THE EARLY QUATERNARY MARINE TO TERRESTRIAL TRANSITION OF THE SOUTHEASTERN WAIRARAPA, NEW ZEALAND

by

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Frontispiece

Nga Waka-o-Kupe, the Windy Peak Range, as viewed from Ruakokoputuna Road to the southwest.

Abstract

This study examines the final emergence of the southeastern Wairarapa within a sequence stratigraphic framework. New exposures of the Pleistocene marginal-marine Hautotara Formation, and non-marine Te Muna Formation allow facies to be detailed and sequence architecture to be analysed.

Cyclicity observed within the facies successions of the Hautotara and Te Muna formations are placed in a series of four motifs. These motifs record 40 kyr glacio-eustatic cyclicity superimposed upon the basinward to landward progression of the environments, showing the region shallowing through time.

The positions of the top of the Pukenui Limestone and the base of the Hautotara Formation are revised, and are now at the top of the “Pukenui C” - a widespread marker bed, which also removes a historical nomenclatural gap. The recognition of the significance of the coccolith *Gephyrocapsa sinuosa* within the underlying Pukenui Limestone allows this contact to be dated at 1.73 Ma.

The ~1.6 Ma age limit provided by a number of tephra within the lower sediments of the Te Muna Formation allow the ages of the examined formations to be constrained further. The eight 40 ka cycles identified within the Hautotara Formation suggests deposition between 1.73 and 1.42 Ma.

The Hautotara - Te Muna Formation is revealed to be diachronous, with the base of the Te Muna Formation type section shown to be much younger, 1.12 Ma, than the 1.58 Ma age of the lower contact observed elsewhere in the region. A series of palaeogeographic reconstructions at 1.73, 1.58 and 1.57 Ma demonstrate how closely related sedimentation patterns are to structural growth, with marginal-marine Hautotara Formation sedimentation persisting in the centre of the study area well after the initiation of Te Muna Formation terrestrial deposition to the north and south of this site.

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Chapter One

Introduction

1.1 Project Aims

This thesis focuses on two Pleistocene sedimentary formations cropping out in the streams and hills east of the lower Wairarapa Valley, in the southern North Island, New Zealand. The Hautotara Formation is an early Pleistocene marginal marine succession representing the final emergence of the Eastern Wairarapa Valley. It exhibits significant lateral variation, is comprised of many different facies, and contains numerous erosional surfaces. The Te Muna Formation is a middle Pleistocene alternating succession of fluvial conglomerates and lacustrine mudstone, and represents the response of a fully terrestrial Wairarapa Valley to changes in sea-level (Collen & Vella, 1984).

The timing of events and units recorded by the formations have previously not been well constrained. This study advances the understanding of the Hautotara and Te Muna Formations, by utilising detailed measured sections, new tephrochronological and biostratigraphic data to provide improved sequence stratigraphic resolution and ultimately an improved geological interpretation of the area.

Aim One:

Produce revised ages for the Hautotara and Te Muna Formations.

Cyclicity present in the Late Miocene to Pleistocene sedimentary deposits of the Eastern Wairarapa Valley has been examined in an attempt to document the pattern of glacio-eustatic sea-level changes in the basin (Gammon, 1995, 1997; Vella, 1963a). With advances in the understanding of the sequence stratigraphic framework, subtle changes in the sedimentary deposits, macrofossil assemblages and boundary conditions of the Hautotara Formation will be used to identify Milankovitch-scale variations of sea-level change in increased detail.

Aim Two:
Identify sequence stratigraphic motifs of the Hautotara and Te Muna Formations.

The study area is located in a fold and thrust belt of the active Hikurangi subduction margin (Figure 1.1A). The timing and rates of growth of the main structural features of the study area can be identified using a well-constrained chronology of the stratigraphic succession (Nicol *et al.*, 2002). By combining the tectonic, biostratigraphic, sedimentary and sequence-stratigraphic data, a palaeogeographic reconstruction of the Eastern Wairarapa Valley over the Quaternary is produced.

Aim Three:
Present the Early Quaternary marine to terrestrial transition of the Eastern Wairarapa Valley, through palaeogeographical reconstructions.

Improved resolution within the Pleistocene marginal marine and terrestrial deposits of the Eastern Wairarapa Valley allows a palaeogeographic reconstruction of the region to be undertaken. A number of palaeogeographic maps presented here allow increased understanding of the timing and spatial evolution of the varying sedimentary sequences within the study area. These may be compared to sedimentary deposits over the corresponding time in the Wanganui and Hawke's Bay Basins (e.g. Erdman & Kelsey, 1992; Pillans *et al.*, 2005; Bland, 2006) to further define the timing of events over the lower North Island.

1.2 Location of Study

The study area is a seventeen kilometre long, southwest to northeast aligned region located approximately ten kilometres south of Martinborough in the southeastern Wairarapa (Figure 1.1B). This area extends from the Ruakokoputuna River Valley, 800 metres southwest of the confluence with Clay Creek, to Hinakura Road in the north, incorporating the Huangarua River and the lower portion of the Blue Rock Stream Valley (Appendix One – Geological Map).

Figure 1.1 Maps and cross section showing: A) The New Zealand plate tectonic setting (modified from Little *et al.*, 2009); B) the location of the study area within the lower North Island, and C) simplified subduction interface of the lower North Island (modified from Little *et al.*, 2009 after Wallace *et al.*, 2005).

Outcrops are largely restricted to recent river or road cuttings, although useable exposures are also found within the many streams draining westwards off the Windy Peak Range (Nga Waka-a-Kupe).

1.3 Geological setting

The study area is located on the eastern margin of the Wairarapa Valley, the southern portion of the emergent Hikurangi forearc basin (Nicol *et al.*, 2002). The Hikurangi forearc basin is a result of the oblique convergence of the Pacific and Australian plates to the east of the North Island, where the Pacific plate is actively being subducted (Figure 1.1C). The deformation within the Hikurangi Margin plate boundary zone has resulted in a series of strike-slip faults within the axial ranges to the west of the Wairarapa Valley, and a fold and thrust belt that extends to the east of the study area (Figure 1.1C).

Over the last 10 Myr, as a result of the plate convergence, the Hikurangi forearc basin has been differentially uplifting (Beanland *et al.*, 1998; Nicol *et al.*, 2002), resulting in the deposition of progressively shallower marine deposits, and in the Mid to Late Pleistocene, terrestrial formations. Basement greywackes and argillites (herein called as greywacke) of Mesozoic age outcrop as physical highs in many areas bounding the Wairarapa Valley, in particular the Aorangi and Rimutaka ranges (Figure 1.1B). Prior to circa 2 Ma, a strongly tidally-influenced palaeoseaway stretched through the forearc basin. This 300 km long, relatively narrow (30-60 km) northeast to southwest trending feature, the Ruataniwha Strait (Beu, 1995), extended from the Cook Strait at the southern end of the Wairarapa Valley through to Gisborne in the north (Nelson *et al.*, 2000). Around 2 Ma, a greywacke high known as the Mt Bruce block, located in the Northern Wairarapa, was uplifted and closed the north-south flow of the Ruataniwha Strait, separating the Hawke's Bay and Wairarapa Basins, the major Quaternary depocentres of the East Coast (Figure 1.1A) (Beu, 1995).

Figure 1.2 East Coast Forearc Basins setting showing location of Ruataniwha Strait, basement rocks and Pliocene Limestones (Modified from Nelson *et al.*, 2003).

The irregular uplift of the forearc basin has resulted in a variation of the depositional settings of the basins, including tidal current-dominated regions and large marine embayments (Beu, 1995). This evolution of the forearc basin culminated in the deposition of Plio-Pleistocene limestones and marginal marine deposits (Lee & Begg, 2002; Caron *et al.*, 2004), which are in turn overlain by the extensive terrestrial deposits of the emergent valleys. Within the Wairarapa Basin, these deposits include the Pleistocene Pukenui Limestone and Hautotara Formations, with the overlying terrestrial Te Muna and Ahiaruhe Formations (Begg & Johnston, 2000).

The main structural fabric of the Wairarapa Basin trends northeast/southwest, and within the study area there are several named and unnamed structural features related to this, including the Huangarua Fault, Huangarua Syncline, Windy Peak Anticline and Monocline, and the Ruakokoputuna Syncline (Appendix One – Geological Map). These contractional features have played an active role in controlling the spatial and temporal distribution of sediment deposition in the study area through the Plio-Pleistocene.

1.4 Previous work in the Study Area

The study area has a long history of geological study, dating back to Crawford (1871), who identified “Fossiliferous Limestone” and “Fine Red Gravels” in the Hautotara region, and McKay (1878, 1879) who noted “*Rotella zelandica*” [*Zethalia zelandica*] in reddish-brown sands and gravels, and the (still common) difficulty of attempting to remove fossils from the near vertical beds next to the Hautotara [Huangarua] River.

Following these preliminary observations were several studies identifying and describing the fossil assemblage of the area, including Thomson (1919), Waghorn (1927) and King (1933). Waghorn (1927) also discussed the fault bounding of the upper Ruakokoputuna Valley.

Beginning in the late 1940’s, Victoria University of Wellington (VUW) students began actively studying within the region, with Couper (1948) mapping an area that included the southern part of this study area, and Vella (1949, 1963a) identifying three cyclothems within strata to the north of the present study area. Rodley (1961) gave informal names to the succession of limestones and marginal marine beds in the Makara/Huangarua River area, and these can still be identified today, although commonly used in a slightly different manner (Chapter Two). Her descriptions of the marginal marine units form the basis of the Hautotara Formation type section (Collen & Vella, 1984). Bates (1967) mapped an extensive area that encompassed Palliser Bay, the western side of the Aorangi Ranges and the Ruakokoputuna and Blue Rock Valleys, correlating late Cenezoic sediments within an area exceeding 350 square kilometres.

Paul Vella’s numerous studies of the Wairarapa Valley include lithostratigraphic investigations and initial cyclothem studies of the rocks east of Martinborough (e.g., Vella, 1963a; Vella & Briggs, 1971). The modern definitions of the Hautotara, Te Muna and Ahiaruhe Formations were presented in a paper by Collen & Vella (1984). A preliminary structural history of the region was published by Lamb & Vella (1987), although it is accepted that the age used for the Te Muna Formation was

incorrect, and a key outcrop used has since been reinterpreted (Nicol & Van Dissen, 1997).

Thomson (1980) mapped the Blue Rock Valley in detail, identifying a shallow-marine succession that differs from that found to the east, and O'Brien (1980) documented a number of tephra within the Te Muna Formation in the north of the study area. Dobbie (1982) investigated the factors influencing recementation of the Quaternary limestones, with levels of calcite and aragonite, changes in the terrigenous content, and water flow as the important variables. Rataul (1988) helped to define the characteristics of the recently-described Hautotara and Te Muna Formations, and confirmed that the mudstones of the Te Muna Formation are lacustrine in origin. Cape *et al.*, (1990), interpreted seismic data across the Wairarapa Valley, and correlated significant reflectors in the wider basin to outcrops of Hautotara and Te Muna Formations in the Huangarua Valley.

Recent student projects include Rampton (1997) who mapped and interpreted the Late Neogene sequence within the northern part of the study area, and helped redefine a section of steeply dipping Hautotara and Te Muna Formation overlain unconformably by Ahiaruhe Formation (Nicol & Van Dissen, 1997). Gammon (1995, 1997) documented many stratigraphic sections in the region and attempted to identify a sequence-stratigraphic signature, and Clarke (1998) provides a valuable and detailed investigation into the biostratigraphy of the limestones of the lower Ruakokoputuna River and Makara Stream. Andrews (2001) constrained the depositional environment of the Pukenui Limestone in the Hinakura Road area, showing that the Pukenui Limestone in this area has characteristics generally ascribed to the Hautotara Formation.

A series of papers in the 1990's, first identified, then progressively modified, the ages of a series of tephra in the Wairarapa region, as methods were refined (Shane, 1990, 1991; Shane & Froggatt, 1991; Shane *et al.*, 1995, 1996). This work in constraining the chronology has been updated by Nicol *et al.*, (2002) who produced a synthesis paper incorporating a wide range of data within the Eastern Wairarapa Valley to constrain the rate and timing of deformation. Formento-Trigilio *et al.*, (2002) focused on the Late Quaternary folding of the study area using terrace

surfaces deformation, allowing insights into the modern structural processes acting upon the study area.

1.5 Methods of analysis

Geological mapping of the region identified the extent of the Hautotara and Te Muna Formations in the area southeast of Martinborough. In addition, mapping of parts of the underlying Pukenui Limestone and overlying Ahiaruhe Formation and Late Quaternary gravels was carried out.

Eight stratigraphic sections were measured in detail through the study area. This was carried out using an Abney level, Jacob's staff, tape and compass. Lithological descriptions and macrofossil identification were carried out on these sections. Tephra, grain size, and bulk macrofossil samples were collected from suitable locations in the stratigraphic sections and throughout the study area.

Macrofossil identification was done where possible in the field, with bulk samples collected from selected beds washed and examined in the Palaeontology Laboratory at Victoria University of Wellington (VUW). Where identification proved to be difficult, samples were referred to, and discussed with, Alan Beu at GNS Science.

Clast shape and fabric data from the conglomerate units of the Te Muna Formation were recorded in the field using callipers and compass, with the length of the A, B and C axis, roundness, and dip and dip direction of the A-B plane recorded. Corrections for tectonic tilt and stereonet projections were calculated using the StereoWin program. Shape and roundness data of the gravel units of the Hautotara Formation were collected both at outcrops and at VUW.

Grain size analysis of predominantly siliciclastic material under 2 mm in diameter was carried out on the Beckman Coulter Laser Sizer 13 320 at VUW. Sediment preparation for this method of analysis is detailed in Appendix Three.

Detailed discussion of the preparation of tephra samples for analysis, on the JEOL JXA-8230 Superprobe electron probe microanalyzer in the Geochemistry labs at VUW, is presented at the start of Appendix Four.

1.6 Notes

1.6.1 Map Series

Land Information New Zealand (LINZ) is in the process of converting New Zealand's topographic mapping system from the NZMS 260 map sheets to the Topo250 and Topo50 sheets. These systems have different coordinate systems, with the easting and northing co-ordinates having moved approximately 200 metres in the new map sheets. As the NZMS 260 map sheets are still the most commonly used at present, and Topo50 to become more used, this thesis will provide a conversion between the two systems in Appendix Seven. Within the body of the thesis, the new Topo50 coordinates will be used.

This thesis covers the area of NZMS 260, Sheet S27 (Lake Wairarapa), and the areas of Topo50, BQ33 (Lake Wairarapa) and BQ34 (Martinborough), although some discussion of sites outside of these regions also occurs (Figure 1.3).

1.6.2 Grain size

Grain size data on the Beckman Coulter Laser Sizer 13 320 is calculated in microns. To enable comparison with previous work done on the Hautotara and Te Muna Formations, and their modern analogues (Rampton, 1997; Woolfe, 1993, 1995) this data has been converted to phi values.

Raw grain size data is presented in Appendix Four, and the graphs can be viewed alongside the appropriate stratigraphy within Appendix Two.

Figure 1.3 Locations of NZMS 260 S27 (Lake Wairarapa) and Topo50 Maps BQ33 (Lake Wairarapa) and BQ34 (Martinborough) used in this thesis.

1.6.3 Ages

The ages of units and formations discussed within this thesis are taken from NZGTS 2010/1 - the revised New Zealand Geological Time Scale (Hollis et al., 2010), and a summary of the time-scale applicable to the Hautotara and Te Muna Formations is provided (Figure 1.4). Not represented in Figure 1.4 is the base of the Nukumaruan Stage (Wn) – which occurs at 2.4 Ma. The stratotype of the base of the Wn is identified as the Hautawa Shellbed, which contains the first occurrence (FO) of the cold-water scallop *Zygochlamys delicatula* in the Wanganui Basin (Beu, 2001). The stratotype for the base of the Castlecliffian Stage (Wc) is currently accepted as the Ototoka Tephra, which has been identified in oxygen isotope stage (OIS) 57, at 1.63 Ma (Beu, 2001; Beu *et al.*, 2004). The boundary between the Castlecliffian and Haweran (Wq) occurs at 0.34 Ma (OIS 10), and is represented by the Rangitawa Tephra. The base of both the Quaternary Period and Pleistocene Epoch is at 2.58 Ma

(OIS 104), after formal ratification in June 2009 by the International Union of Geological Sciences (Gibbard *et al.*, 2009).

Figure 1.4 New Zealand Pliocene-Holocene time-scale as applied in this study. Position of oxygen isotope stages from Carter & Naish (1999). Modified from Beu (2006).

Chapter Two

Stratigraphy

2.1 General Introduction to Stratigraphy

The focus of this study is the depositional history of the Hautotara and Te Muna formations, and an examination of their ages and palaeogeography requires a systematic analysis of the stratigraphy. Therefore, this chapter will provide a descriptive overview of the lithostratigraphy of the Hautotara and Te Muna formations within the study area. In addition, a brief examination of the underlying Pukenui Limestone and the overlying non-marine deposits is also warranted, as these formations provide a broader understanding and context of the marine to terrestrial transition and the structural evolution of the study area. Interpretations of the stratigraphy and facies relationships will be presented in Chapters Three and Four. Eight stratigraphic sections are also discussed in this chapter, and these are presented in Appendix Two.

As the number of geological investigations in the southern Wairarapa region increased over the last four decades, the progressive recognition and identification of lithological and biostratigraphic changes in the record forced workers to adopt new formation names, superseding previous definitions (e.g., Collen & Vella, 1984; Gammon, 1995; Vella & Briggs, 1971). As a result, the position of boundaries between formations have been modified and adapted. Figure 2.1 provides a short summary of the relevant nomenclature, and the position of formations used in previous works and as described in this study. Figure 2.2 shows the location of the four published type localities, and the proposed reference sections of the Pukenui Limestone and Hautotara Formation.

Of particular note, the contact between the Pukenui Limestone and Hautotara Formation has been placed in various stratigraphic positions (Collen & Vella, 1984; Gammon, 1997; Nicol *et al.*, 2002). The basis of a revised formal definition of the

Hautotara Formation, and the lower contact is presented in Section 2.3. This definition closely fits with the interpretation of Gammon (1995) and Rampton (1997).

Stratigraphy (Generalised)	Rodley 1961		Vella & Briggs 1971	Thomson 1980*	Collen & Vella 1984	Gammon 1997	This Study
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Figure 2.1 Previous authors naming of Eastern Wairarapa Valley stratigraphy and that used in this study. [*Thomson (1980) worked in the Blue Rock Valley, identifying a different lithological succession to that found at the Type Sections].

Figure 2.2 Location of Type Sections of the formations discussed in Chapter 2 and of proposed reference sections of the Pukenui Limestone and Hautotara Formations.

Codes to Measured Sections provided in Section 2.7

2.2 Pukenui Limestone

2.2.1 Name and Definition

The Pukenui Limestone is a succession of alternating coquina limestones and blue-grey sandstones and mudstones, and was formally defined by Vella & Briggs (1971), with the formation name derived from the Pukenui 2 Trig Station east of the Ruakokoputuna River (BQ33 035 202). The Pukenui Limestone is the stratigraphically highest formation of the Onoke Group (Begg & Johnston, 2000; Beu, 1995; Vella & Briggs, 1971), and comprises five informal members.

The naming of the members is a convention applied by previous workers in the Eastern Wairarapa Valley, with the terminology modified from Rodley (1961), who included the rocks in her Hautotara Formation. Individual limestone beds have been assigned letters, for example, the lowermost is known as “Limestone A”, which is in turn overlain by the “A-B Interbed”, and so on up the section (Figure 2.1).

2.2.2 Type and Reference Section

The type locality of the Pukenui Limestone is northeast of White Rock Road near the Birch Hill Homestead (BQ34 070 234), and is now overgrown. The type locality does not include the “Limestone C” as this was not considered part of the Pukenui Limestone in the original description of Vella & Briggs (1971). Accessible sections of the Pukenui Limestone are located in streams adjacent to the type locality bluffs, and it is proposed well-defined exposures described by Rodley (1961) and Clarke (1998) in the Makara River near its confluence with the Ruakokoputuna River (BQ34 075 253) are used for a reference section for the Pukenui Limestone (Figure 2.2). This location contains all the members of the Pukenui Limestone under the current usage of the name, and any discussion in this study of the reference section of the Pukenui Limestone refers to this site.

2.2.3 Lower Contact

The Pukenui Limestone conformably overlies the Greycliffs Formation (Figure 2.3) with a gradational contact highlighted by a colour change and increase in *Zygochlamys delicatula* - found convex and concave up, single and double-valve and variously encrusted with *Fosterella tubulatus* (Atkins, 1995). Although not formally defined, the exact location of this contact has been shifted from the original stratigraphic location proposed by Vella & Briggs (1971) (Figure 2.1).

Figure 2.3 Transition from sandy siltstones of the Greycliffs Formation (grey) to the Pukenui Limestone “A” (orange brown), a coquina bed containing abundant *Zygochlamys delicatula* and *Fosterella tubulatus* at the base [BQ34 072 234].

2.2.4 Distribution and Thickness

The Pukenui Limestone occurs in a northeast-southwest trending belt of sporadic outcrops forming hills and high points in the eastern Wairarapa Valley, from the Mt Bruce area in the north, to the southwestern reach of the study area (Dobbie, 1982) (Figure 1.1B, Figure 1.2). A continuous stretch of Pukenui Limestone is found on the Kourarau Hills east of Gladstone and north of the study area. The differentiation between the Pukenui Limestone and the coquina limestones of the Eketahuna Group north of the Wairarapa Valley is largely arbitrary, and more based on historical mapping than any lithological or biological changes (Beu, 1995). Nukumaruan-age Te Aute limestones similar to the Pukenui Limestone are mapped throughout the East Coast Basins as far north as Gisborne (Beu *et al.*, 1980; Beu, 1995; Nelson *et al.*, 2003) (Figure 1.2).

At both the type locality, and the reference section the Pukenui Limestone is approximately 90 metres thick. This appears to be a maximum thickness for the formation. At Hinakura Road in the northern part of the study area, the Pukenui Limestone is much thinner. Dobbie (1982) and Beu (1995) identify a persistently thinner Pukenui Limestone forming ridges in the Wairarapa north of the study area.

2.2.5 Description

The Pukenui Limestone is a succession of alternating coquina limestones and blue-grey sandstones and mudstones (Figure 2.1). At the type locality, the formation consists of three coquina limestone members containing characteristic cold-water species such as *Zygochlamys delicatula*, *Jacquinotia edwardsi*, *Pseudechinus novaezealandiae* and *Tawera subsulcata*, while the interbeds are largely sparsely fossiliferous, although these do include subtropical microfossils (Vella & Briggs, 1971). The most common macrofossil occurring in the interbeds are the bivalve *Panopea zelandica* (Vella & Briggs, 1971; Clarke, 1998).

It has previously been noted that the Pukenui Limestone contains both minor and major lateral variation in facies (Atkins, 1995; Clarke, 1998). Within the study area the Pukenui Limestone changes significantly, becoming predominantly a muddy, fossil-poor deposit in the northern part of the study area (BQ34 141 315) (Andrews, 2001).

In the wider Wairarapa Valley, the Pukenui Limestone contains fewer members (Dobbie, 1982). This suggests that local effects of tectonism and differential uplift have affected the deposition of the Pukenui Limestone, and that within the study area this has produced the right structural control to record three coquina members.

2.2.6 Palaeontology and Age

The Pukenui Limestone is a early- to mid-Nukumaruan formation, but over what period of time the formation was deposited is not particularly well-constrained (e.g., Clarke, 1998; Gammon, 1997; Nicol *et al.*, 2002; Vella & Briggs, 1971). The presence of the coccolith *Gephyrocapsa sinuosa* in the “A-B Interbed” is an indicator that this particular horizon is a maximum of 1.8 Ma (Edwards, 1987).

The presence of *Zygochlamys delicatula* in the Greycliffs Formation near the base of the Pukenui Limestone represents the first Quaternary influxes of cold water into the Ruataniwha Strait, although the specific timing and environment of the deposition of these fossils is subjected to differing interpretations (e.g. Atkins, 1995; Gammon, 1997; Orpin *et al.*, 1998).

The Pukenui Limestone contains no macrofossils that may constrain the formation to a greater resolution than the Nukumaruan (Rampton, 1997). However, the number of cycles postulated to be present in the Pukenui Limestone varies in the literature between two and 10 (e.g. Vella & Briggs, 1971; Clarke, 1998; Gammon, 1997). The number of cycles, however, must be constrained by palaeomagnetic and biostratigraphic datum, with the key Pukenui Limestone indicators the first occurrence of the coccolith *Gephyrocapsa sinuosa* in the “A-B Interbed” placed at 1.80 Ma (Edwards 1976; Nicol *et al.*, 2002), the base of the Olduvai subchron found

in the underlying Greycliffs Formation, and the top near the “Limestone B” (Edwards, 1976, Kennett *et al.*, 1971, Cande & Kent, 1995).

This study infers the Pukenui Limestone to incorporate three 40 kyr glacio-eustatic sea-level cycles, with the “Eringa Motif” (Chapter Four, Figure 4.3), the dominant signature of the formation. By incorporating the age provided by the first appearance of *Gephyrocapsa sinuosa* in the “A-B Interbed”, the Pukenui Limestone spans the time range of approximately 1.86 – 1.73 Ma.

The Pukenui Limestone contains numerous environmentally important fossils, including *Panopea* sp. within the interbeds, and the predominately shoreface *Tawera subsulcata*, prominent in particular on the top of the “Limestone C”.

Rare worn *Austrovenus stutchburyi* and *Limnoperna huttoni* have been noted within the Pukenui Limestone, and these species indicate the presence of estuarine conditions landward of the Pukenui Limestone observed in the study area (Beu & Maxwell, 1990; Clarke, 1998).

2.2.7 Environment of Deposition

The Pukenui Limestone contains sediment deposited within a range of marine depositional environments between the inner shelf and upper shoreface. The lower Pukenui Limestone contains mostly inner shelf sediments, while the upper Pukenui Limestone is characterised by shallower sediments. The deposition of the Pukenui Limestone represents a shallowing of the study area, inferred to be as a result of uplift of the Hikurangi forearc basin combined with on-going sedimentation into the basin, while also containing an overall glacio-eustatic sea level overprint. Lateral variations in the members of the Pukenui Limestone are attributed to ongoing local effects of tectonism (Nicol *et al.*, 2002).

2.3 Hautotara Formation

2.3.1 Name and Definition

The Hautotara Formation contains interbedded siltstones, sandstones, shell beds and conglomerates, and was formally defined by Collen & Vella (1984). The formation name is derived from the name of the area surrounding the confluence of the Ruakokoputuna and Makara Rivers. The Hautotara Formation incorporates the rocks of the upper Eringa Cyclothem and the entire Huangarua Cyclothem of Vella (1963a).

The name Hautotara has previously been used to describe a variety of rocks. For example, the term “Hautotara beds” was used by Hector (1884) to describe strata in the Manawatu Gorge that resemble outcrops present in the study area, while Couper (1948) and Rodley (1961) used the name Hautotara Formation for the succession from the Greycliffs Formation to the Te Muna Formation.

Thomson (1980) mapped and described the Hautotara Formation rocks in the Ruakokoputuna and Blue Rock Valleys under the name Huangarua Formation, but otherwise the usage remained consistent with the Hautotara Formation definition of Collen & Vella (1984) (Figure 2.1).

2.3.2 Type and Reference section

The type locality of the Hautotara Formation comprises 400 metres of river bank on the true right of the Huangarua River immediately downstream of the Hautotara Bridge (commonly referred to as Banana Bridge) (BQ34 072 254). However, the type locality does not start from the “Limestone C” as this was not considered the lower contact in the original description of Collen & Vella (1984) (Figure 2.1). The type locality is poorly exposed, due to the construction of the Hautotara Bridge, and the overgrowth of the river banks. However, outcrops of the type locality sediments

are now visible on the opposite (western) river bank to that originally described by Rodley (1961).

A number of reference sections have been proposed for the Hautotara Formation (Figure 2.2). Rataul (1988) identified an outcrop in cliffs east of the Huangarua River (BQ34 097 302) as an acceptable reference section. However this is not a complete outcrop of the Hautotara Formation, and is severely restricted in the facies present. Gammon (1995) combined a number of his measured sections into a composite section. Comparison and discussion of facies and facies associations as used by Gammon (1995), and the issues with their use are found in Chapter Four.

Here it is proposed that the 71 m-thick exposure of the Hautotara Formation between Ruawaka Stream and the Huangarua River (centred on BQ34 086 267) become a new reference section for the Hautotara Formation. This section contains the thickest observed Hautotara Formation, and contains a wide range of facies in a near-continuous section, constrained by lower contact and upper contacts with the Pukenui Limestone and Te Muna Formation respectively, a feature not found at any other known site. The stratigraphy of this proposed reference section is shown in full as Ruawaka Section in Appendix Two.

2.3.3 Lower Contact

The lower contact, with the Pukenui Limestone, has not been well defined, and has conflicting definitions (e.g., Collen & Vella, 1984; Gammon, 1995; Vella & Briggs, 1971) (Figure 2.1). Following from the interpretation of recent workers, we here propose the top of the “Limestone C” to be the contact between the two formations. The top of the “Limestone C” is taken to be a prominent indurated *Tawera subsulcata*-dominated bed, well-exposed at a number of sections, including in the Makara River near its confluence with the Ruakokoputuna River and also in Ruawaka Stream (Figure 2.4). This *Tawera subsulcata* bed is overlain by a friable well-sorted medium-fine sand of the Hautotara Formation, and this contact probably represents a short hiatus between the formations. Of note, this definition varies from some previous usages, as although this *Tawera subsulcata* bed is the most

prominent, it is not the highest stratigraphically. Previous studies, including the definition of the type section by Collen & Vella (1984), have taken the contact between the Pukenui Limestone and Hautotara Formations to be the highest *Tawera subsulcata* bed.

2.3.4 Distribution and Thickness

The Hautotara Formation is best exposed in a near-continuous band of outcrops flanking the Windy Peak Anticline, from Ngarara Stream in the northeast to just south of Hautotara Bridge in the southwest (Appendix One). The poorly cemented beds of the Hautotara Formation form a prominent break in slope between the underlying, cemented “Limestone C” of the Pukenui Limestone and the lowest massive-to-stratified conglomerate units of the overlying Te Muna Formation. For three kilometres downstream of Hautotara Bridge, the Huangarua River largely flows along strike, cutting through the Hautotara Formation.

The Hautotara Formation is also found within the Blue Rock and Ruakokoputuna Valleys, where exposures are often limited to the base of cliffs, or stream beds. Hautotara Formation beds are also observed to the north of the study area within the Whangaehu Stream Valley, and along the southern flanks of the hills near Oystershell Road (BQ34 120 316).

Figure 2.2. Contact (dashed white line) between the Pukenui Limestone and the Hautotara Formation at: A) Makara Stream (Bq34 075 253), adjacent to the Hautotara Formation type section, below the Pukenui Limestone-Hautotara Formation contact of Collen & Vella (1984). B) In Ruawaka Stream, the proposed reference section (BQ34 086 267).

Outside of the study area, the Hautotara Formation is not as readily identified, and its usage is not always applied under restrictions of its definition. Kennett (1964) identifies Hautotara Formation deposits to the north of the study area, on limbs of the growing Gladstone Anticline at Gladstone (Figure 1.1B). The Wellington Q-Map (Begg & Johnston, 2000) identifies Hautotara Formation within the sea cliffs at Lake Ferry, to the immediate east of Lake Onoke (Figure 1.1B) (BQ32 793 152). These sediments at Lake Ferry have poorly defined, and often contradictory, ages attributed to them (M. Hannah, *pers. comm*), although the presence of the Wn to Recent gastropod *Zethalia zelandica* in a shelly conglomerate, and the moderate dip of the beds suggest the period of deposition of these beds is approximate to that of the Hautotara Formation in the study area.

Collen & Vella (1984) record 40 metres of Hautotara Formation at the type section, although including the strata below this as proposed by the redefinition increases this to around 70 metres (Rodley, 1961). At the proposed reference section at Ruawaka Stream, 71 metres of Hautotara Formation is exposed. The Hautotara Formation appears to be thickest in the Huangarua Syncline, indicating that the syncline was growing during the depositional period of the Hautotara Formation. Away from the near-continuous band of outcrops flanking the Windy Peak Anticline, the formation is often thin (<20 metres) and outcrops are difficult to find.

2.3.5 Description

The Hautotara Formation comprises interbedded siltstones, sandstones, shellbeds and conglomerates, and contains major lateral variation in facies (Figure 2.1; Chapter Three). The Hautotara Formation represents the Quaternary marginal marine deposits of the Eastern Wairarapa Valley associated with the closing of the Ruataniwha Strait and the final emergence of the Wairarapa.

Details of the facies present and their relationships are presented in the following three Chapters.

2.3.6 Palaeontology and Age

The Hautotara Formation is late Nukumaruan, and although representing a period of time with no major biostratigraphic constraints, the timing of deposition can be restricted by evidence from the underlying Pukenui Limestone and overlying Te Muna Formation (e.g. Nicol *et al.*, 2002). Based on new stratigraphic sections and increased resolution of the sequence stratigraphic interpretation, it is inferred deposition of the Hautotara Formation continued into the Castlecliffian stage.

A reverse polarity signature within the “Barytellina siltstone” provides some control on the chronology, with the reversal identified to be from near the Pukenui “Limestone B”, to five metres above the Upper Te Muna Tephra in the Te Muna Formation (Collen & Vella, 1984; Kennett *et al.* 1971; Shane & Froggatt, 1991). This time frame corresponds to the Matuyama reversed chron (Naish, 2005).

The palaeontological evidence from the Hautotara Formation supports deposition within the Nukumaruan and Castlecliffian stages. A number of macrofossils prominent within the Hautotara Formation are first identified in the Nukumaruan (Beu & Maxwell, 1990). Three major indicator species for the start of the Nukumaruan are:

Tawera subsulcata

Zethalia zelandica

Amalda opima

These species are the most common identified within the Hautotara Formation, and although they may be variably preserved, a significant proportion appear *in situ*, and therefore can be reliably used as age diagnostic species.

The gastropod *Amalda opima* is a Nukumaruan restricted species (Beu & Maxwell, 1990), and appears within a massive sandstone of at the Ruawaka measured section (Appendix Six).

A number of macrofossils identified in the Hautotara Formation are extinct, and can limit the upper boundary of the formation to the Castlecliffian. Significantly these include:

Limnoperna huttoni

Tawera subsulcata

Barytellina crassidens

These species are all identified within the upper Hautotara Formation, with *Barytellina crassidens* in particular occurring at the Hautotara-Te Muna Formation contact.

The macrofossils identified within the Hautotara Formation are from a range of environments, with *Panopea zelandica* and *Amalda mucronata* both species indicative of the inner shelf environment, while *Austrovenus stutchburyi*, *Limnoperna huttoni* and *Barytellina crassidens* all low salinity to estuarine species (Beu & Maxwell, 1990). Although *Limnoperna huttoni* has not been identified *in situ*, the presence of transported valves in shellbeds suggests the appropriate habitat was located nearby.

Further discussion of the relationship between the facies and environmentally restricted taxa is provided in Chapter Three.

This study interprets the Hautotara Formation to incorporate seven and a half sea-level cycles at the Ruawaka measured section. These cycles are believed to be 40 kyr Milankovitch forced glacio-eustatic sea-level cycles, and therefore believed to represent a maximum of 300 kyr. This constrains the deposition of the Hautotara Formation between the 1.73 Ma of the top of the Pukenui Limestone, and 1.44 Ma with an angular unconformity with the Te Muna Formation.

The age of the Hautotara–Te Muna Formation contact is believed to vary between sites. This results in the Hautotara Formation incorporating a differing number of sea-level cycles at the various sections. For example, to the north, the Hautotara Formation data from this study and an examination of the work of Rampton (1997)

suggests the formation incorporates three and a half cycles. This would place the formation in this area between around 1.73 – 1.60 Ma. This is in excellent agreement with age constraints provided by tephra deposits in this region, which places the lowest mudstone of the Te Muna Formation at 1.57 Ma (this study; Nicol *et al.*, 2002).

2.3.7 Environment of Deposition

The Hautotara Formation represents a range of marginal marine depositional environments, and contains strata interpreted to have been deposited in settings ranging from inner shelf to estuarine (Chapter 3). Variations in the apparent water depth of these depositional environments are related to Milankovitch-scale glacio-eustatic sea-level change with an overprint of regional structural contraction. Previous studies have highlighted non-marine rocks within the formation (e.g. Collen & Vella, 1984; Gammon, 1997), and although the amplitude of inferred sea-level change is great enough to accommodate both marginal-marine and terrestrial deposition within the Hautotara Formation, no beds observed in this study are able to be confidently assigned to a non-marine origin. Numerous beds observed appear to be reworked from non-marine deposition, and indicate that the lack of non-marine sediments is as a result of erosion during marine transgression.

2.4 Te Muna Formation

2.4.1 Name and Definition

The Te Muna Formation is dominated by alternating conglomerates and mudstones, with associated rare sandstones, lignites, palaeosols, loess and tephra deposited in a non-marine environment (Chapter Three). The formation was formally described by Collen and Vella (1984), who named the formation after the Te Muna Station, which is immediately west of the type section (BQ34 089 276).

Rocks of the lower part of the Te Muna Formation are included as part of the Hautotara Formation of Rodley (1961), while a number of informal names were in use for the non-marine strata prior to the formal definition.

2.4.2 Type section

The type locality of the Te Muna Formation is exposures on both banks of the Huangarua River for a distance of 3.7 km (Collen & Vella, 1984) (BQ34 086 270 to BQ34 098 302). Here the formation is estimated to be 366 metres thick, and contains 15 members (Collen & Vella, 1984). However, as this study shows, the formation appears to contain more than these 15 members.

2.4.3 Lower Contact

The lower contact of the Te Muna Formation has previously not been well defined, and has been interpreted as either a conformable contact, or an angular unconformity. Collen & Vella (1984) describe the contact as an angular unconformity over 60°, although later work by Nicol & Van Dissen (1997) and Rampton (1997) show that in the section described above, steeply-dipping Hautotara Formation beds are overlain by the younger Ahiaruhe Formation, and suggested that poor exposure had resulted in the misinterpretation of the site. In the same area Rampton (1997) also identified the Hautotara–Te Muna Formation contact as near

conformable, with the “Barytellina mudstone” often immediately underlying the contact.

Here, the contact is believed to be diachronous across the study area, and is variably described as conformable to erosional. At the Ruawaka measured section an angular unconformity up to 9° has been identified, while soft deformation structures are observed in the underlying Hautotara Formation at the Huangarua West section (Appendix Two).

2.4.4 Distribution and Thickness

The Te Muna Formation outcrops in a near continuous strip from the the Hinakura Road measured section, and nose of the Windy Peak Anticline in the north, along the western limb of the anticline, to just north of Hautotara Bridge in the southwest (Appendix One). Outcrops are also present within the Ruakokoputuna and Blue Rock Valleys.

The Te Muna Formation has been tentatively identified within the wider Wairarapa Valley, in particular at a section of fault exposed Quaternary gravels west of Lake Onoke (Begg & Johnston, 2000), although the notes incorporated into the palynological data used for this correlation does not appear to support this definition.

Cape *et al.*, (1990) trace subsurface reflectors correlated to known outcrops of the Te Muna Formation through the Wairarapa Valley; these show the Te Muna Formation thickening significantly into synforms. At an estimated 366 metres, the type section is the thickest continuous exposed section of the Te Muna Formation. The type section is located on the eastern limb of the Huangarua Syncline (Appendix One), and in the type section the individual beds of the Te Muna Formation are much thicker than those observed elsewhere in the study area.

2.4.5 Description

The Te Muna Formation comprises interbedded conglomerates and mudstones, with rare sandstones, lignites, loess, palaeosols and tephra.

Only examined briefly in this study, the loess and palaeosols (Figure 2.5) are associated with the “Te Muna Twin Tephra” at the type section, and have previously been examined in detail (e.g. Berger *et al.*, 1992; Rataul, 1988). Details of the remaining Te Muna rock types, and their relationships, are presented in Chapters Three, Four and Five.

Figure 2.5 Gamic structures in the Te Muna Formation (BQ34 089 276)

2.4.6 Palaeontology and Age

The Te Muna Formation does not contain any chronologically significant fossils, although initial pollen and plant material analysis derived from the organic and lignitic units indicate a climate similar to the modern day Wairarapa.

The age controls for the Te Muna Formation are derived from a number of tephra identified within the formation. In particular, the twin tephra of the type section (Upper and Lower Te Muna Tephra) are correlated to the 1.0 ± 0.03 Ma Potaka and 0.86 ± 0.08 Ma Kaukatea Tephra (Collen & Vella, 1984; Nicol *et al.*, 2002, Pillans *et al.*, 2005). A number of tephra are also found in outcrops away from the type section (Table 3.2), and are related to a number of separate events around 1.6 Ma (Allan *et al.*, 2008; Nicol *et al.*, 2002; Rampton, 1997). Utilising ages provided by a number of discrete tephra beds in the lower Te Muna Formation, the age of the base of the formation is placed at 1.58 Ma. While the top of the formation lacks precise stratigraphic control, the number of cycles identified at the type section suggests the top of the formation is probably younger than 0.72 Ma. Previous workers have placed the age of the top of the formation at 0.4 Ma (Collen & Vella, 1984; Nicol *et al.*, 2002; Rampton, 1997).

2.4.7 Environment of Deposition

The Te Muna Formation was deposited in terrestrial settings, with lacustrine mudstones analogous to the modern day environment (Chapter Three; Collen & Vella, 1984; Rampton, 1997; Woolfe, 1993).

The conglomerates of the Te Muna Formation represent fluvial aggradation during glacial periods (Rampton, 1997). It is believed that as a result of the deteriorating climate and reduced vegetation of a glacial period, an increase in erosion, and river loads, would occur (Collen & Vella, 1984; Rampton, 1997).

The modern day Wairarapa Valley contains both a marginal-marine lake (Lake Onoke), and a non-marine lake (Lake Wairarapa) (Figure 1.1B). However, within the Te Muna Formation, no evidence of marine influence in the lacustrine sediments has been observed (Rataul, 1988).

2.5 Ahiaruhe Formation

2.5.1 Name and Definition

The Ahiaruhe Formation was formally defined by Collen & Vella (1984), and contains cemented conglomerate, brown mudstone and the 340 ka Rangitawa (formerly Mt Curl) Tephra (Pillans *et al.*, 1996). The Ahiaruhe Formation is named for the area southwest of Gladstone where the type locality is defined.

2.5.2 Type section

The type section of the Ahiaruhe Formation is 20 km north of the study area, in a road cut east of Ahiaruhe Road, 1.5 km north of the junction with Ponatahi Road (BP34 173 478). In the type section the formation is thin, but Collen & Vella (1984) suggest it contains a complete stratigraphic record. However, the section does not display the base or the top of the Ahiaruhe Formation.

2.5.3 Lower Contact

The Ahiaruhe Formation unconformably overlies the older units of the region (Collen & Vella, 1984; Rampton, 1997). A 55-60° angular unconformity with Hautotara and Te Muna Formations below the Ahiaruhe Formation is observed in cliffs on the true right bank of Huangarua River, east of the Huangarua West measured section, and vertically above the Hautotara Formation reference section of Rataul (Figure 2.2) (Nicol & Van Dissen, 1997; Rampton, 1997; Rataul, 1988). Here the base of the formation is channelised (Rampton, 1997).

2.5.4 Distribution and Thickness

The Ahiaruhe Formation is approximately 80 metres thick at the type section, and inferred to be about 41 metres thick in the axis of the Huangarua Syncline (Collen & Vella, 1984; Rampton, 1997). The Ahiaruhe Formation occurs as scattered

outcrops in the field area; however, it is more continuous outside of the study area. A sixteen kilometre “belt” of Ahiaruhe Formation with the prominent Ahiaruhe Surface on top, extends from the type section south to the Huangarua River near Martinborough (Collen & Vella, 1984).

The Ahiaruhe Formation overlies the Te Muna Formation in the southern parts of the study area (Appendix Two), and also occurs within the Huangarua River area towards the north of the study area.

2.5.5 Description

The Ahiaruhe Formation contains greywacke conglomerates, loess-rich mudstones, and tephra. The poor sorting and stratification, and significantly larger size of the clasts in the Ahiaruhe Formation are the primary feature used to distinguish between the Te Muna and Ahiaruhe formations (Rampton, 1997; Nicol *et al.*, 2002).

2.5.6 Palaeontology and Age

The Ahiaruhe Formation does not contain any chronologically significant fossils, although Moa footprints have been identified within the finer grained units of the Formation (Collen & Vella, 1984). The Rangitawa Tephra is dated at 340 ka, and is observed towards the upper centre of the formation at the type section (Collen & Vella, 1984; Pillans *et al.*, 1996).

The age of the base of the Ahiaruhe Formation is estimated to be in the vicinity of 400 ka, while the Ahiaruhe Surface at the top of the formation is believed to be 20 ka (Collen & Vella, 1984; Nicol *et al.*, 2002; Rampton, 1997).

2.5.7 Environment of Deposition

The Ahiaruhe Formation was deposited in terrestrial settings analogous to the modern day environment. The deposits of loess, lacustrine mudstone and fluvial conglomerates are also observed within the Te Muna Formation stratigraphy.

However, as the conglomerates are poorly sorted, weakly stratified, and contain significantly larger clasts than the Te Muna Formation, this indicates the rivers transporting these sediments differ in flow regime to the Te Muna Formation (Rampton, 1997).

2.6 Younger Sediments

The study area also contains a succession of terrace gravels deposited since the Last Interglacial (Vella 1963b; Formento-Trigilio *et al.*, 2002). These aggradation gravels in the study area are sourced from the Aorangi Ranges, and have been transported by the modern rivers and streams of the area. These conglomerates largely cover the Early Pleistocene succession of sediments in valleys of the Blue Rock, Ruakokoputuna, Huangarua and Whangaehu Rivers. The major terrace mantling the formations studied is the Waiohine Surface, a widespread aggradation surface of the Wairarapa Valley (Vella 1963b).

These younger deposits which also include material in the banks and channels of the rivers, are not mapped, or described in further detail in this study. Further detailed information on these terrace deposits can be found in a recent study provided Formento-Trigilio *et al.*, (2002).

2.7 Section Descriptions

Seven well-exposed outcrops were selected for detailed measured sections. The stratigraphic columns are presented in Appendix Two, and the locations of these sections are shown in Figure 2.2.

2.7.1 Hinakura Road Section (HR)

Grid Reference: BQ34 145 304

The Hinakura Road Section is a north-to-northwest-facing road cut on Hinakura Road, 1.7 kilometres east of the Cannock Road intersection. The 48 m-thick

measured section contains 18 units, and ranges from the Pukenui Limestone to the lower Te Muna Formation.

This measured section builds on the works of Rampton (1997) and Andrews (2001), who documented the underlying Pukenui Limestone. Although exposure is limited, and only approximately 15% of the 34 m thickness of Hautotara Formation is documented (Figure 2.6A), it is nonetheless important, as the overlying Te Muna contains two tephra layers within the lower sandy mudstone units.

2.7.2 Huangarua West Section (HW)

Grid Reference: BQ34 094 303

The Huangarua West Section is within cliffs west of the Huangarua River, one kilometre south of the Huangarua River Bridge on Hinakura Road. The measured section contains 10 units of the upper Hautotara Formation and lower Te Muna Formation, and represents a combined 40 metres of these formations.

The Huangarua West Section is located close to the hinge of the Huangarua Syncline, and south of major traces of the Huangarua Fault. On the true right bank of the Huangarua River, opposite this section (Figure 2.6B), Rampton (1997) records 700 metres of continuous stratigraphy, including the Hautotara and Te Muna Formations.

2.7.3 Ruawaka Section (Rw)

Grid Reference: BQ34 086 267

The Ruawaka Section extends from the upper contact of the Pukenui Limestone, in a westward flowing stream (here named the Ruawaka Stream) to the lowermost Te Muna Formation on the western bank of the Huangarua River, immediately before a right-hand dog-leg bend in the river. The Hautotara Formation is 71 metres thick in this section, and 33 metres of the Te Muna Formation is also documented. The Ruawaka Section records 52 units, from the Pukenui C to the lower Te Muna Formation.

Figure 2.6 A) View of the Hinakura Road measured section. Dashed lines show extent of exposures. Photo taken from the Pukenui C bed. B) View of Rataul's (1988) reference section from the Huangarua West measured section. The strata in this photo has been the focus of numerous studies (e.g. Lamb, 1987; Lamb & Vella, 1987; Nicol & Van Dissen, 1997). C) Expression of faulting (arrowed, orientation of fault plane 037/NW/43) in Te Muna Formation at the Ruawaka Measured section. Attitude of bedding shown by dashed line. D) Ruakokoputuna Bridge Cliff Section, showing relationship and contacts (dashed lines) between the Hautotara, Te Muna and Ahiaruhe formations. Ladder (circled) is 3.5 m high. E) Blue Rock Race Section, showing a shallowing of dips up section (dotted line approximately along contacts between units). F) View west into the Blue Rock Valley from near the Blue Rock measured sections. The hills to the right are dissected greywacke highs, and have numerous slips of younger strata, similar to the one containing the BH section.

At Big Bend (BQ34 079 263), to the south of the Ruawaka Section, the uppermost beds of the Hautotara Formation are exposed, and consists of the “Austrovenus sandstone” containing *Barytellina crassidens* and *Austrovenus stutchburyi*. However this horizon has been truncated by the overlying Te Muna Formation and is therefore not preserved in the Ruawaka Section. The Hautotara-Te Muna Formation contact represents an angular unconformity with a dip of 9°.

Gammon (1995), records two sections of the Hautotara Formation within the area of this measured section, although the interpretation of the region differs from this study. In particular, Gammon identifies a fault running between sections 4 and 5 of his study (Gammon, 1995). However, no fault was identified within the Hautotara Formation at this site, and there appears to be no repeat of the stratigraphy as proposed by Gammon (1995). A fault that can be traced to outcrops at Big Bend and the Makara River is identified in the lower Te Muna Formation (Figure 2.6C; Appendix One).

2.7.4 Ruakokoputuna Bridge Cliff Section (Rk)

Grid Reference: BQ33 038 225

The Ruakokoputuna Bridge Cliff Section is 400 m upstream of the Ruakokoputuna Road Bridge, a north-facing exposure on the true right bank of the Blue Rock Stream (Figure 2.6D). This section contains 16 m of upper Hautotara Formation strata, represented by 11 units, overlain by 22 m of Te Muna and Ahiaruhe Formation conglomerates and mudstones, and a veneer of younger terrace deposits.

Although the Ruakokoputuna Bridge Cliff Section only contains the upper Hautotara Formation, lower Hautotara Formation units are found between the Pukenui Limestone, on the eastern bank of the Ruakokoputuna River, and the base of this site. Grain size data for some of these Hautotara Formation beds are presented in Appendix Three, and a macrofaunal list is included in Appendix Six.

The lower contact of the Te Muna Formation is a wavy contact with relief of 2.3 metres, almost completely eroding the upper unit of the Hautotara Formation in most places. The upper contact of the Te Muna Formation with the Ahiaruhe Formation is subtle, and is identified based upon clast size, due to the lack of other distinguishing features.

2.7.5 Blue Rock Race Section (BR)

Grid Reference: BQ33 026 229

The Blue Rock Race Section is on a new farm race (track) cutting dropping from the Waiohine Surface south of the Blue Rock Stream down to the stream bed. Eight units of the Te Muna Formation crop out at this 10 m outcrop. The outcrop consists of alternating sandy mudstones and massive-to-stratified conglomerate beds, with the contacts between the youngest units having a significantly shallower dip to the oldest (Figure 2.6E), allowing the rate of structural growth in the valley to be determined (Chapter Five).

2.7.6 Blue Rock Hautotara Section (BH)

Grid Reference: BQ33 026 231

The Blue Rock Hautotara Section is 150 metres north of the Blue Rock Race Section, and is located on a rotated slumped block, covering part of the unpublished stratigraphic column of the Blue Rock Valley produced by Thomson (1980) (Figure 2.6F). The Blue Rock Hautotara Section contains three units of the Hautotara and Te Muna Formations over eight metres, showing the transition between the two formations. Not far above this site, within the lowermost mudstone of the Te Muna Formation is the highly weathered “Duggan Ash” (also called the Blue Rock Tuff), which has previously been dated at approximately 1.57 Ma (Shane & Froggatt, 1991; Thomson, 1980).

2.7.7 Clay Creek Section (CC)

Grid Reference: BQ33 014 203

Exposed in cliffs on the true left bank of the Ruakokoputuna River, immediately west of the Clay Creek Bridge (the bridge itself is built upon the Pukenui C), this section is 21 m thick, and contains eight Hautotara Formation units above the Pukenui Limestone. The Clay Creek Section represents the southernmost extent of identified Hautotara Formation in the Ruakokoputuna River Valley.

Chapter Three

Facies Analysis

This chapter provides an objective facies analysis of the Hautotara and Te Muna Formation strata cropping out in the study area. This has been constructed from objective field observations, and supplemented by grain size and faunal information, allowing a facies scheme to be developed for the beds.

The aim of creating this facies scheme is to relate beds from a number of sites and measured sections, allowing the recognition of deposits formed under similar depositional processes. The sedimentological and palaeontological characteristics of the individual facies allow interpretations about the character of the depositional environments these facies were formed in.

By analysing the beds in association with those above and below, successions are repeatedly recognised, strengthening the interpretations, and as a result the understanding of the development of a formation is greatly enhanced. Chapter Four will build on this facies scheme to identify the stratigraphic architecture of the Hautotara and Te Muna formations.

Numerous facies have previously been described in the Hautotara and Te Muna formations (e.g., Collen & Vella, 1984; Gammon, 1995; Rampton, 1997; Rataul, 1988). These studies show that significant vertical and lateral variations of facies occur over relatively short distances. Previous workers have distinguished their facies through a number of varying attributes, and therefore only a passing mention of these previous descriptions is provided in the following chapters where they can appropriately enhance the work.

3.1 Introduction to the Facies Scheme

Walker & James (1992) defined the term facies as “a body of rock characterised by a particular combination of lithology, physical and biological structures that bestow an aspect different from the bodies of rock above, below and laterally adjacent”. Using this definition, a total of eighteen different facies have been identified in this study. In this study, the term subfacies is used to describe sediment that indicates a depositional change within the same environment. The facies and their primary characteristics are summarised at the end of the chapter in Table 3.3. Thirteen of the facies may be characterised as siliciclastic dominated, and five as bioclastic dominated facies.

Grain size is often related to depositional energy (Dunbar & Barrett, 2005), and for the marginal marine and shallow-water environments of an open coastline in particular, wave activity. Although Perrett (1990) showed that grain size can be a reliable indicator of palaeobathymetry using a modern day setting, this study only uses grain size as a comparative tool for facies analysis, and not as a detailed determiner of depth (Figure 3.1).

Figure 3.1 The wave base setting of an open coast shelf to shoreface profile with marine environments as used in this study. The approximate location of marine ichnofacies is also provided. Modified from Walker & James p. 219 (1992).

3.2 Facies C - Conglomerates

Four conglomerate facies are defined in the study area, and are distinguished based on variations in sedimentary structures, fossil content, clast shape, size and sorting. The **massive-to-stratified conglomerate (Cm)** is the most common conglomerate facies within the study area and the dominant facies of the Te Muna Formation. The **fossiliferous conglomerate (Cf)**, **gravel shellbed (Cg)**, and the **shelly conglomerate (Cs)**, are all distinctly different to the **Cm**, occur only in the Hautotara Formation, and are proportionally minor components of the stratigraphy of the study area. The distinctions between the latter three conglomerates are primarily based upon the proportion and preservation of fossils, the species identified, and the contents of the matrix.

Although dominated by greywacke clasts, the conglomerates also contain rare chert and bored mudstone clasts. Rare fossil branches and logs are found in the **Cm**, a single rounded igneous clast of unknown provenance was identified in a **Cs** bed, and an exotic rounded limestone clast was collected from the **Cg** facies. A wide range of molluscan fossils are encountered in the fossiliferous conglomerate and gravel shellbeds.

3.2.1 Conglomerate - Massive to Stratified (Cm)

The massive-to-stratified conglomerate facies (**Cm**), is an orange-brown to brown, moderate to well-cemented, faintly-bedded, greywacke-dominated conglomerate with rare chert clasts. The **Cm** facies is poorly- to well-sorted, and clast supported. Clasts vary from well-rounded to angular, and fossils are restricted to rare large logs and branches (Figure 3.2A). The largest clasts are found in the south of the study area, where the maximum size recorded is 28 cm, while no clasts are observed greater than 8 cm in the northern part of the study area (Figure 3.3B).

Cm beds range in total thickness from <1m in the southwest of the study area to approximately 40 metres at the type section (Collen & Vella, 1984). The lower contact of the **Cm** facies is erosional and channelised, on a decimetre-to-metre scale,

Figure 3.2 A) Fossil log of the Cm facies, from the Te Muna Formation downstream of Hautotara Bridge. B) Clasts of the Cm facies in the HW measured section. These are significantly smaller than those observed in the south of the field area. C) Upper surface of the Cf facies, with numerous worn fossils. D) Stratification present in the Cg facies. E) Burrows from the base of the Cg facies into the underlying sandstone bed. F) Well rounded igneous clast from the base of the Cg facies into the underlying sandstone bed. F) Well rounded igneous clast of unknown provenance collected from the Cs facies of bed Rw 42.

and rarely contains deformation structures (more information on the lower contact in Chapter 5).

Depositional Environment

Cm was deposited under a range of fluvial energy conditions in a braided river system. Evidence for this includes imbrication, shape and size of the clasts, and other sedimentary features including channels and lens-shaped beds (bar deposits) and the orientation of the numerous fossil logs (Figure 3.2A). The sedimentary structures in the **Cm** facies are comparable to those observed in the Gm and Gp facies of Browne & Naish (2003) in late Quaternary terrestrial deposits of the Canterbury Plains.

All **Cm** beds in this study have been identified in the Te Muna Formation; however Rampton (1997) has massive conglomerates in the Hautotara Formation in sections located on the western flank of the Windy Peak Anticline. Collen & Vella (1984) noted that clasts within the conglomerate units of the Te Muna Formation decrease in sorting and rounding up-section, while Rampton (1997) identified a significant reduction in the levels of stratification and imbrication in the younger Te Muna conglomerates. This is consistent with observations of the **Cm** facies in the Te Muna Formation across the study area, with clast size increasing both up-section and also to the south; the inferred major source of Te Muna Formation clasts.

3.2.2 Conglomerate - Fossiliferous (Cf)

The conglomerate - fossiliferous (**Cf**) facies is a grey to yellow-brown, moderately-to-non-cemented, highly fossiliferous conglomerate with a shellhash matrix (Figure 3.2C). **Cf** is matrix to clast supported and contains well-rounded to angular clasts of greywacke with rare bored mudstone, with a maximum clast size of 20 cm.

The proportion of molluscan macrofossils increases from the base to the top of the **Cf** facies. Species identified *within* the **Cf** facies range from marginal marine to inner shelf species (Table 3.1; Appendix Six) and are worn and fragmented. The upper

surface of the Cf has common scallops, *Tucetonia laticostata* and *Alcithoe arabica*, all worn and are distinct from those of the assemblage *within* the Cf.

The maximum thickness of **Cf** is 60 cm, and the lower contact of the facies is erosional, containing burrows extending into the underlying sandstone facies. The upper contact is a planar, often winnowed, surface with worn fossils of epifaunal species known to inhabit gravel substrates (Beu & Maxwell, 1990).

Depositional Environment

The **Cf** facies is interpreted as being formed in a high-energy setting such as a channel within a semi-enclosed embayment. The worn and fragmented character of the fossils identified within the **Cf** facies indicates wave scour and transportation of these fossils has occurred, and therefore the mixed fauna cannot be considered characteristic of the environment the **Cf** facies was deposited within. Instead, the assemblage can be viewed as a combination of a variety of nearby settings, as it is likely that these species have been reworked and redeposited by strong currents, which have also transported the gravel clasts from a proximal source.

Although the fossils within the **Cf** facies are not able to restrict the environment of deposition, the species found on the upper surface of the facies are characteristic of an assemblage that prefers gravel substrate in a relatively high-energy setting, and are interpreted to have been preserved *in situ* in a tidal channel within a semi-enclosed embayment. This assemblage is similar to those identified in modern Northland harbour entrances (Bland, 2006).

3.2.3 Stratified Gravel Conglomerate (Cg)

The stratified gravel conglomerate facies (**Cg**) is a blue-grey, moderately-cemented, clast supported, poorly-sorted fossiliferous conglomerate. **Cg** consists of well-rounded to sub-rounded clasts of greywacke up to 11 cm, and also contains rare chert and bored mudstone.

Fossils within **Cg** vary from fractured to whole and worn. The fossils include species that are restricted to near-shore environments and also include specimens that range from near-shore to mid-shelf settings. Species identified in the **Cg** facies commonly include *Tawera subsulcata*, *Zethalia zelandica*, *Zegalerus tenuis* and *Glycymeris shrimptoni*. The fossils of the **Cg** facies are variably distributed throughout the beds, often in faint horizons, which distinguish this facies from the **Cf** facies, in which the proportion of fossils increases towards the top of the bed (Figure 3.2D).

Cg is a thin facies, with a maximum thickness of 30 cm. The lower contact is either erosional and wavy or rapidly gradational. When overlying a sandstone lithology, burrows infilled with **Cg**-derived sediment extend up to 60 cm from the lower contact into the underlying bed (Figure 3.2E). The upper contact of the **Cg** facies is conformable and gradational up to 10 cm.

Depositional Environment

The **Cg** facies is interpreted as being a fluvially-sourced conglomerate deposit reworked within a semi-protected beachface environment. The clasts of the **Cg** facies were deposited directly into the marine environment by a nearby river, and have been transported within the intertidal zone. The clasts are therefore believed to have developed their discoid shape and well-rounded-to-sub-rounded characteristic within a wave-energy environment. Although the species present in the **Cg** beds are from a variety of environments and depths, many are fractured and abraded; whilst many of the species are also consistent with a near-shore environment. Wave energy appears to be lower than similar facies to the north, and this is interpreted to be as a result of some protection provided by shoaling highs (potentially islands) to the west of the areas where **Cg** has been observed.

3.2.4 Conglomerate - Shelly (Cs)

The shelly conglomerate facies (**Cs**) is a grey to brown, moderately- to well-cemented, fining-up, fossil-poor, clast supported conglomerate. **Cs** is predominantly comprised of greywacke clasts, although it does contain rare chert, bored mudstone,

and also includes a well-rounded igneous clast of unknown provenance (Figure 3.2F). It is possible this clast has come from an outcrop some distance to the east of the study area (Collen *pers comm*). **Cs** is poorly sorted, and contains well-rounded to sub-rounded clasts up to 11 cm across, with a sandy matrix that becomes increasingly shell-rich up unit (Figure 3.3A). The clasts of the **Cs** facies often fine up to granule.

The fossils are predominantly bivalves and typically too abraded and fractured to be identified, although *Austrovenus stutchburyi*, *Ostrea chilensis* and the gastropod *Antisolarium eignum* have been collected from various beds. The **Cs** facies is up to 50 cm thick. Where the lower contact is clearly observed, **Cs** contains shell hash and granule-rich burrows up to 3 cm wide, extending 50 cm into the lower unit (Figure 3.3A).

Depositional Environment

Cs is inferred to represent reworked fluvial gravels within a high-energy intertidal setting. **Cs** beds contain highly worn shells, and well- to subrounded clasts, although some mudstone clasts are extensively bored. Large infilled burrows extending down from the base of the **Cs** facies suggest a period of sediment starvation before the deposition of **Cs**, and the increase in shell material up-unit represents an increase in marine influence. The presence of *Austrovenus stutchburyi* in some beds suggests that the **Cs** facies has incorporated marginal-marine sediments, while *Ostrea chilensis* and *Antisolarium eignum* near the top of the facies probably represent species living on or near the **Cs** facies substrate. Unlike the **Cg** facies, the **Cs** has a low volume of macrofossils and does not show a great diversity of species (Table 3.1).

Facies

Cm	Cf	Cg	Cs
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Common fossils

Logs and branches	<i>Glycymeris shrimptoni</i>	<i>Glycymeris shrimptoni</i>	<i>Ostrea chilensis</i>
	<i>Tucetona laticostata</i>	<i>Tawera subsulcata</i>	<i>Austrovenus stutchburyi</i>
	<i>Zygochlamys delicatula</i>	<i>Micrelenchus sp.</i>	
	<i>Ostrea chilensis</i>	<i>Zethalia zelandica</i>	
	<i>Purpurocardia purpurata</i>	<i>Zegalerus tenuis</i>	
	<i>Paphies australis</i>	<i>Amalda australis</i>	
	<i>Tawera subsulcata</i>	<i>Alcithoe arabica</i>	
	<i>Dosinia subrosea</i>		
	<i>Trochus tiaratus</i>		
	<i>Zethalia zelandica</i>		
	<i>Zeacolpus vittatus</i>		
	<i>Pellicaria vermis</i>		
	<i>Struthiolaria papulosa</i>		

Characteristics of the fossils

Uncommon	Crushed, to whole and worn	Fractured, to whole and worn	Worn and fractured
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Table 3.1 Common fossils of the four conglomerate facies of the study area

Figure 3.3 A) Profile of the Cs facies, including the highly burrowed lower contact. B) Exposure of Sn at the Ruawaka measured section. Note the overlying Cm facies with a channelised base near base of trowel. C) Climbing ripples within a minor bed of Sn north of the Hautotara Formation Type Section (BQ34 072 258). D) The Sw facies at the Ruawaka measured section showing a horizon of *Zethalia zelandica*. E) Disarticulated *Austrovenus stutchburyi* within the Sa facies at the Huangarua West measured section. Arrow is 8 cm long. F) A bed of the Sd facies in the Makara Steam near its confluence with the Ruakokoputuna River (BQ34 073 253). This bed contains a high proportion of the bivalve *Talochlamys gemmulata*.

3.3 Facies S – Sandstones

Five sandstone facies are defined in the study area, and are distinguished based on variations in grain size, fossil content and sedimentary structures. Four of the sandstone facies occur only in the Hautotara Formation. Of these, the **well-sorted sandstone (Sw)**, occurs in several of the measured sections, and has the coarsest grain size mode and also often displays cross-bedding and lenses of shell material or greywacke clasts. **Sw** typically has the gastropod *Zethalia zelandica* and the bivalve *Tawera subsulcata*. The **Panopea sandstone (Sp)**, is the finest sandstone of the study area, and often contains *Panopea smithae* and various forms of burrows. The **Dosinia sandstone (Sd)** is a commonly planar-bedded fine sandstone, and typically contains high proportions of the bivalves *Dosinia subrosea* and *Talochlamys gemmulata*. The **Austrovenus sandstone (Sa)**, is the most poorly-sorted of the sandstone facies, and contains a very distinctive assemblage restricted to *Austrovenus stutchburyi*, *Barytellina crassidens* and *Zeacumantus lutulentus*. The **non-fossiliferous sandstone (Sn)** is a minor component of the stratigraphy, and the only sandstone facies identified in the Te Muna Formation. Although three of the sandstone facies are named for the dominant genus present, the use of these names is more a practical use of distinguishing between beds in the field and has been retained for ease of identification between the facies.

3.3.1 Sandstone - Non-fossiliferous (Sn)

The **non-fossiliferous sandstone (Sn)** facies is a brown to mottled brown, moderately-firm, rarely planar-bedded to containing climbing ripples, poorly- to moderately well-sorted, medium-to-coarse sandstone (Figures 3.3B, C). The **Sn** facies contains over 90% sand, with a coarse (1.22 ϕ) to medium (0.82 ϕ) mode (Figure 3.4). Variations observed include rare thin pockets of dark brown, organic-rich mudstones, and rare isolated gravel-sized greywacke clasts, similar to those of the surrounding **Cm** facies, are observed near the upper contact of some beds. **Sn** is an uncommon facies in the study area, and is restricted to the Te Muna Formation and younger units.

Depositional Environment

The depositional environment of the **Sn** facies is variable and is interpreted as representing deposition in a variety of non-marine environments, including fluvial channel infill, lateral bars and delta formation within a lacustrine setting. The climbing ripples are comparable to the Sr facies of Browne & Naish (2003), and are interpreted as the result of sediment deposition in waning flow conditions.

Figure 3.4 Comparison of grain size distribution and sorting between the sandstone facies. Full descriptions of beds can be found using the relevant Unit Names in Appendix Two.

3.3.2 Sandstone - Well Sorted (Sw)

The well-sorted sandstone (**Sw**) facies is a brown, weakly cemented, occasionally bedded, sparsely-fossiliferous, moderately- to well-sorted fine sandstone. Rare concretionary horizons are observed within the **Sw** facies. Representative grain size distributions for the **Sw** facies exhibit a fine sandstone mode (2.70 ϕ) and a fine-to-very-fine mean (2.98 ϕ), with a fine-grained tail (Figure 3.4). Some low-angle trough cross-bedding may be evident through horizons of *Zethalia zelandica*.

Sw contains moderately-common to rare whole *Zethalia zelandica* (Figure 3.3D), and rare examples of other shoreface species such as broken clypeasteroids (*Fellaster zelandiae*), and also whole *Tawera subsulcata*. Additional minor fossils identified within the **Sw** facies are worm tubes, a 15 cm wide unidentified bryozoan colony (Figure A6.1) and whole echinoids - *Pseudechinus novaezealandiae*. When **Sw** is well exposed, bioturbation can be observed within the facies, including thin (10 mm) mud-filled burrows, and larger (30 mm wide by 400 mm long) shell hash-filled burrows.

Depositional Environment

The **Sw** facies is inferred as having been deposited in an intertidal-to-subtidal environment, with a beachface-to-shoreface environment the most likely setting. The dominant species of this facies is the gastropod *Zethalia zelandica*, often found *in situ* or barely transported. *Zethalia zelandica* is an extremely common shallow water species, particularly characteristic of the near-shore, sandy beach environment, where in modern environments it lives in water depths of 3-5 metres (Beu & Maxwell, 1990). This wave-affected intertidal zone is envisaged as being the predominant setting of the **Sw** facies, with minor depth and energy variations represented by the changes in grain size, sorting, and faunal variations observed.

3.3.3 Sandstone - *Austrovenus* (Sa)

The *Austrovenus* sandstone facies (**Sa**) is a blue-grey to brown, firm, weakly planar-bedded, sparsely fossiliferous, muddy-to-gravelly sandstone. **Sa** is poorly-sorted, and contains two subfacies with distinct variations, where beds grade into organic-rich muds (**Sa_M**), or contain cemented-to-firm lenses and channels of granule-to-pebble sized greywacke clasts (**Sa_G**).

Sa contains rare weakly-planar bedding observable through sparse fossil layers (Figure 3.3E), or the presence of either subfacies. Fossils are restricted to three species; rare *Zeacumantus lutulentus*, and randomly orientated shells of the bivalves *Austrovenus stutchburyi* and *Barytellina crassidens*. The **Sa** facies has a maximum thickness of 4 metres. Where the lower contact is observed, it is graded over 4 cm into the **Sw** facies.

Subfacies

Sa contains two distinct subfacies. The mudstone subfacies, **Sa_M**, consists of organic mud-dominated horizons that often vertically grade with **Sa**, and are typically associated with *Zeacumantus lutulentus*, while **Sa_G** is an unfossiliferous conglomeratic subfacies, and contains many variations in composition and the proportions of matrix to clasts. Many of the **Sa_G** beds have a channelised base into **Sa** muddy sands.

Depositional Environment

The primary **Sa** facies is interpreted to represent deposition in an estuarine setting. The poor sorting of the beds indicates a relatively low-energy environment, while the fossils identified in **Sa_M** - *Austrovenus stutchburyi*, *Barytellina anomalodonta* and *Zeacumantus lutulentus* - are all estuarine species (Beu & Maxwell, 1990). *Zeacumantus lutulentus* is commonly found on intertidal mud flats, and appears to be a good marker for this mud flat setting where observed. *Austrovenus stutchburyi* is known from a wider range of marginal marine environments, but not fully marine situations, and the characteristics of this species in **Sa** (i.e. unabraded and relatively

small) indicates that these specimens have been either preserved in life position within a low saline setting, or transported short distances from one (Beu, 2006).

Sa_M is interpreted as representing a mud flat to a swampy or brackish setting within an estuary, an environment where organic plant matter can accumulate. Subfacies **Sa_G** is interpreted as consisting of fluvially-derived delta granule-to-cobble sized clasts in an estuarine setting, as channel features into the estuarine sands of **Sa** facies can be identified. The internal sedimentary structures of the **Sa_G** are similar to those discussed in **Cm**, further supporting this interpretation.

3.3.4 Dosinia Sandstone (Sd)

The **Sd** facies is a brown to grey, firm, commonly planar-bedded, sparsely fossilised, well-sorted fine sandstone. Representative grain size distribution for the **Sd** facies exhibit a fine sandstone mean and mode (2.40 ϕ), with a standard deviation of 0.45 ϕ (well-sorted) (Figure 3.4). Centimetre-to-decimetre scale planar-bedding is evident through most **Sd** beds.

Sd contains moderately-common to rare whole *Dosinia subrosea*, *Myadora waitotarana* and *Talochlamys gemmulata* (Figure 3.3F), and rare examples of inner-to-mid-shelf species such as *Panopea smithae* and *Amalda mucronata*. Additional minor fossils identified within the **Sd** facies include barnacles, crab chelae and whole echinoids - *Pseudechinus novaezealandiae*. Rarely, the **Sd** facies includes fine gravel lenses, comminuted shell sand, and cross-bedding.

Depositional Environment

The **Sd** facies is inferred as having been deposited within the shoreface environment. The influence of contrasting energy settings provided by this area can be seen in the planar bedding. The dominant species of this facies, the bivalves *Dosinia subrosea* and *Myadora waitotarana*, are often disarticulated, yet unworn. *Dosinia subrosea*

and *Myadora waitotarana* live around low tide off open sandy beaches (Beu & Maxwell, 1990), correlating with the grain size and bedding data.

3.3.5 Panopea Sandstone (Sp)

The **Sp** facies is a brown to blue-grey, moderately-cemented, largely massive, fossil-poor, bioturbated, moderately-well to poorly-sorted, very fine sandstone. The **Sp** facies has a very fine sand mode (3.1 ϕ), with a standard deviation between moderately well-sorted and poorly-sorted (0.5 ϕ , Figure 3.4). The dominant species of the **Sp** facies are *Panopea smithae* preserved in life position, although rare single valves of *Tawera subsulcata* and *Dosinia (Phacosoma) subrosea* are also present. A range of burrows are visible within the **Sp** facies where they consist of a high proportion of fine sand-sized comminuted shell material (Figure 3.5A).

Depositional Environment

The **Sp** facies is inferred to represent the inner to mid shelf, and is the deepest depositional setting in the Hautotara Formation. The dominant species is the infaunal bivalve *Panopea zelandica*, while other species are extremely uncommon, but generally characteristic of an inner- to mid-shelf setting. A mean grain size finer than that of the other open-water sandstone facies indicates that the **Sp** facies was deposited at a greater depth, and in a calmer setting, than the **Sw** and **Sd** facies. This interpretation is reinforced by a lack of current- or tidally-influenced bedding, although this may also be the result of bioturbation. It is inferred that the approximate depositional depth of the **Sp** facies is between 30 and 50 metres.

3.4 Facies SB – Shellbeds

Four shellbed facies are defined in the study area, and are restricted to the Pukenui Limestone and Hautotara Formation. The **limestone (SBI)**, is a minor component of the Hautotara Formation, but is more common in the underlying Pukenui Limestone. **SBI** is found at only one section, and is also closely associated with the **cross-bedded limestone (SBlx)** subfacies. The remainder of the shellbeds are interpreted to have all formed within the same water depth as each other, although they have been formed under different conditions, and have varied macrofauna. The **Zethalia dominated shellbed (SBz)**, occurs at a number of sections, and consists of shoreface species, whereas the **Tawera dominated shellbed (SBt)** contains a slightly deeper marine assemblage. The **Austrovenus-Limnoperna dominated shellbed (SBal)**, contains species from a wide range of environments, from estuarine to inner shelf depths.

The facies are readily differentiated by the macrofauna, however, the named genus need not be present in each bed, and this is particularly true of the **SBal** facies, where the presence of *Limnoperna huttoni* requires an appropriate estuarine environment nearby.

3.4.1 Limestone (SBI)

The **limestone, SBI**, is a brown-grey to white, very- to moderately-cemented and recalcified, highly-fossiliferous limestone. The limestone facies is almost entirely comprised of highly condensed, disarticulated *Tawera subsulcata*, often preserved concave-down, with rare *Zethalia zelandica*, *Dosinia* sp. and *Ostrea chilensis* also observed within the facies. Rare rounded greywacke pebbles have also been observed in several **SBI** beds.

Subfacies

The cross-bedded limestone subfacies **SBlx** is only observed in one section in the Hautotara Formation, and underlies the Hautotara limestone (unit “F” of Rodley,

1961; Figure 3.5B) **SBI** bed. The **SBIx** is an orange-grey cross-bedded shell-hash-rich unit, with minor components of fine sands and mud drapes (Figure 3.5C). Species identified in **SBIx** include *Tawera subsulcata*, *Zethalia zelandica* and *Dosina zelandica*.

Depositional Environment

The **SBI** facies is dominated by the extinct bivalve *Tawera subsulcata*, so the precise environment and depth of the faunal community may only be inferred. The extant *Tawera spissa* is considered a modern analogue to *Tawera subsulcata* and is widespread in water depths of 10 to 50 metres along open coastal beaches, although *Tawera spissa* may be found at depths up to 260 metres (McKnight, 1969). Importantly, *Tawera spissa* is often found on sands and gravelly sands, the same lithologies identified within and directly below the **SBI** and **SBt** (*Tawera* dominated shellbed) facies.

Fine terrigenous sediment is largely absent in the **SBI** facies, and can be attributed to a number of processes. The major influence is inferred to be either strong tidal forces, sediment starvation of the offshore environment, or a combination of the two. The concave-down, disarticulated character of the shells support the interpretation that tidal flows have played a role in the lack of fine sediment in the **SBI** facies (Atkins, 1995).

It is inferred that the *Tawera subsulcata*-dominated **SBI** limestone facies must be deposited somewhere within 10-50 metres of water depth, consistent with modern accumulations of *Tawera* (McKnight, 1969). Therefore the approximate water depth the **SBI** beds were deposited in is estimated to be around 15-25 metres, where tidal influence can still winnow out fine material, but with a water depth comfortably within the living zone of *Tawera*, where a relative lack of stress would allow sizeable communities to form.

The **SBIx** subfacies is believed to have been deposited around storm wave base, offshore of a high-energy open beach environment. The shell hash and fractured

Figure 3.5 A) The Sp facies at the Ruawaka measured section, with *Panopea zelandica* preserved in life position (circled) and burrows filled with comminuted shellmaterial (arrow). *Panopea zelandica* is 12 cm high. B) Pukenui C (base) and Rw6, the “Hautotara limestone” (top), two prominent Sblbeds in the study area. C) The cross-bedded limestone subfacies SBlx, directly below the “Hautotara limestone” SBl bed. D) Collected sample of the SBz facies. Note the unworn nature of the gastropod *Zethalia zelandica*. E) The SBt facies at the Hinakura Road measured section. F) The SBal facies with estuarine characteristic bivalves *Limnoperna huttoni* (arrowed) and *Austrovenus stutchburyi*.

shallow-water fossils are inferred to have been formed and transported by storm events and deposited in an offshore location, with the cross-bedding formed by alternating tidal or current flows.

Alternatively, the sediment of the **SBI** and **SBIx** facies may be a result of production within a “carbonate factory” (Nelson *et al.*, 2003). This setting is a common feature within the Te Aute limestones of the Hawke’s Bay, and forms above antiforms (Nelson *et al.*, 2003). This, however, does not change the inferred depth of deposition.

3.4.2 Zethalia Dominated Shellbed (SBz)

The **SBz** facies is a variably coloured, moderately- to well-cemented *Zethalia zelandica*-dominated shellbed. **SBz** consists of randomly orientated, unworn to slightly-worn *Z. zelandica* and assorted other macrofossils in a medium-fine, poorly-sorted matrix with up to 25% sand-sized comminuted shell fragments (Figure 3.5E).

Although some **SBz** beds consist of > 85% *Zethalia zelandica*, other species found within the shellbed include *Fosterella* sp., *Tawera subsulcata*, *Zegalerus tenuis* and *Pseudechinus novaezealandiae*. Bed thickness varies between 10 and 30 cm, and both the upper and lower contacts of the facies are gradational to sharp and conformable.

Depositional environment

The **SBz** facies is inferred to have been deposited as storm accumulations in the shoreface region just off an open sandy beach. The dominant species within the facies are all shallow-marine, particularly the gastropod *Zethalia zelandica*, which is commonly found in the modern environment living in 3 to 5 metres of water (Beu & Maxwell, 1990). The fossils are unworn to slightly-worn and randomly oriented, indicating some transportation has occurred, while the volume of medium-fine sand matrix suggests a level of wave winnowing of the sediments. It is therefore

interpreted that the **SBz** has been deposited at a depth of between 5 and 15 metres, where storm waves may still have an influence on the substrate.

3.4.3 Tawera Dominated Shellbed (SBt)

The **SBt** facies is a brown to blue-grey, moderately-cemented, faintly-bedded shellbed in a sandy matrix (Figure 3.5E). The **SBt** beds are up to 1 metre thick and largely consist of concave-down *Tawera subsulcata*, with rare whole-to-fragmented *Amalda* (*Baryspira*) *depressa*, scaphopods and barnacles. The matrix is poorly-sorted and consists of fine sands to comminuted shells and rare greywacke granules.

The **SBt** facies is somewhat analogous to the **SBI** facies, with the major differences being the proportion of sands and the amount of post-deposition diagenesis that has occurred within each bed. Some variations in faunal content and proportion occur in the **SBt** facies.

Depositional Environment

The **SBt** facies is dominated by the bivalve *Tawera subsulcata*, although not in as great a proportion in comparison to terrigenous sediments as in the **SBI** facies. Due to the comminuted shells and greywacke granule matrix, it is inferred that the beds of the **SBt** facies were formed in a generally higher energy environment than that of the **SBI** facies.

It is believed that the **SBt** facies represents the lower shoreface region, and has been formed in approximately 10-15 metres of water depth, in a region of moderate current and tidal influences. Although this depth is near to the upper limit of the environment that *Tawera subsulcata* is believed to have lived in – for example, the extant *Tawera spissa* is widespread in water depths of 10 to 50 metres along open coastal beaches (McKnight, 1969) – it is nevertheless consistent with the data provided.

3.4.4 Austrovenus-Limnoperna Dominated Shellbed (SBal)

The **SBal** facies is an orange-brown to blue-grey, hard, variably-bedded matrix-supported shellbed, dominated by a mixed-environment faunal assemblage. **SBal** contains whole and, rarely, articulated fossils in a matrix that varies from poorly-sorted sand with greywacke granules to fine sand with mud drapes (Figure 3.5F).

SBal contains numerous fossils from a wide range of environments, but the most conspicuous are the estuarine species prevalent in most beds. *Limnoperna huttoni*, *Austrovenus stutchburyi* and *Barytellina crassidens* are all distinctive species of low- to moderate-salinity environments (Beu & Maxwell, 1990). Also found within **SBal** are species such as *Tucetonia laticostata*, *Zethalia zelandica*, *Myadora waitotarana* and *Mesopeplum convexum*, all of which inhabit a range of different marine environments (Beu & Maxwell, 1990; Morton & Miller, 1968).

The shellbeds of the **SBal** facies are up to 40 cm thick, with a rapidly gradational lower contact (2-3 cm), while the upper contact is gradational over 30-40 cm (Figure 3.6A). The **SBal** facies is surrounded by both the **Sp** and **Sw** facies.

Depositional Environment

The **SBal** facies is inferred to have been deposited rapidly in an inner shelf setting. The shellbeds are accumulations within a marine environment that have largely been transported from an estuarine setting. *Limnoperna huttoni* and *Austrovenus stutchburyi* are the dominant species of this facies, and *Austrovenus stutchburyi* inhabits a range of low salinity environments, while the extinct *Limnoperna huttoni* is believed to have inhabited brackish lakes and the upper reaches of estuaries (Beu & Maxwell, 1990). The basis for the transportation of this material from the estuarine setting is believed to be a high energy catastrophic event, such as a flood. As well as the estuarine restricted fauna, species from a range of open water environments, such as *Circomphalus parvus*, *Zethalia zelandica* and *Austrofusius cottoni* are also found in the **SBal** facies.

On the top surface of many **SBal** beds are species such as *Tucetonia laticostata* and *Mesopeplum convexum*, which live on gravel and coarse substrate (Beu & Maxwell, 1990). This indicates post-deposition these particular beds have remained stationary, with little to no sediment influx.

Figure 3.6. A) The **SBal** facies containing worn and broken shells and exhibiting the rapidly gradational character of the upper contact. B) Laminations visible in the **Ms** facies at Big Bend. C) Pyrite nodules and yellow jarositic discolouration within the **Ms** facies at Big Bend (BQ34 079 263). D) HW10 showing fine cross-bedding and bioturbated top contact of the **Mc** subfacies at the Hinakura Road section (BQ34 145 304).

3.5 Facies M – Mudstones

The **M** facies consists of two silt-dominated subfacies. The **Sandy Mudstone (Ms)** facies is predominately a mudstone, although there are parts of the stratigraphy where it is a muddy sandstone or coarser. The many variations in sediment, grain size and characteristics present within individual **Ms** beds are here not described as further subfacies, instead, as they represent different energy settings within the same depositional environments, they are kept within the **Ms** facies. The **Cross-bedded Mudstone** facies (**Mc**) is thin, rare and characterised by its poorly sorted grain size and fine cross-laminations.

3.5.1 Mudstone – Sandy (Ms)

The sandy mudstone (**Ms**) facies is a blue-grey to green-grey, firm, massive-to-laminated, barren, very poorly-sorted sandy-mudstone to muddy-sandstone (Figure 3.6B). Some beds contain sandy-to-fine gravel lenses. Although the distribution of the **Ms** grain size varies, for example, the mode ranges from coarse sand to clay, all beds of the facies are very poorly sorted to poorly sorted (SD 1.5 – 2.5 ϕ). The **Ms** appears massive, but weathering allows fine laminations to be observed within some beds. Organic flecks are rarely observed, otherwise, fossils have not been identified in the **Ms** facies. Rare specimens of *Hyridella* sp. (fresh water mussels) have previously been noted from equivalent units in the study area (Collen & Vella, 1984). Laminated beds of **Ms** at Big Bend also contain pyrite nodules and jarositic staining (Figure 3.6C).

Ms beds are up to six metres thick within the measured sections, but are thicker in the Big Bend area, and up to 20 metres thick at the type section (Collen & Vella, 1984). **Ms** predominately overlies **Cm** beds above a conformable, planar contact, although occasionally the **Ms** is interbedded with an organic (**O**) or tephra (**V**) bed. **Ms** is often overlain by **Cm** with an erosional, channelised-to-planar contact.

Depositional Environment

The lack of marine fossils, the stratigraphic relationships of **Ms** with inferred terrestrial deposits, and the previously-identified freshwater *Hyridella* sp. fossils (Collen & Vella, 1984), indicate a non-marine setting for the deposition of **Ms**. Thin laminations present at some locations indicate a slow, relatively low-energy lacustrine environment away from high sedimentation sources such as river mouths. The occurrence of pyrite and yellow jarositic discolouration also implies that the setting was quiet, as pyrite develops in an anoxic setting, suggesting that limited mixing of the water occurred in the lakes. Sandy-to-fine gravel deposits observed within **Ms** are inferred as relating to migrating river mouth or delta settings. Variations of the grain size of **Ms** are similar to those observed by Woolfe (1993, 1995) and Pickrill & Irving (1978), and are discussed in detail in Chapter 5.

Rataul (1988) assessed the clay mineralogy of the equivalent facies at the type section, where a freshwater clay mineral assemblage was identified, based on the presence of high kaolinite, low chloride, and mixed-layer clays.

The **Ms** beds are inferred as having been deposited in a lacustrine setting similar to that of the modern day Lake Wairarapa. The Quaternary lacustrine deposits of the Wairarapa Valley are believed to have formed under the same conditions as the modern Lake Wairarapa, that is, within a highstand period. The processes currently controlling the sedimentation within the valley are similar to those expected in the past, that is, localised uplift and subsidence, higher river base levels and lower gradients, and large gravel beach barrier systems closing the valley from the open ocean.

3.5.2 Mudstone - Cross-Bedded (Mc)

The cross-bedded mudstone (**Mc**) facies is a brown, to white, to dark-grey, moderately-firm, bioturbated, thinly bedded to laminated sandy mudstone (Figure 3.6D). **Mc** is lacking in macrofossils, and contains extensive burrows up to 5 mm wide and 4 cm deep, filled with sediment from the overlying sandstone facies. Faint

cross-bedding is observed. **Mc** is poorly sorted, with at least 60% silt and less than 5% clays.

Depositional Environment

The **Mc** facies is analogous to the muds of the “*Interbedded mud and sand beds*” of Rampton (1997) within the Pukenui Limestone, stratigraphically below this study’s Hinakura Road measured section. Within this unit, Rampton identified a “very shallow, almost estuarine” foraminiferal assemblage. It is proposed that the **Mc** facies represents a sheltered marine setting, with the deposition controlled by low-energy traction currents, with the cross-bedded mudstone probably influenced by tidal motion.

The **Mc** facies is interpreted as representing a tidally-influenced back-barrier lagoon, landward of the **Sw** facies.

3.6 Facies V – Volcaniclastic

The **V** facies is a variable assortment of largely weathered rhyolitic ash identified in the Te Muna and Hautotara formations of the study area. The approach taken to describe the **V** facies differs from the rest of this chapter. Here, each individual bed will be examined in an attempt to identify the depositional controls, and an examination of the major element data will provide correlatives, both between sections and previously studied deposits of the field area, and also tephra identified in the Wanganui Basin and Ocean Drilling Programme (ODP) cores recovered of the east coast of the North Island (e.g. Pillans *et al.*, 2005).

This study has sampled ten discreet tephra beds from the area, although preparation for geochemical analysis reveals that four of these beds have been completely weathered to clay, inhibiting major element correlation to other deposits.

A summary of the location, and state, of each tephra is provided in Table 3.2. The locations of all known Hautotara and Te Muna formation tephra found in the study area are shown in Figure 3.7.

Tephra	Code (this study)	Grid Reference	State of Preservation
Ruawaka	RwT	BQ34 085 267	Weathered to clay
Hinakura Road Lower	HRI	BQ34 144 304	Well Preserved
Hinakura Road Upper	HRu	BQ34 144 305	Well Preserved
Lower Popes Head	LPH	BQ34 145 306	Weathered to clay
Upper Popes Head	UPH	BQ34 145 305	Weathered to clay
Duggan Ash	DA	BQ33 028 231	Weathered to clay
Huangaarua-lower	HWl	BQ34 089 303	Well Preserved
Huangaarua-upper	HWu	BQ34 094 303	Well Preserved
Lower Te Muna	LTM	BQ34 089 276	Well Preserved
Upper Te Muna	UTM	BQ34 089 276	Well Preserved

Table 3.2 Tephra of the Hautotara and Te Muna formations in this study.

Figure 3.7. Map of the study area showing location of important tephra in the Hautotara and Te Muna formations. Names in bold preferred name as used in this study. Tephra of the Hinakura Road area are chemically indistinguishable, and often referred to as a package. Note studies highlighted are representative only and not a complete list.

Hinakura Road Lower & Upper Tephra (This study) *also* Upper & Lower Popes Head Tephra (O'Brien, 1980), Akupe Tephra (Shane & Froggatt, 1991)

Geochemically correlative to the Upper and Lower Popes Head, and Akupe Tephra (Table 3.3; Figures 3.8,10-11; Nicol, *et al.*, 2002), these two deposits appear to have been deposited in a different environment than those found to the immediate north-west (Figure 3.7), and are potentially distinct deposits (e.g. O'Brien, 1980).

Sample/Study	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	MnO	water	<i>n</i>
Hinakura Road Upper Tephra	74.38 <i>0.18</i>	13.76 <i>0.07</i>	0.16 <i>0.02</i>	2.01 <i>0.10</i>	0.11 <i>0.01</i>	1.05 <i>0.03</i>	4.87 <i>0.15</i>	3.59 <i>0.10</i>	0.06 <i>0.03</i>	6.07 <i>0.64</i>	19
Hinakura Road Lower Tephra	74.63 <i>0.21</i>	13.66 <i>0.11</i>	0.17 <i>0.02</i>	2.05 <i>0.08</i>	0.11 <i>0.01</i>	1.04 <i>0.02</i>	4.71 <i>0.22</i>	3.57 <i>0.20</i>	0.07 <i>0.02</i>	5.98 <i>0.59</i>	15
Upper Popes Head (Shane & Froggatt 1991)	75.27 <i>0.20</i>	13.56 <i>0.09</i>	0.17 <i>0.03</i>	2.07 <i>0.09</i>	0.12 <i>0.03</i>	1.06 <i>0.04</i>	4.16 <i>0.29</i>	3.59 <i>0.36</i>	-	4.92 <i>0.88</i>	9
Lower Popes Head (Shane & Froggatt 1991)	75.42 <i>0.33</i>	13.51 <i>0.23</i>	0.17 <i>0.02</i>	2.15 <i>0.08</i>	0.12 <i>0.01</i>	1.05 <i>0.04</i>	4.03 <i>0.38</i>	3.56 <i>0.20</i>	-	5.23 <i>1.00</i>	9
Akupe (Shane & Froggatt 1991)	75.74 <i>0.57</i>	13.59 <i>0.13</i>	0.14 <i>0.03</i>	2.03 <i>0.09</i>	0.12 <i>0.02</i>	1.05 <i>0.06</i>	3.94 <i>0.55</i>	3.39 <i>0.21</i>	-	5.53 <i>0.82</i>	10
AT-112 (Nicol <i>et al.</i> , 2002)	74.71 <i>0.19</i>	13.27 <i>0.14</i>	0.19 <i>0.08</i>	2.18 <i>0.07</i>	0.12 <i>0.02</i>	1.11 <i>0.05</i>	4.73 <i>0.06</i>	3.54 <i>0.09</i>	-	5.08 <i>0.49</i>	12
AT-113 (Nicol <i>et al.</i> , 2002)	74.60 <i>0.23</i>	13.42 <i>0.13</i>	0.17 <i>0.03</i>	2.14 <i>0.03</i>	0.11 <i>0.02</i>	1.12 <i>0.03</i>	4.78 <i>0.10</i>	3.50 <i>0.14</i>	-	4.88 <i>0.59</i>	12
Oyster (Rampton 1997)	74.60 <i>0.53</i>	13.95 <i>0.41</i>	0.19 <i>0.05</i>	2.18 <i>0.15</i>	0.16 <i>0.05</i>	1.10 <i>0.05</i>	3.96 <i>0.20</i>	3.74 <i>0.17</i>	-	7.50 <i>1.44</i>	11
Correlatives											
Maranoa Tephra (AT-359) (Pillans <i>et al.</i> , 2005)	75.13 <i>0.35</i>	13.45 <i>0.17</i>	0.16 <i>0.07</i>	1.99 <i>0.17</i>	0.11 <i>0.04</i>	1.00 <i>0.08</i>	4.05 <i>0.21</i>	3.95 <i>0.33</i>	-	5.06 <i>0.60</i>	14
Ridge Tephra (AT-293) (Pillans <i>et al.</i> , 2005)	74.88 <i>0.42</i>	13.77 <i>0.33</i>	0.19 <i>0.04</i>	2.12 <i>0.19</i>	0.14 <i>0.04</i>	0.98 <i>0.09</i>	3.94 <i>0.20</i>	3.77 <i>0.09</i>	-	5.38 <i>1.30</i>	10
Birdgrove Tephra (BP-548) (Pillans <i>et al.</i> , 2005)	74.41 <i>0.53</i>	13.40 <i>0.27</i>	0.21 <i>0.05</i>	2.09 <i>0.27</i>	0.17 <i>0.06</i>	1.14 <i>0.12</i>	4.40 <i>0.24</i>	3.94 <i>0.28</i>	-	6.77 <i>1.14</i>	9
AT-382 (ODP Core 1123) (Allan 2008)	74.60 <i>0.32</i>	13.60 <i>0.18</i>	0.20 <i>0.40</i>	2.07 <i>0.14</i>	0.12 <i>0.30</i>	1.08 <i>0.80</i>	4.25 <i>0.25</i>	3.73 <i>0.16</i>	0.11 <i>0.60</i>	8.84 <i>1.16</i>	17
AT-383 (ODP Core 1123) (Allan 2008)	74.80 <i>0.53</i>	13.60 <i>0.43</i>	0.19 <i>0.08</i>	2.03 <i>0.28</i>	0.11 <i>0.04</i>	0.97 <i>0.16</i>	4.56 <i>0.39</i>	3.50 <i>0.20</i>	0.12 <i>0.16</i>	5.04 <i>2.09</i>	18
AT-407 (ODP Core 1123) (Allan 2008)	75.20 <i>0.85</i>	13.40 <i>0.53</i>	0.17 <i>0.08</i>	2.11 <i>0.43</i>	0.11 <i>0.04</i>	1.01 <i>0.18</i>	4.22 <i>0.72</i>	3.55 <i>1.11</i>	0.12 <i>0.10</i>	6.12 <i>2.24</i>	17

Table 3.3. Glass composition of tephra in the Hinakura Road area and correlatives from the Wanganui Basin and ODP Cores. All elements calculated on a water-free basis, with water by difference from 100%. All Fe expressed as FeO. Mean and one standard deviation (in italics) based on *n* analysis. Further details provided in Appendix Four.

Major element analysis indicates the Hinakura Road Lower Tephra is from a single event (Figure 3.8). The Hinakura Road Lower Tephra is mottled yellow to white, sometimes pink, massive rhyolitic ash deposit sharply overlying a lacustrine mudstone (Figure 3.9C,D). It is bioturbated from above, while a 10 cm thick organic horizon directly overlying this bed could signify at least a partial disturbance of the local vegetation as a result of the emplacement event, or possibly the presence of a swamp (Bussell & Pillans, 1992).

Figure 3.8. Plots of CaO versus FeO (top) and K₂O versus FeO (base) for the Hinakura Road Lower Tephra. See Table 3.3 and Appendix Four for details. n is the number of analysis run, bars are one standard deviation.

Figure 3.9 A) Lower Popes Head Tephra, weathered to clay. B) Weathered tephra (arrowed) identified in marginal marine facies at the Ruawaka measured section. C, D) Yellow to pink, massive Hinakura Road Lower Tephra near the base of the lacustrine mudstone overlying the lowermost conglomerate of the Te Muna Formation. Note variation in lignite levels between exposures. E) Hinakura Road Upper Tephra, overlain by laminated sandstones.

The Hinakura Road Upper Tephra is a white to light grey, massive rhyolitic ash deposit with some sulphur staining (Figure 3.9E). The lower contact is sharp and wavy over 1 cm. No organic material is observed above or below this tephra. Major element analysis supports the interpretation that this deposit is from a single event (Figure 3.10).

Figure 3.10. Plots of CaO versus FeO (top) and K₂O versus FeO (base) for the Hinakura Road Upper Tephra. See Table 3.3 and Appendix Four for details. n is the number of analysis run, bars are one standard deviation.

A near continuous exposure at the top of the Hinakura Road Measured Section (Figure 2.6A) shows the Hinakura Road Upper and Lower Tephra are separated by 4.5 metres of stratigraphy, including two metres of conglomerate near the base of the Te Muna Formation (Appendix Two). These tephra do not appear to merge along strike, as has been suggested for the Upper and Lower Popes Head and Akupe Tephra to the north-west (Figure 3.7; Shane & Froggatt, 1991).

Major element analysis show the tephra of the Hinakura Road area (Figure 3.7) are correlative to a number of tephra surrounding the Pakihikura Tephra in the Wanganui Basin, and identified in ODP cores. In particular the Ridge (1.56 Ma), Maranoa (1.63 Ma) and Birdgrove (1.60 Ma – all astronomically tuned) are indistinguishable from the tephra of the study area (Table 3.3; Figure 3.12 (Pillans *et al.*, 2005). This agrees well with previous analysis of the Akupe Tephra, which is assigned an Isothermal plateau fission-track (ITPFT) age of 1.64 ± 0.16 Ma (Shane *et al.*, 1996).

Three tephra of the ODP Core 1123 also appear to be correlatives with the tephra of the Hinakura Road area. Samples AT-382, AT-383 and AT-407 appear chemically indistinguishable from the tephra in the Hinakura Road area (Figure 3.12). A reinterpretation of the stratigraphy of the ODP Core 1123 has provided orbitally tuned stable isotope ages of 1.532 Ma (AT-407), 1.566 Ma (AT-382) and 1.584 Ma (AT-383), comparable to the 1.64 ± 0.16 ITPFT age of the Akupe Tephra in the field area (Shane *et al.*, 1996; Allan *et al.*, 2008).

Due to the major element chemistry of tephra in the Hinakura Road region, and possibly their close proximity to one another, past studies have inferred that these tephra have come from a single event and the multiple beds are due to reworking (Shane & Froggatt, 1991). Here the analysis place these Hinakura Road tephra within a timeframe over which numerous chemically indistinguishable eruptive events have occurred, and it is interpreted that these tephra have been emplaced over more than one Milankovitch scale cycle.

Figure 3.11. Plots of CaO versus FeO (top) and K₂O versus FeO (base) for the Hinakura Road Upper and Lower Tephra with their correlatives from this region. See Table 3.3 for details.

Two deposits here identified as the Lower and Upper Popes Head Tephra (Figure 3.7) are exposed in road cuttings on the northern side of Hinakura Road. Both the Lower and Upper Popes Head Tephra are up to 10 cm thick with a planar lower contact, and have been weathered to white clay (Figure 3.9A). As a consequence, no geochemical analysis has been undertaken on these deposits in this study. These two tephra also lack stratigraphic control, although significantly, in contrast to the nearby Hinakura Road Lower Tephra, the Lower Popes Head Tephra was not overlain by organic or lignite deposits.

Figure 3.12. Plots of CaO versus FeO (top) and K₂O versus FeO (base) for tephra of the Hinakura Road area and their correlatives from the Wanganui Basin and ODP Core 1123. See Table 3.3 for details.

Duggan Ash (Thomson, 1980), Blue Rock Tuff (Shane & Froggatt, 1991)

First described by Thomson (1980), this one metre thick deposit is situated in the Te Muna Formation overlying the Blue Rock Hautotara Measured Section (Figure 3.7). Outcrops of the Duggan Ash sampled for this study were weathered to clay, inhibiting geochemical analysis. Nicol *et al*, (2002), note that the chemistry of the Duggan Ash (AT-111) is similar to AT-112 and AT-113, collected from the Hinakura Road area (Figure 3.7), and here it is interpreted to be from the same series of eruptive events as the tephra of the Hinakura Road area.

Ruawaka Tephra (This Study)

This highly weathered deposit is identified within a **Sd** facies bed of the Hautotara Formation in the Ruawaka Measured Section (Figure 3.9B). No glass was recovered from this deposit, and no bedding is discernable. This tephra has not previously been described, but may be correlative to the Hautotara Tephra identified by Rampton (1997) in an estuarine environment to the north of this section (Figure 3.7).

Huangularua-lower (Rampton, 1997)

The Huangularua-lower Tephra is a 13 cm white, massive, fine pumiceous ash deposit in the lowermost lacustrine unit of the Te Muna Formation, 1.5 metres below the Huangularua-upper Tephra at the Huangularua West Measured Section (Figure 3.13B,D; Appendix Two). The Huangularua-lower Tephra has a conformable planar lower contact and is also bioturbated to a depth of five cm from the overlying unit.

A strong cluster and low standard deviation in the major element plot is consistent with the Huangularua-lower Tephra being derived from a single source (Table 3.4; Figure 3.14).

Sample/Study	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	MnO	water	<i>n</i>
Huangularua-lower (This study)	75.89 <i>0.19</i>	13.22 <i>0.14</i>	0.11 <i>0.02</i>	1.67 <i>0.10</i>	0.07 <i>0.01</i>	0.94 <i>0.02</i>	4.58 <i>0.10</i>	3.48 <i>0.08</i>	0.05 <i>0.02</i>	6.61 <i>0.74</i>	18
Local Correlatives											
Huangularua-lower (Rampton 1997)	76.46 <i>0.33</i>	12.73 <i>0.28</i>	0.13 <i>0.04</i>	1.8 <i>0.15</i>	0.12 <i>0.04</i>	0.91 <i>0.06</i>	3.9 <i>0.13</i>	3.94 <i>0.14</i>	-	6.58 <i>0.81</i>	12
AT-99 (Nicol et al., 2002)	76.31 <i>0.13</i>	12.76 <i>0.16</i>	0.10 <i>0.05</i>	1.70 <i>0.06</i>	0.07 <i>0.01</i>	0.99 <i>0.05</i>	4.44 <i>0.12</i>	3.47 <i>0.11</i>	-	5.15 <i>0.34</i>	12
AT-114 (Nicol et al., 2002)	76.13 <i>0.12</i>	12.83 <i>0.1</i>	0.1 <i>0.06</i>	1.74 <i>0.04</i>	0.07 <i>0.02</i>	1 <i>0.05</i>	4.47 <i>0.11</i>	3.53 <i>0.1</i>	-	4.7 <i>0.35</i>	12
Correlatives											
AT-405 (ODP Core 1123) (Allan 2008)	75.6 <i>1.34</i>	13.7 <i>0.91</i>	0.15 <i>0.13</i>	1.57 <i>0.3</i>	0.21 <i>0.61</i>	0.97 <i>0.11</i>	4.02 <i>1.11</i>	3.49 <i>0.26</i>	0.08 <i>0.14</i>	2.65 <i>2.3</i>	11
For Comparison											
Manaroa Tephra (AT-359) (Pillans <i>et al.</i> , 2005)	75.13 <i>0.35</i>	13.45 <i>0.17</i>	0.16 <i>0.07</i>	1.99 <i>0.17</i>	0.11 <i>0.04</i>	1.00 <i>0.08</i>	4.05 <i>0.21</i>	3.95 <i>0.33</i>	-	5.06 <i>0.60</i>	14

Table 3.4. Glass composition of the Huangularua-lower Tephra and correlatives. All elements calculated on a water-free basis, with water by difference from 100%. All Fe expressed as FeO. Mean and one standard deviation (in italics) based on *n* analysis. Further details provided in Appendix Four.

Figure 3.13 A) Upper and Lower Te Muna Tephra surrounded by loess and palaeosols. These tephra correlate to the Kaukatea and Potaka Tephra respectively. B) Spatial relationship between the Huangarua-upper and Huangarua-lower Tephra at the Huangarua West Measured Section. C) The Huangarua-upper Tephra, note the sharp basal contact (arrowed). D) Huangarua-lower Tephra, overlain by bedded mudstone. E) Lignite bed above lowermost Ms unit at Big Bend. Basal 20 cm of lignite is solely comprised of leaf material, while the upper 8 cm also contains branches. F) Planar surface of the O bed at the Ruawaka Measured Section showing leaf inprints (arrowed) and muddy character of the facies at this horizon.

Figure 3.14. Plots of CaO versus FeO (top) and K₂O versus FeO (base) for the Huangarua-lower Tephra. See Table 3.4 and Appendix Four for details. n is the number of analysis run, bars are one standard deviation.

The Huangarua-lower Tephra appears to correlate closest with a sample AT-405 in ODP Core 1123 (Figure 3.15). Although it occurs within a disturbed section of the core, AT-405 has been assigned a provisional age of 1.625 Ma based upon its stratigraphic position and close proximity to reliably dated tephra (Allan *et al.*, 2008). The Maranoa Tephra (AT-359) from the Wanganui Basin is also included for comparison, but while chemically more similar to the Huangarua-lower Tephra than other Wanganui Basin tephra, the Maranoa Tephra does not appear to be correlative.

Figure 3.15 Plots of CaO versus FeO (top) and K₂O versus FeO (base) for the Huangarua-lower Tephra, local and ODP Core correlatives, and the Maranoa Tephra. See Table 3.4 and Appendix Four for details. *n* is the number of analysis run, bars are one standard deviation.

Huangarua-upper (Rampton, 1997)

The Huangarua-upper Tephra occurs in the lowermost lacustrine unit of the Te Muna Formation, 1.5 metres above the Huangarua-lower Tephra at the Huangarua West Measured Section (Figure 3.13B; Appendix Two). The tephra is a 30 cm white, normally graded, medium to fine pumiceous ash deposit with a conformable planar lower contact. A large spread in the major element plot and high standard deviation indicate this sample is from multiple sources (Table 3.5; Figure 3.16).

Sample/Study	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	MnO	water	<i>n</i>
Huangularua-upper	75.53	13.53	0.10	1.61	0.08	0.95	4.64	3.56	0.01	4.56	33
This study	<i>0.81</i>	<i>0.33</i>	<i>0.02</i>	<i>0.25</i>	<i>0.02</i>	<i>0.14</i>	<i>0.41</i>	<i>0.16</i>	<i>0.02</i>	<i>1.06</i>	
Huangularua-upper (Rampton 1997)	76.19	13.13	0.15	1.82	0.12	1.00	3.77	3.82	-	6.70	20
	<i>0.71</i>	<i>0.40</i>	<i>0.05</i>	<i>0.28</i>	<i>0.07</i>	<i>0.18</i>	<i>0.18</i>	<i>0.24</i>		<i>0.74</i>	
AT-98	76.03	12.82	0.15	1.89	0.07	1.07	4.25	3.57	-	5.13	13
(Nicol et al., 2002)	<i>0.90</i>	<i>0.28</i>	<i>0.08</i>	<i>0.36</i>	<i>0.02</i>	<i>0.19</i>	<i>0.45</i>	<i>0.23</i>		<i>0.47</i>	

Table 3.5. Glass composition of the Huangularua-upper Tephra and correlatives from previous studies in the area. All elements calculated on a water-free basis, with water by difference from 100%. All Fe expressed as FeO. Mean and one standard deviation (in italics) based on *n* analysis. Further details provided in Appendix Four.

Figure 3.16 Plots of CaO versus FeO (top) and K₂O versus FeO (base) for the Huangularua-upper Tephra. See Table 3.5 and Appendix Four for details. *n* is the number of analysis run, bars are one standard deviation.

Lower Te Muna Tephra (Collen & Vella, 1984), Potaka Tephra (Shane *et al.*, 1995)

Upper Te Muna Tephra (Collen & Vella, 1984), Kaukatea Tephra (Shane *et al.*, 1995)

These tephra occur in a sequence also containing palaeosols and loess (Figure 3.13A). The Lower Te Muna Tephra is white, 25 cm thick, massive, and contains gammate structures. The Lower Te Muna Tephra has previously been correlated with the Potaka Tephra (e.g. Shane *et al.*, 1995; Nicol *et al.*, 2002). The Lower Te Muna Tephra collected for this study has been analysed and the results published by Allan *et al.*, (2008) as an onshore correlative for Potaka Tephra identified in ODP Core 1123. Their results are reproduced here (Table 3.6).

The Potaka Tephra is correlated between a number of onshore and offshore sites, including both the Wanganui and Hawke's Bay Basins (Table 3.6; Figure 3.17). The Potaka Tephra has a number of indistinguishable, well constrained ages, including an ITPDT age of 1.00 ± 0.03 Ma (Alloway *et al.*, 2004b), and astronomically tuned ages of 0.9977 Ma (from AT-338 ODP Core 1123) and 0.99 Ma from the Wanganui Basin (Naish *et al.*, 1998).

The Upper Te Muna Tephra is white, 30 cm thick and massive, and is 0.6 metres stratigraphically above the Lower Te Muna Tephra on the true left bank of the Huangarua River. The Upper Te Muna Tephra has previously been correlated with the Kaukatea tephra (e.g. Shane *et al.*, 1995; Nicol *et al.*, 2002).

Glass chemistry here shows the correlation between the Upper Te Muna has a number of Kaukatea tephra correlatives (Table 3.7; Figure 3.19), providing a well constrained age. Based on glass chemistry, tephra in the ODP Cores correlated to the Kaukatea tephra include AT-280 (Site 1122) and AT-289 (Site 1125) (Pillans *et al.*, 2005). The Kaukatea tephra has an ITPFT date of 0.86 ± 0.08 Ma in the Wanganui Basin, and an astronomically tuned age of 0.90 Ma (Pillans *et al.*, 2005).

Sample/Study	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	MnO	water	<i>n</i>
Lower Te Muna Tephra	77.50	12.60	0.13	1.18	0.10	0.91	3.44	3.80	0.09	4.40	15
Allan 2008	<i>0.24</i>	<i>0.14</i>	<i>0.04</i>	<i>0.15</i>	<i>0.02</i>	<i>0.13</i>	<i>0.12</i>	<i>0.27</i>	<i>0.05</i>	<i>0.70</i>	
LTM	77.24	12.51	0.13	1.11	0.11	0.93	4.07	3.67	-	5.52	9
Shane & Froggatt 1991	<i>0.35</i>	<i>0.12</i>	<i>0.03</i>	<i>0.08</i>	<i>0.02</i>	<i>0.09</i>	<i>0.12</i>	<i>0.22</i>		<i>0.47</i>	
Lower Te Muna	77.24	12.51	0.14	1.11	0.11	0.93	4.07	3.67	-	5.52	9
Shane et al., 1995	<i>0.3</i>	<i>0.07</i>	<i>0.03</i>	<i>0.08</i>	<i>0.02</i>	<i>0.09</i>	<i>0.12</i>	<i>0.22</i>		<i>0.47</i>	
Correlatives											
BP-441	78.12	12.05	0.12	1.09	0.11	0.89	3.53	3.87	-	4.71	12
(Pillans <i>et al.</i> , 2005)	<i>0.29</i>	<i>0.17</i>	<i>0.03</i>	<i>0.12</i>	<i>0.02</i>	<i>0.08</i>	<i>0.19</i>	<i>0.24</i>		<i>1.15</i>	
BP-545	77.58	12.10	0.18	1.07	0.12	0.86	3.79	4.07	-	5.57	12
(Pillans <i>et al.</i> , 2005)	<i>0.44</i>	<i>0.37</i>	<i>0.04</i>	<i>0.15</i>	<i>0.04</i>	<i>0.12</i>	<i>0.18</i>	<i>0.20</i>		<i>1.23</i>	
BP-478/11B	77.90	12.15	0.10	1.08	0.10	0.88	3.57	3.95	-	5.90	7
(Pillans <i>et al.</i> , 2005)	<i>0.28</i>	<i>0.14</i>	<i>0.03</i>	<i>0.13</i>	<i>0.04</i>	<i>0.09</i>	<i>0.09</i>	<i>0.27</i>		<i>1.36</i>	
BP-484	77.84	12.15	0.10	1.09	0.11	0.93	3.69	3.97	-	3.28	18
(Pillans <i>et al.</i> , 2005)	<i>0.49</i>	<i>0.16</i>	<i>0.03</i>	<i>0.12</i>	<i>0.03</i>	<i>0.10</i>	<i>0.11</i>	<i>0.15</i>		<i>1.05</i>	
BP478/19	78.00	12.20	0.12	1.12	0.11	0.93	3.40	3.90	-	4.50	13
(Pillans <i>et al.</i> , 2005)	<i>0.43</i>	<i>0.17</i>	<i>0.04</i>	<i>0.11</i>	<i>0.04</i>	<i>0.12</i>	<i>0.22</i>	<i>0.19</i>		<i>1.17</i>	
BP-483	77.88	12.13	0.12	1.05	0.11	0.85	3.59	4.05	-	2.96	11
(Pillans <i>et al.</i> , 2005)	<i>0.16</i>	<i>0.12</i>	<i>0.04</i>	<i>0.11</i>	<i>0.03</i>	<i>0.10</i>	<i>0.13</i>	<i>0.25</i>		<i>1.28</i>	
BP560	77.50	12.23	0.15	1.19	0.11	0.85	3.69	3.98	-	4.17	11
(Pillans <i>et al.</i> , 2005)	<i>0.30</i>	<i>0.16</i>	<i>0.04</i>	<i>0.16</i>	<i>0.02</i>	<i>0.13</i>	<i>0.10</i>	<i>0.12</i>		<i>0.77</i>	
BP-506b	77.59	12.33	0.14	1.03	0.13	0.87	3.59	4.10	-	3.85	6
(Pillans <i>et al.</i> , 2005)	<i>0.18</i>	<i>0.10</i>	<i>0.04</i>	<i>0.09</i>	<i>0.04</i>	<i>0.09</i>	<i>0.11</i>	<i>0.19</i>		<i>0.79</i>	
BP-485	77.80	12.12	0.10	1.08	0.09	0.88	3.59	4.12	-	3.56	13
(Pillans <i>et al.</i> , 2005)	<i>0.28</i>	<i>0.15</i>	<i>0.04</i>	<i>0.14</i>	<i>0.03</i>	<i>0.09</i>	<i>0.18</i>	<i>0.24</i>		<i>1.18</i>	
BP-305	78.07	11.87	0.14	1.19	0.10	0.99	3.72	3.68	-	6.01	11
(Pillans <i>et al.</i> , 2005)	<i>0.22</i>	<i>0.16</i>	<i>0.02</i>	<i>0.08</i>	<i>0.05</i>	<i>0.06</i>	<i>0.19</i>	<i>0.15</i>		<i>0.52</i>	
AT-229	77.05	12.67	0.21	1.25	0.14	0.86	3.61	3.93	-	1.42	10
(Pillans <i>et al.</i> , 2005)	<i>0.30</i>	<i>0.15</i>	<i>0.06</i>	<i>0.20</i>	<i>0.03</i>	<i>0.10</i>	<i>0.09</i>	<i>0.20</i>		<i>1.18</i>	
AT-230	77.05	12.63	0.18	1.26	0.10	0.86	3.53	4.13	-	1.52	12
(Pillans <i>et al.</i> , 2005)	<i>0.32</i>	<i>0.09</i>	<i>0.07</i>	<i>0.23</i>	<i>0.04</i>	<i>0.14</i>	<i>0.11</i>	<i>0.18</i>		<i>0.66</i>	
DMBP-18	76.78	13.09	0.13	1.15	0.11	0.84	3.41	4.27	-	7.05	16
(Pillans <i>et al.</i> , 2005)	<i>0.47</i>	<i>0.29</i>	<i>0.04</i>	<i>0.14</i>	<i>0.04</i>	<i>0.13</i>	<i>0.19</i>	<i>0.29</i>		<i>1.62</i>	
DMBP-3	76.75	13.10	0.14	1.09	0.10	0.84	3.50	4.24	-	6.86	12
(Pillans <i>et al.</i> , 2005)	<i>0.44</i>	<i>0.12</i>	<i>0.03</i>	<i>0.13</i>	<i>0.04</i>	<i>0.11</i>	<i>0.16</i>	<i>0.30</i>		<i>1.36</i>	
AT-281	77.86	12.39	0.11	1.13	0.10	0.87	3.55	3.75	-	4.21	15
(Alloway <i>et al.</i> , 2005)	<i>0.17</i>	<i>0.11</i>	<i>0.05</i>	<i>0.13</i>	<i>0.02</i>	<i>0.12</i>	<i>0.10</i>	<i>0.23</i>		<i>0.69</i>	
AT-338	77.43	12.30	0.11	1.16	0.09	0.90	4.09	3.70	-	4.69	14
(Alloway <i>et al.</i> , 2005)	<i>0.66</i>	<i>0.28</i>	<i>0.05</i>	<i>0.30</i>	<i>0.02</i>	<i>0.13</i>	<i>0.26</i>	<i>0.36</i>		<i>0.77</i>	
AT-322	77.67	12.55	0.09	1.17	0.07	0.78	3.86	3.66	-	7.30	15
(Alloway <i>et al.</i> , 2005)	<i>0.16</i>	<i>0.07</i>	<i>0.07</i>	<i>0.06</i>	<i>0.02</i>	<i>0.04</i>	<i>0.10</i>	<i>0.10</i>		<i>0.46</i>	

Table 3.6. Glass composition of the Lower Te Muna Tephra and Potaka Tephra correlatives from the Wanganui Basin and OPD Cores. All elements calculated on a water-free basis, with water by difference from 100%. All Fe expressed as FeO. Mean and one standard deviation (in italics) based on *n* analysis. Further details provided in Appendix Four, locations of correlatives provided in Appendix Seven.

Figure 3.17 Plots of CaO versus FeO (top) and K₂O versus FeO (base) for the Lower Te Muna Tephra, 14 Wanganui Basin and three ODP Core correlatives. See Table 3.5 and Appendix Four for details. *n* is the number of analysis run, bars are one standard deviation.

Sample/Study	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	MnO	water	<i>n</i>
Upper Te Muna Tephra	75.45	13.57	0.15	1.50	0.14	1.01	4.73	3.45	0.00	3.51	17
This Study	<i>0.12</i>	<i>0.11</i>	<i>0.02</i>	<i>0.07</i>	<i>0.02</i>	<i>0.02</i>	<i>0.13</i>	<i>0.08</i>	<i>0.00</i>	<i>0.42</i>	
UTM	76.5	13.31	0.17	1.56	0.15	1.09	4.48	3.54	-	6.57	12
Shane et al., 1996	<i>0.4</i>	<i>0.28</i>	<i>0.04</i>	<i>0.08</i>	<i>0.01</i>	<i>0.05</i>	<i>0.15</i>	<i>0.14</i>		<i>1.01</i>	
Upper Te Muna	75.5	13.31	0.17	1.56	0.15	1.09	4.48	3.54	-	6.57	12
Shane et al., 1995	<i>0.4</i>	<i>0.28</i>	<i>0.04</i>	<i>0.08</i>	<i>0.01</i>	<i>0.05</i>	<i>0.15</i>	<i>0.14</i>		<i>1.01</i>	
Correlatives											
BP-486	76.88	12.7	0.13	1.48	0.11	0.98	4.11	3.45	-	5.23	12
(Pillans <i>et al.</i> , 2005)	<i>0.32</i>	<i>0.19</i>	<i>0.04</i>	<i>0.12</i>	<i>0.03</i>	<i>0.07</i>	<i>0.12</i>	<i>0.14</i>		<i>0.58</i>	
BP232	76.85	12.75	0.15	1.53	0.12	0.99	4.04	3.44	-	5.66	16
(Pillans <i>et al.</i> , 2005)	<i>0.27</i>	<i>0.19</i>	<i>0.04</i>	<i>0.07</i>	<i>0.02</i>	<i>0.06</i>	<i>0.26</i>	<i>0.18</i>		<i>0.75</i>	
BP468	76.6	12.72	0.13	1.54	0.12	0.98	4.28	3.44	-	5.35	22
(Pillans <i>et al.</i> , 2005)	<i>0.33</i>	<i>0.08</i>	<i>0.04</i>	<i>0.12</i>	<i>0.02</i>	<i>0.05</i>	<i>0.19</i>	<i>0.25</i>		<i>0.77</i>	
BP-478/16	76.27	12.77	0.22	1.63	0.16	1.07	4.27	3.4	-	6.25	11
(Pillans <i>et al.</i> , 2005)	<i>0.37</i>	<i>0.16</i>	<i>0.03</i>	<i>0.15</i>	<i>0.03</i>	<i>0.06</i>	<i>0.16</i>	<i>0.25</i>		<i>1.21</i>	
BP-506a	75.99	12.96	0.2	1.55	0.14	1.05	4.39	3.54	-	5.56	7
(Pillans <i>et al.</i> , 2005)	<i>0.27</i>	<i>0.17</i>	<i>0.04</i>	<i>0.11</i>	<i>0.03</i>	<i>0.09</i>	<i>0.16</i>	<i>0.22</i>		<i>0.85</i>	
AT-423	76.68	13.04	0.14	1.58	0.13	0.97	4.46	3.32	-	6.83	16
(Alloway <i>et al.</i> , 2005)	<i>0.19</i>	<i>0.1</i>	<i>0.04</i>	<i>0.05</i>	<i>0.03</i>	<i>0.04</i>	<i>0.14</i>	<i>0.12</i>		<i>0.91</i>	
AT-289	76.72	13.03	0.13	1.62	0.12	1.02	3.83	3.28	-	5.23	12
(Alloway <i>et al.</i> , 2005)	<i>0.29</i>	<i>0.08</i>	<i>0.08</i>	<i>0.08</i>	<i>0.02</i>	<i>0.03</i>	<i>0.21</i>	<i>0.11</i>		<i>0.58</i>	
AT-280	76.61	13.07	0.16	1.58	0.12	0.99	3.87	3.37	-	4.34	15
(Alloway <i>et al.</i> , 2005)	<i>0.3</i>	<i>0.12</i>	<i>0.07</i>	<i>0.06</i>	<i>0.02</i>	<i>0.08</i>	<i>0.45</i>	<i>0.23</i>		<i>0.67</i>	

Table 3.6. Glass composition of the Upper Te Muna Tephra and Kaukatea Tephra correlatives from the Wanganui Basin and OPD Cores. All elements calculated on a water-free basis, with water by difference from 100%. All Fe expressed as FeO. Mean and one standard deviation (in italics) based on *n* analysis. Further details provided in Appendix Four, locations of correlatives provided in Appendix Seven.

Figure 3.18 Plots of CaO versus FeO (top) and K₂O versus FeO (base) for the Upper Te Muna Tephra in this study. See Table 3.6 and Appendix Four for details. n is the number of analysis run for the Upper Te Muna Tephra, thick bars are one standard deviation from the mean for the Upper Te Muna Tephra, and hairline bars are one standard deviation from the mean for the Lower Te Muna Tephra of Allan (2008).

Figure 3.19 Plots of CaO versus FeO (top) and K₂O versus FeO (base) for the Upper Te Muna Tephra, five Wanganui Basin and three ODP Core correlatives. See Table 3.5 and Appendix Four for details. *n* is the number of analysis run, bars are one standard deviation.

3.7 Facies O – Organic

The **O** facies is a brown-to-black, brittle-to-firm, massive-to-laminated, often muddy, overwhelmingly carbonaceous deposit. The **O** facies is extensively- to non-bioturbated, and variably contains lignite seams, leaf imprints, twigs, reeds, plant cuticles, pollen and in some cases larger branches and logs (Figure 3.13F). The lignite and muddy, massive beds of **O** are thin, up to 25 cm thick, while the log-dominated deposits can reach 2 m in thickness (Figure 3.13E).

Depositional Environment

The variable **O** facies is interpreted as being deposited within a range of non-marine environments. Settings include swamps and flood deposits within the lacustrine settings, and catastrophic event accumulations overlying the volcanoclastic (**V**) facies (Bussell & Pillans, 1992).

(opposite page)

Table 3.8 Facies summary

Facies Code	Lithology	Sedimentary Structures and Geometry	Macrofossils and Bioturbation	Palaeoenvironment	Representative Grain Size Curve/Histogram
Cm	Massive to Stratified Conglomerate	Faintly bedded, moderately to well cemented	Rare logs	Terrestrial. Fluvial, braided gravel river	
Cf	Fossiliferous Conglomerate	Winnowed top surface	Marginal marine to inner shelf species. Gravel dwelling fauna on top surface	Semi-enclosed embayment channel. Inner shelf	
Cg	Gravel Shellbed	Stratified, clast supported	<i>Tawera subsulcata</i> , <i>Zethalia zelandica</i> , <i>Glycymeris shrimptoni</i>	Beachface reworked fluvial gravels	
Cs	Shelly Conglomerate	Fines up, clast supported	Large burrows into underlying unit	Intertidal	
Sn	Non-fossiliferous Sandstone	Planar bedded	Rare organic mud	Non-marine, fluvial
Sw	Well-sorted Sandstone	Low-angle cross-bedding	<i>Zethalia zelandica</i> . Some burrows	Beachface to shoreface
Sa Subfacies: Sa _M SaG	Austrovenus Sandstone - Organic Mud Rich - Gravel Rich	Weakly planar bedded, poorly-sorted.	<i>Austrovenus stutchburyi</i> , <i>Barytellina anomalodonta</i> and <i>Zeacumantus lutulentus</i>	Estuarine	
Sd	Dosinia Sandstone	Planar-bedding	<i>Dosinia subrosea</i> , <i>Myadora waitotarana</i> and <i>Talochlamys gemmulata</i>	Shoreface
Sp	Panopea Sandstone	Largely massive	<i>Panopea zelandica</i> . Various forms of burrows	Inner to Mid Shelf
SBI Subfacies: SBlx	Limestone, (cross-bedded)	Subfacies: Cross-bedded, some mud drapes	<i>Tawera subsulcata</i>	Inner shelf	
SBz	Zethalia Dominated Shellbed	Moderately to well cemented	<i>Zethalia zelandica</i>	Shoreface, around 5-15 metres water depth
SBt	Tawera Dominated Shellbed	Faintly bedded, moderately cemented	<i>Tawera subsulcata</i>	Lower shoreface	
SBal	Austrovenus-Limnoperna Dominated Shellbed	Variably bedded. Some mud drapes. Gradational top contact.	Estuarine dominated, but includes open water species. Gravel dwelling fauna on top surface	Inner shelf
Ms	Sandy Mudstone	Laminated to massive	Rare wood	Lacustrine
Mc	Cross-bedded Mudstone	Laminated, fine cross-bedding	Extensive burrows from above	Lagoonal
V	Volcaniclastic	Some faint bedding	Some burrowing from above	Lacustrine to open marine	
O	Organic	Some planar bedding	Logs, lignite, reeds, leaves	Non-marine, swamps, lacustrine	

Chapter Four

Stratigraphic Architecture and Cyclicity

4.1 Introduction

This chapter aims to identify patterns in the deposition of the Te Muna and Hautotara formations, and will attempt to place these within a sequence stratigraphic framework. This will be done by analysing the vertical stacking of the facies described in Chapter Three and documented in Appendix Two. Importantly, especially when considering the marginal marine setting of the Hautotara Formation, the relationship between the *autocyclic* (intra-basinal) and *allocyclic* (extra-basinal) processes will be identified, and thereby ensuring local events are not ascribed to global effects such as the Milankovitch orbital variations. Therefore, this chapter will firstly review the East Coast Basin's sequence stratigraphic model, in particular the relevant surfaces and systems tracts. Secondly, the dominant stacking patterns (motifs) of the study area will be presented, before a discussion of the variations across the study area, and the implications for the palaeogeography of the area.

As the Wairarapa Valley is within a similar setting as the Hawke's Bay (Figures 1.1-1.2), the concepts and stratigraphy of the extensive sequence stratigraphic work in the backarc Wanganui Basin (e.g. Naish, 2005) is not as applicable as that of the recent Hawke's Bay work. Therefore this work borrows from the results of sequence stratigraphic work in the Hawke's Bay region, particularly that of Haywick (2000) and Bland (2006), and re-examines the controls on the Hautotara Formation.

4.2 Background

A number of previous studies have highlighted the cyclicity of the of the late Neogene sediments of the Wairarapa. Vella (1963a) was the first to recognise the cycles as a major feature of the succession, and identified four cyclothems through an area immediately north of this study area, of which the Eringa and Huangarua Cyclothems encompass rocks of the Pukenui Limestone and Hautotara Formation.

Collen & Vella (1984) constrained the Hautotara Formation to between one and one and a half cycles. This was based on the Pukenui Limestone and Hautotara Formation containing a total of seven cycles, and the Pukenui Limestone having evidence for slightly over five of these (Collen & Vella 1984).

Gammon (1995) inferred the Hautotara Formation to represent at least five glacio-eustatic cycles. This was based on the composite standard section that combined data from a number of his individual sections, the works of Collen & Vella (1984), and Rodley (1961). However, there is difficulty following the intended tie points of the composite section, and the composite section does still not include the full stratigraphy of the Hautotara Formation (Gammon 1995).

Rampton (1997) in a study that incorporated the northeast of this study area, identified up to five 40 kyr cycles in the Hautotara Formation. Two of his stratigraphic sections are reproduced later in this chapter to further constrain the basin response to the effects of sedimentation, tectonism and sea-level change.

Here, the sequence stratigraphic cycles observed in the Hautotara and Te Muna formations are attributed to glacio-eustatic sea-level changes. Based on the age of deposition of the Hautotara Formation the major sequences are believed to be as a result of the 6th order (41 kyr) driven climatic oscillations, while the upper Te Muna Formation incorporates the ‘Mid-Pleistocene Transition’, where the control of glacio-eustatic cycles changes from the 6th to the 5th order (100 kyr) driver (e.g. Naish, 2005).

Within this chapter, and for the remainder of this thesis, it is assumed the depositional environments of the facies described in Chapter Three are accepted. Therefore, to allow a flowing description of the various beds, tracts and environments to be discussed, the environment of deposition will be discussed in place of the assigned facies name. For example, the ‘*muddy to gravelly sandstone (Sa) interpreted as being deposited in an estuarine environment*’ may be described as an ‘*estuarine sandstone*’. For detailed descriptions of the facies at particular measured sections, independent of interpretation, the reader is referred to Appendix Two.

The interpreted settings for the systems tracts and surfaces described in this chapter are presented in Figures 4.1 and 4.2, while a summary fence diagram is located after the section descriptions (Figure 4.5).

Figure 4.1 Interpreted sea-level changes through time, and their relationship to the systems tract and surfaces. Note the time taken for the Regressive Systems Tract as Polar Ice slowly accumulates (Modified from Bland, 2006).

Figure 4.2 Relative position of systems tracts and shellbeds. (Modified from McIntyre, 2002; Naish *et al.*, 2005; Bland, 2006)

4.3 Systems Tracts and Surfaces

4.3.1 Lowstand system tract (LST):

The lowstand systems tract refers to sediment accumulation during the lowest relative sea-levels of a cycle (Figure 4.1). In the case of the glacio-eustatic driven cycles of the study area, this systems tract refers to a glacial period. Here, the Hawke's Bay/East Coast Basin's model tends to differ from the Wanganui Basin setting, as the East Coast LST's are dominated by fluvial aggradation as a result of high-bedload river systems that produce low gradient fan-delta systems on the exposed continental shelf (Browne & Naish, 2003; Bland, 2006).

4.3.2 Transgressive surface of erosion (TSE):

A transgressive surface of erosion is formed during the early rise of sea levels, as wave base moves landwards with rising sea level (Caron *et al.*, 2004). The high energy shoreface setting of the TSE causes reworking and erosion of sediments deposited within previous system tracts. The TSE often overlies shoreface sediments, although this depends on the thickness of the sediment package reworked by the TSE. The TSE however, always underlies a deepening succession of sediments.

4.3.3 Transgressive systems tract (TST):

The transgressive systems tract contains the sediment accumulated during relative sea-level rise (Figure 4.1). The TST is usually a thin systems tract, and represents only a short period of time in the glacio-eustatic sea-level cycle, as the rise in sea-level is probably a result of rapid polar ice sheet collapse.

Back-stepping of the shoreface wedge causes sediment starvation on the shelf during a TST (Caron, 2004), which in turn allows bioclastic rich facies to accumulate, while an increase in terrestrial vegetation as a result of climatic warming will also cause a decrease in erosion. As a result, the TST may variably contain mechanically

deposited limestones (Abbott & Carter, 1994; Naish & Kamp, 1997), or reworked pebbles and pebbly shellbeds (Abbott, 1998; Bland, 2006).

4.3.4 Downlap surface (DLS):

The downlap surface (DLS) is at the top of the TST, and therefore representing the deepest relative sea-level (Figure 4.1). Therefore the DSL also equates to the maximum flooding surface (MFS) – and is at the ‘centre’ of the cycles. The DLS is often associated with the downlap shellbed (which overlies the DLS), and the backlap shellbed (located underneath the DLS). The DSL is the position in the stratigraphic package where progradation replaces retrogradation, that is, this surface represents the point in the cycle where landward accommodation space has been filled, or eustatic sea-level falls, thereby forcing the sedimentary system to build basinward (Kidwell 1991; Naish & Kamp, 1997).

4.3.5 Highstand systems tract (HST):

The sediments of the highstand systems tract are deposited during the late rise to early fall of relative sea-level (Figure 4.1). As deposition of the Hautotara and Te Muna formations occurs in the Pleistocene epoch, this system tract coincides with the interglacial phase. The HST is the beginning of progradation in a cycle, and overlies the DLS. The HST is comprised of the finest-grained marine sediments. The HST then passes into the RST, and sediment begins to coarsen upwards.

4.3.6 Regressive surface of erosion (RSE):

The regressive surface of erosion may be found between the HST and the regressive systems tract (RST). The RSE represents rapid sea-level fall, where shoreface wave action affects progressively further seaward offshore sediments deposited during the previous HST (Hunt & Tucker 1992; Nummendal & Swift 1987). The RSE is not recognised in the sediments of this study.

4.3.7 Regressive systems tract (RST):

The regressive systems tract contains all sediments deposited after the RSE (or more practically, the HST) and before the sequence boundary (SB) as defined in this study. The RST is the longest lasting systems tract in the cycle, as sea-level falls slowly as the ice sheets grow in volume. For sediment to be deposited within the RST, the right rate of sediment flux and basin subsidence must be achieved. The RST represents a shallowing of the depositional environments, and often contains massive, well-sorted, and coarser sands than the underlying HST sediments (Bland, 2006). As opposed to the idealised model, the lower surface of the RST is often gradational (Naish & Kamp, 1997), and therefore its location is relatively arbitrary within the coarsening up sequence of a cycle.

Although dominated by siliciclastic sandstones, the RST may also be associated with a series of diagnostic shellbeds including the toplap shellbed (Kidwell, 1991; Kondo *et al.*, 1998; Naish & Kamp, 1997), and event concentrated shellbed (Bland, 2006; Hendy *et al.*, 2006).

4.3.8 Sequence Boundary (SB):

Sequence boundaries enclose the packages of sediments within sequences, and are therefore critical surfaces to identify in a stratigraphic succession. The definition and hence the location of the sequence boundary within a sequence has varied, largely as a result of workers varying definitions, basin dynamics and stratigraphic resolution (e.g. Abbott *et al.*, 2005; Haywick, 2000; Bland, 2006). Within previous Hawke's Bay/East Coast sequence stratigraphic studies, the sequence boundary has been placed at either the erosional base of non-marine deposits (Haywick, 2000), or the upper surface of the non-marine beds, below the TSE (Bland, 2006). The difference between the two studies is the latter's recognition that non-marine beds are chronologically linked to marine deposits, and therefore are not restricted to the LST's (Bland 2006).

Although the definition of Bland (2006) is appropriate to his regional study undertaken in the Hawke's Bay, this study is restricted to marginal marine and terrestrial sediments within a narrow strip of the emerging basin, largely distant from basement rock sources (Figure 1.2). Therefore the sequence boundary in this study is placed at the lower boundary of the LST, or the base of non-marine conglomerates (Cm facies) where preserved. This has a number of advantages in recognising the SB within the sediments described in the study area:

- a) The Cm facies of the LST is completely reworked into the Cs facies above a TSE in many of the cycles observed; therefore the SB remains on the same plane as intended by Bland (2006).
- b) Sedimentation in the Te Muna Formation is dominated by the **Cm** and **Ms** facies. This non-marine deposition lacks a detailed stratigraphic signature of the respective systems tracts, but within the study area the base of the **Cm** is believed to correlate to the base of the LST, whereas the LST - TST plane is not readily identifiable in the facies.
- c) No **Cm** is identified as being deposited into the Hautotara Formation in systems tracts other than the LST, therefore the base of the **Cm** represents the same cyclic position in all motifs presented (Figure 4.2-4.3).

4.4 Stratigraphic Architecture of the Study Area

The facies analysis of the study area identifies cyclic sedimentary packages within the Hautotara Formation, and these packages can be correlated to six and a half glacio-eustatic sea-level cycles. Although only the lower Te Muna Formation is documented in the measured sections, by supplementing this data with the works of previous studies on the formation, at least seven and a half cycles are identified within the Te Muna Formation. Four sequence *motifs* are identified within the Hautotara and Te Muna formations, although variations do occur within individual cycles, largely as a result of autocyclic processes. Variations from the ‘standard’ motifs are as a result of the influence of local palaeogeography and tectonism on deposition, and these will be used to discern the major changes in the palaeogeography of the study area through time.

4.4.1 Motif One: Eringa Motif

The lowermost motif identified in the Hautotara Formation is named after the Eringa Cyclothem of Vella (1963a). The Eringa Cyclothem incorporates the entire Pukenui Limestone, and the lower Hautotara Formation. Presciently Vella identified ‘microcyclothem’ in the Eringa Cyclothem at Makara Stream, and states “*presumably only at Makara Stream were rates of down-drop and deposition balanced just right to record the small fluctuations so clearly*”. The typical stratigraphic architecture of these ‘small fluctuations’ identified by Vella is the Eringa Motif.

The motif appears to be the dominant cycle of the Pukenui Limestone, and also appears in the lower Hautotara Formation at some locations. The base of the cycle is a cross-bedded shellhash rich limestone of the LST which is overlain by a massive limestone bed with rare pebbles, representing the TST (Figure 4.3). At the top of the TST limestone may be a toplap shellbed, with a planar upper surface (as with the top of the Pukenui C).

Idealised Motifs of the Study area

Figure 4.3 Motifs of the study area. Systems tract codes as in Chapter 4.3, lithology as Appendix Two

As the most basinward motif identified, the TST of the Eringa Motif contains a thick HST of inner to mid shelf sands, the deepest facies of the Hautotara Formation (Figure 4.2). From this bed, the succession contains no RSE, and shows a gradual shallowing through the RST.

The Eringa Motif appears to have formed at a position in the basin where the sediments are deposited at or around the wave base of the LST. This motif occurs in the lower Hautotara Formation along the Windy Peak monocline, and is particularly well exposed at the Ruawaka Measured Section.

4.4.2 Motif Two: Huangarua Motif

The Huangarua Motif is the most common cyclothem type identified in the Hautotara Formation, and largely occurs in the middle to upper Hautotara Formation. The Huangarua Motif is named after the Huangarua Cyclothem of Vella (1963a), which corresponds to the entire Hautotara Formation at the type section. A variation of the Huangarua Motif is identified at the Hinakura Road section, and is also discussed.

The base of this motif is effectively at the base of the TSE, which has eroded the underlying LST (Figure 4.3). The gravels of the TST are inferred to have come from fluvial conglomerate deposited during the preceding LST, and as relative sea-level rose, this material is reworked in the high energy shoreface setting. Overlying the shelly conglomerate are inner shelf to lower shoreface HST and RST sandstones and shellbeds with no discernable boundary between the two systems tracts.

The Huangarua Motif is thin, often between 4 to 15 metres, and represents a more landward setting than the Eringa Motif (Figure 4.3). The Huangarua Motif is common in the Hautotara Formation along the western limb of the Windy Peak Anticline, and also occurs in the Ruakokoputuna Valley.

The Hinakura Road section contains a cycle within the Hautotara Formation that contains numerous characteristics of the Huangarua Motif. Importantly however, a lack of gravels within the depositional setting at this site means parts of this motif are not appropriate for the cycle. The HST and LST of the Hinakura Road cycle are comparable to the Huangarua Motif identified elsewhere, however, the TST is represented by beachface sandstones as opposed to beachface reworked gravels, and no TSE is observed. Below the TST is the LST, represented by the backbeach/lagoonal mudstone. This part of the Hinakura Road section is believed to have been influenced by a combination of palaeogeographic setting and tectonism causing a lagoon to form during the late regressive/early lowstand time, as opposed to fluvial braidplains that form in other areas at the time.

4.4.3 Motif Three: Waipuna Motif

The Waipuna Motif (Figure 4.3) occurs at a number of sites, and straddles the boundary between the Hautotara and Te Muna formations. The Waipuna Motif is named for the farm on which the Blue Rock Hautotara measured section is located. The outlay of the Waipuna Motif differs from the other motifs described, as it includes two cycles, from the SB at the base of the marine LST, through to the non-marine SB above the lacustrine mudstone. The SB at the centre of the motif represents the transition from the Hautotara Formation to Te Muna Formation. The Waipuna Motif represents the final emergence of the eastern Wairarapa Valley, and contains marine and marginal marine sediments overlain by terrestrial conglomerates.

The base of the Waipuna Motif is a TSE and TST of the form previously described for the Huangarua Motif. Above this, the HST contains shoreface sands and shellbeds, and is overlain by upper shoreface sands interpreted to represent the lower RST. Above the upper shoreface sands are estuarine sandy mudstones. These estuarine sandy mudstones may be interbedded with organic rich horizons, indicating mudflats to swampy back beach regions, or gravels of a delta. The SB is the base of the LST non-marine conglomerate, which has an erosive to deformable lower contact over the estuarine sediments. Conformably on the conglomerate is the lacustrine

mudstone of the next HST, representing a shift from marine to terrestrial sedimentation and the total emergence of the motif.

The Waipuna Motif is identified in the Blue Rock Valley, the original type section of the Hautotara Formation, at Big Bend, Huangarua West, and in the Whangaehu Valley. The motif is not identified at the Ruawaka Measured Section, where the contact between the Hautotara and Te Muna formations is an angular unconformity.

4.4.4 Motif Four: Te Muna Motif

The Te Muna Motif is the common stratigraphic architecture of the Te Muna Formation, and therefore has been named after the formation.

The cycle contains a fluvial conglomerate overlying the channelised SB, and inferred to represent deposition from the LST to the TST. Conformably overlying the conglomerate is a lacustrine mudstone of the HST, which may contain lignites, or organic rich horizons of a swamp, or fine gravels of a HST river delta (Figure 4.3).

As the base of the LST is an erosive surface, it is difficult to identify if entire cycles have been removed, although it is believed that where observed, only the top of the underlying lacustrine mudstone is eroded, and no complete cycles are eroded.

The Te Muna Motif is the most landward motif of the study (Figure 4.3), and represents a fully terrestrial response to glacio-eustatic sea level changes. This motif is identified in all areas where there are good exposures of the Te Muna Formation. The Te Muna Motif also occurs in the Ahiaruhe Formation and can be observed in recent non-marine formations of the Wairarapa Valley.

4.5 Architecture of Measured Sections

4.5.1 Hinakura Road Section

The Hautotara Formation is poorly exposed at the Hinakura Road Section. However, one SB within the Huangarua Motif is observed. The information provided by this section may be supplemented by the work of Rampton (1997). The “H4” measured section is southwest of the Hinakura Road Section, and also passes from the Pukenui Limestone through the Hautotara Formation and into the Te Muna Formation. Here he has observed five cycles, although a basic reinterpretation of the stratigraphy provided (Figure 4.4) identifies three and a half cycles in the Hautotara Formation. Three and a half cycles appears consistent with the space available to the Hautotara Formation at the Hinakura Road Section, and the contact with the Te Muna Formation is inferred to be an angular unconformity, unlike the conformable contact of the Waipuna Motif.

The Hinakura Road Section also includes most of two cycles of the Te Muna Motif. Within the HST lacustrine mudstones are two tephra beds, allowing constraints on the timing of Te Muna Formation deposition in the north of the study area.

4.5.2 Huangarua West Section

The Huangarua West Section contains the Waipuna Motif, and therefore a conformable transition between the Hautotara and Te Muna formations. Within the shoreface sandstone of the RST are a number of specimens of worn estuarine macrofossils, indicating the presence of a nearby estuarine setting. The lowermost lacustrine mudstone of the Te Muna Formation contains a pair of tephra, with the lower interpreted to have been deposited 1.57 Myr. This indicates that the Hautotara to Te Muna Formation transition at the Huangarua West Section occurred around 1.58 Ma.

Reinterpretation of Rampton Measured Section H4

Figure 4.4 Rampton (1997) reinterpretation. Colours within stratigraphy refer to inferred depositional environment which may be seen on the legend in Figure 4.3.

4.5.3 Ruawaka Section

The Ruawaka Section contains nearly the entire Hautotara Formation, although the top of the formation is eroded by the overlying Te Muna Formation. The Ruawaka Section contains one full Eringa Motif, before a shallowing is observed, with six and a half cycles of the Huangarua Motif observed. The lowermost Huangarua Motif has similarities with the Eringa Motif, indicating the transition from relatively deeper water to near shore and marginal marine sedimentation. One and a half cycles of the Te Muna Motif are observed in the Te Muna Formation, and these are believed to be correlatives of Members One to Three of the type section of Collen & Vella (1984).

The Huangarua Motifs at the Ruawaka Section contains numerous event concentrated shellbeds (Hendy *et al.*, 2006). These are dominated by estuarine fauna such as *Austrovenus stutchburyi* and *Limnoperna huttoni*, indicating the presence of extensive estuarine settings landward of the motif. The extinct *Limnoperna huttoni* is believed to have inhabited the upper parts of estuaries and also brackish lakes (Bland *pers comm*; Beu & Maxwell, 1990), and as it is only found at the Ruawaka Section, this indicates this environment was restricted the area around the modern day Windy Peak.

The TST conglomerates of the Ruawaka Section, and those observed in nearby areas such as Big Bend contain an assortment of fossils. Where the thickness of the unit was sufficient, there was a clear trend to deeper water and gravel-inhabiting fauna. Some of the more fossil sparse beds also included the estuarine *Austrovenus stutchburyi*, indicating the TST has reworked possibly RST to LST estuarine settings.

The Ruawaka Section lacks the Waipuna Motif, with the Hautotara – Te Muna Formation contact an angular unconformity. From correlation with cycles in the Hautotara Formation, and from the Te Muna type section, this unconformity is believed to represent 0.3 Myr (Figure 4.5).

4.5.4 Ruakokoputuna Bridge Cliff Section

The Ruakokoputuna Bridge Cliff Section contains one cycle of the Huangarua Motif, and one cycle of the Waipuna Motif. However, an undefined thickness of Hautotara Formation is below the base of the Ruakokoputuna Bridge Cliff Section, and therefore a number of cycles are not recorded. It appears from observations that the shallowing sequence seen between the Eringa and Huangarua Motifs at Ruawaka also occurs in the lower Hautotara Formation near the Ruakokoputuna Bridge Cliff Section. Two cycles of the Te Muna Motif are seen in the Te Muna Formation.

A number of statements in reference to the palaeogeography of the area surrounding the Ruakokoputuna Bridge Cliff Section can also be made. These include:

1. Some cycles observed in the Pukenui Limestone contain greywacke pebbles in TST limestones, in particular the Bub's Flat Limestone (Clarke, 1998). These are interpreted to have been transported from the Aorangi Ranges to the south, the nearest source of greywacke. This region is the preferred source of greywacke pebbles to the Ruakokoputuna Valley, as although greywacke pebbles are also found in the Pukenui Limestone around the north of the study area, where greywacke highs are also present, the central region of the study area lacks these greywacke clasts until the deposition of the Te Muna Formation.
2. During deposition of the upper Hautotara Formation, this region was increasingly influenced by fluvial sedimentation during lowstands.
3. The upper Hautotara Formation at the Ruakokoputuna Bridge Cliff Section is more sheltered than the central study area (around the Ruawaka Section), evidence includes an increased prevalence of mud drapes at the Ruakokoputuna Bridge Cliff Section.
4. The major source of the fluvial gravels in the Te Muna Formation is from the Ruakokoputuna Valley to the south, with the Blue Rock Valley a minor influence.

4.5.5 Blue Rock Race Section

Five thin cycles of the Te Muna Motif are identified in this section. The upper cycle is not fully exposed and therefore not completely documented in the measured section. The dips of the beds shallow significantly up section, showing growth on the Blue Rock Anticline was occurring as the Te Muna Formation was being deposited.

4.5.6 Blue Rock Hautotara Section

The Blue Rock Hautotara Section contains the Waipuna Motif, and shows the transition between a mudflat dominated estuarine environment into the fluvial Te Muna Formation. Not recorded due to exposure and weathering, but immediately

above the Te Muna Formation conglomerate is the Duggan Ash (Thompson, 1980). Correlation of major element chemistry analysis of the Duggan Ash shows it may be from an eruptive event circa 1.57 Ma meaning the transition between the Hautotara and Te Muna formations occurred circa 1.58 Ma (Nicol et al., 2002; Shane & Froggatt, 1991).

4.5.7 Clay Creek Section

The Clay Creek Section represents the southernmost extent of identified Hautotara Formation, and contains one cycle that appears to have characteristics of both the Eringa and Huangarua Motifs. The well-sorted character of the sandstones and the lack of greywacke clasts show this site was some distance away from fluvial sources within a moderate to high energy wave climate.

Figure 4.5 (Following Page)

Fence diagram for measured section of the study area, including H1 and H4 of Rampton (1997).

Note: * near base of H1 indicates where stratigraphic description precludes a definitive correlation to facies used in this study. Dashed lines with question marks indicate high level of uncertainty with correlation.

Chapter Five

Synthesis and Palaeogeography

5.1 Introduction

This chapter incorporates information documented in previous chapters, and combines this with data from previous investigations of the region, to produce a series of palaeogeographical maps to reconstruct the final emergence of the southeastern Wairarapa Valley.

Three maps are presented; the oldest shows a palaeogeographic reconstruction of the study area during deposition of the top of the Pukenui Limestone at approximately 1.73 Ma, and contains the deepest succession shown. The second map is of the RST close to the third CB in the Hautotara Formation, before many of the areas become the fully terrestrial Te Muna Formation. The last map shows the following HST around 1.57 Ma, with the lacustrine setting prominent in the study area, but Hautotara Formation still present at the centre of the study area.

Contractional structures play a major role in influencing the palaeogeography and sediment distribution in the study area. The major features are the Windy Peak and Harris Ridge Anticlines, the Huangarua and Ruakokoputuna Synclines, and the Huangarua and Dry River Faults (Figure 5.1; Appendix One). The structural evolution of the study area has previously been constrained by multiple works, in particular Lamb & Vella (1987) and Nicol *et al.*, (2002), with recent deformation identified by Formento-Trigilio *et al.*, (2002). This work builds on these study's, and examines the rate of deformation during deposition of the Hautotara and Te Muna Formations.

A number of unpublished works to the north of the study area compliment field observations, and include the works of Vella (1949), Senior (1966) and Rampton (1997). Within the south of the study area, the works of Thompson (1980) and

Figure 5.1 Structural setting of the study area.

Clarke (1998) also provide insights that may be integrated with this studies information to aid palaeogeographic reconstructions. By incorporating data not limited to the immediate study area, or time span, the effects of large scale processes can be assessed.

5.2 Reconstruction One: Top of Pukenui C, Mid Cycle One – ~1.73 Ma

The late Nukumaruan “Pukenui C” is interpreted to represent the transgressive systems tract, with the upper surface approximating the maximum flooding surface. Therefore this palaeogeographic reconstruction represents the deepest widespread environments identified in this study (Figure 5.2).

The study area is bounded by the emergent greywacke highs of the Aorangi Ranges to the southwest and the Jury Ridge to the north. To the east is the landward margin of the valley.

The Windy Peak Monocline and Anticline, along with associated folding to the east are actively growing by this time, while the Huangarua Syncline and structures to the west are not influential features at this time. Although a structural high is developing immediately north of the Blue Rock Hautotara Section (BH*), the facies of the study area progressively deepen basinward.

East of the study area appears to be emergent during deposition of the “Pukenui C”. Evidence includes the identification of the estuarine bivalve *Limnoperna huttoni* within some limestone beds east of the study area. However, as this region largely consists of fine grained formations and is now rounded mudstone hills, difficulties arise in making observations of this area (Vella & Briggs, 1971).

The Pukenui Limestone is a regionally extensive formation, and the “Pukenui C” is a prominent marker horizon in the study area. Lithological variations within the “Pukenui C” reflect the variation of environments within the study area (Figure 5.2). Greywacke clasts are observed within the underlying limestones at a number of sites, although importantly, are not extensive. Outcrops with these clasts include the

Figure 5.2 Palaeogeographic reconstruction of the Pukenui Limestone-Hautotara Formation contact ~1.73 Ma.
 "o" near Rk refers to the location of the Bubs Flat limestone outcrop, "o" north of HR is the location of the outcrop in Figure 5.3.

“Pukenui C” and informally named Bubs Flat limestone in the lower Ruakokoputuna Valley and the “Pukenui C” in the Whangaehu Valley north of the study area (Clarke, 1998; Senior, 1966) (Figures 5.2, 5.3). These clasts are interpreted to have been deposited by rivers draining the emergent greywacke highs of the Aorangi Ranges to the southwest and the Jury Ridge to the north, before being reworked within the shoreface zone.

Figure 5.3 “Pukenui C” within the Whangaehu Valley, north of the study area showing rounded greywacke clasts indicating a depositional setting proximal to river systems draining greywacke highs (BQ 141 321)

At the Hinakura Road Section (HR) the “Pukenui C” is less cemented, and has a higher siliciclastic sand component than observed at sites elsewhere, and is overlain by finely bedded upper to middle shoreface sand, indicating a mid to upper shoreface environment.

*Throughout this chapter the two letter code following the section name refers to the position of the section on the Maps (Figures 5.1, 5.2, 5.4, 5.5).

The Ruawaka and H4 Sections contain well cemented “Pukenui C” of the mid to lower shoreface environment. Inner shelf **HST** deposits overlying these sections indicate that deposition here was more basinward than at the Hinakura Road Section.

The area to the north of the Blue Rock Hautotara Section (BH) is believed to be a sediment starved, current swept high during the deposition of the “Pukenui C”. This area is a greywacke block overlain by gravelly sands and limestones, and although the Pukenui Limestone is not present, the fauna of this area appears to be an equivalent depth to that of the Pukenui Limestone (Thomson, 1980).

Although no outcrops of the “Pukenui C” are identified around the Huangarua West Section (HW), it is inferred that this area represents inner shelf sedimentation (Figure 5.2). Observations of the Pukenui Limestone indicate that this area is basinward, and deeper, than outcrops to the east (Rampton, 1997).

5.3 Reconstruction Two: Late Cycle Four – ~1.58 Ma

Deposition of the Hautotara Formation strongly reflects the structural evolution of the study area. The reconstruction in Figure 5.4 is part way through the Hautotara Formation, during the RST to LST of Cycle 3, as the marine influence on the study area decreases, and immediately before onset of Te Muna Formation sedimentation in the north and south of the study area.

The greywacke highs recorded in the preceding reconstruction have become more prominent features, and continue to be the primary source of the fluvially-derived gravels during deposition of the Hautotara Formation. However, as exhibited by exotic clasts within transgressive conglomerates, these proximal locations are not the only sources of gravels (Figure 5.4). The Windy Peak Anticline and Monocline are continuing to grow, while the Dry River, Huangarua and Ruakokoputuna Faults, and the Huangarua Syncline to the east are now affecting sedimentation. Palaeogeography is now more complicated than during deposition of the “Pukenui C”.

Figure 5.4 Palaeogeographic reconstruction of ~1.58 Ma. Western and eastern settings some distance from the study area are not included (areas without fill)

Rivers are transporting gravels from greywacke highs to the north of the study area, although the continued growth of the Windy Peak Anticline (Figure 5.1) appears to limit this deposition to the northeast. To the south, the structural high to the north of the Blue Rock Hautotara Section (BH) is now fully emergent, while fluvial transportation from early Cenozoic sediments to the southeast is also inferred (Figure 5.4).

A range of estuarine environments are believed to be prominent features landward of the outcrops observed. Throughout the Ruawaka Section (RW) are *Austrovenus-Limnoperna* dominated shellbeds that are inferred to represent storm outwash from estuaries. The presence of the mussel *Limnoperna huttoni* in these beds possibly implies a harder substrate than the *Barytellina crassidens* dominated sandstones at the Hautotara Type Section and the Huangarua West Section (HW) (Figure 5.1). As the structural high to the north of the Blue Rock Hautotara Section (BH) is now fully emergent, estuarine to swampy settings have formed within the Blue Rock Valley (Figure 5.4). Lagoons formed around the Hinakura Road Section during previous Hautotara Formation RSTs, although the RST of Cycle Four is not exposed at this site, it is believed this has occurred again. The presence of the gastropod *Zeacumantus lutulentus* in the estuarine sandstone of the Blue Rock Hautotara Section indicates this area contains mudflats, while the Huangarua West and Hinakura Road sections also contain this gastropod in **SBal** shellbeds, indicating nearby mudflats (Figure 5.4).

The Ruawaka and H1 Sections are open beachface settings during this reconstruction. As the conglomerates within these sections are thin, it is believed the fluvial gravels of the LST were not deposited at these sites. Instead it appears likely these clasts were transported to these sites by longshore drift during transgressions. Fluvial deposition has occurred within previous Hautotara Formation cycles at the H1 Section.

5.4 Reconstruction Three: Cycle Five – ~1.57 Ma

The early cycles of the Te Muna Formation are characterised by lacustrine deposits with multiple tephra (Figure 5.5).

The continued growth of the Huangarua Syncline, Harris Ridge Anticline, and the Huangarua Fault within the northwestern study area are influencing deposition at the time represented by this reconstruction (Figure 5.5). Highstand deposits of the Te Muna Formation are characterised by lower fluvial sediment yields, and low energy lacustrine deposition (Woolfe, 1993).

Although more localised, the lacustrine systems of the lower Te Muna Formation appear comparable to the modern day Lake Wairarapa. It is inferred that two lake systems to the north and south of the study area are bound by reworked fluvial gravels deposited during the preceding LST, and reworked during the following transgression (Figure 5.5).

The patchy tephra record at this time could be as a result of depositional processes or infer that these lakes would shift position within the valleys, although subaerially exposed surfaces have not been observed at the measured sections in this study. Organics and coarse lenses within the lacustrine units of the Hinakura Road Section imply this section is near a lake shore (Figure 5.5).

The sandstones of the Ruawaka and H1 Sections represent a shallow marine environment within an embayment, and this restricted region of Hautotara Formation deposition continues until around 1.45 Ma, when estuarine conditions are recorded at H1.

Figure 5.6 Palaeogeographic reconstruction of ~1.57 Ma. Western and eastern settings some distance from the study area are not included (areas without fill)

Chapter Six

Conclusions

6.1 Major Findings

This study has provided a comprehensive re-evaluation of the final emergence of the eastern Wairarapa Valley. The major findings and outputs of this study are a result of a combination of field observations, lab analysis and synthesis of previous work.

Three major aims were clearly outlined within the introduction to this study (Chapter One). Here an assessment is made of how this study has achieved each of these aims.

Aim One:

Produce revised ages for the Hautotara and Te Muna Formations.

A revised age for the Hautotara Formation is presented in this study, here it is suggested deposition occurred between 1.73 Ma to sometime after 1.42 Ma.

This age range is derived from a combination of:

Biostratigraphic data. The first occurrence of the coccolith *Gephyrocapsa sinuosa* is dated at 1.80 Ma, and occurs in the “A-B Interbed” of the underlying Pukenui Limestone (Edwards 1976; Nicol *et al.*, 2002). The base of the Hautotara Formation must be younger than this, and it is interpreted that the contact is between one and two 40 kyr cycles above the first occurrence of *Gephyrocapsa sinuosa*. This provides an estimated age of 1.73 Ma for the top of the Pukenui Limestone.

Cyclostratigraphic correlations. Eight 40 kyr cycles are identified within the Hautotara Formation (see Aim Two, below), suggesting the deposition between 1.73 and 1.42 Ma.

Tephrochronological data: Tephra within the oldest sediments of the Te Muna Formation is dated ~1.6 Ma, constraining the maximum age of the Te Muna Formation to around this time.

A revision of the character of the Hautotara-Te Muna Formation contact suggests the contact between the formations is diachronous, with the Te Muna Formation being conformably deposited from 1.58 Ma in the north and south of the study area, while the base of the type section (in the centre of the study area) is an angular unconformity over 9°, with deposition above this commencing at 1.12 Ma. Overall, this shows the Te Muna Formation spans the time range of 1.58 Ma to around 0.7 - 0.4 Ma.

In early work (e.g. Vella & Briggs, 1971), the upper surface of the Pukenui Limestone was placed at the top of the “Pukenui B” limestone, while the lower contact of the Hautotara Formation was 30 metres stratigraphically above the “Pukenui C”, and resulting in a nomenclatural gap. This study has placed the top of the Pukenui Limestone at the top of the easily recognisable “Pukenui C” member, and bringing it in line with modern usage. As a consequence of these results, this study has also improved the age control on the Pukenui Limestone, with a new inferred age of 1.86 to 1.73 Ma.

Aim Two:

Identify sequence stratigraphic motifs of the Hautotara and Te Muna Formations.

Seven new, detailed stratigraphic columns of the Hautotara and Te Muna Formations have provided a detailed facies analysis of the Hautotara and Te Muna Formations, allowing the identification of glacio-eustatic sea-level cycles within the formations. Four dominant motifs are described for the Hautotara and Te Muna Formations,

showing a basinward (Eringa Motif) to landward (Te Muna Motif) progression of environments through time. The most common motif identified in the study area is the Huangarua Motif, while the Waipuna Motif records the conformable Hautotara - Te Muna Formation transition.

By incorporating East Coast Basin sequence stratigraphic methods, eight cycles are observed within the Hautotara Formation at the Ruawaka Section. Three and a half cycles are observed in the Hautotara Formation in the northern part of the study area, before Te Muna Formation rocks ~1.6 Ma are deposited in this area, supporting the idea of diachroneity.

A simple mechanism for cyclicity in the non-marine Te Muna Formation is identified, in which the lacustrine units represent the highstand systems tract, while the fluvial conglomerates represent the other three systems tracts.

Aim Three:

Present the Early Quaternary marine to terrestrial transition of the Eastern Wairarapa Valley, through palaeogeographical reconstructions.

Three palaeogeographic reconstructions are presented in Chapter Five, and these show the final emergence of the Eastern Wairarapa Valley. Importantly, the transition has been identified as more complex as originally thought, with deposition of the marginal-marine Hautotara Formation persisting within the central part of the study area well after the initiation of the non-marine Te Muna Formation sediments elsewhere in the basin.

These palaeogeographic reconstructions of the Hautotara and Te Muna formations demonstrate how closely related sedimentation pattern are to structural growth. For example, the evolution of a structural high north of the Blue Rock Hautotara Section (from a current-swept marine setting, to a topographic feature affecting non-marine deposition) can be observed.

6.2 Future Work

Using clay analysis, Rataul (1988) identified no marine influence in the lacustrine units of the Te Muna Formation at the type section. However, this study has shown the units analysed by Rataul (1988) to have been deposited 0.3 Ma after the final emergence of the area. Future analysis of the lower Te Muna Formation lacustrine for a marine influence would appear to be appropriate.

Numerous studies have documented the various tephra of the Hautotara and Te Muna Formations, although the site locations and stratigraphic position have been recorded with varying levels of accuracy. A continuation of this study is providing a comprehensive review of these beds, including using trace element data to allow comparison with a well constrained continuous offshore record (e.g. Allan *et al.*, 2008).

Recent work in the East Coast Basins (e.g. Bland *et al.*, 2004; Bland, 2006; this study) have provided a framework for the re-examination of the cyclicity observed in the Pukenui Limestone. Likewise, although it is outside the scope of this study it is hoped that information provided here, in combination with work in the Wanganui and Hawke's Bay Basins, can further constrain the Plio-Pleistocene palaeogeographic history of the lower North Island.

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Appendices

Appendix One

Geological Map

GEOLOGICAL MAP OF THE HAUTOTARA AND TE MUNA FORMATIONS SOUTHEAST OF MARTINBOROUGH, WAIRARAPA, NEW ZEALAND

Appendix Two

Stratigraphic Columns

Lithology Symbols

Conglomerate

Shellbed

Sandstone

Sandy Mudstone/
Muddy Sandstone

Mudstone

Limestone

Cross-bedded
Limestone

Shell hash

Organics

Tephra

Environment Interpretation

Inner Shelf

Lower Shoreface

Shoreface

Upper Shoreface

Estuarine

Swamp

Lacustrine

Fluvial

Stratigraphic Symbols

Bivalves

Broken Bivalves

Gastropods

Broken Gastropods

Burrows

Echinoderms

Branches/Logs

Bryozoan

Barnacles

Grain Size Sample

System Tract Boundaries

Sequence
Boundary

Tract
Boundary

Indistinct
Tract Boundary

System Tracts

HST

Highstand Systems Tract

RST

Regressive Systems Tract

LST

Lowstand Systems Tract

TST

Transgressive Systems Tract

Hinakura Road Section

Grid References: BQ34 145 304
S27 245 921

Sheet 1:2

Formation		Height (m)	Stratigraphic Column	Graphics	Grain Size	Unit Name	Description	Systems Tract	Facies
Hautotara Formation		24				HR9	Sandstone, brown coarse to fine sands. Contains <i>Glycymeris shrimptoni</i> , <i>Circomphalus yatei</i> and <i>Zethalia zelandica</i> . Lower contact wavy on a cm scale and burrowed to 4 cm.	LST	Sw
						HR8	Clay, light brown to dark grey, finely cross-bedded. Contains extensive sand filled burrows up to 4cm long from overlying unit. Lower contact sharp and wavy to 3 cm.		Mc
						HR7	Sandstone, light brown, consists of 60% comminuted shells, coarse sands and rare fossils, including <i>Circomphalus yatei</i> , <i>Dosinia zelandica</i> and <i>Zethalia zelandica</i> . Lower contact gradational over 5 cm.	RST	Sw
						HR6	Shellbed, brown to white, 70% shells in a sand matrix, upper 5cm highly fossiliferous. Contains <i>Glycymeris shrimptoni</i> , <i>Myadora waitotarana</i> , <i>Alcithoe fusus</i> , <i>Zethalia zelandica</i> and <i>Amalda australis</i> . Lower contact burrowed and gradational over 4 cm.	HST	SBz
						HR5			Sp
						HR4	Sandstone, brown fine sands. Contains <i>Amalda australis</i> , <i>Alcithoe</i> sp., and life position <i>Panopea zelandica</i> . Lower contact gradational over 5cm.		SBal
		22				HR3	Shellbed, brown to white, 70% shells in a sand matrix, upper 5 cm highly fossiliferous. Contains <i>Glycymeris shrimptoni</i> , <i>Circomphalus yatei</i> , <i>Zeacumantus lutulentus</i> and <i>Amalda australis</i> . Lower contact gradational over 5 cm.	TST	Sd
							Sandstone, light brown fine sand with up to 40% comminuted shell sand and shell fragments. No visible bedding, although unit is highly burrowed, often along planes. Fossils include fractured <i>Alcithoe</i> sp.. Lower contact not observed.		
		20							
		18							
		16							
		14							
		12							
		10							
		8							
		6							
		4							
		2							
						HR2	Sandstone, fine brown sand with 15-20% coarse sand sized shell hash. Rare, whole <i>Tawera subsulcata</i> and <i>Zethalia zelandica</i> . Faint 2 cm beds observed. Planar, conformable lower contact.	HST	Sd
Pukenui		0				HR1	Shellbed, light brown, abundant whole, disarticulated <i>Tawera subsulcata</i> , predominantly concave down. Comprised of 20% medium to fine sand, remainder shell hash. Lower contact not observed.	TST	SBt

Hinakura Road Section

Grid References: BQ34 145 304
S27 245 921

Sheet 2:2

Formation	Height (m)	Stratigraphic Column	Graphics	Grain Size	Unit Name	Description	Systems Tract	Facies
Te Muna Formation	48				HR18	Sandstone, brown coarse to fine laminated sands. Lower contact sharp, wavy over 1 cm.		Sn
					HR17	Tephra, white to light grey, massive, ash. Some sulphur present, conformable, planar lower contact.		V
	46				HR16	Mudstone, brown grey at base to blue grey, massive mud. Conformable lower contact.	HST	Ms
	44				HR15	Conglomerate, orange brown, moderately cemented, clast supported. Pebbles to 5 cm with a sand matrix. Lower contact channelised over 10 cm.	LST - TST	Cm
	42				HR14	Mudstone, blue grey to white, with rare medium fine sand lenses. Lower contact gradational over 4 cm.	HST	Ms
					HR13	Organic, black to dark brown, grades into blue grey mud. Conformable lower contact with some bioturbation into lower unit.		O
					HR12	Tephra, mottled yellow to white, top pink, massive, ash. Planar, sharp lower contact.		V
					HR11	Mudstone, blue grey, no bedding, contains rare pebbles. Conformable lower contact.		Ms
	38				HR10	Conglomerate, orange brown, moderately cemented, clast supported. Imbricated pebble clasts to 8 cm, most 1.5-5 cm, subrounded within a sand matrix. Lower contact obscured.	LST - TST	Cm
	36							
Hautotara Formation	34							

Huargarua West Section

Grid References: BQ34 094 303
S27 194 920

Formation Height (m)		Stratigraphic Column	Graphics	Grain Size	Unit Name	Description	Systems Tract	Facies
Te Muna Formation	Hautotara Formation							
24					HW5	Conglomerate , brown, clast supported. No visible bedding. Subangular to subrounded clasts to 11 cm in length. Lower contact convolute and wavy over 40 cm.	LST - TST	Cm
22								
20								
18								
16								
14								
12								
10								
8								
6								
4								
2								
0								

Huangarua West Section

Grid References: BQ34 094 303
S27 194 920

Sheet 2:2

[illegible]

Ruawaka Section

Grid References: BQ34 086 267
S27 186 884

Sheet 1:4

Formation		Height (m)	Stratigraphic Column	Graphics	Grain Size	Unit Name	Description	Systems Tract	Facies
Hautotara Formation		24				Rw10	<p>Shellbed, 50% whole shells and 15% fragments in a hard brown medium fine sand. Matrix supported unit with rare <1 cm well rounded greywacke clasts. Wide range of fossils, dominated by both <i>Limnoperna buttoni</i> (double valved) and <i>Austrovenus stutchburyi</i> (disarticulated), randomly orientated and up to 10 cm. Lower contact is gradational over 2-3 cm.</p> <p>Sandstone, brown, fine, no visible bedding. Contains rare <i>Panopea zelandica</i> and shell filled burrows up to 40 cm long. Shell fragments up to 1cm throughout unit. Lower contact not seen.</p>		Sp
						Rw9			SBal
		22				Rw8		HST	Sp
		20				Rw7			Sw
		18				Rw6	<p>Limestone, grey-brown, hard, weathered. Consists of fragmented shell material, some up to 5 cm and rare greywacke pebbles. Lower contact gradational over 20 cm.</p>	TST	SBI
		16				Rw5	<p>Shellbed, orange to yellow, hard cross-bedded shell rich unit. 70% shells, largely fragments less than 1 cm, 20% grey fine sand and 5% mud drapes. Cross bedding at 20-25° angle and on a 10-30 cm scale. Contains slightly broken <i>Glycymeris modesta</i>, <i>Purpurocardia purpurata</i>, <i>Dosinia zelandica</i>, <i>Tawera subsulcata</i> and whole <i>Zetbalia zelandica</i>. 80% of bivalves are concave down, <i>Zetbalia zelandica</i> occurs upside down. Lower contact is sharp and wavy over 5 cm.</p>	LST	SBlx
						Rw4			Sd
		14				Rw3	<p>Sandstone, 60% fine brown sand, 25% whole and broken shells, 15% greywacke gravels. Weak low-angle cross-bedding, on a 0.6 - 1 m scale, contains large burrows infilled with shell hash and greywacke granules. Shells up to 7 cm, 40% whole, and include <i>Dosinia zelandica</i>, <i>Ostrea chilensis</i> and <i>Zetbalia zelandica</i>. Greywacke clasts are sub to well rounded, slightly elongate and up to 7cm long, although most are <1 cm. Lower contact is gradational over 2 m.</p>	RST	Sw
		12				Rw2	<p>Sandstone, brown, well sorted, fine, massive. Lower contact conformable on top of Pukenui Limestone.</p>	HST	Sp
		10							
Pukenui		0				Rw1	<p>Limestone, grey, well cemented. Contains casts of <i>Tawera subsulcata</i> and <i>Ostrea chilensis</i>. Level upper surface.</p>	TST	SBI
			clay silt f m c sand gravel	gravel sand silt clay					

Ruawaka Section

Grid References: BQ34 086 267
S27 186 884

Sheet 2:4

Formation		Height (m)	Stratigraphic Column	Graphics	Grain Size	Unit Name	Description	Systems Tract	Facies			
Hautotara Formation		48			Q P O	Rw34	Sandstone, blue grey, coarse to medium, shell hash rich. Contains <i>Myadora waitotarana</i> , mud lenses, and plentiful <i>Amalda australis</i> above lower contact. Lower contact sharp, planar.	HST	Sd			
						Rw33	Shellbed, abundant <i>Tawera subsulcata</i> , some articulated in a blue grey sand matrix. Sharp, planar lower contact.		SBt			
						Rw32	Sandstone, brown grey, massive. Rare <i>Panopea zelandica</i> in life position. Conformable lower contact over 3 cm.		Sp			
						Rw31	Gravel Shellbed, grey, poorly sorted, rounded to subangular gravels to 12 cm. Unit fines in top 5 cm. Contains large worn and fragmented shells including <i>Pratulum pulchellum</i> and <i>Tugetona laticostata</i> . Lower contact wavy over 10 cm and burrowed.	TST	Cs			
						Rw30	Sandstone, grey, cross-bedded medium sandstone with sand sized shell hash. Common <i>Zethalia zelandica</i> , rare <i>Circomphalus parvus</i> . Lower contact conformable.		Sw			
						Rw29	Gravel Shellbed, white, worn whole and broken fossils, minor gravels, faintly bedded. Numerous <i>Alcithoe arabica</i> on upper surface, common worn scallops. Lower contact erosional and wavy over 4 cm.	RST	Cf			
		46				Rw28	Sandstone, grey muddy, with whole shells and coarse lenses. Contains <i>Dosinia subrosea</i> layers, some burrows. Planar lower contact marked by pebble and <i>Dosinia subrosea</i> rich layer.	HST	Sd			
		44				Rw27	Gravel Shellbed, yellow grey with 25% gravels and some broken fossils. Poorly sorted, clasts from coarse sand to 5 cm, gravels subrounded to subangular. Lower contact a sharp channel over 15 cm.	TST	Cs			
						Rw26	Sandstone, grey to blue grey laminated comminuted shell sand. Lower contact sharp with worn <i>Dosinia subrosea</i> and gravels in a winnowed basal 5 cm.		Sd			
		42				Rw25	Sandstone, blue grey to grey, largely unfossiliferous fine sandstone. Contains rare lenses of fine gravels with worn bivalves to 6 cm. Lower contact conformable.		Sp			
		40				Rw24	Sandstone, brown-grey, cross-bedded medium fine sandstone with 15% comminuted shells. Contains rare <i>Zethalia zelandica</i> and <i>Zegalerus tenuis</i> . Conformable lower contact.	RST	Sd			
						Rw23	Shellbed, grey, shell sand rich winnowed shellbed with low angle cross-beds. Contains an assortment of worn and fractured fossils including <i>Zethalia zelandica</i> , <i>Tugetona laticostata</i> and <i>Circomphalus parvus</i> . Erosional lower contact.	HST	SBal			
		38				Rw22	Sandstone, grey, muddy fine sand with uncommon <i>Talochlamys gemmulata</i> and <i>Zegalerus tenuis</i> . Lower contact is planar.		Sd			
						Rw21	Gravel Shellbed, grey, moderately cemented shell rich conglomerate. Contains gravels at base, and wide assortment of whole to worn and fractured fossils, including <i>Tawera subsulcata</i> , <i>Amalda mucronata</i> , <i>Tugetona laticostata</i> , <i>Zethalia zelandica</i> and <i>Panopea zelandica</i> . Erosional lower contact with burrows into underlying unit.	TST	Cf			
		36				Rw20	Sandstone, brown grey, silty fine massive sandstone. Contains a wide range of fossils, including <i>Panopea zelandica</i> and <i>Antisolarium egenum</i> . Lower contact not observed.	HST	Sp			
		34				Rw19	Gravel Shellbed, brown, poorly sorted, sub- to well-rounded greywacke and chert clasts in a shell fragment and sand matrix. Shell material decreases up unit. Lower contact sharp, planar.	TST	Cs			
						Rw18	Sandstone, light brown, fine, medium to poorly sorted sands. Unit is laminated and fossil poor towards the upper contact, while faintly cross bedded with <i>Paphies australis</i> and <i>Dosinia subrosea</i> found in a shell fragment matrix with rare granules 20 cm from the top of unit, and rarely lower than this. Contains weathered, massive Tephra. Lower contact conformable.	RST	Sd			
		32				Rw17	Shellbed, light brown with whole <i>Panopea zelandica</i> and <i>Tawera subsulcata</i> in a comminuted shell matrix. Lower contact burrowed with <i>Panopea zelandica</i> to 15 cm and wavy over 5 cm.		SBt			
		30				Rw16	Sandstone, light brown, alternating fossil poor fine sands with intact <i>Paphies australis</i> and <i>Dosinia subrosea</i> to shell fragments and rare granules with <i>Stiracolpus symmetricus</i> and <i>Paphies australis</i> . Lower contact gradational over 2 cm.	HST	Sd			
						Rw15	Gravel Shellbed, grey to light brown, very poorly sorted conglomerate. Clast supported, well to subrounded greywacke clasts with rare cherts and bored mudstone in worn shell fragment matrix including <i>Ostrea chilensis</i> . Lower contact sharp and wavy over 5 cm.	TST	Cs			
		28				Rw14	Sandstone, brown massive fine sand with some comminuted shells. Lower contact obscured.		Sp			
		26				Rw13	Shellbed, brown, with fractured and worn shells in a poorly sorted sand to granule matrix. Lower contact indistinct.		SBal			
24				Rw12	Sandstone, brown fine, with no bedding. Contains rare lenses of fossils, including <i>Pseudochinus novaezealandiae</i> , <i>Amalda mucronata</i> and <i>Panopea zelandica</i> in life position. Lower contact gradational over 30 cm.	RST	Sp					
22				Rw11	Shell Bed, orange brown to blue grey sandy shell bed with rare muds in basal 30 cm. Throughout unit are 10 cm thick cemented fractured shell beds, and in upper 30 cm are alternating beds of shells and sands. Fossils include whole <i>Austrovenus stutchburyi</i> and abraided <i>Limnoperna buttoni</i> . Lower contact is gradational over 2-3 cm.		SBal					
20				Rw10	Sandstone, brown, rare pebbles and abundant comminuted shell sands (70%). Shell hash filled burrows visible throughout unit. Contains <i>Panopea zelandica</i> , <i>Circomphalus parvus</i> and <i>Austrofusus cottoni</i> . Lower contact gradational over 40 cm.		Sp					
			clay silt f m c sand gravel		gravel sand silt clay							

Ruawaka Section

Grid References: BQ34 086 267
S27 186 884

Sheet 3:4

	Formation	Height (m)	Stratigraphic Column	Graphics		Grain Size	Unit Name	Description	Systems Tract	Facies
Te Muna Formation		74					Rw46	Fault, reverse.	LST - TST	Cm
							Rw45		HST	Ms
		72					Rw46	Conglomerate, light orange to brown, moderately cemented, poorly sorted, clast supported. Pebble clasts in a minor sand matrix. Contains weak cross-bedding, silt lenses up to 10 cm thick, and rare wood fragments. Clasts are well to subrounded predominately greywacke with rare red chert and sandstone clasts. Lower contact sharp angular unconformity and wavy over 30 cm.	LST - TST	Cm
Hautotara Formation		64					Rw45	Sandstone, grey, fine, well sorted sands with low angle crossbeds. Contains abundant <i>Zethalia zelandica</i> along bedding planes, also <i>Spisula crassitesta</i> and <i>Paphies australis</i> . Basal 10 cm contains whole fossils. Lower contact is sharp and conformable.	RST	Sw
							Rw44	Shellbed, blue grey, in granule to mud matrix. Contains <i>Tawera subsulcata</i> , <i>Gari lineolata</i> and <i>Zethalia zelandica</i> . Lower contact sharp.		SBz
		62					Rw43	Sandstone, blue grey muddy fine sand. Contains accumulations of shell fragments, common <i>Panopea zelandica</i> and rare <i>Tawera subsulcata</i> . Lower contact is sharp and conformable	HST	Sp
							Rw42	Gravel Shellbed, grey sub- to well-rounded greywacke, chert, bored mudstone and volcanic clasts to 8cm in a coarse sandy matrix. Contains large worn and fragmented bivalves, largely concave down, increasing up unit. Lower contact is sharp and planar, with large burrows to 40 cm deep.	TST	Cs
		60					Rw41			Sd
								Sandstone, blue grey, muddy fine sand with thin beds and rare granule lenses, fossils not seen. Lower contact not observed.		
		58					Rw40	Sandstone, blue grey, grain size with mud “pellets” and subrounded to subangular gravel to 4 cm. Contains <i>Fellaster zelandiae</i> , <i>Zethalia zelandica</i> and <i>Amalda australis</i> . Lower contact not observed.	RST	Sw
		56								
							Rw39	Sandstone, grey muddy fine sand and shell fragments. Moderate to rare bivalves, concave down, scattered along faint bedding planes. Basal 10 cm contains whole fossils. Lower contact is sharp and conformable		Sd
		54					Rw38	Shellbed, blue grey to white with 30% fine sand, 25% shell hash matrix, shell hash increasing up unit. Some bedding on 3 cm scale, with burrows and rare coarse sand lenses. Whole, concave down disarticulated shells. Wavy, gradational lower contact over 5 cm, with some burrows extending 12 cm below unit.		SBt
							Rw37	Sandstone, blue grey, fine sands with faint decimetre scale bedding. Contains some scattered shell fragments, along bedding planes. Lower contact gradational over 10 cm.	HST	Sd
		52					Rw36	Gravel Shellbed, blue grey, poorly sorted, well rounded to rounded gravels. Contains rare chert and bored mudstone clasts, one exotic limestone clast and large worn shells including <i>Ostrea chilensis</i> , <i>Purpurcardia purpurata</i> and <i>Alcitboe arabica</i> . Lower contact gradational, fining down to 1cm pebbles.		Cf
							Rw35			SBt
		50					Rw34			Sd

Ruawaka Section

Grid References: BQ34 086 267
S27 186 884

Sheet 4:4

Formation		Height (m)	Stratigraphic Column	Graphics	Grain Size	Unit Name	Description	Systems Tract	Facies
Te Muna Formation		98 96 94 92 90 88 86 84 82 80 78 76				Rw52	Conglomerate , rust-brown, moderately cemented, poorly sorted, clast supported. Pebbles up to 12 cm in a minor sand matrix. Contains faint cross-bedding. Clasts are rounded to subrounded greywacke. Lower contact channelised and wavy over 20 cm.		Cm
						Rw51	Sandstone , brown, well sorted, medium sand, loose. No visible bedding, rare organics present. Lower contact not observed.		Sn
						Rw50	Conglomerate , rust-brown, moderately cemented, poorly sorted, clast supported. Pebbles up to 12 cm, generally to 4.5 cm with a minor sand matrix. Contains decimetre scale faint <i>rhythmites</i> and faint cross-bedding. Clasts are rounded to subrounded greywacke. Lower contact erosive and wavy over 60 cm.	LST - TST	Cm
						Rw49	Mudstone , white-grey to brown at base, massive. Gradational lower contact over 40 cm.		Ms
						Rw48	Organic Layer, dark brown to grey-brown. Contains logs and branches primarily orientated 020°. Contains organic rich horizons up to 15 cm thick, with increasing mud content towards the top of each horizon. Horizon tops contain numerous leaf imprints. Lower contacts sharp and planar.		O
						Rw47	Mudstone , light grey, massive. Lower contact conformable.	HST	Ms
						Rw46	Conglomerate , light orange to brown, moderately cemented, poorly sorted, clast supported. Pebble sized (<12 cm) clasts with a sand matrix. Contains weak cross-bedding, silt lenses up to 10 cm thick and rare wood fragments. Clasts are well to subrounded predominately greywacke with rare red chert and sandstone clasts.	LST - TST	Cm

Ruakokoputuna Bridge Section

Grid References: BQ33 038 225
S27 138 842

Sheet 1:2

Formation		Height (m)	Stratigraphic Column	Graphics	Grain Size	Unit Name	Description	Systems Tract	Facies
Te Muna Formation		24				Rk14	Conglomerate , brown, loose, clast supported. Poorly sorted with no visible bedding. Subangular to angular clasts from sand sized to 20 cm in length. Sharp, planar lower contact.	LST - TST	Cm
		22				Rk13	Mudstone , blue grey to brown, sandy laminated. Conformable, gradational lower contact.	HST	Ms
		20				Rk12	Conglomerate , light brown, loose, clast supported. Subrounded to subangular clasts up to 28 cm at base of unit. Weak decimetre scale bedding with sand lenses up to 12 cm. Lower contact is sharp and wavy over 2.3 metres.	LST - TST	Cm
Hautotara Formation		16				Rk11	Sandstone , blue grey, contains bivalves up to 5 cm, whole and disarticulated, and gastropods. Rare well rounded to subrounded granule to gravel sized greywacke clasts. Lower contact gradational over 4 cm.		Sa
		14				Rk10	Sandstone , brown very well sorted unfossiliferous fine sandstone. Lower contact gradational over 50 cm.		Sw
		12				Rk9	Sandstone , grey, fine sandstone with rare whole bivalves. Contains mud drapes and lenses of shell fragments. Lower contact conformable.	HST	Sd
		10					Shellbed , brown to grey, with whole and broken shells. Most bivalves concave down and include <i>Limatula maoria</i> and <i>Paphies australis</i> . Centimetre scale planar bedding, and in unit burrows. Lower contact wavy over 10 cm, with burrows extending through underlying unit and into top of Gravel Shell Bed (RW7).		SBt
		8				Rk8	Sandstone , grey to brown, medium fine sand with rare shells, including <i>Trochus (Coelotrochus) tiaratus</i> and <i>Xymene expansus</i> . Lower contact gradational and conformable.		Sp
		7				Rk7	Gravel Shell Bed , brown to grey, clast supported, well rounded to sub-rounded greywacke, bored mudstone clasts and rare red chert gravel. Bedded unit containing many fractured and whole fossils including <i>Tawera subsulcata</i> , <i>Trochus (Coelotrochus) tiaratus</i> and <i>Alcithoe arabica</i> . Sharp lower contact, wavy over 5 cm with extensive burrowing into the underlying unit.		Cg
		6				Rk6	Sandstone , blue grey, medium to fine sand, with a coarse sand shell component. Unit fines up from medium at base to fine at top. Contains 40% shell fragments at base, decreasing to 10% at top. Upper 10 cm contains planar bedding on centimetre scale. Lower contact gradationally conformable.	TST	Sw
		5				Rk5	Shellbed , blue grey, coarse shell sand to silt with shell fragments up to 5 cm. Contains bivalves, gastropods, and <i>Fellaster</i> in lenses with 80% shell material. Burrows visible from shell rich lenses into silt beds. Lower contact planar and burrowed to 20cm depth.		SBz
		4				Rk4			
		3				Rk3	Sandstone , blue grey, fine grained, firm. Moderately common whole shells up to 8 cm, including <i>Dosinia lambata</i> . Contains organic material and a 20 cm long carbonised branch. Abundant broken shells towards top of unit. Lower contact is gradational over 50 cm.	RST	Sw
		2				Rk2	Sandstone , blue grey, fine grained, firm. Some fining up, planar bedding on a centimetre scale. Rare whole shells. Lower contact is gradational.	HST	Sd
		1				Rk1	Gravel Shell Bed , yellow brown moderately to non cemented with a coarse sand and shell hash matrix. Well rounded to angular greywacke and rare bored mudstone clasts to 20 cm. High speciation, large worn shells including <i>Tucetona laticostata</i> . Lower contact not observed.	TST	Cf

Ruakokoputuna Bridge Section

Grid References: BQ33 038 225
S27 138 842

Formation		Height (m)	Stratigraphic Column	Graphics		Grain Size	Unit Name	Description	Systems Tract	Facies
Ahiaruhe Formation		48
		46								
		44								
		42								
		40								
		38								
		36								
		34								
		32								
		30								
	28									
Te Muna		26					Rk15	Mudstone, grey to white, massive. Conformable, gradational lower contact.	HST	Ms
							Rk14		LST - TST	Cm

Blue Rock Race Section

Grid References: BQ33 026 229
S27 126 847

Sheet 1:1

	Formation Height (m)	Stratigraphic Column	Graphics	Grain Size	Unit Name	Description	Systems Tract	Lithofacies
Te Muna Formation	10			BR9	Mudstone, grey, massive. Lower contact with conglomerate obscured.	HST	Ms	
	BR8			Mudstone, grey, massive. The lower contact is conformable.	HST	Ms		
	BR7			Conglomerate, light brown, cemented, poorly sorted, clast supported. Cobble to pebble clasts of greywacke and argillite in a 25% sandy matrix. Unit fines upwards. Lower contact sharp and planar.		Cm		
	BR6			Mudstone, grey, sandy, massive. Contains a coarse sand lens between 22 and 30 cm, with 70% mud and rare sub-angular pebbles. Conformable lower contact.	HST	Ms		
	BR5			Conglomerate, light brown, cemented, poorly sorted, clast supported. Cobble to pebble clasts of greywacke and argillite in a sandy matrix. Finer clasts are rounded to sub-rounded, coarser clasts are sub-angular. Unit fines upwards. Lower contact sharp and wavy.	LST - TST	Cm		
	BR4			Mudstone, grey, massive. Conformable lower contact.	HST	Ms		
	BR3			Conglomerate, light brown, cemented, poorly sorted, clast supported. Cobble to pebble clasts of greywacke and argillite in a sandy matrix. Clasts are sub-rounded to sub-angular. Lower contact is planar.	LST - TST	Cm		
	BR2			Mudstone, grey, weakly laminated. Conformable irregular lower contact.	HST	Ms		
	BR1			Conglomerate, light brown, cemented, poorly sorted, clast supported. Cobble to pebble clasts of greywacke and argillite in a minor silty clay matrix. Clasts are sub-rounded to sub-angular. Lower contact not observed.	LST - TST	Cm		

Blue Rock Hautotara Section

Grid References: BQ33 026 231
S27 126 848

Formation	Height (m)	Stratigraphic Column	Graphics	Grain Size	Unit Name	Description	Systems Tract	Lithofacies
Te Muna Formation	8					BH3		
	6					Conglomerate , light brown, weakly cemented, poorly sorted, clast supported. Pebble clasts of greywacke and argillite in a coarse sandy matrix. Clasts are sub-rounded to sub-angular. Lower contact is a planar angular unconformity.	LST	Cm
Hautotara Formation	4					BH2		Sam
	2					Sandstone , blue grey, muddy, with beds of fossils. Contains <i>Barytellina crassidens</i> , <i>Zeacumantus lutulentus</i> and whole, articulated <i>Austrovenus stutchburyi</i> . lower contact not observed.	RST	Sa
	0	clay silt f m c sand gravel		gravel sand silt clay				

Clay Creek Bridge Section

Grid References: BQ33 014 203
S27 114 820

Sheet 1:1

Appendix Three

Grain size

Appendix Three: Grain Size Analysis

Hinakura Road Section

Hinakura Road Section

Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
Class limits	-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10

HR8

Mc

Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	1.34	2.15	3.01	5.26	8.83	15.48	17.01	14.79	10.26	6.39	4.54	3.80	3.33	2.47	1.11	0.13	0.00
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	1.42	3.58	6.59	11.85	20.68	36.16	53.17	67.96	78.22	84.62	89.16	92.97	96.30	98.76	99.87	100	100
Hinaku_3lb_39.\$ls	Mean:	Median:			Mode:			S.D.																	
	4.91	5.4			5.12			1.43																	
%>	5	16	25	75	84	95				%	Gravel	Sand	Silt	Clay											
	3.28	4.28	4.66	6.31	6.94	8.3					0.00	20.68	75.62	3.70

HR8

Mc

Frequency %	0.00	0.00	0.00	0.83	1.23	2.23	2.15	1.75	3.78	3.88	4.49	6.00	8.57	13.75	14.54	12.29	8.27	4.95	3.39	2.79	2.44	1.80	0.80	0.09	0.00
Cumulative %	0.00	0.00	0.00	0.83	2.06	4.29	6.44	8.19	11.97	15.85	20.34	26.34	34.90	48.65	63.19	75.48	83.74	88.69	92.08	94.87	97.31	99.11	99.91	100	100
Hinaku_3lb_38.\$ls	Mean:	Median:			Mode:			S.D.																	
	3.51	5.05			4.99			1.92																	
%>	5	16	25	75	84	95				%	Gravel	Sand	Silt	Clay											
	1.13	3.02	3.9	5.98	6.52	8.03					0.00	34.90	62.41	2.69

HR3

Sd

Frequency %	0.00	0.00	0.00	0.43	1.65	5.51	6.00	5.41	10.52	15.43	14.72	10.82	8.08	5.28	2.99	2.89	2.60	2.01	1.67	1.48	1.26	0.87	0.34	0.02	0.00
Cumulative %	0.00	0.00	0.00	0.43	2.09	7.59	13.60	19.01	29.53	44.96	59.68	70.50	78.58	83.86	86.85	89.74	92.34	94.36	96.03	97.51	98.77	99.64	99.98	100	100
Hinaku_2a_37.\$ls	Mean:	Median:			Mode:			S.D.																	
	2.56	3.16			2.97			1.78																	
%>	5	16	25	75	84	95				%	Gravel	Sand	Silt	Clay											
	0.81	1.76	2.32	4.26	5.02	7.19					0.00	78.58	20.19	1.23

HR2

Sd

Frequency %	0.00	0.00	0.00	0.00	0.01	4.69	2.83	1.24	13.22	26.78	28.54	11.31	3.31	2.06	0.83	1.19	0.99	0.73	0.69	0.64	0.57	0.33	0.03	0.00	0.00
Cumulative %	0.00	0.00	0.00	0.00	0.01	4.70	7.53	8.77	22.00	48.78	77.32	88.63	91.95	94.00	94.83	96.02	97.01	97.74	98.43	99.06	99.63	99.97	100	100	100
Hinaku_1b_36.\$ls	Mean:	Median:			Mode:			S.D.																	
	2.72	3.02			3.1			1.04																	
%>	5	16	25	75	84	95				%	Gravel	Sand	Silt	Clay											
	1.02	2.32	2.57	3.44	3.7	5.59					0.00	91.95	7.69	0.37

Appendix Three: Grain Size Analysis

Hinakura Road Section

Hinakura Road Section																									
Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
Class limits	-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10
HR2	Sd																								
Frequency %	0.00	0.00	0.00	0.00	0.01	4.78	2.75	1.21	12.96	27.00	28.91	11.41	3.30	2.02	0.79	1.16	0.96	0.69	0.65	0.59	0.52	0.29	0.03	0.00	0.00
Cumulative %	0.00	0.00	0.00	0.00	0.01	4.79	7.54	8.75	21.70	48.70	77.61	89.02	92.31	94.33	95.12	96.27	97.23	97.92	98.57	99.16	99.69	99.97	100	100	100
Hinaku_1b_35.\$ls	Mean:					Median:					Mode:					S.D.									
	2.72					3.02					3.1					1.01									
%>	5	16	25	75	84	95					%	Gravel	Sand	Silt	Clay										
	1.01	2.33	2.58	3.44	3.69	5.44						0.00	92.31	7.37	0.31

Appendix Three: Grain Size Analysis

Huangularua West Section

Huangularua West Section

Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
Class limits	-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10

HW 3

Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.01	4.21	25.10	27.81	10.36	4.80	5.12	4.60	3.60	3.32	2.94	2.38	1.96	1.62	1.23	0.73	0.21	0.00	0.00
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.01	4.21	29.31	57.13	67.48	72.28	77.40	82.00	85.60	88.92	91.86	94.24	96.20	97.82	99.05	99.78	100	100	100
HinaW_Smple1_29.\$ls	Mean:	Median:	Mode:	S.D.																					
	2.98	2.84	2.57	1.53																					
%>	5	16	25	75	84	95																			
	2.03	2.28	2.43	4.26	5.27	7.18																			
									%	Gravel	Sand	Silt	Clay												
										0.00	77.40	21.65	0.95

HW 3

Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.01	4.51	26.28	28.43	10.23	4.55	4.75	4.18	3.26	3.04	2.74	2.25	1.89	1.59	1.24	0.78	0.27	0.01	0.00
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.01	4.51	30.80	59.23	69.45	74.00	78.75	82.93	86.19	89.23	91.97	94.22	96.11	97.70	98.94	99.72	99.99	100	100
HinaW_Smple1_30.\$ls	Mean:	Median:	Mode:	S.D.																					
	2.94	2.8	2.57	1.51																					
%>	5	16	25	75	84	95																			
	2.02	2.27	2.41	4.1	5.15	7.2																			
									%	Gravel	Sand	Silt	Clay												
										0.00	78.75	20.20	1.06

HW2

Frequency %	0.00	0.00	0.59	4.29	10.40	17.30	20.79	18.18	11.80	5.44	2.49	2.08	1.76	1.19	0.79	0.66	0.57	0.46	0.38	0.31	0.24	0.16	0.08	0.02	0.00
Cumulative %	0.00	0.00	0.59	4.89	15.28	32.59	53.38	71.56	83.36	88.80	91.29	93.36	95.12	96.32	97.11	97.77	98.34	98.80	99.18	99.49	99.73	99.89	99.98	100	100
HinaW_Smple2_31.\$ls	Mean:	Median:	Mode:	S.D.																					
	1.22	1.42	1.22	1.18																					
%>	5	16	25	75	84	95																			
	0.01	0.52	0.8	2.12	2.54	4.46																			
									%	Gravel	Sand	Silt	Clay												
										0.59	94.53	4.61	0.27

HW2

Frequency %	0.00	0.00	0.46	6.55	16.97	22.55	21.32	14.58	7.67	3.10	1.31	1.20	0.93	0.79	0.48	0.49	0.43	0.31	0.25	0.22	0.21	0.15	0.04	0.00	0.00
Cumulative %	0.00	0.00	0.46	7.01	23.98	46.53	67.85	82.44	90.10	93.21	94.51	95.71	96.64	97.43	97.91	98.39	98.83	99.13	99.38	99.60	99.81	99.96	100	100	100
HinaW_Smple2_32.\$ls	Mean:	Median:	Mode:	S.D.																					
	0.95	1.07	0.95	1.02																					
%>	5	16	25	75	84	95																			
	-0.09	0.29	0.52	1.71	2.07	3.69																			
									%	Gravel	Sand	Silt	Clay												
										0.46	96.18	3.17	0.19

Huargarua West Section

Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
Class limits	-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10

HW 1

Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	11.29	31.30	18.35	6.74	5.73	5.08	3.84	3.72	3.37	2.70	2.27	2.01	1.70	1.18	0.46	0.03	0.00
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	11.53	42.83	61.18	67.92	73.65	78.73	82.57	86.29	89.66	92.36	94.63	96.64	98.34	99.51	99.97	100	100
HinaW_Smple3_33.\$ls	Mean:	Median:		Mode:		S.D.																			
	3.29	3.14		2.84		1.58																			
%>	5	16	25	75	84	95			%	Gravel	Sand	Silt	Clay												
	2.33	2.58	2.72	4.62	5.69	7.59				0.00	73.65	24.69	1.66

HW 1

Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	11.66	30.53	17.73	6.53	5.48	4.98	3.92	3.96	3.68	2.97	2.50	2.19	1.84	1.26	0.47	0.02	0.00
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	11.95	42.48	60.20	66.73	72.21	77.19	81.11	85.07	88.74	91.72	94.21	96.40	98.24	99.50	99.98	100	100
HinaW_Smple3_34.\$ls	Mean:	Median:		Mode:		S.D.																			
	3.3	3.15		2.84		1.63																			
%>	5	16	25	75	84	95			%	Gravel	Sand	Silt	Clay												
	2.32	2.57	2.72	4.77	5.87	7.67				0.00	72.21	26.03	1.76

Te Muna Type Section Twin Tephra

Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
Class limits	-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10
TT S1																									
Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.81	4.44	6.85	12.62	18.34	17.93	11.46	5.41	4.69	4.12	3.11	2.75	2.64	2.47	1.73	0.61	0.02	0.00
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.81	5.25	12.10	24.71	43.06	60.98	72.45	77.86	82.55	86.68	89.79	92.54	95.17	97.64	99.37	99.98	100	100
TT_S1_07.\$ls	Mean:	Median:		Mode:		S.D.																			
	3.93	4.18		3.19		1.573																			
%>	5	16	25	75	84	95		%	Gravel	Sand	Silt	Clay													
	2.476	3.192	3.509	5.2	6.158	7.964			0.00	60.98	36.66	2.36

TT S1

Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83	4.15	6.08	11.86	17.94	18.24	12.14	5.78	4.92	4.31	3.27	2.87	2.72	2.51	1.74	0.61	0.02	0.00
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83	4.98	11.06	22.93	40.87	59.11	71.25	77.03	81.95	86.26	89.53	92.40	95.11	97.63	99.37	99.98	100	100
TT_S1_08.\$ls	Mean:	Median:		Mode:		S.D.																			
	3.98	4.24		4.05		1.572																			
%>	5	16	25	75	84	95		%	Gravel	Sand	Silt	Clay													
	2.502	3.249	3.567	5.294	6.219	7.977			0.00	59.11	38.52	2.37

TT S2

Frequency %	0	0	0	0	0	0	0	0.199	2.388	4.441	8.147	12.77	14.57	12.24	7.253	6.664	6.246	5.121	4.852	4.932	4.94	3.727	1.437	0.068	0
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	2.59	7.03	15.18	27.95	42.52	54.76	62.01	68.68	74.92	80.04	84.89	89.83	94.77	98.49	99.93	100	100
TT_S2_09.\$ls	Mean:	Median:		Mode:		S.D.																			
	4.4	4.78		4.32		1.836																			
%>	5	16	25	75	84	95		%	Gravel	Sand	Silt	Clay													
	2.796	3.538	3.893	6.507	7.409	8.527			0.00	42.52	52.25	5.23

TT S2

Frequency %	0	0	0	0	0	0	0	0.045	1.514	3.735	7.012	11.67	14.08	12.85	8.399	7.863	7.322	5.875	5.243	4.993	4.738	3.408	1.198	0.041	0
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	1.56	5.29	12.31	23.98	38.07	50.92	59.32	67.18	74.50	80.38	85.62	90.61	95.35	98.76	99.96	100	100
TT_S2_10.\$ls	Mean:	Median:		Mode:		S.D.																			
	4.54	4.96		4.45		1.75																			
%>	5	16	25	75	84	95		%	Gravel	Sand	Silt	Clay													
	2.967	3.677	4.037	6.539	7.345	8.461			0.00	38.07	57.29	4.65

Te Muna Type Section Twin Tephra

Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10					
Class limits	-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10					
TT S3																														
Frequency %	0	0	0	0	0	0	0	0.101	2.108	5.321	10.12	15.65	17.43	12.7	6.307	5.459	5.015	3.783	3.353	3.432	3.615	3.122	1.854	0.592	0.041					
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	2.21	7.53	17.65	33.29	50.72	63.43	69.73	75.19	80.21	83.99	87.34	90.78	94.39	97.51	99.37	99.96	100					
TT_S3_11.\$ls	Mean:	Median:		Mode:		S.D.																								
	4.24	4.48		4.18		1.77																								
%>	5	16	25	75	84	95	%																				Gravel	Sand	Silt	Clay
	2.797	3.44	3.752	5.982	7.002	8.589																					0.00	50.72	43.67	5.61

TT S3

Frequency %	0	0	0	0	0	0	0	0.333	3.546	7.364	12.66	17.97	17.81	11.82	5.165	4.34	3.929	2.943	2.623	2.673	2.758	2.321	1.336	0.394	0.021	
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	3.88	11.24	23.90	41.87	59.68	71.50	76.66	81.00	84.93	87.87	90.50	93.17	95.93	98.25	99.58	99.98	100	
TT_S3_12.\$ls	Mean:	Median:		Mode:		S.D.																				
	3.99	4.22		3.91		1.66																				
%>	5	16	25	75	84	95		%	Gravel	Sand	Silt	Clay														
	2.591	3.221	3.534	5.303	6.366	8.33			0.00	59.68	36.25	4.07														

Grain Size	Percentage (%)
Gravel	0.00
Sand	59.68
Silt	36.25
Clay	4.07

TT S4

Frequency %	0.00	0.00	0.00	0.00	0.08	2.04	5.52	12.88	21.70	19.50	12.13	8.56	5.96	3.25	1.79	1.56	1.36	1.08	0.87	0.70	0.54	0.33	0.13	0.01	0.00	
Cumulative %	0.00	0.00	0.00	0.00	0.08	2.12	7.64	20.52	42.22	61.72	73.85	82.42	88.37	91.62	93.42	94.98	96.34	97.42	98.29	98.99	99.53	99.87	99.99	100	100	
TT_S4sp_13.\$ls	Mean:	Median:		Mode:		S.D.																				
	2.54	2.68		2.43		1.27																				
%>	5	16	25	75	84	95		%	Gravel	Sand	Silt	Clay														
	1.306	1.867	2.116	3.56	4.112	6.006			0.00	88.37	11.16	0.47

TT S4

Frequency %	0.00	0.00	0.00	0.00	0.05	1.84	4.41	11.53	21.96	20.31	12.52	8.84	6.17	3.34	1.84	1.65	1.46	1.17	0.96	0.79	0.62	0.39	0.15	0.01	0.00	
Cumulative %	0.00	0.00	0.00	0.00	0.05	1.89	6.30	17.83	39.79	60.10	72.62	81.46	87.62	90.96	92.80	94.45	95.91	97.08	98.04	98.83	99.45	99.84	99.99	100	100	
TT_S4sp_14.\$ls	Mean:	Median:		Mode:		S.D.																				
	2.6	2.73		2.43		1.28																				
%>	5	16	25	75	84	95			%	Gravel	Sand	Silt	Clay													
	1.386	1.949	2.18	3.622	4.179	6.176				0.00	87.62	11.83	0.55													

The plot displays the grain size distribution of a soil sample. The x-axis represents grain size in millimeters (mm) on a logarithmic scale, with major ticks at 0.075, 0.15, 0.3, 0.6, 1.2, 2.5, 5, 10, 20, 40, and 60. The y-axis represents the percentage of soil components, ranging from 0 to 50. The plot includes a cumulative distribution curve (solid line) and a histogram (shaded bars). The soil is classified as follows: Gravel (0.075 to 2.0 mm), Sand (2.0 to 0.075 mm), Silt (0.075 to 0.002 mm), and Clay (0.002 to 0.075 mm). The cumulative curve shows that approximately 87.62% of the soil is finer than 0.075 mm (Silt and Clay), and 99.84% is finer than 0.002 mm (Clay).

Grain Size (mm)	Percentage (%)
0.075	0.00
0.15	0.00
0.3	0.00
0.6	0.05
1.2	1.84
2.5	4.41
5	11.53
10	21.96
20	20.31
40	12.52
60	8.84
0.075	0.00
0.15	0.00
0.3	0.00
0.6	0.05
1.2	1.84
2.5	4.41
5	11.53
10	21.96
20	20.31
40	12.52
60	8.84

Te Muna Type Section Twin Tephra

Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
Class limits	-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10

TT S4

Frequency %	0	0	0	0	0	0	0.012	2.367	10.34	14.61	19.13	20.59	14.52	6.174	2.003	1.942	1.881	1.483	1.305	1.229	1.128	0.826	0.388	0.065	###
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.01	2.38	12.72	27.33	46.46	67.05	81.58	87.75	89.75	91.69	93.58	95.06	96.36	97.59	98.72	99.55	99.93	100	100
TT_S4pp_15.\$ls	Mean:	Median:	Mode:	S.D.																					
	3.37	3.58	3.64	1.23																					
%>	5	16	25	75	84	95																			
	2.163	2.622	2.928	4.237	4.635	6.979																			
							%	Gravel	Sand	Silt	Clay														
								0.00	81.58	17.14	1.28

TT S4

Frequency %	0.003	0	0	0	0	0	0	1.78	9.24	14.14	19.83	22.14	15.85	6.532	1.82	1.607	1.52	1.16	1.035	1.025	0.997	0.782	0.421	0.111	0.004
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.78	11.02	25.17	45.00	67.13	82.99	89.52	91.34	92.95	94.47	95.63	96.66	97.69	98.68	99.46	99.89	100	100
TT_S4pp_16.\$ls	Mean:	Median:	Mode:	S.D.																					
	3.4	3.61	3.64	1.15																					
%>	5	16	25	75	84	95																			
	2.221	2.692	2.995	4.213	4.549	6.717																			
							%	Gravel	Sand	Silt	Clay														
								0.00	82.98	15.69	1.32

TT S5

Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	1.62	6.38	14.59	19.69	15.51	7.61	6.25	5.69	4.56	4.35	4.47	4.42	3.32	1.39	0.11	0.00
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	1.68	8.05	22.64	42.33	57.84	65.45	71.70	77.38	81.94	86.29	90.76	95.18	98.50	99.89	100	100
TT_S5_17.\$ls	Mean:	Median:	Mode:	S.D.																					
	4.61	4.71	4.32	1.64																					
%>	5	16	25	75	84	95																			
	3.328	3.805	4.062	6.274	7.24	8.479																			
							%	Gravel	Sand	Silt	Clay														
								0.00	42.33	52.85	4.82

TT S5

Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	2.06	6.92	16.18	22.01	16.93	7.69	5.72	4.88	3.61	3.23	3.26	3.27	2.57	1.25	0.20	0.00
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	2.28	9.20	25.38	47.39	64.31	72.00	77.72	82.60	86.21	89.45	92.71	95.98	98.55	99.80	100	100
TT_S5_18.\$ls	Mean:	Median:	Mode:	S.D.																					
	4.47	4.56	4.32	1.50																					
%>	5	16	25	75	84	95																			
	3.269	3.746	3.991	5.761	6.68	8.346																			
							%	Gravel	Sand	Silt	Clay														
								0.00	47.39	48.59	4.02

Ruawaka Section

Class midpoints

Class limits

-1.75 -1.25 -0.75 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 4.75 5.25 5.75 6.25 6.75 7.25 7.75 8.25 8.75 9.25 9.75 10
-2.00 -1.50 -1.00 -0.50 0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00 5.50 6.00 6.50 7.00 7.50 8.00 8.50 9.00 9.50 10

RW51

Frequency %

Cumulative %

TM SAND_44

Sn

0.00 0.00 0.00 0.96 4.38 13.85 22.09 19.37 13.83 8.27 4.46 3.11 2.10 1.73 1.01 1.10 0.97 0.68 0.56 0.49 0.50 0.40 0.12 0.00 0.00

0.00 0.00 0.00 0.96 5.34 19.19 41.28 60.65 74.48 82.74 87.21 90.32 92.42 94.15 95.16 96.26 97.23 97.92 98.48 98.98 99.47 99.88 100 100 100

Mean: Median: Mode: S.D.

1.6 1.71 1.22 1.295

%> 5 16 25 75 84 95

0.477 0.92 1.133 2.526 3.111 5.406

% Gravel Sand Silt Clay

0.00 92.42 7.06 0.53

RW51

Frequency %

Cumulative %

Ruawak_TM SS Top_02.\$ls

Sn

0 0 0 0.183 3.079 12.08 20.64 20.81 15.65 9.245 4.891 3.174 2.428 1.783 1.246 1.081 0.923 0.734 0.603 0.513 0.422 0.306 0.161 0.047 0.00

0.00 0.00 0.00 0.18 3.26 15.34 35.98 56.79 72.44 81.68 86.58 89.75 92.18 93.96 95.21 96.29 97.21 97.95 98.55 99.06 99.48 99.79 99.95 100 100

Mean: Median: Mode: S.D.

1.72 1.83 1.49 1.271

%> 5 16 25 75 84 95

0.616 1.02 1.247 2.611 3.201 5.409

% Gravel Sand Silt Clay

0.00 92.18 7.31 0.52

RW51

Frequency %

Cumulative %

Ruawak_TM SS Top_03.\$ls

Sn

0 0 0 0.017 2.657 14.07 22.25 20.05 15.75 9.52 4.68 3.098 1.89 1.475 0.795 0.856 0.746 0.52 0.436 0.394 0.394 0.307 0.087 ### 0

0.00 0.00 0.00 0.02 2.67 16.74 39.00 59.05 74.80 84.32 89.00 92.10 93.99 95.46 96.26 97.12 97.86 98.38 98.82 99.21 99.60 99.91 100 100 100

Mean: Median: Mode: S.D.

1.67 1.77 1.22 1.132

%> 5 16 25 75 84 95

0.64 0.981 1.185 2.508 2.978 4.819

% Gravel Sand Silt Clay

0.00 93.99 5.61 0.40

RW51

Frequency %

Cumulative %

Ruawak_TM SS Top_04.\$ls

Sn

0 0 0 0.017 2.266 13.18 22.49 19.81 15.11 9.374 4.894 3.331 2.166 1.758 0.99 1.047 0.935 0.655 0.539 0.474 0.476 0.378 0.106 ### 0

0.00 0.00 0.00 0.02 2.28 15.46 37.95 57.76 72.88 82.25 87.14 90.47 92.64 94.40 95.39 96.44 97.37 98.03 98.57 99.04 99.52 99.89 100 100 100

Mean: Median: Mode: S.D.

1.71 1.79 1.22 1.227

%> 5 16 25 75 84 95

0.669 1.014 1.214 2.593 3.137 5.266

% Gravel Sand Silt Clay

0.00 92.64 6.87 0.48

Ruawaka Section

Class midpoints

Class limits

-1.75 -1.25 -0.75 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 4.75 5.25 5.75 6.25 6.75 7.25 7.75 8.25 8.75 9.25 9.75 10
-2.00 -1.50 -1.00 -0.50 0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00 5.50 6.00 6.50 7.00 7.50 8.00 8.50 9.00 9.50 10

RW51

Frequency %

Cumulative %

RW_TM49_02

Sn

0 0 0 0.261 3.974 13.63 21.18 19.59 14.27 8.961 5.166 3.332 2.418 1.734 1.217 1.042 0.86 0.66 0.525 0.43 0.346 0.243 0.125 0.033 0
0 0 0 0.261 4.235 17.86 39.04 58.64 72.91 81.87 87.03 90.36 92.78 94.52 95.73 96.77 97.63 98.29 98.82 99.25 99.6 99.84 99.97 100 100
Mean: Median: Mode: S.D.
1.66 1.76 1.35 1.26
%> 5 16 25 75 84 95
0.542 0.948 1.177 2.596 3.174 5.183
% Gravel Sand Silt Clay
0.00 92.78 6.81 0.40

RW51

Frequency %

Cumulative %

RW_TM49_01.\$ls

Sn

0 0 0 0.255 4.082 13.65 21.04 19.91 14.61 8.879 4.933 3.122 2.349 1.741 1.254 1.053 0.862 0.662 0.515 0.407 0.313 0.214 0.111 0.033 0
0 0 0 0.255 4.337 17.99 39.03 58.94 73.55 82.43 87.36 90.48 92.83 94.57 95.83 96.88 97.74 98.41 98.92 99.33 99.64 99.85 99.97 100 100
Mean: Median: Mode: S.D.
1.651 1.762 1.355 1.247
%> 5 16 25 75 84 95
0.535 0.944 1.176 2.566 3.13 5.155
% Gravel Sand Silt Clay
0.00 92.83 6.81 0.36

RW51

Frequency %

Cumulative %

RW49_TMsand_16.\$ls

Sn

0 0 0 0.064 3.157 13.27 20.82 19.84 15.05 9.623 5.552 3.542 2.545 1.786 1.207 0.977 0.775 0.573 0.429 0.324 0.238 0.153 0.071 0.014 ###
0 0 0 0.064 3.22 16.49 37.31 57.14 72.19 81.82 87.37 90.91 93.45 95.24 96.45 97.42 98.2 98.77 99.2 99.52 99.76 99.91 99.99 100 100
Mean: Median: Mode: S.D.
1.699 1.809 1.355 1.20
%> 5 16 25 75 84 95
0.604 0.986 1.213 2.621 3.165 4.919
% Gravel Sand Silt Clay
0.00 93.45 6.31 0.24

RW51

Frequency %

Cumulative %

Ruawak_TMSS1_01.\$ls

Sn

0 0 0 1.013 3.963 14.76 22.47 19.45 13.74 8.111 4.349 2.945 1.988 1.653 0.982 1.042 0.918 0.647 0.529 0.471 0.475 0.377 0.126 0.003 0
0.00 0.00 0.00 1.01 4.98 19.73 42.20 61.65 75.38 83.49 87.84 90.79 92.78 94.43 95.41 96.45 97.37 98.02 98.55 99.02 99.50 99.87 ### ###
Mean: Median: Mode: S.D.
1.59 1.69 1.22 1.25
%> 5 16 25 75 84 95
0.501 0.911 1.115 2.482 3.043 5.259
% Gravel Sand Silt Clay
0.00 92.78 6.72 0.50

Ruawaka Section

Class midpoints

Class limits

-1.75 -1.25 -0.75 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 4.75 5.25 5.75 6.25 6.75 7.25 7.75 8.25 8.75 9.25 9.75 10
-2.00 -1.50 -1.00 -0.50 0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00 5.50 6.00 6.50 7.00 7.50 8.00 8.50 9.00 9.50 10

RW51

Frequency %

Cumulative %

Ruawak_TMSS1_02.\$ls

Sn

0 0 0 0.089 3.2 12.91 20.2 19.58 15 9.394 5.442 3.487 2.45 1.75 1.23 1.118 0.98 0.792 0.667 0.578 0.5 0.371 0.203 0.063 0.004

0.00 0.00 0.00 0.09 3.29 16.20 36.39 55.97 70.97 80.36 85.81 89.29 91.74 93.49 94.72 95.84 96.82 97.61 98.28 98.86 99.36 99.73 99.93 ### ###

Mean: Median: Mode: S.D.

1.72 1.84 1.35 1.34

%> 5 16 25 75 84 95

0.603 0.994 1.226 2.683 3.303 5.622

% Gravel Sand Silt Clay

0.00 91.74 7.61 0.64

RW51

Frequency %

Cumulative %

Ruawak_TMS_25.\$ls

Sn

0 0 0 0.623 3.532 13.98 22.99 20.1 14.39 8.428 4.333 2.942 1.923 1.569 0.894 0.958 0.848 0.601 0.498 0.447 0.458 0.366 0.121 0.002 0

0.00 0.00 0.12 0.49 0.95 1.39 1.89 2.49 3.34 4.30 5.19 6.76 8.68 11.63 15.96 24.39 38.77 58.87 81.86 95.85 99.38 ### 100 100 100

Mean: Median: Mode: S.D.

1.62 1.71 1.22 1.20

%> 5 16 25 75 84 95

0.558 0.947 1.152 2.473 2.997 5.081

% Gravel Sand Silt Clay

0.12 8.56 90.69 0.62

RW51

Frequency %

Cumulative %

RUAWAKA TM UNIT 5_32

Sn

0 0 0 0.451 1.655 8.131 18.19 22.44 19.6 11.6 5.372 3.536 2.244 1.746 0.912 0.965 0.835 0.573 0.482 0.434 0.433 0.322 0.083 0 0

0.00 0.00 0.00 0.45 2.11 10.24 28.43 50.86 70.46 82.06 87.44 90.97 93.22 94.96 95.87 96.84 97.67 98.25 98.73 99.16 99.60 99.92 100 100 100

Mean: Median: Mode: S.D.

1.85 1.98 1.89 1.13

%> 5 16 25 75 84 95

0.78 1.177 1.418 2.661 3.138 5.014

% Gravel Sand Silt Clay

0.00 93.22 6.38 0.40

RW51

Frequency %

Cumulative %

Ruawak_TM SS Top_01.\$ls

Sn

0 0 0 0.158 4.153 14.38 21.58 19.71 14.06 8.421 4.647 2.984 2.238 1.71 1.266 1.112 0.939 0.736 0.588 0.475 0.382 0.27 0.199 0 0

0.00 0.00 0.00 0.16 4.31 18.69 40.26 59.97 74.03 82.45 87.10 90.08 92.32 94.03 95.30 96.41 97.35 98.09 98.67 99.15 99.53 99.80 100 100 100

Mean: Median: Mode: S.D.

1.64 1.73 1.35 1.29

%> 5 16 25 75 84 95

0.535 0.927 1.155 2.546 3.137 5.374

% Gravel Sand Silt Clay

0.00 92.32 7.21 0.47

Ruawaka Section

Class midpoints

-1.75 -1.25 -0.75 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 4.75 5.25 5.75 6.25 6.75 7.25 7.75 8.25 8.75 9.25 9.75 10

Class limits

-2.00 -1.50 -1.00 -0.50 0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00 5.50 6.00 6.50 7.00 7.50 8.00 8.50 9.00 9.50 10

RW45

Frequency %

Sw
0 0 0 0 0 0 0 0.819 17.03 33.79 24.09 11.59 5.77 2.755 0.741 0.975 0.796 0.481 0.489 0.405 0.225 0.042 0 0 0

Cumulative %

0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.82 17.85 51.64 75.73 87.32 93.09 95.85 96.59 97.56 98.36 98.84 99.33 99.73 99.96 100 100 100 100

Ruawak_River1_21.\$ls

Mean: Median: Mode: S.D.

2.98 2.98 2.84 0.73

%> 5 16 25 75 84 95

2.213 2.464 2.614 3.477 3.815 4.773

% Gravel Sand Silt Clay

0.00 93.09 6.87 0.04

RW45

Frequency %

Sw
0 0 0 0 0 0 0 0.801 17.29 34.74 23.57 10.07 4.458 2.565 1.009 1.321 1.174 0.835 0.789 0.655 0.504 0.218 0.006 0 0

Cumulative %

0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.80 18.09 52.83 76.40 86.47 90.92 93.49 94.50 95.82 96.99 97.83 98.62 99.27 99.78 99.99 100 100 100

Ruawak_River1_22.\$ls

Mean: Median: Mode: S.D.

2.99 2.96 2.84 0.87

%> 5 16 25 75 84 95

2.211 2.459 2.608 3.453 3.828 5.712

% Gravel Sand Silt Clay

0.00 90.92 8.85 0.22

RW 43

Frequency %

Sp
0 0 0 0 0 0 0 0.022 3.632 21.23 27.97 13.02 5.346 5.059 3.646 4.144 3.965 3.242 2.758 2.371 1.971 1.248 0.366 0.005 0

Cumulative %

0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.02 3.65 24.89 52.86 65.88 71.22 76.28 79.93 84.07 88.04 91.28 94.04 96.41 98.38 99.63 99.99 100 100

Ruawak_River2_23.\$ls

Mean: Median: Mode: S.D.

3.55 3.44 3.1 1.57

%> 5 16 25 75 84 95

2.549 2.837 3.002 4.857 5.991 7.693

% Gravel Sand Silt Clay

0.00 71.22 27.16 1.62

RW 43

Frequency %

Sp
0 0 0 0 0 0 0 0.023 3.729 21.35 27.74 12.96 5.221 4.944 3.691 4.179 4.008 3.295 2.795 2.392 1.981 1.267 0.41 0.013 0

Cumulative %

0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.02 3.75 25.11 52.84 65.81 71.03 75.97 79.66 83.84 87.85 91.14 93.94 96.33 98.31 99.58 99.99 100 100

Ruawak_River2_24.\$ls

Mean: Median: Mode: S.D.

3.55 3.44 3.1 1.58

%> 5 16 25 75 84 95

2.544 2.833 2.998 4.889 6.018 7.712

% Gravel Sand Silt Clay

0.00 71.03 27.29 1.69

Ruawaka Section

Class midpoints

-1.75 -1.25 -0.75 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 4.75 5.25 5.75 6.25 6.75 7.25 7.75 8.25 8.75 9.25 9.75 10

Class limits

-2.00 -1.50 -1.00 -0.50 0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00 5.50 6.00 6.50 7.00 7.50 8.00 8.50 9.00 9.50 10

RW 41

Sd

Frequency %

0 0 0 0 0.013 1.194 0.761 8.85 40.96 36.37 6.984 1.99 0.864 0.529 0.315 0.271 0.275 0.211 0.176 0.134 0.079 0.024 ### 0 0

Cumulative %

0 0 0 0 0.013 1.208 1.969 10.82 51.78 88.15 95.13 97.12 97.99 98.51 98.83 99.1 99.38 99.59 99.76 99.9 99.98 100 100 100 100

RW40_3 or Ab_12.\$ls

Mean: Median: Mode: S.D.

2.432 2.481 2.432 0.45

%> 5 16 25 75 84 95

1.848 2.096 2.215 2.761 2.902 3.464

% Gravel Sand Silt Clay

0.00 97.99 1.99 0.02

RW 40

Sw

Frequency %

0 0 0 0 0 0 0 0.319 18.58 36.9 20.27 10.07 4.34 2.438 1.063 1.369 1.229 0.91 0.859 0.725 0.603 0.31 0.013 0 0

Cumulative %

0 0 0 0 0 0 0.319 18.9 55.8 76.07 86.14 90.48 92.92 93.98 95.35 96.58 97.49 98.35 99.07 99.68 99.99 100 100 100

RW39_4 or Aa_13.\$ls

Mean: Median: Mode: S.D.

2.977 2.911 2.701 0.90

%> 5 16 25 75 84 95

2.247 2.453 2.581 3.461 3.853 5.882

% Gravel Sand Silt Clay

0.00 90.48 9.20 0.32

RW 37

Sd

Frequency %

0 0 0.293 0.481 0.564 3.917 3.83 1.746 8.566 21.74 31.7 13.26 4.021 2.577 1.225 1.608 1.279 0.855 0.829 0.69 0.566 0.254 0.005 0 0

Cumulative %

0 0 0.293 0.773 1.337 5.254 9.084 10.83 19.4 41.13 72.83 86.09 90.11 92.69 93.92 95.52 96.8 97.66 98.49 99.18 99.74 100 100 100 100

RW36_X above sh_11.\$ls

Mean: Median: Mode: S.D.

2.664 3.128 3.104 1.12

%> 5 16 25 75 84 95

0.979 2.332 2.685 3.547 3.848 5.842

% Gravel Sand Silt Clay

0.29 89.82 9.63 0.26

RW 37

Sd

Frequency %

0 0 0.165 1.585 2.11 4.742 4.26 2.405 8.672 21.55 30.24 12.32 3.694 2.34 1.062 1.402 1.092 0.69 0.68 0.549 0.349 0.094 ### 0 0

Cumulative %

0 0 0.165 1.749 3.859 8.601 12.86 15.27 23.94 45.49 75.73 88.05 91.74 94.08 95.14 96.55 97.64 98.33 99.01 99.56 99.91 100 100 100 100

RW36_X above sh_10.\$ls

Mean: Median: Mode: S.D.

2.424 3.07 3.104 1.13

%> 5 16 25 75 84 95

0.748 2.058 2.538 3.484 3.745 5.439

% Gravel Sand Silt Clay

0.16 91.58 8.16 0.09

Ruawaka Section

Class midpoints

Class limits

-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10

RW 30

Frequency %

Cumulative %

RW_S_03.\$ls

Sw

0	0	0	0	0.01	1.936	1.225	1.316	20.61	39.84	21.1	6.816	2.94	1.631	0.614	0.601	0.49	0.307	0.295	0.209	0.061	0.001	0	0	0
0	0	0	0	0.01	1.946	3.171	4.488	25.1	64.94	86.03	92.85	95.79	97.42	98.04	98.64	99.13	99.43	99.73	99.94	100	100	100	100	100
Mean:	Median:	Mode:	S.D.																					
2.716	2.808	2.701	0.61																					
%>	5	16	25	75	84	95																		
	2.032	2.354	2.499	3.166	3.412	4.331																		
								%	Gravel	Sand	Silt	Clay												
									0.00	95.79	4.21	0.00

RW 30

Frequency %

Cumulative %

RW29_S_04.\$ls

Sw

0	0	0.535	1.586	0.928	3.491	2.111	1.29	19.72	38.07	19.81	6.21	2.562	1.414	0.52	0.526	0.435	0.277	0.268	0.192	0.059	0.001	0	0	0
0	0	0.535	2.121	3.048	6.539	8.65	9.94	29.66	67.73	87.54	93.75	96.31	97.72	98.24	98.77	99.2	99.48	99.75	99.94	100	100	100	100	100
Mean:	Median:	Mode:	S.D.																					
2.364	2.765	2.701	0.78																					
%>	5	16	25	75	84	95																		
	0.856	2.243	2.422	3.123	3.348	4.199																		
								%	Gravel	Sand	Silt	Clay												
									0.53	95.77	3.69	0.00

RW 26

Frequency %

Cumulative %

RW25_O lam_09.\$ls

Sd

0	0	0.367	1.662	1.349	3.887	2.112	1.474	17.61	35.32	24.28	6.461	1.664	1.143	0.447	0.599	0.514	0.351	0.341	0.27	0.127	0.017	0	0	0
0	0	0.367	2.03	3.378	7.266	9.377	10.85	28.47	63.78	88.07	94.53	96.19	97.33	97.78	98.38	98.89	99.25	99.59	99.86	99.98	100	100	100	100
Mean:	Median:	Mode:	S.D.																					
2.358	2.813	2.835	0.79																					
%>	5	16	25	75	84	95																		
	0.791	2.224	2.431	3.173	3.369	4.11																		
								%	Gravel	Sand	Silt	Clay												
									0.37	95.82	3.79	0.02

RW 26

Frequency %

Cumulative %

RW25_O lam_08.\$ls

Sd

0	0	1.667	2.525	1.564	3.76	2.055	1.866	17.59	33.95	23.29	6.167	1.698	1.149	0.459	0.581	0.52	0.359	0.337	0.277	0.155	0.031	0	0	0
0	0	1.667	4.192	5.756	9.516	11.57	13.44	31.03	64.98	88.27	94.43	96.13	97.28	97.74	98.32	98.84	99.2	99.54	99.81	99.97	100	100	100	100
Mean:	Median:	Mode:	S.D.																					
2.1	2.786	2.835	0.93																					
%>	5	16	25	75	84	95																		
	0.068	2.112	2.373	3.158	3.356	4.129																		
								%	Gravel	Sand	Silt	Clay												
									1.67	94.46	3.84	0.03

Ruawaka Section

Class midpoints

Class limits

-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10

RW 25

Frequency %

Cumulative %

RW24_Ntop_07.\$ls

Sp

0	0	0	0	0	0	0	0.011	5.478	30.83	42.05	14.53	2.824	1.535	0.342	0.768	0.579	0.387	0.392	0.237	0.031	0	0	0	0
0	0	0	0	0	0	0	0.011	5.489	36.32	78.37	92.91	95.73	97.27	97.61	98.37	98.95	99.34	99.73	99.97	100	100	100	100	100
Mean:	Median:	Mode:	S.D.																					
3.131	3.147	3.104	0.50																					
%>	5	16	25	75	84	95					%	Gravel	Sand	Silt	Clay									
	2.479	2.734	2.866	3.443	3.609	4.363						0.00	95.73	4.27	0.00

RW 24

Frequency %

Cumulative %

RW24_Nmidbase_06.\$ls

Sd

0	0	0.084	0.339	0.378	2.454	2.337	1.737	7.187	19.54	25.83	14.13	6.405	4.661	2.805	2.704	2.495	2.046	1.723	1.419	1.048	0.567	0.118	###	0
0	0	0.084	0.423	0.801	3.255	5.592	7.329	14.52	34.06	59.88	74.01	80.41	85.08	87.88	90.59	93.08	95.13	96.85	98.27	99.31	99.88	100	100	100
Mean:	Median:	Mode:	S.D.																					
2.984	3.295	3.104	1.44																					
%>	5	16	25	75	84	95					%	Gravel	Sand	Silt	Clay									
	1.296	2.552	2.811	4.064	4.86	6.967						0.08	80.33	18.90	0.69

RW 24

Frequency %

Cumulative %

RW24_Nmidbase_05.\$ls

Sd

0	0	0	0	0	0	0	0.313	5.971	21.62	29.12	16.9	7.924	5.158	2.856	2.542	2.271	1.794	1.416	1.066	0.698	0.314	0.04	0	0
0	0	0	0	0	0	0	0.313	6.284	27.91	57.02	73.92	81.85	87	89.86	92.4	94.67	96.47	97.88	98.95	99.65	99.96	100	100	100
Mean:	Median:	Mode:	S.D.																					
3.378	3.368	3.104	1.10																					
%>	5	16	25	75	84	95					%	Gravel	Sand	Silt	Clay									
	2.438	2.775	2.949	4.055	4.677	6.583						0.00	81.85	17.80	0.35

RW 18

Frequency %

Cumulative %

Penin_GB-1_42

Sd

0	0	0	0	0	0	0	0.057	2.64	11.77	23.13	19.62	9.054	5.397	4.125	5.107	5.058	4.125	3.422	2.813	2.188	1.255	0.239	###	0
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	2.70	14.47	37.60	57.22	66.27	71.67	75.79	80.90	85.96	90.08	93.50	96.32	98.51	99.76	100	100	100
Mean:	Median:	Mode:	S.D.																					
3.8	3.78	3.37	1.59																					
%>	5	16	25	75	84	95					%	Gravel	Sand	Silt	Clay									
	2.649	3.044	3.246	5.408	6.295	7.752						0.00	66.27	32.23	1.49

Ruawaka Section

Class midpoints

Class limits

-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10

RW 18

Frequency %

Cumulative %

Penin_GB-1_43

Sd

0	0	0	0	0	0	0	0.353	4.367	14.51	26.43	20.57	8.875	4.779	3.223	3.726	3.497	2.79	2.32	1.943	1.516	0.89	0.216	0.001	0
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	4.72	19.23	45.66	66.22	75.10	79.88	83.10	86.83	90.32	93.11	95.43	97.38	98.89	99.78	100	100	100
Mean:	Median:			Mode:			S.D.																	
3.58	3.58			3.37			1.42																	
%>	5	16	25	75	84	95				%	Gravel	Sand	Silt	Clay										
	2.514	2.923	3.122	4.492	5.629	7.4					0.00	75.10	23.79	1.11										

Grain Size	Percentage (%)
Gravel	0.00
Sand	75.10
Silt	23.79
Clay	1.11

RW 18

Frequency %

Cumulative %

Penin_underGSB1_32.\$ls

Sd

0	0	0	0	0	0	0	0.017	2.405	11.98	17.66	16.54	18.37	15.78	6.517	3.367	2.476	1.601	1.117	0.873	0.696	0.446	0.155	0.007	0
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	2.42	14.41	32.06	48.61	66.97	82.75	89.26	92.63	95.11	96.71	97.82	98.70	99.39	99.84	99.99	100	100
Mean:	Median:			Mode:			S.D.																	
3.8	4.04			4.45			1.08																	
%>	5	16	25	75	84	95				%	Gravel	Sand	Silt	Clay										
	2.652	3.049	3.303	4.72	5.06	6.474					0.00	66.97	32.42	0.61										

Grain Size	Percentage (%)
Gravel	0.00
Sand	66.97
Silt	32.42
Clay	0.61

RW 18

Frequency %

Cumulative %

GSB1_33.\$ls

Sd

0	0	0	0	0	0	0	0.017	2.491	12.82	18.89	16.83	17.56	15.03	6.218	3.214	2.348	1.505	1.048	0.821	0.652	0.411	0.134	0	0
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	2.51	15.33	34.22	51.05	68.61	83.64	89.86	93.08	95.42	96.93	97.98	98.80	99.45	99.86	100	100	100
Mean:	Median:			Mode:			S.D.																	
3.76	3.97			3.24			1.07																	
%>	5	16	25	75	84	95				%	Gravel	Sand	Silt	Clay										
	2.642	3.02	3.258	4.681	5.017	6.392					0.00	68.61	30.84	0.55

RW 18

Frequency %

Cumulative %

Penin_clay_36.\$ls

V

0	0	0	0.752	1.349	3.96	4.775	4.801	8.385	9.293	7.368	5.217	3.385	3.758	3.258	3.853	4.336	4.048	4.101	5.062	6.419	6.598	4.768	2.578	1.936
0.00	0.00	0.00	0.75	2.10	6.06	10.83	15.64	24.02	33.31	40.68	45.90	49.28	53.04	56.30	60.15	64.49	68.53	72.63	77.70	84.12	90.71	95.48	98.06	100
Mean:	Median:		Mode:		S.D.																			
2.98	4.6		2.57		2.91																			
%>	5	16	25	75	84	95	% Gravel		Sand	Silt	Clay													
	0.901	2.026	2.549	7.751	8.491	9.436	0.00		49.28	34.83	15.88													

A pie chart illustrating the soil composition. The chart is divided into four segments: Gravel (0.00%), Sand (49.28%), Silt (34.83%), and Clay (15.88%). The segments are labeled with their respective percentages and soil types. The chart is set against a background of horizontal lines.

Soil Type	Percentage (%)
Gravel	0.00
Sand	49.28
Silt	34.83
Clay	15.88

Ruawaka Section

Class midpoints

Class limits

-1.75 -1.25 -0.75 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 4.75 5.25 5.75 6.25 6.75 7.25 7.75 8.25 8.75 9.25 9.75 10
-2.00 -1.50 -1.00 -0.50 0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00 5.50 6.00 6.50 7.00 7.50 8.00 8.50 9.00 9.50 10

RW 18

Frequency %

Cumulative %

Penin_clay_37

V

0 0 0 0.578 1.787 4.405 5.099 4.701 8.386 8.82 7.206 4.868 3.667 4.179 3.782 4.418 4.928 4.41 4.212 4.925 6.056 6.087 4.272 2.107 1.106
0.00 0.00 0.00 0.58 2.36 6.77 11.87 16.57 24.96 33.78 40.98 45.85 49.52 53.70 57.48 61.90 66.82 71.23 75.45 80.37 86.43 92.51 96.79 98.89 100
Mean: Median: Mode: S.D.
2.92 4.56 2.43 2.86
%> 5 16 25 75 84 95
0.844 1.96 2.502 7.449 8.309 9.257
% Gravel Sand Silt Clay
0.00 49.52 36.91 13.57

RW 14

Frequency %

Cumulative %

Penin_underGSB3_34.\$ls

Sp

0 0 0 0 0 0 0 0.047 3.346 20.86 31.07 14.83 5.462 4.937 3.257 3.464 3.109 2.414 2.044 1.847 1.63 1.157 0.483 0.042 ###
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.05 3.39 24.25 55.33 70.15 75.62 80.55 83.81 87.27 90.38 92.80 94.84 96.69 98.32 99.47 99.96 100 100
Mean: Median: Mode: S.D.
3.5 3.4 3.1 1.42
%> 5 16 25 75 84 95
2.564 2.855 3.013 4.44 5.529 7.541
% Gravel Sand Silt Clay
0.00 75.62 22.70 1.68

RW 14

Frequency %

Cumulative %

Penin_underGSB3_35.\$ls

Sp

0 0 0.078 0.319 0.424 1.133 0.47 0.05 3.564 22.13 32.73 15.45 4.768 4.036 2.759 2.781 2.434 1.888 1.56 1.339 1.093 0.709 0.259 0.014 0
0.00 0.00 0.08 0.40 0.82 1.95 2.42 2.47 6.04 28.17 60.90 76.36 81.12 85.16 87.92 90.70 93.14 95.02 96.59 97.92 99.02 99.73 99.99 100 100
Mean: Median: Mode: S.D.
3.2 3.32 3.1 1.20
%> 5 16 25 75 84 95
2.431 2.79 2.95 3.917 4.838 6.993
% Gravel Sand Silt Clay
0.08 81.05 17.89 0.98

RW 9

Frequency %

Cumulative %

Sample_Xeno_40.\$ls

SBal

0 0 1.106 2.692 4.105 5.74 4.352 7.106 17.81 18.2 9.898 6.665 6.419 4.965 2.916 2.184 1.724 1.3 1.049 0.838 0.592 0.294 0.05 ### 0
0 0 1.106 3.798 7.903 13.64 17.99 25.1 42.91 61.11 71 77.67 84.09 89.05 91.97 94.15 95.88 97.18 98.23 99.06 99.66 99.95 100 100 100
Mean: Median: Mode: S.D.
2.01 2.67 2.43 1.74
%> 5 16 25 75 84 95
0.132 1.211 1.989 3.79 4.489 6.223
% Gravel Sand Silt Clay
1.11 82.98 15.57 0.34

Ruawaka Section

Class midpoints

-1.75 -1.25 -0.75 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 4.75 5.25 5.75 6.25 6.75 7.25 7.75 8.25 8.75 9.25 9.75 10

Class limits

-2.00 -1.50 -1.00 -0.50 0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00 5.50 6.00 6.50 7.00 7.50 8.00 8.50 9.00 9.50 10

RW 9

SBal

Frequency %

0 0 1.249 2.993 3.786 5.429 4.588 7.545 18.74 18.11 8.565 4.94 4.967 4.7 3.322 2.754 2.252 1.735 1.459 1.243 0.963 0.545 0.118 ### 0

Cumulative %

0 0 1.249 4.241 8.028 13.46 18.04 25.59 44.33 62.44 71 75.94 80.91 85.61 88.93 91.68 93.94 95.67 97.13 98.37 99.34 99.88 100 100 100

Sample_Xeno_41.\$ls

Mean: Median: Mode: S.D.

1.995 2.63 2.432 1.92

%> 5 16 25 75 84 95

0.07 1.22 1.972 3.893 4.809 6.79

% Gravel Sand Silt Clay

1.25 79.66 18.43 0.66

RW 8

Sp

Frequency %

0 0 0 0 0.046 1.362 2.107 11.66 27.65 21.03 7.675 4.354 4.159 4.095 3.675 3.408 2.825 2.106 1.565 1.126 0.734 0.357 0.066 ### 0

Cumulative %

0.00 0.00 0.00 0.00 0.05 1.41 3.51 15.17 42.82 63.86 71.53 75.88 80.04 84.14 87.81 91.22 94.05 96.15 97.72 98.84 99.58 99.93 100 100 100

Xeno2__38.\$ls

Mean: Median: Mode: S.D.

2.66 2.63 2.3 1.51

%> 5 16 25 75 84 95

1.64 2.018 2.195 3.895 4.982 6.708

% Gravel Sand Silt Clay

0.00 80.04 19.53 0.42

RW 8

Sp

Frequency %

0 0 0.035 0.186 0.539 2.743 5.481 15.59 28.32 19.75 6.326 3.27 3.00 2.658 2.262 2.186 1.985 1.64 1.358 1.108 0.845 0.523 0.194 0.012 0

Cumulative %

0.00 0.00 0.04 0.22 0.76 3.50 8.98 24.57 52.89 72.64 78.96 82.23 85.23 87.89 90.15 92.34 94.32 95.96 97.32 98.43 99.27 99.79 99.99 100 100

Xeno2__39

Mean: Median: Mode: S.D.

2.37 2.45 2.3 1.46

%> 5 16 25 75 84 95

1.171 1.792 2.008 3.123 4.286 6.696

% Gravel Sand Silt Clay

0.04 85.19 14.04 0.73

RW 7

Sw

Frequency %

0 0 0 0 0 0 0 1.703 25.35 38.91 16.31 5.757 2.682 2.245 1.23 1.379 1.248 0.887 0.795 0.678 0.55 0.273 0.011 0 0

Cumulative %

0.00 0.00 0.00 0.00 0.00 0.00 0.00 1.70 27.05 65.96 82.26 88.02 90.70 92.95 94.18 95.56 96.81 97.69 98.49 99.17 99.72 99.99 100 100 100

Ruawak_BelowXeno_20.\$ls

Mean: Median: Mode: S.D.

2.84 2.78 2.7 0.88

%> 5 16 25 75 84 95

2.126 2.345 2.471 3.19 3.619 5.811

% Gravel Sand Silt Clay

0.00 90.70 9.01 0.28

Ruawaka Section

Class midpoints

Class limits

-1.75 -1.25 -0.75 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 4.75 5.25 5.75 6.25 6.75 7.25 7.75 8.25 8.75 9.25 9.75 10
-2.00 -1.50 -1.00 -0.50 0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00 5.50 6.00 6.50 7.00 7.50 8.00 8.50 9.00 9.50 10

RW 7

Frequency %

Cumulative %

Ruawak_BelowXeno_21.\$ls

Sw

0 0 0 0 0 0 0 1.235 23.65 37.71 16.29 6.119 3.215 2.78 1.579 1.726 1.584 1.138 1.02 0.842 0.72 0.379 0.016 0 0
0.00 0.00 0.00 0.00 0.00 0.00 0.00 1.23 24.89 62.60 78.88 85.00 88.22 91.00 92.58 94.30 95.89 97.02 98.04 98.89 99.61 99.98 100 100 100
Mean: Median: Mode: S.D.
2.9 2.82 2.7 0.99
%> 5 16 25 75 84 95
2.151 2.373 2.501 3.3 3.894 6.197
% Gravel Sand Silt Clay
0.00 88.22 11.39 0.39

RW 4 Top

Frequency %

Cumulative %

Ruawak_Smple3_29.\$ls

Sd

0 0 0 0 0.046 4.486 6.904 6.05 12.78 27.13 27.71 9.912 2.381 1.055 0.202 0.437 0.344 0.233 0.213 0.105 0.006 0 0 0 0
0.00 0.00 0.00 0.00 0.05 4.53 11.44 17.49 30.27 57.40 85.11 95.02 97.40 98.46 98.66 99.10 99.44 99.68 99.89 99.99 100 100 100 100
Mean: Median: Mode: S.D.
2.49 2.89 2.97 0.84
%> 5 16 25 75 84 95
1.029 1.908 2.334 3.28 3.47 3.997
% Gravel Sand Silt Clay
0.00 97.40 2.60 0.00

RW 4 Top

Frequency %

Cumulative %

Ruawak_Smple3_30.\$ls

Sd

0 0 0.005 0.616 0.445 4.319 5.526 3.975 11.89 29.01 28.99 10.08 2.524 1.092 0.214 0.431 0.349 0.24 0.203 0.088 0.003 0 0 0 0
0.00 0.00 0.00 0.62 1.07 5.38 10.91 14.88 26.77 55.78 84.77 94.85 97.38 98.47 98.69 99.12 99.47 99.71 99.91 100 100 100 100
Mean: Median: Mode: S.D.
2.48 2.92 2.97 0.81
%> 5 16 25 75 84 95
0.973 2.077 2.445 3.291 3.479 4.02
% Gravel Sand Silt Clay
0.00 97.37 2.62 0.00

RW 4 Top

Frequency %

Cumulative %

Ruawak_Smple3_31.\$ls

Sd

0 0 0 0 0.005 2.856 3.695 2.561 11.66 30.02 31.99 11.64 2.835 1.223 0.216 0.458 0.378 0.252 0.168 0.044 ### 0 0 0 0
0.00 0.00 0.00 0.00 0.00 2.86 6.56 9.12 20.78 50.80 82.78 94.43 97.26 98.48 98.70 99.16 99.54 99.79 99.96 100 100 100 100
Mean: Median: Mode: S.D.
2.71 2.99 2.97 0.73
%> 5 16 25 75 84 95
1.199 2.355 2.594 3.346 3.529 4.073
% Gravel Sand Silt Clay
0.00 97.26 2.74 0.00

Ruawaka Section

Class midpoints

Class limits

-1.75 -1.25 -0.75 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 4.75 5.25 5.75 6.25 6.75 7.25 7.75 8.25 8.75 9.25 9.75 10
-2.00 -1.50 -1.00 -0.50 0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00 5.50 6.00 6.50 7.00 7.50 8.00 8.50 9.00 9.50 10

RW 4 Centre

Frequency %

Cumulative %

Ruawak_Smple2_27.\$ls

Sd

0 0 0 0 0 0 0 0.184 8.233 26.87 30.43 12.47 5.621 4.342 2.044 2.428 2.148 1.491 1.41 1.094 0.858 0.379 0.004 0 0
0 0 0 0 0 0 0 0.184 8.417 35.29 65.72 78.18 83.8 88.14 90.19 92.62 94.76 96.25 97.66 98.76 99.62 100 100 100 100
Mean: Median: Mode: S.D.
3.26 3.21 3.10 1.09
%> 5 16 25 75 84 95
2.373 2.69 2.851 3.808 4.518 6.572
% Gravel Sand Silt Clay
0.00 83.80 15.81 0.38

RW 4 Centre

Frequency %

Cumulative %

Ruawak_Smple2_28.\$ls

Sd

0 0 0 0 0 0 0 0.236 8.885 27.96 30.69 12.26 5.512 4.249 1.891 2.187 1.901 1.253 1.186 0.915 0.644 0.227 ### 0 0
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.24 9.12 37.08 67.77 80.03 85.55 89.79 91.68 93.87 95.77 97.03 98.21 99.13 99.77 100 100 100 100
Mean: Median: Mode: S.D.
3.22 3.18 2.97 1.02
%> 5 16 25 75 84 95
2.351 2.667 2.827 3.721 4.363 6.265
% Gravel Sand Silt Clay
0.00 85.55 14.23 0.23

RW 2

Frequency %

Cumulative %

Ruawak_Unit1sand_19.\$ls

Sp

0 0 0 0 0 0 0 0 1.89 16.62 37.78 23.26 7.121 3.523 1.678 2.323 1.741 1.156 1.133 0.896 0.643 0.233 0 0 0
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 1.89 18.51 56.29 79.55 86.67 90.20 91.87 94.20 95.94 97.09 98.23 99.12 99.77 100 100 100 100
Mean: Median: Mode: S.D.
3.45 3.42 3.37 0.87
%> 5 16 25 75 84 95
2.659 2.954 3.099 3.832 4.295 6.198
% Gravel Sand Silt Clay
0.00 86.67 13.09 0.23

RW 2

Frequency %

Cumulative %

Ruawak_Unit1sand_18.\$ls

Sp

0 0 0 0 0 0 0 0 1.271 17.2 38.09 24.09 8.084 3.845 1.424 1.879 2.107 0.813 0.662 0.424 0.109 ### ### 0 0
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 1.27 18.47 56.56 80.65 88.74 92.58 94.01 95.88 97.99 98.80 99.47 99.89 100 100 100 100
Mean: Median: Mode: S.D.
3.43 3.41 3.37 0.77
%> 5 16 25 75 84 95
2.682 2.956 3.098 3.816 4.18 5.768
% Gravel Sand Silt Clay
0.00 88.74 11.26 0.00

Ruakokopatuna Bridge Section

Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
Class limits	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10

RK 13 Top

Frequency %	0	0	0	0	0	0	###	1.013	6.328	6.77	6.937	9.299	9.931	10.86	7.68	8.153	8.063	6.227	5.228	4.634	4.453	3.437	0.971	0.01	0
Cumulative %	0	0	0	0	0	0	###	1.014	7.342	14.11	21.05	30.35	40.28	51.14	58.82	66.98	75.04	81.27	86.49	91.13	95.58	99.02	99.99	100	100
Ruakok_Unit12abov_07.\$ls	Mean:	Median:	Mode:	S.D.																					
	4.17	4.94	4.72	1.946																					
%>	5	16	25	75	84	95		%	Grave	Sand	Silt	Clay													
	2.349	3.16	3.718	6.497	7.254	8.435			0	40.28	55.3	4.418

RK 13 Top

Frequency %	0	0	0	0	0	0	0.001	0.998	5.267	6.237	6.944	8.341	10.53	10.53	8.013	7.869	7.618	6.046	5.068	4.804	4.715	4.011	2.309	0.672	0.036
Cumulative %	0	0	0	0	0	0	0.001	0.999	6.266	12.5	19.45	27.79	38.31	48.84	56.85	64.72	72.34	78.39	83.45	88.26	92.97	96.98	99.29	99.96	100
Ruakok_Unit12abov_08.\$ls	Mean:	Median:	Mode:	S.D.																					
	4.27	5.06	4.58	2.034																					
%>	5	16	25	75	84	95		%	Grave	Sand	Silt	Clay													
	2.397	3.259	3.849	6.706	7.556	8.734			0	38.31	54.66	7.028

RK 13 Top

Frequency %	0	0	0	0	0	0	0	0.124	2.294	3.759	5.201	7.024	9.225	11.2	9.259	9.69	9.423	7.786	6.659	6.117	5.641	4.358	2.014	0.23	###
Cumulative %	0	0	0	0	0	0	0	0.124	2.418	6.176	11.38	18.4	27.63	38.82	48.08	57.77	67.19	74.98	81.64	87.76	93.4	97.76	99.77	100	100
Ruakok_Unit12abov_09.\$ls	Mean:	Median:	Mode:	S.D.																					
	4.74	5.61	4.72	1.844																					
%>	5	16	25	75	84	95		%	Grave	Sand	Silt	Clay													
	2.843	3.838	4.377	7.002	7.689	8.661			0	27.63	65.77	6.602

RK 13 Top

Frequency %	0	0	0	0	0	0	0	0.07	1.999	4.726	6.873	9.637	11.4	11.07	8.052	8.007	7.998	6.72	5.942	5.664	5.398	4.259	1.971	0.219	###
Cumulative %	0	0	0	0	0	0	0	0.07	2.068	6.794	13.67	23.3	34.7	45.77	53.82	61.83	69.83	76.55	82.49	88.15	93.55	97.81	99.78	100	100
Ruakok_Unit12abov_10.\$ls	Mean:	Median:	Mode:	S.D.																					
	4.58	5.24	4.45	1.881																					
%>	5	16	25	75	84	95		%	Grave	Sand	Silt	Clay													
	2.829	3.634	4.077	6.878	7.632	8.649			0	34.7	58.85	6.448

Ruakokopatuna Bridge Section

Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
Class limits	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10

RK 13 Top

Frequency %	0	0	0	0	0	0	0.034	1.518	3.573	5.38	9.321	11.39	11.58	8.065	8.15	8.302	7.058	6.34	6.132	5.928	4.742	2.227	0.254	###
Cumulative %	0	0	0	0	0	0	0.034	1.553	5.125	10.51	19.83	31.22	42.8	50.87	59.02	67.32	74.38	80.72	86.85	92.78	97.52	99.75	100	100
Ruakok_Unit12abov_11.\$ls	Mean:	Median:	Mode:	S.D.
	4.73	5.44	4.58	1.857																				
%>	5	16	25	75	84	95	%	Grave	Sand	Silt	Clay													
	2.983	3.812	4.237	7.049	7.767	8.71		0	31.22	61.56	7.224

RK 13 Top

Frequency %	0	0	0	0	0	0	0	0.132	4.084	9.958	13.63	15.15	13.74	10.54	5.898	5.574	5.055	3.789	3.154	2.964	2.816	2.241	1.105	0.175	###
Cumulative %	0	0	0	0	0	0	0	0.132	4.216	14.17	27.8	42.95	56.69	67.23	73.13	78.7	83.76	87.55	90.7	93.66	96.48	98.72	99.82	100	100
Ruakok_Unit12abov_12.\$ls	Mean:	Median:	Mode:	S.D.																					
	3.96	4.25	3.64	1.725																					
%>	5	16	25	75	84	95																			
	2.544	3.076	3.407	5.675	6.528	8.234																			

Grain Size	Percentage (%)
Gravel	0
Sand	45
Silt	50
Clay	5

RK 13 Centre

Frequency %	0	0	0	0	0	###	0.903	6.772	9.479	10.92	12.85	13.46	11.66	7.143	6.225	5.295	3.812	3.087	2.839	2.623	1.983	0.868	0.085	###
Cumulative %	0	0	0	0	0	###	0.903	7.675	17.15	28.07	40.92	54.38	66.04	73.18	79.41	84.7	88.52	91.6	94.44	97.06	99.05	99.92	100	100
RuaK_BRB12lam_17.\$ls	Mean:	Median:	Mode:	S.D.																				
	3.89	4.34	4.32	1.743																				
%>	5	16	25	75	84	95	%	Grave	Sand	Silt	Clay													
	2.346	2.94	3.371	5.647	6.422	8.104		0	54.38	42.69	2.935

RK 13 Centre

Frequency %	0	0	0	0	0	###	0.955	6.8	9.566	11.28	12.86	13.17	11.25	6.808	5.96	5.184	3.846	3.188	2.984	2.804	2.184	1.032	0.127	###
Cumulative %	0	0	0	0	0	###	0.955	7.755	17.32	28.6	41.46	54.63	65.88	72.69	78.65	83.83	87.68	90.87	93.85	96.66	98.84	99.87	100	100
RuaK_BRB12lam_18.\$ls	Mean:	Median:	Mode:	S.D.																				
	3.88	4.32	4.32	1.784																				
%>	5	16	25	75	84	95	%	Grave	Sand	Silt	Clay													
	2.34	2.933	3.352	5.696	6.519	8.2		0	54.63	42.03	3.344

Ruakokopatuna Bridge Section																									
Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
Class limits	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10

Frequency %	0	0	0	0	0	0	0	0.358	4.422	7.82	8.998	12.15	14	13.01	9.055	7.948	6.53	4.387	3.257	2.825	2.585	1.914	0.716	0.032	0
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Ruakok_Unit12lami_05.\$ls	Mean:	Median:	Mode:	S.D.

%>	5	16	25	75	84	95	%	Grave	Sand	Silt	Clay
	2.514	3.205	3.654	5.825	6.473	8.048		0	47.75	49.59	2.661

RK 13 Centre	Ms																								
Frequency %	0	0	0	0	0	0	0	0.386	5.325	9.555	8.877	9.291	9.784	7.497	4.588	4.673	6.299	6.401	6.299	6.392	6.733	5.619	2.186	0.094	0
Cumulative %	0	0	0	0	0	0	0	0.386	5.712	15.27	24.14	33.43	43.22	50.72	55.3	59.98	66.28	72.68	78.98	85.37	92.1	97.72	99.91	100	100

Cumulative %	0	0	0	0	0	0	0	0.386	5.712	15.27	24.14	33.43	43.22	50.72	55.3	59.98	66.28	72.68	78.98	85.37	92.1	97.72	99.91	100	100
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4.18	4.94	4.05	2.165
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2.454	3.04	3.551	7.185	7.896	8.731	0	43.22	48.88	7.899
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RK 13 Lower	Ms																								
Frequency %	0	0	0	0	0	0	####	1.08	9.117	15.4	15.95	14	11.69	8.827	4.936	4.314	3.642	2.57	2.087	1.979	1.903	1.539	0.801	0.159	0.001
Cumulative %	0	0	0	0	0	0	####	1.081	10.2	25.6	41.55	55.55	67.24	76.07	81	85.32	88.96	91.53	93.62	95.6	97.5	99.04	99.84	100	100

Cumulative %	0	0	0	0	0	0	###	1.081	10.2	25.6	41.55	55.55	67.24	76.07	81	85.32	88.96	91.53	93.62	95.6	97.5	99.04	99.84	100	100
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	3.56	3.79	3.1	1.632
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2.278	2.696	2.981	4.921	5.848	7.849	0	67.24	30.26	2.5	
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RK 13 Lower	Ms																								
Frequency %	0	0	0	0	0	0	###	1.043	8.716	13.81	13.64	12.23	10.54	8.54	5.032	4.738	4.281	3.182	2.769	2.851	2.994	2.733	1.826	0.822	0.248
Cumulative %	0	0	0	0	0	0	###	1.044	9.76	23.57	37.21	49.44	59.98	68.52	<u>73.56</u>	78.29	82.57	85.76	88.53	91.38	<u>94.37</u>	97.1	98.93	99.75	100

Cumulative %	0	0	0	0	0	0	####	1.044	9.76	23.57	37.21	49.44	59.98	68.52	<u>73.56</u>	78.29	<u>82.57</u>	85.76	88.53	<u>91.38</u>	<u>94.37</u>	97.1	98.93	99.75	100
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	3.69	4.02	2.84	1.953	
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2.287	2.729	3.052	5.66	6.709	8.608	0	59.98	34.39	5.629
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Ruakokopatuna Bridge Section

Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
Class limits	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10

RK 10

Sw

Frequency %	0	0	0	0	0	0	0	2.239	28.95	42.05	17.69	4.542	1.141	0.777	0.341	0.436	0.455	0.354	0.329	0.306	0.25	0.132	0.014	0	0
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Cumulative %	0	0	0	0	0	0	0	2.239	31.19	73.24	90.92	95.46	96.6	97.38	97.72	98.16	98.61	98.97	99.3	99.6	99.85	99.99	100	100	100
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Ruakok_Unit9-top_16.\$ls

Mean: Median: Mode: S.D.

2.71	2.71	2.7	0.503
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%>	5	16	25	75	84	95	%	Grave Sand	Silt	Clay
	2.101	2.302	2.423	3.027	3.216	3.911		0	96.6	3.249 0.146

RK 10

Sw

Frequency %	0	0	0	0	0	0	0	2.069	28.85	42.48	17.75	4.459	1.066	0.743	0.306	0.417	0.446	0.351	0.328	0.309	0.261	0.148	0.021	0	0
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Cumulative %	0	0	0	0	0	0	0	2.069	30.92	73.4	91.15	95.6	96.67	97.41	97.72	98.14	98.58	98.93	99.26	99.57	99.83	99.98	100	100	100
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Ruakok_Unit9-top_17.\$ls

Mean: Median: Mode: S.D.

2.71	2.71	2.7	0.495
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%>	5	16	25	75	84	95	%	Grave Sand	Silt	Clay	
	2.107	2.308	2.427	3.024	3.21	3.882		0	96.67	3.161	0.169

RK 9 Top

Sd

Frequency %	0	0	0	0	0	0	0	0.499	13.2	29.36	22.31	10.48	4.486	2.949	2.06	2.414	2.501	2.233	2.038	1.906	1.686	1.231	0.561	0.076	###
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Cumulative %	0	0	0	0	0	0	0	0.499	13.7	43.06	65.37	75.86	80.34	83.29	85.35	87.77	90.27	92.5	94.54	96.44	98.13	99.36	99.92	100	100
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Ruakok_Unit9-1mup_13.\$ls

Mean: Median: Mode: S.D.

3.2	3.13	2.84	1.465
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%>	5	16	25	75	84	95	%	Grave Sand	Silt	Clay	
	2.278	2.541	2.698	3.937	5.164	7.618		0	80.34	17.79	1.869

RK 9 Top

Sd

Frequency %	0	0	0	0	0	0	0	0.176	15.32	32.56	24.52	12.08	4.305	2.287	0.976	1.454	1.352	1.146	1.066	0.953	0.948	0.711	0.144	0	0
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Cumulative %	0	0	0	0	0	0	0	0.176	15.5	48.06	72.58	84.66	88.96	91.25	<u>92.23</u>	93.68	95.03	96.18	<u>97.24</u>	98.2	99.14	99.86	100	100	100
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Ruakok_Unit9-1mup_14.\$ls

Mean: Median: Mode: S.D.

3.07	3.03	2.84	0.999
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%>	5	16	25	75	84	95	%	Grave Sand	Silt	Clay
	2.279	2.508	2.652	3.57	3.952	6.486		0	88.96	10.18 0.856

Ruakokopatuna Bridge Section

Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
Class limits	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10

RK 9 Top

Frequency %	0	0	0	0	0	0	0	0.305	16.05	32.49	23.73	12.03	4.225	2.3	1.014	1.528	1.321	1.106	1.042	0.955	0.963	0.753	0.192	###	0			
Cumulative %	0	0	0	0	0	0	0	0.305	16.35	48.84	72.57	84.6	88.83	91.13	92.14	93.67	94.99	96.09	97.14	98.09	99.06	99.81	100	100	100			
Ruakok_Unit9-1mup_15.\$ls	Mean:	Median:		Mode:		S.D.
	3.06	3.02		2.84		1.008																						
%>	5	16	25	75	84	95	%																		Grave	Sand	Silt	Clay
	2.257	2.493	2.641	3.568	3.952	6.504																			0	88.83	10.23	0.945

RK 9 Lower

Frequency %	0	0	0.024	0.642	2.405	5.236	6.028	8.4	15.03	19.58	18.3	11.18	5.22	2.557	1.193	0.935	0.87	0.753	0.632	0.498	0.333	0.163	0.031	###	0
Cumulative %	0	0	0.024	0.666	3.071	8.307	14.33	22.73	37.76	57.34	75.64	86.81	92.03	94.59	95.78	96.72	97.59	98.34	98.97	99.47	99.81	99.97	100	100	100
RuaK_Bed10wK&C_11.\$ls	Mean:	Median:	Mode:			S.D.																			
	2.31	2.82	2.97			1.222																			
%>	5	16	25	75	84	95	% Grave Sand Silt Clay																		
	0.714	1.627	2.095	3.479	3.835	5.14	0.024 92.01 7.771 0.194

RK 9 Lower

Frequency %	0	0	0.006	0.526	2.376	5.227	6.173	8.578	14.97	19.18	18.06	11.35	5.578	2.767	1.21	0.887	0.821	0.712	0.598	0.474	0.32	0.158	0.031	###	0
Cumulative %	0	0	0.006	0.532	2.909	8.136	14.31	22.89	37.85	57.04	75.1	86.44	92.02	94.79	96	96.89	97.71	98.42	99.02	99.49	99.81	99.97	100	100	100
RuaK_Bed10wK&C_12.\$ls	Mean:	Median:		Mode:		S.D.																			
	2.32	2.82		2.97		1.214																			
%>	5	16	25	75	84	95	%	Grave	Sand	Silt	Clay														
	0.732	1.625	2.088	3.497	3.858	5.062		0.006	92.02	7.788	0.19														

A soil composition chart showing the percentage distribution of soil types. The y-axis represents percentage from 0 to 50. The x-axis is divided into four categories: GRAVEL, SAND, SILT, and CLAY. The chart shows a red curve peaking in the SILT region. The data values are: GRAVEL: 0.006%, SAND: 92.02%, SILT: 7.788%, CLAY: 0.19%.

Soil Type	Percentage (%)
GRAVEL	0.006
SAND	92.02
SILT	7.788
CLAY	0.19

RK 8

Frequency %	0	0	2.133	4.248	7.022	11.02	13.39	14.76	15.26	11.73	7.534	4.578	2.857	1.676	0.773	0.562	0.538	0.488	0.433	0.376	0.298	0.201	0.097	0.024	###
Cumulative %	0	0	2.133	6.381	13.4	24.42	37.81	52.57	67.83	79.56	87.1	91.68	94.53	96.21	96.98	97.54	98.08	98.57	99	99.38	99.68	99.88	99.98	100	100
Ruakok_Unit8crse_25.\$ls	Mean:	Median:	Mode:		S.D.
	1.39	1.91	2.16		1.39																				
%>	5	16	25	75	84	95																			%
	-0.2	0.611	1.004	2.774	3.258	4.602		2.133	92.4	5.144	0.323

Ruakokopatuna Bridge Section

Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
Class limits	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10

RK 8

SBt

Frequency %	0	0	0.48	2.622	6.472	11.78	14.87	16.03	15.65	11.53	7.536	4.813	2.934	1.553	0.686	0.553	0.554	0.503	0.443	0.381	0.3	0.201	0.095	0.022	###
Cumulative %	0	0	0.48	3.102	9.574	21.35	36.23	52.25	67.9	79.43	86.96	91.77	94.71	96.26	96.95	97.5	98.05	98.56	99	99.38	99.68	99.88	99.98	100	100
Ruakok_Unit8crse_26.\$ls	Mean:	Median:	Mode:	S.D.																					
	1.57	1.93	2.03	1.284																					
%>	5	16	25	75	84	95																			
	0.191	0.796	1.127	2.782	3.277	4.57																			
							%	Grave	Sand	Silt	Clay														
								0.48	94.23	4.973	0.318

RK 7

Sp

Frequency %	0	0	0	0	0.007	0.458	0.537	1.365	8.753	17.62	19.93	13.75	9.502	6.717	3.636	3.435	3.148	2.474	2.163	2.087	1.967	1.539	0.77	0.144	0.001
Cumulative %	0	0	0	0	0.007	0.464	1.001	2.366	11.12	28.74	48.66	62.42	71.92	78.64	82.27	85.71	88.86	91.33	93.49	95.58	97.55	99.08	99.86	100	100
RuaK_Bed8wK&C_09.\$ls	Mean:	Median:	Mode:	S.D.																					
	3.41	3.54	3.1	1.629																					
%>	5	16	25	75	84	95																			
	2.214	2.662	2.91	4.697	5.758	7.861																			
							%	Grave	Sand	Silt	Clay														
								0	71.92	25.63	2.454

RK 7

Sp

Frequency %	0	0	0	0	0.015	0.562	0.519	1.21	8.312	17.69	20.5	14.57	9.943	6.916	3.666	3.368	3.01	2.32	1.993	1.868	1.687	1.242	0.553	0.063	###
Cumulative %	0	0	0	0	0.015	0.577	1.096	2.305	10.62	28.3	48.8	63.37	73.31	80.23	83.9	87.26	90.27	92.59	94.59	96.45	98.14	99.38	99.94	100	100
RuaK_Bed8wK&C_10.\$ls	Mean:	Median:	Mode:	S.D.																					
	3.39	3.53	3.1	1.524																					
%>	5	16	25	75	84	95																			
	2.233	2.678	2.921	4.6	5.516	7.608																			
							%	Grave	Sand	Silt	Clay														
								0	73.31	24.83	1.858

RK 5

Sw

Frequency %	0	0	3.774	6.528	9.35	12	9.724	8.38	12.58	15.28	10.87	4.001	1.335	0.98	0.696	0.739	0.778	0.741	0.683	0.605	0.482	0.317	0.138	0.022	###
Cumulative %	0	0	3.774	10.3	19.65	31.65	41.37	49.75	62.33	77.62	88.48	92.48	93.82	94.8	95.49	96.23	97.01	97.75	98.44	99.04	99.52	99.84	99.98	100	100
Ruakok_Unit5-30ab_23.\$ls	Mean:	Median:	Mode:	S.D.																					
	1.19	1.98	2.7	1.589																					
%>	5	16	25	75	84	95																			
	-0.49	0.271	0.689	2.901	3.242	5.092

Ruakokopatuna Bridge Section

Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
Class limits	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10

RK 5

Frequency %	0	0	2.529	5.261	8.223	10.95	9.388	8.532	13.33	16.8	12.15	4.52	1.494	1.128	0.839	0.876	0.89	0.82	0.732	0.628	0.481	0.3	0.117	0.012	###
Cumulative %	0	0	2.529	7.791	16.01	26.97	36.35	44.89	58.22	75.01	87.16	91.68	93.18	94.3	95.14	96.02	96.91	97.73	98.46	99.09	99.57	99.87	99.99	100	100
Ruakok_Unit5-30ab_24.\$ls	Mean:	Median:	Mode:	S.D.																					
	1.38	2.21	2.7	1.576																					
%>	5	16	25	75	84	95																			
	-0.3	0.471	0.89	2.994	3.325	5.392																			
					%	Grave	Sand	Silt	Clay																
						2.529	90.65	6.395	0.429

RK 5

Frequency %	0	0	0.055	2.738	2.753	6.221	7.169	7.973	17.19	24.03	18.63	6.171	1.343	1.003	0.483	0.843	0.809	0.67	0.656	0.565	0.457	0.225	0.009	0	0
Cumulative %	0	0	0.055	2.793	5.546	11.77	18.94	26.91	44.1	68.14	86.77	92.94	94.28	95.28	95.77	96.61	97.42	98.09	98.74	99.31	99.77	99.99	100	100	100
RuaK_Bed5wK&C_07.\$ls	Mean:	Median:	Mode:	S.D.																					
	2.03	2.64	2.84	1.21																					
%>	5	16	25	75	84	95	%	Grave	Sand	Silt	Clay														
	0.373	1.235	1.925	3.145	3.393	4.802		0.055	94.23	5.485	0.233

RK 5

Frequency %	0	0	0.384	1.883	2.976	6.495	6.766	8.155	17.14	24.08	18.65	6.235	1.31	0.975	0.514	0.871	0.848	0.711	0.689	0.596	0.474	0.235	0.013	0	0		
Cumulative %	0	0	0.384	2.267	5.243	11.74	18.5	26.66	43.8	67.88	86.53	92.76	94.07	95.05	95.56	96.43	97.28	97.99	98.68	99.28	99.75	99.99	100	100	100		
RuaK_Bed5wK&C_08.\$ls	Mean:	Median:	Mode:			S.D.
	2.05	2.64	2.97			1.218																					
%>	5	16	25	75	84	95	%	Grave																	Sand	Silt	Clay
	0.456	1.256	1.936	3.149	3.4	4.958		0.384																	93.69	5.678	0.247

RK 3

Frequency %	0	0	1.609	2.787	3.294	4.757	3.667	4.364	12.49	24	23.18	8.149	1.575	1.323	0.898	1.205	1.351	1.274	1.17	1.06	0.884	0.618	0.291	0.055	###
Cumulative %	0	0	1.609	4.397	7.69	12.45	16.11	20.48	32.97	56.97	80.15	88.3	89.87	91.19	92.09	93.3	94.65	95.92	97.09	98.15	99.04	99.65	99.94	100	100
Ruakok_Unit3-80cm_20.\$ls	Mean:	Median:	Mode:	S.D.																					
	2.03	2.87	2.97	1.56																					
%>	5	16	25	75	84	95																			
	0.024	1.404	2.22	3.356	3.643	6.624																			
					%	Grave	Sand	Silt	Clay																
						1.609	88.26	9.165	0.964

Ruakokopatuna Bridge Section

Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
Class limits	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10

RK 3

Sw	0	0	0.361	1.529	1.805	3.845	2.664	3.741	13.61	25.69	27.19	9.017	1.762	1.217	0.648	1.196	1.205	1.102	1.016	0.878	0.829	0.584	0.103	0	0
Frequency %	0	0	0.361	1.89	3.695	7.54	10.2	13.94	27.56	53.25	80.44	89.46	91.22	92.44	93.09	94.28	95.49	96.59	97.61	98.48	99.31	99.9	100	100	100
Cumulative %	0	0	0.361	1.89	3.695	7.54	10.2	13.94	27.56	53.25	80.44	89.46	91.22	92.44	93.09	94.28	95.49	96.59	97.61	98.48	99.31	99.9	100	100	100
Ruakok_Unit3-80cm_21.\$ls	Mean:	Median:	Mode:	S.D.																					
	2.41	2.95	3.1	1.209																					
%>	5	16	25	75	84	95																			
	0.813	2.096	2.418	3.367	3.616	6.288																			
							%	Grave	Sand	Silt	Clay														
								0.361	90.86	8.091	0.687

RK 3

Sw	0	0	1.899	2.727	2.729	3.978	3.381	4.453	12.67	24.43	23.39	8.262	1.656	1.387	0.983	1.259	1.407	1.336	1.22	1.083	0.873	0.583	0.256	0.04	###
Frequency %	0	0	1.899	4.626	7.355	11.33	14.71	19.17	31.84	56.27	79.65	87.92	89.57	90.96	91.94	93.2	94.61	95.94	97.16	98.25	99.12	99.7	99.96	100	100
Cumulative %	0	0	1.899	4.626	7.355	11.33	14.71	19.17	31.84	56.27	79.65	87.92	89.57	90.96	91.94	93.2	94.61	95.94	97.16	98.25	99.12	99.7	99.96	100	100
Ruakok_Unit3-80cm_22.\$ls	Mean:	Median:	Mode:	S.D.																					
	2.04	2.88	2.97	1.518																					
%>	5	16	25	75	84	95																			
	-0.04	1.633	2.264	3.369	3.663	6.631																			
							%	Grave	Sand	Silt	Clay														
								1.899	87.67	9.549	0.88

RK 3

Sw	0	0	0.178	1.323	1.847	4.258	4.032	4.656	11.33	20.91	21.83	9.492	3.098	2.663	1.904	2.274	2.246	1.915	1.681	1.528	1.329	0.971	0.459	0.078	###
Frequency %	0	0	0.178	1.501	3.347	7.605	11.64	16.29	27.63	48.53	70.36	79.85	82.95	85.61	87.52	89.79	92.04	93.95	95.63	97.16	98.49	99.46	99.92	100	100
Cumulative %	0	0	0.178	1.501	3.347	7.605	11.64	16.29	27.63	48.53	70.36	79.85	82.95	85.61	87.52	89.79	92.04	93.95	95.63	97.16	98.49	99.46	99.92	100	100
RuaK_Bed3wK&C_05.\$ls	Mean:	Median:	Mode:	S.D.																					
	2.49	3.03	3.1	1.67																					
%>	5	16	25	75	84	95																			
	0.741	1.982	2.408	3.669	4.683	7.306																			
							%	Grave	Sand	Silt	Clay														
								0.178	82.77	15.54	1.509

RK 3

Sw	0	0	0.487	1.052	1.649	4.154	4.406	5.343	12.26	21.71	21.86	9.238	3.087	2.391	1.687	1.951	1.972	1.712	1.483	1.302	1.085	0.764	0.352	0.058	###
Frequency %	0	0	0.487	1.54	3.189	7.343	11.75	17.09	29.35	51.06	72.92	82.16	85.24	87.63	89.32	91.27	93.24	94.96	96.44	97.74	98.83	99.59	99.94	100	100
Cumulative %	0	0	0.487	1.54	3.189	7.343	11.75	17.09	29.35	51.06	72.92	82.16	85.24	87.63	89.32	91.27	93.24	94.96	96.44	97.74	98.83	99.59	99.94	100	100
RuaK_Bed3wK&C_06.\$ls	Mean:	Median:	Mode:	S.D.																					
	2.41	2.98	2.97	1.536																					
%>	5	16	25	75	84	95																			
	0.744	1.918	2.352	3.566	4.265	7.011																			
							%	Grave	Sand	Silt	Clay														
								0.487	84.76	13.58	1.175

Ruakokopatuna Bridge Section

Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
Class limits	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10

RK 2

Frequency %	0	0	0	0	0	0	0	0.238	4.278	17.41	27.48	16.88	6.507	4.339	2.971	3.714	3.787	3.247	2.826	2.491	2.064	1.345	0.418	0.009	0
Cumulative %	0	0	0	0	0	0	0	0.238	4.516	21.92	49.4	66.28	72.79	77.13	80.1	83.81	87.6	90.85	93.67	96.16	98.23	99.57	99.99	100	100
RuaK_BRB2_13.\$ls	Mean:	Median:	Mode:	S.D.																					
	3.57	3.51	3.24	1.581																					
%>	5	16	25	75	84	95		%	Grave	Sand	Silt	Clay													
	2.521	2.875	3.06	4.73	6.023	7.758			0	72.79	25.44	1.773

RK 2

Frequency %	0	0	0	0	0	0	0	0.361	4.809	17.28	26.42	15.89	6.181	4.468	3.268	4.115	4.196	3.555	3.02	2.588	2.102	1.347	0.389	0.005	0
Cumulative %	0	0	0	0	0	0	0	0.361	5.17	22.45	48.87	64.77	70.95	75.41	78.68	82.8	86.99	90.55	93.57	96.16	98.26	99.61	99.99	100	100
RuaK_BRB2_14.\$ls	Mean:	Median:	Mode:	S.D.																					
	3.58	3.52	3.24	1.619																					
%>	5	16	25	75	84	95		%	Grave	Sand	Silt	Clay													
	2.489	2.858	3.052	4.944	6.136	7.767			0	70.95	27.31	1.742													
	2.431	2.79	2.95	3.917	4.838	6.993			Median	###	0.00	0.00

Appendix Three: Grain Size

Blue Rock Race Section

Blue Rock Section

Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
Class limits	-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10

BR 8 Upper

Frequency %	0.00	0.00	0.01	1.40	3.42	4.90	4.15	4.11	6.64	5.83	5.40	5.66	6.05	6.93	5.91	6.56	6.77	5.60	4.79	4.58	4.59	3.95	2.19	0.53	0.01					
Cumulative %	0.00	0.00	0.01	1.41	4.83	9.73	13.88	17.99	24.64	30.47	35.87	41.52	47.57	54.50	60.41	66.98	73.75	79.35	84.14	88.73	93.31	97.26	99.45	99.99	100					
BlueRo_Unit8c_28.\$ls	Mean:	Median:		Mode:		S.D.
	2.77	4.68		6.06		2.66																								
%>	5	16	25	75	84	95	%																				Gravel	Sand	Silt	Clay
	0.52	1.80	2.53	6.60	7.49	8.70																					0.01	47.56	45.74	6.69

BR 8 Upper

Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	1.57	1.26	2.91	6.15	8.01	10.19	8.89	9.61	9.81	8.27	7.32	7.23	7.34	6.38	3.68	1.04	0.05	
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	1.87	3.14	6.05	12.19	20.20	30.39	39.28	48.89	58.70	66.97	74.29	81.52	88.86	95.23	98.91	99.95	100	
BlueRo_Unit8c_27.\$ls	Mean:	Median:		Mode:		S.D.																				
	5.11	6.05		4.72		1.83																				
%>	5	16	25	75	84	95			%	Gravel	Sand	Silt	Clay													
	3.38	4.26	4.74	7.55	8.17	8.98				0.00	20.20	68.66	11.14													

Grain size distribution chart showing percentages of Gravel, Sand, Silt, and Clay. The y-axis ranges from 0 to 50. Gravel is 0%, Sand is 20.20%, Silt is 68.66%, and Clay is 11.14%.

BR 8 Upper

Frequency %	0.00	0.00	0.00	0.00	0.10	3.47	4.74	4.58	9.71	10.66	9.67	8.93	8.14	7.82	5.62	5.34	4.79	3.59	3.01	2.91	2.90	2.44	1.31	0.28	0.00	
Cumulative %	0.00	0.00	0.00	0.00	0.10	3.57	8.31	12.89	22.60	33.25	42.92	51.85	60.00	67.82	73.44	78.78	83.56	87.15	90.16	93.08	95.97	98.41	99.71	100	100	
BlueRo_Unit8c_26.\$ls	Mean:	Median:		Mode:		S.D.																				
	3.08	3.89		2.57		2.18																				
%>	5	16	25	75	84	95			%	Gravel	Sand	Silt	Clay													
	1.12	2.19	2.61	5.65	6.55	8.33				0.00	60.00	35.98	4.03													

Grain Size	Percentage (%)
Gravel	0.00
Sand	60.00
Silt	35.98
Clay	4.03

BR 8 Centre

Frequency %	0.00	0.00	0.44	2.75	5.08	10.16	9.76	7.25	9.07	8.40	7.97	7.92	7.33	5.84	3.19	2.84	2.51	1.77	1.52	1.60	1.69	1.51	0.95	0.37	0.08	
Cumulative %	0.00	0.00	0.44	3.19	8.26	18.42	28.18	35.43	44.50	52.91	60.88	68.80	76.13	81.98	85.17	88.01	90.51	92.28	93.80	95.40	97.09	98.60	99.55	99.92	100	
BlueRo_Unit8b_25.\$ls	Mean:	Median:		Mode:		S.D.																				
	1.95	2.82		0.95		2.26																				
%>	5	16	25	75	84	95			%	Gravel	Sand	Silt	Clay													
	0.22	0.90	1.31	4.42	5.29	7.88				0.44	75.69	20.95	2.91

Appendix Three: Grain Size

Blue Rock Race Section

Blue Rock Section																									
Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
Class limits	-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10
BR 8 Centre	Ms																								
Frequency %	0.00	0.00	0.01	0.44	1.03	5.27	5.58	4.18	8.02	9.19	10.16	10.54	9.66	7.84	4.72	4.46	4.06	3.05	2.64	2.65	2.68	2.26	1.24	0.31	0.01
Cumulative %	0.00	0.00	0.01	0.45	1.48	6.75	12.33	16.51	24.53	33.72	43.88	54.42	64.08	71.92	76.64	81.10	85.15	88.21	90.85	93.50	96.17	98.43	99.68	99.99	100
BlueRo_Unit8b_24.\$ls	Mean:	Median:		Mode:		S.D.																			
	2.83	3.79		3.64		2.22																			
%>	5	16	25	75	84	95					%	Gravel	Sand	Silt	Clay										
	0.88	1.96	2.52	5.30	6.34	8.28						0.01	64.07	32.09	3.83

BR 8 Lower	Ms																								
Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	3.00	5.48	9.46	14.20	15.73	13.41	8.05	6.88	5.73	3.96	3.16	3.02	3.01	2.58	1.53	0.50	0.04
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	3.27	8.75	18.20	32.40	48.13	61.54	69.59	76.47	82.19	86.16	89.31	92.33	95.34	97.92	99.46	99.96	100
BlueRo_Unit8a_23.\$ls	Mean:	Median:		Mode:		S.D.																			
	4.22	4.56		4.32		1.70																			
%>	5	16	25	75	84	95					%	Gravel	Sand	Silt	Clay										
	2.67	3.41	3.75	5.89	6.71	8.44						0.00	48.13	47.21	4.66

BR 8 Lower	Ms																								
Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	3.10	7.06	12.87	18.04	17.54	12.50	6.44	5.24	4.25	2.87	2.29	2.20	2.17	1.82	1.04	0.32	0.02
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	3.32	10.38	23.25	41.29	58.83	71.33	77.78	83.02	87.27	90.14	92.43	94.63	96.80	98.62	99.67	99.98	100
BlueRo_Unit8a_22.\$ls	Mean:	Median:		Mode:		S.D.																			
	4.01	4.24		3.91		1.54																			
%>	5	16	25	75	84	95					%	Gravel	Sand	Silt	Clay										
	2.64	3.25	3.55	5.25	6.10	8.09						0.00	58.83	37.97	3.20

BR 6 Upper	Ms																								
Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	5.44	11.80	13.87	14.49	13.26	10.47	6.07	5.32	4.49	3.16	2.59	2.52	2.52	2.14	1.22	0.35	0.02
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	5.72	17.52	31.39	45.88	59.13	69.60	75.68	81.00	85.49	88.65	91.24	93.75	96.27	98.41	99.63	99.98	100
BlueRo_Unit6-top_21.\$ls	Mean:	Median:		Mode:		S.D.																			
	3.85	4.15		3.64		1.72																			
%>	5	16	25	75	84	95					%	Gravel	Sand	Silt	Clay										
	2.46	2.94	3.28	5.44	6.31	8.25						0.00	59.13	37.14	3.73

Appendix Three: Grain Size

Blue Rock Race Section

Blue Rock Section																									
Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
Class limits	-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10
BR 6 Upper	Ms																								
Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44	6.96	14.43	16.68	16.16	13.26	9.15	4.69	4.04	3.38	2.33	1.91	1.89	1.90	1.60	0.91	0.25	0.01
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44	7.40	21.82	38.51	54.67	67.94	77.09	81.78	85.82	89.20	91.53	93.44	95.33	97.23	98.83	99.74	99.99	100
BlueRo_Unit6-top_20.\$ls	Mean:	Median:		Mode:		S.D.																			
	3.65	3.85		3.51		1.58																			
%>	5	16	25	75	84	95					%	Gravel	Sand	Silt	Clay										
	2.39	2.81	3.10	4.85	5.78	7.91						0.00	67.94	29.30	2.77

BR 6 Lower	Ms																								
Frequency %	0.00	0.00	0.00	0.00	0.12	1.64	1.02	1.14	6.68	8.82	9.40	9.82	9.47	8.97	6.55	6.70	6.39	4.96	4.18	4.02	4.05	3.51	2.01	0.53	0.02
Cumulative %	0.00	0.00	0.00	0.00	0.12	1.76	2.78	3.92	10.59	19.41	28.82	38.64	48.11	57.08	63.64	70.33	76.72	81.68	85.86	89.88	93.93	97.44	99.45	99.98	100
BlueRo_Unit6-base_16.\$ls	Mean:	Median:		Mode:		S.D.																			
	3.73	4.60		3.64		2.10																			
%>	5	16	25	75	84	95					%	Gravel	Sand	Silt	Clay										
	2.12	2.81	3.31	6.35	7.27	8.64						0.00	48.11	45.82	6.07

BR 6 Lower	Ms																								
Frequency %	0.00	0.00	0.00	0.01	0.28	1.06	0.67	0.77	5.12	7.82	9.33	10.45	10.35	9.76	7.06	7.11	6.69	5.16	4.33	4.12	4.06	3.45	1.92	0.47	0.01
Cumulative %	0.00	0.00	0.00	0.01	0.29	1.34	2.02	2.78	7.90	15.72	25.05	35.50	45.85	55.61	62.67	69.78	76.47	81.63	85.96	90.08	94.14	97.60	99.52	99.99	100
BlueRo_Unit6-base_15.\$ls	Mean:	Median:		Mode:		S.D.																			
	3.88	4.70		3.78		2.02																			
%>	5	16	25	75	84	95					%	Gravel	Sand	Silt	Clay										
	2.27	3.02	3.50	6.38	7.27	8.61						0.00	45.85	48.29	5.86

BR 4 Upper	Ms																								
Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48	1.22	1.63	3.69	5.89	9.41	10.19	11.79	12.22	10.40	8.71	7.76	7.14	5.80	3.06	0.61	0.00
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48	1.70	3.34	7.03	12.92	22.33	32.52	44.31	56.52	66.92	75.64	83.40	90.54	96.33	99.39	100	100
BlueRo_Unit4-top_14.\$ls	Mean:	Median:		Mode:		S.D.																			
	5.47	6.22		6.06		1.61																			
%>	5	16	25	75	84	95					%	Gravel	Sand	Silt	Clay										
	3.76	4.68	5.13	7.46	8.04	8.87						0.00	12.92	77.62	9.46

Appendix Three: Grain Size

Blue Rock Race Section

Blue Rock Section																										
Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10	
Class limits	-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10	
BR 4 Upper	Ms																									
Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.74	1.22	3.13	5.37	9.16	10.16	11.86	12.54	10.65	8.81	7.87	7.45	6.32	3.61	0.97	0.03	
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.84	2.07	5.19	10.57	19.73	29.90	41.76	54.30	64.95	73.76	81.63	89.07	95.39	99.00	99.97	100	
BlueRo_Unit4-top_13.\$ls	Mean:	Median:		Mode:		S.D.																				
	5.65	6.32		6.06		1.59																				
%>	5	16	25	75	84	95		%	Gravel	Sand	Silt	Clay														
	3.98	4.81	5.26	7.58	8.16	8.96			0.00	10.57	78.50	10.93

BR 4 Lower	Ms																									
Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.81	3.14	3.30	4.60	5.55	6.81	6.76	8.60	10.62	10.56	9.85	9.33	8.82	7.13	3.56	0.56	0.00	
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.82	3.96	7.25	11.86	17.41	24.22	30.98	39.57	50.19	60.75	70.60	79.93	88.75	95.88	99.43	100	100	
BlueRo_Unit4-base_12.\$ls	Mean:	Median:		Mode:		S.D.																				
	5.27	6.49		6.33		1.83																				
%>	5	16	25	75	84	95		%	Gravel	Sand	Silt	Clay														
	3.17	4.38	5.06	7.73	8.23	8.93			0.00	17.41	71.34	11.25

BR 4 Lower	Ms																									
Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	2.53	2.69	3.81	4.70	6.08	6.40	8.26	10.42	10.63	10.31	10.23	10.04	8.28	4.25	0.75	0.00	
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	3.13	5.82	9.63	14.32	20.41	26.81	35.07	45.49	56.12	66.43	76.67	86.71	94.99	99.24	100	100	
BlueRo_Unit4-base_11.\$ls	Mean:	Median:		Mode:		S.D.																				
	5.47	6.71		6.60		1.78																				
%>	5	16	25	75	84	95		%	Gravel	Sand	Silt	Clay														
	3.36	4.65	5.36	7.92	8.36	9.00

BR 2 Upper	Ms																									
Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	1.33	1.27	1.82	2.20	4.48	6.38	9.46	12.75	13.26	12.33	11.34	10.32	8.11	4.02	0.66	0.00	
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	1.58	2.85	4.67	6.87	11.35	17.73	27.20	39.95	53.21	65.54	76.88	87.20	95.31	99.33	100	100	
BlueRo_Unit1-top_10.\$ls	Mean:	Median:		Mode:		S.D.																				
	5.95	6.88		6.60		1.48																				
%>	5	16	25	75	84	95		%	Gravel	Sand	Silt	Clay														
	4.09	5.38	5.90	7.92	8.34	8.98			0.00	6.87	80.33	12.80

Appendix Three: Grain Size

Blue Rock Race Section

Blue Rock Section																									
Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
Class limits	-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10
BR 2 Upper	Ms																								
Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.49	1.67	1.34	1.94	2.18	4.66	6.80	10.16	13.25	13.25	11.91	10.68	9.60	7.56	3.83	0.68	0.00
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.49	2.16	3.51	5.44	7.62	12.28	19.08	29.24	42.49	55.73	67.64	78.32	87.93	95.49	99.32	100	100
BlueRo_Unit1-top_09.\$ls	Mean:	Median:		Mode:		S.D.																			
	5.83	6.78		6.60		1.52																			
	%>	5	16	25	75	84	95	% Gravel Sand Silt Clay																	
		3.88	5.29	5.81	7.84	8.29	8.96	0.00 7.62 80.31 12.07

BR 2 Centre	Ms																								
Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	2.31	5.12	3.35	3.64	2.86	4.10	4.72	6.56	8.93	10.04	10.63	11.24	11.44	9.51	4.76	0.74	0.00
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	2.35	7.48	10.83	14.46	17.32	21.43	26.14	32.70	41.63	51.67	62.30	73.54	84.98	94.49	99.25	100	100
BlueRo_Unit1-cent_08.\$ls	Mean:	Median:		Mode:		S.D.																			
	5.15	6.92		8.22		2.00																			
	%>	5	16	25	75	84	95	% Gravel Sand Silt Clay																	
		2.74	4.27	5.38	8.07	8.46	9.04	0.00 17.32 67.66 15.02

BR 2 Centre	Ms																								
Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	1.98	4.22	3.96	3.03	2.70	4.14	4.46	6.24	9.06	10.53	11.08	11.57	11.69	9.69	4.85	0.76	0.00
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	2.02	6.24	10.20	13.23	15.92	20.06	24.53	30.77	39.83	50.36	61.44	73.01	84.70	94.39	99.24	100	100
BlueRo_Unit1-cent_07.\$ls	Mean:	Median:		Mode:		S.D.																			
	5.25	6.98		8.22		1.93																			
	%>	5	16	25	75	84	95																		
		2.85	4.51	5.55	8.09	8.47	9.04

BR 2 Centre	Ms																								
Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	3.13	8.30	5.19	3.97	4.23	5.43	5.85	7.48	9.59	9.69	9.17	8.85	8.72	7.07	3.07	0.24	0.00
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	3.16	11.46	16.65	20.62	24.84	30.27	36.12	43.60	53.18	62.88	72.05	80.90	89.62	96.69	99.76	100	100
BlueRo_Unit1-cent_06.\$ls	Mean:	Median:		Mode:		S.D.																			
	4.72	6.34		6.60		2.14																			
	%>	5	16	25	75	84	95	% Gravel Sand Silt Clay																	
		2.61	3.42	4.52	7.66	8.18	8.86	0.00 24.84 64.78 10.38

Appendix Three: Grain Size

Blue Rock Race Section

Blue Rock Section																									
Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
Class limits	-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10
BR 2 Centre	Ms																								
Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.91	7.61	9.69	6.73	5.10	4.04	5.12	4.53	5.90	7.55	7.92	7.96	8.16	8.54	7.12	2.97	0.16	0.00
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.91	8.53	18.22	24.94	30.04	34.08	39.20	43.73	49.63	57.18	65.10	73.06	81.21	89.75	96.87	99.84	100	100
BlueRo_Unit1-cent_05.\$ls	Mean:	Median:		Mode:		S.D.																			
	4.23	6.02		2.57		2.31																			
%>		5	16	25	75	84	95	% Gravel Sand Silt Clay																	
		2.32	2.87	3.50	7.62	8.17	8.84	0.00 34.08 55.67 10.25

BR 2 Lower																									
Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	2.38	5.03	10.03	14.14	15.18	11.35	10.45	8.97	6.09	4.40	3.69	3.42	2.81	1.46	0.26	0.00
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	2.71	7.75	17.78	31.92	47.10	58.44	68.90	77.87	83.96	88.36	92.04	95.47	98.28	99.74	100	100
BlueRo_Unit1-base_04.\$ls	Mean:	Median:		Mode:		S.D.																			
	4.75	5.11		4.58		1.55																			
%>		5	16	25	75	84	95	% Gravel Sand Silt Clay																	
		3.28	3.93	4.27	6.32	7.00	8.43	0.00 31.92 63.55 4.53

BR 2 Lower																									
Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	2.03	4.17	8.50	12.93	14.84	12.46	11.30	9.57	6.69	4.90	4.07	3.68	2.96	1.52	0.27	0.00
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	2.14	6.31	14.81	27.73	42.57	55.03	66.33	75.89	82.58	87.48	91.56	95.24	98.21	99.73	100	100
BlueRo_Unit1-base_03.\$ls	Mean:	Median:		Mode:		S.D.																			
	4.88	5.28		4.72		1.54																			
%>		5	16	25	75	84	95																		
		3.37	4.05	4.40	6.44	7.13	8.47																		

BR 2 Lower																									
Frequency %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	1.91	5.07	10.73	15.52	17.64	12.17	10.51	8.31	5.11	3.50	2.93	2.75	2.24	1.09	0.14	0.00
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	2.29	7.36	18.09	33.61	51.25	63.42	73.93	82.24	87.35	90.85	93.78	96.53	98.77	99.86	100	100
BlueRo_Unit1-base_02.\$ls	Mean:	Median:		Mode:		S.D.																			
	4.69	4.96		4.58		1.42																			
%>		5	16	25	75	84	95	% Gravel Sand Silt Clay																	
		3.33	3.92	4.25	6.05	6.65	8.22	0.00 33.61 62.92 3.47

Clay Creek Section

Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
Class limits	-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10

CC 7	Sw																								
Frequency %	0.00	0.00	0.00	0.00	0.02	3.65	3.11	9.30	34.75	30.41	9.45	3.29	1.20	0.99	0.53	0.65	0.64	0.49	0.45	0.42	0.37	0.23	0.04	0.00	0.00
Cumulative %	0.00	0.00	0.00	0.00	0.02	3.67	6.78	16.08	50.83	81.24	90.69	93.98	95.18	96.18	96.71	97.36	98.00	98.49	98.94	99.35	99.72	99.96	100	100	100
ClayCk_sample9_19.\$ls	Mean:		Median:		Mode:		S.D.																		
	2.37		2.49		2.43		0.77																		
	%>		5	16	25	75	84	95	% Gravel		Sand	Silt	Clay												
			1.11	2	2.16	2.86	3.09	4.4	0.00		95.18	4.54	0.28

CC 7	Sw																													
Frequency %	0	0	0	0	0.04	3.85	3.12	9.17	34.8	30.5	9.36	3.19	1.2	1.01	0.58	0.66	0.64	0.48	0.42	0.38	0.33	0.19	0.03	0	0					
Cumulative %	0.00	0.00	0.00	0.00	0.04	3.89	7.00	16.17	50.99	81.52	90.88	94.07	95.28	96.29	96.87	97.53	98.17	98.65	99.07	99.45	99.78	99.97	100	100	100					
ClayCk_sample9_18.\$ls	Mean:				Median:				Mode:				S.D.
	2.36				2.49				2.43				0.76																	
	%>				5	16	25	75	84	95					%	Gravel												Sand	Silt	Clay
					1.09	2	2.16	2.85	3.07	4.36						0.00												95.28	4.50	0.22

CC 6	SBz																													
Frequency %	0.00	0.00	0.65	1.88	1.94	5.22	4.98	10.62	31.43	26.09	7.10	2.85	1.21	1.10	0.64	0.79	0.82	0.67	0.60	0.53	0.48	0.32	0.08	0.00	0.00					
Cumulative %	0.00	0.00	0.65	2.53	4.47	9.69	14.67	25.29	56.71	82.80	89.91	92.75	93.97	95.07	95.71	96.51	97.32	97.99	98.59	99.12	99.60	99.92	100	100	100					
ClayCk_sample8_17.\$ls	Mean:		Median:		Mode:		S.D.
	2.01		2.4		2.43		1.00																							
	%>		5	16	25	75	84	95																		%	Gravel	Sand	Silt	Clay
			0.61	1.66	1.99	2.8	3.04	4.96																			0.65	93.32	5.63	0.40

CC 6	SBz																								
Frequency %	0.00	0.00	0.78	1.86	2.41	5.89	5.15	10.85	31.47	25.72	6.76	2.57	1.05	0.95	0.56	0.69	0.73	0.61	0.55	0.51	0.47	0.33	0.09	0.00	0.00
Cumulative %	0.00	0.00	0.78	2.64	5.05	10.94	16.09	26.94	58.41	84.13	90.89	93.46	94.51	95.47	96.02	96.71	97.44	98.06	98.61	99.12	99.59	99.91	100	100	100
ClayCk_sample8_16.\$ls	Mean:		Median:		Mode:		S.D.																		
	1.95		2.38		2.43		1.03																		
	%>		5	16	25	75	84	95	%	Gravel	Sand	Silt	Clay												
			0.47	1.47	1.96	2.77	3	4.75		0.78	93.73	5.07	0.41

Clay Creek Section

Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10					
Class limits	-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10					
CC 6	SBz																													
Frequency %	0.00	0.00	0.02	1.71	2.97	4.41	3.41	3.83	25.31	28.82	11.59	4.71	2.17	1.97	1.18	1.49	1.45	1.21	1.10	0.95	0.90	0.65	0.12	0.00	0.00					
Cumulative %	0.00	0.00	0.02	1.74	4.71	9.12	12.53	16.36	41.68	70.50	82.09	86.80	88.98	90.94	92.12	93.61	95.06	96.27	97.37	98.32	99.23	99.88	100	100	100					
ClayCk_sample7_15.\$ls	Mean:	Median:		Mode:		S.D.
	2.24	2.63		2.57		1.31																								
	%>	5	16	25	75	84	95																			%	Gravel	Sand	Silt	Clay
		0.62	1.99	2.22	3.13	3.66	6.47																				0.02	88.95	10.25	0.77

CC 6	SBz																													
Frequency %	0	0	1.03	2.74	2.25	4.32	3.24	4.13	25.9	28.9	11.2	4.35	1.95	1.78	1.06	1.35	1.33	1.1	1	0.86	0.81	0.56	0.09	0	0					
Cumulative %	0.00	0.00	1.03	3.78	6.03	10.35	13.59	17.72	43.67	72.58	83.76	88.11	90.06	91.84	92.90	94.25	95.58	96.67	97.68	98.54	99.35	99.91	100	100	100					
ClayCk_sample7_14.\$ls	Mean:	Median:		Mode:		S.D.																								
	2.08	2.59		2.57		1.32																								
	%>	5	16	25	75	84	95																			%	Gravel	Sand	Silt	Clay
		0.17	1.93	2.18	3.06	3.52	6.26																				1.03	89.03	9.29	0.65

CC 5	Sw																									
Frequency %	0	0	0.93	2.27	2.78	4.78	3.38	10.5	32.5	22.1	8.03	3.69	1.65	1.44	0.82	1.02	0.98	0.79	0.72	0.64	0.59	0.41	0.08	0	0	
Cumulative %	0.00	0.00	0.93	3.20	5.98	10.76	14.14	24.62	57.09	79.17	87.20	90.88	92.53	93.97	94.79	95.80	96.78	97.57	98.28	98.92	99.51	99.92	100	100	100	
ClayCk_sample6_13.\$ls	Mean:	Median:		Mode:		S.D.																				
	1.98	2.39		2.3		1.19																				
	%>	5	16	25	75	84	95			%	Gravel	Sand	Silt	Clay												
		0.27	1.74	2.01	2.86	3.24	5.62				0.93	91.60	6.98	0.49

CC 5	Sw																														
Frequency %	0	0	1.55	2.3	2.97	4.99	3.4	11	32.8	21.7	7.64	3.46	1.54	1.28	0.69	0.87	0.87	0.72	0.66	0.59	0.54	0.38	0.08	0	0						
Cumulative %	0.00	0.00	1.55	3.85	6.82	11.81	15.21	26.21	58.98	80.67	88.32	91.77	93.31	94.59	95.28	96.15	97.03	97.75	98.41	99.00	99.55	99.92	100	100	100						
ClayCk_sample6_12.\$ls	Mean:		Median:		Mode:		S.D.
	1.87		2.36		2.3		1.16																								
	%>		5	16	25	75	84	95																			%	Gravel	Sand	Silt	Clay
			0.12	1.61	1.97	2.82	3.15	5.25																				1.55	91.76	6.24	0.45

Clay Creek Section

Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10													
Class limits	-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10													
CC 3	Sw																																					
Frequency %	0	0	0	0	0	0	0	0.11	19	41.3	15.5	5.26	2.85	2.87	1.79	2.15	2.07	1.69	1.52	1.32	1.34	1.05	0.21	0	0													
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	19.11	60.40	75.88	81.14	83.98	86.85	88.64	90.79	92.87	94.55	96.08	97.40	98.73	99.79	100	100	100													
ClayCk_sample5_11.\$ls	Mean:				Median:				Mode:				S.D.
	3				2.86				2.7				1.25																									
	%>				5				16				25														75				84				95			
					2.27				2.45				2.57														3.44				4.5				7.14			

Clay Creek Section

Class midpoints

Class limits

CC 3

Frequency %

-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10	
-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10	
Sw																									
0	0	0	0	0	0	0	0.18	22.2	45.4	16	4.65	2.01	1.88	1.00MC	1MCD	7041an	none>>	DC	0	0	1	597.44	560.21	622.00MC	1M

Clay Creek Section

Class midpoints	-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
Class limits	-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10

CC 3	Sw																											
Frequency %	0	0	0	0	0	0	0	0.24	18.2	41.4	18.2	5.95	2.65	2.64	1.67	1.99	1.87	1.43	1.3	1.05	0.9	0.51	0.03	0	0			
Cumulative %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	18.44	59.86	78.01	83.96	86.61	89.25	90.92	92.91	94.78	96.21	97.51	98.56	99.46	99.97	100	100	100			
ClayCk_sample1_03.\$ls	Mean:				Median:				Mode:				S.D.
	2.98				2.87				2.7				1.04															
	%>				5				16				25				75				84				95			
					2.26				2.46				2.58				3.34				4.01				6.57			

Appendix Three: Grain Size

Additional Grain Size Samples

Additional Samples

Class midpoints

Class limits

-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10

Ms

Frequency %

Cumulative %

RuaKRD_TMPoss_05.\$ls

###	0	0	0	0	0	0	0	0.081	0.192	0.575	1.882	2.695	5.67	7.556	10.14	12.44	12.24	11.3	10.6	10.26	8.458	4.691	1.19	0.031
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.27	0.85	2.73	5.42	11.09	18.65	28.79	41.23	53.47	64.77	75.37	85.63	94.09	98.78	99.97	100
Mean:	Median:		Mode:		S.D.																			
6.12	6.85		6.33		1.47																			
% <	5	16	25	75	84	95	%	Gravel	Sand	Silt	Clay													
Size	4.44	5.34	5.83	7.98	8.42	9.07		0.00	5.42	80.21	14.37													

A grain size distribution chart with a vertical axis from 0 to 50. The chart is divided into four sections: GRAVEL (0-5%), SAND (5-80.21%), SILT (80.21-94.09%), and CLAY (94.09-100%). The percentages are labeled at the bottom of each section.

Grain Size	Percentage (%)
Gravel	0.00
Sand	5.42
Silt	80.21
Clay	14.37

Ms

Frequency %

Cumulative %

RuaKRD_TMPoss_06.\$ls

0	0	0	0	0	0	0	0	0.007	0.228	0.763	1.998	2.92	5.492	6.35	7.941	10.04	10.82	11.22	11.72	12.25	10.51	5.991	1.673	0.077
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.23	1.00	3.00	5.92	11.41	17.76	25.70	35.73	46.56	57.77	69.49	81.75	92.26	98.25	99.92	100
Mean:	Median:		Mode:		S.D.																			
6.2	7.16		8.22		1.54																			
% <	5	16	25	75	84	95	%	Gravel	Sand	Silt	Clay													
Size	4.38	5.36	5.96	8.22	8.60	9.18		0.00	5.92	75.83	18.25													

Grain Size	Percentage (%)
Gravel	0.00
Sand	5.92
Silt	75.83
Clay	18.25

Sw

Frequency %

Cumulative %

Ruawak_FarmersBri_03.\$ls

0	0	0	0	0	0	0	0	1.598	18.42	45.3	26.77	6.208	1.699	0	0	0	0	0	0	0	0	0	0	0	0.003
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.60	20.02	65.32	92.09	98.30	100	100	100	100	100	100	100	100	100	100	100	100	100
Mean:	Median:		Mode:		S.D.																				
3.3	3.34		3.37		0.44																				
% <	5	16	25	75	84	95			%	Gravel	Sand	Silt	Clay												
Size	2.67	2.94	3.07	3.62	3.77	4.19				0.00	98.30	1.70	0.00

Sw

Frequency %

Cumulative %

Ruawak_FarmersBri_04.\$ls

0	0	0	0	0	0	0	0	1.877	19.51	45.47	25.66	5.811	1.66	0	0	0	0	0	0	0	0	0	0	0	0.003
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.88	21.39	66.86	92.53	98.34	100	100	100	100	100	100	100	100	100	100	100	100	100
Mean:	Median:		Mode:		S.D.																				
3.28	3.32		3.24		0.44																				
% <	5	16	25	75	84	95			%	Gravel	Sand	Silt	Clay												
Size	2.66	2.92	3.05	3.60	3.75	4.17				0.00	98.34	1.66	0.00

Appendix Three: Grain Size

Additional Grain Size Samples

Additional Samples

Class midpoints

-1.75 -1.25 -0.75 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 4.75 5.25 5.75 6.25 6.75 7.25 7.75 8.25 8.75 9.25 9.75 10

Class limits

-2.00 -1.50 -1.00 -0.50 0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00 5.50 6.00 6.50 7.00 7.50 8.00 8.50 9.00 9.50 10

Ms

Frequency %

0 0 0 0 0 0 0 0.049 1.59 4.383 7.905 10.65 10.07 8.642 5.881 6.371 7.027 6.438 6.456 6.974 7.647 6.48 3.101 0.343 ###

Cumulative %

0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.05 1.64 6.02 13.93 24.58 34.64 43.28 49.16 55.54 62.56 69.00 75.45 82.43 90.08 96.56 99.66 100 100

TTH_mud_19.\$ls

Mean: Median: Mode: S.D.

4.65 5.58 3.78 2.03

% < 5 16 25 75 84 95 % Gravel Sand Silt Clay

Size 2.91 3.60 4.02 7.47 8.10 8.86 0.00 34.64 55.43 9.92

Ms

Frequency %

0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.06 1.99 5.36 9.72 11.53 11.03 9.15 5.93 6.28 6.78 6.10 5.89 6.09 6.41 5.20 2.29 0.18 0.00

Cumulative %

0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.06 2.06 7.42 17.14 28.67 39.70 48.84 54.78 61.06 67.84 73.94 79.83 85.92 92.33 97.53 99.82 100 100

TTH_mud_20.\$ls

Mean: Median: Mode: S.D.

4.46 5.08 3.64 2.00

% < 5 16 25 75 84 95 % Gravel Sand Silt Clay

Size 2.81 3.45 3.84 7.09 7.84 8.73 0.00 39.70 52.63 7.67

Ms

Frequency %

0 0 0 0 0 0 0 0 0.973 10.44 18.61 15.11 9.698 6.62 5.683 4.016 4.22 4.353 3.65 3.318 3.381 3.548 3.207 2.099 0.878

Cumulative %

0 0 0 0 0 0 0 0 0.973 11.41 30.02 45.13 54.83 61.45 67.13 71.15 75.37 79.72 83.37 86.69 90.07 93.62 96.82 98.92 99.8

RuaK_WSampleLow_28.\$ls

Mean: Median: Mode: S.D.

3.57 3.72 2.84 2.09

% < 5 16 25 75 84 95 % Gravel Sand Silt Clay

Size 2.27 2.63 2.86 5.96 7.09 8.70 0.00 54.83 35.24 9.73

Ms

Frequency %

0 0 0 0 0 0 0 0 0.457 6.754 14.05 13.15 10.03 7.992 7.168 4.856 5.11 5.267 4.391 3.997 4.153 4.49 4.128 2.676 1.091

Cumulative %

0 0 0 0 0 0 0 0 0.457 7.211 21.26 34.41 44.44 52.44 59.6 64.46 69.57 74.84 79.23 83.22 87.38 91.87 95.99 98.67 99.76

RuaK_WestSample_27.\$ls

Mean: Median: Mode: S.D.

3.87 4.34 2.84 2.17

% < 5 16 25 75 84 95 % Gravel Sand Silt Clay

Size 2.40 2.82 3.13 6.52 7.60 8.87 0.00 44.44 42.93 12.38

Appendix Three: Grain Size

Additional Grain Size Samples

Additional Samples

Class midpoints

-1.75 -1.25 -0.75 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 4.75 5.25 5.75 6.25 6.75 7.25 7.75 8.25 8.75 9.25 9.75 10

Class limits

-2.00 -1.50 -1.00 -0.50 0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00 5.50 6.00 6.50 7.00 7.50 8.00 8.50 9.00 9.50 10

Ms

Frequency %

0 0 0 0 0 0 0 ### 0.925 6.599 9.858 8.604 7.001 6.228 7.069 5.944 6.325 6.487 5.561 5.256 5.749 6.451 6.003 3.903 1.629

Cumulative %

0 0 0 0 0 0 0 ### 0.925 7.525 17.38 25.99 32.99 39.22 46.28 52.23 58.55 65.04 70.6 75.86 81.61 88.06 94.06 97.96 99.59

RuaK_WestSample_26.\$ls

Mean: Median: Mode: S.D.

4.15 5.30 2.70 2.34

% < 5 16 25 75 84 95 % Gravel Sand Silt Clay

Size 2.36 2.93 3.44 7.42 8.19 9.10 0.00 32.99 48.62 17.99

Ms

Frequency %

0 0 0 0 0 0 0 0 0.716 7.039 11.63 10.93 9.204 8.213 8.249 6.033 6.061 5.824 4.58 4.112 4.332 4.713 4.3 2.757 1.091

Cumulative %

0 0 0 0 0 0 0 0 0.716 7.755 19.39 30.32 39.52 47.74 55.99 62.02 68.08 73.9 78.48 82.6 86.93 91.64 95.94 98.7 99.79

RuaK_WestSample_25.\$ls

Mean: Median: Mode: S.D.

3.96 4.63 2.84 2.19

% < 5 16 25 75 84 95 % Gravel Sand Silt Clay

Size 2.36 2.86 3.25 6.61 7.67 8.88 0.00 39.52 47.40 12.86

Ms

Frequency %

0 0 0 0 0 0 0 0 0.007 0.999 3.314 3.959 5.337 5.525 6.83 6.723 8.356 10.02 9.662 9.001 8.725 8.617 7.32 4.269 1.271

Cumulative %

0 0 0 0 0 0 0 0 0.007 1.006 4.319 8.279 13.62 19.14 25.97 32.69 41.05 51.07 60.73 69.73 78.46 87.07 94.39 98.66 99.93

RuaK_River Samp_24.\$ls

Mean: Median: Mode: S.D.

5.18 6.45 6.33 1.93

% < 5 16 25 75 84 95 % Gravel Sand Silt Clay

Size 3.10 4.22 4.93 7.80 8.32 9.05 0.00 13.62 64.84 21.48

Ms

Frequency %

0 0 0 0 0 0 0 0 0.025 1.472 3.68 3.593 4.259 4.283 5.984 6.698 8.682 10.51 10.15 9.374 9.01 8.883 7.565 4.429 1.328

Cumulative %

0 0 0 0 0 0 0 0 0.025 1.498 5.177 8.77 13.03 17.31 23.3 29.99 38.68 49.19 59.34 68.71 77.72 86.61 94.17 98.6 99.93

RuaK_River Samp_23.\$ls

Mean: Median: Mode: S.D.

5.20 6.54 6.33 1.92

% < 5 16 25 75 84 95 % Gravel Sand Silt Clay

Size 2.97 4.36 5.13 7.85 8.35 9.07 0.00 13.03 64.69 22.21

Appendix Three: Grain Size

Additional Grain Size Samples

Additional Samples

Class midpoints

Class limits

-1.75	-1.25	-0.75	-0.25	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10
-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10

Sp

Frequency %

Cumulative %

RuaK_Bridge4_20.\$ls

0	0	0	1.025	2.826	4.16	5.729	5.429	6.798	13.28	20.81	19.14	6.781	1.535	1.576	1.349	1.66	1.698	1.511	1.357	1.215	1.028	0.716	0.326	0.051
0	0	0	1.025	3.85	8.01	13.74	19.17	25.97	39.25	60.06	79.2	85.98	87.51	89.09	90.44	92.1	93.8	95.31	96.66	97.88	98.91	99.62	99.95	100
Mean:		Median:		Mode:		S.D.																		
1.99		2.77		2.97		1.67																		
% <	5	16	25	75	84	95			%	Gravel	Sand	Silt	Clay											
Size	0.12	1.17	1.94	3.36	3.75	6.89				0.00	85.98	11.90	2.12

Sp

Frequency %

Cumulative %

RuaK_Bridge4_19.\$ls

0	0	0	0.712	2.106	3.421	5.236	4.718	6.207	13.35	21.74	20.33	7.253	1.632	1.728	1.477	1.799	1.836	1.622	1.441	1.273	1.058	0.718	0.308	0.035
0	0	0	0.712	2.818	6.239	11.48	16.19	22.4	35.75	57.49	77.82	85.07	86.71	88.43	89.91	91.71	93.54	95.17	96.61	97.88	98.94	99.66	99.97	100
Mean:		Median:		Mode:		S.D.																		
2.15		2.84		2.97		1.60																		
% <	5	16	25	75	84	95			%	Gravel	Sand	Silt	Clay											
Size	0.33	1.47	2.12	3.41	3.84	6.94				0.00	85.07	12.81	2.12

Sp

Frequency %

Cumulative %

RuaK_Bridge3_22.\$ls

0	0	0	0.235	0.825	1.677	3.681	3.054	3.758	11.93	24.47	24.54	8.658	1.909	2.093	1.868	2.274	2.274	1.944	1.636	1.342	1.017	0.61	0.203	0.009
0	0	0	0.235	1.06	2.736	6.418	9.472	13.23	25.15	49.63	74.16	82.82	84.73	86.82	88.69	90.96	93.24	95.18	96.82	98.16	99.18	99.79	99.99	100
Mean:		Median:		Mode:		S.D.																		
2.55		3.01		2.97		1.46																		
% <	5	16	25	75	84	95			%	Gravel	Sand	Silt	Clay											
Size	0.83	2.16	2.49	3.53	4.29	6.95				0.00	82.82	15.34	1.84

Sp

Frequency %

Cumulative %

RuaK_Bridge1_21.\$ls

0	0	0	0.079	0.391	0.793	2.365	1.522	1.153	9.239	25.47	28.74	11.28	2.825	2.532	1.865	2.195	2.226	1.947	1.699	1.459	1.164	0.746	0.286	0.02
0	0	0	0.079	0.47	1.263	3.628	5.15	6.303	15.54	41.01	69.76	81.04	83.86	86.4	88.26	90.45	92.68	94.63	96.33	97.79	98.95	99.69	99.98	100
Mean:		Median:		Mode:		S.D.																		
2.88		3.14		3.10		1.38																		
% <	5	16	25	75	84	95			%	Gravel	Sand	Silt	Clay											
Size	1.35	2.51	2.72	3.65	4.53	7.10				0.00	81.04	16.75	2.21

Appendix Three: Grain Size

Additional Grain Size Samples

Additional Samples

Class midpoints

Class limits

-1.75 -1.25 -0.75 -0.25 0.25 0.75 1.25 1.75 2.25 2.75 3.25 3.75 4.25 4.75 5.25 5.75 6.25 6.75 7.25 7.75 8.25 8.75 9.25 9.75 10
-2.00 -1.50 -1.00 -0.50 0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00 5.50 6.00 6.50 7.00 7.50 8.00 8.50 9.00 9.50 10

Ms

Frequency %

Cumulative %

RRoad_Tm_30.\$ls

0 0 0 0 0 0 0 0 0 ### 0.121 0.297 0.4 1.616 3.403 8.127 10.37 12.33 12.9 11 9.238 8.366 8.07 7.028 4.541 1.844
0 0 0 0 0 0 0 0 0 ### 0.121 0.418 0.818 2.435 5.837 13.96 24.33 36.67 49.56 60.56 69.8 78.16 86.23 93.26 97.8 99.65
Mean: Median: Mode: S.D.
5.94 6.52 6.06 1.53
% < 5 16 25 75 84 95 % Gravel Sand Silt Clay
Size 4.42 5.10 5.53 7.81 8.36 9.16 0.00 2.43 75.73 21.48

Ms

Frequency %

Cumulative %

RRoad_Tm_29.\$ls

0 0 0 0 0 0 0 0 0 ### 0.104 0.376 0.461 1.675 3.778 8.387 9.963 11.44 12.1 10.56 9.105 8.476 8.363 7.434 4.971 2.214
0 0 0 0 0 0 0 0 0 ### 0.104 0.48 0.941 2.616 6.394 14.78 24.74 36.18 48.28 58.84 67.95 76.42 84.79 92.22 97.19 99.41
Mean: Median: Mode: S.D.
5.93 6.58 6.06 1.59
% < 5 16 25 75 84 95 % Gravel Sand Silt Clay
Size 4.37 5.06 5.51 7.91 8.45 9.24 0.00 2.62 73.81 22.98

Cm-Sand

Frequency %

Cumulative %

Oyster_HnearO_02.\$ls

0 0 0 0 0 0 0 0 0 0.089 2.009 3.785 14.86 25.12 17.73 8.572 5.094 5.247 4.596 3.357 2.702 2.398 2.156 1.574 0.664 0.055
0 0 0 0 0 0 0 0 0 0.089 2.098 5.883 20.74 45.85 63.59 72.16 77.25 82.5 87.1 90.45 93.15 95.55 97.71 99.28 99.94 100
Mean: Median: Mode: S.D.
4.06 4.09 3.78 1.44
% < 5 16 25 75 84 95 % Gravel Sand Silt Clay
Size 2.92 3.39 3.59 5.27 6.15 7.88 0.00 45.85 49.70 4.45

Cm-Sand

Frequency %

Cumulative %

Oyster_HnearO2_03.\$ls

0 0 0 0 0 0 0 0 0 ### 0.327 3.865 16.87 27.73 18.38 7.349 3.816 4.334 4.127 3.173 2.655 2.428 2.251 1.731 0.831 0.122
0 0 0 0 0 0 0 0 0 ### 0.328 4.193 21.07 48.8 67.18 74.53 78.35 82.68 86.81 89.98 92.64 95.06 97.32 99.05 99.88 100
Mean: Median: Mode: S.D.
4.06 4.02 3.78 1.44
% < 5 16 25 75 84 95 % Gravel Sand Silt Clay
Size 3.05 3.39 3.58 5.05 6.15 7.99 0.00 48.80 46.27 4.94

Appendix Four

Tephra Analysis

Methods

The methods described here are largely those previously developed for the project of Allan (2008).

Sample preparation

Volcanic glass was separated from bulk tephra samples and mounted in ‘half moon’ epoxy resin blocks for geochemical characterisation by EPMA (major elements) and LA-ICP-MS (trace elements). Samples were rinsed through a 33 μm nylon mesh to remove excess mud. This produced a residue of approximately 80-95% volcanic glass shards with the remainder comprising variable proportions of feldspar, mafic igneous minerals. The separated glass was then rinsed and decanted several times and left to dry at 50°C for 2-3 days. The epoxy blocks were ground down using 400 – 4000 grit silicon carbide paper to expose the glass shards and then polished using 1 μm liquid diamond suspension. A 25 nm carbon coating was then applied to each sample prior to major element characterisation by EPMA.

Sample Analysis

EPMA tephra analyses were made by John Creech, and were made using a JEOL JXA-8230 Superprobe equipped with 5 wavelength dispersive x-ray spectrometers. Glass shards were analysed with an accelerating potential of 15kV, probe current of 8nA and a spot size of 20 μm , counting for 30 s and 15 s on peak and background, respectively. X-ray intensity calibrations were made against the MPI-DING rhyolite glass standard ATHO-G (Jochum *et al.*, 2006). Approximately 15 shards were analysed from each tephra unit. Repeat analyses were made on ATHO-G and the rhyolite glass standard VG-568 (Jarosweich *et al.*, 1980) to estimate the internal precision.

References:

Allan, A. S. (2008). *An elemental and isotopic investigation of Quaternary silicic Taupo Volcanic Zone tephra from ODP Site 1123: chronostratigraphic and petrogenetic applications*. (Unpublished M.Sc. thesis). Wellington: Victoria University of Wellington.

Jarosweich et al. (1980). *Geostandards Newsletter*, 4(1): 43-47

Jochum, K. P., et al. (2006), MPI-DING reference glasses for in situ microanalysis: New reference values for element concentrations and isotope ratios, *Geochem. Geophys. Geosyst.*, 7, Q02008, doi:10.1029/2005GC001060.

Hinakura Road Lower Tephra										<i>n</i>	15
No.	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	MnO		water
3	74.714	13.548	0.168	2.009	0.089	1.022	4.877	3.523	0.049		6.056
4	74.785	13.592	0.181	2.094	0.129	1.053	4.538	3.572	0.055		6.303
6	74.660	13.677	0.157	1.979	0.108	1.029	4.768	3.524	0.099		5.759
7	74.921	13.705	0.175	1.924	0.098	1.006	4.732	3.366	0.073		6.277
9	74.412	13.723	0.152	2.121	0.109	1.035	4.859	3.561	0.027		4.962
10	74.645	13.658	0.184	2.137	0.121	1.049	4.628	3.512	0.067		5.890
11	74.487	13.558	0.200	1.899	0.113	1.040	4.922	3.674	0.109		6.032
12	74.388	13.566	0.168	2.047	0.136	1.040	4.373	4.227	0.055		5.266
13	74.543	13.719	0.174	2.077	0.108	1.052	4.568	3.710	0.048		6.839
14	75.111	13.553	0.160	1.963	0.094	1.075	4.630	3.362	0.052		5.699
15	74.578	13.714	0.159	2.149	0.099	1.041	4.689	3.494	0.077		6.214
16	74.552	13.914	0.181	2.099	0.128	1.039	4.481	3.525	0.080		7.300
17	74.552	13.849	0.158	2.168	0.106	1.029	4.522	3.528	0.088		5.726
18	74.316	13.608	0.138	2.003	0.116	1.026	5.276	3.484	0.032		5.379
19	74.719	13.590	0.145	2.032	0.097	1.040	4.858	3.446	0.073		5.995
Mean	74.626	13.665	0.167	2.047	0.110	1.038	4.715	3.567	0.066		5.980
St Dev	0.21	0.11	0.02	0.08	0.01	0.02	0.22	0.20	0.02		0.59

Hinakura Road Upper Tephra										<i>n</i>	19
No.	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	MnO		water
2	74.561	13.853	0.150	1.876	0.105	1.090	4.828	3.479	0.057		7.084
3	74.505	13.692	0.150	1.893	0.103	1.029	4.942	3.630	0.055		5.145
4	74.318	13.796	0.159	1.965	0.119	1.049	4.813	3.754	0.026		5.410
5	74.564	13.672	0.162	2.157	0.131	1.064	4.493	3.710	0.047		6.390
6	74.484	13.683	0.154	2.016	0.128	1.033	4.804	3.590	0.109		6.480
7	74.322	13.809	0.179	1.899	0.097	1.061	5.013	3.551	0.068		6.284
8	74.444	13.777	0.167	1.925	0.118	1.031	4.909	3.590	0.039		5.839
9	74.252	13.813	0.184	2.007	0.109	1.053	5.011	3.476	0.096		6.991
10	74.017	13.887	0.150	2.039	0.104	1.071	4.975	3.703	0.055		6.558
11	73.966	13.801	0.171	2.141	0.145	1.067	5.100	3.532	0.077		5.411
12	74.476	13.741	0.163	1.974	0.099	1.052	4.783	3.604	0.107		6.363
13	74.518	13.707	0.156	2.006	0.130	0.992	4.665	3.761	0.066		5.162
14	74.329	13.868	0.153	2.118	0.123	1.049	4.905	3.404	0.050		6.016
15	74.265	13.755	0.140	2.083	0.113	1.084	4.920	3.563	0.077		5.261
16	74.436	13.704	0.179	1.977	0.106	1.093	4.912	3.515	0.078		6.101
17	74.310	13.759	0.188	2.222	0.118	1.038	4.881	3.485	0.000		5.746
18	74.672	13.682	0.153	2.052	0.100	1.022	4.651	3.597	0.072		7.053
19	74.443	13.637	0.170	1.960	0.100	1.045	4.994	3.584	0.067		5.468
21	74.355	13.798	0.200	1.915	0.128	1.119	4.890	3.595	0.000		6.525
Mean	74.381	13.760	0.165	2.012	0.115	1.055	4.868	3.585	0.060		6.068
St Dev	0.18	0.07	0.02	0.10	0.01	0.03	0.15	0.10	0.03		0.64

Lower Huangarua West Tephra										<i>n</i>	18
No.	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	MnO	water	
2	75.914	13.257	0.100	1.680	0.083	0.943	4.495	3.467	0.061	6.236	
3	76.089	13.138	0.102	1.482	0.065	0.927	4.538	3.616	0.043	6.155	
4	76.153	13.176	0.080	1.553	0.061	0.913	4.563	3.446	0.055	6.578	
5	76.167	13.245	0.096	1.550	0.066	0.935	4.404	3.477	0.059	7.950	
6	75.925	13.178	0.131	1.671	0.065	0.947	4.635	3.399	0.048	6.247	
9	76.064	12.932	0.103	1.809	0.056	0.935	4.576	3.466	0.059	6.178	
10	75.924	13.093	0.130	1.677	0.057	0.940	4.653	3.472	0.055	5.924	
11	75.896	13.215	0.098	1.624	0.062	0.951	4.659	3.431	0.062	7.192	
12	75.614	13.188	0.128	1.692	0.089	0.943	4.818	3.463	0.065	7.103	
13	75.823	13.333	0.096	1.701	0.084	0.942	4.659	3.363	0.000	6.996	
14	75.743	13.315	0.112	1.614	0.089	0.914	4.528	3.629	0.058	6.308	
15	75.655	13.298	0.120	1.873	0.092	0.939	4.425	3.600	0.000	7.210	
16	75.961	13.339	0.100	1.576	0.074	0.923	4.543	3.413	0.071	7.933	
17	75.903	13.226	0.140	1.738	0.048	0.921	4.531	3.493	0.000	6.606	
18	76.057	13.031	0.106	1.759	0.064	0.934	4.482	3.518	0.049	5.566	
19	75.844	13.301	0.100	1.561	0.053	0.953	4.586	3.546	0.056	7.440	
20	75.441	13.547	0.120	1.768	0.083	0.991	4.630	3.354	0.066	5.672	
21	75.837	13.070	0.108	1.778	0.070	0.911	4.690	3.487	0.049	5.657	
Mean	75.889	13.216	0.109	1.673	0.070	0.937	4.579	3.480	0.048	6.608	
St Dev	0.19	0.14	0.02	0.10	0.01	0.02	0.10	0.08	0.02	0.74	

Upper Huangarua West Tephra										<i>n</i>	33
No.	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	MnO	water	
3	76.161	12.953	0.109	1.477	0.059	0.794	4.687	3.695	0.064	3.416	
4	76.015	13.377	0.088	1.324	0.082	0.851	4.242	3.965	0.055	7.216	
5	75.725	13.349	0.100	1.481	0.071	0.869	4.628	3.711	0.067	3.860	
6	74.268	14.022	0.135	1.960	0.103	1.137	4.963	3.366	0.045	5.141	
8	75.770	13.223	0.092	1.568	0.062	0.871	4.815	3.588	0.010	3.940	
9	75.323	13.570	0.116	1.689	0.108	0.994	4.762	3.439	0.000	3.899	
10	76.307	13.148	0.052	1.273	0.061	0.783	4.704	3.673	0.000	3.541	
11	74.730	13.911	0.124	1.793	0.124	1.099	4.812	3.409	0.000	5.275	
12	76.125	13.024	0.072	1.467	0.053	0.765	4.602	3.893	0.000	3.713	
13	76.037	13.301	0.097	1.243	0.032	0.845	4.737	3.707	0.000	3.451	
14	78.048	13.482	0.109	1.193	0.037	0.824	2.578	3.728	0.000	5.001	
15	74.536	13.910	0.109	1.808	0.101	1.100	4.693	3.743	0.000	5.334	
16	75.058	13.587	0.125	1.816	0.075	1.082	4.779	3.477	0.000	3.823	
17	76.173	13.214	0.120	1.423	0.048	0.788	4.614	3.619	0.000	4.972	
18	74.769	13.839	0.117	1.862	0.097	1.046	4.910	3.360	0.000	4.950	
19	74.928	13.625	0.100	1.884	0.080	1.096	4.909	3.379	0.000	4.930	
20	76.013	13.473	0.093	1.328	0.064	0.829	4.431	3.770	0.000	7.738	
21	76.325	13.191	0.072	1.307	0.061	0.774	4.725	3.545	0.000	4.436	
22	76.093	13.226	0.083	1.479	0.055	0.795	4.574	3.696	0.000	3.493	
3	74.993	13.942	0.123	1.840	0.091	1.078	4.481	3.453	0.000	5.815	
4	75.416	13.467	0.097	1.699	0.052	0.976	4.873	3.419	0.000	4.486	
5	76.222	13.091	0.074	1.431	0.050	0.786	4.738	3.608	0.000	4.061	
6	74.402	14.088	0.119	1.932	0.100	1.230	4.711	3.417	0.000	5.716	
7	75.913	13.466	0.089	1.372	0.075	0.890	4.699	3.496	0.000	3.741	
8	75.830	13.439	0.097	1.439	0.087	0.893	4.724	3.490	0.000	4.390	
10	74.621	13.925	0.132	1.977	0.102	1.188	4.568	3.486	0.000	5.339	
11	75.951	13.482	0.103	1.445	0.076	0.884	4.605	3.454	0.000	5.269	
13	74.405	13.905	0.120	1.950	0.088	1.097	5.022	3.412	0.000	3.732	
14	75.781	13.372	0.085	1.511	0.068	0.901	4.743	3.538	0.000	4.079	
15	76.228	13.184	0.079	1.439	0.063	0.821	4.683	3.503	0.000	4.299	
16	74.589	13.904	0.128	1.915	0.109	1.129	4.963	3.262	0.000	4.877	
17	75.083	13.917	0.115	1.927	0.083	1.047	4.228	3.599	0.000	2.889	
22	74.793	13.787	0.121	1.896	0.098	1.037	4.844	3.424	0.000	3.687	
Mean	75.534	13.527	0.103	1.611	0.076	0.948	4.638	3.555	0.007	4.561	
St Dev	0.81	0.33	0.02	0.25	0.02	0.14	0.41	0.16	0.02	1.06	

Upper Te Muna Tephra										<i>n</i>	17
No.	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MgO	CaO	Na ₂ O	K ₂ O	MnO		water
24	75.485	13.564	0.16	1.445	0.118	0.998	4.728	3.5	0	0	3.349
25	75.405	13.579	0.136	1.539	0.153	0.996	4.785	3.408	0	0	3.01
26	75.452	13.757	0.118	1.557	0.138	1.015	4.572	3.391	0	0	4.135
27	75.357	13.576	0.149	1.4	0.148	1.041	4.78	3.549	0	0	3.111
28	75.195	13.627	0.141	1.541	0.135	1.012	4.758	3.593	0	0	2.64
29	75.75	13.525	0.164	1.471	0.101	1.04	4.665	3.284	0	0	3.809
30	75.52	13.795	0.141	1.467	0.139	1.029	4.383	3.526	0	0	4.03
31	75.555	13.488	0.175	1.478	0.126	1.008	4.807	3.362	0	0	3.123
32	75.331	13.462	0.141	1.601	0.156	1.033	4.816	3.46	0	0	3.303
33	75.488	13.496	0.114	1.514	0.138	0.969	4.852	3.43	0	0	3.165
34	75.416	13.499	0.199	1.577	0.15	1.046	4.679	3.434	0	0	3.827
35	75.389	13.671	0.159	1.514	0.162	0.999	4.667	3.44	0	0	3.657
36	75.47	13.503	0.148	1.62	0.153	1.013	4.631	3.462	0	0	3.783
38	75.585	13.374	0.173	1.415	0.166	0.99	4.882	3.414	0	0	3.469
39	75.372	13.609	0.143	1.433	0.127	1.016	4.81	3.491	0	0	3.672
40	75.497	13.498	0.172	1.496	0.146	1.014	4.864	3.313	0	0	3.432
43	75.428	13.617	0.143	1.432	0.166	1.027	4.651	3.535	0	0	4.113
Mean	75.453	13.567	0.152	1.500	0.142	1.014	4.725	3.447	0.000		3.508
St Dev	0.12	0.11	0.02	0.07	0.02	0.02	0.13	0.08	0.00		0.42
Lower Te Muna Tephra										<i>n</i>	15
Analysed by Allan (2008)											
	77.50	12.60	0.13	1.18	0.10	0.91	3.44	3.80	0.09		4.40
St Dev	0.24	0.14	0.04	0.15	0.02	0.13	0.12	0.27	0.05		0.70

Appendix Five

Location Conversion

	NZTopo 50	NZMS260
Ahiaruhe Formation Type Section	BP34 173 478	S27 273 095
Big Bend	BQ34 079 263	S27 179 880
Blue Rock Hautotara Section (BH)	BQ33 026 231	S27 126 848
Blue RockRace Section (BR)	BQ33 026 229	S27 126 846
Clay Creek Section (CC)	BQ33 014 203	S27 114 820
Duggan Ash	BQ33 028 231	S27 128 848
Gammate Structures in Te Muna Formation	BQ34 089 276	S27 189 893
Greycliffs Fm - Pukenui Limestone Contact (Fig 2.3)	BQ34 072 234	S27 172 851
Hinakura Road Lower Tephra	BQ34 144 304	S27 244 921
Hinakura Road Section (HR)	BQ34 145 304	S27 245 921
Hinakura Road Upper Tephra	BQ34 144 305	S27 244 922
Huangularua West Section (HW)	BQ34 094 303	S27 194 920
Huangularua-lower Tephra	BQ34 089 303	S27 189 920
Huangularua-upper Tephra	BQ34 094 303	S27 194 920
Lake Ferry	BQ32 793 152	R28 893 769
Lower Popes Head Tephra	BQ34 145 306	S27 245 923
Lower Te Muna Tephra	BQ34 089 276	S27 189 893
Oystershell Road	BQ34 120 316	S27 220 933
Popes Head	BQ34 141 315	S27 241 932
Proposed Pukenui Limestone Reference Section	BQ34 075 253	S27 175 870
Pukenui 2 Trig Station	BQ33 035 202	S27 135 819
Rataul outcrop (Chapter 2.3.2)	BQ34 097 302	S27 197 919
Ruakokoputuna Bridge Cliff Section (Rk)	BQ33 038 225	S27 138 842
Ruawaka	BQ34 085 267	S27 185 884
Ruawaka Section (Rw)	BQ34 086 267	S27 186 884
Te Muna Type Section	BQ34 089 276	S27 189 893
The Hautotara Bridge (Banana Bridge)	BQ34 072 254	S27 172 871
Type locality of the Pukenui Limestone	BQ34 070 234	S27 170 851
Upper Popes Head Tephra	BQ34 145 305	S27 245 922
Upper Te Muna Tephra	BQ34 089 276	S27 189 893
Waipuna	BQ33 025 228	S27 125 845

Appendix Six

Macrofossil Identification

Bivalvia

Unit Name	CC2	CC4	CC5	CC6	CC7	CC8	R41	R42	R43	R45	R46	R47	R48	HW2	HW4	HR4	HR6	HR7	HR9	R4G	O4 R
Facies	SBz	SBz	Sw	SBz	Sw	SBz	Cf	Sd	SBz	Cg	Cg	Sp	SBt	SBal	Sa	Sbal	SBz	Sz	Sz	Sp-w	Sd
<i>Glycymeris shrimpstoni</i>							X		X	X	X					X	X	X	X		
<i>Glycymeris (Glycymerula) modesta</i>									X	X	X			X			X	X	X		
<i>Tucetona laticostata</i>							X														
<i>Limnoperna huttoni</i>																					
<i>Atrina pectinata zelandica</i>							X						X								
<i>Zygochlamys delicatula</i>																					
<i>Talochlamys gemmulata</i>		X					X				X										X
<i>Mesopeplum convexum</i>																					
<i>Limatula maoria</i>													X								
<i>Ostrea chilensis</i>		X													X						
<i>Fellaniella zelandiae</i>							X														
<i>Mytiliella sp.</i>				X	X		X		X												X
<i>Cardita aoteana</i>			X																		
<i>Pleuromeris sp.</i>			X				X														
<i>Purpurocardia purpurata</i>							X														
<i>Spisula crassitesta</i>																					
<i>Zenatia acinaces</i>																					
<i>Paphies australis</i>							X			X			X	X							
<i>Barytellina crassidens</i>														X							
<i>Gari lineolata</i>							X	X	X												
<i>Dosina zelandica</i>														X		X		X			
<i>Austrovenus stutchburyi</i>														X	X						
<i>Circomphalus parvus</i>							X														X
<i>Circomphalus yatei</i>																X		X	X		
<i>Tawera subsulcata</i>	X	X	X	X			X			X	X		X				X				X
<i>Dosinia (Fallartemis) lambata</i>									X												
<i>Dosinia (Phacosoma) subrosea</i>							X	X								X	X				
<i>Eumarcia plana</i>							X														
<i>Panopea zelandica</i>																					
<i>Pholad</i>																					
<i>Myadora waitotara</i>				X			X		X							X	X				X

Gastropoda

Unit Name	CC2	CC4	CC5	CC6	CC7	CC8	R41	R42	R43	R45	R46	R47	R48	HW1	HW2	HR4	HR6	HR7	HR9	R4G	O4 R
Facies	SBz	SBz	Sw	SBz	Sw	SBz	Cf	Sd	SBz	Cg	Cg	Sp	SBt	SBal	Sa	Sbal	SBz	Sz	Sz	Sp-w	Sd
<i>Micrelenchus sp.</i>			X				X		X	X	X		X				X				X
<i>Trochus (Coelotrochus) tiaratus</i>									X	X	X	X									X
<i>Antisolarium egenum</i>															X						X
<i>Zethalia zelandica</i>	X	X	X	X		X	X		X	X	X			X			X	X	X	X	
<i>Calliostoma (Maurea) hawera</i>																					X
<i>Pisina sp.</i>							X														
<i>Zeacumantus lululentus</i>											X			X		X					
<i>Stiracolpus symmetricus</i>																					X
<i>Zeacolpus sp.</i>		X																			
<i>Zeacolpus (Zeacolpus) vittatus</i>							X							X							X
<i>Pellicaria vermis</i>			X	X			X			X										X	X
<i>Struthiolaria (Struthiolaria) papulosa</i>							X														X
<i>Zegalerus tenuis</i>				X			X				X									X	X
<i>Tanea zelandica</i>										X											X
<i>Taniella planisuturalis</i>																	X				X
<i>Aeneator sp.</i>							X														X
<i>Austrofusus sp.</i>									X			X									
<i>Austrofusus cottoni</i>											X										
<i>Cominella (Eucominella) elegantula</i>										X											
<i>Xymene sp.</i>																					X
<i>Xymene ambiguus</i>																					
<i>Xymene drewi</i>							X			X											
<i>Xymene expansus</i>												X									
<i>Amalda (Baryspira) australis</i>							X	X			X					X	X				
<i>Amalda (Baryspira) depressa</i>									X		X			X						X	
<i>Amalda (Baryspira) mucronata</i>																					X
<i>Amalda (Baryspira) opima</i>																					
<i>Alciiothoe sp.</i>							X														
<i>Alciiothoe arabica</i>								X			X										
<i>Alciiothoe fusus</i>							X										X				X
<i>Patellacea</i>																					

"Others"

Unit Name	CC2	CC4	CC5	CC6	CC7	CC8	R41	R42	R43	R45	R46	R47	R48	HW1	HW2	HR4	HR6	HR7	HR9	R4G	O4 R
Facies	SBz	SBz	Sw	SBz	Sw	SBz	Cf	Sd	SBz	Cg	Cg	Sp	SBt	SBal	Sa	Sbal	SBz	Sz	Sz	Sp-w	Sd
<i>Pseudechinus novaezealandiae</i>			X	X																	
<i>Austromegabalanus decorus</i>																					X
<i>Fosterella tubulatus</i>			X	X																	X
Undifferentiated Barnacle Plates																					
<i>Bryozoa</i>	*			X	X												X	X			
Worm Tubes				X	X												X				X
<i>Fellaster zelandiae</i>									X												
<i>Crab chelae</i>																					
Whale Bone																					
<i>Antalis nana</i>																					

* Large Bryozoan colony (Figure A6.1)

Bivalvia

Gastropoda

"Others"