23	0.79	0.73	0.04	0.06	99.55	0.312		
0.07	11.49	1.19	44.99	39.84	0.85	0.61	0.23	0.13	99.42	0.336		
7	0.02	0.76	0.18	1.85	0.56	0.14	0.15	0.14	0.10	0.82	0.024	
03802 Kukumoa-D: (mbx) [integr]												
0.07	12.15	1.22	42.62	40.00	0.89	0.54	0.23	0.00	97.72	0.362		
0.12	11.13	1.05	43.15	38.52	0.86	0.48	0.28	0.07	95.66	0.338		
0.13	11.50	1.10	43.17	39.41	0.84	0.56	0.00	0.19	96.90	0.347		
0.03	11.32	0.98	44.06	38.97	0.87	0.49	0.28	0.06	97.06	0.336		
0.06	11.00	1.06	44.85	39.18	0.80	0.41	0.15	0.00	97.51	0.328		
0.04	11.26	0.99	44.35	39.12	0.87	0.50	0.13	0.00	97.26	0.334		
0.08	11.39	1.07	43.70	39.20	0.86	0.50	0.18	0.05	97.02	0.341		
6	0.04	0.41	0.09	0.85	0.49	0.03	0.05	0.11	0.07	0.73	0.012	
7	0.10	4.85	3.76	54.96	32.46	0.35	2.03	0.11	0.41	99.03	0.149	
7	0.10	8.62	2.83	48.09	35.95	0.62	1.55	0.09	0.11	97.76	0.264	
03803 Kukumoa-C: (mbx) [integr]												
0.10	12.77	1.21	42.24	41.18	0.88	0.48	0.23	0.15	99.24	0.377		
0.09	12.67	1.05	43.28	41.45	0.75	0.41	0.36	0.13	100.19	0.368		
0.13	12.07	1.12	43.53	40.11	1.05	0.60	0.19	0.00	98.86	0.353		
0.09	11.07	0.99	45.65	39.79	0.78	0.33	0.25	0.06	99.01	0.325		
0.05	12.12	1.15	44.89	40.39	1.35	0.53	0.26	0.00	100.74	0.346		
0.11	11.15	1.38	45.77	39.64	0.87	0.68	0.21	0.08	99.89	0.326		
0.10	11.97	1.15	44.23	40.43	0.95	0.51	0.25	0.07	99.66	0.349		
6	0.03	0.73	0.14	1.43	0.74	0.22	0.13	0.06	0.06	0.74	0.021	
b	0.06	12.21	2.60	41.03	38.73	0.34	1.87	0.13	0.26	97.23	0.375	
b	0.07	14.59	2.43	37.79	41.80	0.58	1.43	0.23	0.00	98.92	0.441	
b	0.10	10.37	3.55	44.99	37.02	0.40	2.24	0.35	0.20	99.22	0.316	
b	0.07	7.92	4.52	48.19	33.86	0.28	2.85	0.16	0.16	98.01	0.245	
0.08	11.27	3.28	43.00	37.85	0.40	2.10	0.22	0.16	98.35	0.344		
4	0.02	2.82	0.97	4.54	3.32	0.13	0.60	0.11	0.10	0.90	0.084	
03804 Kukumoa-B: (mbx) [integr]												
0.00	12.03	0.98	43.52	40.21	0.74	0.43	0.25	0.09	99.25	0.355		
0.00	12.17	1.15	43.89	40.39	0.93	0.56	0.17	0.07	99.33	0.355		
0.09	11.30	1.29	44.97	39.78	0.66	0.60	0.25	0.13	99.07	0.334		
0.00	12.12	1.11	44.12	40.33	0.99	0.53	0.20	0.00	99.40	0.352		
0.06	12.14	1.03	43.11	40.47	0.55	0.50	0.21	0.00	98.07	0.360		
0.05	11.10	1.26	45.25	39.38	0.69	0.68	0.10	0.11	98.62	0.328		
0.04	11.95	0.97	44.58	40.21	0.77	0.52	0.48	0.00	99.52	0.345		
0.07	12.31	1.06	44.21	41.28	0.80	0.46	0.18	0.26	100.63	0.358		
0.04	11.89	1.11	44.21	40.26	0.77	0.54	0.23	0.08	99.24	0.348		
8	0.04	0.44	0.12	0.72	0.55	0.14	0.08	0.11	0.09	0.74	0.012	
b	0.00	7.87	2.16	52.56	33.21	0.79	2.85	0.27	0.08	99.79	0.212	
b	0.14	8.50	2.00	50.15	36.38	0.86	1.70	0.08	0.11	100.32	0.254	
0.07	8.39	2.08	51.36	34.80	0.83	2.28	0.18	0.10	100.06	0.233		
2	0.10	0.73	0.11	1.70	2.24	0.05	0.81	0.13	0.02	0.37	0.030	

SiO₂ TiO₂ Al₂O₃ Fe₂O₃ FeO MnO MgO ZnO Cr₂O₃ total ulvöspin.
site 39 = McCoy Rd -(1) (W15/676454)

03901 Waingarara Ignimbrite: (pum) [integr]												
a	0.12	10.04	1.52	46.92	38.90	0.48	0.54	0.32	0.39	99.23	0.302	
a	0.08	10.54	1.55	45.12	38.71	0.54	0.68	0.24	0.52	97.98	0.321	
a	0.16	10.41	1.51	45.49	38.66	0.60	0.63	0.05	0.22	97.73	0.314	
a	0.10	9.87	1.37	46.50	38.34	0.54	0.53	0.17	0.22	97.64	0.300	
0.12	10.22	1.49	46.01	38.65	0.54	0.60	0.20	0.34	98.15	0.309		
4	0.03	0.31	0.08	0.84	0.23	0.05	0.07	0.11	0.15	0.74	0.010	
b	1.16	12.74	1.56	36.25	41.15	0.56	0.49	0.60	0.26	94.77	0.418	
b	1.75	13.44	1.23	32.73	42.46	0.57	0.43	0.34	0.33	93.28	0.458	
1.46	13.09	1.40	34.49	41.81	0.57	0.46	0.47	0.30	94.03	0.438		
2	0.42	0.49	0.23	2.49	0.93	0.01	0.04	0.18	0.05	1.05	0.028	
c	2.91	15.72	1.23	24.89	46.19	0.46	0.25	0.29	0.17	92.11	0.572	
c	4.29	18.41	1.89	16.38	50.08	0.25	0.86	0.35	0.28	92.79	0.721	
c	4.62	13.57	1.94	23.49	46.13	0.15	0.21	0.82	n.d.	90.94	0.559	
c	5.32	13.63	2.00	20.76	46.67	0.15	0.21	1.00	0.21	89.95	0.597	
c	4.20	12.61	1.76	26.21	45.06	0.23	0.11	0.44	0.26	90.88	0.513	
c	5.47	16.36	1.50	16.57	50.09	0.09	0.19	0.53	0.10	90.90	0.690	
c	5.66	13.90	1.87	19.18	47.42	0.17	0.21	0.71	0.27	89.39	0.623	
c	4.87	13.60	1.96	21.12	46.45	0.10	0.10	0.58	0.53	89.31	0.607	
4.67	14.73	1.77	21.08	47.26	0.20	0.27	0.59	0.26	90.78	0.610		
8	0.89	1.93	0.27	3.64	1.86	0.12	0.24	0.24	0.14	1.23	0.068	
d	6.72	17.77	2.82	8.53	52.95	0.13	0.14	0.69	0.12	89.87	0.863	

site 42 = Rax Hill Point (W15/748466)

04201 Tirohanga: (mbx) [integr]												
0.10	11.12	2.15	45.67	39.49	0.65	1.11	0.14	n.d.	100.43	0.328		
0.13	10.93	2.22	45.79	39.39	0.48	1.19	0.23	0.14	100.50	0.325		
0.09	11.14	2.08	45.20	39.35	0.52	1.16	0.13	n.d.	99.67	0.331		
0.09	10.76	2.14	45.75	38.77	0.60	1.25	0.06	n.d.	99.42	0.320		
0.10	10.74	2.18	44.74	38.12	0.75	1.27	0.09	n.d.	97.99	0.323		
0.11	11.01	2.25	44.68	38.73	0.65	1.25	0.15	n.d.	98.83	0.320		
0.12	10.96	2.15	44.56	38.48	0.60	1.25	0.10	n.d.	98.22	0.329		
0.08	11.55	2.37	43.62	38.70	0.78	1.43	0.25	n.d.	98.78	0.345		
0.17	11.13	2.41	45.08	38.84	0.60	1.59	0.14	n.d.	99.96	0.329		
0.09	11.11	2.18	44.73	38.94	0.59	1.23	0.15	n.d.	99.02	0.332		
<hr/>												
0.11	11.05	2.21	44.98	38.88	0.62	1.27	0.14		99.28	0.328		
10	0.03	0.23	0.10	0.67	0.43	0.09	0.14	0.06		0.87	0.007	

SiO₂ TiO₂ Al₂O₃ Fe₂O₃ FeO MnO MgO ZnO Cr₂O₃ total ulvöspin.

SiO₂ TiO₂ Al₂O₃ Fe₂O₃ FeO MnO MgO ZnO Cr₂O₃ total ulvöspin.

site 48 = Copenhagen Rd (X14/233737)

site 84 = Wilson's Driveway (V15/386622)

[illegible]

08401 Wilson: (pum) (integr)											
	0.13	9.78	2.06	47.09	37.67	0.53	1.16	0.23	n.d.	98.65	0.292
	0.10	9.84	2.00	48.08	38.03	0.59	1.16	0.24	n.d.	100.04	0.288
	0.11	10.17	2.16	47.62	38.53	0.43	1.20	0.31	n.d.	100.53	0.298
	0.12	10.23	2.01	47.04	38.42	0.58	1.19	0.11	n.d.	99.70	0.302
	0.09	9.81	2.00	46.79	37.59	0.54	1.11	0.24	n.d.	98.17	0.294
	0.04	10.17	2.11	46.76	37.93	0.60	1.23	0.21	n.d.	99.05	0.301
	0.10	10.00	2.06	47.23	38.03	0.55	1.18	0.22		99.36	0.296
6	0.03	0.21	0.07	0.52	0.38	0.06	0.04	0.07		0.89	0.005
im	0.04	46.41	0.24	13.95	37.26	0.72	2.03	n.d.	n.d.	100.65	0.863

site 92 = Ohiwa Harbour Rd. (W15/764468)

04802 Tarens: (mb) (integr)											
0.07	8.34	2.01	51.38	36.09	0.74	1.54	0.13	0.00	100.30	0.238	
0.04	7.18	1.80	54.81	35.46	0.80	1.30	0.40	0.00	101.79	0.201	
0.03	7.31	1.67	54.77	35.72	0.68	1.34	0.23	0.07	101.82	0.204	
0.08	6.61	1.67	55.05	34.57	1.06	1.25	0.20	0.00	100.49	0.186	
0.08	7.23	1.83	53.46	35.29	0.81	1.31	0.14	0.07	100.22	0.207	
0.05	7.56	1.74	51.90	34.91	0.79	1.37	0.19	0.05	98.56	0.218	
0.06	7.37	1.79	53.56	35.34	0.81	1.35	0.22	0.03	100.53	0.209	
6	0.02	0.57	1.13	1.60	0.55	0.13	0.10	0.10	1.21	0.018	
?	0.11	10.23	1.57	48.67	39.37	0.55	0.83	0.36	0.13	101.82	0.295

09202 Ohlwa Harbour-II (7): (mtb) [integr]											
0.07	8.40	1.47	50.26	37.08	0.66	0.51	0.17	n.d.	98.62	0.250	
0.06	8.27	1.63	50.91	37.00	0.81	0.64	0.10	n.d.	99.42	0.244	
0.09	8.62	1.60	49.94	37.62	0.49	0.69	0.22	0.48	99.75	0.258	
0.09	9.89	1.60	46.33	38.17	0.55	0.55	0.20	n.d.	97.38	0.301	
0.06	7.94	1.58	50.36	36.12	0.52	0.69	0.26	n.d.	97.53	0.238	
0.09	8.21	1.51	50.71	36.88	0.53	0.74	0.17	0.33	99.17	0.244	
0.09	7.54	1.85	51.55	35.79	0.71	0.97	0.10	0.13	98.73	0.224	
0.08	7.72	1.85	51.08	36.08	0.62	0.82	0.08	n.d.	98.33	0.231	
0.08	8.32	1.64	50.14	36.84	0.61	0.70	0.16	.	98.62	0.249	
8	0.01	0.73	0.14	1.62	0.82	0.11	0.15	0.06	0.85	0.024	
b	0.31	9.04	2.49	45.56	35.96	0.50	1.49	0.09	n.d.	95.44	0.283
b	0.11	10.46	2.12	45.89	37.88	0.59	1.46	0.05	n.d.	98.56	0.310
2	0.21	9.75	2.31	45.73	36.92	0.55	1.48	0.07	97.00	0.297	
2	0.14	1.00	0.26	0.23	1.36	0.06	0.02	0.03	2.21	0.019	

04803 Copenhagen: (mb) [integ]												
	0.00	8.89	1.26	50.15	37.32	0.67	0.72	0.23	0.10	99.34	0.259	
	0.05	8.94	1.51	48.75	37.35	0.58	0.62	0.22	0.09	98.11	0.268	
	0.06	9.69	1.38	47.28	37.31	0.82	0.93	0.00	0.13	97.59	0.287	
	0.03	9.17	1.38	48.73	37.33	0.69	0.76	0.15	0.11	98.35	0.271	
3	0.03	0.45	0.13	1.44	0.02	0.12	0.16	0.13	0.02	0.90	0.014	
b	0.24	5.35	6.84	51.11	31.03	0.33	3.77	0.00	0.14	98.81	0.171	
b	0.23	9.15	4.04	47.03	34.18	0.63	3.40	0.19	0.06	98.91	0.269	
b	0.18	6.17	6.77	49.59	31.25	0.52	3.82	0.00	0.00	98.30	0.196	
b	0.11	6.04	3.08	54.52	33.56	0.61	1.97	0.21	0.11	100.21	0.176	
b	0.13	8.95	3.05	48.39	34.66	0.71	2.71	0.24	0.19	100.33	0.259	
	0.18	7.13	4.76	50.13	32.94	0.56	3.13	0.13	0.10	99.05	0.214	
s	0.06	1.78	1.91	2.88	1.69	0.15	0.79	0.12	0.07	0.70	0.047	
?	0.12	10.93	2.10	44.95	37.76	0.71	1.59	0.37	0.54	99.07	0.322	
?	0.16	8.72	1.57	50.88	37.53	1.39	0.64	0.00	0.00	99.24	0.252	
?	0.06	7.54	1.86	52.41	34.79	0.89	1.57	0.12	0.00	99.24	0.215	

09204 Jackson Rd: (mb) [integer]												
	0.06	7.99	1.82	51.66	36.76	0.48	0.94	0.15	0.03	99.89	0.235	
	0.05	8.10	1.71	50.26	36.74	0.49	0.75	0.13	0.39	98.62	0.245	
	0.07	8.42	1.65	50.52	36.48	1.26	0.73	0.25	0.17	99.55	0.246	
	0.12	7.93	1.72	50.87	36.32	0.63	0.82	0.30	0.08	98.79	0.236	
	0.07	7.76	1.77	50.53	36.22	0.49	0.84	0.07	0.36	98.11	0.236	
	0.10	7.94	1.84	51.21	36.67	0.51	0.88	0.25	0.25	99.65	0.236	
	0.14	8.07	1.79	50.22	36.71	0.42	0.87	0.19	0.32	98.73	0.244	
	0.09	8.03	1.76	50.75	36.56	0.61	0.83	0.19	0.23	99.05	0.240	
7	0.03	0.20	0.07	0.53	0.22	0.29	0.07	0.08	0.14	0.65	0.005	
im	0.06	44.22	0.21	15.72	35.60	0.76	1.88	0.13	0.16	98.74	0.842	

site 93 = Ornalo (X15/181648)

site 62 = Relhama Rd (U17/093098)

06201 Kataragora kimbibite: (pum) (integr)										
	0.10	12.18	42.42	39.99	0.84	0.72	0.09	n.d.	97.69	0.365
	0.08	12.34	1.29	42.53	39.29	0.80	0.56	0.38	0.10	98.35
	0.06	12.03	1.41	42.88	39.80	0.72	0.72	0.38	0.31	98.30
	0.07	12.29	1.43	43.27	40.50	0.81	0.66	0.23	0.08	99.34
	0.08	12.13	1.40	43.74	40.41	0.77	0.67	0.31	0.06	99.57
	0.12	11.79	1.44	43.66	39.96	0.89	0.77	0.07	0.23	98.87
	0.07	11.92	1.46	43.92	40.18	0.81	0.71	0.19	0.01	99.35
	0.08	12.11	1.41	43.19	40.16	0.81	0.68	0.23	.7	98.78
7	0.02	0.19	0.06	0.63	0.26	0.05	0.06	0.12		0.69

09301 Kalingaraa (?): (mhz) [integr]											
	0.00	12.18	1.93	42.05	40.01	0.72	0.66	0.17	0.00	97.72	0.360
	0.06	12.18	0.93	45.00	37.90	0.44	1.06	0.12	0.06	97.40	0.360
	0.00	12.29	0.93	43.19	40.32	0.73	0.50	0.15	0.00	98.11	0.359
	0.00	11.28	1.08	44.79	39.64	0.66	0.46	0.16	0.14	98.21	0.335
	0.04	10.79	1.00	45.85	38.87	0.72	0.70	0.16	0.33	98.46	0.317
	0.00	11.39	0.79	44.06	39.67	0.62	0.23	0.19	0.02	96.97	0.340
	0.07	9.17	1.02	48.25	37.43	0.47	0.49	0.15	0.06	97.31	0.274
	0.03	11.04	1.06	45.01	39.15	0.62	0.59	0.16	0.09	97.74	0.327
7	0.04	1.10	0.23	1.86	1.05	0.12	0.26	0.02	0.12	0.54	0.031

06202 Matahina Ignimbrite: (total) (integr)											
	0.07	11.95	1.47	44.17	40.55	0.56	0.65	0.22	n.d.	99.64	0.352
	0.06	10.42	1.42	47.83	39.25	0.88	0.59	0.31	0.13	100.89	0.302
	0.04	10.05	1.51	46.74	38.71	0.50	0.52	0.12	0.12	98.31	0.303
	0.17	11.97	1.57	43.58	40.60	0.61	0.70	0.16	n.d.	99.36	0.356
	0.14	10.49	1.62	47.51	39.95	0.68	0.60	0.01	n.d.	101.00	0.308
	0.10	11.61	1.51	45.61	40.77	0.53	0.73	0.14	0.35	101.35	0.339
	0.11	10.40	1.50	47.34	39.51	0.58	0.50	0.22	n.d.	100.16	0.326
	0.10	10.98	1.51	46.11	39.91	0.62	0.61	0.17	.7	100.10	0.324
7	0.05	0.82	0.07	1.70	0.78	0.13	0.09	0.09		1.08	0.024
?	0.12	14.76	3.23	36.53	40.28	0.34	2.59	0.11	n.d.	97.96	0.448
?	0.06	8.78	2.60	49.15	35.95	0.53	1.85	0.11	n.d.	99.03	0.258

b	0.00	8.75	1.37	48.71	36.19	0.40	1.14	0.09	0.20	96.85	0.260
b	0.00	7.02	1.49	52.02	34.00	0.97	1.10	0.18	0.04	96.82	0.205
	0.00	7.89	1.43	50.37	35.10	0.69	1.12	0.14	0.12	96.84	0.233
2	0.00	1.22	0.08	2.34	1.55	0.40	0.03	0.06	0.11	0.02	0.039
c	0.00	12.83	2.28	40.10	38.37	0.49	2.14	0.08	0.06	96.35	0.385

site 83 = Wilson's farm-(5) (V15/384620)

06302 reworked(?) Chinkao-L: (pum) [integ]												
0.08	10.32	2.77	46.27	36.81	0.55	2.29	0.16	0.15	99.40	0.08	0.02	0.02
0.19	9.66	2.99	45.55	35.28	0.43	3.08	0.11	0.36	98.65	0.293		
0.09	10.92	2.88	45.45	37.41	0.49	2.45	0.22	0.28	100.19	0.319		
0.15	10.79	2.93	45.02	37.14	0.63	2.37	0.15	0.10	99.28	0.318		
0.10	10.75	2.88	45.77	37.71	0.53	2.45	0.12	0.04	100.35	0.313		
0.10	10.12	3.37	46.22	35.96	0.51	2.85	0.12	0.12	99.37	0.297		
0.13	9.56	3.91	46.79	35.09	0.52	3.16	0.18	0.19	99.53	0.282		
0.10	9.66	4.12	46.40	35.28	0.31	3.16	0.29	0.18	99.50	0.288		
0.12	10.22	3.36	45.93	36.34	0.50	2.73	0.17	0.18	99.53	0.302		
8	0.04	0.56	0.57	0.58	1.06	0.09	0.38	0.06	0.10	0.53	0.014	

09302 Terephthalate (T): (mtb) [integr]											
	0.00	11.06	1.20	44.40	39.56	0.38	0.41	0.13	0.15	97.29	0.336
	0.07	9.33	1.25	47.63	37.37	0.51	0.75	0.08	0.08	97.07	0.280
	0.04	10.20	1.23	46.02	38.47	0.45	0.58	0.11	0.12	97.18	0.308
2	0.05	1.22	0.04	2.28	1.55	0.09	0.24	0.04	0.05	0.16	0.040

09303 Torsen-1 (?): (mb) (integer)											
irm	0.01	37.82	0.29	24.97	30.79	0.39	1.64	0.04	0.03	96.08	0.712
irm	0.01	38.20	0.23	24.12	30.99	0.93	1.35	0.03	0.09	95.95	0.750
irm	0.01	37.40	0.35	26.85	30.11	0.66	1.56	0.10	0.06	97.10	0.725
irm	0.00	37.64	0.08	26.07	30.23	0.99	1.44	0.05	0.00	96.50	0.732
irm	0.00	36.85	0.30	26.61	30.04	0.44	1.47	0.04	0.01	95.76	0.725
irm	0.00	37.50	0.37	25.55	29.80	0.59	1.84	0.05	0.01	95.71	0.734
	0.02	37.57	0.27	25.70	30.33	0.67	1.55	0.05	0.03	96.18	0.735
6	0.04	0.45	0.11	1.03	0.46	0.25	0.17	0.02	0.04	0.53	0.100

SiO₂ TiO₂ Al₂O₃ Fe₂O₃ FeO MnO MgO ZnO Cr₂O₃ total ulvöspin.

site 94 = Whitely Rd. (V16/350152)

09401 Quartz-biotite ignimbrite (unknown?): (mb) (integr)												
0.10	4.05	1.32	59.68	33.66	0.96	0.20	0.39	0.05	100.41	0.118		
0.15	6.40	1.55	55.16	36.09	1.06	0.31	0.16	0.17	100.05	0.188		
0.06	4.83	1.52	59.09	34.79	1.03	0.29	0.20	0.08	101.89	0.140		
0.14	6.80	1.81	53.57	36.06	1.11	0.34	0.33	0.34	100.50	0.203		
0.22	6.20	1.28	55.58	35.97	1.11	0.22	0.11	n.d.	100.69	0.181		
0.16	6.16	1.50	55.21	35.16	1.40	0.30	0.32	0.07	100.28	0.180		
0.02	4.46	1.78	58.26	33.84	0.87	0.28	0.30	n.d.	99.81	0.133		
0.10	3.83	1.23	58.83	32.95	0.87	0.27	0.19	0.04	98.31	0.114		
0.15	4.38	1.60	57.18	33.46	0.83	0.30	0.30	0.03	98.23	0.132		
0.12	5.23	1.51	56.95	34.66	1.03	0.28	0.26	0.11	100.02	0.154		
0.06	1.14	0.21	2.15	1.23	0.18	0.04	0.09	0.11	1.15	0.034		
9												
b	0.10	12.90	1.24	41.49	40.93	1.40	0.42	0.07	0.37	98.98	0.384	
b	0.16	11.71	1.41	42.48	39.63	1.21	0.39	0.14	0.27	97.40	0.357	
0.13	12.31	1.33	41.99	40.28	1.31	0.41	0.32	0.11	98.19	0.371		
2	0.04	0.84	0.12	0.70	0.92	0.13	0.02	0.07	0.05	1.12	0.019	
c	n.d.	9.96	1.14	48.23	38.49	1.42	0.29	n.d.	0.06	99.59	0.290	
c	0.12	9.70	1.46	46.84	37.80	1.27	0.40	0.13	0.17	97.89	0.292	
0.12	9.83	1.30	47.54	38.15	1.35	0.35	0.12	0.13	98.74	0.291		
2	--	0.18	0.23	0.98	0.49	1.11	0.08	0.08	--	1.20	0.001	

site 95 = Parapara Rd. (V16/294147)

09501 Quartz-biotite ignimbrite; altered (unknown?): (pum) (integr)												
0.11	8.64	1.37	49.89	37.00	0.92	0.64	0.23	0.12	98.92	0.254		
0.13	8.56	1.40	50.44	37.60	0.92	0.44	0.11	0.05	99.65	0.253		
0.07	7.65	1.42	50.19	35.70	0.83	0.43	0.29	0.11	96.69	0.233		
0.11	8.88	1.32	48.86	37.14	0.95	0.55	0.12	0.09	98.02	0.264		
0.07	8.59	1.42	48.57	36.25	0.90	0.65	0.19	0.07	96.71	0.258		
0.13	8.80	1.32	49.86	37.22	1.08	0.57	0.22	0.05	99.25	0.257		
0.09	8.48	1.32	49.31	36.73	0.85	0.51	0.12	0.06	97.47	0.254		
0.10	8.51	1.37	49.59	36.81	0.92	0.54	0.18	0.08	98.10	0.253		
7	0.02	0.41	0.05	0.69	0.64	0.08	0.09	0.07	0.03	1.21	0.010	
7	0.09	5.96	1.57	54.78	34.99	0.72	0.51	0.16	0.18	98.96	0.178	

site 111 = Peach Rd. (????????)

11101 Whakamaru, pre-ignimbrite airfall (weathered): (mb) (integr)												
0.20	8.37	1.49	48.65	36.41	0.70	0.77	0.21	0.44	97.24	0.255		
0.18	8.61	1.56	49.02	36.92	0.54	0.82	0.21	0.09	97.95	0.258		
0.13	8.41	1.46	50.09	36.97	0.54	0.89	0.13	0.45	99.07	0.250		
0.16	8.57	1.48	48.38	36.79	0.52	0.79	0.02	0.27	96.98	0.262		
0.19	8.85	1.55	48.37	36.83	0.73	0.87	0.19	0.12	97.7	0.265		
0.13	8.68	1.47	49.10	36.98	0.44	0.83	0.29	0.23	98.15	0.260		
0.12	8.32	1.44	49.94	36.68	0.53	0.78	0.32	0.33	98.46	0.248		
0.22	8.75	1.54	48.29	37.07	0.59	0.84	0.14	0.46	97.90	0.266		
0.17	8.57	1.50	48.98	36.83	0.57	0.82	0.19	0.30	97.93	0.258		
8	0.04	0.19	0.05	0.71	0.21	0.10	0.04	0.09	0.15	0.66	0.007	
11102 unknown?: (mb) (integr)												
0.18	7.50	1.45	50.11	35.61	0.88	0.48	0.22	0.13	96.56	0.229		
0.25	7.66	1.32	51.10	36.83	0.79	0.35	0.16	0.20	98.66	0.231		
0.20	7.63	1.24	50.71	36.05	0.94	0.43	0.25	0.22	97.67	0.229		
0.10	7.86	1.21	51.31	36.62	0.82	0.45	0.20	0.24	98.81	0.233		
0.10	7.55	1.20	51.72	36.21	0.93	0.41	0.14	0.16	98.42	0.224		
0.21	8.65	1.30	48.51	37.21	0.56	0.50	0.27	0.24	97.45	0.263		
0.17	7.81	1.29	50.58	36.42	0.82	0.44	0.21	0.20	97.93	0.234+		
6	0.06	0.43	0.09	1.15	0.58	0.14	0.05	0.05	0.04	0.86	0.014	
b	0.13	8.61	4.10	48.53	34.11	0.58	3.10	0.40	0.11	99.67	0.253	

site 112 = Reid's Reserve (W15/611452)

11201 Reid's Reserve: (mb) (integr)												
0.05	11.00	1.36	45.24	39.37	0.63	0.58	0.25	0.11	98.59	0.327		
0.05	10.51	1.46	46.56	38.92	0.66	0.68	0.28	0.11	99.23	0.310		
0.08	10.88	1.38	45.59	39.50	0.61	0.55	0.23	0.11	98.93	0.324		
0.14	11.02	1.32	45.56	39.66	0.52	0.66	0.27	0.00	99.15	0.325		
0.12	10.82	1.38	46.40	39.57	0.64	0.71	0.28	0.09	100.21	0.316		
0.10	11.38	1.41	44.64	39.93	0.63	0.63	0.16	0.10	98.98	0.338		
0.09	10.94	1.39	45.70	39.49	0.62	0.64	0.25	0.09	99.18	0.323		
6	0.04	0.29	0.05	0.76	0.34	0.06	0.06	0.05	0.04	0.55	0.010	

APPENDIX - H:

Hornblende chemical data

- microprobe analyses of
Bay of Plenty tephras

	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	total		SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	total
00101 Herepuru: (pum) (pkarch)											01401 unknown?: below road level: (pum) (pkarch)										
	47.84	0.79	6.33	17.78	0.48	12.75	8.85	1.45	0.39	96.66		47.20	1.83	7.31	12.27	0.57	15.53	11.23	1.55	0.36	97.85
	48.00	0.82	6.54	16.50	0.39	13.79	8.89	1.14	0.36	96.43		47.45	1.71	7.00	12.13	0.63	14.84	11.27	1.39	0.34	96.76
	46.03	1.03	8.12	16.87	0.46	12.68	7.01	1.76	0.40	94.36		47.03	1.92	7.37	12.36	0.56	15.31	11.40	1.66	0.32	97.93
	47.87	0.60	5.85	18.32	0.73	12.75	7.05	1.28	0.25	94.70		47.88	1.62	6.96	12.33	0.58	15.68	11.13	1.55	0.30	98.03
	47.16	0.41	6.71	17.68	0.66	12.66	7.97	1.39	0.38	95.02		47.03	1.88	7.14	11.85	0.58	15.49	11.00	1.61	0.30	96.88
	45.72	1.18	7.61	18.18	0.47	11.84	8.68	1.58	0.48	95.74		46.41	1.81	7.43	12.22	0.66	15.16	11.47	1.69	0.33	97.18
	47.10	0.81	6.86	17.56	0.53	12.75	8.08	1.43	0.38	95.49		47.17	1.80	7.20	12.19	0.60	15.34	11.25	1.58	0.33	97.44
6	1.00	0.28	0.85	0.72	0.13	0.62	0.87	0.22	0.08	0.94	6	0.49	0.11	0.20	0.19	0.04	0.30	0.17	0.11	0.02	0.57
? 46.96 0.51 6.70 18.90 0.60 11.85 4.29 1.45 0.36 91.62																					
00201 Matahina: pre-igb. airfall (near base): (pum) (pkarch)											01501 Matahina: coarse pumice near base: (pum) (integr)										
	45.57	1.28	6.88	19.14	0.60	11.42	10.50	1.44	0.34	97.17		45.26	2.00	8.51	14.81	0.45	13.18	10.73	1.65	0.24	96.83
	45.49	1.60	7.20	16.75	0.38	12.70	10.91	1.59	0.33	96.95		43.10	2.10	10.13	13.31	0.32	13.75	10.88	1.96	0.40	95.95
	46.01	1.29	6.77	18.97	0.58	11.61	10.17	1.41	0.27	97.08		43.30	2.42	9.88	12.18	0.19	14.73	11.13	2.02	0.36	96.21
	45.78	1.56	7.25	18.86	0.54	11.19	10.55	1.52	0.34	97.59		43.67	2.66	10.16	12.08	0.33	14.35	11.12	2.02	0.26	96.65
	46.17	1.59	7.61	16.79	0.55	11.94	10.82	1.62	0.47	97.56		43.88	2.13	9.86	13.77	0.29	13.51	10.60	1.93	0.36	96.33
	45.19	1.26	6.53	18.61	0.55	11.50	10.35	1.48	0.35	95.82		44.84	1.87	9.41	12.11	0.26	14.76	11.00	1.87	0.35	96.47
	45.70	1.43	7.04	18.19	0.53	11.73	10.55	1.51	0.35	97.03		45.95	1.81	7.40	17.13	0.44	12.11	10.37	1.65	0.27	97.13
6	0.36	0.17	0.39	1.11	0.08	0.54	0.28	0.08	0.07	0.65		44.43	2.60	9.47	10.00	0.37	14.24	10.82	2.05	0.37	94.35
												44.30	2.20	9.35	13.17	0.33	13.83	10.83	1.89	0.33	96.24
											8	1.00	0.32	0.95	2.14	0.09	0.89	0.26	0.16	0.06	0.85
00502 Anaputa: (pum) (pkarch)											01505 Ohirua Hill: (total) (integr)										
	46.81	1.41	6.91	16.50	0.41	12.70	10.80	1.65	0.33	97.52		44.93	2.21	8.55	13.70	0.44	14.26	10.79	1.72	0.33	96.93
	45.73	1.82	7.21	16.55	0.56	12.23	11.32	1.62	0.38	97.42		44.52	1.83	8.84	14.02	0.30	13.40	10.80	1.75	0.26	95.72
	45.91	1.79	7.56	16.92	0.43	12.36	10.86	1.76	0.38	97.97		41.86	3.03	10.79	14.54	0.25	12.53	10.52	2.28	0.24	96.04
	45.04	2.17	8.63	14.85	0.38	12.92	11.09	1.94	0.35	97.37		43.61	2.69	9.68	13.81	0.37	13.43	10.54	2.05	0.25	96.43
	44.99	1.83	7.63	16.94	0.47	11.52	10.86	1.64	0.35	96.23		42.39	3.12	9.92	14.13	0.35	12.92	10.53	2.28	0.25	95.89
	47.99	1.44	6.06	15.38	0.48	13.51	10.96	1.28	0.32	97.42		45.13	1.87	8.13	11.49	0.57	14.89	10.94	1.65	0.32	94.99
	46.82	1.30	6.50	17.15	0.56	12.26	10.72	1.39	0.30	97.00		46.84	1.69	7.51	12.93	0.55	14.61	10.68	1.65	0.38	96.84
	46.18	1.68	7.21	16.35	0.47	12.50	10.94	1.61	0.34	97.28		44.18	2.35	9.06	13.52	0.40	13.72	10.69	1.91	0.29	96.12
7	1.09	0.31	0.84	0.87	0.07	0.63	0.20	0.22	0.03	0.54	7	1.71	0.60	1.13	1.02	0.12	0.88	0.16	0.29	0.05	0.68
00801 Kohiaawa-3: (pum) (pkarch)											01707 Kaingaroa: (mtb) (integr)										
	47.57	1.21	6.63	16.17	0.45	13.42	9.12	1.55	0.40	96.52	a	44.60	1.74	7.20	17.48	0.50	11.68	10.71	1.68	0.34	95.93
	47.64	1.14	6.79	16.35	0.39	13.40	8.84	1.44	0.42	96.41	b	42.33	3.13	9.92	12.42	0.29	13.91	10.74	2.07	0.37	95.28
	47.23	1.12	6.67	17.90	0.54	12.59	8.99	1.43	0.42	96.89											
	46.71	1.39	7.86	15.07	0.39	13.40	9.37	1.56	0.37	96.12											
	47.29	1.22	6.99	16.37	0.44	13.20	9.08	1.50	0.40	96.49											
4	0.43	0.12	0.59	1.16	0.07	0.40	0.22	0.07	0.02	0.32											
b 44.20 1.96 10.09 15.87 0.37 12.84 9.50 2.02 0.17 97.02											01902 Ohirua Harbour-B (?): (mtb) (integr)										
b 44.69 1.80 10.01 15.63 0.32 12.89 9.38 2.06 0.15 96.93												46.04	1.41	6.84	16.46	0.44	13.30	10.40	1.51	0.33	96.76
	44.45	1.88	10.05	15.75	0.35	12.87	9.44	2.04	0.16	96.98		46.77	1.15	6.66	17.36	0.70	12.94	10.30	1.36	0.43	97.67
2	0.35	0.11	0.06	0.17	0.04	0.04	0.08	0.03	0.01	0.06		48.27	1.10	5.56	15.74	0.60	13.85	10.16	1.22	0.28	96.78
												47.11	1.37	6.45	16.81	0.57	12.76	10.24	1.57	0.51	97.39
												47.46	1.22	6.10	16.71	0.71	12.96	10.69	1.41	0.37	97.63
												46.69	1.12	6.17	16.53	0.72	12.74	9.98	1.36	0.28	95.59
												45.93	1.24	6.43	17.77	0.70	12.63	10.29	1.19	0.38	96.56
												46.96	1.20	6.81	17.22	0.75	12.45	10.20	1.23	0.39	97.21
												47.73	1.56	6.75	15.65	0.56	12.75	10.79	1.22	0.41	97.42
												47.59	1.18	6.95	16.21	0.57	12.90	10.32	1.34	0.46	97.52
												48.04	1.19	6.52	15.63	0.51	13.35	9.89	1.37	0.42	96.92
												47.37	1.70	6.39	16.21	0.59	12.88	10.33	1.38	0.34	97.19
												45.73	1.32	6.65	16.82	0.64	12.26	10.09	1.38	0.54	95.43
												46.35	1.26	6.79	16.62	0.61	12.93	9.98	1.35	0.46	96.35
												46.72	1.26	6.29	15.21	0.43	13.39	10.32	1.22	0.39	95.23
												46.98	1.29	6.49	16.46	0.61	12.94	10.27	1.34	0.40	96.78
											15	0.77	0.17	0.36	0.71	0.10	0.40	0.24	0.11	0.08	0.81
00901 Ohinekoao-1: (pum) (pkarch)											01903 Reeves-A: (mtb) (integr)										
	44.24	1.92	9.70	13.75	0.24	13.82	9.11	2.02	0.22	95.02		45.37	1.24	7.04	19.52	0.61	11.39	9.71	1.33	0.42	96.63
	44.92	1.85	8.84	16.04	0.33	12.93	9.10	1.89	0.28	96.18		45.90	1.32	7.23	16.67	0.40	13.18	10.37	1.40	0.38	96.85
	45.03	2.10	9.37	15.33	0.25	13.40	9.20	1.91	0.30	96.89		44.75	1.28	7.57	17.42	0.57	12.08	10.30	1.32	0.42	95.71
	43.47	2.12	9.63	13.83	0.30	13.38	8.75	1.95	0.23	93.66		45.48	1.19	7.59	18.26	0.62	11.55	10.25	1.24	0.39	96.57
	44.03	2.25	9.73	13.65	0.39	13.40	9.02	1.99	0.28	95.42		46.94	1.30	7.43	17.82	0.50	12.37	10.40	1.16	0.37	98.29
	44.62	1.97	9.04	15.60	0.37	13.20	9.03	1.84	0.28	95.95		45.99	1.47	7.22	15.76	0.49	13.25	10.80	1.31	0.42	96.71
	44.39	2.04	9.39	14.70	0.31	13.47	9.04	1.93	0.27	95.52		45.59	1.17	7.53	17.61	0.40	11.94	10.24	1.58	0.37	96.43
6	0.59	0.15	0.37	1.07	0.06	0.42	0.15	0.07	0.03	1.12		45.72	1.28	7.37	17.58	0.51	12.25	10.30	1.33	0.40	96.74
											7	0.67	0.10	0.21	1.19	0.09	0.73	0.32	0.13	0.02	0.78
b 45.37 1.64 7.98 17.48 0.43 12.24 9.01 1.54 0.35 96.04											01906 Jackson (?): (mtb) (integr)										
01301 Torere School: (pum) (integr)												47.25	1.23	6.86	15.11	0.31	13.90	10.58	1.32	0.39	96.95
	48.73	1.49	6.66	14.64	0.34	14.22	11.07	1.18	0.31	98.64		46.61	1.30	6.97	14.66	0.44	14.15	10.98	1.31	0.39	97.81
	47.92	1.26	6.11	14.02	0.41	14.64	11.04	1.17	0.27	96.84		46.87	1.37	6.97	15.63	0.56	13.69	11.14	1.34	0.43	98.00
	47.45	1.55	6.87	14.55	0.41	14.27	11.14	1.42	0.29	97.95		47.78	1.39	6.98	14.43	0.36	14.48	10.94	1.29	0.36	98.01
	46.71	1.50	7.24	15.36	0.36	13.77	11.06	1.35	0.39	97.74		46.81	1.31	7.36	17.24	0.55	12.69	10.54	1.29	0.49	98.28
	47.03	1.50	6.92	14.36	0.34	14.15	11.28	1.29	0.29	97.16		47.17	1.62	7.19	15.45	0.32	13.71	11.16	1.41	0.45	98.48
	48.34	1.47	6.64	15.18	0.49	13.62	11.16	1.33	0.31	98.54		47.99	1.61	6.58	16.15	0.45	13.04	10.80	1.41	0.48	98.51
	47.64	1.54	6.72	14.09	0.29	13.98	11.22	1.23	0.26	96.97		46.33	1.27	6.86	16.66	0.51	12.77	10.67	1.29	0.40	96.76
	47.89	1.39	6.40	14.99	0.48	13.99	11.41	1.20</													

	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	total
02105 Paerata; (crs-ash) (pkrsch)										
	43.14	1.71	11.16	12.78	0.30	14.06	9.19	1.84	0.24	94.42
02106 Otawairere; (crs-ash) (pkrsch)										
	48.00	0.46	5.85	17.77	0.61	12.50	8.90	1.08	0.41	95.58
	46.73	0.53	6.80	18.45	0.64	11.98	8.83	1.40	0.43	95.79
	47.96	0.48	6.13	18.06	0.67	12.40	8.89	1.34	0.35	96.28
	49.52	0.49	6.64	17.91	0.58	12.83	8.64	1.47	0.44	98.52
	48.05	0.49	6.36	18.05	0.63	12.43	8.82	1.32	0.41	96.54
4	1.14	0.03	0.44	0.29	0.04	0.35	0.12	0.17	0.04	1.35
02301 Matahina; pre-ignimbrite airfall; (pum) (pkrsch)										
	46.52	1.20	6.69	19.04	0.57	11.37	10.46	1.48	0.30	97.63
	46.50	1.56	7.04	15.13	0.37	13.29	11.32	1.50	0.30	97.01
	45.06	1.77	7.78	16.68	0.52	12.17	11.11	1.66	0.38	97.13
	46.93	1.44	6.72	16.06	0.52	12.84	10.95	1.45	0.31	97.22
	46.15	1.23	6.74	18.30	0.46	11.03	10.78	1.44	0.26	96.39
	46.36	1.59	6.70	17.30	0.57	12.15	10.71	1.51	0.32	97.21
	46.25	1.47	6.95	17.09	0.50	12.14	10.89	1.51	0.31	97.10
6	0.64	0.22	0.43	1.44	0.08	0.85	0.31	0.08	0.04	0.41
02701 Hiwarau; (pum) (integr)										
	42.39	2.42	9.83	18.49	0.42	10.68	10.53	2.18	0.41	97.35
	45.79	1.85	8.36	15.21	0.44	13.25	10.47	1.52	0.23	97.12
	44.09	2.14	9.10	16.85	0.43	11.97	10.50	1.85	0.32	97.24
2	2.40	0.40	1.04	2.32	0.01	1.82	0.04	0.47	0.13	0.16
02802 Waingarara Ignimbrite; many pumices; (pum) (integr)										
	43.98	2.18	8.69	18.59	0.53	10.71	10.52	1.85	0.49	97.54
	46.11	1.53	6.99	18.86	0.57	11.38	10.26	1.69	0.45	97.84
	44.43	2.32	8.61	18.75	0.47	10.73	10.47	1.88	0.54	98.40
	46.68	1.13	6.55	18.58	0.58	12.24	9.56	1.53	0.39	97.24
	42.95	1.15	6.44	18.49	0.64	10.23	9.80	1.32	0.38	91.40
	45.95	1.79	6.89	17.99	0.50	11.46	10.11	1.62	0.59	96.90
	44.89	2.06	8.26	18.37	0.39	11.11	10.11	1.81	0.46	97.46
	45.00	1.74	7.49	18.52	0.53	11.12	10.12	1.67	0.47	96.65
7	1.33	0.48	0.99	0.28	0.08	0.65	0.35	0.20	0.08	2.35
03202 Jackson Rd.; (mtx) (integr)										
	46.73	1.08	5.25	16.65	0.65	12.99	9.80	1.09	0.35	94.59
	46.47	1.29	6.07	17.02	0.66	12.49	10.53	1.30	0.44	96.27
	46.12	1.23	6.10	17.03	0.54	12.25	10.17	1.37	0.40	95.21
	45.82	1.28	6.48	17.32	0.67	11.93	10.41	1.51	0.50	95.92
	44.57	1.23	5.77	17.04	0.63	11.98	10.31	1.08	0.40	93.01
	45.33	1.38	6.67	17.49	0.60	12.06	10.45	1.34	0.46	95.78
	46.94	1.39	6.99	17.54	0.69	13.04	10.05	1.44	0.44	98.52
	46.74	1.35	6.28	16.34	0.60	13.17	10.20	1.42	0.40	96.50
	45.70	1.50	6.52	15.19	0.30	13.25	10.58	1.44	0.42	94.90
	47.54	1.51	6.18	15.49	1.15	13.90	10.48	1.40	0.43	98.08
	46.20	1.32	6.23	16.71	0.65	12.71	10.30	1.34	0.42	95.88
10	0.87	0.13	0.49	0.81	0.21	0.66	0.24	0.15	0.04	1.62
03902 Waingarara; pre-ignimbrite airfall; (mtx+) (integr)										
	44.52	2.03	7.70	18.36	0.55	10.56	10.67	1.93	0.52	96.84
	45.34	2.11	9.14	16.92	0.40	10.63	10.24	2.11	0.44	97.33
	43.83	2.14	8.06	18.84	0.46	10.96	10.32	2.01	0.45	97.07
	46.93	1.71	6.93	17.17	0.45	11.10	10.48	1.74	0.58	97.09
	43.01	2.05	8.31	17.83	0.50	10.46	10.86	1.75	0.57	95.34
	41.94	2.12	8.19	17.86	0.32	10.06	10.69	1.90	0.52	93.60
	45.43	1.73	7.04	17.84	0.45	11.10	10.17	1.66	0.46	95.88
	44.43	1.98	7.91	17.83	0.45	10.70	10.49	1.87	0.51	96.16
7	1.67	0.18	0.77	0.65	0.07	0.38	0.26	0.16	0.06	1.34
04103 Westend; (unknown?); (total) (integr)										
	46.40	1.86	8.50	14.52	0.34	13.24	10.86	1.72	0.43	97.87
	46.06	1.63	7.94	17.04	0.21	11.92	10.66	1.62	0.38	97.46
	45.29	1.94	8.27	18.15	0.34	11.74	10.57	1.56	0.43	98.29
	48.33	1.32	7.00	12.48	0.58	15.46	10.77	1.47	0.34	97.75
	47.56	1.30	8.30	12.78	0.32	15.03	10.32	1.11	0.34	97.06
	45.96	1.46	8.02	17.21	0.36	12.01	10.56	1.60	0.39	97.57
	44.86	1.90	8.22	18.11	0.39	11.33	10.45	1.80	0.40	97.46
	46.35	1.63	8.04	15.76	0.36	12.96	10.60	1.55	0.39	97.64
7	1.22	0.28	0.49	2.45	0.11	1.67	0.18	0.22	0.04	0.39
?	44.39	1.32	12.17	14.65	0.27	13.19	10.29	1.69	0.27	98.24
04105 Paerata; near base (mixed Paerata/Tab-D); (total) (integr)										
	43.40	2.36	12.83	13.59	0.33	13.82	10.71	2.05	0.28	99.37

	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	total
04201 Tirohanga; (mtx) (integr)										
	43.66	2.13	8.69	14.53	0.26	13.12	10.68	1.59	0.38	95.04
	45.20	1.68	7.63	15.86	0.45	12.70	10.66	1.73	0.37	96.28
	43.83	2.38	9.25	15.43	0.22	12.37	10.96	1.90	0.43	96.77
	43.77	2.31	8.92	14.87	0.31	12.53	10.85	1.78	0.36	95.70
	45.84	1.64	7.03	16.44	0.45	12.85	10.44	1.36	0.30	96.35
	44.54	2.02	8.63	14.44	0.33	13.23	10.52	1.92	0.35	95.98
	43.34	2.43	9.59	14.42	0.41	12.63	10.69	2.10	0.45	96.06
	44.31	2.08	8.53	15.14	0.35	12.78	10.69	1.77	0.38	96.03
7	0.92	0.32	0.90	0.79	0.09	0.31	0.18	0.24	0.05	0.55
04202 Jackson Rd.; (mtx) (integr)										
	47.17	1.39	6.34	17.00	0.69	12.16	10.21	1.44	0.45	96.85
	47.37	1.33	6.54	17.48	0.71	12.30	10.47	1.44	0.49	98.13
	47.10	1.21	6.03	17.00	0.60	12.81	10.48	1.27	0.40	96.90
	46.75	1.24	6.41	16.93	0.76	12.42	10.04	1.24	0.40	96.19
	44.12	1.49	6.10	15.58	0.53	12.30	9.87	1.23	0.42	91.64
	43.67	1.31	6.00	16.11	0.44	12.19	10.42	1.18	0.43	91.75
	44.52	1.66	7.11	16.27	0.58	12.17	10.47	1.59	0.58	94.95
	46.47	1.27	6.65	17.33	0.61	12.23	10.23	1.41	0.53	96.73
	46.97	1.25	6.65	16.17	0.68	12.79	10.41	1.55	0.47	96.93
	46.02	1.35	6.43	16.65	0.62	12.37	10.29	1.37	0.46	95.56
9	1.47	0.14	0.36	0.64	0.10	0.25	0.22	0.15	0.06	2.34
b	43.75	2.29	8.93	13.57	0.45	13.01	10.55	1.81	0.32	94.68
06208 Reihana-F(1); (mtx) (integr)										
	44.73	2.72	9.75	14.38	0.49	13.03	10.78	2.14	0.46	98.48
	41.30	2.70	10.32	13.68	0.31	12.63	10.58	2.21	0.30	94.03
	43.22	2.65	8.92	15.02	0.37	12.66	10.72	1.99	0.28	95.83
	41.80	2.89	10.42	13.78	0.33	13.84	11.19	2.08	0.35	95.68
	41.77	2.71	11.01	14.06	0.26	13.22	11.02	2.57	0.26	96.88
	42.56	2.73	10.08	14.18	0.35	12.88	10.86	2.20	0.33	96.18
5	1.41	0.09	0.79	0.54	0.09	0.24	0.24	0.22	0.08	1.64
?	46.06	1.87	7.38	12.19	0.45	15.04	11.17	1.59	0.37	96.12
06601 Te Piki (Hiwarau/unknown?); (mtx) (integr)										
	45.35	2.03	9.18	14.36	0.33	13.45	11.88	1.82	0.40	98.80
	46.97	1.63	6.89	14.28	0.41	13.25	11.02	1.32	0.32	96.09
	45.29	2.17	8.78	17.51	0.50	11.33	10.67	1.45	0.43	98.13
	46.26	2.37	8.79	13.34	0.23	13.64	11.43	1.86	0.34	98.26
	44.12	2.16	9.96	14.59	0.38	12.64	11.50	2.10	0.46	97.91
	45.65	1.42	7.00	16.45	0.53	11.98	10.46	1.74	0.46	95.62
	45.61	1.96	8.43	15.09	0.40	12.72	11.16	1.72	0.40	97.48
6	0.97	0.36	1.23	1.56	0.11	0.91	0.54	0.29	0.06	1.27
?	42.91	2.16	9.56	12.50	0.29	12.34	10.59	1.58	0.41	92.34
06701 Matahina (?); (mtx+) (integr)										
	45.33	1.33	8.21	15.34	0.22	12.81	10.40	1.36	0.36	95.36
	47.05	1.41	8.27	12.88	0.43	13.40	10.67	1.67	0.19	95.97
	44.93	2.13	9.75	12.96	0.34	14.16	10.92	1.96	0.44	97.59
	44.31	1.67	8.76	14.04	0.28	13.65	11.07	1.73	0.23	95.74
	44.67	2.12	9.04	13.66	0.32	14.10	11.17	1.81	0.23	97.12
	44.43	1.96	8.95	14.29	0.29	12.89	10.76	1.68	0.32	95.57
	45.12	1.77	8.83	13.86	0.31	13.50	10.83	1.70	0.30	96.23
6	1.01	0.35	0.57	0.92	0.07	0.58	0.28	0.20	0.10	0.91
b	42.92	1.43	6.10	16.14	0.62	11.51	10.18	1.24	0.34	90.48
b	42.81	1.41	6.20	16.54	0.57	11.55	10.33	1.29	0.43	91.13
	42.87	1.42	6.15	16.34	0.60	11.53	10.26	1.27	0.39	90.81
2	0.08	0.01	0.07	0.28	0.04	0.03	0.11	0.04	0.06	0.46
07806 unknown?; reworked rounded pumices; (pum) (integr)										
	47.43	1.02	5.95	17.31	0.71	12.67	10.15	1.28	0.27	96.79
	45.87	1.28	6.85	16.28	0.37	12.43	10.70	1.48	0.31	95.57
	46.75	1.62	6.83	16.49	0.35	12.30	10.90	1.45	0.32	97.01
	44.96	1.40	6.24	18.18	0.78	11.41	9.92	1.46		

	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	total		SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	total	
08201 Te Whaiti Ignimbrite; unwelded base; (mtb) (integr)											11102 unknown; (mtb) (integr)											
	46.80	1.72	7.02	15.49	0.43	13.09	10.79	1.60	0.55	97.49		47.13	1.25	7.13	18.37	0.82	11.46	10.27	1.49	0.44	98.36	
	45.69	1.73	6.76	15.78	0.45	12.99	10.53	1.34	0.50	95.77		47.14	1.29	6.83	17.06	0.54	12.63	10.24	1.39	0.45	97.57	
	46.42	1.62	6.96	15.64	0.31	13.15	10.78	1.54	0.50	96.92		46.11	1.24	6.64	16.75	0.61	12.00	10.09	1.41	0.44	95.29	
	45.92	1.68	7.44	15.54	0.32	12.60	10.69	1.70	0.54	96.43		46.07	1.32	6.47	16.67	0.71	12.12	10.17	1.36	0.41	95.30	
	46.68	1.67	7.10	15.31	0.36	13.23	11.00	1.61	0.43	97.32		45.14	1.49	6.64	16.47	0.50	11.85	10.13	1.53	0.53	94.28	
	46.30	1.68	7.06	15.55	0.37	13.01	10.76	1.56	0.50	96.80		46.36	1.25	6.93	18.43	0.80	11.45	10.48	1.40	0.52	97.62	
5	0.48	0.04	0.25	0.17	0.06	0.25	0.17	0.13	0.05	0.71		47.58	1.35	7.05	16.96	0.61	11.91	10.08	1.43	0.44	97.41	
?	44.19	1.83	6.47	15.38	0.38	11.61	10.74	1.22	0.61	92.43		46.50	1.31	6.81	17.24	0.66	11.92	10.21	1.43	0.46	96.55	
												7	0.83	0.09	0.24	0.81	0.12	0.41	0.14	0.06	0.05	1.55
08301 Ohinekoao-J; (crs-ash) (integr)																						
	46.17	1.17	6.34	17.39	0.65	12.77	9.96	1.41	0.34	96.20												
	46.96	1.29	6.23	17.25	0.69	12.93	10.41	1.37	0.40	97.53												
	46.97	1.25	6.02	16.69	0.59	12.92	10.50	1.39	0.26	96.59												
	46.79	1.09	6.05	15.84	0.61	13.61	10.12	1.28	0.36	95.75												
	46.53	1.38	6.90	17.41	0.53	12.52	10.31	1.51	0.43	97.52												
	46.33	1.37	6.88	18.04	0.40	12.32	10.24	1.40	0.40	97.38												
	47.30	1.08	6.00	17.70	0.73	12.72	10.18	1.30	0.44	97.45												
	44.55	1.67	6.40	16.36	0.58	12.25	10.52	1.17	0.49	93.99												
	46.46	1.41	6.92	15.85	0.55	13.31	10.53	1.46	0.46	96.95												
	46.45	1.30	6.42	16.95	0.59	12.82	10.31	1.37	0.40	96.60												
9	0.80	0.18	0.39	0.80	0.10	0.44	0.20	0.10	0.07	1.17												
?	41.70	2.77	9.74	17.14	0.65	11.18	10.71	2.46	0.59	96.94												
08302 reworked Ohinekoao-I; (pum) (integr)																						
a	44.66	1.81	8.06	17.14	0.60	11.16	10.56	1.52	0.44	95.95												
a	46.17	1.24	6.21	16.26	0.64	12.59	10.15	1.35	0.41	95.02												
a	46.39	1.21	6.45	17.17	0.46	12.37	9.93	1.35	0.38	95.71												
a	46.42	1.18	6.37	15.66	0.57	13.21	10.28	1.27	0.41	95.37												
a	46.54	1.15	6.39	16.67	0.48	13.26	10.32	1.33	0.43	96.57												
	46.04	1.32	6.70	16.58	0.55	12.52	10.25	1.36	0.41	95.72												
5	0.78	0.28	0.77	0.64	0.08	0.85	0.23	0.09	0.02	0.59												
b	44.43	2.50	10.06	13.74	0.39	13.50	10.86	2.02	0.38	97.88												
b	44.76	2.29	8.71	14.70	0.45	12.83	10.44	1.75	0.32	96.25												
b	44.18	2.15	8.66	14.90	0.28	12.96	10.71	1.85	0.37	96.06												
b	42.68	2.55	9.70	14.01	0.44	13.30	10.41	1.91	0.41	95.41												
	44.01	2.37	9.28	14.34	0.39	13.15	10.61	1.88	0.37	96.40												
4	0.92	0.19	0.71	0.55	0.08	0.31	0.22	0.11	0.04	1.05												
08303 Ohinekoao-K; (pum) (integr)																						
	42.33	1.44	6.52	16.42	0.57	10.98	9.87	1.23	0.40	89.76												
	42.32	2.40	8.90	17.47	0.52	10.93	10.31	2.12	0.43	95.40												
	42.33	1.92	7.71	16.95	0.55	10.96	10.09	1.68	0.42	92.58												
2	0.01	0.68	1.68	0.74	0.04	0.04	0.31	0.63	0.02	3.99												
08401 Wilson; (pum) (integr)																						
	46.13	1.55	7.12	16.52	0.53	12.62	10.66	1.45	0.36	96.94												
	47.26	1.25	6.83	16.30	0.34	13.28	10.03	1.38	0.26	96.93												
	44.71	1.87	8.62	16.55	0.42	12.27	10.13	1.83	0.33	96.73												
	45.75	1.83	7.03	15.39	0.44	12.99	10.24	1.36	0.28	95.31												
	43.55	2.15	9.21	16.10	0.38	12.19	10.47	1.73	0.34	96.12												
	46.91	1.78	7.34	16.05	0.37	13.45	10.86	1.52	0.31	98.59												
	45.72	1.74	7.69	16.15	0.41	12.80	10.40	1.55	0.31	96.77												
6	1.39	0.31	0.98	0.43	0.07	0.52	0.32	0.19	0.04	1.09												
08402 reworked Ohinekoao-A, -B, -C; (pum) (integr)																						
	46.64	1.43	6.85	14.61	0.37	14.06	10.58	1.17	0.36	96.07												
	47.38	1.22	5.72	17.49	0.70	13.01	10.22	1.24	0.40	97.38												
	45.29	1.50	7.03	17.35	0.40	11.83	10.23	1.66	0.40	95.69												
	45.75	1.38	6.14	16.17	0.64	12.87	10.50	1.32	0.45	95.22												
	47.85	1.34	6.14	16.82	0.62	12.04	10.40	1.33	0.44	96.98												
	45.69	1.17	6.12	17.20	0.75	12.23	10.27	1.26	0.41	95.10												
	46.43	1.34	6.33	16.61	0.58	12.67	10.37	1.33	0.41	96.07												
6	1.03	0.13	0.50	1.09	0.16	0.82	0.15	0.17	0.03	0.93												
09202 Ohiwa Harbour-B; (mtb) (integr)																						
	47.35	1.31	6.31	15.59	0.49	13.27	10.26	1.29	0.42	96.29												
	47.91	1.22	6.52	16.17	0.70	13.24	10.07	1.27	0.36	97.46												
	45.77	1.46	7.01	15.64	0.44	12.51	10.68	1.42	0.41	95.34												
	45.99	1.35	6.64	15.89	0.50	12.78	10.33	1.44	0.38	95.30												
	47.63	1.18	6.58	17.55	0.16	11.23	10.30	1.29	0.36	96.28												
	49.37	1.20	6.04	16.47	0.67	12.51	10.26	1.32	0.39	98.23												
	47.34	1.29	6.52	16.22	0.49	12.59	10.32	1.34	0.39	96.48												
6	1.33	0.11	0.33	0.73	0.19	0.75	0.20	0.07	0.03	1.17												
11101 Whakamaru; pre-ignimbrite airfall; (mtb) (integr)																						
	45.66	1.54	6.29	16.15	0.51	12.62	10.33	1.45	0.51	95.06												
	46.62	1.58	6.76	15.29	0.46	13.29	10.65	1.42	0.55	96.62												
	46.65	1.64	7.16	15.38	0.63	12.99	10.78	1.55	0.51	97.29												
	45.15	1.76	6.95	15.83	0.51	12.83	10.85	1.47	0.58	95.93												
	47.58	1.70	6.81	15.88	0.42	12.95	10.73	1.62	0.45	98.14												
	46.33	1.64	6.79	15.71	0.51	12.94	10.67	1.50	0.52	96.61												
5	0.95	0.09	0.32	0.36	0.08	0.24	0.20	0.08	0.05	1.19												

APPENDIX - I:

Cummingtonite chemical data

- microprobe analyses of
Bay of Plenty tephras

	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	CaO	Na ₂ O	K ₂ O	Cl	total		SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	CaO	Na ₂ O	K ₂ O	Cl	total		
00811 Paerata: (total) (pkarch)											06501 Rotolli: (mb) (pkarch)												
	51.60	0.37	2.16	23.81	1.23	16.47	1.59	0.38	0.07	0.05	97.73		53.82	0.00	1.43	19.35	1.27	19.01	1.87	0.33	0.00	97.08	
	52.38	0.22	1.76	22.94	1.30	16.92	1.61	0.35	0.00	0.05	97.53		53.04	0.23	1.42	18.59	1.47	19.14	1.86	0.32	0.00	96.07	
	52.21	0.36	1.81	23.76	1.33	16.67	1.36	0.33	0.06	0.05	97.94		50.55	0.40	2.35	19.34	1.51	18.64	1.93	0.51	0.00	95.23	
	51.90	0.33	1.73	23.40	1.28	16.79	1.39	0.29	0.08	0.00	97.19		52.47	0.21	1.73	19.09	1.42	18.93	1.89	0.39	0.00	96.13	
	53.66	0.19	1.56	23.11	1.28	16.84	1.35	0.45	0.06	0.00	98.50	3	1.71	0.20	0.53	0.44	0.13	0.26	0.04	0.11	0.00	0.93	
	52.35	0.29	1.80	23.40	1.28	16.74	1.46	0.36	0.05	0.03	97.78	07702 Rotolli: (mb) (Integr)											
5	0.79	0.08	0.22	0.39	0.04	0.18	0.13	0.06	0.03	0.49		54.59	0.35	1.83	18.70	1.60	19.04	1.89	0.36	0.00	0.04	98.40	
01303 Rotolli: (mb) (Integr)												53.72	0.33	1.85	18.89	1.49	18.95	2.41	0.40	0.06	0.00	98.10	
	52.47	0.45	2.13	19.22	1.48	19.08	2.28	0.60	0.00	0.07	97.78		52.21	0.28	2.05	18.77	1.52	18.64	2.53	0.44	0.00	0.10	96.54
	53.45	0.39	1.98	19.25	1.49	19.00	2.13	0.50	0.05	0.05	98.29		53.00	0.23	1.41	18.65	2.67	18.58	1.82	0.33	0.00	0.00	96.69
	54.06	0.27	1.46	18.81	1.55	19.23	1.78	0.34	0.00	0.06	97.56		52.76	0.30	1.45	19.29	1.34	19.19	1.84	0.37	0.00	0.07	96.61
	53.86	0.43	2.32	18.62	1.50	18.69	2.53	0.49	0.05	0.05	98.54		52.86	0.39	1.65	19.01	1.58	19.36	1.78	0.33	0.07	0.00	97.03
	54.93	0.29	1.47	18.88	1.45	19.32	1.62	0.45	0.06	0.07	98.54		53.19	0.31	1.71	18.89	1.70	18.96	2.05	0.37	0.02	0.04	97.23
	52.84	0.31	1.41	19.52	1.50	19.53	1.62	0.35	0.00	0.06	97.14	6	0.84	0.06	0.25	0.24	0.48	0.31	0.33	0.04	0.03	0.04	0.81
	51.73	0.17	1.27	19.49	1.45	19.20	1.65	0.34	0.05	0.09	95.44	08401 Wilson: (pum) (Integr)											
	52.56	0.38	1.63	18.70	1.70	19.41	1.94	0.45	0.00	0.07	96.84		55.39	0.15	4.17	20.33	0.86	13.83	1.32	0.67	0.56	0.00	97.28
	52.91	0.26	1.76	18.96	1.55	19.66	2.21	0.48	0.00	0.00	97.79	09304 Rotolli: (mb) (Integr)											
	53.20	0.33	1.71	19.05	1.52	19.24	1.97	0.44	0.02	0.06	97.55		53.75	0.15	1.32	18.03	1.47	19.67	1.72	0.22	0.04	0.05	96.42
9	0.97	0.09	0.36	0.33	0.08	0.29	0.33	0.09	0.03	0.98		52.91	0.24	1.22	18.41	1.50	18.97	1.58	0.32	0.00	0.05	95.20	
7 54.88 0.23 1.23 19.43 1.66 19.53 0.34 0.00 0.00 0.00 97.30												52.94	0.25	1.10	18.60	1.54	18.84	1.45	0.23	0.00	0.06	95.01	
												53.54	0.11	1.13	18.61	1.42	19.41	1.59	0.34	0.05	0.05	96.25	
												52.37	0.34	1.54	19.39	1.51	18.95	1.58	0.43	0.00	0.04	96.15	
												52.60	0.23	1.25	18.71	1.54	18.80	1.58	0.33	0.00	0.04	95.08	
												53.02	0.22	1.26	18.63	1.50	19.11	1.58	0.31	0.02	0.05	95.69	
											8	0.53	0.08	0.16	0.45	0.05	0.35	0.09	0.08	0.02	0.01	0.65	
											7 49.82 0.33 1.59 18.48 1.62 17.55 1.97 0.47 0.08 0.05 91.96												

APPENDIX - J:

Biotite chemical data

- microprobe analyses of
Bay of Plenty tephra

	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	Cl	total
00101 Herepuru; (pum) (pkscrh)											
	36.31	2.53	13.32	20.67	0.29	11.14	0.00	0.50	7.41	0.38	92.55
	36.79	2.57	13.56	20.91	0.26	11.09	0.00	0.55	7.42	0.35	93.50
	36.01	3.29	13.37	22.08	0.33	10.37	0.00	0.43	7.56	0.31	93.75
	36.50	1.63	13.47	21.40	0.29	11.15	0.00	0.51	6.80	0.35	92.10
	36.79	2.15	13.36	21.52	0.20	11.06	0.00	0.52	7.12	0.39	93.11
	36.48	2.43	13.42	21.32	0.27	10.96	0.00	0.50	7.26	0.36	93.00
5	0.33	0.61	0.10	0.55	0.05	0.33	0.00	0.04	0.30	0.03	0.68
?	36.14	3.05	10.00	20.86	0.24	11.16	0.00	0.51	5.63	0.36	87.95
00803 Kohioawa Stream; (pum) (pkscrh)											
	35.29	4.68	13.50	20.21	0.34	11.26	0.05	0.57	8.92	0.38	95.20
	35.66	4.41	13.26	19.97	0.28	11.21	0.00	0.52	8.82	0.38	94.51
	36.10	4.69	13.28	20.05	0.37	10.98	0.19	0.45	8.73	0.38	95.22
	35.07	4.67	13.45	19.67	0.25	11.29	0.00	0.53	9.09	0.47	94.49
	35.53	4.61	13.37	19.98	0.31	11.19	0.06	0.52	8.89	0.40	94.86
4	0.45	0.14	0.12	0.23	0.05	0.14	0.09	0.05	0.15	0.05	0.41
	33.63	4.07	12.75	19.17	0.29	10.93	0.06	0.60	8.60	0.44	90.54
00810 Tablelands-C; (mtx+) (integr)											
	35.81	4.51	13.29	18.36	0.40	7.99	0.17	0.18	7.11	0.29	88.11
	38.80	3.97	16.79	16.00	0.37	7.23	0.25	0.18	6.07	0.24	89.90
	36.82	4.14	13.85	18.33	0.38	8.41	0.15	0.12	7.11	0.27	89.58
	35.61	4.44	13.56	21.27	0.29	8.45	0.13	0.13	7.62	0.32	91.82
	35.64	4.63	13.59	20.92	0.37	8.70	0.07	0.24	7.78	0.33	92.27
	36.54	4.34	14.22	18.98	0.36	8.16	0.15	0.17	7.14	0.29	91.34
5	1.36	0.27	1.45	2.16	0.04	0.58	0.07	0.05	0.67	0.04	1.71
01902 Ohiwa Harbour-B (?); (mtx) (integr)											
	38.17	4.15	13.56	18.21	0.24	10.76	0.06	0.57	7.97	0.27	93.96
	40.15	4.49	13.94	18.19	0.21	10.06	0.09	0.25	8.08	0.35	95.81
	39.16	4.32	13.75	18.20	0.23	10.41	0.08	0.41	8.03	0.31	94.89
2	1.40	0.24	0.27	0.01	0.02	0.49	0.02	0.23	0.08	0.06	1.31
01906 Jackson (?); (mtx+) (integr)											
	40.03	3.17	20.20	13.24	0.00	7.10	0.21	0.12	5.55	0.35	89.97
02106 Otawairere; (crs-ash) (pkscrh)											
	35.10	1.80	12.96	23.22	0.26	9.00	0.10	0.41	6.97	0.35	90.17
	36.19	1.92	13.33	21.71	0.30	10.36	0.00	0.41	7.33	0.33	91.88
	35.78	2.05	13.10	23.17	0.39	9.21	0.00	0.22	7.17	0.51	91.60
	35.69	1.92	13.13	22.70	0.32	9.52	0.03	0.35	7.16	0.40	91.22
3	0.55	0.13	0.19	0.86	0.07	0.73	0.06	0.11	0.18	0.10	0.92
04101 Tablelands-D; (total) (integr)											
	33.99	4.27	13.38	20.97	0.45	8.97	0.00	0.46	8.65	0.36	91.50
	35.20	4.57	13.28	21.62	0.37	10.42	0.07	0.38	8.88	0.33	95.12
	36.96	4.04	14.21	19.07	0.32	7.83	0.19	0.27	7.90	0.35	91.14
	34.38	4.36	13.00	21.59	0.35	9.02	0.11	0.39	8.51	0.41	92.12
	34.72	4.34	12.88	21.82	0.29	9.27	0.09	0.47	8.74	0.45	93.07
	35.05	4.32	13.35	21.01	0.36	9.10	0.09	0.39	8.54	0.38	92.59
5	1.16	0.19	0.52	1.13	0.06	0.92	0.07	0.08	0.38	0.05	1.59
07806 unknown(?); reworked rounded pumices; (pum) (integr)											
	35.69	4.47	13.39	19.20	0.21	11.34	0.14	0.59	8.59	0.34	93.96
08301 Ohinkoo-J; (crs-ash) (integr)											
	35.51	4.28	12.49	21.28	0.28	9.66	0.24	0.47	7.43	0.26	91.90
	35.96	4.42	13.93	20.46	0.24	11.34	0.07	0.51	8.30	0.31	95.54
	38.73	4.39	14.02	18.60	0.24	10.78	0.14	0.36	8.23	0.31	95.80
	34.50	4.40	13.26	18.44	0.14	11.77	0.06	0.46	8.37	0.39	91.79
	36.18	4.37	13.43	19.70	0.23	10.89	0.13	0.45	8.08	0.32	93.76
4	1.81	0.06	0.71	1.40	0.06	0.91	0.08	0.06	0.44	0.05	2.21
09202 Ohiwa-B (?); (mtx) (integr)											
	40.11	4.45	14.14	17.02	0.24	10.41	0.12	0.24	6.44	0.26	93.43
	41.44	4.54	14.29	16.31	0.13	10.67	0.09	0.37	6.54	0.30	94.68
	39.84	4.54	13.52	15.74	0.25	9.65	0.11	0.61	5.88	0.30	90.44
	40.87	4.73	13.78	17.32	0.13	9.15	0.06	0.22	6.65	0.29	93.20
	40.57	4.57	13.93	16.60	0.19	9.97	0.10	0.36	6.38	0.29	92.94
4	0.73	0.12	0.35	0.71	0.07	0.70	0.03	0.18	0.34	0.02	1.79

APPENDIX - K:

Pyroxene chemical data

- microprobe analyses of
Bay of Plenty tephras

	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	water		SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	water
01010 Herepuru; (pum) (pkrsch)																					
	52.24	n.d.	0.50	26.67	0.95	19.85	0.62	n.d.	n.d.	100.83		01401 Torere-I (77); below road level; (crs-ash) (pkrsch)	51.86	0.17	0.82	22.95	1.08	20.76	1.46	n.d.	99.10
													51.42	0.19	0.67	26.59	1.41	18.25	1.07	n.d.	99.60
													52.39	0.16	0.62	22.69	0.95	21.34	1.18	n.d.	99.33
													52.08	0.11	0.42	26.25	1.30	18.81	0.93	n.d.	99.90
													52.44	n.d.	0.37	22.30	1.45	21.24	1.00	n.d.	98.80
00201 Matahina; pre-igb. airfall (near base); (pum) (pkrsch)																					
	50.64	0.09	0.38	25.34	1.17	17.37	1.26	0.08	n.d.	96.33		5	52.04	0.13	0.58	24.16	1.24	20.08	1.13	n.d.	99.35
	51.22	0.13	0.40	26.93	1.21	18.25	1.22	0.11	0.07	99.54			0.42	0.08	0.19	2.08	0.22	1.45	0.21	n.d.	0.43
	50.93	0.11	0.39	26.14	1.19	17.81	1.24	0.10	0.04	97.94											
2	0.41	0.03	0.01	1.12	0.03	0.62	0.03	0.02	0.05	2.27											
b	50.03	0.12	0.39	32.70	1.76	14.36	0.74	n.d.	n.d.	100.10		01501 Matahina; coarse pumice near base; (pum) (integr)									
00502 Anaputa; (pum) (pkrsch)																					
	49.92	n.d.	0.69	31.51	1.63	14.52	0.88	n.d.	n.d.	99.15		a	54.66	0.22	1.00	17.59	0.64	26.01	1.47	n.d.	101.59
	51.75	0.16	0.50	26.52	1.46	18.18	1.09	n.d.	n.d.	99.66		a	52.33	0.33	1.98	17.51	0.65	25.06	1.51	n.d.	0.04
	50.93	n.d.	0.39	28.09	1.55	17.37	0.91	n.d.	n.d.	99.24		a	52.34	0.28	1.23	18.29	0.72	24.33	1.41	n.d.	98.60
	51.74	n.d.	0.35	27.31	1.51	17.63	0.92	n.d.	n.d.	99.46			53.11	0.28	1.40	17.80	0.67	25.13	1.46	n.d.	0.01
	52.19	0.15	0.33	27.30	1.13	18.01	1.00	n.d.	n.d.	100.11		3	1.34	0.06	0.51	0.43	0.04	0.84	0.05	n.d.	0.02
	52.18	n.d.	0.33	25.83	1.34	18.61	0.96	n.d.	n.d.	99.25		b	49.66	0.13	0.42	32.33	1.77	14.38	0.79	0.11	99.59
	51.83	n.d.	0.22	29.42	1.77	16.71	0.85	n.d.	n.d.	100.80		b	50.90	0.13	0.58	28.22	1.19	16.75	1.05	n.d.	98.82
	51.26	n.d.	0.30	28.31	1.58	16.75	0.93	n.d.	n.d.	99.13		b	50.04	0.08	0.34	32.70	1.75	14.46	0.78	0.10	100.25
	51.48	0.04	0.39	28.04	1.50	17.22	0.94	n.d.	n.d.	99.60			50.20	0.11	0.45	31.08	1.57	15.20	0.87	0.07	99.55
8	0.76	0.07	0.15	1.78	0.19	1.28	0.08	n.d.	n.d.	0.59		3	0.64	0.03	0.12	2.49	0.33	1.35	0.15	0.06	0.72
00801 Kohioawa-3; (pum) (pkrsch)																					
	52.33	n.d.	0.37	28.60	1.32	18.62	0.68	n.d.	n.d.	101.92		c	52.71	0.15	0.42	25.37	1.12	18.88	1.23	0.04	0.04
	52.32	n.d.	0.26	28.25	1.23	18.95	0.70	n.d.	n.d.	101.71		c	52.03	0.17	0.83	24.70	0.79	19.73	1.21	n.d.	99.46
	52.08	0.16	0.33	28.45	1.36	18.69	0.68	n.d.	n.d.	101.75			52.37	0.16	0.63	25.04	0.96	19.31	1.22	0.02	0.02
	52.17	n.d.	0.38	27.70	1.29	18.84	0.79	n.d.	n.d.	101.17		2	0.48	0.01	0.29	0.47	0.23	0.60	0.01	0.03	0.03
	52.56	0.10	0.41	27.94	1.40	18.80	0.74	n.d.	n.d.	101.95											
	52.29	0.05	0.35	28.19	1.32	18.78	0.72	n.d.	n.d.	101.70											
5	0.18	0.07	0.06	0.37	0.07	0.13	0.05	n.d.	n.d.	0.31											
00803 Kohioawa Stream; (pum) (pkrsch)																					
	52.23	0.14	0.71	23.80	1.16	21.27	1.07	n.d.	n.d.	100.38		01602 Paerata; (crs-ash) (pkrsch)									
	52.06	n.d.	0.40	26.41	1.37	19.98	0.72	n.d.	n.d.	100.94			51.25	n.d.	0.39	28.30	1.74	17.37	0.62	n.d.	99.67
	50.47	0.08	0.51	25.63	1.13	19.01	1.32	0.12	0.08	98.35		01707 Kaingaroa; (mtb) (integr)									
	52.40	0.17	0.42	25.42	1.16	20.35	0.77	0.06	n.d.	100.75			50.12	0.20	0.52	27.44	1.37	17.22	1.05	0.07	n.d.
	50.71	n.d.	0.55	28.20	1.94	17.37	0.81	0.08	n.d.	99.66			49.52	0.22	0.28	28.23	1.83	15.82	0.99	n.d.	96.89
	52.18	0.18	0.40	26.61	1.33	18.79	0.73	n.d.	0.06	100.28			50.06	0.22	0.30	28.21	1.72	17.18	1.02	0.06	n.d.
	51.68	0.10	0.50	26.01	1.35	19.46	0.90	0.04	0.02	100.06			49.74	0.22	0.52	28.22	1.63	16.28	1.22	0.06	n.d.
6	0.85	0.08	0.12	1.46	0.31	1.37	0.24	0.05	0.04	0.95			52.07	0.17	0.39	29.25	1.56	16.29	0.99	n.d.	100.72
00811 Paerata; (total) (integr)																					
	52.44	0.10	0.30	27.93	1.61	17.73	0.62	n.d.	n.d.	100.73		5	50.30	0.21	0.40	28.27	1.62	16.56	1.05	0.04	n.d.
	51.15	0.12	0.59	28.23	1.71	18.36	0.61	n.d.	n.d.	100.77			1.02	0.02	0.12	0.64	0.17	0.62	0.10	0.03	n.d.
	51.22	0.18	0.55	29.38	1.10	17.11	0.72	0.15	n.d.	100.41		b	52.66	0.22	0.86	24.35	0.92	19.20	1.30	0.05	n.d.
	51.40	0.15	0.59	27.85	1.65	18.16	0.57	0.11	0.06	100.54											
	50.88	0.12	0.58	28.79	1.55	17.96	0.61	0.13	n.d.	100.62											
	51.42	0.13	0.52	28.44	1.52	17.86	0.63	0.08	0.01	100.61											
5	0.60	0.03	0.13	0.64	0.24	0.48	0.06	0.07	0.03	0.15											
00901 Ohinekoao-I; (pum) (pkrsch)																					
	51.75	n.d.	0.44	28.60	1.20	18.15	0.92	n.d.	n.d.	101.06		02106 Otaraire; (crs-ash) (pkrsch)									
	51.60	n.d.	0.52	27.79	1.00	18.61	0.89	n.d.	n.d.	100.41			51.22	n.d.	0.63	29.73	1.26	17.64	0.23	n.d.	100.71
	51.86	n.d.	0.46	28.53	1.03	18.68	0.88	n.d.	n.d.	101.44		02301 Matahina; pre-igb. airfall; (pum) (pkrsch)									
	50.89	n.d.	0.47	30.80	1.46	16.05	0.87	n.d.	n.d.	100.54			50.97	0.14	0.42	28.11	1.53	16.83	0.86	n.d.	98.86
	51.42	0.15	0.68	26.67	1.05	19.60	0.98	n.d.	n.d.	100.55			50.57	0.14	0.38	31.58	1.71	14.60	0.89	n.d.	99.87
	51.50	0.03	0.51	28.48	1.15	18.22	0.91	n.d.	n.d.	100.80			51.13	n.d.	0.19	30.53	1.78	15.34	0.77	n.d.	99.74
5	0.38	0.07	0.10	1.51	0.19	1.32	0.04	n.d.	n.d.	0.44			50.64	0.11	0.35	31.25	1.74	14.69	0.80	n.d.	99.58
b	53.25	0.23	1.57	19.53	0.75	25.05	1.16	n.d.	n.d.	101.54			50.24	0.11	0.26	31.14	1.73	14.71	0.72	n.d.	98.91
01301 Torere School; (pum) (integr)																					
	52.42	0.08	0.53	26.92	1.47	18.99	0.88	0.09	n.d.	101.38		5	50.71	0.10	0.32	30.52	1.70	15.23	0.81	n.d.	99.39
	53.14	0.12	0.43	26.99	1.20	19.30	0.81	n.d.	0.06	102.06			0.35	0.06	0.09	1.40	0.10	0.94	0.07	n.d.	0.47
	53.39	n.d.	0.55	26.49	1.22	19.16	0.78	n.d.	n.d.	101.59		b	52.06	0.20	0.78	22.26	1.01	21.11	1.05	n.d.	98.47
	52.90	0.12	0.51	26.35	0.96	19.67	0.76	n.d.	n.d.	101.27											
	52.24	0.15	0.50	26.05	1.14	19.10	0.64	0.12	0.06	100.00											
	50.91	0.17	0.61	26.06	1.23	18.56	0.87	0.06	n.d.	98.47											
	51.04	0.21	1.02	24.60	1.04	19.41	1.10	n.d.	n.d.	98.42											
	51.37	0.11	0.73	25.48	1.22	19.85	0.92	n.d.	n.d.	99.68											
	52.18	0.12	0.61	26.12	1.19	19.26	0.85	0.03	0.02	100.36											
8	0.97	0.06	0.19	0.79	0.15	0.40	0.13	0.05	0.03	1.42											
01303 Rototiti; (mtb) (integr)																					
	52.29	0.18	0.44	23.22	1.88	21.42	0.76	0.06	n.d.	100.25		02505 Paerata; (total) (pkrsch)									
	51.55	0.11	0.49	23.44	2.20	20.50	0.78	0.07	n.d.	99.14			51.27	n.d.	0.51	27.41	1.67	17.56	0.54	n.d.	98.96
	52.30	0.12	0.60	21.62	1.56	22.17	1.07	n.d.	n.d.	99.44			51.27	n.d.	0.34	27.74	1.76	17.56	0.61	n.d.	99.28
	51.37	0.10	0.49	24.01	2.61	20.52	0.61	0.07	n.d.	99.78			51.09	n.d.	0.54	27.00	1.67	17.70	0.67	n.d.	98.67
	51.88	0.13	0.51	23.07	2.06	21.15	0.81	0.05	n.d.	99.65			51.17	n.d.	0.56	27.90	1.76	17.07	0.63	n.d.	99.19
4	0.49	0.04	0.07	1.02	0.45	0.80	0.19	0.03	n.d.	0.48			51.27	n.d.	0.30	27.59	1.83	17.32	0.58	n.d.	98.82
01401 Torere-I (77); below road level; (crs-ash) (pkrsch)																					
	51.86	0.17	0.82	22.95	1.08	20.76	1.46	n.d.	n.d.	99.10			51.21	n.d.	0.45	27.53					

	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	water		SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	water	
02801 Ruatuna-C (unknown?); (pum) (integr)											06701 Te Piti West (Matahina?); (mtb+) (integr)											
	50.09	0.21	0.63	28.71	1.31	17.17	1.20	n.d.	n.d.	99.32		51.72	0.11	0.34	26.51	1.16	17.91	1.17	n.d.	n.d.	98.92	
	50.10	0.10	0.29	29.39	1.38	16.17	1.07	n.d.	n.d.	98.50		49.68	0.24	0.87	30.23	0.88	14.93	0.85	n.d.	n.d.	97.68	
	50.80	0.10	0.53	28.56	1.16	17.16	1.06	0.06	0.07	99.50		50.80	0.09	0.35	29.49	1.25	16.45	1.12	n.d.	n.d.	99.55	
	50.99	0.13	0.38	28.53	1.26	17.02	1.16	0.10	0.04	99.61		51.35	0.19	0.48	26.38	1.36	18.84	1.16	0.11	n.d.	99.87	
	51.14	0.09	0.49	29.20	1.49	16.75	0.96	n.d.	0.05	100.17		50.89	0.16	0.51	28.15	1.16	17.03	1.08	0.03	n.d.	99.00	
	50.74	0.14	0.38	28.90	1.21	17.01	1.18	0.05	n.d.	99.61	4	0.89	0.07	0.25	2.00	0.21	1.71	0.15	0.06	n.d.	0.97	
	50.58	0.13	0.42	28.23	1.28	17.30	1.10	0.06	n.d.	99.10												
	51.29	0.13	0.56	28.46	1.32	17.24	1.11	n.d.	n.d.	100.11	b	52.34	0.29	1.63	22.63	0.75	21.66	1.29	n.d.	n.d.	100.59	
	50.72	0.13	0.46	28.75	1.30	16.98	1.11	0.03	0.02	99.49												
8	0.44	0.04	0.11	0.39	0.10	0.37	0.08	0.04	0.03	0.54												
b 51.06 0.25 1.17 24.13 1.35 20.90 1.33 n.d. 0.18 100.37																						
02802 Waingarara Ignimbrite; many pumices; (pum) (integr)											07806 unknown?; reworked rounded pumices; (pum) (integr)											
	48.96	n.d.	0.38	30.31	1.43	15.75	0.74	0.15	n.d.	97.72		50.46	n.d.	0.27	29.79	1.67	16.63	0.73	0.08	n.d.	99.63	
	51.38	0.09	0.35	30.96	1.65	15.93	0.88	0.08	n.d.	101.32		51.42	0.20	0.56	26.08	0.91	18.05	1.31	n.d.	n.d.	98.53	
	51.12	0.16	0.42	30.05	1.45	15.69	1.04	0.08	n.d.	100.01		50.38	0.16	0.41	28.41	1.70	17.13	0.81	n.d.	n.d.	99.00	
	5 n.d.	0.12	0.49	29.66	1.58	14.98	0.99	n.d.	n.d.	97.82		50.37	0.10	0.69	28.41	1.17	16.89	0.77	n.d.	n.d.	98.40	
	51.96	0.11	0.38	29.42	1.56	16.42	0.94	0.12	n.d.	100.91		50.34	0.13	0.44	29.03	2.13	16.30	0.72	n.d.	n.d.	99.09	
	50.91	0.07	0.32	29.69	1.80	15.67	0.94	n.d.	n.d.	99.40		53.34	0.16	0.38	29.22	1.93	15.99	0.79	n.d.	n.d.	101.81	
	51.04	0.10	0.29	31.47	1.80	14.67	0.82	n.d.	n.d.	100.19		51.22	0.14	0.48	27.98	1.88	16.75	0.74	n.d.	n.d.	99.19	
	51.08	0.14	0.45	29.75	1.43	15.98	1.17	0.07	n.d.	100.07	7	51.08	0.13	0.46	28.42	1.63	16.82	0.84	0.01	n.d.	99.38	
	50.81	0.10	0.39	30.16	1.59	15.64	0.94	0.06	n.d.	99.68		7	1.09	0.06	0.13	1.19	0.44	0.66	0.21	0.03	n.d.	1.15
8	0.92	0.05	0.07	0.71	0.15	0.56	0.13	0.06	n.d.	1.31												
03902 Waingarara; pre-ignimbrite arial; (mtb+) (integr)											08001 Rangitawa; (mtb+) (integr)											
	49.93	0.11	0.22	31.02	1.64	14.51	0.81	0.07	n.d.	98.31		51.16	0.29	0.84	25.30	1.06	18.24	1.50	0.10	0.06	98.55	
	49.66	0.21	0.38	29.62	1.19	15.78	0.87	n.d.	n.d.	97.71		51.05	0.08	0.39	26.64	1.37	18.75	0.94	0.06	0.06	99.34	
	51.42	0.18	0.36	28.71	1.42	16.99	0.92	0.08	0.06	100.14		50.74	0.21	0.37	24.78	1.35	19.10	1.06	0.07	0.06	97.74	
	50.85	0.17	0.45	28.46	1.31	16.11	1.09	n.d.	n.d.	98.44		51.22	0.10	0.31	26.16	1.43	18.48	0.91	n.d.	n.d.	98.61	
	50.47	0.17	0.35	29.45	1.39	15.85	0.92	0.04	0.02	98.65		50.45	n.d.	0.33	26.23	1.19	18.98	0.93	n.d.	n.d.	98.11	
4	0.82	0.04	0.10	1.16	0.19	1.03	0.12	0.04	0.03	1.04		50.58	0.07	0.29	26.16	1.02	18.85	0.98	0.10	n.d.	98.05	
												50.62	0.09	0.41	25.85	1.43	18.88	0.92	0.05	n.d.	98.25	
												50.83	0.12	0.42	25.87	1.26	18.75	1.03	0.05	0.03	1.62	
											7	0.31	0.10	0.19	0.63	0.17	0.30	0.21	0.04	0.03	0.52	
04103 Westend (unknown?); (total) (integr)											08302 reworked Ohinekoao-I; (pum) (integr)											
a	48.56	0.20	0.39	33.38	1.27	12.65	1.34	n.d.	n.d.	97.79		51.23	0.17	0.55	25.30	1.22	18.50	1.15	0.05	n.d.	98.17	
a	48.23	0.14	0.30	38.64	1.44	9.61	1.13	0.13	n.d.	99.62		51.43	0.09	0.24	29.23	1.63	16.27	1.06	0.08	n.d.	100.03	
a	48.97	0.13	0.39	34.07	1.60	13.20	1.39	n.d.	n.d.	99.75		51.56	0.25	0.91	22.85	0.95	20.87	1.34	n.d.	n.d.	98.73	
a	49.92	0.13	0.28	31.95	1.50	15.06	1.17	n.d.	n.d.	100.01		50.55	0.08	0.49	24.95	0.95	19.93	0.95	0.10	0.04	98.04	
a	48.79	0.09	0.44	32.88	1.05	14.22	0.76	n.d.	n.d.	98.23		50.61	0.16	0.52	26.39	1.43	18.22	0.79	n.d.	n.d.	98.12	
a	49.56	0.10	0.44	32.13	1.52	14.48	1.09	n.d.	n.d.	99.32		50.56	0.23	0.72	25.82	1.26	19.25	1.25	n.d.	n.d.	99.09	
a	48.93	0.12	0.28	34.17	1.48	12.86	0.96	n.d.	n.d.	98.80		50.99	0.16	0.57	25.76	1.24	18.84	1.09	0.04	0.01	98.70	
a	49.07	0.15	0.33	34.28	1.37	12.60	1.40	n.d.	n.d.	99.20	6	0.47	0.07	0.23	2.09	0.27	1.59	0.20	0.04	0.02	0.77	
a	48.82	0.14	0.33	36.39	1.65	10.80	1.40	n.d.	n.d.	99.53												
a	49.74	0.17	0.66	31.22	1.54	15.19	1.19	0.09	0.06	99.86												
	49.06	0.14	0.38	33.91	1.44	13.07	1.18	0.02	0.01	99.21												
10	0.53	0.03	0.11	2.22	0.18	1.81	0.21	0.05	0.02	0.73												
b 51.34 0.34 1.82 22.02 0.61 22.03 1.61 0.06 0.09 99.92											08303 Ohinekoao-K; (pum) (integr)											
b	51.85	0.31	1.02	23.08	0.50	21.97	1.42	n.d.	n.d.	100.15		50.88	0.09	0.30	26.76	1.40	19.03	0.89	0.05	n.d.	99.40	
b	52.73	0.23	1.28	18.54	0.43	24.68	1.46	n.d.	n.d.	99.35												
b	52.09	0.47	0.87	22.71	0.47	21.67	1.60	n.d.	n.d.	99.88												
b	53.57	0.31	1.12	18.75	0.76	24.16	1.79	n.d.	n.d.	100.46												
b	53.12	0.18	0.89	24.59	0.92	20.50	0.81	0.08	n.d.	101.02												
	52.45	0.31	1.17	21.62	0.62	22.50	1.45	0.02	0.02	100.14												
6	0.84	0.10	0.35	2.45	0.19	1.59	0.34	0.04	0.04	0.59												
c 52.04 0.29 3.21 17.12 0.45 24.58 1.51 n.d. n.d. 99.20											08401 Wilson; (pum) (integr)											
? 48.87 0.10 1.14 34.24 0.69 14.00 0.45 n.d. n.d. 99.49											52.35 0.12 0.53 25.53 1.34 19.33 0.88 0.11 n.d. 100.19											
04105 Paerata; near base; (total) (integr)											50.20 0.15 0.65 27.89 1.37 17.62 0.66 0.12 n.d. 98.66											
	51.32	n.d.	0.37	28.35	1.82	17.40	0.59	n.d.	n.d.	99.85		51.93	0.18	0.68	25.67	1.22	19.44	0.98	0.07	n.d.	100.17	
	51.87	0.13	0.29	28.05	0.74	17.48	0.65	0.06	n.d.	99.27		51.49	0.15	0.62	26.36	1.31	18.80	0.84	0.10	n.d.	99.67	
	51.60	0.07	0.33	28.20	1.28	17.44	0.62	0.03	n.d.	99.56	3	1.14	0.03	0.08	1.32	0.08	1.02	0.16	0.03	n.d.	0.88	
2	0.39	0.09	0.06	0.21	0.76	0.06	0.04	0.04	n.d.	0.41												
06208 Reihana-F(1); (mtb) (integr)											08402 reworked pumiceous sediment; (pum) (integr)											
	52.12	0.08	0.33	30.08	1.35	15.65	1.18	0.06	n.d.	100.85		50.74	0.11	0.48	25.84	1.31	18.95	0.76	n.d.	n.d.	98.19	
	49.86	0.21	0.55	28.76	1.20	15.55	1.21	n.d.	n.d.	97.34		51.49	0.12	0.43	26.00	1.22	19.29	0.77	0.06	n.d.	99.38	
	50.40	0.10	0.33	28.79	1.28	15.46	1.04	0.10	n.d.	97.50		50.50	0.21	0.78	22.72	0.99	20.82	1.09	0.07	n.d.	97.18	
	49.91	0.13	0.41	29.06	1.45	15.69	1.09	n.d.	0.06	97.80		52.79	0.08	0.45	26.44	1.30	17.89	0.71	n.d.	n.d.	99.66	
	49.26	0.14	0.39	29.30	1.47	15.34	1.08	n.d.	n.d.	96.98		50.40	0.08	0.45	26.70	1.08	18.42	0.75	n.d.	n.d.	97.88	
	50.31	0.13	0.40	29.20	1.35	15.54	1.12	0.03	0.01	98.09		50.32	0.17	0.50	27.62	1.15	17.45	0.87	n.d.	n.d.	98.08	
5	1.09	0.05	0.09	0.54	0.11	0.14	0.07	0.05	0.03	1.57		50.63	0.23	0.46	25.84	1.07	18.68	0.66	n.d.	n.d.	97.57	
												50.98	0.14	0.51	25.88	1.16	18.79	0.80	0.02	n.d.	98.28	
											7	0.89	0.06	0.12	1.53	0.12	1.09	0.14	0.03	n.d.	0.92	
b 49.40 0.30 1.27 26.93 0.66 17.78 1.44 n.d. n.d. 97.78											09304 Rotoli; (mtb) (integr)											
c 55.34 0.18 0.70 19.69 0.71 23.55 1.03 0.08 n.d. 101.28											52.63 0.14 0.44 23.38 2.05 20.60 0.61 n.d. n.d. 99.85											
06601 Te Piki (Hiwarau?); (mtb) (integr)											52.77 0.18 0.49 23.33 2.11 20.56 0.64 0.07 0.07 100.22											
	53.34	0.12	0.33	25.90	1.76	18.56	0.72	0.11	0.06	100.90		52.70	0.16	0.47								

APPENDIX - L:

**Ferromagnesian
mineral assemblages**

of Bay of Plenty tephra samples

Relative proportions of minerals in the ferromagnesian mineral separate.

@	almost all	> 90 %.	<u>bold underline</u>
\$	abundant	> 60 %.	bold
*	essential	> 30 %.	<u>underline</u>
#	common	> 10 %.	plain text
~	present	< 10 %	<i>italics</i>
(t)	trace	< 4 %.	<i>italics(t)</i>

biot. = biotite; hyp. = hypersthene; hornb. = hornblende; aug. = augite
 cumm. = cummingtonite; px. = undifferentiated pyroxene amph. = undiff. amphibole
 (\$) = not enough minerals identified for accurate assignment of assemblage; or comes from a tephra with a mixture of two or more glass shard chemistries.
 (¥) = from a reworked deposit and therefore may be a mixture.
 (dup.) = duplicate sample

Tephra are presented roughly from youngest to oldest, with the deposits with uncertain stratigraphic positions at the end. Sample numbers in italics show a tentative, though likely correlation.

tephra/samp. no.	polarising microscope	non-polarising binocular microscope
Omataroa		
03903	—	<u>hornb.</u> * + hyp.# + cumm.? = very few minerals
Mangaone		
01302	—	<u>hyp.</u> * + hornb.#
01513	—	<u>hornb.</u> * + hyp.#
03906	—	<u>hornb.</u> *
04308	—	<u>hyp.</u> * + hornb.*
uncertain tephra identification		
03904	—	<u>hornb.</u> * + biot.#
Earthquake Flat – Rotoiti		
06503	—	<u>hornb.</u> * + cumm.#? + biot.#
Rotoiti		
01303	—	<u>cumm.</u> * + <u>hyp.</u> *? + hornb.#
01516	—	<u>cumm.</u> .\$
04307	—	<u>cumm.</u> .\$ + hornb.# + hyp.#
06501	<u>cumm.</u> * + hornb.# + <i>augite?</i>	<u>cumm.</u> * = virtually no Fe-Mg minerals
07702	—	<u>hyp./cumm.</u> *
08505	—	<u>cumm.</u> .\$ + hornb.#
09304	—	<u>cumm.</u> .\$ + hornb.#
Little Waihi		
03105	—	<u>hornb.</u> * + hyp.#
Reid's Reserve		
11201	—	<u>hyp.</u> * + <u>hornb.</u> * + <i>biot.(t)</i>

tephra/samp. no.	polarising microscope	non-polarising binocular microscope
Wairuru		
04801	—	<i>hornb.~</i>
(¥) 05101	—	<i>biot.* + hornb.#</i>
(¥) 05301	—	<i>px.~ + hornb.(t)</i>
Copenhagen		
(¥) 04803	—	<i>hornb.#</i>
Torere School		
(¥) 01301	<i>hornb.* + hyp.* [2:1]</i>	<i>hornb.\$ + hyp.#</i>
(¥) 04802	—	<i>hornb.*</i>
07701	—	<i>hornb.* + hyp.*</i>
Kutarere		
01410	—	<i>hyp.\$ + hornb.#</i>
01518	—	<i>hyp.\$ + hornb.# or ...</i> <i>... hyp.* + hornb.# + biot.~</i>
08704	—	none
08703	— very weathered	nothing recognizable
08801	—	<i>hyp.# + hornb.~ = not much</i>
09004	—	<i>hyp.# + hornb.# + biot.(t)</i>
09002	—	<i>hornb.~ = virtually no Fe-Mg minerals</i>

- ignimbrite	—	<i>hornb.~ + hyp.~ = virtually no Fe-Mg</i>
07901	—	<i>hornb.(t) + hyp.(t)</i>
minerals	—	
10402	—	
? uncertain ?		
01511	—	none
Welcome-F		
08804	—	<i>hornb.*</i>
Huntress-F		
08502	—	<i>hornb.* + hyp.*</i>
08805	<i>hornb.\$ + hyp.# + biot.(t)</i>	<i>hyp.* + hornb.* + biot.(t)</i>
Huntress-E		
01512	—	<i>hornb.#</i>
Huntress-D		
01407	—	<i>hornb.* + hyp.# + biot.(t)</i>
01510	—	<i>hyp.* + hornb.#</i>
02712	—	<i>hornb.* + hyp.* + biot.(t)</i>
08503	—	<i>hyp.* + hornb.*</i>
08705	—	<i>hyp.\$ + hornb.(t)</i>
08803	—	<i>hyp.*</i>
09005	—	none

(\$) 01515	<i>hyp.\$ + hornb.*</i>	<i>hornb.* + hyp.#</i>
Welcome-C		
03104	—	<i>hyp.(t)? = virtually no Fe-Mg minerals</i>
08702	—	<i>hyp.\$ + hornb.~</i>
08806	—	<i>hornb.* + hyp.~</i>

tephra/samp. no.	polarising microscope	non-polarising binocular microscope
Huntress-C		
01514	—	<u>hornb.</u> * + <u>hyp.</u> ~
02711	—	<u>hornb.</u> * + <u>hyp.</u> *
Huntress-B		
01509	—	<u>hyp.</u> * + <u>hornb.</u> (t) + <u>biot.</u> (t)
02715	—	<u>hyp.</u> * + <u>hornb.</u> (t)
08504	—	<u>biot.</u> ~ + <u>hyp.</u> (t)
03102	<u>hyp.</u> \$ + <u>hornb.</u> (t)	a few px. + trace <u>hornb.</u>
09003	—	<u>hyp.</u> * + <u>hornb.</u> *
Kaingaroa		
01402	<u>hornb.</u> * + <u>hyp.</u> * [2:1]	virtually no Fe-Mg minerals
01413	—	no recognizable minerals
01519	<u>hyp.</u> @ + <u>hornb.</u> (t) + <u>biot.</u> (t)?	<u>hyp.</u> \$ + <u>hornb.</u> #
01707	—	<u>hyp.</u> \$ + <u>hornb.</u> # + <u>biot.</u> (t)
02214	—	<u>hornb.</u> ~
02716	—	<u>hyp.</u> * + <u>hornb.</u> * + <u>biot.</u> (t)
04304	—	<u>hornb.</u> * + <u>hyp.</u> (t) + <u>biot.</u> (t)
08506	—	<u>hyp.</u> \$ + <u>biot.</u> ~ + <u>hornb.</u> ~
88/12	<u>hyp.</u> \$ + <u>hornb.</u> # + <u>aug.</u> (t)	<u>hyp.</u> * + <u>hornb.</u> *

- kg-2 ignimbrite		
06101	—	<u>hyp.</u> (t) + <u>hornb.</u> (t)

- kg-1(a & b) ignimbrite		
06102	—	virtually none
06103	—	none
06201	—	px.# = very few
09901	—	<u>hornb.</u> (t) + <u>hyp.</u> (t) = virtually none

- kg-1c ignimbrite		
06213	<u>hyp.</u> @ + <u>hornb.</u> (t) + <u>aug.</u> (t)	<u>hyp.</u> *

06209	—	<u>hyp.</u> \$ + <u>hornb.</u> #
09301	—	<u>hyp.</u> \$ + <u>hornb.</u> *
Reihana-M		
06204	—	<u>hyp.</u> * + <u>hornb.</u> # + <u>biot.</u> #
Torere-O		
(§) 01411	<u>hyp.</u> \$ + <u>cumm.</u> [very few Fe-Mg minerals]	<u>biot.</u> * + <u>cumm.</u> (t)??
(§) 01403	<u>biot.</u> @ + <u>hornb.</u> ~ + <u>hyp.</u> ~ + <u>cumm.</u> + <u>aug.</u>	<u>biot.</u> @
01521	—	<u>biot.</u> # + <u>hornb.</u> # + <u>hyp.</u> ~
02205	[no Fe-Mg minerals]	—
02501	<u>hyp.</u> \$ + <u>hornb.</u> # + <u>biot.</u> #	<u>biot.</u> ~ + <u>hyp.</u> (t) = virtually no Fe-Mg
minerals		
02714	—	<u>hyp.</u> * + <u>hornb.</u> ~ + <u>biot.</u> (t)
(§) 06214	<u>hyp.</u> @	<u>px.</u> * = not much
08501	—	<u>hyp.</u> * + <u>hornb.</u> ~
Torere-N		
02206	[no Fe-Mg minerals]	
02507	<u>hornb.</u> * + <u>hyp.</u> ~	<u>hornb.</u> \$
06217	—	<u>hyp.</u> \$ + <u>hornb.</u> #
Torere-M		
02213	—	none
06206	—	<u>hyp.</u> # + <u>biot.</u> (t) = virtually no Fe-Mg minls.

tephra/samp. no.		polarising microscope	non-polarising binocular microscope
Torere-L			
01520	—	very weathered	<u>hornb.</u> * + <u>biot.</u> (t)
02204	—		a few px.
02713	—		<u>hornb.</u> *
06203	—		<u>hornb.</u> * + hyp.#
Torere-K			
(¥\$) 01412	—		<u>biot.</u> (t) + <u>hyp.</u> (t) = virtually no Fe-Mg minls.
01406	—		px.~ + <u>biot.</u> (t) = very few
(¥) 01405	—		<u>biot.</u> (t)
02207	[no Fe-Mg minerals]		none
06205	—		<u>hyp.</u> * + hornb.#
Torere-J			
01404	hyp.\$		<u>hyp.</u> @
Torere-I			
01401	hyp.\$ + hornb.# + ? <u>biot.</u> ?(t)		hyp.\$ + hornb.* + <u>biot.</u> (t)
(§) 01904	<u>hornb.</u> * + <u>hyp.</u> * + <u>aug.</u> (t)?		<u>hyp.</u> * + <u>hornb.</u> *
02503	<u>hornb.</u> \$ + <u>hyp.</u> (t)		
01507	<u>hyp.</u> * + <u>hornb.</u> * + <u>aug.</u> (t)		<u>hyp.</u> * + <u>hornb.</u> *
02201	<u>hornb.</u> \$ + hyp.# + <u>biot.</u> ~		virtually no Fe-Mg minerals
02709	<u>hornb.</u> \$ + hyp.#		hornb.#
09001	<u>hornb.</u> @ + <u>hyp.</u> ~		<u>hornb.</u> * + hyp.#
Reihana-G			
06218	—		<u>hornb.</u> * + <u>hyp.</u> *
(§) 06219	—		px. + <u>hornb.</u> + <u>biot.</u>
08701	—		<u>hornb.</u> ~ = virtually no Fe-Mg minerals
08807	<u>hornb.</u> @ + <u>hyp.</u> ~		<u>hornb.</u> * + <u>hyp.</u> ~ + <u>cumm.</u> ~?
10303	—		<u>hornb.</u> ~ = swamped
Opotiki			
01703	<u>hornb.</u> @ + <u>hyp.</u> ~		<u>hornb.</u> @
02211	<u>hornb.</u> * + hyp.#		hyp.\$ + <u>hornb.</u> *
04303	<u>hornb.</u> @ + <u>hyp.</u> (t)		<u>hornb.</u> \$ + <u>cumm.</u> ~? + <u>hyp.</u> (t)
01701	—		
02210	hornb. = no Fe-Mg minerals		
Reihana-F			
06216	—		<u>hyp.</u> * + <u>hornb.</u> *
06208	—		<u>hornb.</u> \$ + <u>hyp.</u> *
Torere-G			
01706	<u>hornb.</u> \$ + <u>hyp.</u> (t)		<u>hornb.</u> \$
(§) 02215	—		<u>hyp.</u> ~
Ohiwa Hill			
01505	<u>hornb.</u> @ + <u>biot.</u> (t)		<u>hornb.</u> * + <u>hyp.</u> * + others?
01704	<u>hornb.</u> @ + <u>hyp.</u> ~		<u>hornb.</u> ~ + <u>hyp.</u> (t) = virt. no Fe-Mg minls.
02208	hyp. + <u>biot.</u> + <u>hornb.</u> = virtually no Fe-Mg minls.		none
02603	<u>hornb.</u> \$		hornb.# + <u>hyp.</u> (t)? + <u>biot.</u> (t)?
(§) 04302	<u>hornb.</u> * + <u>hyp.</u> * [few Fe-Mg minerals]		hornb.# + hyp.#
(dup.) 04309	—		<u>hornb.</u> \$ + <u>hyp.</u> * + <u>cumm.</u> (t)? + <u>biot.</u> (t)?

tephra/samp. no.	polarising microscope	non-polarising binocular microscope
Torere-E		
01705	—	hornb.# + hyp.#
02203	biot. = [no Fe-Mg minerals]	none
02601	hyp.* + hornb.* [2:1]	hornb.*
Torere-D		
02602	hornb.\$ + biot.~ + hyp.(t)	hornb.# + biot.#
Hiwarau		
(§) 01702	biot. + hyp. + hornb. = no Fe-Mg minerals	none
02202	hornb.* + hyp.*	a few px. & hornb.
02506	hornb.\$ + hyp.~ + biot.(t)	hornb.~ = virtually no Fe-Mg minerals
02701	hyp.\$ + hornb.* [2:1]	
(§) 04305	—	hornb.\$ + hyp.*
(§) 04401	—	hornb. + hyp.
06601	—	hornb.\$ + biot.~
06803	—	biot.* + hornb.~
Reihana-E		
06212	—	hyp.* + hornb.~
Reihana-C		
06207	—	hyp.\$ + hornb.# + biot.#
Torere-B		
02209	no Fe-Mg. minerals	
(§) 04402	—	hornb.*
06211	—	hornb.* + hyp.*
Torere-A		
(§) 01504	hornb.@ + hyp.(t)	hornb.# + biot.~ + hyp.~ or biot.* + hornb.*
(¥) 02212	—	none
02710	biot.~	
04403	—	hornb.* + biot.~
06210	—	hornb.* + hyp.# = very few
06215	—	hornb.* + px.# + biot.#
Matahina		
01501	hornb.* + hyp.*	
01508	—	hornb.* + hyp.*
01901	hornb.* + biot.# + hyp.#	hornb.* + hyp.#
02708	hornb.* + hyp.* + aug.(t)	hornb.* + hyp.*
(§) 02901	hornb.\$ + biot.*	hornb.* + px.~
04102	hornb.* + hyp.* [1:1]	hyp.* + hornb.* = few Fe-Mg minerals
04306	—	hornb.* + hyp.#
04404	—	hornb.\$ + hyp.#
06701	—	hyp.* + hornb.* + biot.(t)

- ignimbrite		
00202	—	hornb.# + hyp.(t) = few Fe-Mg minerals
03302	hornb.* + hyp.#	hornb.* + hyp.#
06202	—	hornb.* + hyp.* + biot.(t)
07801	—	hornb.* + hyp.(t) + biot.(t) (weathered)
09601	—	hornb.* + px.#
09801	—	hornb.* + hyp.#
101/1	—	hornb.# + hyp.~

continued over...

tephra/samp. no.	polarising microscope	non-polarising binocular microscope
Matahina continued		
- pre-ignimbrite airfall		
00201	<u>hornb.</u> * + <u>hyp.</u> * + [<i>biot.?(t)</i>]	<u>hornb.</u> * + <u>hyp.</u> *
00405	—	<i>px.</i> ~ = very few Fe-Mg minerals
00406	—	<u>hyp.</u> #
00501	<u>hyp.</u> * + <u>biot.</u> * [2:1] + <i>hornb.(t)</i>	virtually no Fe-Mg minerals
(S) 02301	<u>hornb.</u> * + <u>hyp.</u> # + <u>biot.</u> #	-
03301	<u>hornb.</u> * + <u>biot.</u> # + <u>hyp.</u> #	<u>hornb.</u> * + <u>biot.</u> ~ + <u>hyp.</u> ~
Murupara-G		
00403	<u>hornb.</u> * + <u>hyp.</u> #	
01523	—	<u>hyp.</u> \$ + <u>hornb.</u> *
Anaputa		
00404	<u>hornb.</u> * + <u>hyp.</u> * [1:1]	<u>hornb.</u> * + <u>hyp.</u> #
00502	<u>hyp.</u> * + <u>hornb.</u> * [2:1]	
00503	—	<i>hornb.</i> ~
01523	—	<u>hyp.</u> \$ + <u>hornb.</u> *
01522	—	<u>hornb.</u> * + <u>hyp.</u> #
01502	<u>hornb.</u> \$ + <u>hyp.</u> # + <u>biot.</u>	<u>hornb.</u> # + others = not much
02302	<u>hornb.</u> * + <u>hyp.</u> * + <i>biot.(t)</i>	
02706	<u>hornb.</u> * + <u>hyp.</u> * [2:1]	<u>hornb.</u> # + <u>hyp.</u> ~
Murupara-E		
00402	—	<u>hornb.</u> \$
00504	—	none
10003	—	<u>hornb.</u> * + <u>hyp.</u> ~
Bonisch		
00401	<u>hyp.</u> \$	<u>hyp.</u> ~?
01503	<u>hyp.</u> * + <u>biot.</u> # + <u>hornb.</u> #	<u>hornb.</u> # + <u>biot.</u> #
02304	<u>hyp.</u> \$ + <i>hornb.(t)</i>	a few <i>px.</i> & <u>hornb.</u>
02305	<u>hyp.</u> *	<u>hyp.</u> *
02707	<u>hornb.</u> # + <u>hyp.</u> ~ + <u>biot.</u> ~ = virtually no Fe-Mg minls.	<u>hornb.</u> # + <u>hyp.</u> ~ + <u>biot.</u> (t)?
04603	—	<u>hornb.</u> *
Murupara-C		
01506	<u>biot.</u> \$ + <u>hornb.</u> # + <u>hyp.</u> ~	<u>biot.</u> * + <u>hornb.</u> * + <u>hyp.</u> #
02303	<u>hyp.</u> * + <u>biot.</u> * + <u>hornb.</u> #	<u>biot.</u> \$
02702	<u>hornb.</u> * + <u>biot.</u> * [2:1]	<u>hornb.</u> * + <u>biot.</u> *
(S) 04113	—	<u>hornb.</u> + <u>hyp.</u> + <u>biot.</u>
04601	—	<u>biot.</u> * + <u>hornb.</u> ~ + <i>px.</i> ?
Murupara-B		
(S) 04112	—	<u>hyp.</u> + <u>hornb.</u> + <u>biot.</u> (t)
Murupara-A		
(S) 02703	<u>hornb.</u> \$ + <u>hyp.</u> # + <u>biot.</u> (t)	<u>hornb.</u> \$ + <u>hyp.</u> ~
04111	—	<u>hyp.</u> \$ + <u>hornb.</u> *
04602	—	<u>hornb.</u> \$ + <u>hyp.</u> #
10002	—	<u>hyp.</u> * + <u>hornb.</u> *
- pumiceous loess		
(Y) 04109	—	<u>hornb.</u> * + <u>biot.</u> # + <i>cumm.</i> ~? + <u>hyp.</u> ~

tephra/samp. no.	polarising microscope	non-polarising binocular microscope
Kohioawa		
01517	—	<u>biot.</u> \$ + <u>hornb.</u> ~
01603	<u>hyp.</u> \$ + <u>biot.</u> # + <u>hornb.</u> ~	<u>biot.</u> * + <u>hyp.</u> * + <u>hornb.</u> ~
02103	<u>biot.</u> * + <u>hyp.</u> * + <u>hornb.</u> #	<u>biot.</u> * + <u>hyp.</u> ~
02705	<u>biot.</u> @ + <u>hyp.</u> (t) + <u>hornb.</u> (t)	<u>biot.</u> @
00806	—	<u>biot.</u> \$ + <u>hornb.</u> #
00805	—	<u>biot.</u> \$ + <u>hyp.</u> #
00809	—	<u>biot.</u> * + <u>hyp.</u> # + <u>hornb.</u> ~
01601	<u>biot.</u> * + <u>hyp.</u> * + <u>hornb.</u> ~	<u>biot.</u> @ + <u>hornb.</u> ~ + <u>hyp.</u> ~
01605	—	<u>biot.</u> @ + <u>hyp.</u> ~
01606	—	<u>biot.</u> @
07802	—	<u>biot.</u> # + <u>hornb.</u> (t)
00801	<u>hyp.</u> \$ + <u>hornb.</u> # + <u>biot.</u> ~	<u>hyp.</u> \$ + <u>hornb.</u> # + <u>biot.</u> ~
00808	—	<u>hyp.</u> \$ + <u>hornb.</u> # + <u>biot.</u> ~
00807	—	<u>hyp.</u> * + <u>biot.</u> # + <u>hornb.</u> #
01604	—	<u>hyp.</u> * + <u>hornb.</u> * + <u>biot.</u> (t)
01801	<u>hyp.</u> \$ + <u>biot.</u> # + <u>hornb.</u> ~	<u>hyp.</u> \$ + <u>biot.</u> * + <u>hornb.</u> (t)
02101	<u>hyp.</u> \$ + <u>hornb.</u> # + <u>biot.</u> #	<u>biot.</u> \$
02502	<u>hyp.</u> * + <u>biot.</u> * [2:1] + <u>hornb.</u> ~	<u>hyp.</u> \$ + <u>biot.</u> *
04604	—	<u>hyp.</u> \$ + <u>hornb.</u> * + <u>biot.</u> (t)?
- Whakamaru Ignimbrite & Rangitawa Tephra		
08001	—	<u>hyp.</u> \$ + <u>hornb.</u> * [2:1]
08201	—	<u>hyp.</u> * + <u>hornb.</u> * + <u>biot.</u> (t)?
10001	—	<u>hyp.</u> # + <u>hornb.</u> ~
10301	—	<u>biot.</u> ~ = swamped by others.
11101	—	<u>biot.</u> \$ + <u>hornb.</u> # + <u>hyp.</u> ~
Paerata		
00811	—	<u>cumm.</u> \$ + <u>hyp.</u> *
01602	<u>cumm.</u> \$ + <u>biot.</u> # + <u>hyp.</u> ~	<u>cumm.</u> \$
02105	<u>cumm.</u> \$ + <u>biot.</u> # + <u>hyp.</u> ~ + <u>hornb.</u> (t)	<u>hyp.</u> * + <u>cumm.</u> * + <u>biot.</u> ~
02505	<u>hyp.</u> * + <u>cumm.</u> * + <u>hornb.</u> (t) + <u>biot.</u> (t)	<u>cumm.</u> \$ + <u>hyp.</u> # + <u>hornb.</u> #
02704	<u>cumm.</u> * + <u>hyp.</u> # + <u>biot.</u> (t)	<u>px.</u> \$ + <u>amph.</u> *
04105	—	<u>cumm.</u> \$ + <u>hyp.</u> # + <u>hornb.</u> # + <u>biot.</u> (t)
04606	—	<u>cumm.</u> * + <u>hyp.</u> * + <u>hornb.</u> #
07804	—	<u>cumm.</u> * + <u>hyp.</u> *
Tablelands-D		
04106	—	<u>biot.</u> @
04107	—	<u>biot.</u> @
04104	—	<u>biot.</u> @ + <u>hornb.</u> ~
04101	<u>biot.</u> @	<u>biot.</u> @
Tablelands-C		
00810	—	<u>biot.</u> \$ + <u>hornb.</u> #
07803	—	<u>biot.</u> @ + <u>hornb.</u> ~
Otarawairere		
00802	<u>biot.</u> @ + <u>hyp.</u> (t) + <u>hornb.</u> (t)	<u>biot.</u> @
01607	—	<u>biot.</u> * + <u>hornb.</u> *
02106	<u>biot.</u> @ + <u>hornb.</u> (t)	<u>biot.</u> \$ + <u>hornb.</u> ~
02504	<u>biot.</u> @ + <u>hornb.</u> (t)	<u>biot.</u> @
04605	—	<u>biot.</u> *

tephra/samp. no.	polarising microscope	non-polarising binocular microscope
Tablelands-A		
00804	<u>hornb.</u> * + <u>hyp.</u> * + <u>biot.</u> ~	<u>hyp.</u> * + <u>hornb.</u> * + <u>biot.</u> ~
(dup.) 00804	<u>hornb.</u> \$ + <u>hyp.</u> * + <u>aug.</u> (t) + [<u>biot.</u> ~]?	
02104	<u>biot.</u> * + <u>hornb.</u> * [2:1]	<u>biot.</u> * + <u>hornb.</u> ~ + <u>px.</u> (t)
Ohiwa-G		
02110	—	<u>biot.</u> \$ + <u>hornb.</u> ~ + <u>hyp.</u> (t)
(§) 00803	<u>biot.</u> * + <u>hornb.</u> * + <u>hyp.</u> #	<u>biot.</u> \$ + <u>hornb.</u> # + <u>px.</u> #
Ohiwa-F		
02109	<u>hornb.</u> @ + <u>biot.</u> (t)	<u>hornb.</u> * + <u>biot.</u> # + <u>cumm.</u> ~?
Tirohanga		
02108	—	<u>hornb.</u> * + <u>hyp.</u> / <u>cumm.</u> #
04201	—	<u>hornb.</u> + <u>biot.</u> (t)?
05901	—	<u>hornb.</u> \$ + <u>biot.</u> (t)?
Ohiwa-D		
(§) 04203	—	<u>biot.</u> # + <u>hornb.</u> # + ??
Ohiwa-C		
04204	—	<u>biot.</u> * + <u>hornb.</u> # + ??
09201	—	<u>biot.</u> \$ + <u>hornb.</u> #
Ohiwa-B		
03201	<u>biot.</u> \$ + <u>hornb.</u> #	<u>biot.</u> @ + <u>hornb.</u> #
09202	—	<u>hornb.</u> * + <u>biot.</u> *
Jackson		
01906	—	<u>hornb.</u> * + <u>biot.</u> # + <u>hyp.</u> (t)
02107	—	<u>biot.</u> @ + <u>hornb.</u> (t)
03202	<u>biot.</u> * + <u>hornb.</u> * [2:1]	<u>biot.</u> \$ + <u>hornb.</u> #
Reeves-D		
09203	—	<u>hyp.</u> #?? + <u>hornb.</u> ~
Reeves-C		
01908	—	<u>hyp.</u> * + <u>hornb.</u> # + <u>biot.</u> ~
(dup.) 01909	—	<u>hornb.</u> # + <u>biot.</u> ~?
Reeves-B		
01907	—	<u>hornb.</u> * + <u>hyp.</u> ~ + <u>biot.</u> ~
Reeves-A		
01905	<u>hyp.</u> \$ + <u>hornb.</u> *	<u>hornb.</u> * + <u>hyp.</u> #
01903	<u>hornb.</u> * + <u>cumm.</u> # + <u>biot.</u> # + <u>hyp.</u> ~	<u>hornb.</u> \$ + <u>hyp.</u> # + <u>biot.</u> ~
Waiotahi		
(¥) 02508	—	<u>hornb.</u> * + <u>hyp.</u> #
(¥) 03501	—	<u>hornb.</u> \$ + <u>biot.</u> ~
(dup.) 03502	—	<u>hornb.</u> \$ + <u>biot.</u> ~ (weathered)

tephra/samp. no.	polarising microscope	non-polarising binocular microscope
Ohinekoao-M		
00911	—	<u>hornb.</u> * + <u>px.</u> *
? uncertain ?		
(¥) 00905	—	<u>hornb.</u> * + <u>px.</u> # + <i>biot.</i> (t)
Ohinekoao-L		
00909	—	<u>hornb.</u> * + <u>px.</u> * + <i>biot.</i> #
Ohinekoao-K		
08303	—	<i>biot.</i> .\$ + <u>hornb.</u> *
Ohinekoao-J		
00902	<i>hornb.</i> .\$ + <i>hyp.</i> #	<i>hornb.</i> # + others
08301	—	<u>hornb.</u> * + <i>biot.</i> # + <i>hyp.</i> (t) + <i>cumm.</i> ?
Ohinekoao-I		
00901	<u>hornb.</u> * + <u>hyp.</u> *	<i>hornb.</i> .\$ + <u>hyp.</u> * + <i>cumm.</i> ?? + <i>biot.</i> (t)
(¥) 08302	—	<i>hornb.</i> .\$ + <i>hyp.</i> #
08304	—	<u>hyp.</u> * + <u>hornb.</u> * + <i>cumm.</i> (t)?
Ohinekoao-H		
00907	<i>hyp.</i> .\$ + <i>hornb.</i> # + <i>aug.</i> (t) + <i>biot.</i> (t)	<u>hyp.</u> * + <i>hornb.</i> # + <i>biot.</i> #
Ohinekoao-E (+ G)		
(¥) 00906	—	<i>biot.</i> * + <u>hornb.</u> * + <i>hyp.</i> ~
Ohinekoao-G		
00903	—	<i>biot.</i> * + <u>hornb.</u> *
Ohinekoao-E		
00904	<i>hyp.</i> .\$ + <i>hornb.</i> ~ + <i>biot.</i> ~	<i>hyp./cumm.</i> .\$? + <i>hornb.</i> # + <i>biot.</i> (t)
Ohinekoao-D		
00910	<i>hyp.</i> .\$ + <i>hornb.</i> # + <i>aug.</i> (t) + <i>biot.</i> (t)	<u>hyp.</u> * + <i>hornb.</i> #
Ohinekoao-C (+ A & B)		
(¥) 00908	<u>hornb.</u> * + <i>hyp.</i> # + <i>biot.</i> #	<u>hornb.</u> * + <i>biot.</i> * + <i>hyp.</i> # + <i>cumm.</i> (t)?
(¥) 08402	<u>hornb.</u> * + <u>hyp.</u> * + <i>biot.</i> (t) + <i>aug.</i> (t)?	<u>hornb.</u> * + <i>biot.</i> * + <i>hyp./cumm.</i> #?
Ohinekoao-B		
00912	<u>hornb.</u> * + <i>hyp.</i> # + <i>biot.</i> #	<i>hornb.</i> .\$ + <i>biot.</i> * + <i>hyp.</i> #?
Ohinekoao-A		
00913	<u>hornb.</u> * + <i>hyp.</i> # + <i>biot.</i> ~ + <i>aug.</i> ~	<i>hornb.</i> .\$ + <i>biot.</i> # + <i>hyp.</i> ~
Wilson		
08401	—	<i>hyp.</i> # + <i>hornb.</i> # + <i>cumm.</i> ~?

tephra/samp. no.	polarising microscope	non-polarising binocular microscope
Herepuru Tephra		
00101	<u>biot.</u> * + <u>hornb.</u> * + <u>hyp.</u> (t)	<u>biot.</u> @ + <u>hornb.</u> # + <u>px.</u> ~
Ruatuna-D Tephra		
02803	—	<u>hyp.</u> ~? = virtually no Fe-Mg minerals
Ruatuna-C Tephra		
02801	<u>hyp.</u> \$ + <u>hornb.</u> ~ + ? <u>aug.</u> ?(t)	<u>hyp.</u> * + <u>hornb.</u> #
Waingarara Tephra		
- ignimbrite		
(¥) 02810	<u>hornb.</u> * + <u>hyp.</u> * + <u>biot.</u> #	<u>hornb.</u> * + <u>hyp.</u> * + <u>biot.</u> *
02802	<u>hornb.</u> * + <u>hyp.</u> * + <u>biot.</u> #	<u>hyp.</u> * + <u>hornb.</u> * + <u>biot.</u> ~
02809	<u>biot.</u> * + <u>hornb.</u> * + <u>hyp.</u> #	<u>biot.</u> * + <u>hornb.</u> * + <u>hyp.</u> *
02804	—	<u>hornb.</u> \$ + <u>hyp.</u> *
02805	—	none
02806	—	<u>hyp.</u> * + <u>hornb.</u> *
02807	—	<u>hornb.</u> * + <u>hyp.</u> *
02808	<u>hornb.</u> \$ + <u>hyp.</u> #	<u>hornb.</u> \$ + <u>hyp.</u> *
03601	—	<u>biot.</u> @
03901	<u>hyp.</u> * + <u>hornb.</u> # + <u>biot.</u> #	<u>hyp.</u> * + <u>hornb.</u> * + <u>biot.</u> #
- pre-ignimbrite airfall		
03902	—	<u>hornb.</u> \$ + <u>hyp.</u> * + <u>biot.</u> ~
06301	—	<u>hornb.</u> \$ + <u>hyp.</u> # + <u>biot.</u> # (weathered)
Pikowai Tephra		
- upper unit		
03001	<u>hornb.</u> * + <u>hyp.</u> *	some <u>hornb.</u> + a few <u>px.</u>
03004	—	<u>hornb.</u> * + <u>hyp.</u> * + ??
- intermediate layer		
03005	<u>hornb.</u> \$ + <u>hyp.</u> * + <u>biot.</u> (t)	<u>hornb.</u> * + <u>hyp.</u> * + ??
- lower unit		
03003	—	<u>hornb.</u> * + <u>hyp.</u> *
03002	—	none?
Pikowai-B		
(¥) 03007	—	<u>hornb.</u> * + <u>hyp.</u> #
Pikowai-A		
03006	—	<u>hornb.</u> * + <u>biot.</u> # + <u>hyp.</u> #
Maketu-B		
03103	—	<u>hornb.</u> \$ + <u>hyp.</u> #
Maketu-A		
(¥0) 03101	<u>hornb.</u> \$ + <u>hyp.</u> # + <u>biot.</u> (t)	<u>hornb.</u> * +
McCoy		
03905	—	<u>hornb.</u> \$ + <u>hyp.</u> *

tephra/samp. no.	polarising microscope	non-polarising binocular microscope
Waiopua-I		
(¥) 03702 —		hornb.* + yellow px.#
Waiopua-A		
03701	hornb.* + hyp.#	
Westend Tephra		
04103 —		cumm./px.*? + hornb.# or px.* + hornb.#
Ngatiawa Tephra		
04301 —		hyp.\$ + hornb.#
Waimana-C		
06402 —		biot.*
Waimana-B		
(§) 06401 —		biot.* = very few
Waimana-A		
(§) 06403 minerals —		hyp.\$ + biot.# + hornb.# = very few
Te Piki farm track-D		
06804 —		hornb.* + hyp.*
Te Piki farm track-C		
(§) 06805	hornb.\$ + hyp.# + aug.# [few Fe-Mg minerals]	hyp.~ + others?
Te Piki farm track-B		
06801 —		hyp.\$ + hornb.#
Wilson's farm-(2 & 3) pumice gravels		
(¥) 07806 —		yellowish px.* + biot.* + hornb.*
(¥) 07805	hyp.* + hornb.* [2:1]	hyp.* + hornb.*
Quartz-biotite ignimbrites		
09401 —		biot.* + hyp.# + hornb.#
09501 —		biot.* + hornb.*
11102 —		biot.\$ + hornb.*
Burke		
10201 —		biot.@ + hornb.(t)
Pokai Ignimbrite		
10302 —		none
10401	hyp.@ + hornb.(t) + aug.(t)	px.* + hornb.#

Allocation of the tephras to the various ferromagnesian mineral assemblages.

The various ferromagnesian mineral assemblages (with the diagnostic minerals underlined) are:-

- (i) hypersthene ± augite ± hornblende
- (ii) hypersthene + hornblende ± augite;
- (iii) hypersthene + hornblende + biotite
- (iv) hypersthene + cummingtonite ± hornblende
- (v) hypersthene + augite ± olivine (uncommon assemblage)
- (vi) aegirine ± riebeckite ± ænigmatite ± olivine ± tuhualite
(only from the Tuhua Volcanic Centre)

[from Ewart *et al.*, 1975; Kohn, 1973; Froggatt & Lowe, 1990]

group (I)	group (II)	group (III)	group (IV)
Torere-J	Little Waihi	Reihana-M	Rotoiti
	Copenhagen	Torere-O	Paerata
	Torere School	Reihana-C	Reeves-A
	Kutarere	Torere-A	Wilson ⁵
	Welcome-F	Bonisch	
	Huntress-F	Murupara-C	
	Huntress-E	Kohioawa	
	Huntress-D	Tablelands-D	
	Welcome-C	Tablelands-C	
	Huntress-C	Otarawairere	
	Kaingaroa ¹	Tablelands-A	
	Torere-N	Ohiwa-G	
	Torere-L	Ohiwa-F ²	
	Torere-K	Ohiwa-D	
	Torere-I	Ohiwa-C	
	Reihana-G	Ohiwa-B	
	Opotiki	Jackson	
	Reihana-F	Reeves-B ³	
	Torere-G	Ohinekoao-L	
	Ohiwa Hill	Ohinekoao-K	
	Torere-E	Ohinekoao-J ⁴	
	Hiwarau	Ohinekoao-H	
	Reihana-E	Ohinekoao-G	
	Torere-B	Ohinekoao-B	
	Murupara-G	Ohinekoao-A	
	Anaputa	Herepuru	
	Murupara-E	Waingarara	
	Murupara-A	Pikowai-A	
	Tirohanga	Waimana-C	
	Reeves-D	Waimana-B	
	Reeves-C	Waimana-A	
	Ohinekoao-M	Wilson's farm-(2)	
	Ohinekoao-I	Quartz-biotite Ignimbrites	
	Ohinekoao-D	Burke	
	Ruatuna-C		
	Pikowai		
	Pikowai-B		
	Maketu-B		
	Maketu-A		
	Waiopua-A		
	McCoy		
	Westend		
	Ngatiawa		
	Te Piki farm track-D		
	Te Piki farm track-C		
	Te Piki farm track-B		
	Wilson's farm-(3)		
	Pokai Ignimbrite		

¹ = The Kaingaroa Tephra occasionally contains biotite, but never in significant amounts.

² = The Ohiwa-F Tephra contains very little biotite.

³ = The Reeves-B Tephra contains very little biotite.

⁴ = The Ohinekoao-J Tephra contains biotite in only one of two samples taken. Otherwise belongs in group (ii).

⁵ = The Wilson Tephra definitely contains cummingtonite, but only in very small amounts. Otherwise group (ii).

Other tephras which have uncertain placement within the ferromagnesian mineral assemblages.

Reid's Reserve :	probably group (ii), but possibly group (iii).
Huntress-B :	either group (ii) or group (i).
Matahina :	generally group (ii), but occasionally contains significant amounts of biotite — group (iii).
Ohinekoao-E :	probably group (iii), but possibly group (ii).
Wairuru :	unknown — too much variation within the various reworked samples.
Torere-M :	unknown — not enough minerals in sample for accurate determination.
Murupara-B :	unknown — not enough minerals in sample for accurate determination.
Waiotahi :	unknown — sampled from mixed reworked deposit.
Ohinekoao-C :	unknown — sampled from mixed reworked deposit.
Ruatuna-D :	unknown — not enough minerals in sample for accurate determination.
Waiopua-I :	unknown — sampled from mixed reworked deposit.

Most of the tephras in this study had ferromagnesian mineral assemblages of type (ii), with type (iii) being the next most common. Types (i) and (iv) were also present but were rare. Types (v) and (vi) were not recognised. The ferromagnesian mineral assemblage alone was not enough to identify a tephra, but the presence of biotite can preclude correlation in many cases, and abundant cummingtonite is very distinctive.

APPENDIX - M:

Stratigraphic sections

in the Bay of Plenty region

Stratigraphic Sections

(in alphabetical order)

SECTION	PAGE	SECTION	PAGE
Key	M-0	Otarawairere	M-40 (3 p.)
Airstrip Road	M-1	Paerata Ridge Road	M-41 (2 p.)
Anaputa Point	M-2	Pahekeheke	M-42
Awaawakino	M-3	Pakuranui Bridge	M-43
Awakeri Springs	M-4	Pikowai Reserve	M-44
Bonisch	M-5	Pukeruru Point	M-45 (3 p.)
Brown's driveway	M-6	Raukokore	M-46
Burchett	M-7	Reeves	M-47 (3 p.)
× Copenhagen Road	M-8	Reihana Road	M-48 (4 p.)
Downer Road	M-9 (2 p.)	Rocky Cutting Road	M-49
Flax Hill Point	M-10	Ruatuna Road	M-50 (2 p.)
Gault's Slip	M-11	Tablelands Road	M-51 (2 p.)
× Hawai	M-12	Taneatua	M-52 (2 p.)
Herepuru Bridge	M-13	× Te Piki area	M-53 (2 p.)
Herepuru Road-(2)	M-14	Tirohanga	M-54
Hiwarau	M-15 (2 p.)	× Torere School	M-55
Hokianga Island	M-16	× Torere West	M-56
Huntress Creek	M-17 (2 p.)	× Waihapokopoko Bridge	M-57
Jackson Road	M-18	Waimana Hill	M-58
Kohioawa	M-19 (3 p.)	Waingarara	M-59
Kukumoa cutting	M-20	Waioeka River	M-60
Kutarere Wharf	M-21	Waipoua	M-61
Little Waihi	M-22 (4 p.)	Waiotahi River	M-62
McCoy Road-(1a)	M-23a	Waiotuma	M-63
McCoy Road-(1b)	M-23b	× Wairuru cemetery	M-64
McCoy Road-(1c)	M-23c	Welcome Bay	M-65
McCoy Road-(2)	M-24	Wilson's farm	M-66 (4 p.)
Murupara-(1)	M-25		
Murupara-(2)	M-26		
Murupara-(3)	M-27		
Newdicks Beach	M-28		
Ngatiawa lookout	M-29 (3 p.)		
Ohinekoao Reserve	M-30 (2 p.)		
Ohinekoao Stream	M-31		
Ohiwa Beach	M-32 (2 p.)		
Ohiwa Harbour Road West	M-33 (3 p.)		
Ohiwa Hill	M-34		
Ohiwa Loop Road	M-35		
× Omaio	M-36		
Omokoroa East	M-37		
Omokoroa Slump	M-38 (2 p.)		
Opape	M-39 (2 p.)		

Key for stratigraphic sections in Appendix-(M)

The right hand side of stratigraphic column shows the variation in the grain size of the individual beds. It especially well shows any reverse grading, normal grading, or any alternating fine and coarse beds.

Loess has been consistently portrayed as coarse silt, occasionally coarser than some fine ash layers.

Sample collection positions are shown by the sample number located adjacent to the column — on left.

AIRSTRIP ROAD (sect. no. 69) G.R. = [Y14/561899]

thickness (m)

ANAPUTA POINT (05) [V15/243422]

AWAAWAKINO (58) [X15/005493]

AWAKERI SPRINGS (44) [V15/488477]

BONISCH ROAD (110) [V16/300207]

BROWN'S DRIVEWAY (113) [X15/902476]

BURCHETT TRACK (46) [W15/884468]

COPENHAGEN ROAD (48) [X14/233737]

DOWNER ROAD (103) [T16/646335]

thickness (m)

continues for 4 m below

DOWNER ROAD - continued

FLAX HILL (42) [W15/748466]

thickness (m)

hidden erosional break

GAULTS SLIP (47) [W15/892447]

Rotoiti & Mangaone Tephra can be seen above;
 ~4 m of unknown material (couldn't reach) between
 these tephra and the tephra below

HAWAI (81) [X15/061527]

HEREPURU BRIDGE (02) [V15/344642]

depth (m)

HEREPURU ROAD (06) [V15/374604]

HIWARAU (27) [W15/722450]

thickness (m)

HUNTRESS CREEK (15) [W15/833472]

JACKSON ROAD (32) [X15/955468]

thickness (m)

KOHIOAWA CLIFFS (08) [V15/366631]

KOHIOAWA CLIFFS *continued*

continues for 4.5 m above

KOHIOAWA CLIFFS *continued*

continues for 3 m above

29.2

~15 m massive light brown/grey fine sand (no pumice).

41.0

Tablelands-A

00804 -

41.5

0.6 m well bedded, highly pumiceous sand & silt

fossils

>4 m grey very fine sand/silt containing macrofossils fauna;
coarsens downwards slightly,
and has occasional lenses of fine sand, and of gravel

KUKUMOA CUTTING (38) [W15/843469]

KUTARERE WHARF (34) [W15/730435]

LITTLE WAIHI ROAD (31) [V14/163766]

LITTLE WAIHI ROAD *continued*

LITTLE WAIHI ROAD *continued*

continued for 0.5 m above

22.5

29 m finely bedded greyish sand & pumice sand, (cmbdd), with occasional layer of coarser pumice (5 cm across)

continued for ≈9 m below

LITTLE WAIHI ROAD *continued*

continued for 5 m above

McCOY ROAD-(1a) (39) [W15/675455]

McCOY ROAD-(1b) (39) [W15/675454]

McCOY ROAD-(1c) (39) [W15/676454]

McCOY ROAD-(2) (40) [W15/677455]

MURUPARA-(1) (23) [V17/306992]

MURUPARA-(2) (100) [V17/316991]

MURUPARA-(3) (114) [V17/282996]

NEWDICKS BEACH (79) [V14/159781]

NGATIWA LOOKOUT (43) [W15/636522]

NGATIWA LOOKOUT *continued*

NGATIWA WEST (43-b) [W15/636523]

OHINEKOAO RESERVE (09) [V15/369629]

OHINEKOAO RESERVE *continued*

OHIWA BEACH (18) [W15/761487]

OHIWA BEACH *continued*

OHIWA HARBOUR ROAD WEST (92) [W15/764468]

Depth (m)

continued for 6 m above

36.5

— sharp colour change —

>6 m blue-grey very fine sand

uncertain - obscured

weathered gravels

OHIWA HILL (17) [W15/765468]

OHIWA LOOP ROAD (85) [W15/739466]

OMAIO (93) [X15/181648]

thickness (m)

OMOKOROA EAST (87) [U14/790889]

OMOKOROA SLUMP (86) [U14/789922]

OPAPE (14) [X15/984484]

OPAPE *continued*

OTARAWAIRERE [41] (W15/637531-2)

thickness (m)

continues for 1 m above

PAERATA RIDGE ROAD (16) [W15/822479]

PAERATA RIDGE ROAD *continued*

PAHEKEHEKE (04) [V16/356186]

PAKURANUI BRIDGE (50) [X14/246754]

PIKOWAI RESERVE (30) [V15/326651]

PUKERURU POINT (25) [W15/737459]

PUKERURU POINT *continued*

continues for 4 m below

thickness (m)

PUKERURU POINT *continued*

11.4

17.4

19.4

gravels

erosional

erosional boundary

Waiotahi (?)

2 m well bedded pumiceous sand (horizontally, cmbdd)

>2.5 m unconsolidated grey-brown sands

RAUKOKORE (52) [Y14/401822]

depth (m)

1.9

recent paleosol

medium sandy ash

20 cm darker fine/very fine sandy ash
2 cm white fine sandy ash

90 cm paleosol; well developed into fine/very fine sand/silt;
with occasional large gravel clasts (especially in upper part)

>3 m gravels

REEVES (19) [W15/751463]

thickness (m)

erosion & hidden

continued below

REEVES *continued*

REEVES *continued*

thickness (m)

erosion, colluvium & channel fill

REIHANA ROAD *continued*

continued from previous page - adjacent section

erosion, colluvium & channel fill

ROCKY CUTTING ROAD (90) [U14/956810]

thickness (m)

RUATUNA ROAD (28) [W15/739441]

TABLELANDS ROAD (21) [W15/887462]

elsewhere at
same section

see next page

TABLELANDS ROAD *continued*

TANEATUA *continued*

TE PIKI AREA (66) [Y14/562905]

Te Piki West (67) [Y14/577903]

TE PIKI AREA - "FARM TRACK" (68) [Y14/560904]

depth (m)

=15 m obscured (not exposed)

=4 m obscured

TIROHANGA (59) [X15/911476]

TORERE SCHOOL (13) [X15/048517]

TORERE WEST (22) [X15/028507]

(Note larger scale than other sections)

thickness (m)

WAIHAPOKOPOKO BRIDGE (77) [X15/155634]

WAIMANA HILL (64) [W16/662344]

WAINGARARA (63) [W15/677419]

WAIOEKA RIVER (45) [W15/847416]

WAIOPUA (37) [W16/661354]

WAIOTAHU RIVER (29) [W15/788477]

WAIOTUMA (53) [Y14/478872]

WILSON'S FARM-(1) (78) [V15/384618]

WILSON'S FARM-(1) *continued*

FAULT - unknown thickness not represented

>3 m slightly bedded, light brown marine sand

>7 m massive light brown marine sand

15 - 25 m obscured

WILSON'S FARM-(2) (78) [V15/383617]

pumiceous gravel and sand

massive sand

≈10 m unexposed - to top of Wilson's farm-(3)

≈10 m unexposed - to base of Wilson's farm-(2)

WILSON'S FARM-(3) (78) [V15/382619]

WILSON'S FARM-(5) (83) [V15/384620]

≈20 m not reachable

WILSON'S DRIVEWAY (84) [V15/386622]

APPENDIX - N:

Nomenclature

Types of volcanic rocks and ejecta

rhyolite

- a high silica volcanic rock (generally >74 % SiO₂ by weight; see diagram below). Aphanitic (volcanic) equivalent of a granite.

dacite

- a rock that is chemically mid-way between a rhyolite and and andesite. The extrusive equivalent of a quartz diorite.

andesite

- a medium silica volcanic rock (generally 57–63 % SiO₂ by weight; see diagram below). The extrusive equivalent of a diorite.

basalt

- a low silica volcanic rock (generally 45–52 % SiO₂ by weight; see diagram below). The extrusive equivalent of a gabbro.

Total alkali versus silica (TAS) diagram, showing basalt (B), basaltic andesite (BA), andesite (A), dacite (D), and rhyolite (R) fields. [after *Le Maitre* (1984)]

rhyo-dacite

- this term is used in this thesis for those rocks/deposits that chemically are rhyolitic, but which plot much closer to the dacitic field than most of the other rhyolites, and generally have much higher contents of FeO, CaO, MgO and TiO₂.

pisolites

- accretionary lapilli or volcanic hailstones; also known as chalazoidites. Fine ash which has been formed into spherules by the accretion of concentric layers. Generally indicative of phreatomagmatic eruptions.

lithics

- pieces of generally denser rock (not pumice or single crystals, – but solidified lava and/or basement rock) erupted with the pumice. Often represents entrainment, during eruption, of surrounding country rock, perhaps from a previous eruption. Obsidian lithics, however, generally represent quenched primary magma from the same eruption as produced the pumice.

obsidian

- non-vesicular glass (contains few volatiles) that appears black (or at least dark). Generally of rhyolitic composition.

free crystals

- crystals — feldspar, quartz, biotite, hornblende, hypersthene — that occur as lithics within the deposit, not attached or within pumice lapilli.

scoria

- vesicular volcanic rock ejecta, generally basaltic — equivalent to rhyolitic pumice but much less dense and less vesicular due to the different viscosities of the magma types.

When describing the deposits in a section the descriptive terms used in this thesis are:

blocks	–	pyroclastic particles	> 64 mm across.
coarse lapilli	–	" "	16 mm–64 mm across.
lapilli	–	" "	4 mm–16 mm across.
granular lapilli	–	" "	2–4 mm across.
coarse sandy ash	–	" "	0.5–2.0 mm across.
medium sandy ash	–	" "	0.25–0.50 mm across.
fine sandy ash	–	" "	0.125–0.250 mm across.
ash and fine ash	–	" "	<0.125 mm across.

Many previously published tephra formations have included a grain size or textural term (e.g. Kaharoa Ash, Taupo Lapilli, Oruanui Breccia). In this thesis these terms will be dropped and be replaced by the term "tephra". Individual members of these formations may keep their descriptive terms where appropriate.

"Ages" have been discussed throughout the thesis instead of "dates", as dates imply a point on the calendar rather than an age before present (present taken as 1950 A.D.).

- **Ma** = Mega-annums = millions of years before present.
- **ka** = kilo-annums = thousands of years before present.

Measurements are in metric units:

m = metres; **cm** = centimetres; **mm** = millimetres; decimetre = 10 cm

Many of the terms used in this thesis follow those defined by Froggatt & Lowe (1990).

In summary these are:

tephra

- includes all primary unconsolidated pyroclastic deposits, derived from airfall, pyroclastic flow and pyroclastic surge mechanisms. This also includes subaqueously deposited layers where the pyroclasts were deposited by primary volcanic mechanisms (i.e. were not washed in by alluvial processes).

ignimbrite

- all primary deposits formed by pyroclastic flows. These may be welded or unwelded ignimbrites as appropriate.

tephric alluvium

- reworked or secondary volcanic material (epiclastic) with a very high volcanoclastic component (e.g. 75–100%). Often (but not always) these deposits consist of material from a single eruption which has been catastrophically deposited coeval with or just after eruption. Seward (1976) included deposits of these types found in the Wanganui Basin within her definition of tephra.

pumiceous sand/silt

- a typical sedimentary deposit (e.g. marine, fluvial, aeolian dune) which contains a component of volcanoclastic material but is less volcanoclastic than tephric alluvium.

tephric loess

- a loess deposit (i.e. subaerially deposited) where the dominant component is of pyroclastic origin. Can usually be distinguished from primary tephra by its massive well sorted nature, and from normal quartzo-feldspathic loess by its larger grain size and predominantly glass shard composition.

Tephra Formation

- for rhyolitic tephra, a formation contains all the primary pyroclastic deposits of one eruptive episode. Each episode is separated by significant time intervals that are often marked by paleosols. The base of a tephra formation is always isochronous but the top may be time transgressive. This is because individual members within the formation have differing extents due to the varying wind speeds and directions during the eruption, and post depositional erosion may also have occurred.

Andesitic eruptions are more intermittent than the paroxysmal rhyolitic events and one period of eruption (before another hiatus or dormant period) may encompass considerable time (sometimes many thousands of years). Andesitic tephra formations have commonly included the products of more than one eruption, and generally the combined products of one period of eruption with many individual members.

subgroup

- includes all the deposits (tephra, loess, paleosol, fluvial sediments) present between two specified stratigraphic positions; i.e. a defined portion of the stratigraphic column. It is designed to split large sequences into more easily managed units. It is an informal grouping which allows for future definitions of Tephra Formations within the subgroups.

eruptive episode

- all the primary volcanic material including tephra, welded ignimbrite and lava, produced during one relatively short-lived eruption sequence.

phreatomagmatic eruption

- a volcanic eruption associated with water, often a caldera lake or the ocean, but occasionally rivers or ground-water (water-table). The eruptions are generally very violent as when the water contacts the hot magma it flashes to steam, fracturing and brecciating the rock.

isopach

- lines of equal thickness — e.g. for airfall tephra a line on a map showing where the tephra is, say, 1 m thick. The line is generally closed (where there is enough data) with the area inside the circular/elliptical shape containing airfall tephra deposits >1 m thick, and the area outside the line containing deposits <1 m thick.

Taupo Volcanic Zone (T.V.Z.)

- a belt of subsidence and volcanic eruption stretching from Taupo to White Island through the central North Island.

Central Volcanic Region (C.V.R.)

- a large area in the central North Island to either side of the T.V.Z., where volcanic rock/ignimbrite forms the bulk of the landscape.

Bay of Plenty region

- general geographical region located inland from the Bay of Plenty coast, bounded by Tauranga Harbour in the west, Reporoa (perhaps as far as Taupo?) and Murupara in the south, and Te Kaha and Waihou Bay in the east.

eastern Bay of Plenty

- specifically — for the deposits discussed in this thesis— the area east of Whakatane (i.e. Ohiwa Harbour, Opotiki, Torere, Te Kaha, and Waihou Bay).

Kaingaroa Plateau

- a plateau to the east of the T.V.Z. formed from several large ignimbrite sheets, of which the Kaingaroa Ignimbrite is the youngest.

Kaingaroa forest

- large area of managed pine plantation, much of which is located on the Kaingaroa Plateau. Consists of several named forests, but boundaries are arbitrary.

Tokoroa forest

- large area of managed pine plantation to the west of Rotorua and around Tokoroa.

APPENDIX - O:

Combined stratigraphic sections

repeated from Chapter Five;
Figures 5-16, 5-17, 5-18 & 5-19

Figure 5-16 : Stratigraphic sections of the coastal cliff exposures west of Matata

Figure 5-17: Correlations between the major stratigraphic sections

Figure 5-18: Comparison of sections across widespread areas of the Bay of Plenty