MICHAEL ROBERT JOHNSTON

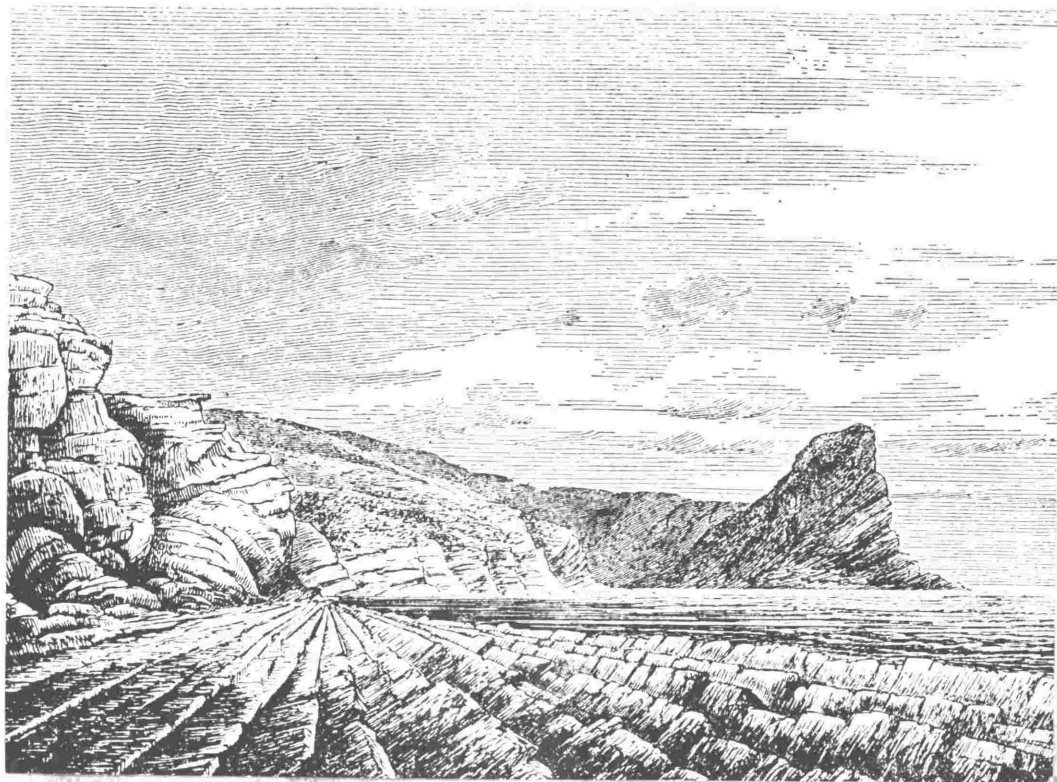GEOLOGY OF THE TINUI DISTRICT

Thesis submitted for the degree of

Doctor of Philosophy in Geology

at

Victoria University of Wellington

September 1971

Frontispiece: Shore platform, south of Castlepoint,
showing graded beds of the Whakataki
Formation; from a sketch by Captain
W.M. Smith.

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(abridged captions)

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ABSTRACT

The Tinui District is assumed to be typical
of the more deformed part of the New Zealand
Mobile Belt. It contains an unusually complete
stratigraphic record, rocks representing most
stages from Upper Jurassic to Recent being
present. Although the rocks are strongly deformed,
the complex diapiric structures that occur in
the northeast of the mobile belt are absent.

The stratigraphy is described in terms of
formations which are then used to infer the
paleogeography for eight periods of time.

An attempt is made to treat the structure
according to its development with time. The
main conclusion is that there was a change in
the strike of the fold axes and in the sense of
movement of the faults. Strong folds, striking
approximately northeast, are Paleocene in age
and weak folds, striking approximately north,
are post-Miocene. There are two fault trends,
one NNE and the other ENE. The ENE striking
faults were dominant in the Early Cenozoic and
the NNE striking faults were dominant in the
Late Cenozoic. The sense of movement on the

NNE faults changed from sinistral to dextral. The change in the direction of the fold axes and in the sense of movement on the faults can be expressed as a change in the direction of maximum horizontal shortening, which is inferred to have changed with time.

It is also found that the rates of tilting, and probably faulting, have not been constant with time, but occurred as bursts (disturbances) in the Paleocene, Early Miocene, Late Pliocene, and Late Quaternary. The Mesozoic part of the geological history of the Tinui District is scrappy and far less complete than the Cenozoic part.

In order to place the Tinui District in a broader setting, the central part of the New Zealand landmass in the Cenozoic, called the New Zealand Mobile Belt, is discussed in some detail. The mobile belt consists of fault blocks which form a geanticline along the New Zealand landmass and a geosynclinal trough between the east coast and the Hikurangi Trench. It is shown that a clear distinction has to be made between tilting and uplift.

A main feature of the New Zealand Mobile
Belt is the dextral faulting, on major NNE
striking faults, in the Late Cenozoic. A major
reversal in the direction of maximum horizontal
shortening was found in the Tinui District to
have taken place at the beginning of the Miocene
or in the Oligocene. The reversal indicates
that the dextral faulting of the New Zealand
Mobile Belt may have started at that time, and
that earlier strike-slip movement had been
sinistral. This conclusion contradicts existing
reconstructions of the New Zealand landmass
with time, and a more complex reconstruction is
required to satisfy the tectonics of the Tinui
District.

INTRODUCTION - THE PROBLEM

The east coast of New Zealand, from Kaikoura to East Cape, is complexly folded and faulted and can be contrasted with the more stable classical regions of New Zealand such as those in the west and southeast of the South Island. In the classical regions a single major unconformity separates younger, gently dipping, fossiliferous rocks from older, complexly folded, sparsely fossiliferous rocks. In the East Coast Region there is no one single unconformity. Instead there are several. Steep dips, poor exposures, and extensive superficial slumping make the geology difficult to interpret. As compared with most other regions of New Zealand the East Coast Region as a whole is little known, and this gap in geological knowledge prohibits a complete understanding of the stratigraphy, structure and paleogeography of New Zealand.

The Tinui District (Fig. 1) is representative of the East Coast Region. It lies near the centre of the region and is 300 square miles in area and comprises the eastern part of Sheet N158, Masterton, and all of Sheet N159, Tinui, N.Z.M.S.1. (Figs. 2, 3, in pocket at back).

It contains the biggest range of ages from Upper Jurassic to Recent (Fig. 4) of any district in the east coast of the North Island. Several strike-slip faults exist and earthquakes have occurred nearby in historic times. Rates of tilting as high as $30/10^6$ years have been recorded from Upper Pleistocene and Holocene rocks on the coast to the north and south of the district. In the north of the Tinui District fold axes in Cretaceous-Lower Tertiary rocks are at an appreciable angle to the fold axes in Upper Tertiary rocks (Ongley, 1935), indicating that the direction of maximum horizontal shortening has changed. The high tilt rates, different fold directions and the unusually complete record of sedimentation were expected to permit the change of tectonics of the region with time to be determined.
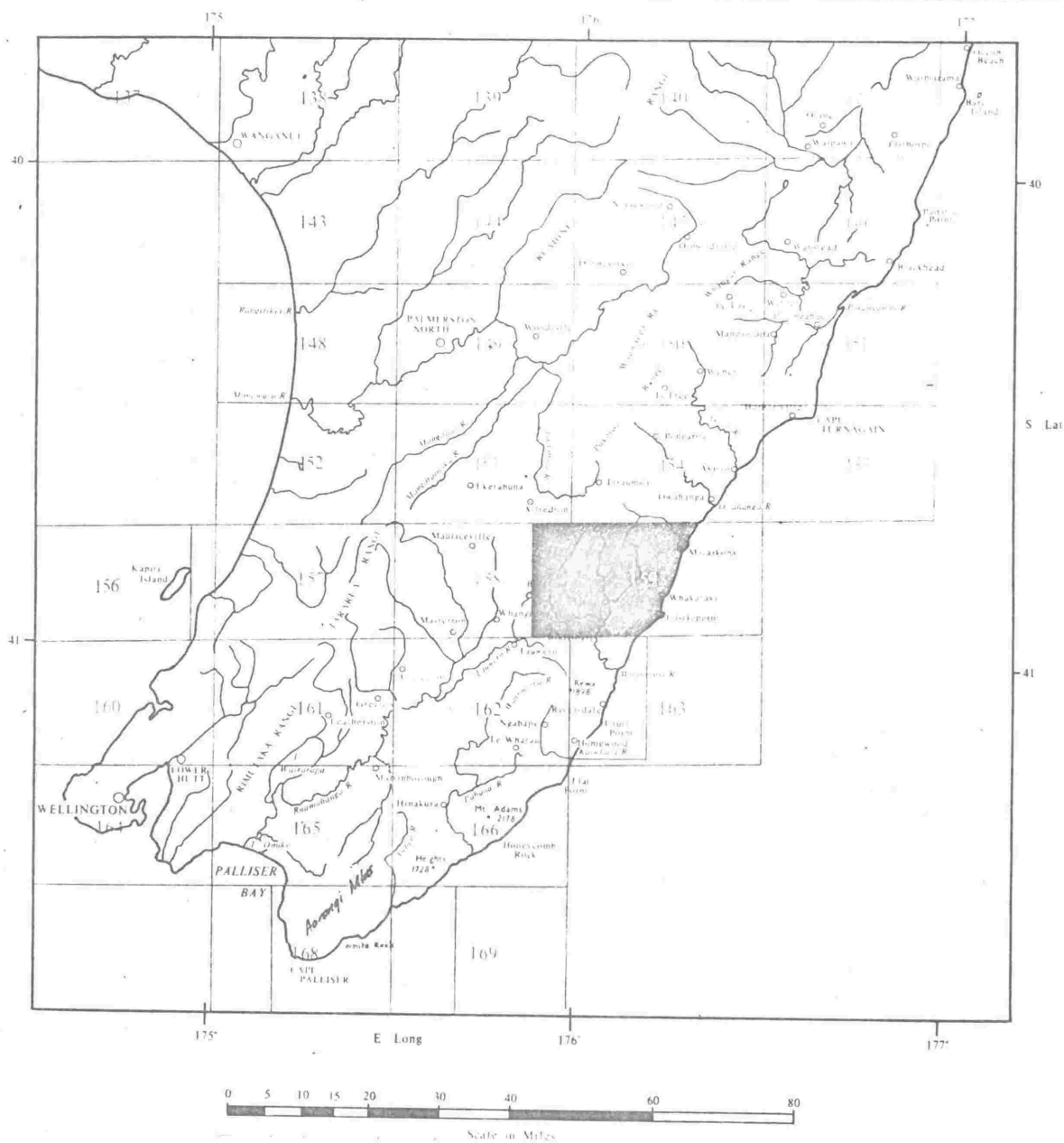
Fig. 1. Map of the southern part of the North Island,
showing N.Z.M.S. 1 sheet boundaries and the limits
of the Tinui District.
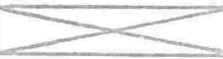
GROUP	FORMATION	STAGE	SERIES			YRS. ×10⁶	AVERAGE DURATION OF EACH STAGE
	(SEVERAL FORMATIONS)		HOLOCENE		QUATERNARY		< 1×10⁶ yrs
		HAWERA		PLEISTOCENE			
	CASTLE POINT	CASTLECLIFFIAN	WANGANUI				
		NUKUMARUAN					
		MANGAPANIAN		PLIOCENE			
		WAIPIPIAN					
	RANGIWHAKAOMA	OPOITIAN				3·3	
HURUPI	NGARATA / WAIHOKI	KAPITEAN	TARANAKI				4×10⁶ yrs
		TONGAPORUTUAN					
	MAUNSELL	WAIAUAN	SOUTHLAND	MIOCENE	TERTIARY		
		LILLBURNIAN					
ANNEDALE	TAKIRITINI	CLIFDENIAN					
		ALTONIAN	PAREORA			25	
	WHAKATAKI	OTAIAN					
		WAITAKIAN					
	WEBER	DUNTROONIAN	LANDON	OLIGOCENE			3×10⁶ yrs
		WHAINGAROAN					
WANSTEAD		RUNANGAN	ARNOLD	EOCENE			
		KAIATAN					
		BORTONIAN					
	HUATOKITOKI	PORANGAN					
		HERETAUNGAN	DANNEVIRKE				
		MANGAORAPAN					
		WAIPAWAN					
TINUI	WHANGAI / WAIPAWA	TEURIAN		PALEOCENE		65	
	TE MAI	HAUMURIAN	MATA		CRETACEOUS		5×10⁶ yrs
		PIRIPAUAN					
	GENTLE ANNIE / GLENBURN	TERATAN	RAUKUMARA	UPPER			
		MANGAOTANEAN					
		AROWHANAN					
MANGAPURUPURU	SPRINGHILL	NGATERIAN	CLARENCE				
	MARINGI	MOTUAN					
		URUTAWAN				106	
		KORANGAN	TIATIA	LOWER			
		MOKOIWIAN					
TORLESSE SUPER GROUP	TAIPO						
	WAEWAEPA	PUAROAN	OTEKE		JURASSIC	146	

Fig. 4. Stratigraphic Outline, Tinui District.

PHYSIOGRAPHY AND STRATIGRAPHY OF THE
TINUI DISTRICT

PHYSIOGRAPHY

The Tinui District is bounded in the east
by a fairly straight coastline containing
only one promontory - the headland and reef
at Castlepoint. The district is hilly and
is divided into two parts by the valley of the
south flowing Whareama River. Hills east of
the river reach a height of 1,557 ft at Mt Percy
and those west of the river reach a height of
1,704 ft at Mangapurupuru. Many of the hills
in the west have strikingly rugged profiles
and because of their unusual shape are locally
called "taipos". Most of the district is in
grass and is used for sheep farming. In the
east there are large areas of thick scrub and
regenerating bush and some plantations of
exotic pines.

The hills are dominantly of Cretaceous
and Upper Jurassic rocks. In the Whareama
Valley and on the coast the rocks are dominantly
Tertiary (Fig. 5).

Fig 5. GENERALISED STRUCTURAL MAP of the
TINUI DISTRICT and ADJOINING AREA

(Geology of area surrounding the Tinui District
adopted from Kingma, 1967)

Map labels: DEPRESSION, HIGH, ANTICLINAL, BIDEFORD, BLAIRLOGIE, WHAREAMA, TAWHERO, SYNCLINAL, Castlepoint

Rivers: Owahanga River, Mataikona River, Tauweru River, Whareama River

Strike/dip values: 15, 153 154, 158 159, 15, 25, 20, 2, 60, 40, 162 163

N

5 0 5 miles

Legend:
Upper Tertiary-Quaternary

Lower Tertiary-Upper Cretaceous

Lower Cretaceous Upper Jurassic

Regional strike and dip of Upper
Tertiary beds

Fault controlling drainage

Point of River capture by western
tributaries of the Whareama River

STRATIGRAPHY

PREVIOUS GEOLOGICAL WORK

The only accounts of the geology prior to 1930 were those by A. McKay (1877), Park (1888), W.A. McKay (1899) and Morgan (1910, 1914). In the early 1930s the northern part of the sheet was mapped in detail by Mr M. Ongley but only a small scale map (Ongley, 1935) and brief descriptions were published (Ongley, 1933; 1934; 1935; 1936a). Some of the Cretaceous rocks are highly fossiliferous and were referred to by Wellman (1959) and a small Cretaceous area was mapped by Haskell (1964). A small area of Tertiary rocks in the north of the district was mapped by Ridd (1967). A late Quaternary tectonic map of the western part (Sheet N158) has been published (Lensen, 1968).

GEOLOGICAL TIME SCALE

The presently accepted sequence of New Zealand Cenozoic stages is that of Finlay and Marwick (1947) with the following modifications:

Scott (in press) has shown that the Altonian Stage overlaps the type Hutchinsonian and the type Awamoan. The Altonian is widespread but

the Awamoan and Hutchinsonian are local. The
following changes have been proposed. The Pareora
Series will contain two stages only: the Otaian (Po)
and a new Altonian (Pl). The new Altonian
contains the Hutchinsonian, Awamoan and the
lower part of the old Altonian. The upper part
of the old Altonian is added to the old Clifdenian
to form the new Clifdenian. The revision of
the Wanganui Series stages by Beu (1969) is
adopted in Fig. 4.

The presently accepted sequence of New
Zealand Cretaceous stages is that of Wellman
(1959). Wellman proposed 12 stages, 10 of them
new. The stages with the exception of the
Korangan and the Teurian, are based largely on
species of Inoceramus. The Teurian was later
placed in the lowermost Tertiary Dannevirke
Series (Hornibrook, 1962). The remaining
Cretaceous sequence was modified by Hall (1963)
who showed that the Coverian stage was equal
to the Ngaterian and proposed that the Coverian
stage be abandoned.

The numerical time scale in Fig. 4 is
approximate, being based on only a few accurately
dated points (for example see Berggren, 1969).
However, it gives the length of stages sufficiently

accurately so that rates of tilting can be calculated.

PRESENT MAPPING

The writer spent ten months mapping the Tinui District. Field sheets, prepared by the writer from aerial photographs, were on a scale of 4 inches to a mile. Mapping was based on formations of which 22 are recognised. In Figs. 2 and 3, which are from Johnston (in press a;b), each formation is represented by a mapping symbol consisting of two letters. For most formations the age is reasonably well defined by either foraminifera or macrofossils. Ages given by various species of Inoceramus are based on identifications by the writer. Ages given by other fossils have been provided by those paleontologists acknowledged at the end of this thesis. A list of fossil localities is given in Appendix I.

MESOZOIC STRATIGRAPHY

Torlesse Supergroup

Indurated greywacke and argillite beds,
thick greywacke lenses with minor conglomerates,
spilites and associated volcanic derived rocks
make up the Torlesse Supergroup.

Waewaepa Formation (Waewaepa Series; Ongley, 1935) ew

The Waewaepa Series, named from the Waewaepa
Range, was introduced by Ongley (1935) for a
thick sequence of dominantly greywacke-argillite
beds. It crops out extensively in the west
and occurs as a small faulted inlier in the
northeast. It consists of severely crushed,
graded greywacke-argillite beds, with scattered
greywacke and conglomerate beds, rare limestone
lenses, and interbedded spilites. Zeolite
veins are common. The conglomerates contain
well-rounded greywacke pebbles and a few,
commonly highly polished, pebbles of extrusive
and intrusive igneous rocks.

The formation is at least tens of thousands
of feet thick, but because of structural
complexity its true thickness is uncertain.

Indeterminable <u>Inoceramus</u> fragments occur
rarely. A limestone boulder (N159f435) found
in the North Branch of Makirikiri Stream
(N159/464818) by Mr M. Ongley and Dr J. Marwick
and assumed to have been derived from the
formation contained <u>Buchia</u> cf. <u>hochstetteri</u>
Fleming (C.A. Fleming, <u>pers. comm.</u>), indicating
an uppermost Jurassic (Puaroan Stage) age.

<u>Taipo Formation</u> (Taipo Beds, Hutton, 1872) et

 The name Taipo Beds was used by several
writers for rocks that form the taipos. The
name is here used for thick beds of massive,
medium to dark grey greywacke, of pre-Tertiary
age. A 3,200 ft thick section from the
Mangapokia Valley (N158/447665) to the Mangapakeha
Valley (N158/448669) is here designated the type.
The line of section crosses several conspicuous
taipos and the place is named "The Taipos".
Bedding is rarely discernable in most outcrops
although the strike can commonly be seen on aerial
photographs. The formation contains a few thin
lenses of conglomerate, and the conglomerates
contain pebbles of the same rocks as those

in the Waewaepa Formation. Thin sequences of
interbedded greywacke-argillite beds occur locally.
The formation is unconformably overlain by the
Mangapurupuru Group and almost certainly grades
down into the Waewaepa Formation. The maximum
observed thickness is 7,200 ft.

No fossils, other than rare plant and
Inoceramus fragments, have been found. The
age of the formation is inferred from its
stratigraphic position to be uppermost Jurassic
to lowermost Cretaceous.

Mangapurupuru Group

The name Mangapurupuru Series was first
used by Mr M. Ongley on his field sheets of the
former Eketahuna Subdivision for rocks now
known to be largely of Clarence and Raukumara
age. The name was never formally defined and is
here introduced as a group name. The group
unconformably overlies the Torlesse Supergroup
and conformably underlies the Tinui Group. It
consists of grey, commonly bluish-grey,
fossiliferous mudstone, siltstone and graded
beds.

<u>Maringi Formation</u> (new formation) um

The formation is named after Maringi Trig. station (N158/433813), north of Makirikiri Stream. A section 3,100 ft thick exposed in Makirikiri Stream (N158/443765 to 448758) is proposed as the type (Fig. 6). The formation crops out in the west of the district. It consists of a basal conglomerate, 50 ft thick, indurated grey siltstone and occasional graded beds, and layers of <u>Inoceramus ipuanus</u> Wellman   . shells at its top.

In the west the formation grades into a pebbly siltstone named the Bideford Member. A 900 ft thick section exposed along Coopers Road (N158/368756 to 385766) is proposed as the type section for the member. The relations with the overlying and the underlying formations are unknown.

The formation contains numerous fossils, including <u>Inoceramus</u> cf. <u>kapuus</u> Wellman, <u>I</u>. <u>ipuanus</u> Wellman, <u>Aucellina euglypha</u> Woods, ammonites, echinoids, nautiloids, belemnites and foraminifera, indicating a ?Urutawan and Motuan age.

Fig. 6. Stratigraphic Columns

CENTRE STREAM—REWA STREAM

Glauc. sstne. beds. Belemnites, Kossmaticeras.
159/770

gy. glauc. siltstone,
159/613

gy. mstne; concretions

gy. siltstone with sandstone beds & concretions
159/557
159/520

gy. mstne; scatt. thin sstne & siltstone beds.
159/780, 785

Burk Fault

gy. mstne; scatt. thin siltstone beds & concrs.

gy. mstne; scatt. large concretions
159/774

gy. mstne; scatt. thin siltstone & sstne beds.

gy. sstne.

gy. sstne; well bedded, ripple marks

gy. siltstone; scatt. sstne beds, concrs.

gy. siltstone, layers of Inoceramus fragments.
159/774

490759

SPRINGHILL (Type Section)

468770
467772

TARGET STREAM

FORMATION   GRID REF.   Fossil Record No.

SPRINGHILL

450748

158/712

Core of Mangapurupuru Syncline

mass. gy. mstne; scatt. large subspherical concretions with numerous macrofossils

gy. mstne; scatt. siltstone beds & concrs.

gy. siltstone; thin sstne beds
158/781

gy. siltstone; layers of Inoceramus shell frags.
158/780

lam. sstne–siltstone

gy. siltstone

sstne with thin siltstone beds

gy. sstne

F 158/tryp

mass. siltstone; angular chips of siltstone & sstne.

gy. siltstone; thin scatt. sstne beds, fossils
158/548,710

sstne–siltstone; grades fossils
158/709,774

sstne–mstne; ymb 1995
715,778,1777

UNCONFORMITY

argillite with thick spoke beds

448758

443765

443765

MARINGI (Type Section)

FEET
0
500
1000

Springhill Formation (new formation) us

The formation consists dominantly of massive
mudstone or siltstone containing numerous
fossiliferous concretions. It crops out
extensively in the west and is named after
Springhill Station in the south branch of
Makirikiri Stream. A 6,000 ft section, between
Centre Stream (N159/468770) and Rewa Stream
(N159/490759), is proposed as the type (Fig. 6).
Its base is defined as the base of massive
siltstone conformably overlying the top of the
Maringi Formation. Its top is defined as the
base of the conformably overlying Te Mai Formation.
Between Mt Cameron and Mangapurupuru, lenses of
ripple bedded sandstone, upto 450 ft thick, form
conspicuous scarps. East of Mt Cameron thin
poorly graded sandstone beds crop out. In the
Mangapakeha and Mangapokia valleys the formation
contains a basal conglomerate and unconformably
overlies the Torlesse Supergroup.

The formation is richly fossiliferous.
Inoceramus species include I. ipuanus Wellman,
I. hakarius Wellman, I. fyfei Wellman, I. nukeus
Wellman, I. opetius Wellman, I. urius Wellman,
I. pacificus Woods and I. n.sp. aff. concentricus
Park. Ammonites are not uncommon as is the

belemnite <u>Dimitobelus</u> <u>superstes</u> (Hector). The
fossils are of Motuan, Ngaterian, Arowhanan,
Mangaotanean, Teratan and Piripauan age.

<u>Gentle Annie Formation</u> (new formation) ua

The formation consists of a chaotic mixture
of angular to rounded, dark grey to black chips
of sandstone in a fine grained matrix. It crops
out in the upper Mangapakeha Valley where a
1,000 ft thick section (N158/400701 to 415708)
in Gentle Annie Stream is proposed as the type.
The formation unconformably overlies the Torlesse
Supergroup and is in thrust contact with the
upper part of the Maringi Formation.

Sandstone blocks in the formation contain
probable Motuan fossils and many of the chips
are highly polished. The formation is interpreted
as a breccia caused by the gravity sliding of
the lower part of the Maringi Formation during
Raukumara time.

<u>Glenburn Formation</u> (Eade, 1966) ug

According to Eade (1966) the Glenburn
Formation in the Mt Adams area consists of
graded beds, commonly conglomeratic, of Ngaterian
and Arowhanan age. The formation is here expanded

to include all graded beds of Cretaceous age
younger than those of the Torlesse Supergroup.
It crops out in the northeast of the Tinui
District as a NNE striking strip that extends
from the head of the west branch of the Whakataki
River into Sheet N153 and as three faulted
inliers in Smith Creek. It consists of 800 ft
of poorly bedded light grey siltstone and fine
sandstone overlain by about 5,000 ft of graded
beds. Flute casts indicate a northwest sediment
source.

Species of _Inoceramus_, commonly abundant
at the base of many of the graded beds, include
I. _rangatira_ Wellman, I. _bicorrugatus_ Marwick,
I. _opetius_ Wellman, I. _nukeus_ Wellman, and
I. _pacificus_ Woods. No diagnostic microfossils
were obtained. The fossils are of Arowhanan,
Mangaotanean, Teratan, and Piripauan age.

Tinui Group (Tinui Series; Ongley, 1935)

The Tinui Group, comprising rocks formerly
mapped as Tapuwaeroa, Whangai, and Waipawa
formations, conformably overlies the Mangapurupuru
Group and underlies unconformably the Wanstead Group.
Most of the rocks are poorly calcareous; some are
non-calcareous, and some are stained yellow by
jarosite.

Te Mai Formation (new formation) tt

The formation crops out extensively and
consists of well-bedded alternating sandstone
and siltstone, commonly cross-bedded with
interbedded thick grit and conglomerate beds.
A section 3,000 ft thick in the head of Puketewai
Stream (N159/671860 to 661864) is proposed as the
type. The formation conformably overlies the
Glenburn Formation in the east and the Springhill
Formation in the west. Conglomerates are abundant
in the east, but are known from two localities
only in the west. At one, in the lower Whakarora
Valley, the conglomerate is at the base of the
formation and unconformably overlies the
Springhill Formation. In the west a 5 ft thick,
red, volcanic derived siltstone crops out in
the lower part of the formation. Because of
faulting and probable lateral transition into
the Whangai Formation the true thickness of the
formation is not known, but it is not less
than 5,000 ft.

Fossils include Inoceramus pacificus Woods,
I. australis Woods, I. matatorus Wellman,
Dimitobelus? ongleyi Stevens, D. lindsayi (Hector),
Ostrea lapillicola Marwick and foraminifera.
The formation also contains Dimitobelus superstes

(Hector) which is considered to be derived from
the Springhill Formation. The age of the
formation is Piripauan, Haumurian, and Teurian.

Whangai Formation (Whangai Series; Quennell and Brown, 1937) tw

The Whangai Formation crops out extensively
and consists of light to dark grey, poorly-bedded
indurated siltstone with scattered calcareous
concretions, and glauconitic sandstone as beds
and dikes. The siltstone contains small flakes
of hydromica, scattered glauconite grains and is
commonly slightly calcareous. Locally it is
sufficiently calcareous to be a clayey limestone.
In the east glauconitic sandstone occurs as
beds upto 40 ft thick and as dikes upto 1 ft
thick. In the west the glauconitic sandstone
beds are upto 2 ft thick and there are no
dikes. The formation weathers to an orange-brown
colour and exposed surfaces are commonly
covered with a yellow efflorescence of jarosite.
It is about 5,000 ft thick in the Tinui District.

Worm tubes, and Nucula and Nuculana fragments
are scattered throughout the siltstones but
are useless for dating. Foraminifera are
commonly abundant. They indicate a Teurian age

with the base of the formation possibly extending down into the Haumurian.

Waipawa Formation (Waipawa Black Shale; Finlay, 1940) tp

The formation consists of lenses of dark siltstone, with high organic content that lie within the Whangai Formation. Two lenses, each less than 100 ft thick are exposed on the Tinui Valley-Whakataki Road. The western lens (N159/581737) is a soft dark grey to brown, carbonaceous siltstone with flattened worm tubes and bands of glauconitic siltstone beds. No fossils were found. The eastern lens (N159/631832) is an indurated dark grey, almost black, fissile siltstone with numerous macrofossil fragments and gypsum crystals. The macrofossils have "Wangaloan" affinites (A.G. Beu, pers. comm.). The Wangaloan stage, based on macrofossils, was the youngest Cretaceous stage in the sequence of New Zealand stages proposed by Finlay and Marwick (1947). It is equivalent to the lower Dannevirke Series but because it could not be fitted accurately into the New Zealand standard stage sequence it was proposed by Hornibrook and Harrington (1957) that the Wangaloan be omitted. Foraminifera, abundant in the eastern lens, are Teurian in age. No fossils were found in the western lens.

TERTIARY AND EARLY QUATERNARY
STRATIGRAPHY

Wanstead Group

(Wanstead Series; Ongley, 1936b)

The Wanstead Series, introduced by Ongley
(1936b), was redefined as the Wanstead Group by
Waterhouse and Bradley (1957). It contains
poorly bedded, fine grained sediments that are
commonly bentonitic in their lower part.

Huatokitoki Formation (van den Heuvel, 1960) wh

Bentonitic sediments are poorly exposed on
either side of the lower Whareama Valley and in
addition occur as slivers within or close to the
Tinui Fault Zone, and are correlated with the
Huatokitoki Formation of van den Heuvel (1960).
The formation consists of well to poorly bedded
pale grey, greenish grey to dark grey almost black
mudstone, grey siltstone and sandstone, glauconitic
sandstone, minor conglomerate and bentonite
beds. Bentonite crops out only in the north
and causes extensive slumping. The thickest
bentonite bed, at Ekenui Stream, is 50 ft thick.
In the south large blocks of "chalky" mudstone
crop out near the base of the formation.

Because of poor exposures no stratigraphic

sequence was established and the thickness of
the formation is estimated at 1,500 ft. In
the Mangapokia Valley a 5 ft thick glauconitic
sandstone at the base of the formation rests,
probably unconformably, on the Whangai Formation.
In the Mangapakeha Valley the formation rests
unconformably on rocks of the Torlesse Supergroup.
Macrofossils are absent. Foraminifera, with
benthic forms dominant, are abundant and show
that the Waipawan, Heretaungan and Bortonian stages
are present. No Porangan or Mangaorapan
foraminifera were found, although the stages
are probably present.

Weber Formation (Weber Series; Ongley and Williamson,
1931) ww

The formation consists of massive dark-grey,
locally with a greenish tinge, to light-grey
almost white mudstone and siltstone, with
scattered grit, conglomerate and impure limestone
beds. It crops out as fault slivers in or on
the west side of the Tinui Fault Zone. The
thickest section is about 2,500 ft thick. The
base of the formation is unknown, all contacts
seen being faulted. Macrofossils are absent.
Foraminifera, particularly planktonics, are
abundant and indicate a Whaingaroan to Duntroonian
age.

Annedale Group

The group is named after Annedale Station in the upper Whareama Valley. It contains the Whakataki Formation, consisting of a thick sequence of graded beds, and the Takiritini Formation consisting of sandstone and algal limestone. It lies between the Wanstead and Hurupi groups.

Whakataki Formation (new formation) aw

The formation consists of thick sequences of graded beds. It crops out extensively in the east and is well exposed near Whakataki. No complete section through the formation was found at any one locality and no single type section can be designated. Instead the base of the formation is defined in the upper Mataikona River (N159/641872) where a sequence of graded beds grades down into the Weber Formation, and the top is defined in the lower Whareama River (N159/529664) where the formation grades up into massive mudstone of the Maunsell Formation. Individual graded beds are from a few inches to several feet thick. Each bed grades from grit or sandstone at the base to mudstone at the top.

The base of each bed commonly contains flute casts. The lower part of each bed is laminated and in its middle part commonly convolutely bedded. In the northeast the formation conformably overlies the Weber Formation. Elsewhere it is unconformable, with a basal conglomerate, on older rocks.

Macrofossils are rare and of no use for dating. Microfossils are sparse and poorly preserved. The age and the thickness of the formation are different in different localities:

Area	Thickness (ft)	Age
Northeast	700	Lw – Po
Lower Whareama Valley	6,000	Pl – Sc
Coast	10,000	Lw – Sc
Southeast	c.500	S?

Takiritini Formation (new formation) at

The formation consists of thick sandstone and thick algal limestone, with interbedded minor siltstone and minor graded bedded sequences. It forms conspicuous outcrops within and on both sides of the Tinui Fault Zone from Takiritini Stream to Maunsell, and as a fault sliver on the west side of the lower Whareama

Valley. A 650 ft thick section in Takiritini
Stream (N159/618837) is proposed as the type.
The formation disconformably overlies the
Whakataki Formation and conformably underlies
the Maunsell Formation.

The sandstone is grey, medium to coarse-grained,
with bedding planes from a few to many feet
apart, and scattered elliptical, rarely
fossiliferous concretions. It is 3,500 ft thick
at Maunsell but thins northwards and grades
into the algal limestone. The limestone is
off-white to cream and weathers pink. It
contains numerous rounded to elongate, partly
worn algal structures of the Lithothamnion
group and scattered foraminifera shell fragments.

The age of the formation is Altonian (Pl)
to Clifdenian and it is thus the same age as
the upper part of the Whakataki Formation in
the lower Whareama Valley.

Hurupi Group (Hurupi Series; King, 1933)

The Hurupi Series was introduced by King
(1933) for coarse fossiliferous beds at Hurupi
Creek, Palliser Bay, that lie between basement
"greywacke" and overlying unfossiliferous

means no macrofossils
4bb x 1984: 500

mudstone. It was redefined as the Hurupi
Formation by Vella (1954) to include the
fossiliferous and unfossiliferous beds. The
formation is here raised to group status.

Maunsell Formation (new formation) hm

The Maunsell Formation crops out extensively
in the west of the Tinui District. It consists
dominantly of massive mudstone and siltstone
with minor sandstone and pebbly shell limestone
beds and concretions. A section, 9,200 ft
thick, in the Tinui Valley (N159/600814 to 563808)
is designated as the type. The lower part of
the formation grades in the northwest into a
thick sequence of graded beds mapped as the
Tanawa Member (hmt) and in the northeast into
thick sandstone mapped as the Grassendale
Member (hmg).

In the Tinui Valley the formation conformably
overlies the Takiritini Formation but in the
upper Whareama Valley it is unconformable on
older formations. In the lower Whareama Valley
it is conformable on the Whakataki Formation.

The Tanawa Member (type section N159/615837 to
601838) is named after Tanawa Trig. It is upto
3,500 ft thick and consists of graded beds.

In the Tinui Valley it conformably overlies the
Takiritini Formation but further north it rests
unconformably on older rocks and contains a
basal conglomerate upto 100 ft thick.

The Grassendale Member (type section N159/497790
to 507784) is named after Grassendale homestead.
It consists of thick sandstone and thin interbedded
calcareous sandstone and conglomerate beds. It
is 200 ft thick in the type section and 2,300 ft
thick further north. It unconformably
overlies older rocks and is disconformably
overlain, probably with little time missing,
by the Maunsell Formation.

Microfossils are abundant in the massive
fine grained sediments of the formation but are
rare or absent in other lithologies. Macrofossils
are locally abundant in the coarse grained
sediments. The age of the Maunsell Formation
is Lillburnian, Waiauan, and lower Tongaporutuan.
The age of the Tanawa and Grassendale members is
Lillburnian to Waiauan.

Ngarata Formation (Neef, in press) hn

The Ngarata Formation was introduced by
Neef (in press) for sandstone and overlying
fine grained beds cropping out in Sheet N153.

In the Tinui District it is restricted to thick
poorly bedded sandstones with scattered conglomerates,
shelly limestone beds and concretions. It is
2,400 ft thick and unconformably overlies the
Waihoki Formation and the Grassendale Member
of the Maunsell Formation in the east, and
older formations in the west. Macrofossils, which
are poorly preserved and difficult to extract,
indicate a Tongaporutuan age. Microfossils are
probably present but could not be extracted.

Waihoki Formation (Waihoki Series; Ongley, 1935) hk

The Waihoki Series was introduced by
Ongley (1935) for coarse sandstone beds occupying
the core of the Tawhero Syncline. It is here
used for thick well-bedded, commonly poorly
graded, coarse sandstone and siltstone beds,
and massive mudstone. The base is defined as
the base of the lowest scarp-forming-sandstone
bed in the head of Ekenui Stream (N159/559849).
No contact with younger beds was seen. The
formation crops out between the upper Whareama
and Tinui valleys. In the southwest the basal
beds are tuffaceous and in the northwest they
are commonly glauconitic. The formation is
4,000 ft thick. Except in the northwest, where

it probably unconformably overlies the Grassendale
Member of the Maunsell Formation, it conformably
overlies the Maunsell Formation. Scattered
macrofossils and abundant microfossils are
middle and upper Tongaporutuan, and Kapitean
in age.

Rangiwhakaoma Formation (new formation) hr

The Rangiwhakaoma Formation consists of
grey, calcareous siltstone, formerly mapped as
the Opoiti Series by Ongley (1935). It takes
its name from the Maori name for Castlepoint.
An 80 ft thick section on the southeast side
of the Castle (N159/662673) is proposed as
the type. The formation also crops out on
the northwest side of the reef at Castlepoint.
Locally it contains concretions and lenses of
commonly laminated sandstone. On the northeast
side of the Castle there is a thin sequence of
sandstone and siltstone beds. The base of the
formation is not exposed. It is unconformably
overlain by the Castlepoint Formation. Macrofossils
are rare. Microfossils are abundant, and are
Opoitian in age.

<u>Castlepoint Formation</u> (Castle Point Beds; McKay,
1877) cp

The formation is the youngest in the Tinui
District consisting of consolidated sediments.
It is composed of well-bedded coquina limestone
and shelly calcareous sandstone with scattered
pebbles and concretions. It is known definately
only from Castlepoint. The limestone is light
grey and porous. It contains numerous comminuted
shell fragments and scattered complete shells
in a calcareous sandy matrix. The sandstone
is less porous and contains abundant shell
material. Bedding planes are commonly many
feet apart. The formation is 450 ft thick on
the Castle and 150 ft thick on the reef. On
the northeast side of the reef it disconformably
overlies the Rangiwhakaoma Formation; elsewhere
it rests on it with marked angular unconformity.
Macrofossils are very abundant, the most common
species being <u>Glycymeris</u> (<u>Grandaxinea</u>) <u>wairarapaensis</u>
Powell, <u>Chlamys</u> <u>delicatula</u> (Hutton), <u>Phialopecten</u>
<u>triphooki</u> (Zittel), <u>Mesopeplum</u> <u>convexum</u> (Quoy
and Gaimard), <u>Venericardia</u> <u>purpurata</u> (Deshayes),
<u>Dosina</u> <u>creba</u> (Hutton), <u>Neothyris</u> n.sp. (A.G. Beu,
pers. comm.). The age of the formation is
Nukumaruan.

A 2 ft boulder of coquina limestone (N158 f650)
was found at Maringi Trig. (N158/433813), 15.5
miles northwest of Castlepoint. It is lithologically
similar to the limestone at Castlepoint and contains
the same Nukumaruan foraminifera. The boulder
has either been transported from Castlepoint, or
is the last remnant of sheet that once extended
over the Tinui District.

LATE QUATERNARY STRATIGRAPHY

Undifferentiated Marine Benches (bf)

Remnants of dissected marine benches at
about 270 ft, 400 ft and possibly at 550 ft above
sea level are present on the coast at Castlepoint,
and are pre-Last Interglaciation in age.

Otahome Formation (new formation) bo

A prominent marine bench, extending from a
mile south of the Castle to south of the Tinui
District, is capped by weathered fossiliferous
marine grits and gravels mapped as the Otahome
Formation after Otahome homestead. The type
locality is on the cliffs (N159/640665) south of
the Castle. King (1930) described the bench as
sloping longitudinally from 90 ft above sea level
near the Castle to 160 ft above sea level in the

south. The fossils (N159f497), collected by Mr
M. Ongley, consist of _Cellana_ _radians_ (Gmelin),
Zeacumantus _subcarinatus_ (Sowerby), _Buccinulum_
(_Euthrena_) _littorinoides_ (Reeve) and _Neoguraleus_
murdochi (Finlay) and indicate a probable Hawera
age. The formation is probably Last Interglaciation
in age.

Rorokoko Formation (new formation) h_3

Weathered, poorly sorted greywacke gravel
capped by loess underlies an extensive surface
in the west of the district and is mapped as the
Rorokoko Formation. It is named after Rorokoko
Stream (N158/359679). The formation is tentatively
considered to be early Last Glaciation in age.

Ngapopatu Formation (new formation) h_2

Fine gravel, grit, sand, silt and clay
underlie remnants of an aggradational surface,
about 40 ft above the floor of the Mataikona and
Whareama valleys. The largest area, covering about
0.5 of a square mile, is in the upper Whareama
Valley at Ngapopatu (N159/518775) and is proposed
as the type locality. The formation is late Last
Glaciation in age.

Whareama Formation (new formation) h_1

Sand, silt and clay fill the floors of the
main valleys and are most extensive in the lower
Whareama Valley (N159/499617) which is proposed
as the type locality. Although the major rivers
are incised into the surface capping the formation,
an extensive system of drains was required before
the surface was suitable for farming. Included
in the formation are dune sands forming narrow
strips parallel to the coast and locally covering
large areas of the adjoining hillsides at
Castlepoint, south of the Whakataki River, and
north of the Mataikona River. The age of the
formation is Holocene.

PALEOGEOGRAPHY OF THE TINUI DISTRICT

Definition of terms

The major problem in paleogeography is to
infer the topography at any particular time from
the facies of the sediments deposited at that
time. It is essential to distinguish between the
inferred topography and the known facies and
the following terms are defined in order to
make the distinction clear:

Geosynclinal trough – a linear topographic feature
of regional extent that subsided deeply
throughout a long period of time. It consists
of an extensive deep water axial part surrounded
by a narrow shallow water part on its margins.

Geosyncline – a thick succession of stratified
and massive sediments, and possible extrusive
volcanics, inferred to have been deposited
in a geosynclinal trough.

Basin – a wide topographic feature largely of
shallow depth.

Fault basin – an elongated topographic feature
bounded on one or more sides by a fault scarp.

Axial facies - stratified, commonly graded and
commonly poorly fossiliferous sediments
inferred to have been deposited in deep
water, such as in the axial part of a geosynclinal
trough, or close to a fault bounding a fault
basin.

Marginal facies - massive, commonly richly
fossiliferous sediments inferred to have
been deposited in shallow water, such as in
the margins of a geosynclinal trough, a basin,
or a fault basin.

Transgression - the advance of the sea over a
landmass.

Regression - the withdrawal of the sea from a landmass.

Outcrop maps - maps which show the known distribution
of rocks of a particular age and their known
and inferred facies boundaries.

Paleogeographic maps - maps in which strike-slip
movement and shortening by folding have been
allowed for. In practice it is difficult to
allow for shortening, and only the inferred
strike slip movement has been allowed for.

NEW ZEALAND GEOSYNCLINAL TROUGH

With the formation of the New Zealand
Geosynclinal Trough the pattern of sedimentation
changed in the New Zealand area at some time
between the Devonian and Permian (Suggate, 1965).
The axis of the trough extended from the Bay of
Plenty south along the western side of the
axial ranges of New Zealand (Fleming, 1962; fig. 3).
The trough consisted of a deep-water rapidly
sinking axial part, in which turbidity currents
deposited graded beds, surrounded by a shallow-
water marginal part. The Tinui District was
near the axis of the trough and the sediments
deposited in it are mapped as the Torlesse
Supergroup. The supergroup consists of two
formations: the Waewaepa Formation (Upper Jurassic)
and the Taipo Formation (Uppermost Jurassic to
lowermost Cretaceous).

The Waewaepa Formation is composed of many
thousands of feet of graded beds, with minor
conglomerate beds and lava flows. In the Tinui
District bedding-plane shear has destroyed any
scour or flute casts that may have existed. In
the Aorangi Mountains, 60 miles southwest of the

Tinui District (Fig. 1), linear scour casts, striking NNE-SSW (T.E. Bates, pers. comm.) in the Torlesse Supergroup suggest that sediment transportation was parallel to the inferred axis of the New Zealand Geosynclinal Trough. Diagnostic features for distinguishing between a NNE or a SSW direction are absent. As the geosynclinal trough filled, 7,000 ft or more of coarse sandstone and conglomerate were deposited to form the Taipo Formation.

The pebbles in the conglomerates of the Torlesse Supergroup are of well rounded, indurated greywacke, minor quartz, jasper, and acidic volcanic rocks. Acid igneous pebbles (e.g. granites and porphyries) have been described by Marshall (1903) from the marginal facies of the New Zealand Geosyncline. The pebbles indicate that the Torlesse Supergroup in the Tinui District was derived from older sediments deposited in the geosynclinal trough, rather than directly from an adjacent landmass. Later burial and folding metamorphosed the sediments, the sandstone becoming greywacke and the finer beds argillite.

The folding of rocks of the Torlesse Supergroup was followed by a period of non-deposition estimated

at $10\text{-}12 \times 10^6$ years by Fleming (1962) and
possibly as long as $20\text{-}25 \times 10^6$ years (Fig. 4).

WAIRARAPA GEOSYNCLINAL TROUGH

Eastern Geosyncline was the name used by
Macpherson (1946) and Eastern Basin that used
by Kingma (1960), for the Upper Cretaceous and
Tertiary rocks in the east of New Zealand.
Wellman (1959; fig. 1) inferred that in the
Cretaceous a geosynclinal trough extended along
the east coast from Marlborough to East Cape.
On the west side of the trough, near Gisborne,
there was a northeast striking peninsula.
Grindley (1961) "eliminated" the peninsula and
called the geosynclinal trough the "East Coast
Geosyncline". Within the Cretaceous rocks
Wellman (1959) recognised three facies:- shelf,
transitional and redeposited. Grindley (1961)
recognised two facies only, shelf and redeposited.
The writer, following the nomenclature of Fleming
(1962), has divided the rocks of the geosyncline
into a marginal and an axial facies. The
marginal facies consists of the Maringi and
Springhill formations and the axial facies
consists of the Glenburn Formation. All three

formations are included in the Mangapurupuru
Group.

Because of the usage of "East", "Eastern"
and "East Coast" for rocks of different ages
and distribution, the name Wairarapa Geosynclinal
Trough is proposed for the whole of the
geosynclinal trough which extended from
Marlborough to East Cape during the Upper
Cretaceous.

Marginal Facies

In the west of the Tinui District during
the Motuan and possibly the Urutawan, the
Maringi Formation, consisting of siltstone with
basal fossiliferous conglomerate, and thin graded
bedded sequences, was deposited unconformably
on the Torlesse Supergroup. In the extreme
west of the district the basal conglomerate is
very thick and is mapped as the Bideford Member.
The conglomerate, which contains shallow water
fossils that are not considered to have been
transported, is inferred to have been deposited
close to a shoreline. The overlying siltstone
contains relatively abundant fossils and near
its top, fossiliferous, poorly graded, alternating

sandstones and siltstones. Flute cast directions show a current direction from the southwest consistent with a shoreline to the west. It is inferred that the sea had transgressed westward.

The outcrop map of Motuan rocks (Fig. 7a) suggests that there was a total of 9 miles of sinistral offset caused by displacement on the Carterton Fault. The displacement has been allowed for in the construction of the Motuan paleogeographic map (Fig. 7b).

During late Motuan to lower Piripauan time the Springhill Formation, consisting of fossiliferous siltstone with numerous fossiliferous concretions and lenses of graded beds and sandstone, was deposited. In the southwest of the Tinui District the formation has a basal conglomerate that unconformably overlies rocks of the Torlesse Supergroup. Elsewhere in the district it conformably overlies the Maringi Formation. The Springhill Formation is inferred to have been deposited as the sea continued to transgress westward. In the Ngaterian, ripple bedded sandstone was deposited locally and some water shallowing is inferred.

Fig. 7a Outcrop Map of Motuan Rocks

Marginal Facies — Axial Facies

Land

siltstone with sandstone

siltstone with pebbly

silstone and fossil beds

silstone with conglomerate and graded beds

graded beds?

Carterton

Fault

Land

Areas of outcrop ⟨...⟩
shell bed ++++

☐ Maringi Formation
▩ (Bideford Member)
☐ Glenburn Formation

One Mile

Fig. 7b   Motuan Paleogeography

Land

silt

pebbly

Inner Shelf

(silt with sand streaks and banks
of Inoceramus shell(s)

(shallow water)

Outer Shelf

(silt with pebble bands and graded beds)

turbidite deposition

(deep water)

Beds of the marginal facies were deposited
in the Dannevirke Subdivision (Raukumara Formation
of Lillie, 1953), in the Aorangi Mountains
(the upper part of the Whatarangi Formation of
Bates, 1969) and in Marlborough (G.J. Lensen,
pers. comm.). Paleogeographic patterns in the
Upper Cretaceous (see below under Tinui
Transgression) suggests that an eastern
marginal facies existed to the east of the
axial facies and to the east of the present day
coastline.

Axial Facies

In eastern Wairarapa graded bedded sediments
of the Glenburn Formation were deposited from
the Ngaterian (possibly from the Motuan) to
the lower Piripauan. The base of the formation
has not been seen. Flute casts in the Mt Adams
area (Eade, 1966), to the southeast of the Tinui
District, show that from the Ngaterian to the
Arowhanan the currents flowed ESE. Flute
casts in the Tinui District show that in the
Arowhanan the currents flowed northeast. The
formation is interpreted as being deposited by

turbidity currents in the axial region of the
Wairarapa Geosynclinal Trough.

In Marlborough the Good Creek Formation
(of the same facies and of the same age as the
Glenburn Formation) was deposited by northeast
flowing turbidity currents (G.J. Lensen,
pers. comm.). Stratigraphic columns from
Marlborough to Hawkes Bay (Figs. 8, 9), have
been used to construct a generalised paleogeographic
map of the Wairarapa Geosynclinal Trough from the
Motuan to Ngaterian (Fig. 10).

Gentle Annie Gravity Slide

The Gentle Annie Breccia is inferred to have
formed by the northward sliding and brecciation
of the lower part of the Maringi Formation off
a rising high of rocks belonging to the Taipo
Formation. The high is considered to have
formed by the uplift of the north side of the
Carterton Fault. The time of brecciation is
uncertain but is inferred to be Upper Cretaceous
from the degree of compaction of the Maringi
Formation and the Gentle Annie Breccia.

Fig. 8

(Note: for location of columns see Figs. 10, 12)

COMPOSITE STRATIGRAPHIC COLUMNS

LITHOLOGIES

Graded beds
Fine grained sediments and concretions
Coarse grained sediments
Greywacke and argillite
Limestone and flint beds
Volcanics
Conglomerates

SERIES

Dannevirke
Mata
Raukumara
Clarence

UPPER CLARENCE VALLEY

8/6 AWATERE VALLEY
Most. Fract
(after Challis 1966)

Gridiron
Swale
Split Rock
Undifferentiated

8/5

Herring
Mead Hill
Amuri
Whorfe

8/4 COVERHAM
(After G.J. Lensen, pers. comm.)

Good Creek
Swale
Nidd
Paton
Woolshed
Ess Creek
Mirza
Butt
Ouse

8/3 WELD CONE

Burnt Creek
Mirza
Butt
Maringi
Springhill
Whangai

8/2 MAKIRIKIRI

Te Mai
Glenburn

8/1 COASTAL WAIRARAPA

Undifferentiated Torlesse Supergroup

Dt Mh

Feet
5,000
1,000
0

Fig. 8.

52

Fig. 2. (Note: for location of columns see Figs. 10, 12)

COMPOSITE STRATIGRAPHIC COLUMNS

South ... North

FORMATION
(Undifferentiated Tertiary)
Huatokitoki
Mungaroa
Whangai
Tutu Member
Glenburn

9/6 MT. ADAMS (After Eade, 1966)
9/5 FLAT POINT (After Van den Heuvel, 1960)
9/4 NGAHAPE (After P. Wellman, 1970)
9/3 TINUI
Weber
9/2 WHANGAI RANGE (After Lillie, 1953)
Te Mai
Springhill
9/1 WAIPAWA (After Hornibrook & Harrington, 1957)
Waipawa

LITHOLOGIES
Graded beds
Coarse grained well bedded sediments
Fine grained poorly bedded sediments
Limestone and flint
Bentonitic sediments

——— Lithological Boundary
——— Stage Boundary
WWWW Unconformity
——— Base of Unit not exposed
F Fault Contact
A,B,C,D, Lithological units within Whangai Formation
C "Upper Whangai" of Lillie (1953)
W Waipawa Black Siltstone

5,000
0
1,000 feet

Fig. 9.

5.

Fig. 10. Generalised map of the Wairarapa Geosynclinal Trough in Motuan-Ngaterian time. Outline of present coast superimposed for convenience of location.

TINUI TRANSGRESSION

At the beginning of the Piripauan the rate
of sinking of the Wairarapa Geosynclinal Trough
had decreased and the degree of infilling had
advanced to such an extent that by the end of
the lower Piripauan the trough had ceased to
exist. New Zealand was then a mature landscape
over which the sea transgressed. The transgression
in the Wairarapa is named the Tinui Transgression.
During the transgression rocks of the Tinui
Group (Te Mai, Whangai and Waipawa formations)
were deposited.

Lower Piripauan to lower Haumurian

Except locally, the Te Mai Formation was
deposited conformably both on the marginal and
on the axial facies of the Wairarapa Geosyncline.
In the east the formation consists of conglomerates,
grits and coarse sandstones. Cross-bedding in
the coarse sandstones indicates that the formation
was derived from the east (Fig. 11). The
conglomerates and grits contain <u>Ostrea</u> cf.
<u>lapillicola</u> Marwick and belemnites. One of the

Coarse grained beds, with
abundant cross bedding and *Ostrea*
Fine grained beds, with abundant
Inocerami and belemnites
} Te Mai Formation

→ Current direction (from cross bedding)
—·— Facies boundary
⋰ Areas of outcrop

One
Mile
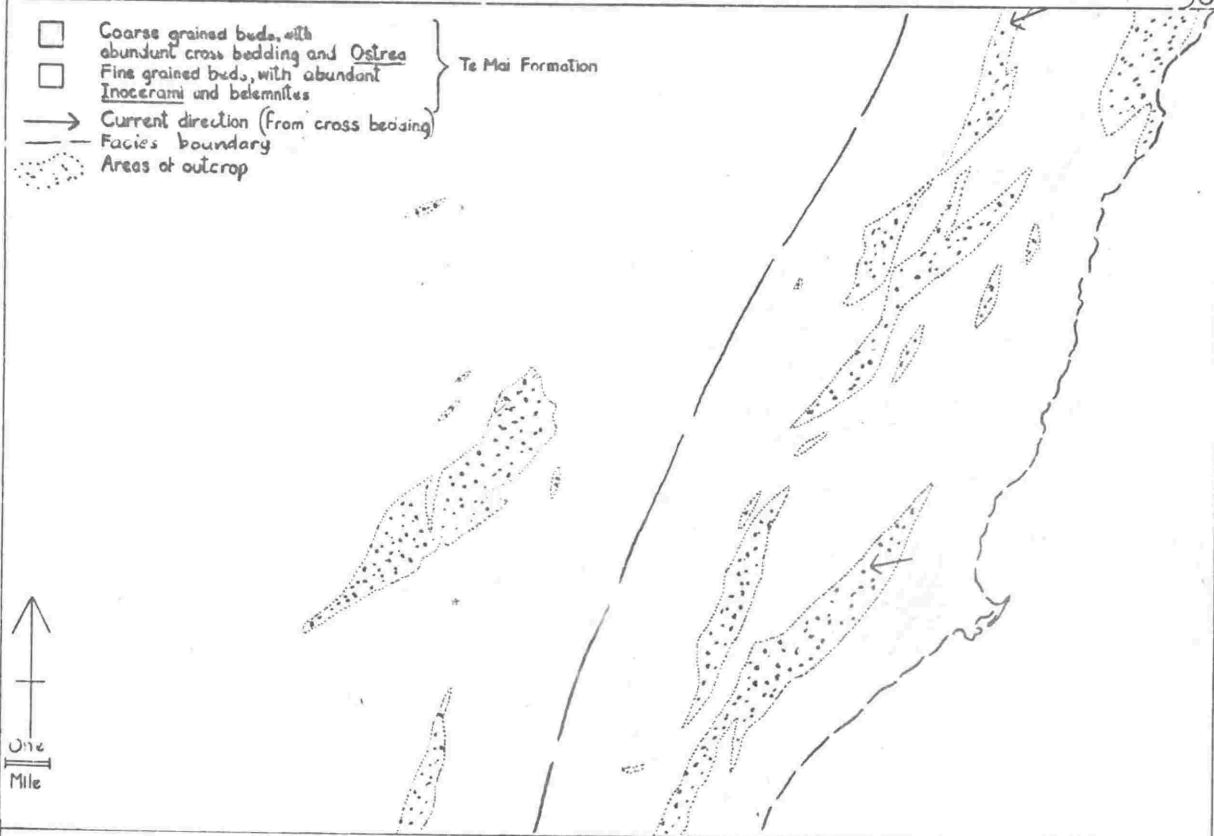
Fig. 11. Outcrop Map of Piripauan Rocks

← Direction of sediment movement (from cross bedding)
←- inferred

⇐ Direction of transgression
⇐ inferred

37/2
◎ Location of Stratigraphic Column
(see Figs.
⑰ Area of outcrop

20   0   20 Miles
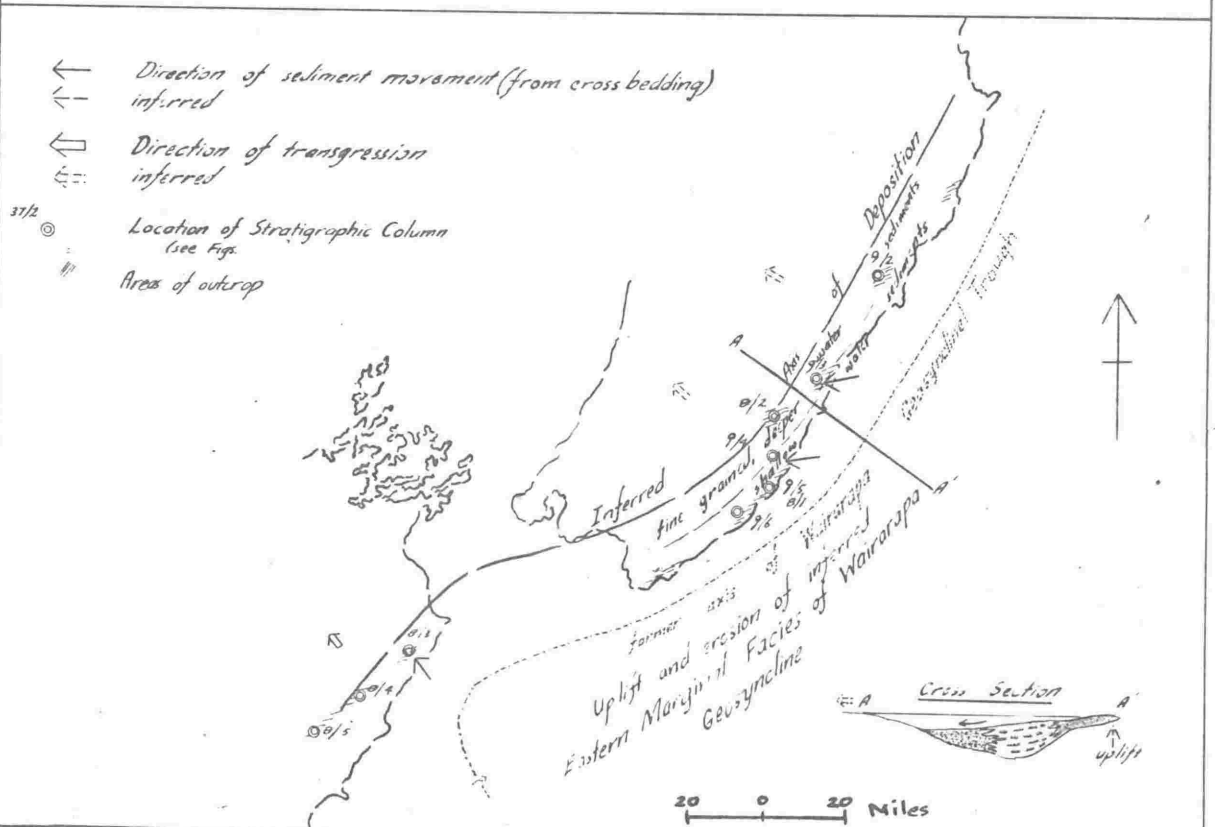
Fig. 12. Distribution of Piripauan–Lower Haumurian Rocks
(Outline of Present East Coast Superimposed)

belemnites is _Dimitobelus_ _superstes_ (Hector)
which, being Motuan to Mangaotanean in age
(Stevens, 1965), is assumed to have been derived
from the eastern marginal facies of the
Wairarapa Geosyncline (Fig. 10). In the west
the formation contains fewer conglomerates and
grits. Cross-bedding and _Ostrea_ _lapillicola_
Marwick, which is generally restricted to coarse
sediments, are absent. It contains, however,
sandstone beds with numerous fragments of
Inoceramus _pacificus_ Woods, _I._ _matatorus_ Wellman,
and _Dimitobelus_ _lindsayi_ (Hector). Planktonic
foraminifera are more abundant in the west than
in the east.

In southern Hawkes Bay, Upper Cretaceous
sediments coarsen eastwards (Kingma, 1962).
In the Dannevirke Subdivision, conglomerate at
the base of beds equivalent to the Te Mai
Formation suggests a local unconformity, although
Lillie (1953; p. 78) stated that there was no
major folding at this time. Stratigraphic
columns (Figs. 8, 9) are used to construct a
map (Fig. 12) showing the distribution of
Piripauan and lower Haumurian rocks in Marlborough,
in Wairarapa and in Hawkes Bay.

Upper Haumurian to Teurian

During the upper Haumurian dark well bedded
mudstones and siltstones were deposited to
form the upper part of the Te Mai Formation.
Macrofossils other than abundant worm borings
are absent. It is inferred that over the whole
of the Tinui District deposition was uniformly
in deep water. In the late Haumurian and Teurian
poorly bedded siltstone, in which calcareous
concretions now occur, was deposited to form the
Whangai Formation. At most places it rests
conformably on the Te Mai Formation. Locally
it is the lateral time equivalent of the Whangai
Formation. In the east of the Tinui District
layers of commonly glauconitic sandstone were
deposited. In the upper Teurian, lenses of
dark siltstone, with gypsum and a high organic
content, accumulated to form the Waipawa Formation.

In southern Hawkes Bay, deposition of the
Whangai Formation began in the lower Haumurian,
as did sediments of the same facies - Woolshed
Formation - in Marlborough.

Conditions of deposition of the Whangai
and Waipawa Formations

Kingma (1967) reported pumice fragments
and glass shards in the Whangai Formation in
eastern Wairarapa and inferred extensive rhyolitic
volcanism to the east of the present day coastline
at the end of the Cretaceous. In spite of an
extensive search, no pumice or glass shards
were found in the Tinui District or in samples
from the type locality of the formation in the
Whangai Range, southern Hawkes Bay. The intrusion
of basic igneous rocks near Ngahape (Grapes, 1970)
is the only known igneous activity in the
Wairarapa and southern Hawkes Bay at this time.

The formation contains quartz, montmorillonite,
illite and kaolinite; minerals that form after
prolonged weathering. Their source was probably
from a landmass to the west that was approaching
senility. The land to the east (Fig. 12), which
earlier supplied the bulk of the Piripauan
sediments does not appear to have provided a
significant amount of sediments. In the east,
conditions were favourable for the formation of
glauconite.

Locally in the Tinui District, sediments

with a very high organic content were deposited
and are mapped as the Waipawa Formation.
Hornibrook and Harrington (1957) suggested that
in Hawkes Bay the formation was deposited in
stagnant lagoons. However, the plant fragments
and coal seams that would be expected in such
an environment are completely absent, indicating
that the formation was deposited in deep water.

PONGAROA BASIN

In Wairarapa and southern Hawkes Bay the
basins (or basin) that formed in the Lower
Tertiary are collectively called the Pongaroa
Basin. In it was deposited the Wanstead Group
comprising the Huatokitoki (Waipawan to Runangan)
and Weber (Whaingaroan to Duntroonian) formations.
Little is known, particularly in the Wairarapa,
of the paleogeography.

The Huatokitoki Formation, from the Tinui
Valley to the coastal part of southern Hawkes
Bay, contains thick bentonite deposits. The
origin of the bentonite is uncertain. Fyfe
(1934), following overseas workers, suggested

that the bentonite is derived from the weathering
of acidic volcanic material but did not infer
any source for the volcanic material. Kingma
(1967) inferred rhyolitic volcanoes at an
unspecified distance to the east of the present
day coastline. However, there is no recognisable
volcanic material in rocks of the Tinui and
Wanstead groups and hence no evidence for nearby
volcanoes.

Siliceous limestone, mapped as the Mungaroa
(Waterhouse and Bradley, 1957) or Kaiwhata
(van den Heuvel, 1960) formations, were deposited
in the south of the basin (Fig. 13) and represent
the northernmost limit of the Amuri Limestone
of Marlborough and North Canterbury (Fig. 8).
In Whaingaroan and Duntroonian time planktonic
foraminiferal ooze accumulated to form the light
grey coloured Weber Formation.

WHAKATAKI FAULT BASIN

In the Tinui District, the Whakataki Fault
Basin formed in Waitakian and the Whakataki
(Waitakian to Clifdenian) and the overlying
Takiritini (Altonian to Clifdenian) formations
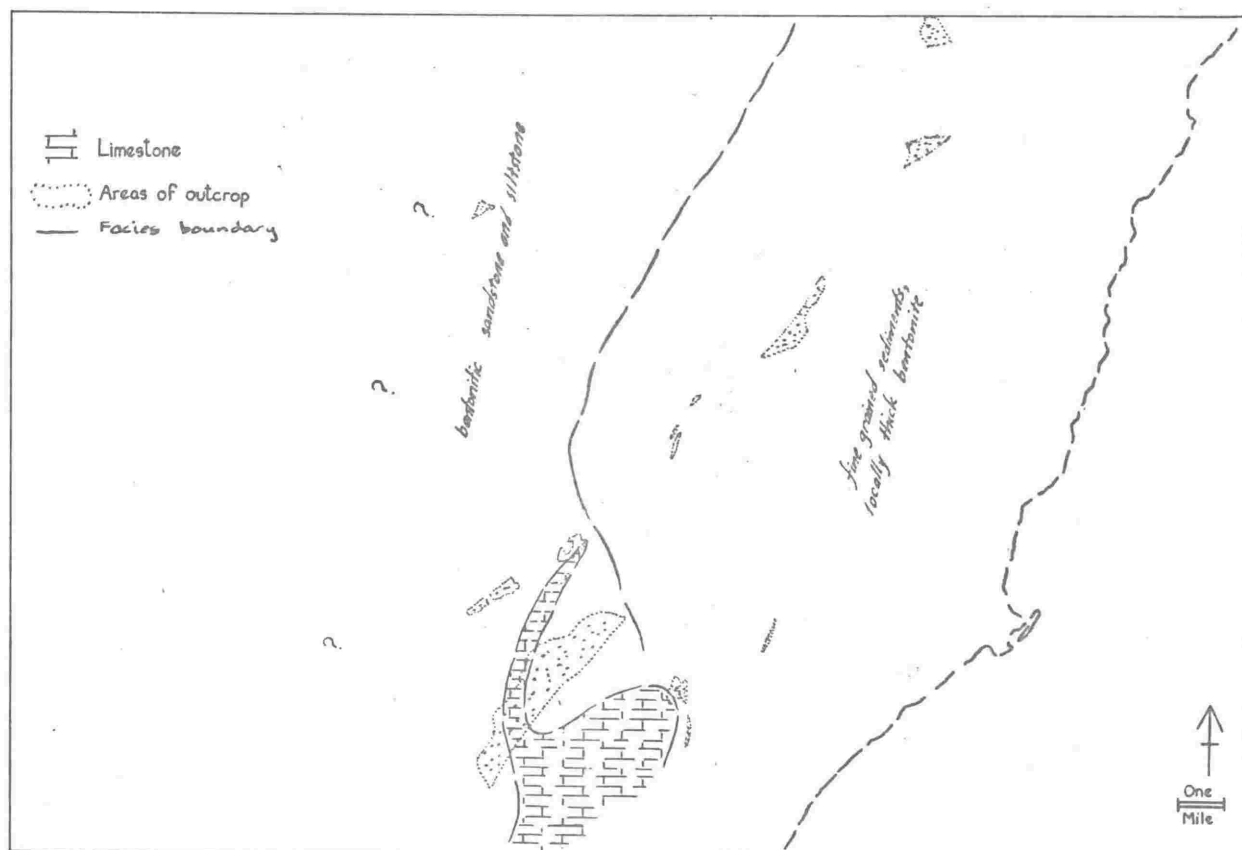
Fig. 13.   Outcrop map of Waipawan to Bortonian rocks
(Huatokitoki Formation).

were deposited in it. In the east of the district
the Whakataki Formation, consisting of a thick
graded bedded sequence with basal conglomerate,
was deposited unconformably on older rocks.
Near Te Mai the conglomerate is absent and the
graded bedded sequence conformably overlies
the Weber Formation. The Whakataki Formation is
thicker in the east than in the west and in the
west it contains massive siltstone. Widespread
flute casts show that currents flowed from the
east and south.

It is inferred that the Whakataki Fault
Basin was formed by the sudden downthrow of
the west side of a fault to the east of the
present day coastline (Fig. 14a). Erosion of
the fault scarp formed the basal conglomerate.
As erosion of the scarp decreased, graded beds
(axial facies) were deposited by turbidity
currents flowing eastwards towards the axis of
the basin and by turbidity currents flowing
north along the axis of the basin. In the west,
massive siltstone, containing a rich fauna of
benthic foraminifera, was deposited in shallow
water close to a landmass (marginal facies).
The offset of the shoreline of the landmass is
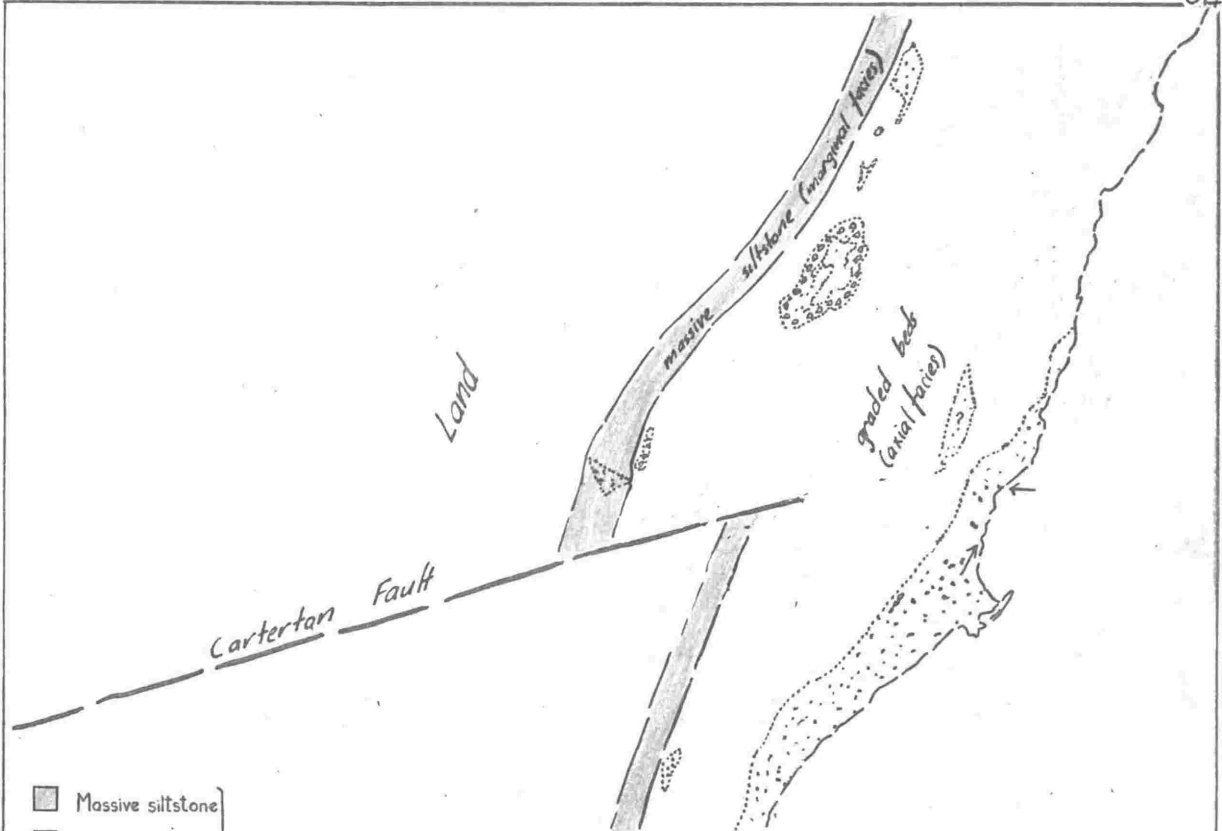
Fig. 14-a Outcrop map of Waitakian — Otaian Rocks

Legend:
- Massive siltstone ⎫
- Graded beds ⎬ Whakataki Formation
- Conglomerate ⎭
- Inferred axis of trough
- Flute cast direction
- Facies boundary
- Area of outcrop

One Mile

Labels on map (Fig. 14-a): Land; Cartertan Fault; massive siltstone (marginal facies); graded beds (axial facies)
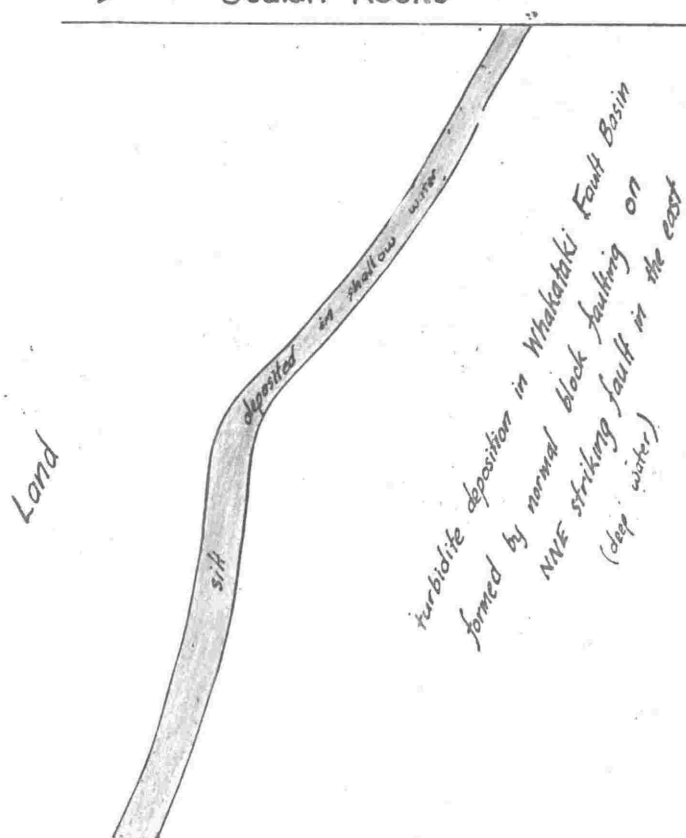
Labels on map (Fig. 14-b): Land; silt deposited in shallow water; turbidite deposition in Whakataki Fault Basin formed by normal block faulting on NNE striking fault in the east (deep water)

Fig. 14 b. Waitakian—Otaian Paleogeography

inferred to have been caused by movement on the
ENE striking Carterton Fault and this is allowed
for in the paleogeographic map (Fig. 14b) and the
block diagram (Fig. 14c). The offset (apparent
strike-slip displacement) of the shoreline by the
Carterton Fault is sinistral (Fig. 14a). However,
the shoreline would initially have been a gently
east dipping reference plane and any vertical
movement on the fault would produce a large apparent
horizontal displacement. Real and apparent
horizontal displacements by faulting are discussed
further under Structure.

In the Altonian, the Whakataki Fault Basin
broadened and graded beds continued to accumulate.
In the northwest the sea shallowed and sandstone
and algal limestone of the Takiritini Formation
were deposited disconformably on the Whakataki
Formation (Fig. 15a). From the distribution of
the Takiritini Formation it is inferred that the
south side of the Carterton Fault was downthrown.
On the upthrown side of the fault, shoal areas
formed in the margin of the fault basin. A
fault sliver in the lower Whareama Valley (Fig. 2)
is inferred to have been dragged southwards into
its present position by dextral strike-slip movement
on a fault on the west limb of the Whareama Syncline.
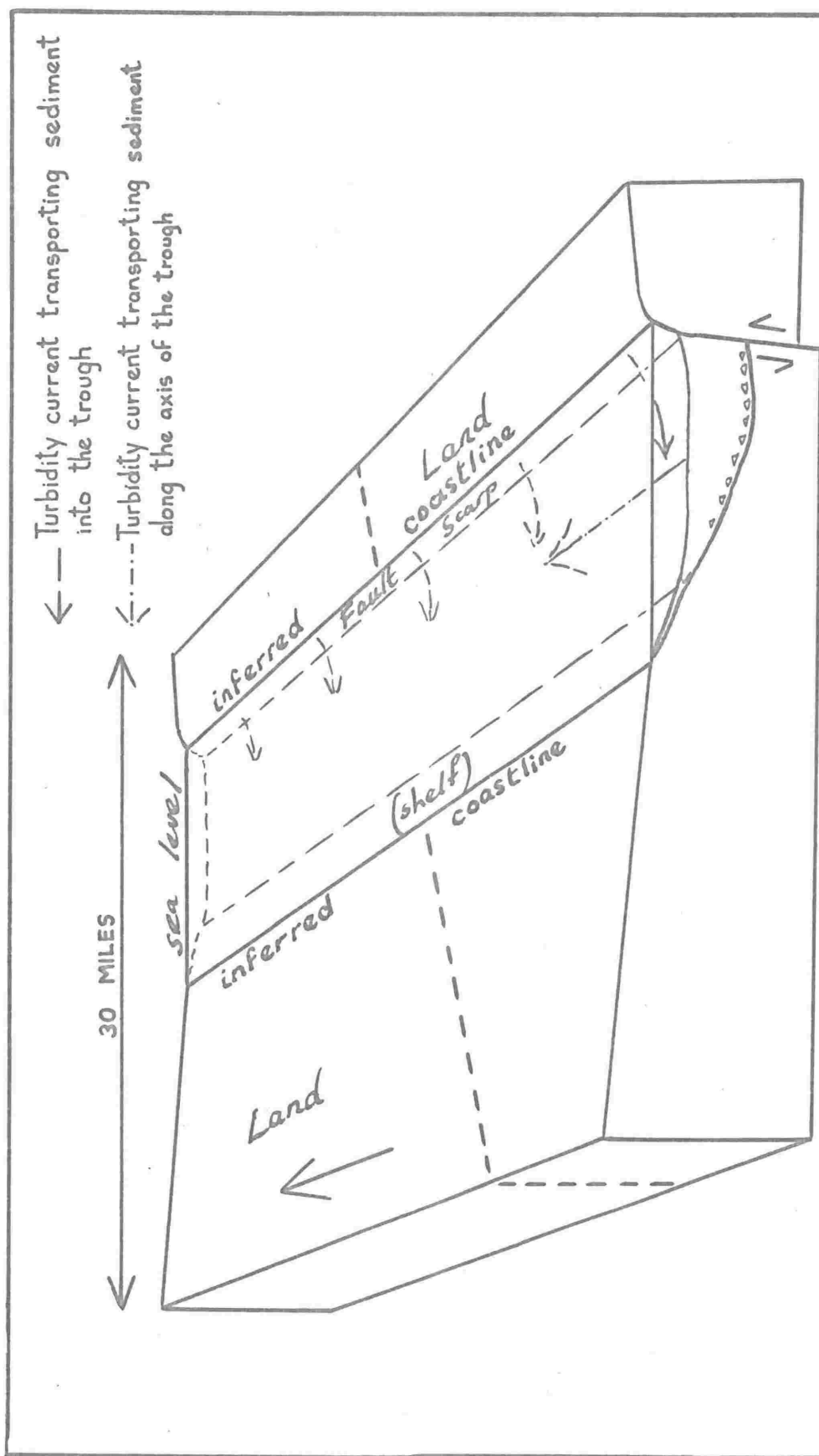
Fig. 14.c. Block Diagram of the Whakataki Fault Basin at the end of the Otaian (Deposition of the Whakataki Formation)

Fig.15a. Outcrop Map of Altonian — Clifdenian Rocks

Legend:
- Graded beds
- Graded bedded sequence with basal pebble conglomerate (ooo) angular conglomerate (▽∆▽)
- Sandstone, algal limestone disconformably overlying Whakataki Formation
- → Flute cast direction
- → Inferred erosion of fault scarp
- --→ Inferred direction of movement of beds due to faulting
- — Facies boundary
- Area of outcrop

Whakataki Formation
Takiritini Formation

Fig. 15 b.   Altonian — Clifdenian Paleogeography

On the south side of the Carterton Fault,
the area of deposition of the Whakataki Formation
increased in the Altonian and it probably
increased again in the Clifdenian. The increase
was probably caused by block faulting. In the
new areas of deposition, graded beds with a basal
conglomerate, were deposited. The conglomerate
is angular close to the Carterton Fault and is
inferred to have been derived from the fault
scarp. Elsewhere it contains rounded pebbles
considered to have been derived from the erosion
of littoral deposits on the southeast edge of
the basin. Flute casts in the graded beds show
that most currents flowed from the SSE, and a
few from the north. It is inferred that the
currents from the SSE flowed along the axis of
the basin after originating from a landmass to
the east (Fig. 15c). The north flowing currents
are considered to have originated from the
Carterton Fault scarp. The later interaction of
the Carterton Fault and the NNE striking faults
is thought to have displaced an area of graded
beds northeastwards (Fig. 15a). This displacement
is allowed for in the paleogeographic map of
lower Southland time (Fig. 15b). By the end of
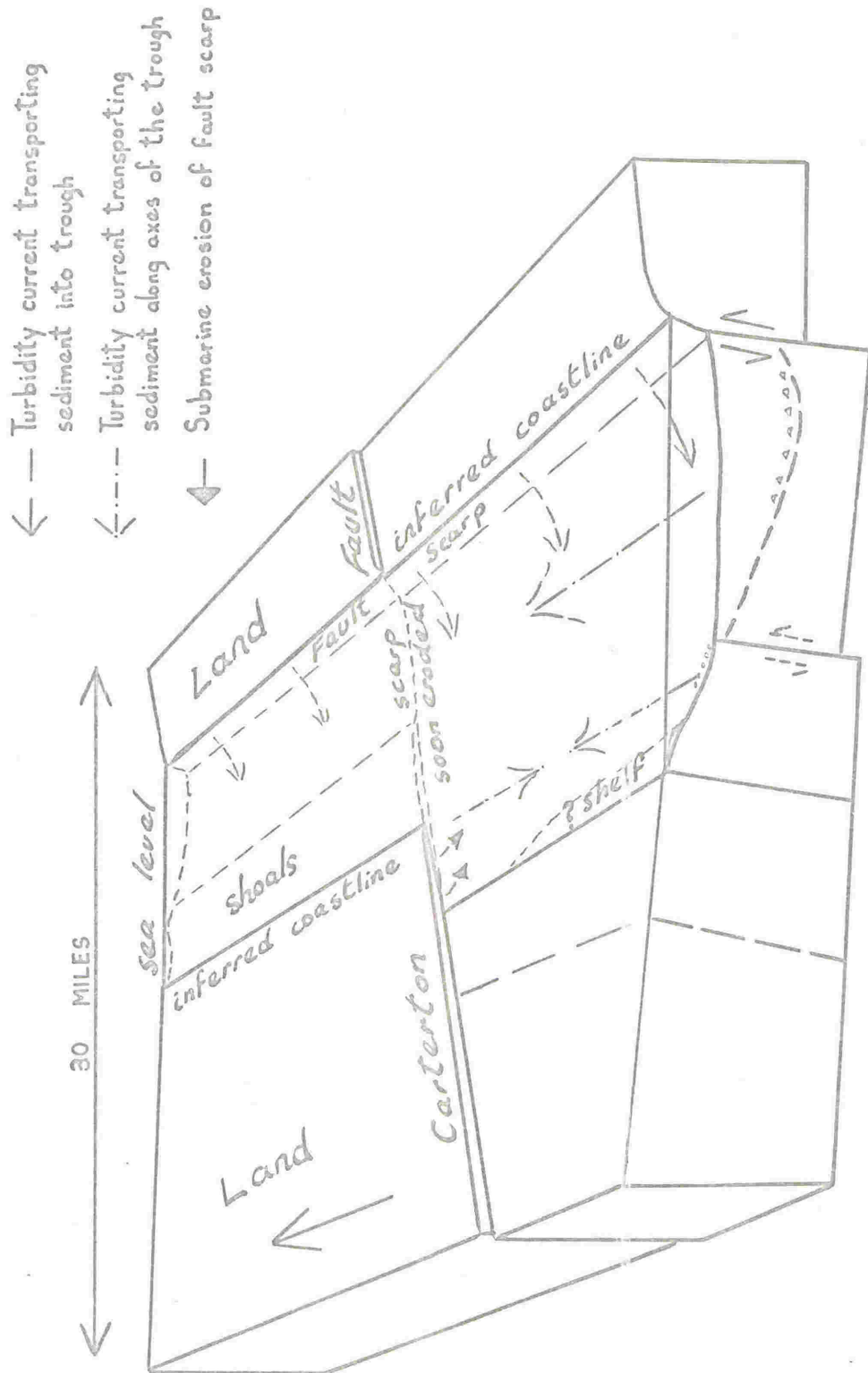
Fig. 15c. Block Diagram of the Whakataki Fault Basin at the beginning of the Lower Southland. (Deposition of Whakataki and Takiritini Formations)

Legend:

← — Turbidity current transporting sediment into trough

←·—·— Turbidity current transporting sediment along axes of the trough

⟵ Submarine erosion of fault scarp

Labels on diagram: 30 MILES · sea level · Land · Fault · inferred coastline · scarp · shoals · inferred coastline · scarp soon eroded · Carterton · ?shelf · Land

Clifdenian time, subsidence of the Whakataki Fault Basin slowed down and the sea began to transgress westward.

HURUPI TRANSGRESSION

A westward transgression of the sea in the Wairarapa in upper Southland and Taranaki time, when the sediments of the Hurupi Group were deposited, is termed the Hurupi Transgression. In the west the group was deposited unconformably on Mesozoic rocks and as indicated by Lower Tertiary foraminifera, rocks of the Wanstead Group made up part of the source rocks. In the centre of the Tinui District in Lillburnian time, massive, fine-grained sediments of the Maunsell Formation were deposited conformably on the Whakataki and Takiritini formations. To the west, coarse fossiliferous sediments of the Grassendale Member of the Maunsell Formation were deposited unconformably on older sediments. In the northeast, graded beds of the Tanawa Member of the Maunsell Formation were deposited unconformably, with basal conglomerate, on the Whakataki and older formations. The graded beds are interpreted

as a deep water deposit (axial facies) deposited by turbidity currents. Flute casts in the graded beds show that the currents flowed from the SSW and from the southeast (Figs. 16a, 16b). It is inferred that the eastern part of the Tinui District was uplifted by movement on one of the NNE striking faults. Erosion of the fault scarp produced the basal conglomerate. The currents that formed the flute casts are thought to have flowed off the landmass and then parallel to the fault. In the west, as the sea transgressed westward, littoral sediments and then massive siltstone were deposited as a marginal facies.

In the Waiauan (Fig. 17) graded beds (of the Tanawa Member) are thinner and contain a greater number of interbedded mudstone beds than do the Lillburnian graded beds. In the west a disconformity lies at the top of the Grassendale Member and it is inferred that there was a temporary eastward regression. Following the regression the sea began to transgress rapidly westward depositing the Maunsell Formation.

By the middle Tongaporutuan the only land was in the northwest of the district (Fig. 18). In the north the Waihoki Formation, consisting of
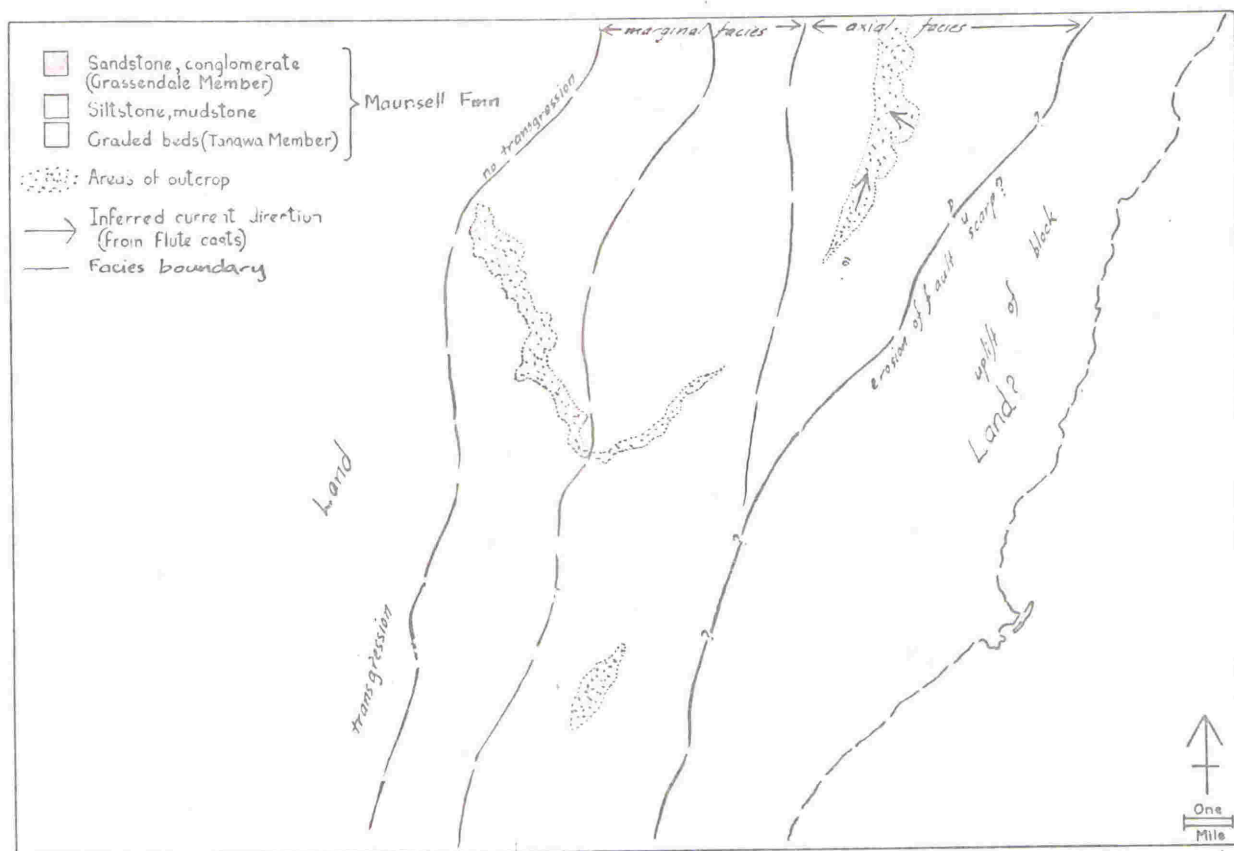
Fig. 16a. Outcrop map of Lillburnian rocks.
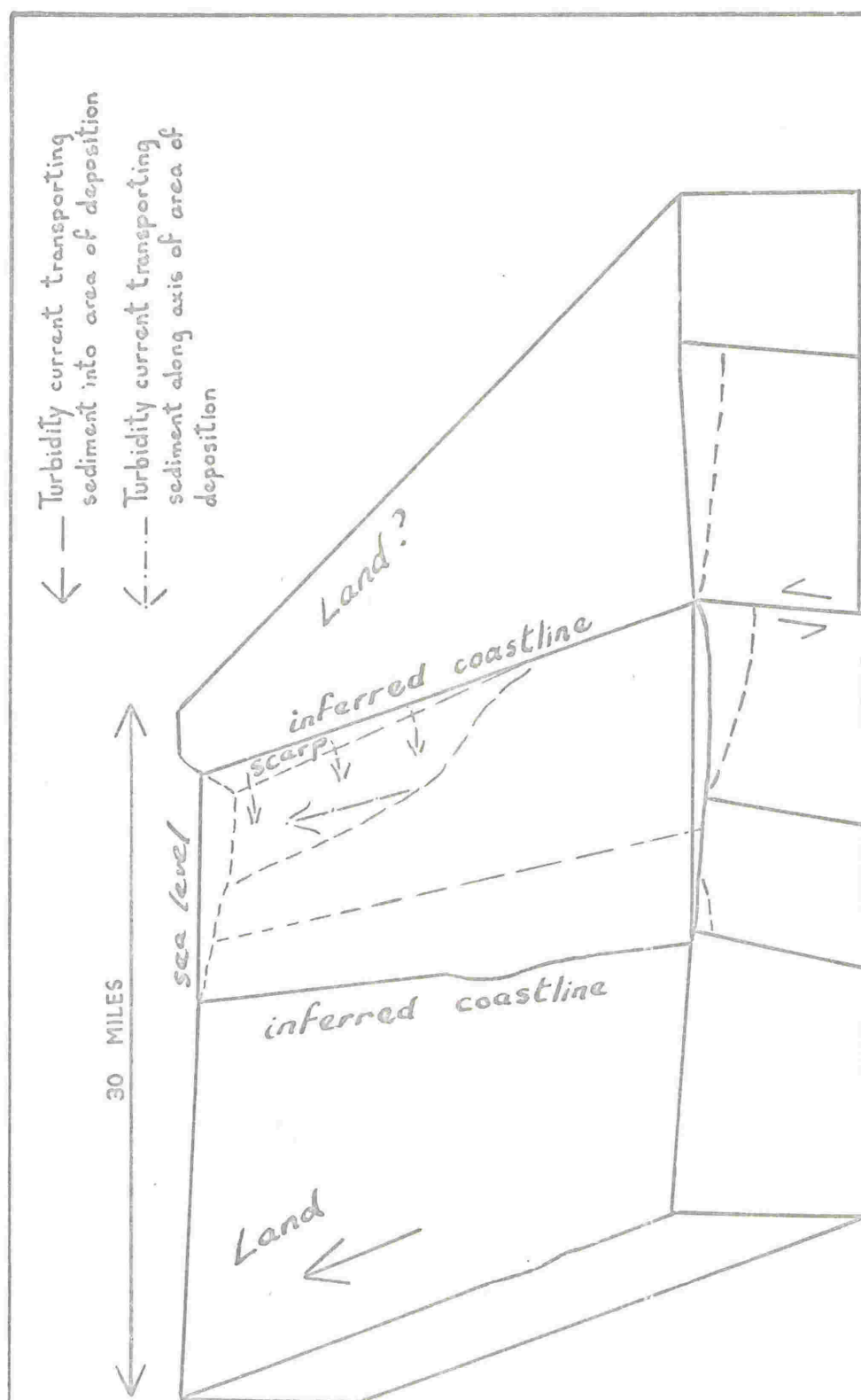
Fig. 16 b.   Block Diagram showing the Hurupi Transgression in the Lillburnian (Deposition of the Maunsell Formation)

Fig. 17. Outcrop map of Waisuan rocks.

Land

Transgression

Transgression

Land

or transgression

Aerial erosion of scarp

rising

Land?

block

	Siltstone and mudstone with	Maunsell
	thin basal coarser beds	Formation
	Poorly bedded graded beds	
	Siltstone, with scattered	Waihoki
	sandstone beds and glauconite	Formation
	Areas of outcrop	
	Facies boundary	

One Mile
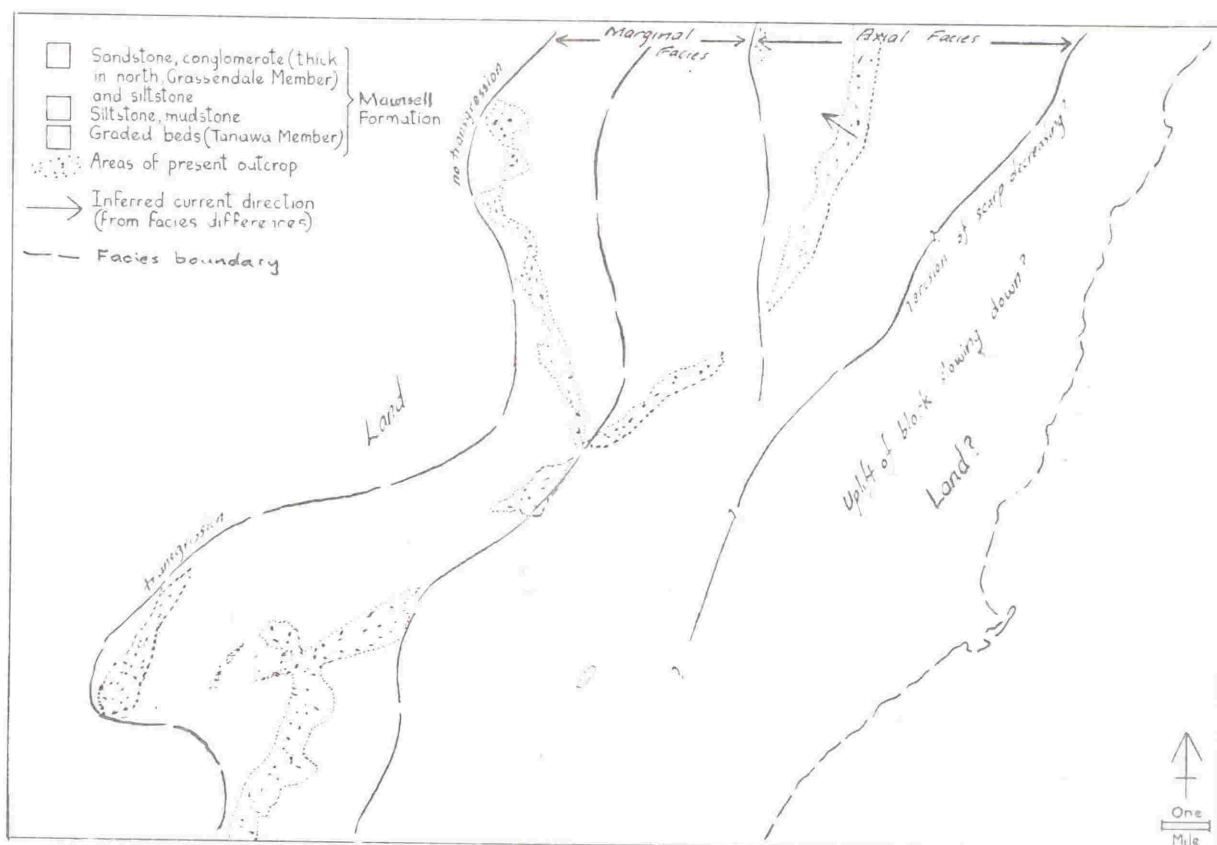
← marginal facies ———→ ← axial facies →
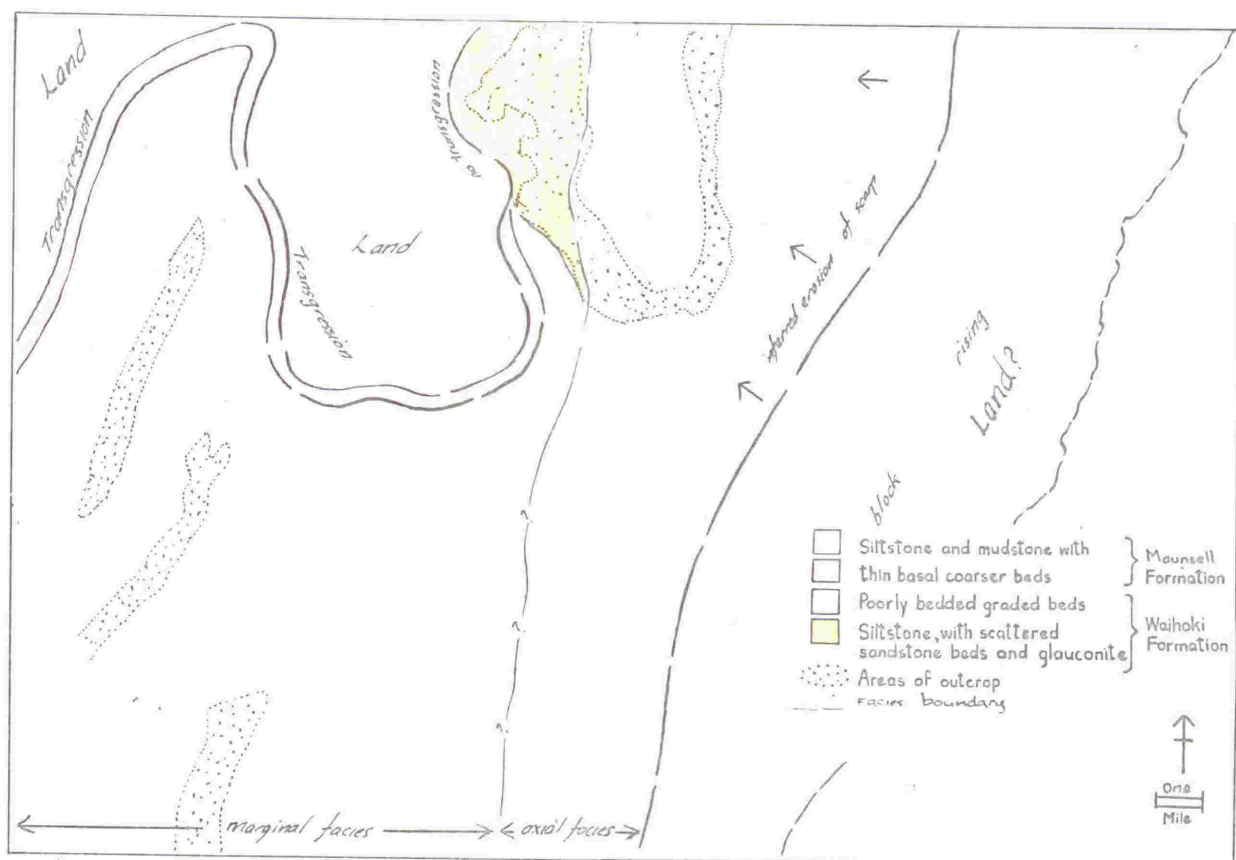
Fig. 18. Outcrop map of middle Tongaporutuan rocks.

poorly graded sandstone-siltstone beds with
interbedded mudstone, was deposited conformably
on the Maunsell Formation. In the west the
Waihoki Formation is finer grained and more
massive than in the west. Locally it contains
glauconitic sandstone. It is inferred that
there was uplift and erosion in the east. In
the west there was little sedimentation. In
the southwest the base of the formation is a
tuffite, the origin of which is uncertain.
Kear (1957) inferred that it came from a
"south-eastern volcanic zone". However, tuffite
is abundant in the upper Miocene Mapiri Formation
of northern Hawkes Bay and Poverty Bay and it
is more likely that it originated from the
"Coromandel andesite zone" where volcanism of
Upper Tertiary age is known (Grindley et al., 1959).

In the northeast of the Tinui District
coarse sediments of the Ngarata Formation were
deposited during the middle or upper Tongaporutuan.
In the west the formation is unconformable on
the Torlesse Supergroup and in the east it is
unconformable on the Waihoki Formation (Fig. 19).
Deposition of the Ngarata, Waihoki and Maunsell
formations continued in Kapitean time. In the
Opoitian, siltstone of the Rangiwhakaoma Formation
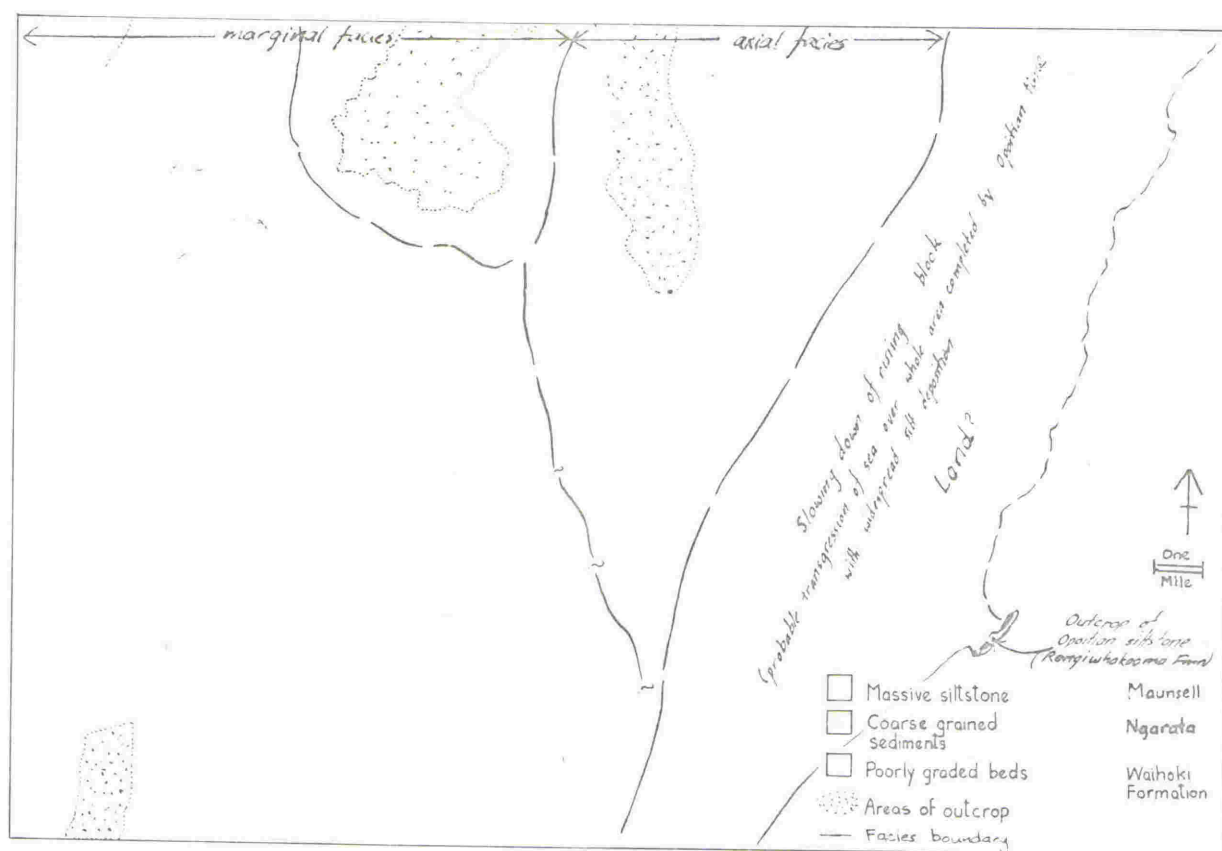
Fig. 19. Outcrop map of upper Tongaporutuan and Kapitean rocks.

was deposited at Castlepoint and it is inferred that the siltstone was once much more widely deposited than it is now.

CASTLEPOINT TRANSGRESSION

Shelly sandstone and coquina limestone of the Nukumaruan Castlepoint Formation is known in place only at Castlepoint. A 2 ft boulder of coquina limestone was found at Maringi Trig. 15.5 miles northwest of Castlepoint. If the boulder is substantially in place and not man-transported, it indicates that the limestone once rested directly on Cretaceous rocks at this locality. The Hurupi Group, inferred to have been deposited at this place (Fig. 19), must have been eroded prior to the deposition of the limestone. West of the Tinui District deposition continued apparently without interruption from the Opoitian to the Castlecliffian. During Nukumaruan and Castlecliffian times deposition changed from marine to non-marine (Kingma, 1967).

It is inferred that during Waipipian and Mangapanian times the Tinui District became land. In the Nukumaruan the sea transgressed onto the

district (Castlepoint Transgression). During
the transgression shallow water sediments were
deposited unconformably on deeper water older
sediments. The formation contains Chlamys
delicatula (Hutton) - a cold climate indicator.
Therefore the transgression was caused by the
tectonic lowering of the land below a sea level
already lowered because of the cold climate.
Vella (1963) included the formation in his
Te Ahitaitai Cyclothem, the second oldest of
four he recognised in the Wairarapa. He inferred
that the cyclothems were deposited while the
Wairarapa was sinking tectonically at a decelerating
rate. The basal beds of the cyclothem contain
cold water faunas which he inferred were probably
deposited during glacio-eustatic sea level
fluctuations.

PRESENT DAY RELIEF

The present day relief of the Tinui District
is dominated by depressions along the Whareama
and Tawhero synclines (Fig. 5). The two major
rivers, however - the Whareama and the Mataikona -
do not flow for any great distance along the
depressions. Instead, to reach the coast they

flow in gorges cut through hills to the east.
It is considered that headward erosion of **rivers** ~~streams~~
draining eastward from the hills captured the
rivers that once flowed in the depressions.
Later uplift produced the hills, and continued
river erosion the gorges. In turn western
tributaries of the Mataikona and Whareama **rivers**
captured the eastern tributaries of the Tauweru
River (Fig. 5).

Three periods of aggradation, followed by
degradation, formed three sets of terraces in
the floors of the Mataikona and Whareama valleys.
On the coast, marine benches have been cut at
100 ft, 270 ft, 400 ft and possibly at 550 ft.

TECTONIC DISTURBANCES IN THE TINUI DISTRICT

It will be shown that the rate of tectonic
movement with time was not uniform but varied
widely. During short intervals of time, rates
of tilting rose from about $1^{\circ}/10^{6}$ years to as
high as $30^{\circ}/10^{6}$ years and then declined. The
intervals of rapid tilting are called disturbances.
Four disturbances are recognised in the Cenozoic:
in the Paleocene; in the Early Miocene; in the
Late Pliocene; and in the Late Quaternary.

Paleocene Disturbance

Teurian rocks of the Tinui Group are
unconformably overlain by Waipawan rocks belonging
to the Wanstead Group. The rocks of the Tinui
Group are strongly folded about northeast striking
axes whereas rocks of the Wanstead Group are
not folded in this direction (Fig. 20). The
strong folding therefore took place in a short
interval of time equal to about a Lower Tertiary
stage (i.e. about 3×10^{6} years; Fig. 4). The
strong folding is called the Paleocene Disturbance.
The Wanstead Group is too poorly exposed to provide
a meaningfull tilt rate for the disturbance.

Fig. 20a. MAJOR STRUCTURAL FEATURES, TINUI DISTRICT

Bideford Anticlinal High

Blairlogie

Tinui

Balfour Syncline

Whareama Tawhero Syncline

Whareama

Aupiripiri

Peak

Whakataki Mataikona

Syncline

Fault

Fault

Fault

Fault

Tawhero Synclinal Depression

Syncline

Zone

Oamaru Zone

Zone

Syncline

AGE DIVISIONS

3 Waipawan — Nukumaruan
2 Teurian to Urutawan
1 Rocks older than Urutawan

(Rocks younger than Nukumaruan omitted).

0   1   2
miles
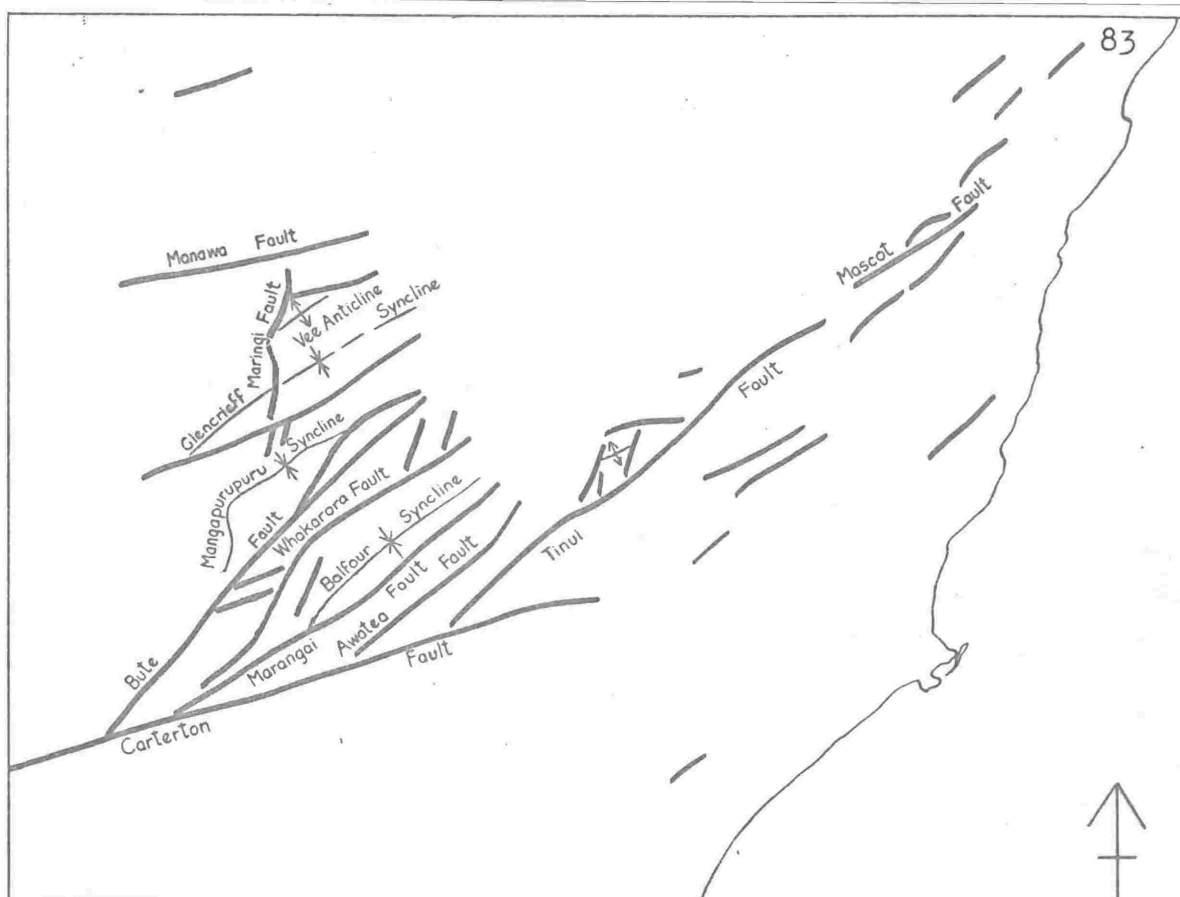
Fig. 20b.   Structures younger than Urutawan but older than Waipawan.

Fig. 20c.   Structures younger than Teurian.
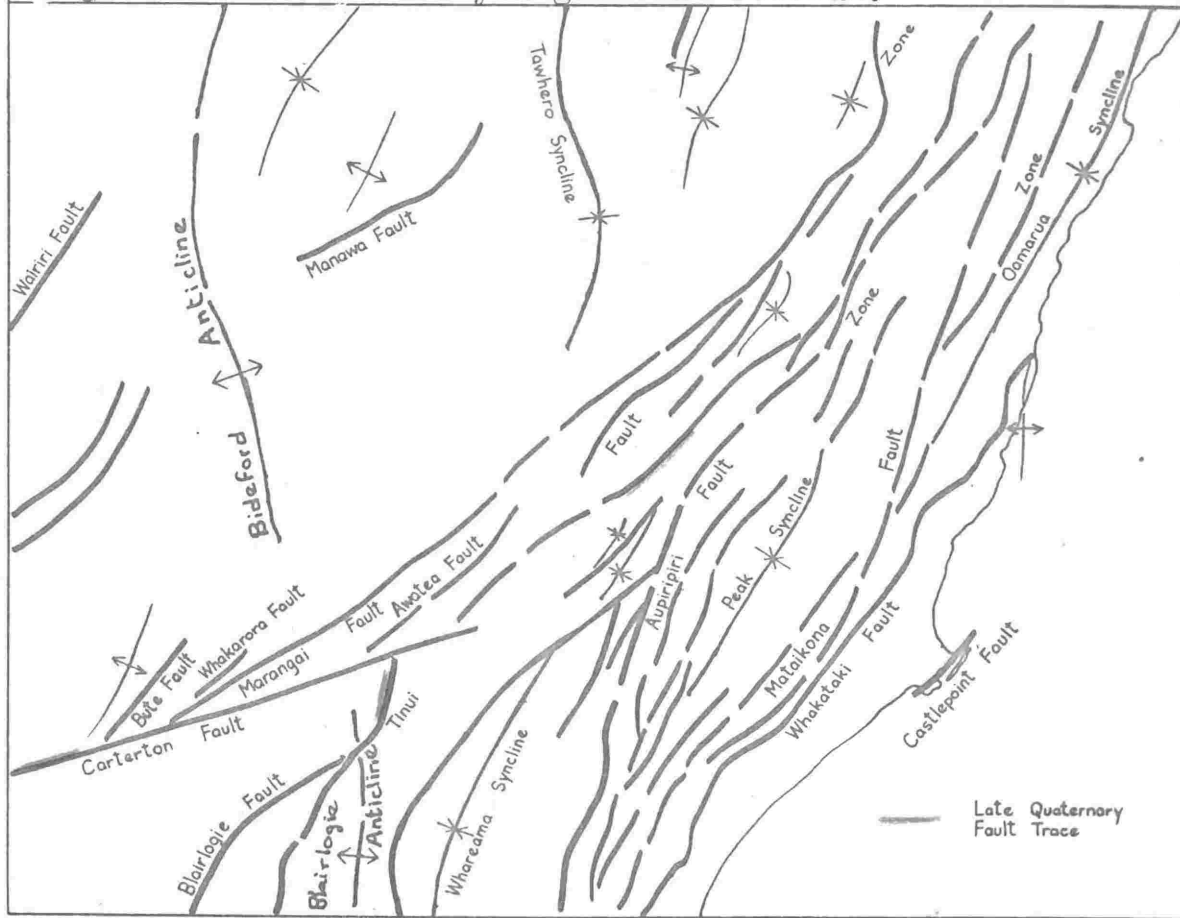
Early Miocene Disturbance

The slow uniform deposition of the Wanstead
Group ceased in the Duntroonian, to be followed
by rapid, variable deposition of the Annedale
Group in the Waitakian. The Annedale Group,
with a basal conglomerate, unconformably overlies
the Wanstead and older groups except in the
upper Mataikona Valley where the two groups are
conformable. From the lithological change at
the conformable contact it is inferred that the
unconformity - called the Early Miocene Disturbance -
represents a period of time of about a stage in
duration (say 3×10^6 years). No fold axes can
be related to this disturbance.

Late Pliocene Disturbance

It has already been mentioned that at
Castlepoint the Nukumaruan shallow water
Castlepoint Formation rests with angular unconformity
on the deep water Opoitian Rangiwhakaoma Formation,
the Waipipian and Mangapanian stages being absent.
On the Castle, the angular difference between
the two formations is about 12°. The unconformity
represents Waipipian and Mangapanian time, assumed

to be no more than 1×10^6 years giving a tilt
rate of at least $12^{\circ}/10^6$ years. The interval
of rapid tilting is called the Late Pliocene
Disturbance.

Late Quaternary Disturbance

In the Wairarapa there are a number of
places where the amount that Upper Pleistocene
and Holocene rocks have been tilted has been
determined. King (1930) mapped uplifted marine
benches on the Wairarapa coast, noted that
uplift had not been uniform, and inferred tilting.
Wellman, 1967 surveyed six Holocene raised marine
beach ridges which extend along the west flank
of the southern end of the Rimutaka Range at
Cape Turakirae. He showed that uplift and
tilting took place suddenly at intervals of about
1,000 years over the past 6,000 years. He
concluded that the range has been rising at an
average rate of about $12 \text{ ft}/10^3$ years. The
average rate of tilting on the western side of
the range is about $30^{\circ}/10^6$ years. Tilt rates in
terrace deposits in eastern Wairarapa (Singh,
in press) and Holocene marine sediments off

Hawkes Bay (Lewis, in press) are about $20°/10^6$ years.

The Rimutaka and Tararua ranges have strongly concordant summit heights that are interpreted (Wellman, 1948) as marking the present altitude of an old peneplain. The peneplain is folded into an anticline and the dip of the peneplain surface on the western side of the range is about $6°$. The age of the surface is not known, but Wellman suggested that it is younger, rather than older, than rocks of the Wanganui Series which crop out on the flanks of the ranges. It is assumed that the Rimutaka Range peneplain was ∧formed near sea level during a period when there was no uplift, and that the uplift and tilting at Cape Turakirae represents the last part of the uplift of the ranges. The present tilt rate is $30°/10^6$ years and the tilt of the peneplain is about $6°$ demonstrating that tilting at the present rate cannot have started more than 0.20×10^6 years. The present interval of high tilt rates is called the Late Quaternary Disturbance.

DISTURBANCES AND THE REST OF NEW ZEALAND

An attempt is now made to determine if the
four disturbances recognised in the Tinui District
in the Paleocene, in the Early Miocene, in the
Late Pliocene and in the Late Quaternary took
place elsewhere in New Zealand.

Paleocene Disturbance

In the Dannevirke Subdivision Lillie
(1953; p. 35) noted that "previous to the deposition
of these lower Tertiary beds /Wanstead Group/
the Cretaceous was very considerably folded and
most of the Whangai rocks /Whangai Formation/
removed by erosion". In the Gisborne area
Stoneley (1968) recognised a "local unconformity"
at the base of the Waipawan. In the Waipara
District of North Canterbury, which "exposes the
most complete fossiliferous sequence through the
Dannevirke Series in North Canterbury" (Hornibrook
in Wilson, 1963), Wilson (1963) noted that the
Dannevirke Series is separated from the Teurian
stage by minor breaks representing no great
interval of time. However, he stated "but local

tectonic movements had already caused local erosion".

It would appear that rates of tilting were sufficiently rapid to cause short breaks in deposition over most of the eastern part of New Zealand, but only in southern Hawkes Bay and in the Wairarapa, were the rates of tilting high enough to form noticeable unconformities.

Early Miocene Disturbance

In the Dannevirke area there was a major change in sedimentation at this time and the Pareora Series is absent (Lillie, 1953; Kingma, 1960) although in many places the stratigraphic sequence appears to be continuous (Lillie, 1953). The absence of the Pareora Series is not now as important as it was previously considered to be because of the recent recognition that the series represents only a relatively short period of time (Scott, in press). Lillie (1953) stated that the Ihungia Formation (Altonian to Clifdenian) is often difficult to distinguish from the underlying Weber Formation although at some localities there is a marked unconformity.

For example in Mototaria Survey District, the
base of the Ihungia Formation is a fossiliferous
conglomerate, several hundred feet thick, which
unconformably overlies a reduced thickness of
Wanstead Group rocks. In the Akitio Syncline
the basal bed of the Ihungia Formation is a
limestone containing pebbles derived from the
Weber Formation. It is therefore concluded that
the major change in sedimentation was accompanied
by uplift and erosion.

North of the Dannevirke area there are many
diapiric structures and a possibility of large
scale gravity sliding (Stoneley, 1962, 1968)
and the geology is confused. The most southerly
known diapiric structure is the Elsthorpe
Anticline, south of Hastings, which developed in
the Early Miocene (Kingma, 1957). Stoneley (1968)
showed that there was an unconformity within
the Waitakian east of Gisborne, which, although
representing only a short period of time, marks
a major change in sedimentation. He inferred
that the area about immediately east of Mt
Hikurangi was uplifted with extensive décollement.

In North Canterbury a disconformity between
the lower Landon Amberley Limestone and the upper

Landon Weka Pass Stone (also a limestone), although
representing only a short period of time, is
apparently important for Wilson (1963) stated
that "a sudden regression, caused, perhaps by
earth movements in the Alpine region, took place
before the deposition of the Weka Pass Stone".

On the west coast of the North Island in
the Waikato Coalfield there was a major change
in sedimentation during the Waitakian. The
change is at the contact, at most places an
unconformity, between the Te Kuiti Group and
those overlying: the Waikawau Group in the north
and the Mahoenui Group in the south (Kear and
Schofield, 1959). Kear and Schofield stated that
"deposition of the Te Kuiti Group finally ceased
when tectonic activity produced (1) an angular
unconformity between it and younger sediments
and (2) uplift of the source province from which
the subsequent clastic sediments were derived".
The unconformity does not represent a great length
of time and at one locality it can be shown to be
within the Waitakian Stage.

In north Westland, between the end of the
Oligocene and the end of the middle Miocene
(Gage, 1949; Wellman, 1949), the sites of Lower

Tertiary deposition became mountain ranges and
Lower Tertiary mountain ranges became sites of
Upper Tertiary deposition because of reversal
of movement on major faults.

Late Pliocene Disturbance

In the Dannevirke Subdivision there is an
unconformity similar to the one already described
from the Tinui District, except that the shallow-
water limestone above the unconformity, the Te
Aute Limestone, is older and Mangapanian in age.
The base of the limestone was described by Lillie
(1953) as an important erosional break which
affected all areas of Mangapanian sedimentation.
The limestone commonly contains greywacke pebbles,
with composition similar to the greywacke forming
the Ruahine Range. The pebbles increase in
abundance westward towards the range, and show
that the range was being uplifted. The Te Aute
Limestone is unconformably overlain by the
Nukumaruan Petane Limestone (Kumeroa Formation
of Lillie, 1953). Lillie recorded an angular
discordance that indicates westward tilting
between 2° and 15° between the two limestones.

In the Gisborne area diapiric structures
developed (Stoneley, 1962; Ridd, 1964) and
décollement took place. Ridd considered that
the climax of tectonic movements was reached in
the Early Pliocene. At Waerengaokuri, Tongaporutuan
beds are the youngest part of a diapiric intrusion
and are overlain by undeformed Castlecliffian
lacustrine beds (Bishop, 1968).

In the South Island widespread gravel
formations (e.g. Moutere Gravel, Old Man Gravel,
Kowhai Gravel) show that rapid uplift of the
Southern Alps took place in late Pliocene time
immediately prior to the Nukumaruan. That the
uplift of the Southern Alps was sudden is shown
in the Moutere Depression of Nelson, where
Waitotaran coal measures (Glenhope Formation),
are conformably overlain by the Moutere Gravel.
The Glenhope Formation is locally derived from
rocks on the west side of the Alpine Fault but
the Moutere Gravel is derived from the Southern
Alps on the east side of the fault (Johnston, 1971).

Late Quaternary Disturbance

The high rates of tilting determined from
marine ridges and marine benches in the Wairarapa

and southern Hawkes Bay have already been discussed.
Ridges and benches are known elsewhere in New
Zealand, such as one in Westland giving a tilt
rate of 15 $^o/10^6$ years (Suggate, 1968), but few
rates of tilting have been determined. Active
fault traces are present throughout most of New
Zealand (Lensen, 1965) and some show horizontal
movement averaging 0.5 in/year (Clark and Wellman,
1959).

DISTURBANCES WITHIN NEW ZEALAND AS A WHOLE THAT
CANNOT BE CORRELATED WITH THOSE IN THE TINUI DISTRICT

In addition to the disturbances described
above, which correlate with those in the Tinui
District, other disturbances have been recognised.
Lillie (1953; p. 80) described the deposition of
the upper Southland Tutamoe Formation in the
Dannevirke Subdivision as being tectonically
important. According to him new sites of deposition
formed and new areas were uplifted and eroded.
In the Tinui District the topographic change may
be represented by the Hurupi Transgression. In
the Gisborne area, Stoneley (1968) recognised
that the main movements in a Tertiary décollement
took place in Pareora time. It was followed by

the widespread deposition of Altonian (Pl) or
younger sediments unconformably on older sediments.
The uplift of the Kaikoura Ranges is well dated
by the formation in Southland time of the Great
Marlborough conglomerate (Lensen, 1962).

It would be inappropriate to discuss here
all the disturbances within New Zealand, but it
is likely that sudden disturbances similar to
those that took place in the Tinui District
occurred in all parts of New Zealand but they
were not necessarily synchronous with those that
took place in the Tinui District.

STRUCTURE OF THE TINUI DISTRICT

In order to discuss folding and faulting
in the Tinui District with time, it is convenient
to consider the stratigraphic sequence to be
divided into three major age divisions (Fig. 20a):

Division 1: rocks older than Urutawan (Torlesse
Supergroup)

Division 2: rocks between Urutawan and Teurian
in age (Mangapurupuru and Tinui
groups)

Division 3: rocks between Waipawan and Nukumaruan
in age (Annedale and Hurupi groups
and Castlepoint Formation).

It is also convenient to consider first the area
west of the Tinui Fault Zone, and then the area
east of it.

West of the Tinui Fault Zone

Folds

Rocks of division 1 are strongly and complexly
folded, the only well defined fold being the Vee
Anticline which is parallel to the folds in
Division 2 (Fig. 20b). Division 1 is not considered
further. Rocks of division 2 are strongly folded,

with dips of about 50° to 70° whereas rocks of
division 3 (Fig. 20c) are relatively weakly
folded, with dips of generally less than 50° and
commonly between 10° and 25°. The weak folding
in division 3 almost certainly affected the rocks
of divisions 1 and 2, but as the rocks had already
been fairly strongly folded its effect was
negligible. Similarly, the strong folding which
affected rocks of Division 2, had, with the
exception of the Vee Anticline, negligible effect
on the strongly deformed rocks of division 1. The
axes of the strong and weak folding have different
strikes. The strong folds strike approximately
northeast the weak folds approximately north.
The strong folding is Early Cenozoic (Paleocene)
in age, and the weak folding is Late Cenozoic
(Post-Miocene) in age.

Faults

The faults are grouped according to the age
of the rocks they displace. Within rocks of
divisions 1 and 2 the major faults strike between
ENE and northeast, and minor faults strike NNE.
These faults are not well developed in division 3.
In division 3 the major faults strike approximately
NNE, parallel to major Late Cenozoic faults in

the Wairarapa. They extend through rocks of
divisions 1 and 2, but are relatively unimportant
there. Hence the ENE faults are inferred to have
been dominant in the Early and the NNE faults are
inferred to have been dominant in the Late Cenozoic.

East of the Tinui Fault Zone

The strike of the fold axes, faults, and the
dip of the rocks is the same in division 2 as it
is in division 3. Consequently it is impossible
to distinguish between Early and Late Cenozoic
folding and faulting. Early Cenozoic folding
about ENE striking axes is inferred for the
district west of the Tinui Fault Zone. ENE
folding to the east of the fault is thought to
have been obliterated by the later faulting and
folding along NNE trends.

Early Cenozoic Folds and Faults (Fig. 20b)

Folds

Early Cenozoic folds are mostly determined
by opposing dips some distance apart, and only
rarely are the fold axes themselves exposed.
Four folds are mapped: the Vee Anticline in the

northwest, and the Glencrieff, Mangapurupuru, and Balfour synclines in the southwest. All the folds are separated by faults and there are no complementary anticlines between the three synclines in the southwest. The synclines plunge northeast and the single anticline southwest. The age of the youngest beds in each syncline becomes progressively younger in a southeast direction indicating that the "synclines" are the northwest limb of a larger syncline (Fig. 3) that has been faulted and folded.

Faults

The major faults are the ENE striking Carterton, Target and Manawa faults. A number of faults striking northeast to ENE branch off towards the Target Fault. The only NNE striking fault of importance is the Maringi Fault between the Target and Carterton faults. Because of poor exposures and wide zones of crushing, it is impossible to observe the dip of many of the faults directly. However, as the surface trace of each fault is linear across hilly topography, the fault planes are inferred to dip steeply. For convenience, the faults with unknown dip are shown as being vertical in Fig. 3.

Late Cenozoic Folds and Faults (Fig. 20c).

Folds

Folds in the Late Cenozoic rocks usually have exposed axes. Where the axes are not exposed the folds are determined from opposing dips and from the slope of exhumed erosional surfaces on Early Cenozoic or older rocks. Folds are more numerous in the west than in the east, and only the major folds are named in Fig. 20c. In the west there is a major upfold, the Bideford-Blairlogie Anticlinal High, made up of the Bideford Anticline north of the Carterton Fault and the Blairlogie Anticline south of the fault. To the east of the high there is a major downfold, the Tawhero-Whareama Synclinal Depression, made up of the Tawhero Syncline in the north and the Whareama Syncline in the south. Between the synclinal depression and the coast there are two major synclines, the Oamarua and Peak synclines. The folds are described in turn, beginning in the west.

The axis of the Bideford Anticline is defined in the north of the Tinui District by the crest of an exhumed erosional surface cut across Cretaceous and older rocks. In the south the

surface has been largely destroyed and the
position of the axis is uncertain. The Blairlogie
Anticline is poorly defined by an exhumed
erosional surface which shows that most of the
eastern limb of the anticline is faulted out by
the Tinui Fault Zone. North of the Tinui District
the Bideford Anticline, defined by opposing dips
in Upper Tertiary beds, can be traced as far as
Pongaroa. South of the district it the lairlogie Anticline
crosses the coast near Pahoa.

The axis of the approximately north-striking
Tawhero Syncline is well defined by dips in Late
Cenozoic rocks. The axis of the NNE striking
Whareama Syncline is concealed by alluvium but
is inferred to be parallel to the Aupiripiri
Fault Zone and to the Buxton Fault (Fig. 2).
Vertical drag on the faults may have caused the
dips in the Whareama Syncline to be 15° to 20°
steeper than dips in the Tawhero Syncline. The
northern end of the Whareama Syncline has been
offset by dextral faulting.

The Tawhero Syncline can be traced for a
short distance north of the Tinui District where
it disappears, or has been obliterated in a
complexly faulted area south of Pongaroa. The
Whareama Syncline extends south to cross the coast

at Flat Point (Fig. 1).

In the east the axes of the Oamarua and Peak synclines strike NNE and are parallel to major faults. The complementary anticlines are absent but their axes are approximately represented by the Aupiripiri and Mataikona fault zones; the rocks dipping away from the fault zones towards the synclinal axes. The axes of the synclines are parallel with the faults and it is inferred that the folding is controlled by the faulting. This contrasts with the situation at most other parts of the Tinui District where the faults and folds are not parallel, and the folds are inferred to have formed by compression.

Faults

The major NNE striking faults are, from west to east: the Wairiri Fault, the Tinui Fault Zone, the Whakataki Fault, and the Castlepoint Fault Zone.

The Wairiri Fault, east side downthrown, has brought the Waewaepa Formation into contact with the Maunsell Formation. It dips vertically, and north of Wairiri Road has a sliver of Whangai Formation infaulted along it.

The Tinui Fault Zone is the most important fault in the Tinui District. North of Tinui Village the fault zone is 1.5 miles wide and contains active traces. The downthrown side is to the west. South of Tinui Village the fault zone is narrow. The east side is downthrown, and as its dip is 70° west it has a reverse component. Several faults branch off the fault zone, the most important being the Blairlogie Fault in the southwest. North of the Tinui District the fault zone extends north into southern Hawkes Bay. Southwards it probably joins the Adams Fault of Eade (1966) which reaches the coast near the Pahoa River.

The Whakataki Fault extends from Reef Point to south of the Tinui District. The curve of the fault trace across hill country suggests a westerly dip of about 60°. It is downthrown to the east and is thus inferred to have a reverse component. The fault disappears out to sea at Reef Point, and probably reappears as the fault, on the coast near the Owahanga River, which continues northwards into the Dannevirke Subdivision (Lillie, 1953). South of the Tinui District it reaches the coast at Flat Point.

The Castlepoint Fault Zone is exposed at

Castlepoint. Associated with it are the only
definite outcrops of Opoitian and Nukumaruan rocks
in the Tinui District. The fault dips steeply,
and is downthrown to the east. A collinear
steeply dipping fault at Cape Turnagain is
probably its northern continuation.

So far it has been tacitly assumed that
new faults appear and old faults become inactive.
The true situation is more complex and a
particular fault may change its rate of movement
or even its sense of movement with time. However,
in order to determine the history of a particular
fault, many well dated reference lines (Fig. 21)
or reference planes are required. It is important
to distinguish between reference lines and the
outcrop of reference planes. In the general case,
a fault displaced inclined reference plane shows
on a map as an outcrop line which is "offset"
by the fault (Fig. 22). The offset has a
horizontal length, which in general does not
represent the horizontal (strike-slip) displacement
of the reference plane by the fault.

To determine the amount of horizontal
displacement the dip of the reference plane at
the time of faulting must be known, and also
the sense of movement in one direction. In

Displacement of reference line A = a'
Displacement of reference line B = b' = o
∴ Amount of displacement is a in A - B
years
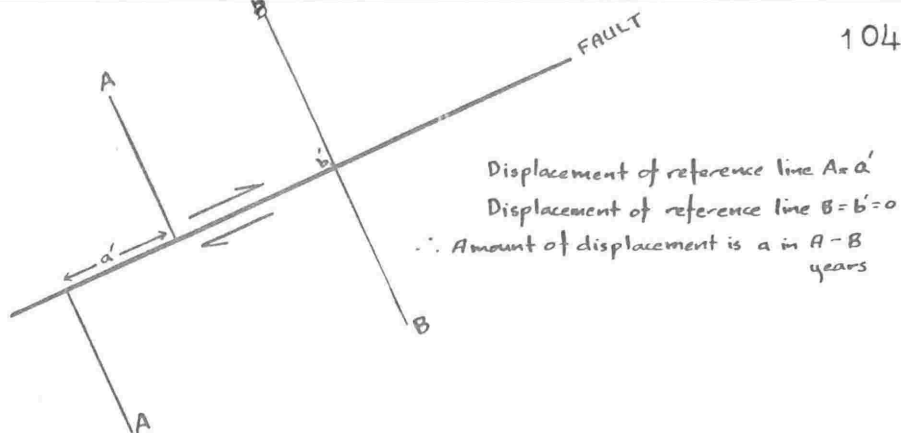
Fig. 21. Reference lines (or vertical reference planes) offset by a fault.
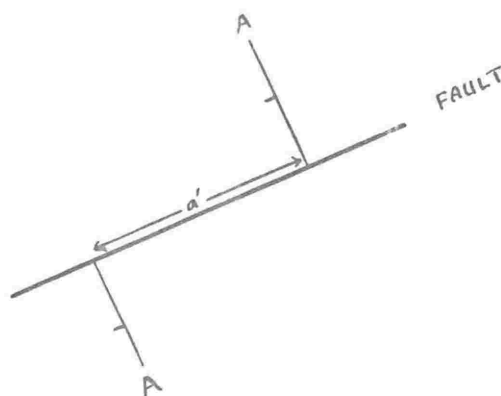
Fig. 22. Dextral offset of an inclined reference plane (A).

Vertical movement = x
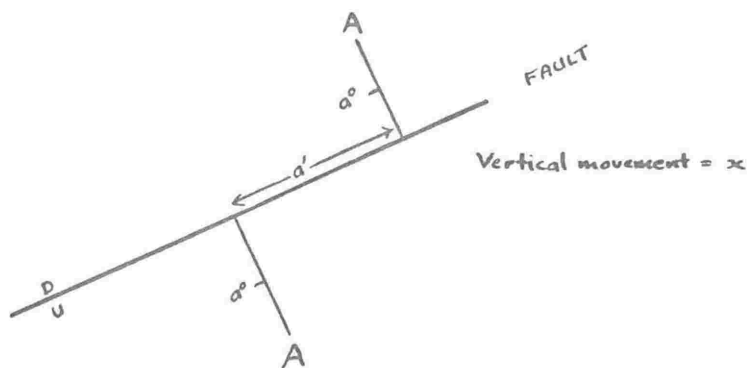
Fig. 23. Plan showing vertical displacement of a reference plane (A).

Fig. 22 the dextral offset (a') of an inclined
reference plane A could have been entirely caused
by vertical fault movement. The lower the angle
of dip, the greater the horizontal offset. If
the amount of vertical movement, and the downthrown
side are known, then the true horizontal
displacement of reference plane A is a'. The
amount of horizontal displacement (y) by vertical
movement (x) can be calculated by using the
following solution

$$\tan. a^{\circ} = \frac{y}{x}$$

if y equals a' then there has only been
vertical movement on the fault. If it is more,
then y - a' equals the amount of sinistral
movement on the fault and if it less then a' - y
equals the amount of dextral movement on the fault.

Horizontal movement on a fault may have all
been in the same direction or in different
directions, and in all cases the total displacement
is the algebraic sum of the movements on that
fault. Movements on the major faults in the
Tinui District are considered in terms of the
previous discussion and an attempt is made to
determine the amount and sense of movement at
different times in the past. The NNE striking
faults are discussed first.

Horizontal Movement on the NNE Striking Faults

The NNE striking Tinui Fault Zone truncates
the ENE striking Carterton Fault and associated
faults (Fig. 2). ENE striking faults immediately
north of the Tinui District (Kingma, 1967), and
on the opposite side of the fault zone to the
Carterton Fault, are assumed to have been the
continuation of the Carterton Fault and associated
faults. The ENE striking faults are inferred to
have been sinistrally displaced by about 16 miles
by the Tinui Fault Zone (Fig. 24).

In the Mt Adams area, Eade (1966) mapped a
facies discontinuity in his Kaiwhata Formation
(Teurian) across the NNE striking Tutu Fault.
The fault is almost collinear with, and may be
the continuation of, the Tinui Fault. Eade
suggested that the change was due to strike-slip
faulting of at least 12 miles, although the sense
of movement was not specified. P. Wellman (1970)
showed that if movement had been strike-slip then
it would have been sinistral, that is, in the same
sense as the movement inferred on the Tinui Fault
Zone. Further evidence is provided by glauconitic
sandstone dikes in the Whangai Formation (Teurian)
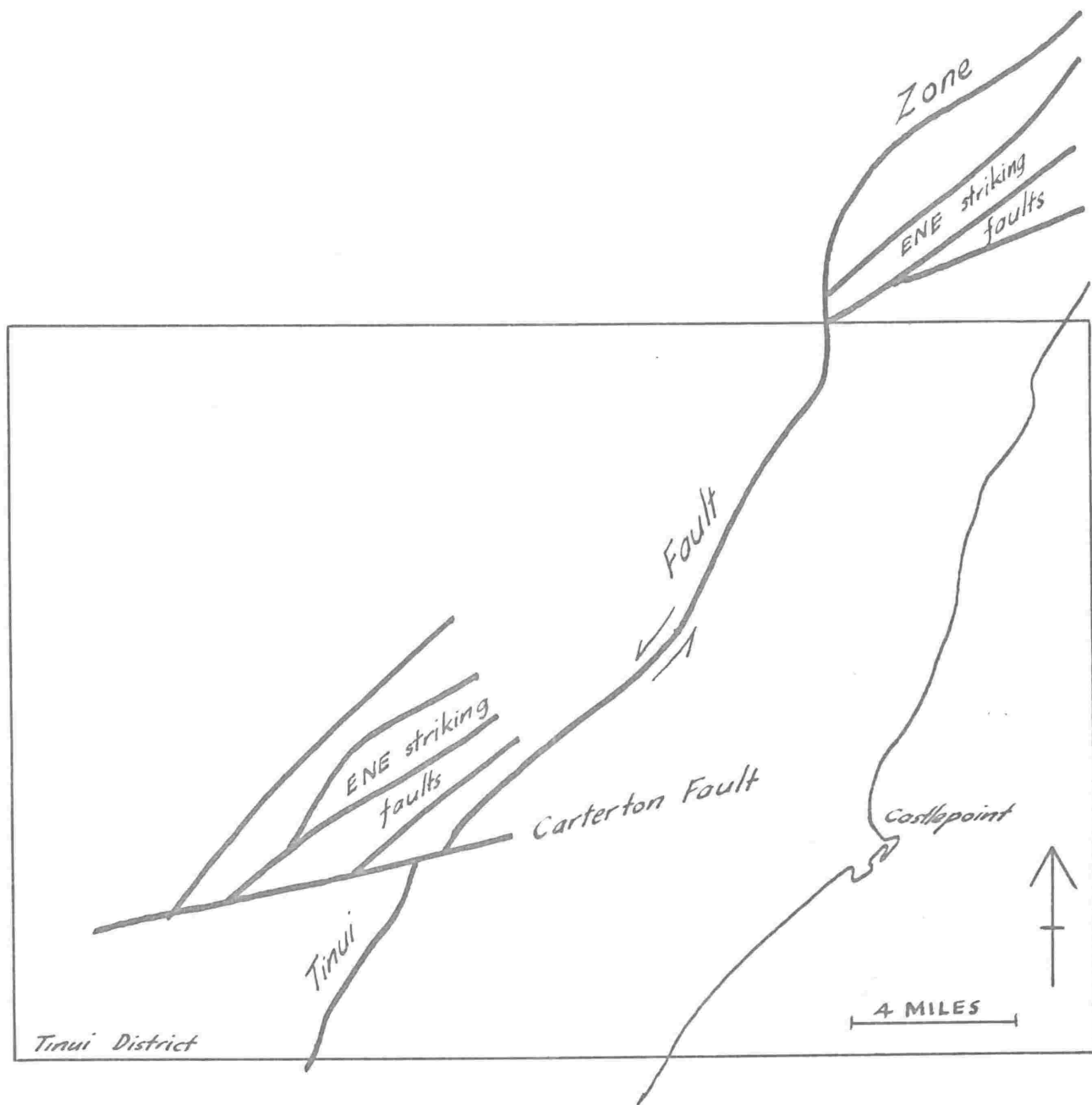
Fig. 24. Inferred sinistral displacement of
ENE striking faults by the Tinui
Fault Zone.

exposed on a coastal platform south of the Awhea River (Professor H.W. Wellman, pers. comm.). Wellman has recorded small sinistral offsets on northeast to NNE striking faults which displace the dikes.

In the Tinui District a NNE striking fault on the west limb of the Whareama Syncline has a sliver of the Takiritini Formation (Lower Miocene) along it. The sliver is 8 miles south of similar rocks in the Tinui Valley. At least 8 miles of dextral movement on the fault is thus possible. Ridd (1967) inferred that the northeast to NNE striking Pongaroa Fault continued southwards, beneath Upper Miocene sediments, to join the Tinui Fault Zone. From paleogeographic patterns on either side of the Pongaroa Fault, Ridd inferred that there was about 8 miles of dextral movement on the fault during the Miocene.

In conclusion, all the NNE striking faults for which there is any information, have moved in a dextral sense since the Miocene. However, there is evidence for sinistral movement on some of the faults prior to the Miocene. Therefore it is inferred that movement on all the NNE striking faults prior to the Miocene was sinistral.

For some faults the early sinistral movement was greater than the late dextral movement.

Vertical Movement on the NNE Striking Faults

Within the Tinui Fault Zone in the Tinui Valley a well defined active fault trace, 4 miles long, is downthrown 12 ft to the west for part of its length. The Whakataki Fault has downthrown the Lower Miocene Whakataki Formation on its eastern side. The fault plane dips 60° west and the sense of movement is reverse. In the southeast of the Tinui District the Tinui Fault Zone dips 70° west and the sense of movement is reverse.

Horizontal Movement on the ENE Striking Faults

According to Lensen (1968) the Carterton Fault immediately west of the Tinui District dextrally displaces by 45 ft the edge of gravels which are here mapped as the Rorokoko Formation of early Last Glaciation age. The 70° westerly dipping Tinui Fault Zone has an offset of 1.2 miles across the fault. The offset is

partly due to vertical movement and partly due
to dextral displacement. The vertical movement
would have produced sinistral offset of the
Tinui Fault Zone of about 0.2 miles. The true
dextral movement on the fault is therefore about
1.4 miles (Fig. 25). The 15° westerly dipping
base of the Maunsell Formation is dextrally
offset by 1.7 miles across the Carterton Fault.
However, the dip of the formation was initially
gently east (Fig. 17) and has since rotated to
15° west. During vertical movement the sense
of apparent horizontal movement would therefore
have changed from dextral to sinistral.

The Motuan shoreline (Fig. 7a) and the
Waitakian shoreline (Fig. 14a) are sinistrally
offset by the Carterton Fault. As the dip of
the shorelines would be gently east for a consider-
able time after their formation, a small amount
of vertical movement would produce a large
horizontal offset and there is no evidence for
any horizontal displacement. It is inferred
that the NNW side of the fault was upthrown in
the Upper Cretaceous to initiate the Gentle
Annie gravity slide and again in the Otaian
when the Takiritini Formation was deposited.
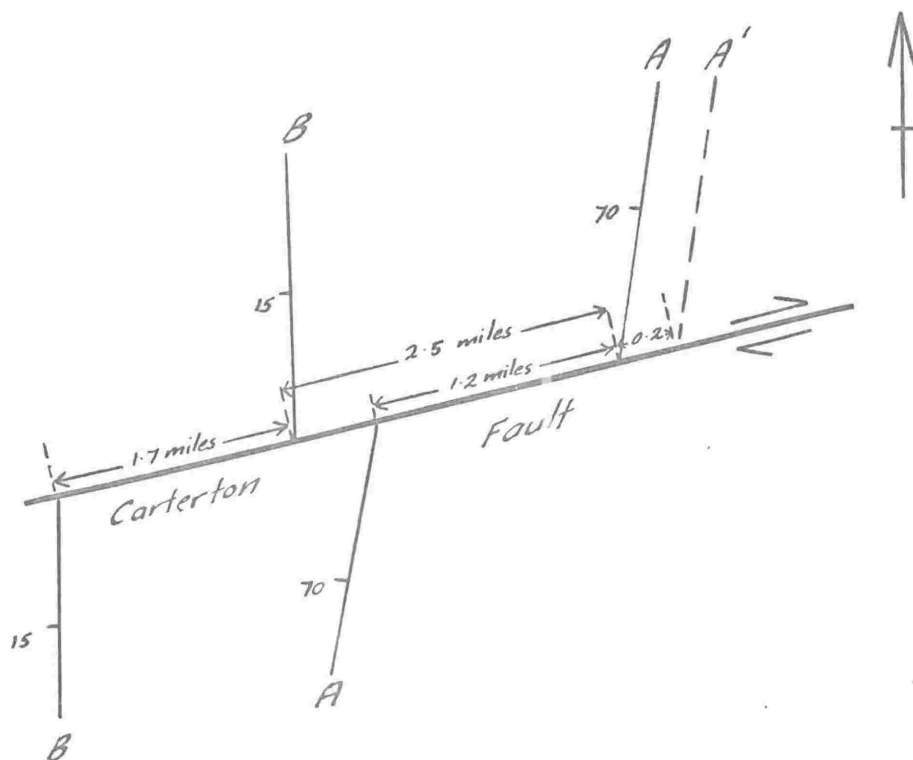
A = Tinui Fault Zone
B = base of Maunsell Formation

Fig. 25. Diagrammatic representation of
apparent and real horizontal offsets
on the Carterton Fault.

Such vertical movement would cause dextral offsetting of the shorelines. It is therefore inferred that there was sinistral movement on the Carterton Fault prior to the Late Cenozoic. It is impossible, without further information on the amount and direction of vertical movement on the fault, and the dip of the shorelines at the time of vertical movement, to determine the true amount of sinistral displacement.

Vertical Movement on the ENE Striking Faults

The Carterton Fault vertically displaces the edge of the early Last Glaciation Rorokoko Formation by up to 15 ft. The downthrown side is different at different places. In the east, opposite Awatoitoi, it is the SSE side, whereas further west it is the NNW side. In the Pliocene the SSE side of the fault was downthrown. It is inferred that the SSE side was also downthrown in the Otaian and in the Upper Cretaceous. The dip of the fault is unknown, but is greater than 70° from its linear trace. Vertical movements on other faults are unknown.

Intersecting Strike-slip Faults

Two fault trends, one striking NNE and the other striking ENE, have existed in the Tinui District during the Cenozoic. Although it is inferred that the NNE trend was dominant in the Late Cenozoic and the ENE trend was dominant in the Early Cenozoic, some interaction between the two trends has occurred throughout the Cenozoic. The horizontal displacement of the ENE striking faults by the Tinui Fault Zone (Fig. 24) is shown diagrammatically in Fig. 26. Such offsetting would form the numerous fault slivers, striking ENE, that exist within the Tinui Fault Zone (Fig. 2).
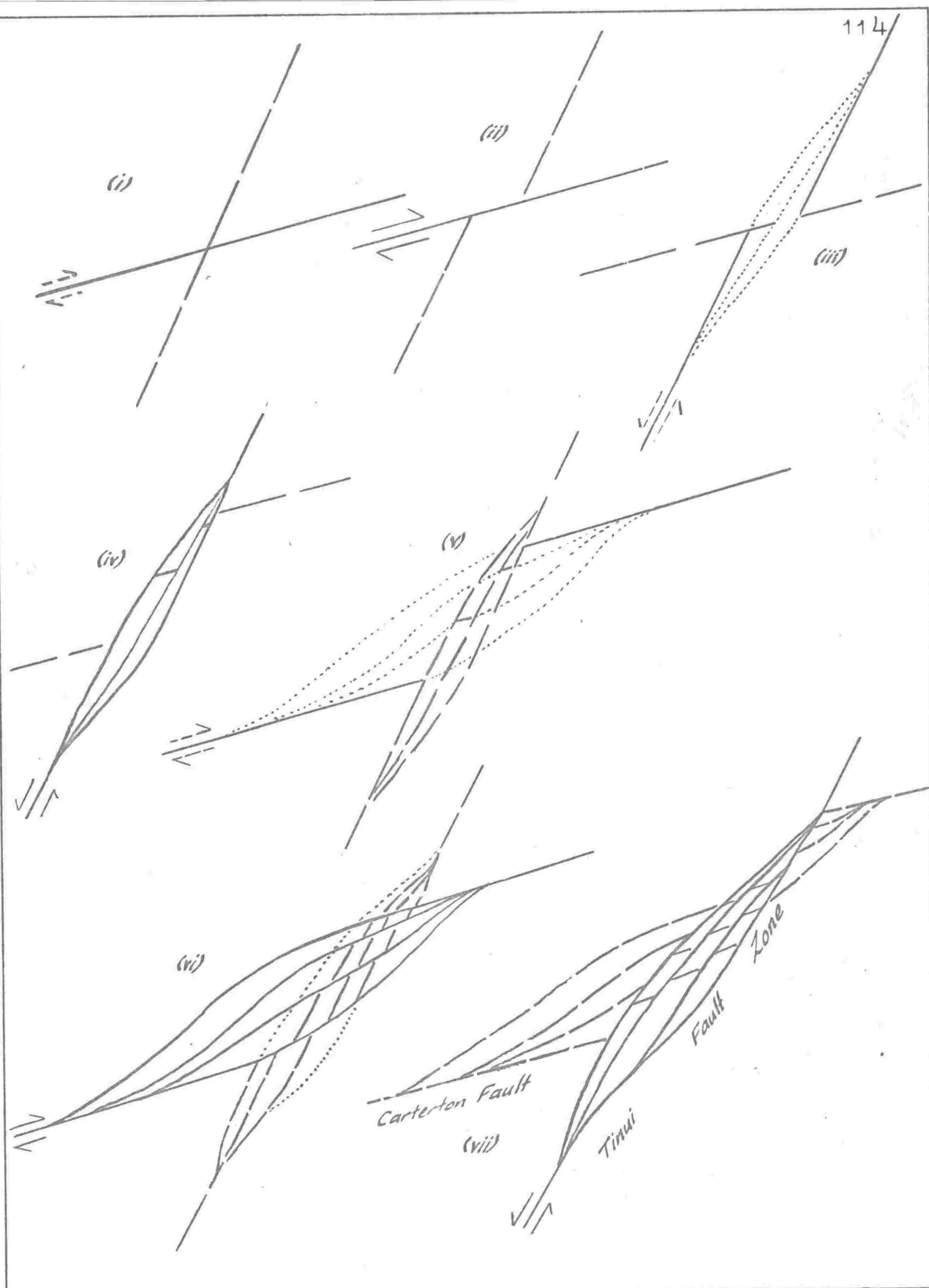
Fig. 26. Diagrammatic representation of formation of Fault Slivers

THE NEW ZEALAND MOBILE BELT

It has already been mentioned (p. 9) that the Tinui District forms part of a complexly folded and faulted region which extends from Kaikoura to East Cape. The region, along with the rest of the central part of the New Zealand landmass, contains strongly tilted Late Cenozoic rocks. This is in contrast to the southeast of the South Island and the northeastern half of the North Island where dips in Late Cenozoic rocks are gentle. For convenience, the central part of New Zealand is termed the New Zealand Mobile Belt (Fig. 27). There are many features in common to all parts of the belt in the New Zealand landmass, and in order to more fully understand the structure of the Tinui District, they will be discussed and a simple model proposed.

The New Zealand Mobile Belt is elongated approximately NNE-SSW with a major trench, the Hikurangi Trench, along its northeastern side. The landmass can be regarded as the crest of a major upfold or geanticline and the sea bed to the east as a major downfold or geosynclinal trough. Approximately parallel to the sides of the mobile
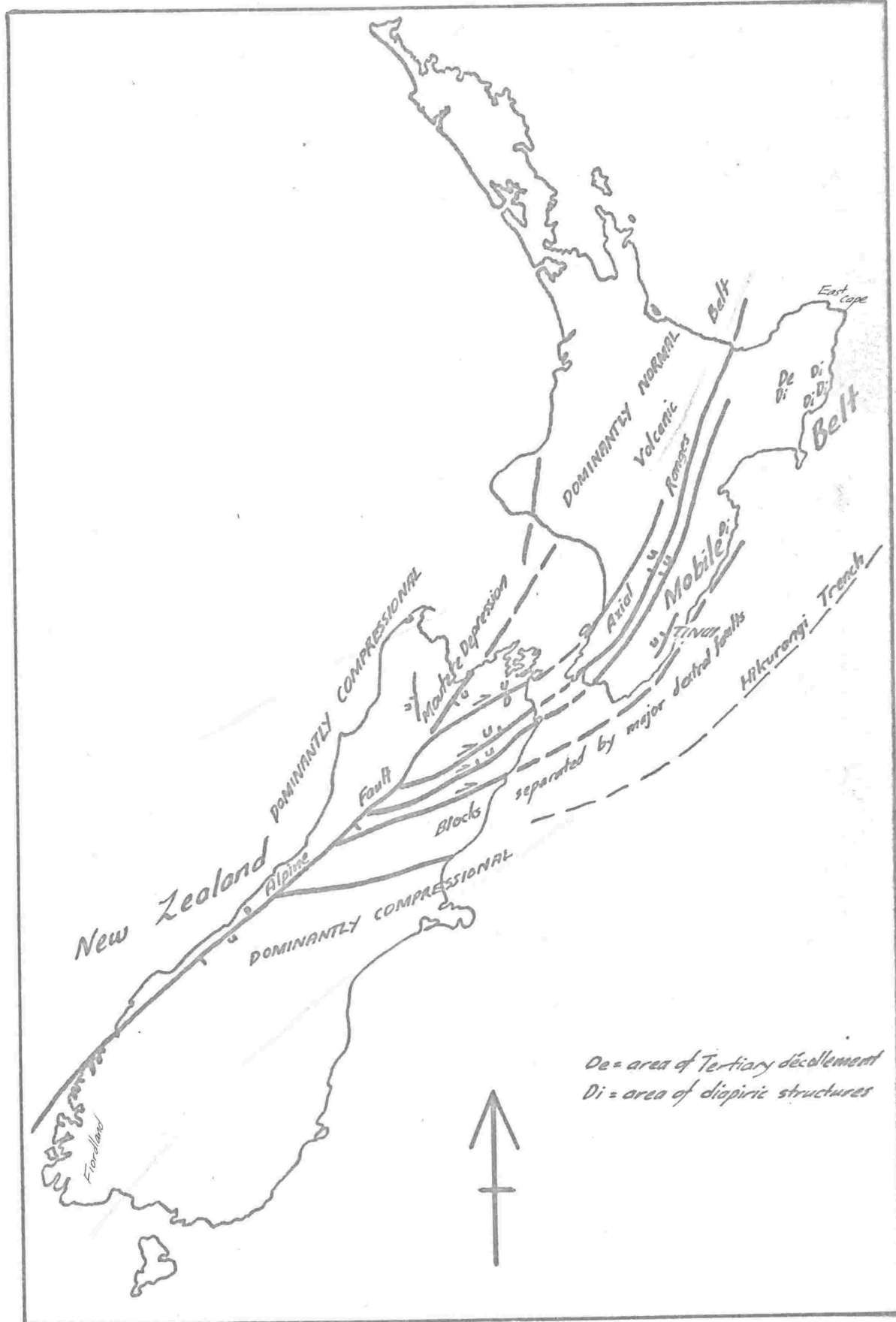
Fig. 27.   New Zealand Mobile Belt.

belt are major dextral faults. The faults diverge
from the Alpine Fault in the northern end of the
South Island and cross Cook Strait into the east
of the North Island (Fig. 27). The best known
feature of the faults is the hypothesis, first
introduced by Wellman in 1949 (Bensen, 1952), of
a postulated 300 miles dextral displacement by
the Alpine Fault of several major structures in
the South Island. Although the displacement is
accepted by most New Zealand geologists there is
little agreement as to when it occurred. In the
south of the South Island the dip on the fault
is eastward, the western side is downthrown, and
the sense of movement is reverse. In the north
of the South Island and in the North Island the
dip on the faults branching off the Alpine Fault
is westward, the eastern side is downthrown, and
the sense of movement is reverse.

The possibility that the dip on many of the
faults is decreased by gravity creep of the
upthrown side must be considered (Fig. 28).
However, it is inferred that the faults remain
reverse at depth because retriangulation surveys
across the Alpine Fault in Marlborough (Wellman,
1955), across the White Creek Fault before and
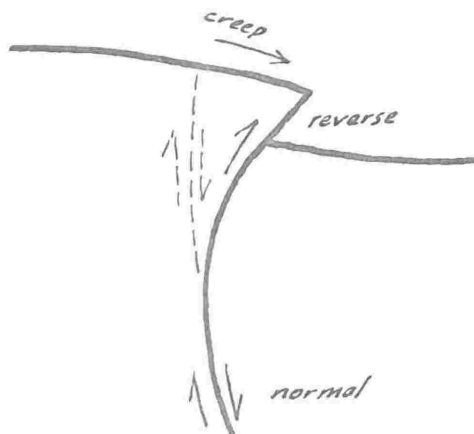
(a) normal fault
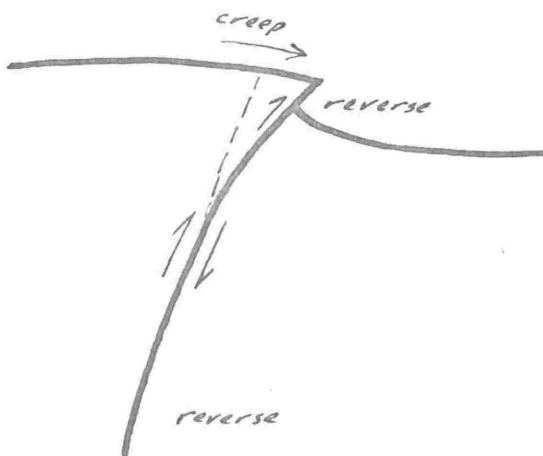
(b) reverse fault

Fig. 28.   Cross sections showing alternative
explanations of a fault with a reverse
component at the surface.

after the 1929 movement on the fault (Henderson, 1937), and in Hawkes Bay before and after the 1931 Napier earthquake (Professor H.W. Wellman, pers. comm.), and recently in the Wellington area (P.M. Otway, pers. comm.), show that the New Zealand Mobile Belt is undergoing shortening as well as strike-slip displacement.

Between the major dextral faults are a large number of elongated fault blocks (Cotton, 1916; Houtz et al., 1967), at an acute angle to the strike of the major dextral faults (Fig. 29). It is assumed that the blocks are separated by reverse faults and that blocks and faults rotate together so that the total width of the mobile belt decreases with time.

Within each fault block, asymmetrical synclines developed in the lows and asymmetrical anticlines developed in the highs (Fig. 30a, b). As rotation of the block advanced, faulting sometimes removed the steep limb of the fold (Fig. 30c) and growing folds will form. Such growing folds are typical features of the east coast of the North Island, were first described from New Zealand by Macpherson (1946), and are independent of uplift or depression of the mobile belt. The

Fig. 29.
LATE CENOZOIC STRUCTURAL MAP, WAIRARAPA

(a)

(b)

block
width

(c)

fault replacing
limb

reverse fault
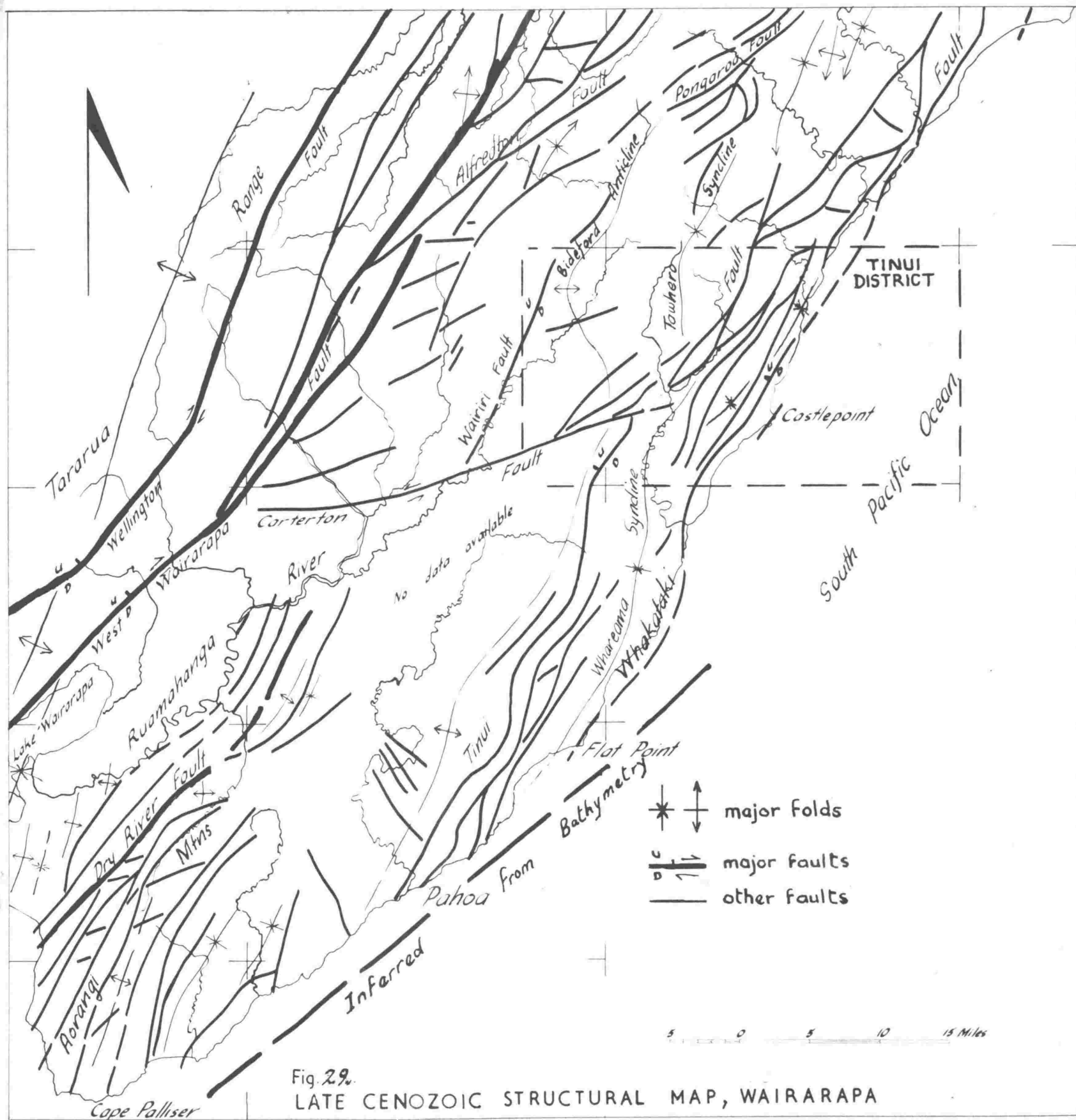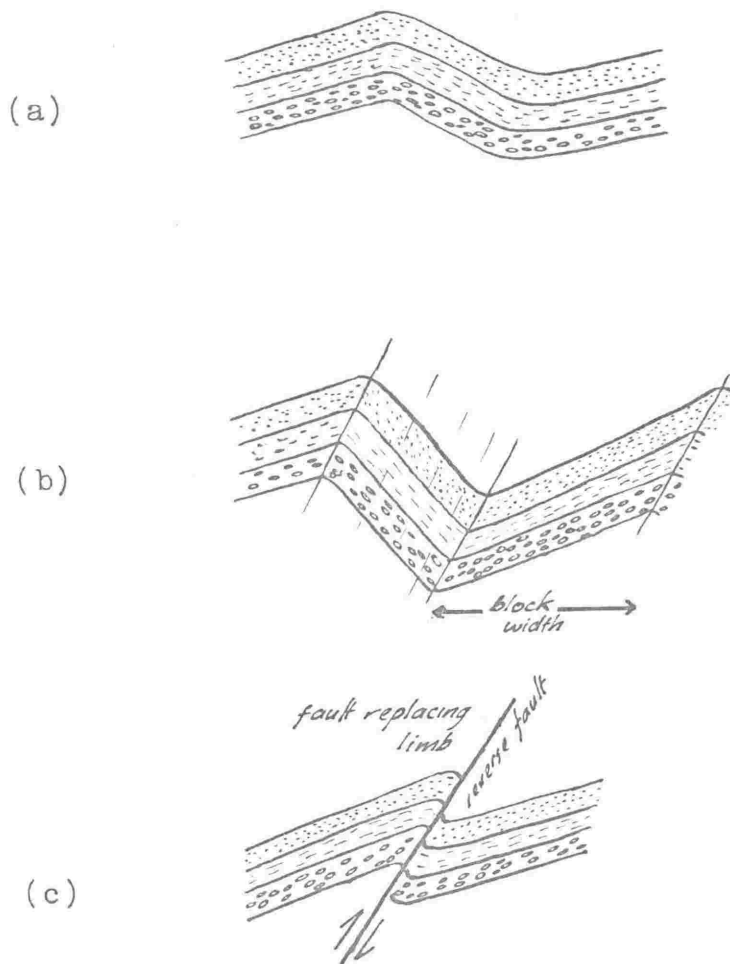
Fig. 30. Cross sections showing asymmetrical folds and
fault replacing limb.

major dextral fault

asymmetrical
fold

fault blocks

reverse ⌐ fault
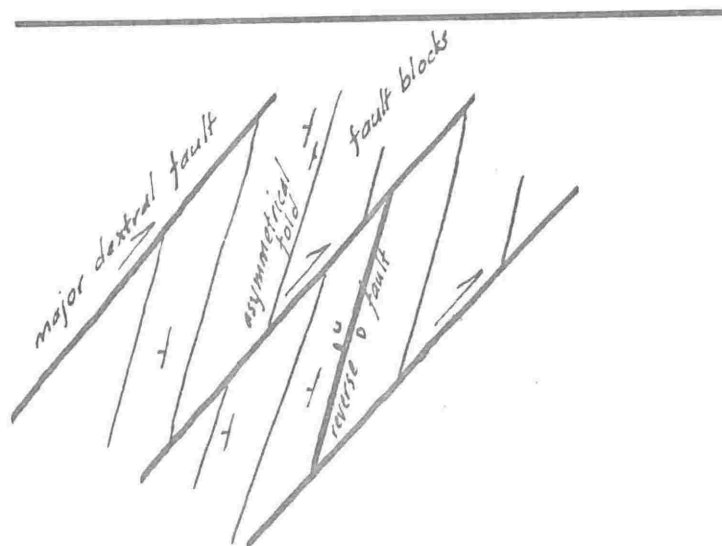
Fig. 31. Plan showing major dextral faults and fault
blocks.

Late Cenozoic major dextral faults, fault blocks
and folds, in the Wairarapa are shown in Fig. 31.

The amount of rotation of fault blocks in the
past can be measured by (a) tilt rates and (b) faulting.

(a) Tilt rates can be determined from:

(i) Unconformities

The difference in dip, in degrees, divided
by the age difference, in years, between
two rock units separated by an unconformity
(Fig. 32) gives the tilt rate.

The meaningfullness of the result depends on
the uniformity of the rate of tilting and on
the accuracy of dating the time interval
represented by the unconformity. For
instance if the tilting takes place in short
bursts of time equal to only a few million
years, and the unconformity represents
scores of millions of years, the average
tilt rate will be less than the maximum rate.

(ii) Isopachs

Provided that the sediments at any particular
time were deposited at the same depth below
sea level, then isopachs drawn from sediments
deposited between two time planes will give
the amount of tilt that has taken place
(Fig. 33).
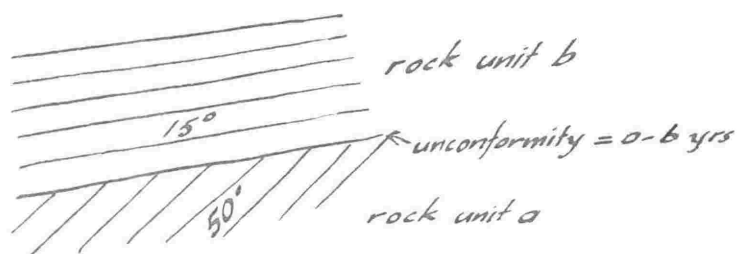
$$\text{Tilt rate} = \frac{\text{dip difference}}{\text{time represented by the unconformity}} = \frac{35}{\text{a-b yrs}}$$

Fig. 32. Unconformity.
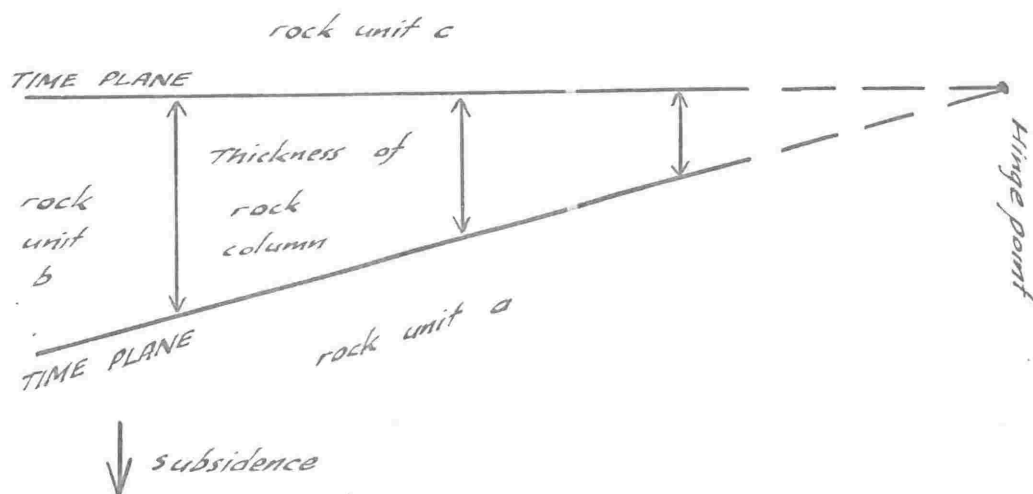
Fig. 33. Cross section normal to isopachs

The following tilt rates are indicated by
the change in sediment thicknesses within
individual basins in the Tinui District:

Urutawan to Piripauan $\frac{1}{2}-1^{\circ}/10^{6}$ years

Waitakian to Otaian $1^{\circ}/1-2 \times 10^{6}$ years

Middle Tongaporutuan to
Kapitean $1^{\circ}/10^{6}$ years

The tilt rates, although very low compared
with tilt rates during the disturbances,
are an order of magnitude higher than tilt
rates in continental regions.

(b) Faulting

That faulting has taken place in the past
is inferred from coarse conglomerates with a
nearby source that are considered to have been
eroded from the upthrown side of an active fault
and to have been deposited on the downthrown side.

In the Tinui District the basal conglomerate
at the base of the Whakataki Formation (Waiktakian
to Clifdenian) is interpreted as having been
deposited in a fault basin (Fig. 14). On the
west coast of the South Island the coarse breccia
of the Eocene Omotumotu Formation is somewhat similar
and according to Gage (1952) was derived from a
fault coast.

THEORETICAL AND OBSERVED FAULT MOVEMENTS

An attempt will be made to determine the changes in the sense of fault movements with time in the Tinui District. The fault movements are directly related to the direction of maximum horizontal shortening which is assumed to be at right angles to the axes of growing folds (**Fig. 34**).

The position and strike of the folds have already been described in detail. The northeast striking folds formed during the Paleocene Disturbance indicating a southeast direction of maximum horizontal shortening (Fig. 35). The north-south striking folds formed during the Late Pliocene and Late Quaternary disturbances indicating an east-west direction of maximum horizontal shortening (Fig. 36). No folds have been recognised as forming during the Early Miocene Disturbance but it is inferred, from fault movements, that the direction of maximum horizontal shortening was about northeast.

Having determined the direction of maximum horizontal shortening it is possible to infer the theoretical sense of movements, that is whether sinistral (S), dextral (D), reverse (R), or normal (N) (Fig. 34), on the faults that
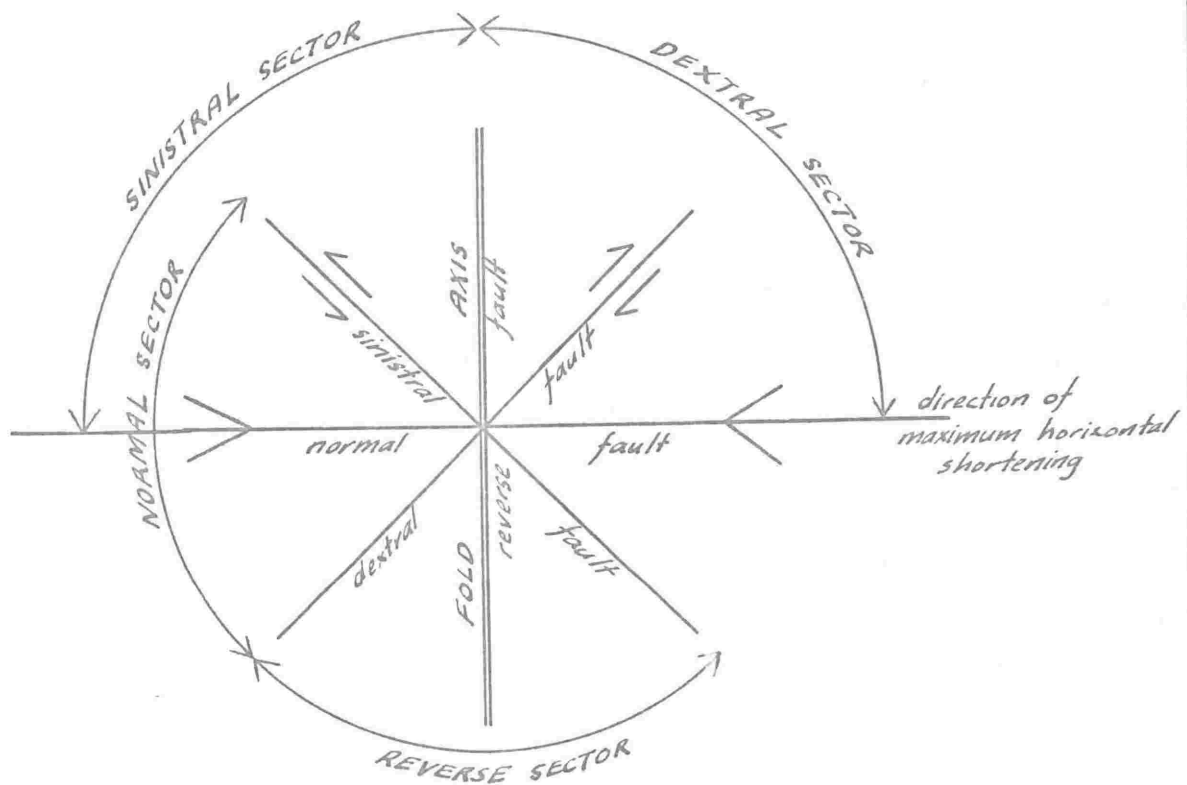
Fig. 34. Inferred relationship between fold axes,
faults and the direction of maximum
horizontal shortening.

Fold Axes (in rocks older than Waipawan)

Tinui District
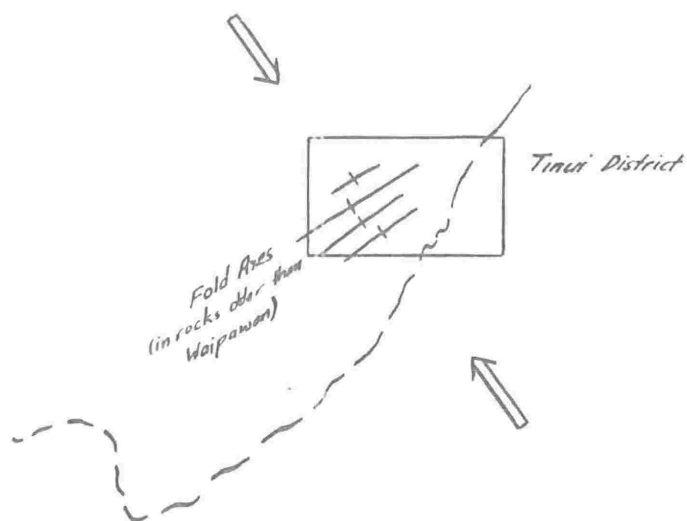
Fig. 35. Inferred direction of maximum horizontal shortening during the Paleocene Disturbance.

direction of maximum horizontal shortening

Fold Axes (in rocks younger than Pliocene)

Tinui District
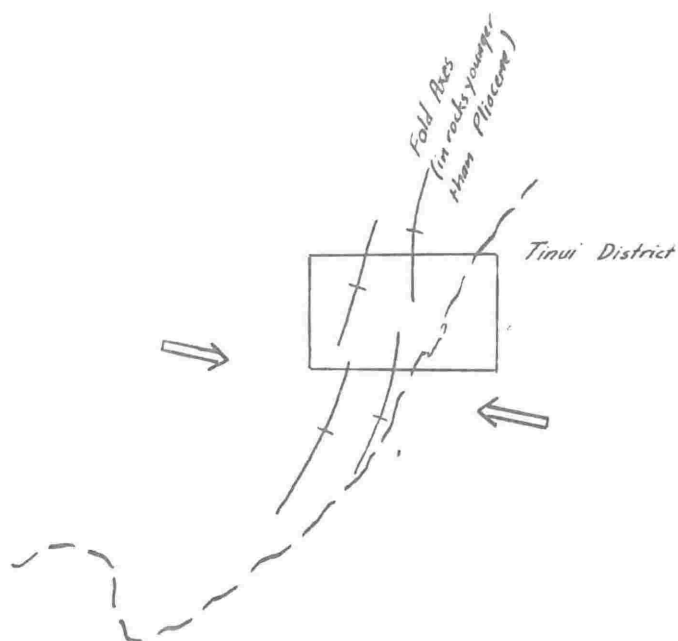
Fig. 36. Inferred direction of maximum horizontal shortening during the Late Pliocene Disturbance.

were active at those times, and to compare the
theoretical with the observed movements (Fig. 37).
It should be noted that Figs. 34 and 37 give the
ideal solution in determining the sense of
movement on a fault but in practice only when
a fault lies well within a sector (Fig. 33) is
it possible to assume its sense of movement
with reasonable certainty.

Reversal of Movement

Provided the fault movements retain their
sense with time (dextral faults remaining dextral
faults, reverse faults remaining reverse faults
etc.) the tectonic pattern remains the same
irrespective of the change in the rate of
movement and irrespective of the formation of
similar new structures.

However, reversal in the sense of movement
of the faults, that is from dextral to sinistral
and reverse to normal, represents a basic change
in the tectonic régime. Such changes have
taken place and they provide critical information
for the interpretation of the tectonic history of
New Zealand as a whole.

DISTURBANCE	STRIKE OF FOLDS	INFERRED SHORTENING DIRECTION	THEORETICAL (1) AND OBSERVED (2) MOVEMENT ON NNE FAULTS		ENE FAULTS	
			1	2	1	2
LATE QUATERNARY	NORTH	EAST	DR	D	DN	D
LATE PLIOCENE	NORTH	EAST	DR	DR	DN	D
EARLY MIOCENE	⇒	NORTHEAST*	DN	D	SN	S
PALEOCENE	NORTHEAST	SOUTHEAST	SR	S	DR	

*Inferred from columns 2

Note: horizontal movement given first; dextral (D),
        sinistral (S), normal (N), reverse (R).

Fig. 37. Theoretical and observed sense of
          movement on the NNE and ENE striking
          faults.

In the Tinui District the sense of movement
of the NNE striking faults changed from sinistral
in the Early Cenozoic to dextral in the Late
Cenozoic. The reversal in the sense of movement
was accompanied by a change in the direction of
maximum horizontal shortening from southeast in
the Early Cenozoic to east in the Late Cenozoic.
A similar reversal has been observed on the west
coast of the South Island where in the Oligocene
highs became lows and lows became highs. During
the reversal, faults changed their sense of
movement, from normal to reverse (Wellman, 1956)
and from sinistral to dextral (Grindley, et al.,
1959), and the direction of maximum horizontal
shortening changed from NNE to ESE (Laird, 1968).

The timing of the reversal is directly
related to the timing of the beginning of the
dextral movement on the Alpine Fault which shows
a 300 mile dextral displacement. Fleming (1970)
in his most recent reconstruction of the New
Zealand landmass considered that the beginning
of the displacement was in the Early Cretaceous
(Fig. 38). If, as the simplest model, it is
assumed that the displacement continued in the

Fig. 38. Palaeogeographical reconstructions of the New Zealand region from Triassic to Tertiary. (a) Triassic (New Zealand Geosyncline); (b) Early Cretaceous (early Rangitata Orogeny); (c) Tertiary (after rupture of Alpine Fault).

A—Auckland Islands.   B—Bounty Islands.
C—Campbell Island.   CH—Chatham Islands.
H—Lord Howe Island.   N—Norfolk Island.
NG—New Caledonia.

Oceanic crust stippled; continental crust of foreland, crosses; sites of future marginal ocean basins, black. Facies boundary and axis of geosyncline, light and heavy dashed lines. Arrows inferred directions of sea-floor spreading.

Fig. 38.   Reconstructions of the New Zealand
landmass (Fleming, 1970).

same sense but not necessarily at the same rate until the present day then the direction of maximum horizontal shortening will remain the same. On the other hand if the direction of shortening is found to differ from that of the present day at any particular place then the model proposed by Fleming needs modification.

In the Tinui District and on the west coast of the South Island it has been shown that the expected direction of maximum horizontal shortening (about east-west) has existed only since the beginning of the Miocene. Both areas are close to the major dextral faults and it can be assumed that over the New Zealand landmass the east-west direction of maximum horizontal shortening has existed only since the beginning of the Miocene. Therefore, strike-slip movement on the Alpine Fault would have been dextral only since the Oligocene.

Clark and Wellman (1959) recognised that if the rate of movement on the fault (0.5 in/yr) that they calculated for the Late Quaternary was extrapolated back in time then the "...300 mile shift could have accomplished since the Oligocene..."

The Alpine Fault dextrally offsets a number of reference lines which may include a belt of mylonite by 145 miles and a belt of lamphrophre dikes by 80 miles. The age of mylonite and dikes is no younger than Lower Cretaceous (Wellman and Cooper, 1971) giving a possible dextral displacement of 80 miles since the Lower Cretaceous. However, in discussing the various reference lines offset by the fault, Wellman (1964) considered the dikes to be a "poor" reference line, and concluded that the Alpine Fault was post-Miocene in age. Hattori (1966) has postulated an "Older Alpine Fault" striking about NNE, which is dextrally displaced about 300 miles by the Alpine Fault and which could have formed the mylonite zones. Therefore any reconstruction of the New Zealand landmass will have to consider whether an "Older Alpine Fault" existed and also if there have been any reversals in the tectonic regime prior to the Cenozoic. Such a reconstruction is well outside the scope of this thesis.

CONCLUSIONS

The detailed mapping of the Tinui District
has provided critical information on the rate
of folding and faulting of part of the New
Zealand Mobile Belt in the Cenozoic. In the
east of the mobile belt, from Marlborough to
East Cape, tilt rates averaging $1\overset{o}{0}/10^6$ years
have occurred for the whole of the Holocene
(10,000 years). Tilting at this rate has not
occurred throughout the Cenozoic but has taken
place at this rate for short periods of time,
equal to or less than a stage in duration,
called disturbances. Disturbances have been
recognised in many parts of New Zealand but
are not everywhere synchronous. Tilting has
taken place between disturbances, to allow
deposition to continue, at a much slower rate
of about $1^o/10^6$ years (Fig. 39).

During the Oligocene or Early Miocene there
was a major change in the tectonic regime with
dextral movement beginning on the major NNE
striking faults. At this time the direction of
maximum horizontal shortening changed from
southeast to about northeast or east.
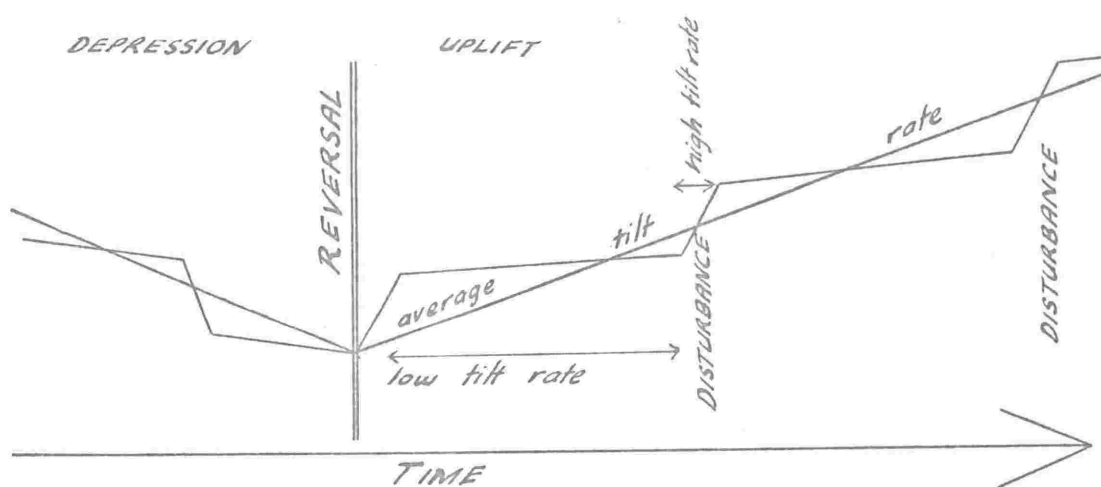
Fig. 39. A simple model showing tectonic reversal
and the amount of tilting during and
between disturbances.

ACKNOWLEDGMENTS

LITERATURE CITED

BATES, T.G. 1969: The Whatarangi Formation (Lower
    Cretaceous), Aorangi Range, Wairarapa, New
    Zealand. Transactions of the Royal Society
    of New Zealand, Geology, 6 (11): 139-42.

BENSON, W.N. 1952: Meeting of the Geological
    Division of the Pacific Science Congress in
    New Zealand. Proceedings of Geological
    Society of America, 1950: 11-15.

BERGGREN, W.A. 1969: Cenozoic chronostratigraphy,
    planktonic foraminiferal zonation and the
    radiometric time scale. Nature, 224: 1072-5.

BEU, A.G. 1969: Index macrofossils and New Zealand
    Pliocene and Lower Pleistocene time-stratigraphy.
    New Zealand Journal of Geology and Geophysics,
    12 (4): 643-58.

BISHOP, D.G. 1968: The geology of an area of
    accelerated erosion at Wairengaokuri, near
    Gisborne. New Zealand Journal of Geology
    and Geophysics, 11 (3): 551-63.

CHALLIS, G.A. 1966: Cretaceous stratigraphy and
    structure of the Lookout area, Awatere
    Valley. Transactions of the Royal Society
    of New Zealand, Geology, 4 (5): 119-37.

CLARK, R.H; WELLMAN, H.W. 1959: The Alpine Fault from Lake McKerrow to Milford Sound. <u>New Zealand Journal of Geology and Geophysics,</u> <u>2 (3)</u>: 590-601.

COTTON, C.A. 1916: The structure and late geological history of New Zealand. <u>Geological Magazine, 6</u>: 314-20.

EADE, J.V. 1966: Stratigraphy and structure of the Mount Adams area, eastern Wairarapa. <u>Transactions of the Royal Society of New Zealand, Geology, 4 (4)</u>: 103-17.

FINLAY, H.J. 1940: New Zealand foraminifera: key species in stratigraphy. <u>Transactions of the Royal Society of New Zealand, 69 (4)</u>: 448-72.

FINLAY, H.J; MARWICK, J. 1947: New divisions of the Upper Cretaceous and Tertiary in New Zealand. <u>New Zealand Journal of Science and Technology, B28 (4)</u>: 228-36.

FLEMING, C.A. 1962: New Zealand biogeography - a paleontologist's approach. <u>Tuatara, 10 (2)</u>: 53-108.

_____ 1970: The Mesozoic of New Zealand: chapters in the history of the Circum-Pacific Mobile Belt. <u>Quaterly Journal of the Geological Society of London, 125 (2)</u>: 125-70.

FYFE, H.E. 1934: Bentonite and its occurrence in
New Zealand. New Zealand Journal of Science
and Technology, 15 (6): 386-94.

GAGE, M. 1949: Late Cretaceous and Tertiary
geosynclines in Westland. Transactions of
the Royal Society of New Zealand, 77 (3):
325-37.

_____ 1952: Greymouth Coalfield. New Zealand
Geological Survey Bulletin (n.s.) 45.

GRAPES, R.H. 1970: A petrological study of the
Kaiwhata Sill, Ngahape, east Wairarapa.
Transactions of the Royal Society of New
Zealand, Earth Sciences, 7 (10): 177-96.

GRINDLEY, G.W. 1961: Mesozoic orogenies in New
Zealand. Proceedings of 9th Pacific Science
Congress, 12: 71-5.

GRINDLEY, G.W; HARRINGTON, H.J; WOOD, B.L. 1959:
The geological map of New Zealand, 1:2,000,000.
New Zealand Geological Survey Bulletin
(n.s.) 66.

HALL, W.D.M. 1963: The Clarence Series at Coverham,
Clarence Valley. New Zealand Journal of
Geology and Geophysics, 6 (1): 28-37.

HATTORI, H. 1966: The metamorphic belts of New
Zealand and their ages. Journal of the
Japanese Geological Society, 72 (5): 233-43.

HASKELL, T.R. 1964: The Cretaceous geology of
the Whakarora area, Wairarapa, New Zealand.
New Zealand Journal of Geology and Geophysics,
7 (3): 554-60.

HENDERSON, J. 1937: The West Nelson earthquakes
of 1929 (with notes on the geological
structure of West Nelson). New Zealand
Journal of Science and Technology, 19 (2):
65-144.

HOUTZ, R; EWING, J; EWING, M; LONARDI, A.G. 1967:
Seismic reflection profiles of the New
Zealand Plateau. Journal of Geophysical
Research, 72 (18): 4713-29.

HORNIBROOK, N. de B 1962: The Cretaceous-Tertiary
boundary in New Zealand. New Zealand
Journal of Geology and Geophysics, 5 (2):
295-303.

HORNIBROOK, N. de B; HARRINGTON, H.J. 1957:
The status of the Wangaloan Stage. New
Zealand Journal of Science and Technology,
B38 (6): 655-70.

HUTTON, F.W. 1872: Synopsis of the younger
        formations of New Zealand. New Zealand
        Geological Survey, Report on Geological
        Explorations, 1871-2, (7): 182-4.

JOHNSTON, M.R. 1971: Pre-Hawera geology of the
        Kaka District, North-west Nelson. New
        Zealand Journal of Geology and Geophysics,
        14 (1): 82-108.

_____ (in press a): Sheet N159 - Tinui
        and part Sheet N158 - Masterton. "Geological
        map of New Zealand, 1:63,360". New Zealand
        Department of Scientific and Industrial
        Research, Wellington.

_____ (in press b): Geology of Castlepoint
        Headland and Reef, Wairarapa, New Zealand.
        New Zealand Journal of Geology and Geophysics.

KEAR, D. 1957: Pumice chronology in New Zealand.
        New Zealand Journal of Science and Technology,
        B38 (8): 862-70.

KEAR, D; SCHOFIELD, J.C. 1959: Te Kuiti Group.
        New Zealand Journal of Geology and
        Geophysics, 2 (4): 685-717.

KING, L.C. 1930: Raised benches and other features
    of the south-east coast of the North Island
    of New Zealand. Transactions of the New
    Zealand Institute, 61 (3-4): 498-523.

————— 1933: Tertiary molluscan faunas from
    the southern Wairarapa. Transactions of
    the New Zealand Institute, 63 (3): 334-54.

KINGMA, J.T. 1957: The North Island Geanticline
    in the Hawke's Bay Sector. New Zealand
    Journal of Science and Technology, B38 (6):
    496-9.

————— 1960: Outline of the Cretaceo-Tertiary
    sedimentation in the Eastern Basin of New
    Zealand. New Zealand Journal of Geology
    and Geophysics, 3 (2): 222-34.

————— 1962: Sheet 11 - Dannevirke.
    "Geological Map of New Zealand 1:250,000".
    New Zealand Department of Scientific and
    Industrial Research, Wellington.

————— 1967: Sheet 12 - Wellington.
    "Geological Map of New Zealand 1:250,000".
    New Zealand Department of Scientific and
    Industrial Research, Wellington.

LAIRD, M.G. 1968: The Paparoa Tectonic Zone.
    New Zealand Journal of Geology and Geophysics,
    11 (2): 435-54.

LENSEN, G.J. 1962: Sheet 16 - Kaikoura.

"Geological Map of New Zealand 1:250,000".
New Zealand Department of Scientific and
Industrial Research, Wellington.

_____ 1965: Active faults and major
earthquakes in New Zealand (map). New
Zealand Journal of Geology and Geophysics,
8 (6).

_____ 1968: Sheet N158 - Masterton.
"Late Quaternary tectonic map of New
Zealand 1:63,360". New Zealand Department
of Scientific and Industrial Research, Wellington.

LEWIS, K.B. (in press): Growing folds on the
. Hawke Bay coast and continental margin.
In "Recent Crustal Movements and associated
Seismicity". Royal Society of New Zealand
Bulletin 9.

LILLIE, A.R. 1953: The geology of the Dannevirke
Subdivision. New Zealand Geological Survey
Bulletin (n.s.) 46.

McKAY, A. 1877: Report on country between Cape
Kidnappers and Cape Turnagain. New Zealand
Geological Survey, Report of Geological
Explorations, 1874-6, (9): 43-53.

McKAY, W.A. 1899: Report on the geology of the
    Trooper Range, Castlepoint District, Wellington.
    Appendix to Journal of House of Representatives,
    N.Z.C. - 9: 33-6.

MACPHERSON, E.O. 1946: An outline of Late Cretaceous
    and Tertiary diastrophism in New Zealand.
    New Zealand Geological Survey Memoir 6.

MARSHALL, P. 1903: Boulders in Triassic conglomerate,
    Nelson. Transactions of the New Zealand
    Institute, 36: 467-71.

MORGAN, P.G. 1910: Report on probable occurrence
    of petroleum and other minerals in eastern
    Wairarapa districts. Appendix to Journal
    .of House of Representatives. N.Z.C. - 16: 6.

_____ 1914: Petroleum prospects in
    Southern Hawke's Bay and eastern Wellington.
    New Zealand Geological Survey 8th Annual
    Report (n.s.): 131-5.

NEEF, G. (in press): Sheet N153 - Eketahuna.
    "Geological map of New Zealand 1:63,360".
    New Zealand Department of Scientific and
    Industrial Research, Wellington.

ONGLEY, M. 1933: Eketahuna Subdivision. New
    Zealand Geological Survey 27th Annual
    Report (n.s.): 4-5.

ONGLEY, M. 1934: Eketahuna Subdivision. New
    Zealand Geological Survey 28th Annual
    Report (n.s.): 2-3.

_____ 1935: Eketahuna Subdivision. New
    Zealand Geological Survey 29th Annual
    Report (n.s.): 1-6.

_____ 1936a: Blairlogie Gas Vent. New
    Zealand Geological Survey 30th Annual
    Report (n.s.): 9-12.

_____ 1936b: Dannevirke Subdivision. New
    Zealand Geological Survey 30th Annual
    Report (n.s.): 1-4.

ONGLEY, M; WILLIAMSON, J.H. 1931: Eketahuna
    Subdivision. New Zealand Geological Survey
    25th Annual Report (n.s.): 3-5.

PARK, J. 1888: On the probable discovery of oil
    and coal in Wairarapa North County. New
    Zealand Geological Survey Report of Geological
    Explorations, 1887-88, 19: 20-4.

QUENNELL, A.M; BROWN, D.A. 1937: Dannevirke
    Subdivision. New Zealand Geological Survey
    31st Annual Report: 1-6.

RIDD, M.F. 1964: Succession and structural interpretation of the Whangara-Waimata area. New Zealand Journal of Geology and Geophysics, 7 (2): 279-98.

_____ 1967: Miocene transcurrent movement on the Pongaroa fault, Wairarapa, New Zealand. New Zealand Journal of Geology and Geophysics, 10 (1): 209-16.

SCOTT, G.H. (in press): Revision of Hutchinsonian, Awamoan and Altonian Stages (lower Miocene, New Zealand). New Zealand Journal of Geology and Geophysics.

SINGH, L.J. (in press): The Whareama Syncline: a growing fold on the Wairarapa coast. In "Recent Crustal Movements and associated Seismicity". Royal Society of New Zealand Bulletin 9.

STEVENS, G.R. 1965: The Jurassic and Cretaceous Belemnites of New Zealand and a review of the Jurassic and Cretaceous Belemnites of the Indo-Pacific region. New Zealand Geological Survey Paleontological Bulletin 36.

STONELEY, R. 1962: Marl diapirism near Gisborne, New Zealand. New Zealand Journal of Geology and Geophysics, 5 (4): 630-41.

STONELEY, R. 1968: A Lower Tertiary décollement
on the east coast, North Island, New
Zealand. New Zealand Journal of Geology
and Geophysics, 11 (1): 128-56.

SUGGATE, R.P. 1965: The tempo of events in New
Zealand geological history. New Zealand
Journal of Geology and Geophysics, 8 (6):
1139-48.

_____ 1968: The Thirty Foot raised beach
at Rapahoe, North Westland. New Zealand
Journal of Geology and Geophysics, 11 (3):
648-50.

VAN DEN HEUVEL, H.B. 1960: The geology of the
Flat Point area, eastern Wairarapa. New
Zealand Journal of Geology and Geophysics,
3 (2): 309-20.

VELLA, P. 1954: Tertiary mollusca from south-east
Wairarapa. Transactions of the Royal Society
of New Zealand, 81 (4): 539-55.

_____ 1963: Plio-Pleistocene cyclothems,
Wairarapa, New Zealand. Transactions of the
Royal Society of New Zealand, Geology,
2 (2): 16-50.

WATERHOUSE, J.B; BRADLEY, J. 1957: Redeposition
and slumping in the Cretaceo-Tertiary strata
of SE Wellington. Transactions of the Royal
Society of New Zealand, 84 (3): 519-48.

WELIMAN, H.W. 1948: Tararua Range summit height
accordance. New Zealand Journal of Science
and Technology, B30 (2): 123-7.

_____ 1949: Geology of the Pike River
Coalfield, New Zealand. New Zealand
Journal of Science and Technology, B30 (1):
84-95.

_____ 1955: New Zealand Quaternary
Tectonics. Geologischen Rundschau, 43 (1):
248-57.

_____ 1956: Structural outline of New
Zealand. New Zealand Department of Scientific
Research, Bulletin 121.

_____ 1959: Divisions of the New Zealand
Cretaceous. Transactions of the Royal
Society of New Zealand, 87 (1,2): 99-163.

_____ 1964 [i.e. 1970] : Age of Alpine
Fault, New Zealand. International Geological
Congress. India. 22nd. Compte Rendus. Part 4,
Section 4. Rock deformation and tectonics:
146-62.

WELIMAN, H.W. 1967: Tilted marine beach ridges
    at Cape Turakirae, N.Z. Journal of Geoscience,
    Osaka City University, 10 (1): 123-9.

WELIMAN, P. 1970: Geology of the Ngahape area,
    eastern Wairarapa. Transactions of the
    Royal Society of New Zealand, Earth Sciences,
    8 (11): 157-71.

WELIMAN, P; COOPER, A. 1971: Potassium-Argon age
    of some New Zealand lamphrophyre dikes
    near the Alpine Fault. New Zealand Journal
    of Geology and Geophysics, 14 (2): 341-50.

WILSON, D.D. 1963: Geology of Waipara Subdivision.
    New Zealand Geological Survey Bulletin
    (n.s.) 64.

APPENDIX   I

Appendix I gives a brief summary of nearly a thousand
fossil localities in the Tinui District.

Collectors

AA	A.D. Allen	SK	S. Keston
AB	A.G. Beu	IK	I.W. Keyes
WB	W.M. Briggs	JK	J.T. Kingma
DC	D. Campbell	TK	T. Kotaka
DJ	D.J. Cullen	ML	M. Lehner
RC	R.A. Cooper	JM	J. Marwick
AC	R.A. Couper	JMc	J. McKay
JE	J.V. Eade	KM	K.J. McNaught
CF	C.A. Fleming	GN	G. Neef
GG	G.W. Grindley	MO	M. Ongley
MG	M. Gage	HP	H.M. Pantin
MH	W.D.M. Hall	MP	M. Pick
RH	R.F. Hay	IS	I.G. Speden
TH	T.R. Haskell	GS	G.R. Stevens
JH	J. Hector	PV	P. Vella
NH	N. de B. Hornibrook	HW	H.W. Wellman
MJ	M.R. Johnston	JW	J.E. Wellman
		PW	P. Wellman

Abbreviations

c   grid reference approximate

( )   grid reference (amended to 1949 geodetic datum) or age adopted direct from the fossil record form

F   microfaunal collection held at Victoria University of Wellington

F 17891   microfaunal collection held at N.Z. Geological Survey

F ——   microfaunal collection discarded

V   macrofaunal collection held at Victoria University of Wellington

GS   macrofaunal collection held at N.Z. Geological Survey

NL   collection not located

——   collection not in place

?   data unknown

der   derived

rec   recollection

ND   no determination

SHEET N158 MASTERTON (east of grid 35)

Sheet Fossil Number	Register Number	Grid Reference	Age	Adopted Age	Formation	Collector
456	GS 7948	420635	Cm-Rm	Cm-Cn	us	MO
	F 9506		C			MO
466	GS 1843	430694	Cm	Cm	um	MO
467	GS 1850	374683	NL	Sw-Tt	hm	MO
468	GS 1851	379696	Cm	Cm	ua	JM, MO
469	GS 1852	436703	Cm	Cm	um	JM, MO
470	GS 1853	426673	Sl-Sw	Sw	hm	JM, MO
471	GS 1854	c 384718	NL	Sw-Tt	hm	JM, MO
472	GS 1854b	c 384718	Sc-Tt	Sw-Tt	hm	JM, MO
473	GS 1865	450778	NL	C	um	JM, MO
474	GS 1866	446774	ND	Cm	um	JM, MO
478	GS 1875	443765	Cm	Cm	us	JM, MO
479	GS 1876	442754	? Cm	Cm-Cn	us	JM, MO
480	GS 1877	447760	Cm, C	Cm	um+s	JM, MO
488	GS 2017	c 402756	low Tt	low Tt	hm	MO
491	GS 2020	398753	Tt	Tt	hm	MO
492	GS 2021	414763	? C	Cm-Cn	us	MO
493	GS 2022	408760	C	Cm	us	MO
503	F 7115	354662	Sw	Sw	hm	DC

			upp Tt	upp Tt		
506	F 7118	360618			hm	DC
507	F 7119	(380627)			hm	DC
512	F 7300	355645	Tk-Wo	Tk	hm	DC
	F rec		upp Tt-Tk	Tk		?
537	GS 5895	435643	Mp	Mp	us+t	MG, MO
	F		NF			MG, MO
538	GS 1843	430694	NL	Cm	um	HW, JW
	F 9494		upp C			HW, JW
539	GS 6088	430693	Cm	Cm	um	HW, JW
540	GS 6089	435698	Cm	Cm	um	HW, JW
	F 9495		upp C			HW, JW
541	GS 6090	416709	Cm	Cm	um	HW, JW
542	GS 6091	426709	Cu?-Cm	Cu?-Cm	um	HW, JW
	F 9496		upp C			HW, JW
543	GS 6439	444763	?Cu-Cm	?Cu-Cm	um	RH, HW
544	GS 6440	444767	Cu?-Cm	?Cu-Cm	um	RH, HW
545	GS 6443	446755	Cn	Cn	um+s	RH, HW
546	GS 6447	435641	Cn?	Cn	us	HW
547	GS 6448	(435643)	NL	Sw	hm	HW
548	GS 6131	c 421690	Cm	Cm	um	HW
631	F 17633	445745	C	Cn	us	MJ
632	F 17634	420677	Mh	Mh	tt	MJ
633	F 17635	415677	Cm-Cn	Cm-Cn	us	MJ
634	F	426677	M-D	Mh	tt	MJ
635	F 17742	399770	Cm-Cn	Cm	um	MJ

636	F 17743	395770	Cm–Cn	Cm	um	MJ
637	F 17744	391774	Cm–Cn	Cm	um	MJ
638	F 17745	404786	Cm–Cn	Cm	um	MJ
639	F 17746	398778	Cm–Cn	Cm	um	MJ
640	F 17747	422803	C–?R	Cm	um	MJ
641	F 17748	409794	Cm–Cn	Cm	um	MJ
642	F	379810	low Tt	low Tt	hm	MJ
643	F	370785	low Tt	low Tt	hm	MJ
644	F	357764	low Tt	low Tt	hm	MJ
645	F	376695	low Tt	low Tt	hm	MJ
646	F	352717	mid Tt	mid Tt	hm	MJ
647	F	365735	Sw–Tt,Tt?	mid Tt	hm	MJ
648	F 17749	400760	C–R	Cm	um	MJ
649	F	359754	ND	low Tt	hm	MJ
650	F	433813	Wn	Wn	cp?	MJ
651	F	430670	Sw–Tt,Tt?	Tt	hm	MJ
652	F	357645	upp Tt–Tk	upp Tt–Tk	hm	MJ
653	GS 9942	386715	Cm–Rm	Cm	um	MJ
657	GS 9943	398728	Cret	Cm	um	MJ
658	GS 9944	405738	Cm–Rm	Cm–Cn	um	MJ
659	GS 9945	410788	Cret	Cm	um	MJ
660	GS 9946	419805	pre–Cn	Cm	um	MJ
661	GS 9947	410740	Cm–Cn	Cm	um	MJ

No.	Coll.	Spec.		Field No.	ID 1	ID 2		Collector
691	F	17850		412647	S1–Sw	Sw	hm	MJ
692	GS	9997		373754	Sw?	Sw	hm	MJ
693	GS	9998		367754	S1–Sw	Sw	hm	MJ
694	F	17900		430704	Cm–Cn	Cn	us	MJ
695	GS	10020		417710	Cm–Cn	Cm	um	MJ
	F	17901			Cm–Cn			MJ
696	F	17902		422710	Cm–Cn	Cn	us	MJ
697	F	17929		350647	Sc–Tt	Sw	hm	MJ
698	F	17930		352645	Tt–Wo?	Tk	hm	MJ
699	F	17931		359679	Sc–Tt?	Sw	hm	MJ
700	F	17932		359676	?S1–Tt	Sw	hm	MJ
701	V	?		430693	<u>Cm</u>	Cm	um	RC
702	V	?	c	431694	<u>Cm–Cn?</u>	Cm	um	JE
704	V	1609		442811	<u>Cm</u>	Cm	us	MJ
705	V	1611		447803	<u>Cm?</u>	Cm	um	MJ
706	V	1612		438798	ND	Cm	um	MJ
707	V	1613		435799	<u>Cu?–Cm</u>	Cu?–Cm	um	MJ
708	V	1614		441776	Cu?–Cm	Cu?–Cm	um	MJ
709	V	1626		441769	Cu?–Cm	Cu?–Cm	um	MJ
710	V	1627		444763	<u>Cm</u>	Cm	um	MJ
	F				ND			MJ, IS
711	V	1998		446721	<u>Cm</u>	Cm	um	MJ
712	V	1628		449756	<u>Cn;Cn;</u> <u>Cm–Rm</u>	Cn	us	MJ

713	V	1629	442754	Cm?;Cm?; Cm;Cm?	Cm	um+s	MJ
714	V	1631	441750	Cm-Rm;Cn	Cn	us	MJ
715	V	1634	434751	Cm	Cm	us	MJ
716	V	1635	434746	Cn	Cn	us	MJ
717	F	17750	424757	Cm-Cn	Cn	us	MJ
718	V	1637	420795	Cm?	Cm	um	MJ
719	V	1638	414802	Cm	Cm	um	MJ
720	V	1986	c 445732	Cm?	Cm-Cn	us	MJ
721	V	1987	444723	Cu?-Cm	Cu?-Cm	um	MJ
722	V	1988	441722	Cm	Cm	um	MJ
723	V	1989	443717	Cm	Cm	um	MJ
724	V	1991	448702	Mp; Mp	Mp	tt	MJ
725	V	1992	406710	ND;Cu?-Cm	Cu?-Cm	ua	MJ
726	V / F	1993	415707	Cm? / NF	Cm / Cu?-Cm	um / ua	MJ / MJ
727	V	1994	427693	Cm;Cm;Cm?	Cm	um	MJ
728	V	1995	433694	Cm	Cm	um	MJ
729	V	1996	449731	Cu?	Cu?-Cm	um	MJ
730	V	1997	442728	Cm?	Cm	um	MJ
731	V	?	421688	Cm	Cm	um	WB, RH
732	V	?	(416686)	Cm	Cm	um	RH, TK, HW
733	V	?	(c 427694)	Cm	Cm	um	HW
734	V	2011	424735	Cn?	Cn	us	MJ

735	V 2012 F 17636	C ? Cm–Cn	Cm	um	MJ MJ
736	V 2013	Cm?, Cm	Cm	us	MJ
737	V 2014 F 18021	Cm? C–R	Cm	um	MJ MJ
738	V 2018	Cm?; Cm	Cm	us+t	MJ
739	F 17637	Mp–low Mh	Mp	tt	MJ
740	F 17638	Cm–Cn	Cm–Cn	us	MJ
741	F 17639	R	Cm–Cn	us	MJ
742	F 17640	Cm–Cn	Cm	um	MJ
743	F 17641	Cm–Cn	Cm–Cn	us	MJ
744	F	Sw?	Sw	hm	MJ
745	F ——	?–S?	Sa–Sc	aw	MJ
746	F 17642	Cm–Cn	Cn	us	MJ
749	F	mid–upp Tt	mid Tt	hm	MJ
750	GS 9948 F 17751	ND Cm–Cn	Cm	um	MJ
751	F 17752	Cm–Cn	Cn	**um**	MJ
752	F	low Tt	low Tt	hm	MJ
753	F	mid–upp Tt	Tt	hm	MJ
754	F 17753	Cm	Cm	um	MJ
755	F	low Tt	low Tt	hm	MJ
756	F 17754	Cm–Cn	Cm	um	MJ
757	F	mid–upp Tt?	Tt	hm	MJ

758	F 17755	389729	C	Cm	um	MJ
759	F 17756	401755	C, Cm?–Cn?	Cm	um	MJ
760	F 17757	410766	C	Cm	um	MJ
761	F 17758	413765	Cm–Cn	Cm	um	MJ
762	F ——	415761	ND	Cm	um	MJ
763	F 17759	375751	C	Cu?–Cm	umb	MJ
764	F 17760	372759	C	Cu?–Cm	umb	MJ
765	F ——	360684	NF	Tt	hm	MJ
766	F 17928	420642	?S1–Tt?	Sw	hm	MJ
767	F ——	431663	NF	Cm–Cn	us	MJ
768	F ——	433872	NF	Tt	hm	MJ
769	F ——	438869	ND	Tt	hn	MJ
770	F ——	438868	ND	Tt	hn	MJ
771	F ——	416705	NF	Cu?–Cm	ua	MJ
772	F 17956	355795	M?	Mh–Dt	t,w	MJ
773	F 17957	355794	Tt	Tt	hm	MJ
774	GS10059	441768		Cu?–Cm	um	MJ, IS
775	GS10060	441769		Cu?–Cm	um	MJ, IS
776	GS10061	442766		Cu?–Cm	um	MJ, IS
777	GS10062 / F 18016	442765	Cu? / ND	Cu?–Cm	um	MJ, IS
778	F 18017	444763	ND	Cu?–Cm	um	MJ, IS
779	F 18018	444762	C	Cu?–Cm	um	MJ, IS
780	F ——	448758	NF	Cm	um	MJ, IS

SHEET N159 TINUI

Sheet Fossil Number	Register Number	Grid Reference	Age	Adopted Age	Formation	Collector
434	GS 1879	513892	Tk	Tk	hk	MO
435	GS 1867	464818	O	O	ew	JM, MO
436	GS 1873	459764	Cm	Cm	um	JM, MO
437	GS 1874	459765	Cm?	Cm	um	JM, MO
438	GS 1817	682895	Rt?	Mp	tt	MO, KM
439	GS 1813	690894	Rm	Rm	ug	MO, KM
440	GS 93	c 538737	Sc?	Sc	at	JH
441	GS 201	?	NL	Sw-Tt	hm?	JMc
442	GS 4477	538737	Pl-Sc	Pl-Sc	at	JM
443	GS 4439	538737	Pl-Sc	Pl-Sc	at	JM
444	GS 5844	?	NL	?	?	JH
445	GS 37	?	(Wn?)	Wn	cp	JMc
446	GS 81	?	Wn	Wn	cp	JMc
447	GS 1811	684793	ND	Dt	tw	MO
448	GS 1814	649834	Rt	Rt	ug	MO, KM
449	GS 1816	663849	Rt?	Mp	tt	KM
450	GS 1819	662675	Wn	Wn	cp	MO, KM
451	GS 1820	663675	Wn	Wn	cp	MO, KM
452	GS 1827	632731	ND	Dt	tw	KM
453	GS 1828	635724	NL	Dt	tw	KM

454	GS 1829	682769	ND	Dt	tw	KM
455	GS 1830	686763	ND	Dt	tw	KM
456	GS 1831	677730	ND	Lw–Po	aw	KM
457	GS 1832	c 631754	NL	Dt	tw	KM
458	GS 1833	548721	NL	Sa	aw	KM
459	GS 1834	608797	NL	Ph–Sa	at	KM
460	GS 1835	607799	NL	Ph–Sa	at	MO, KM
461	GS 1836	c 551757	Mp	Mp	tt	KM
462	GS 1837	550746	Cm?–Rm?	Cm–Ra?	us	KM
463	GS 1838	561738	NL	Mh–Dt	tt?	KM
464	GS 1839	609791	NL	Pl	at	KM
465	GS 1840	608787	NL	Lw–Po	aw	KM
466	GS 1841	604775	(Cret)	Mp–Mh	tt	KM
467	GS 1842	c 593777	NL	Dt	tt	KM
468	GS 1855	484851	Tt	Tt	hn	MO
469	GS 1856	485856	Tt	Tt	hn	MO
470	GS 1857	513892	ND	Tt–Tk	hk	MO
471	GS 1858	497859	Sl–Sw	Sw	hmg	MO
472	GS 1859	463823	Rt	Rt	us+t	MO
473	GS 1860	?	NL	Tt	hm?	MO
474	GS 1861	524794	NF	mid Tt	hk	JM, MO
475	GS 1862	?	NL	?	?	?
476	GS 1863	477791	NL	Cm	um	JM, MO

477	GS 1864	510726	Mp	Mp	tt	JM, MO
478	GS 1868	493757	Mp	Mp	tt	JM, MO
479	GS 1869	489759	Mp	Mp	tt	JM, MO
480	GS 1870	486759	ND	Cn-Ra	us	JM, MO
481	GS 1871	468770	Cm	Cm	um	JM, MO
482	GS 1872	564713	ND	Sa	aw	JM, MO
483	GS 1878	479806	Cret	Cu?-Cm	um	JM, MO
484	GS 1880	c 534728	S1-Sw	S1-Sw	at+h?	JM, MO
485	GS 1881	c 532727	ND	?	?	JM, MO
486	GS 1882	659673	Wo?	Wo	hr	JM, MO
487	GS 2821	664677	Wo?	Wo	hr	KM, MO
488	GS 2822	676762	ND	Dt	tw	KM
489	GS 2823	671795	ND	Dt	tw	KM
490	GS 2824	594737	ND	Dt	tw	KM
491	GS 2825	630733	ND	Dt	tw	KM
492	GS 2826	631732	low D?	Dt	tp	KM
493	GS 5341	672685	NL	Wn	cp	CF, JM
494	GS 6996	538737	P1?	P1-Sc	at	MO
495	GS 6997	c 534747	P1-Sw	Sc-S1	at+h	MO
496	GS 7040	(686803)	ND	Dt	tw	
497	GS 7050	c 640665	H-R	H-R	bo	MO
498	F 7092	673687	(Wo?)	Wo	hr	ML
499	F ___	466681	NF	low Cret?	ew	ML
500	GS 5241	672685	NL	Wn	cp	CF, JM

			Mh-Dw, D mixed	Mh-Dt		
501	F 8371	464617			tt?	MP
502	F 8372	(486657)	ND	Dt	tw	MP
503	F 8373	501652	(Pl)	Pl	aw	MP
504	F 8374	552642	(M-D)	Dw-Ab	wh	MP
505	F 8375	553642	(Lw?)	Pl	aw	MP
506	F 8376	546653	(Pl?)	Pl	aw	MP
507	F 8377	577613	(Pl)	Pl	aw	MP
508	GS 6041	694893	Rm?	Rm	ug	HW
509	GS 6040	690894	Rm	Rm	ug	HW
510	GS 6039	c 684900	(Mh)	Mp-Mh	tt	HW
511	F 9037	527619	Pl	Pl	aw	MP
512	F 9038	536627	Pl-Sc	Pl	aw	MP
513	F 9039	528669	S1	S1	hm	MP
514	F 9040	529665	S, ?Sc-Sw	S1	hm	MP
515	F 9041	534621	Pl	Pl	aw	MP
516	F 9042	535627	Pl	Pl	aw	MP
517	F 9043	513658	S1-Sw	S1	hm	MP
518	GS 6444	462760	(Cn)	Cn	us	RH, HW
519	GS 6445	483759	(Rm)	Ra	us	GG, HW
520	GS 6446	486759	Ra?	Ra	us	GG, HW
521	GS 6441	462761	(Cm-Cn;Ra)	Cn; Ra	us	RH, HW
522	GS 6442	464757	Ra ?	Ra	us	HW

523	V ?	606798	Pl	Pl	at	SK, HW
524	F 11648	660673	Wo	Wo	hr	SK
525	F ———	658674	NF	Lw-Po	aw	SK
526	F ———	676731	NF	Lw-Po	aw	SK
527	F ———	700794	NF	Mh-Dt	tw	SK
528	F ———	601679	NF	Mh	tt	SK
529	F ———	671767	NF	Mh-Dt	tw	SK
529a	F 13660	671767	Mh	Mh-Dt	tw	SK
530	F ———	630733	NF	Dt	tp	SK
530a	F 13661	630733	Dt	Dt	tp	SK
531	F 11649	606798	Pl	Pl	at	SK, HW
532	F 11650	604798	Po-Pl	Lw-Po	aw	SK, HW
533	F	668722	(R)	(R)	hl	SK
534	F	500789	(Sw?)	Sl?-Sw	hmg	PV, HW
534	F 13663	673688	Wo	Wo	hr	SK
535	F 13662	667724	ND	Lw-Po	aw	SK
536	F 13664	(675735)	Lw-Sw?	Lw-Po	aw	SK
537	F 13665	608795	Lw-Po?,S? mixed	S1?-Sw	aw	SK
537a	F 13689	607796	(Lw-P, P?)	Lw-Po	aw	JK, SK
538	F 13666	625706	Mh	Mh	tt	SK
539	F 13667	(607795)	Po+contam upp Po-1	Lw-Po	aw	SK
	F					

540	F	—	642722	NF	Mh	tt	SK
541	F		(608797)	(Pl-Sc)	Pl	at	SK
542	F		597799	(Dt?)	Mh	tt	SK
543	F	—	(626817)	NF	Mh	tt	SK
544	F		?	(P?)	Lw-Po	aw	SK
545	F		628652	L-P	Lw-Po	aw	SK
546	F	—	(627785)	NF	Dt	tw	SK
547	F		625798	NF	Mh	tt	SK
548	F	—	643727	NF	Mh	tt	SK
549	F		607797	(Pl-Sc)	Pl	at	SK
550	F	13679 rec	607798	Pl / Pl	Pl	at / at	SK / MJ
551	F		608794	ND	Pl	at	SK
552	F		608794	?Pl	Pl	at	SK
553	F		?	Pl	Pl	at?	SK
554	F		609818	(?Lwh-Ld)	Lwh-Ld	ww	SK
555	F		(590800)	(S?)	Sl-Sw	hm	SK
556	F		(591800)	Ab	Ab	wh	SK, PV
557	F		593803	(Lwh-Ld)	Lwh-Ld	ww	SK, PV
558	F		594802	NL	Sl-Sw?	hm?	SK, PV
559	F		(592757)	(Mh-Dt)	Dt	tw	SK, PV
560	F		597800	P-S?	?	a?	SK, PV

561	F 13797	594801	Dw	Dw	wh	SK, PV
562	F	?	(P?)	?	a?	SK, PV
563	F ——	598800	ND	?	?	SK, PV
564	F 17903	596799	Dh / Dh	Dw–Ab	wh	SK, PV / MJ
565	F	No form				
566	F 13680	(567750)	(Dw–Dh)	Dw–Ab	wh	JK, SK, HP
567	F 13681	(566751)	Dt	Dt	tt	JK, SK, HP
568	F 13682	566751	Dt	Dt	tt	JK, SK, HP
569	F	548721	Pl	Pl	aw	SK, PV
570	F	(614787)	(Mh–D)	Mp–Mh	tt	SK
571	F	?	(A)	Dw–Ab	wh	SK
572	F	588810	(S–T)	Sw	hmt	SK
573	F	606807	(P?)	Po	aw	SK
574a	F	(584799)	(S1–Tt)	Sw	hm	SK
574b	F	(592788)	(P)	Lw–Po	aw	SK
575	F	(592803)	(Po)	Po	aw	SK
576	F	(616842)	(S1–Sw)	S1–Sw	hmt	SK
577	F	589804	(S1–Sw)	Sw	hm	SK
578	F	603813	(Po)	Po	aw	SK
579	F	608819	(S1–Sw)	S1–Sw	hm	AC, SK, PV
580	F	611818	(Po)	Po	aw	AC, SK, PV
581	GS 5367	608797	Po–R	Pl	at	AC
581	F	c 614815	NL	Pl.	at?	AC, SK, PV

							AC, SK, PV
582	F		c 608808	(P)	Po	aw	SK
583	F		c 594804	(Dm–Dh)	Dm–Dh	wh	SK
584	F		599789	(Pl?)	Po	aw	SK
585	F		(595790)	(Po)	Po	aw	SK
586	F		615795	(Po)	Lw–Po	aw	SK
587	F		c 620797	NL	Mp–Mh	tt	SK
588	F		574787	(S1–?)	S1–Sw	hm	SK
589	F		575787	(Lwh–Ld)	Lwh–Ld	ww	SK
590	F		584793	(upp S?)	S1–Sw	hm	SK
591	F		585792	(Lw–P)	Po	aw	SK
592	F		574778	(Pl)	Pl	at	SK
593			574778	(Pl–Sc)	Pl	at	SK
594	F		c 584787	Lwh–Ld	Lwh–Ld	ww	SK
595	F		c 584785	S1–?,Sw–low Tt?	S1–Sw	hm	SK
596	F		c592810	(upp S?)	Sw	hmt	SK
597	F		598845	S1–?,Sw–low Tt?	Sw	hm	SK
598	F		620844	Lwh–Ld?	Lwh–Ld	ww	SK
599	V	1313	617793	Mp	Mp	tt	SK
600	F		(592804)	(S?)	S1–Sw	hm?	SK
601	F	13683	535711	Dt	Dt	tw	JK
602	F	13684	583753	Mh–Dt	Dt	tw	JK

603	F 13685	604738	Dt	Dt	tw	JK
604	F 13686	618737	Dt	Dt	tw	JK
605	F 13687	630733	Dt	Dt	tp	JK
606	F 13798	(519757)	Sc-Ww?	Sw-Tt	hm	JK
607	F 13799	(485853)	S1-Sw?	Tt	**hm**	JK
608	F 13800	608797	Pl	Pl	at	JK
609	F 13801	608797	Pl?	Pl	at	JK
610	F 13802	608797	Lw-P	Po	aw	JK
611	F 13803	(459611)	Mh	Mh	tt	JK
612	F 13945	(493844)	Sw?	Sw	hmg	JK
613	F 17695	491758	ND	Mp	tt	WB, RH
614	F 17696	493757	Rt-Mp	Mp	tt	WB, RH
615	V 2033	483802	Cu?-Cm?	Cu?-Cm	um	MJ
616	V 2034	490797	Cu?-Cm?	Cu?-Cm	um	MJ
	F 18023		C-R			MJ
	F ——		ND			
617	F ——	603799	ND	Lw-Po	aw	MJ
618	F 17697	556746	Cm-Cn	Cm-Cn	us	MJ
619	F	561760	Ak?-Lwh?	Dw-Ab	wh	MJ
620	F 18019	468624	Dt	Dt	tp	MJ
621	F ——	581736	NF	Dt	tw	MJ
622	F 18030	667687	Lw-Po	Lw-Po	aw	MJ
701	V 1021	463786	ND	low Cret?	ew	JE

702	V 1022	458759	Cn	Cn	us	AA, MH
703	V 1024	489761	Ra	Ra	us	AA, MH
704	V 1025	463758	Cn?	Cn	us	AA, MH
705	V ?	480717	(Mp?)	Mp–Mh	tt	RC, JE
706	V 1027	450783	Cu?–Cm	Cu?–Cm	um	HW
707	V 1028	472741	ND	Cn	us	RC, JE
708	V 1029	479737	Cu?	Cn	us	RC, JE
709	V 1030	c 479765	Cm–Cn	Cn	us	HW
710	V 1031	463735	Cm	Cm	us	JW
711	V 1208	473744	Cn?	Cn	us	HW
712	V 1209	470742	ND	Cn	us	HW
713	V 1210	459739	Cm	Cm	um	JE
714	V 1211	485740	Cm	Cm	us	JE
715	V 1212	485740	ND	Cm–Cn	us	JE
716	V 1213	458771	ND	Cm–Cn	um+s	JE
717	GS 7929	665848	Mp	Mp	tt	GS, IK
718	GS 7930	664849	Mp	Mp	tt	GS, IK
719	GS 7931	662850	Mp	Mp	tt	GS, IK
720	GS 7932	661851	ND	Mp–Mh	tt	GS, IK
721	F 14783	660851	Rt–Mp	Mp	tt	GS, IK
722	GS 7933	660851	Mp–Mh	Mp–Mh	tt	GS, IK
723	GS 7934	660851	Mp	Mp	tt	GS, IK
	F 14784		Rm–Mp			GS, IK

No.						
724	GS 7935 F	666848	ND ND	Mp Mp	tt tt	GS, IK GS, IK
725	GS 7936 F 14785	682895	Rt? Rt-Mp	Mp Mp	tt tt	GS, IK GS, IK
726	F 15379	673688	Wo	Wo	hr	NH
727	AG B #	674688	Wo-Wn	Wn	cp	AB, PW
728	AG B	674687	Wn	Wn	cp	AB, PW
729	AG B	669679	Wn	Wn	cp	AB, GN
730	AG B	665676	Wn	Wn	cp	AB, CF, PW
731	AG B	665675	Wn	Wn	cp	AB, CF, PV, PW
732	V 1023	489763	Ra	Ra	us	TH
733	V 1039	460764	Cm	Cm	us	RC
734	V 1040	459765	ND	Cm	um	TH
735	V 1207	488785	Cm?	Cm	um	TH
736	GS 9610	c 664676	Wn	Wn	cp	JM
737	GS 9611	674687	Wn	Wn	cp	JM
738	GS ?	463823	Mh?	Mp-Mh	us+t	MO
739	F 17231	c 696773	Lw?-Po?	Lw-Po	aw	DJ
740			vacant			
741	V 1682 *	660676	ND	Lw-Po	aw	WB
742	V 1683	672682	ND	Wn	cp	WB
743	V 1684	674687	ND	Wn	cp	WB
744	V 1685	674687	ND	Wn	cp	WB
745	V 1686	674687	ND	Wn	cp	WB

746	V	1687	674687	ND	Wn	cp	WB
747	V	1688	674687	ND	Wn	cp	WB
748	V	1689	674687	ND	Wn	cp	WB
749	V	1690	674687	ND	Wn	cp	WB
750	V	1691	674687	ND	Wn	cp	WB
751	V	1692	674687	ND	Wn	cp	WB
752	V	1693	674687	ND	Wn	cp	WB
753	V	1694	674687	ND	Wn	cp	WB
754	V	1695	674688	ND	Wn	cp	WB
755	V	1696	672686	ND	Wn	cp	WB
756	V	1697	659674	ND	Wn	cp	WB
757	V	1698	665675	ND	Wn	cp	WB
758	GS	9734	535710	ND	Dt	tw	SK
759	V	1608	454775	Cm-Cn;Cn	Cm-Cn	us	MJ, HW
760	V	1610	450805	Cret	Cm-Cn	us	MJ
761	V	1615	491783	Cm	Cm	us	MJ
762	V	1616	481796	pre Cn	Cu?-Cm	um	MJ
763	V	1617	c 481805	C; ?Cm-Rm?	Cu?-Cm	um	MJ
764	V	1618	490794	ND	low Cret?	ew	MJ
765	V	1619	475782	Cm	Cm	um	MJ
766	V	1620	458818	Rm; Mp?	Rm-Mp	us+t	MJ
767	V	1621	459771	Cu?-Cm	Cu?-Cm	um	MJ

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* V 1682 - V 1698 microfaunal samples

768	V	1622	462769	Cm?	Cm	um	MJ
769	V	1623	459763	Cm?	Cm	us	MJ
770	V	1624	458759	Cn	Cn	us	MJ
771	V	1625	480785	C?	Cu?–Cm	um	MJ
772	V	1630	462762	Cm–Cn;Ra?	Cn, Ra	us	MJ
773	V	1632	467772	Cm; Cm	Cm	um	MJ
774	V	1633	468770	Cm–Cn;Mp?	Cm–Cn;Mp	us;tt	MJ
775	V	1640	499768	Rt	Rt	us	MJ
776	V	1641	485767	Cn?	Cn	us	MJ
777	V	1642	488765	Cn	Cn	us	MJ
778	V	1643	491758	Mp	Mp	tt	MJ
	F	17643	494757	Rt–Mp, Mp?		tt	MJ
779	V	1644	487759	Ra;Ra	Ra	us	MJ
	F	17644		Ra			MJ
780	V	1645	480761	Cn	Cn	us	MJ
781	V	1646	495749	Mh?	Mh	tt	MJ
	F	17645		Mp–Mh, Mh?			MJ
782	V	1647	483743	Cn	Cn	us	MJ
	F	17646		?C–R			MJ
783	V	1648	476747	Cn	Cn	us	MJ
	F	17647		Cm–Cn			MJ
784	V	1649	472752	Mp	Mp	tt	MJ
785	V	1650	478758	ND	Cn	us	MJ
786	V	1651	482750	Cn	Cn	us	MJ
787	V	1652	477740	Cn	Cn	us	MJ

788	V 1653	471742	Cn; Cn	Cn	us	MJ
789	V 1654	467744	Cn	Cn	us	MJ
	GS10058		ND			MJ
	F 17648		Cm-Cn			MJ
790	V 1655	460772	Cu?-Cm	Cu?-Cm	um	MJ
791	V 1656	510726	Mp	Mp	tt	MJ
792	V 1657	492742	Mh	Mh	tt	MJ
793	V 1982	462724	Cm-Rm	Rt?-Mp	tt	MJ
	GS10000		Cm-Rm	Rt-Mp		MJ
	F 17904		Rt-Mp;	Rt-Mp,		
			Cm-Cn	Cm-Cn	tt;us	MJ
794	V 1983	459742	Cm; Cm	Cm	us	MJ
795	V 1984	455728	Cm?	Cm	um	MJ
796	V 1985	452722	Cm	Cm	um	MJ
797	V 1990	453710	Mp	Mp	tt	MJ
798	V 1999	468720	pre-Tert	Cm-Cn	us	MJ
799	V 2000	683823	Rm	Rm	ug	MJ
800	V 2001	712881	Rm?	Rm	ug	MJ
801	V 2002	679874	Rt; Mp	Rt-Mp	ug;tt	MJ
802	V 2003	671860	Mp;Mh?	Mp-Mh	tt	MJ
803	V 2004	687891	Rm;Rt;R	Rm-Rt	ug	MJ
804	V 2005	678886	Mp?	Mp	ug	MJ
805	V 2006	674886	Cm-Mp?	Mp	tt	MJ
806	V 2007	682895	Rt?	Mp	tt	MJ
807	V 2009	681849	Ra	Ra	ug	MJ

808	V	2010	673839	Ra	Ra	ug	MJ, HW
809	V	1658	499707	low Cn	low Cn	us	MJ
810	V	2015	637818	Rt	Rt	ug	MJ
811	V	2016	662850	Mp	Mp	ug	MJ
812	V	2017	620797	Mp	Mp	tt	MJ
813	V	2019	673828	Mp	Mp	ug	MJ
814	V	2020	674832	Rm	Rm	ug	MJ
815	V	2021	658810	Mh?	Mh	tt	MJ
	F	17649		Mh, low Mh?		tt	MJ
816	V	2022	653815	Mp–Mh	Mp–Mh	tt	MJ
817	V	2023	655821	Ra	Ra	ug	MJ
818	V	2024	657831	Rm	Rm	ug	MJ
819	V	2025	646834	Rt	Rt	ug	MJ
820	V	2026	652838	Rt; Mp?	Rt; Mp	ug	MJ
821	V	2027	669856	Mp	Mp	ug	MJ
822	V	2028	718867	Mh?	Mh	tt	MJ
823	V	2029	680830	Rt	Rt	ug	MJ
824	V	2030	679812	Rt; Mp	Rt;Mp	ug; tt	MJ
825	V	2031	644827	Rt	Rt	ug	MJ
826	V		554752	?Cm–Rm?	Cm–Ra?	us	MJ
	F	17650		?C–R, low R?			
827	V	2032	5537444	?Cm–Rm?	Cm–Ra?	us	MJ
828	V	1040b	459765	ND	Cm	um	MJ
829	F	17651	460698	Rt–Mp	Mp	tt	MJ
830	F		641871	upp Lw–Po, Po?	Lw–Po	aw	MJ

831	F	641873	upp Lw-Po, Po?	upp Lw-Po, Lw-Po	aw	MJ
832	F	640873	Po	Po	aw	MJ
833	F	635881	Lw	Lw	aw	MJ
834	F 17652	645888	Dt	Dt	tw	MJ
835	F	614889	S1-Tt, Sw-low Tt?	Sw	hm	MJ
836	F	574898	mid-upp Tt, upp Tt?	upp Tt	hm	MJ
837	F	629853	Ab	Ab	wh	MJ
838	F	517735	Lwh-Ld	Lwh-Ld	ww	MJ
839	F 17653	676900	Dt-Mh	Mh	tt	MJ
840	F	497794	S1-Tt?, Sw?	S1?-Sw	hmg	MJ
841	F	528683	mid-upp Sa	Sa	aw	MJ
842	F ___ rec	452689	ND low Tt, der D	ND Tt	hm	MJ
843	F	620836	low Lwh	Lwh	ww	MJ
844	F	504766	ND	S1?-Sw	hmg	MJ
845	F 17654	501767	Mp-Mh	Mp	tt	MJ
846	F 17655	484740	R-Mp	Mh	tt	MJ
847	F 17656	482738	Cm-Cn	Cm-Cn	us?	MJ
848	F 17657	495743	Mp-Mh	Mh	tt	MJ
849	F 17659	466708	?Cm-Cn	Cm-Cn	us	MJ

850	F 17660	460713	Rt-Mp	Mp	tt	MJ
851	F 17661	503764	Rt-Mp	Mp-Mh	tt	MJ
852	F 17662	504765	Rt-Mh	Mp-Mh	tt	MJ
853	F 17663	496767	Rt-Mp	Rt	us	MJ
854	F 17668	500758	Mp-Mh	Mh	tt	MJ
855	F 17664	496757	Mp-Mh	Mp	tt	MJ
856	F 17665	495757	R-D	Mp	tt	MJ
857	F ———	489759	ND	Ra-Rm	us	MJ
858	F 17666	458751	Cm-Cn	Cn	us	MJ
859	F 17658	652824	Mh-Dt	Mh	tt	MJ
860	F	564776	Lwh?	Lwh-Ld	ww	MJ
861	F	548754	low Lwh	Lwh	ww	MJ
862	F	612793	upp Lw-P, upp Po?	Po	aw	MJ
863	F	483646	D	Dw-Ab	wh	MJ
864	F 17698	582764	Dt	Dt	tt	MJ
865	F	586781	Ar?	Dw-Ab	wh	MJ
866	F	596828	Sl-Sw	Sw	hm	MJ
867	F	591809	Sl-Sw	Sw	hmt	MJ
868	F	590805	Sw-Tt	Sw	hmt	MJ
869	V 2163	673689	Ww-Wn	Wn	cp	AB
870	F	559841	Tt	mid Tt	hm	MJ
871	F	563776	ND	Sw	hm	MJ
872	F	581768	Dt?	Dt	tt	MJ

873	F	544755	Sw? / S1-Sw	S1-Sw	hm	MJ / MJ
874	F 17958	549754	Lwh?	Lwh-Ld	ww	MJ
875	F	603813	Lw-Po	Lw-Po	aw	MJ
876	F	600817	Sw?	Sw	hm	MJ
877	F	591802	Sw-Tt, Sw?	Sw	hm	MJ
878	F	593802	upp Po-H, Po?	Po	aw	MJ
879	F 17699	618795	Mh-Dt	Mh	tt	MJ
880	F	610818	low Lwh	Lwh-Ld	ww	MJ
881	F	615822	upp Po	Po	aw	MJ
882	F	597797	Lw-Po, upp Po?	Po	aw	MJ
883	F	583793	upp S-T	Sw	hm	MJ
884	F	595779	ND	Dt	tt	MJ
885	F 17703	598781	Dt	Dt	tt	MJ
886	F	609788	Pl	Lw-Po	aw	MJ
887	F	576823	upp Tt	mid Tt	hmt	MJ
888	F	597799	ND	Lw-Po	aw	MJ
889	F	564823	S1-Tt	upp Tt	hk	MJ
890	V 2035	535730	pre Cn	Cm	um	MJ
891	V 2036	551602	Mp	Mp	tt	MJ
892	V	573677	Mp	Mp	tt	MJ
893	GS 9910	500789	P-low S	S1?-Sw	hmg	PW

894	F 17761	566774	Dt	Dt	tw	MJ
895	F	557766	Sw-low Tt, Sw?	Sw	hm?	MJ
896	F	498845	Sw	Sw	hmg	MJ
897	F 17959 GS 9995	550768	Lwh? Sw S1-Sw	Sw	hm	MJ MJ MJ
898	F	574778	**Pl**	Pl	at	MJ
899	F	594792	Lw-Po	Po	aw	MJ
900	F	536831	Sw-upp Tt, Sw?	Tt-Tk	hk	MJ
901	F	549722	**Pl**	**Pl**	aw	MJ
902	F 17762	548725	Dt	Dt	tw+wh	MJ
903	F	544740	Lwh?	Lwh-Ld	ww	MJ
904	F	543739	Po	Po	aw	MJ
905	F 17767	535731	Lw-Po	Po	aw	MJ
906	F 17768	527732	Lw-Po	Po	aw	MJ
907	F 17769	621781	Dt	Dt	tw	MJ
908	F 17773	629744	Dt-Dw	Dt	tw	MJ
909	F	583801	Sw	Sw	hmt	MJ
910	F	564807	upp Tt-Tk	upp Tt	hk	MJ
911	F	565807	mid Tt-upp Tk	mid Tt	hm	MJ
912	F	552705	**Pl**	**Pl**	aw	MJ
913	F 17763	567751	Dt	Dt	tt	MJ
914	F 17764	566752	Dt	Dt	tt	MJ

No.	Type	Ref	Number				
915	F		568728	Pl	Pl	aw	MJ
916	F		563729	Pl	Pl	aw	MJ
917	F		635692	D,Lwh-Po	Lw-Po	aw	MJ
918	F		531748	Sw?-Tt?	Sw	hm	MJ
	F	17961		Sc-Tt	Sw		
919	F	17765	556600	Mh-Dt	Mp-Mh	tt	MJ
920	F		535630	Pl	Pl	aw	MJ
921	F		552627	Lw-Po	Lw-Po	aw	MJ
922	F		550641	D-Ab?	Dw-Ab	wh	MJ
923	F		529664	Sc	Sc	aw	MJ
924	F	17770	545656	Dm, Sw	Dw-Ab	wh	MJ
925	F		547652	Pl - ?	Pl	aw	MJ
926	F	17771	577675	Dw-?Sw	Dw-Ab	wh	MJ
927	F		584625	L,Lwh?	Lw-Po	aw	MJ
928	V	2038	607678	Mh	Mh	tt	MJ
929	V	2039	583655	Mp	Mp	tt	MJ
930	F		548689	Pl	Pl	aw	MJ
931	F		530872	Sw-low Tt?	Tt	hk	MJ
932	F		511876	mid Tt	mid Tt	hk	MJ
933	F		499881	mid Tt	mid Tt	hk	MJ
934	F		499843	upp Tt-Tk	upp Tt	hk	MJ
935	F		508900	mid Tt-Tk	upp Tt-Tk	hk	MJ

No.	Coll.	Specimen				Code	
936	F	526897	upp Tt	upp Tt	upp Tt-Tk	hk	MJ
937	F	561887	mid-upp Tt	upp Tt		hk	MJ
938	F	484873	upp Tt-Tk	Tt		hk	MJ
939	F	564891	Tt-Tk	mid Tt		hm	MJ
940	F 17891	494862	ND	Sw		hmg	MJ
	GS 9986		Sw-Tt				MJ
			Po-Sw				MJ
941	F	496861	Sw?-low Tt?	Sw		hmg	MJ
942	F	490873	ND	Tt		hk	MJ
943	F 17969	485870	Sc-Tt, upp S?	Sl-Sw		hmg	MJ
944	F	463698	upp S?	Sw-Tt		hm	MJ
945	F 17766	582768	Dt	Dt		tt	MJ
946	F	620782	NF	Dt		tw	MJ
947	F	455680	Sl-Sw, Sw?	Sw		hm	MJ
948	F	475829	Ab	Ab		wh	MJ
949	F	486831	Sw-Tt, Sw?	Sw		hm	MJ
950	F	485833	Sw-Tt?	Sw		hm	MJ
951	F	510836	Sw-Tt, Tt?	Tt		hm	MJ
952	F	497830	mid Tt	mid Tt		hk	MJ
953	F	511799	low Tt	low Tt		hm	MJ
954	F	500785	Sl-low Tt	Sl?-Sw		hmg	MJ
955	F	518749	low Tt?	Sw		hm	MJ
	F.17960		?Sa-Tt?				MJ

956	F		620810	Lw-P?, Lw?	Lw-Po	aw	MJ
957	F		619818	upp Lw-Po, Po?	Po	aw	MJ
958	F		617820	Pl	Po	aw	MJ
959	F		636884	A-Lwh, Lwh?	Lwh-Ld	ww	MJ
960	F		642861	Lwh-Ld	Lwh-Ld	ww	MJ
961	F		628853	D-Ab	Dw-Ab	wh	MJ
962	F	17808	608812	Sl-Sw	Sl	hmt	MJ
963	F	17809	612823	Sl-Sw	Sw	hm	MJ
964	F	17810	608797	Pl	Pl	at	MJ
965	F	17811	606799	Pl	Pl	at	MJ
966	F	17812	612824	Lw-Pb	Po	aw	MJ
967	F	17813	602800	Lw-Po	Po	aw	MJ
968	F	17814	599799	Lw-Po	Lw-Po	aw	MJ
969	F	17815	597799	Lw-Po	Lw-Po	aw	MJ
970	F	17816	637892	Dh	Dh	wh	MJ
971	F	17817	632897	Lw-Po	Lw-Po	aw	MJ
972	F	17818	631896	Lw-Po, Lw?	Lw-Po	aw	MJ
973	F	17819	628880	Lw-Fo	Lw-Po	aw	MJ
974	F	17820	629880	Lw-Fo, Lw?	Lw-Po	aw	MJ
975	F	17821	630881	Lw-Fo	Lw-Po	aw	MJ
976	F	17822	631881	Lwh-Ld	Lwh-Ld	ww	MJ
977	F	17823	632880	Ab	Ab	wh	MJ

978	F 17824	629852	Ab	Ab	wh	MJ
979	F 17839	634852	Dm-Dh	Dm-Dh	wh	MJ
980	F 17840	625855	S1-Sw	S1	hmt	MJ
981	F 17841	627854	Lw-Po	Lw-Po	aw	MJ
982	F 17842	615839	S1	S1	hmt	MJ
983	F 17843	616837	Pl -S1	Pl-Sc	at	MJ
984	F 17844	617837	Sc-S1	Pl-Sc	at	MJ
985	F 17845	618837	Pl	Pl	at	MJ
986	F 17846	618837	Pl	Lw-Po	aw	MJ
987	F 17847	618837	Lw-Po	Lw-Po	aw	MJ
988	F 17848	619837	Lw-Po	Lw-Po	aw	MJ
989	F 17849	597847	S1-Sw	S1-Sw	ah	MJ
990	F 17851	516677	Dh	Dh	wh	MJ
991	GS 9987	623829	Mh?	Mh	tt	MJ
992	F 17890	627881	S1-Sw	S1-Sw	hmt	MJ
993	F 17905	473684	low Mh	Mh	tt	MJ
994	F 17892	486849	S1?-Tt?	Tt	hn	MJ
995	F 17893	512851	Tt	Tt	hk	MJ
996	F 17894	508853	Tt	Tt	hk	MJ
997	F 17895	504855	Tt	Tt	hk	MJ
998	F 17896	500858	Tt	Tt	hk	MJ
999	F 17897	497859	?S1-Tt	S1-Sw	hmg	MJ
1000	F 17898	492863	S1-Sw	Sw	hmg	MJ

1001	GS 9996	527750	low S	upp S	hm	MJ
1002	F 17933	487832	Sw-Tt	Sw	hm	MJ
1003	F 17934	489832	Sw-Tt	Sw	hm	MJ
1004	F 17935	490832	low Tt	low Tt	hm	MJ
1005	F 17936	492832	low-mid Tt	low Tt	hm	MJ
1006	F 17937	495831	mid Tt	mid Tt	hm	MJ
1007	F 17938	573894	mid Tt	mid Tt	hm	MJ
1008	F 17939	573893	mid Tt	mid Tt	hm	MJ
1009	F 17940	576889	Tt,mid Tt?	upp Tt	hmt	MJ
1010	F 17941	579890	S1-Sw?	Sw	hmt	MJ
1011	F 17942	584882	S1-Sw	Sw	hmt	MJ
1012	F 17943 GS 9999	504793	?S1-Tt / Lw-S1	S1 / S1	hm	MJ
1013	F 17899	667680	Po-Pl	Po-Pl	aw	MJ
1014	F 17962	549765	?S1-Tt	S1-Sw	hm	MJ
1015	F 17963	552765	Lw-Po?	Lw-Po	aw	MJ
1016	F 17964	548755	Lw-Po?	Lw-Po	aw	MJ
1017	F 17965	544751	S1-Sw	S1-Sw	hm	MJ
1018	F 17966	537749	upp Sa-Sw, ? S1-Sw	S1	hm	MJ
1019	F 17967	536748	?S1-Sw	S1	hm	MJ
1020	F 17968	531745	?S1-Sw	S1	hm	MJ
1021	F 18024	485689	Dw	Dw	wh	MJ
1022	F 18029	490796	R-C	Cu?-Cm	um	MJ

1023	F 18025	586746	Dt	Dt	tt	MJ
1024	F ———	587746	NF	Dt	tt	MJ
1025	F 18026	563667	Mh	Mh	tt	MJ
1026	F 18027	559685	Dt	Dt	tt	MJ
1027	F 18028	466721	C	Cm-Cn	us	MJ
1028	F ———	464723	NF	Cm-Cn	us	MJ