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Plio-Pleistocene Cyclothems, Wairarapa, New Zealand

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Abstract

SEA which covered Wairarapa in the late Tertiary shallowed and became filled with sediments during the late Pliocene and early Pleistocene. Overall shallowing was interrupted by rhythmic fluctuations in depth which caused five regressions and five transgressions. Cyclothems were developed where conditions were favourable, and can be correlated with cyclothems which developed at the same time in Southern Hawke's Bay. Unconformities in the less distinctly cyclic sediments of the Wanganui Basin are considered to be coeval with unconformities and shallow-water phases in the cyclothems of Wairarapa and Hawke's Bay.

Amplitudes of apparent sea-level oscillations ranged from about 150ft to 500ft, and were in phase over at least the southern half of the North Island, but at many places they are difficult to determine accurately because of rapid secular tectonic movements. The second and largest apparent sea-level fall coincided with the appearance of cool-water Mollusca at the beginning of the Hautawan Age, considered to be the beginning of the Pleistocene in New Zealand, and the cyclothems were probably due to glacio-eustatic sea-level fluctuations.

Fossils cannot be used for detailed correlation because their stratigraphic ranges are not consistent relative to one another in the three regions. Low sea-level phases represented by unconformities are considered to be more reliable than fossils for correlation.

The cyclothems in Wairarapa were deposited while the region was tectonically sinking at a decelerating rate. Their deposition ceased when the region ceased to sink and commenced to rise. The tectonic phase change caused a mid-Pleistocene break in the stratigraphic sequence.

INTRODUCTION

THE following account describes the marine Upper Pliocene and early Pleistocene sediments of Wairarapa. Cyclothems form convenient stratigraphic units which extend north-eastward into Southern Hawke's Bay. Cyclothem-boundary unconformities can be recognised in the Wanganui Basin.

Wairarapa is the eastern part of Wellington Land District. To the west lie the Rimutaka and Tararua ranges, to the east the Pacific Ocean, to the south Cook Strait, and to the north, without any physiographic break, southern Hawke's Bay.

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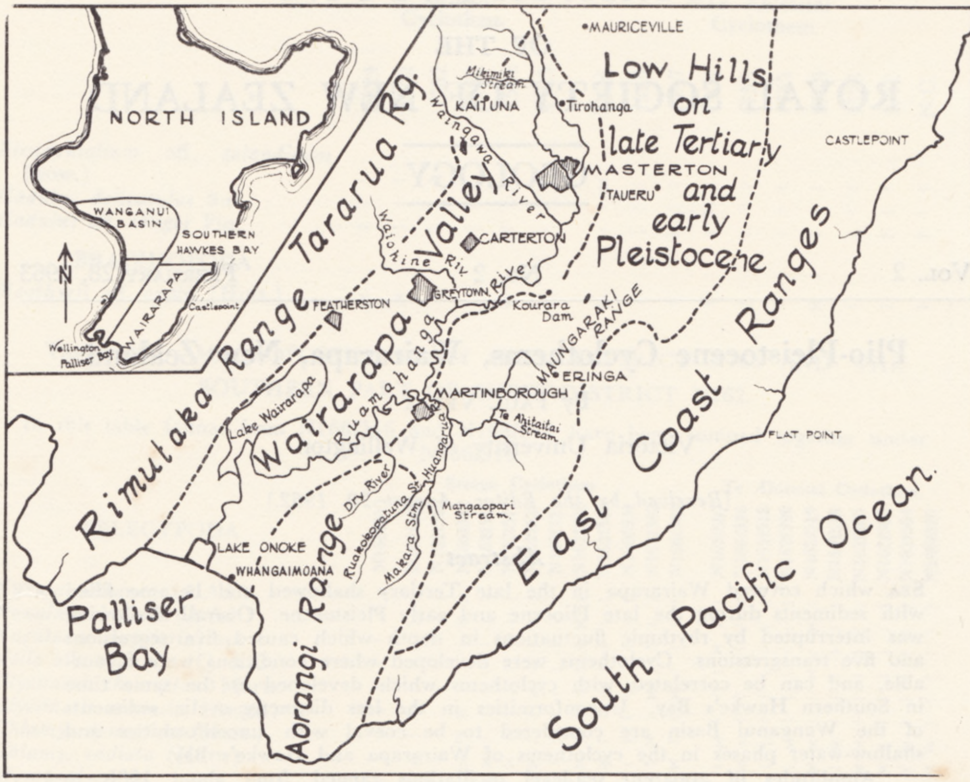

FIG. 1.—Map showing main localities mentioned in the text and physiographic areas in Wairarapa.

The western part is the Wairarapa Valley, a large structural depression floored with late Pleistocene and Holocene deposits and with Palliser Bay at its southern end. The central part is mostly rolling hills of upper Tertiary and early Pleistocene marine sediments, with the Aorangi Range, of Mesozoic greywacke, at its southern end. The eastern part is the East Coast ranges, of Cretaceous and early Tertiary rocks.

Marine early Pleistocene and Pliocene rocks outcrop along the western margin of the central part, flanking the eastern margin of the Wairarapa Valley. Coquina limestones, resistant to erosion, form prominent ridges with regular dip-slopes facing the Wairarapa Valley, and steep scarps facing east. The largest ridge, the 2,000ft high Maungaraki Range, lies south-east of the township of Gladstone, in Sheet District N162.

An isolated outlier of Pliocene and Pleistocene occurs at Castle Point, on the east coast, and there are larger outliers in the foothills of the Tararua Range, north-west of Masterton.

Wairarapa Pliocene and Pleistocene rocks have not previously been described comprehensively. They were briefly mentioned by Crawford (1871) and by McKay (1879). In an account of the northern part of the region Ongley (1935) recognised Te Aute "Series" and Petane "Series", which roughly correspond to Upper Pliocene and Lower Pleistocene of this account.

King (1933) listed and described Mollusca from several localities in southern Wairarapa. His Onoke "Series" included Upper Pliocene (Waitotaran) to Lower Pleistocene (late Nukumaruan) rocks, and is not well enough defined to be useful. Paleontological zones based on species of the gastropod genus *Pelicaria* were established by Vella (1953).

CYCLOTHEMS

Weller (footnote in Wanless and Weller, 1932: 1003) proposed the word cyclothem for "a series of beds deposited during a single sedimentary cycle of the type that prevailed during the Pennsylvanian Period". Cyclothems have since been recognised in rocks of many different ages.

Theories to explain cyclothems were fully reviewed by Wells (1960: 397–401). They invoke: (1) tectonic movements, (2) compaction of sediments, and (3) eustatic sea-level changes. Wanless and Shepard (1936) pointed out that the well-developed Pennsylvanian cyclothems correspond in time with the Gondwanaland glaciation, and considered them to have been caused by glacio-eustatic sea-level changes analogous with those of the Pleistocene. Wanless (1950) noted Pleistocene sedimentary cycles similar to Pennsylvanian cyclothems in the deltas of the Po and Ganges and below the Texas coastal plain. In order to explain the formation of cyclothems in non-glacial periods Wells (1960: 394-396) proposed a modified form of the "glacial control theory" of Wanless and Shepard. He suggested that the fluctuations of sea level resulted from displacement of oceanic water by a combination of vertical tectonic movements of the lithosphere beneath the sea and deposition of sediment in the sea, and that at times these fluctuations became roughly cyclic.

Cyclothems with non-marine members indicate an overall apparent sea-level rise equal to at least the total thickness of strata between the lowest and topmost marine members of the sequence, plus the compaction which has taken place since the final withdrawal of the sea. This apparent sea-level rise was due to either eustatic sea-level rise, or tectonic down-drop, or both. The cyclic changes in lithology were caused by cyclic changes in height of the surface of deposition relative to the base level of deposition, the base level of deposition being generally sea level, but exceptionally the surface of a lake or inland basin. In short cyclothems were produced by vertical oscillations of sea level, or other base level, relative to the surface of deposition.

Cyclothems were best developed where the surface of deposition remained close to sea level. Where the surface of deposition was well below sea level vertical oscillations were purely depth changes, and depth changes that were less than one-tenth of the average depth had little effect on sediments. Similarly, where the surface of deposition was well above sea level vertical oscillations were purely elevation changes, and when a small fraction of the average height probably had little effect on sediments. The larger the sea-level oscillation, the more widespread were its effects both inland and seaward.

For sustained formation of cyclothems at one place there had to be a balance between rate of overall subsidence and rate of deposition. If deposition was relatively too slow the surface of deposition would become too deep. If deposition was relatively too rapid the surface of deposition would be built up too high.

Development of cyclothems was inhibited where supply of sediment and tectonic down-drop were rapid and the surface of deposition was steep. Under such conditions a near equilibrium between deposition and by-passing of sediment could maintain the surface of deposition at a nearly uniform shallow depth, despite sea-level oscillations. Conditions approaching this affected deposition during the Pleistocene in the Wanganui Basin, where cyclothems were poorly developed. The Wanganui Basin was relatively small, with a fairly steep gradient to nearby deep water, and was exposed to the prevailing wind driving in strong ocean waves, so that conditions were suitable for rapid by-passing. The surface of deposition rarely rose above sea level and rarely sank more than a few hundred feet below sea-level. The sediments are many thousands of feet thick, indicating very rapid down-drop and deposition. By contrast, the Pennsylvanian cyclothems in central North America were deposited on a vast area that was near sea level. The seaward gradient was extremely gentle and did not permit rapid by-passing in the sea, or rapid transport on land. Sea-level oscillation had a large effect on rate of deposition and a small effect on lithology in Wanganui during the Pleistocene; it had a small effect on rate of deposition and a large effect on lithology in central North America during the Pennsylvanian.

That cyclothems were best and most widely developed when glaciation was widespread supports the glacial-control theory of their origin. It is generally assumed (see Wells, 1960) that glacio-eustatic sea-level changes could occur only in times of widespread glaciation. Ice-caps may well have existed in non-glacial times, however, and small glacio-eustatic sea-level oscillations resulting from their waxing and waning may have caused the development of cyclothems in relatively restricted areas with favourable conditions.

The Pennsylvanian cyclothems range from entirely marine through partly marine and partly non-marine to entirely non-marine. Most Wairarapa and Southern Hawke's Bay cyclothems are not unlike the entirely marine Pennsylvanian cyclothems, but only a limited number were able to form before the basins of deposition filled.

The base of each cyclothem is marked by a regional disconformity (no definite discordance of dip). Wairarapa cyclothems vary from strongly asymmetrical and dominantly transgressive, like the Pennsylvanian cyclothems (Weller, 1960: 371), to symmetrical. Asymmetry is due to erosion or non-deposition during the regressive phase.

A typical entirely marine cyclothem in Wairarapa consists of:

(disconformity)	shallowing culmination
Sandstone with shell-beds	shallowing
Sandy mudstone with scattered fossils	deepening culmination
Sandstone with shell-beds	deepening
Coquina limestone	deepening
(disconformity)	shallowing culmination

A typical partly marine and partly non-marine cyclothem consists of:

Lignite measures	" shallowing " culmination
Beach conglomerate	shallowing
Estuarine mudstone	shallowing
Sublittoral sand	deepening culmination
Beach conglomerate	deepening
Lignite measures (top of underlying cyclothem)	" shallowing " culmination

STRATIGRAPHY

In North America each cyclothem is treated as a formation, but cyclothems differ from formations as strictly defined because they vary in lithology laterally as well as vertically, and because they are bounded by time planes. As in the Lias of north-west Europe (Hallam, 1961), cyclothem boundaries in the New Zealand Pleistocene and upper Pliocene coincide with boundaries of fossil zones and hence of stages. Cyclothems are more widespread and more useful as stratigraphic units than are formations.

Four well-developed cyclothems from the upper part of a mid-Miocene to Lower Pleistocene sequence in Wairarapa (Vella, 1962a, Fig. 2). Cyclothems could not have developed earlier because the sea was too deep. A thin marine deposit restricted to a small area near Mikimiki Stream, at the western side of Wairarapa Valley, represents a later marine transgression, but is poorly exposed and is not described as a cyclothem. The sequence, with New Zealand and overseas correlations, is given in Table I.

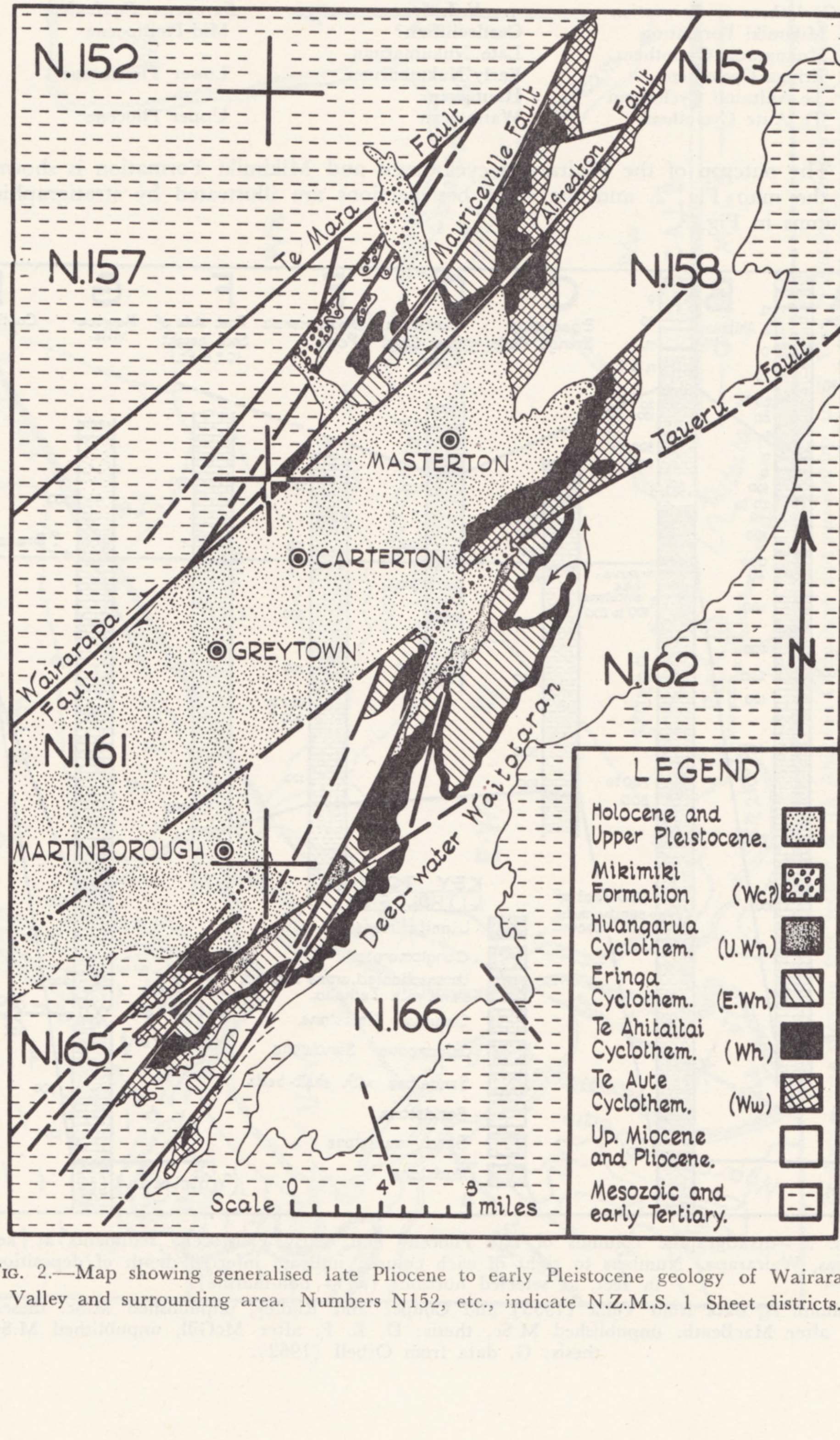

FIG. 2.—Map showing generalised late Pliocene to early Pleistocene geology of Wairarapa Valley and surrounding area. Numbers N152, etc., indicate N.Z.M.S. 1 Sheet districts.

Table I

Cyclothem or Formation	*N.Z. Stage*	*European Equivalent*
Mikimiki Formation	Castlecliffian?	Mid-Pleistocene
Huangarua Cyclothem	Late Nukumaruan	
Eringa Cyclothem	Early Nukumaruan	Lower Pleistocene
Te Ahitaitai Cyclothem	Hautawan	
Te Aute Cyclothem	Waitotaran	Upper Pliocene

The outcrop of the Wairarapa cyclothems and Mikimiki Formation is shown on the map Fig. 2, and the eight best sections are illustrated by stratigraphic columns in Fig. 3.

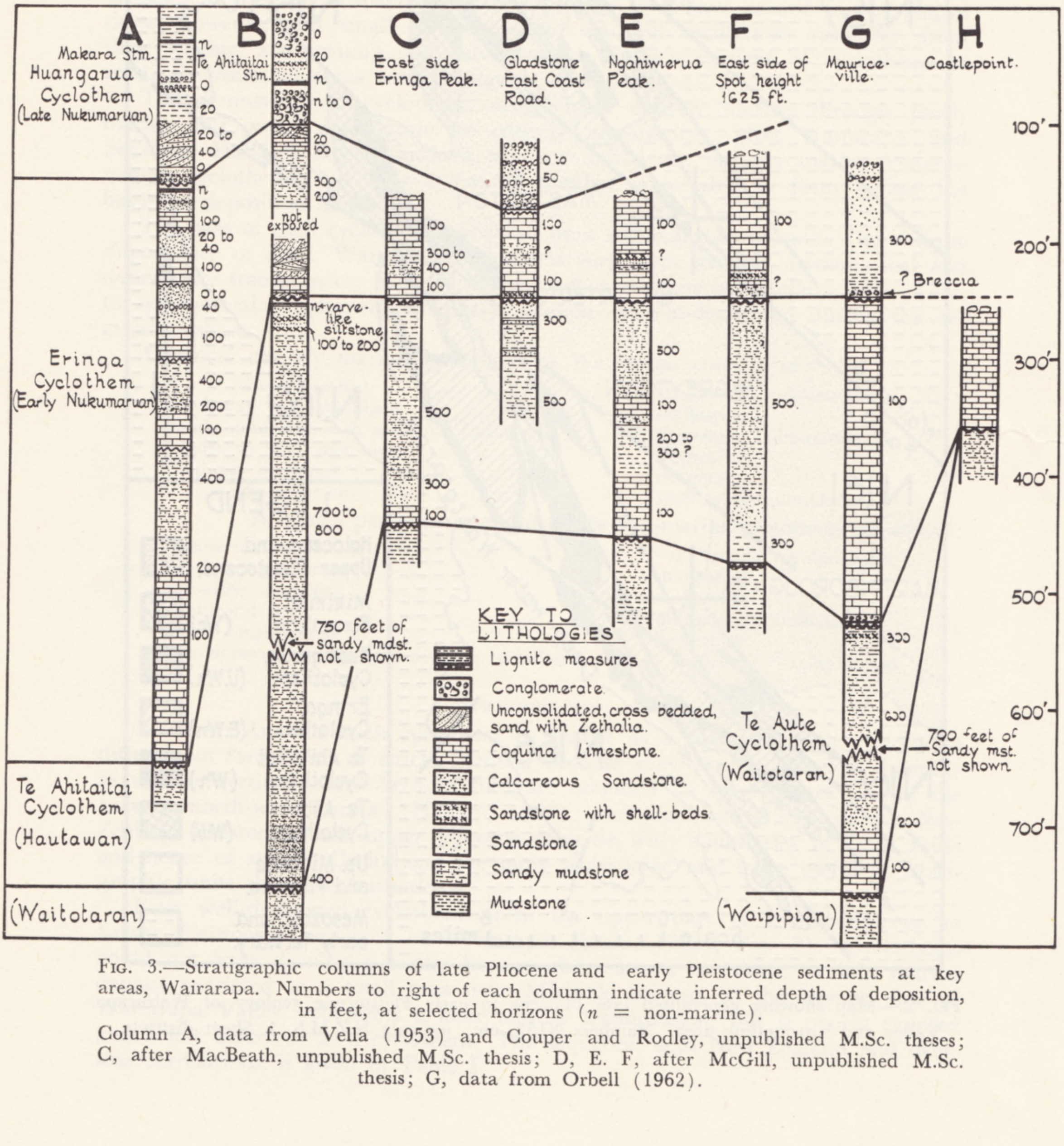

Fig. 3.—Stratigraphic columns of late Pliocene and early Pleistocene sediments at key areas, Wairarapa. Numbers to right of each column indicate inferred depth of deposition, in feet, at selected horizons (n = non-marine).

Column A, data from Vella (1953) and Couper and Rodley, unpublished M.Sc. theses; C, after MacBeath, unpublished M.Sc. thesis; D, E. F, after McGill, unpublished M.Sc. thesis; G, data from Orbell (1962).

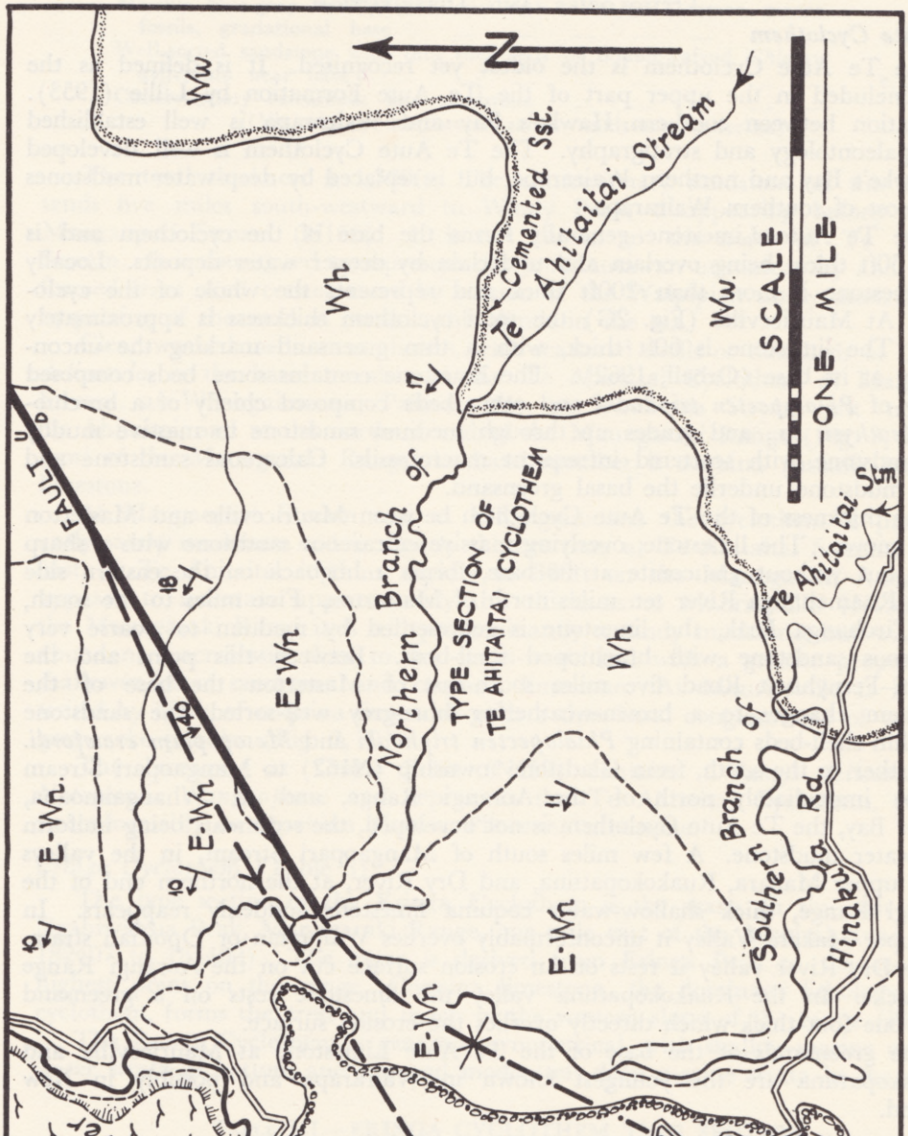

FIG. 4.—Geological map showing type section of Te Ahitaitai Cyclothem and surrounding area. Ww, Waitotaran deep-water mudstone. Wh, Hautawan–Te Ahitaitai Cyclothem. E.Wn, Early Nukumaruan–Eringa Cyclothem. U.Wn, Late Nukumaruan–Huangarua Cyclothem. wi, late Pleistocene river-aggradation gravels.

Lithologies and Distribution

Te Aute Cyclothem

The Te Aute Cyclothem is the oldest yet recognised. It is defined as the rocks included in the upper part of the Te Aute Formation by Lillie (1953). Correlation between southern Hawke's Bay and Wairarapa is well established from paleontology and stratigraphy. The Te Aute Cyclothem is well developed in Hawke's Bay and northern Wairarapa, but is replaced by deep-water mudstones over most of southern Wairarapa.

The Te Aute Limestone generally forms the base of the cyclothem and is about 50ft thick, being overlain and underlain by deeper water deposits. Locally the limestone is more than 200ft thick and represents the whole of the cyclothem. At Mauriceville (Fig. 2G) the total cyclothem thickness is approximately 900ft. The limestone is 60ft thick, with a thin greensand marking the unconformity at its base (Orbell, 1962). The limestone contains some beds composed chiefly of *Phialopecten triphooki* and other beds composed chiefly of a brachiopod *Neothyris* sp., and grades up through medium sandstone to massive muddy fine sandstone with scattered infrequent macrofossils. Calcareous sandstone and sandy mudstone underlie the basal greensand.

The thickness of the Te Aute Cyclothem between Mauriceville and Masterton is not known. The limestone, overlying massive calcareous sandstone with a sharp break, but without glauconite at its base, forms a hogback on the eastern side of the Ruamahanga River ten miles north of Masterton. Five miles to the south, near Tirohanga Peak, the limestone is represented by medium to coarse very calcareous sandstone with brachiopod shell-beds. Between this point and the Weraiti–Fernyhurst Road five miles south-east of Masterton the base of the cyclothem changes to a brown-weathering blue-grey well-sorted fine sandstone with thin shell-beds containing *Phialopecten triphooki* and *Mesopeplum crawfordi.*

Further to the south, from Gladstone township (N162) to Mangaopari Stream (N165) immediately north of the Aorangi Range, and at Whangaimoana, Palliser Bay, the Te Aute Cyclothem is not developed, the sediments being uniform deep-water mudstone. A few miles south of Mangaopari Stream, in the valleys of the upper Makara, Ruakokopatuna, and Dry River, at the northern end of the Aorangi Range, thick shallow-water coquina limestone suddenly reappears. In the upper Makara Valley it unconformably overlies Waipipian or Opoitian strata. In the Dry River valley it rests on an erosion surface cut on the Aorangi Range greywacke. In the Ruakokopatuna valley the limestone rests on a greensand about one foot thick which directly overlies the erosion surface.

The greensands at the base of the Te Aute Limestone at Mauriceville and Ruakokopatuna are the youngest known in Wairarapa and possibly in New Zealand.

Te Ahitaitai Cyclothem (Table II)

The type section of the Te Ahitaitai Cyclothem is in the north branch of the Te Ahitaitai Stream, N166, grid references 063283 to 083278 (Fig. 4).

Table II.—Te Ahitaitai Cyclothem Type Section

(Fig. 3, Column B.)

(Eringa Cyclothem overlies)	Feet
Probably fresh-water varve-like siltstone	10
Coarse blue-grey sandstone with shell-beds, gradational base	50
Massive blue-grey muddy sandstone with badly preserved macrofossils, gradational base	c. 50
Massive blue-grey sandy mudstone with scattered infrequent macrofossils, gradational base	1100

Massive blue-grey muddy sandstone with scattered common macrofossils, gradational base	c. 50
Well-sorted sandstone with thin shell-beds of double-valved *Chlamys delicatula* near base	c. 40
Concretionary calcareous fine sandstone	1
(Waitotaran deep-water sandy mudstone underlies)	

The total thickness is 1,300ft. The concretionary sandstone at the base extends five miles south-westward to Windy Peak, disappearing before reaching Mangaopari Stream (N165). It is not known to the north of Te Ahitaitai Stream. It is considered to represent the pre-Hautawan unconformity and to have formed from sand concentrated by erosion of the Waipipian sandy mudstone and by-passing of the mud at considerable depth in the sea.

Clean-washed medium sandstone, with scattered shells or thin beds of *Chlamys delicatula,* is the basal member of the Te Ahitaitai Cyclothem at Mangaopari Stream, at Whangaimoana, Palliser Bay, at Whakarua Stream just north of Te Ahitaitai, and at the northern end of the Maungaraki Range (Fig. 3, F). On most of the Maungaraki Range the basal member is coquina (usually barnacle) limestone.

At Mangaopari Stream and at Whangaimoana the cyclothem is predominantly sandy mudstone and is slightly thinner than at Te Ahitaitai Stream. North-east of Te Ahitaitai it thins rapidly to 300ft on the Maungaraki Range, and appears to maintain approximately this thickness to Mauriceville (N158). On the Maungaraki Rangi it is still predominantly a sandy mudstone, but with more abundant macrofossils than to the south-west, and with a greater proportion of shallower-water sandstone and coquina limestone. At Mauriceville it is represented by 300ft of coquina limestone with a thin basal conglomerate of well-worn greywacke pebbles (Fig. 3, G).

The limestone at Castle Point (N159) contains *Chlamys delicatula* and *Notorotalia mangaoparia* and represents the Te Ahitaitai Cyclothem. It rests unconformably on Opoitian (Lower Pliocene) mudstone.

Eringa Cyclothem (Table 3)

The type section of the Eringa Cyclothem is the scarp on the east face of Ngahiwierua Peak, Maungaraki Range, one mile east of the Admiral Road (N162 182407 to 184409). The name is derived from Eringa Peak to the south, the highest point on the range. Coquina limestone, the dominant lithology of the cyclothem, forms the crest and much of the western slope of the range (Fig. 5).

The Eringa Cyclothem is generally symmetrical, with shallow-marine or fresh-water strata at bottom and top and moderately-deep marine strata in the middle.

TABLE III.—ERINGA CYCLOTHEM TYPE SECTION

(Fig. 3, Column E)

	Feet
Coarse barnacle limestone (top eroded)	50
Chlamys delicatula shell-bed	2
Calcareous medium sandstone	4
Blue-grey muddy sandstone with abundant macrofossils	3
Medium-grained barnacle limestone, unconformity at base	30
(Te Ahitaitai Cyclothem underlies)	

The original total thickness is estimated as being about 100ft. Near Te Ahitaitai Stream (Fig. 3, Column B) the lower and upper limestones are thinner, and the intervening sandstone and sandy mudstone are much thicker. In Whangaehu Stream, north of the junction of Te Ahitaitai Stream, the coquina limestones are replaced by shallow-water sandstones and conglomerates.

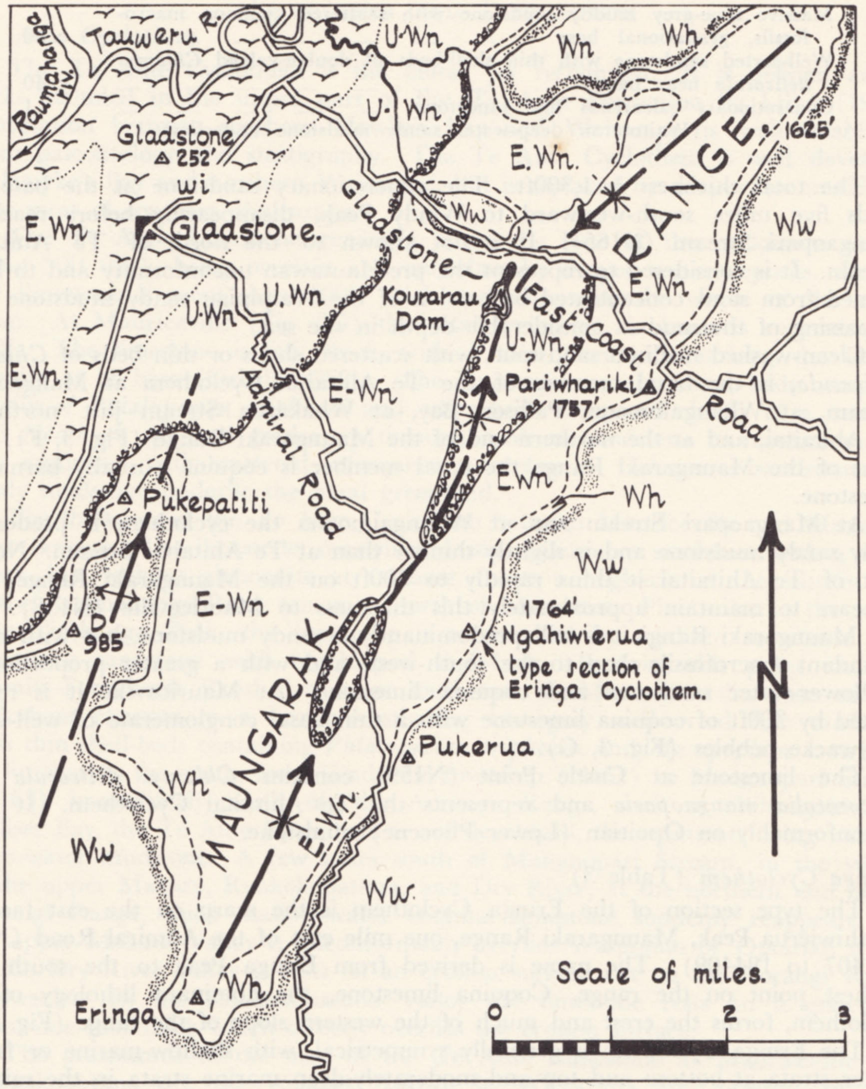

FIG. 5.—Geological map showing type section of Eringa Cyclothem and surrounding area. Ww, Waitotaran deep-water mudstone and sandy mudstone. Wh, Hautawan-Te Ahitaitai Cyclothem. E.Wn, early Nukumaruan–Eringa Cyclothem. U.Wn, late Nukumaruan–Huangarua Cyclothem. wi, late Pleistocene river-aggradation gravels.

The Eringa Cyclothem as exposed is thickest at the junction of the Ruakokopatuna and Makara streams (N165), where it consists of several microcyclothems (Fiege, 1951), each containing coquina limestone and deeper-water and shallower-water sediments (Fig. 3, Column A). The relationship of the microcyclothems to the Eringa Cyclothem is discussed below under the heading of "Eustatic Sea-level Changes" in the section on geological history.

A conglomeratic limestone at Lake Ferry, Palliser Bay, has not been examined carefully, but probably represents the Eringa Cyclothem.

At Gladstone, five miles north of the Te Ahitaitai Stream, beds representing the upper part of the Eringa Cyclothem are exposed in cliffs on the south-east side of the Ruamahanga River. These are the "lower group" of gravels which McKay (1879) correlated with the Petane beds of Napier. The sequence is similar to, though thicker than, that in Whangaehu Stream, near Te Ahitaitai.

The northernmost known occurrence of the Eringa Cyclothem is at Mauriceville (Fig. 3, Column G). The sequence is: (1) a basal breccia composed mainly of blocks of mudstone and of the Te Ahitaitai Limestone and possibly the Te Aute Limestone; (2) about 100ft of massive blue-grey muddy sandstone with abundant Mollusca, barnacles, bryozoans, echinoid spines, ostracodes, and upper neritic Foraminifera; (3) an unknown thickness of interbedded marine sandstone and conglomerate; (4) probably fluvial conglomerate (Orbell, 1962).

Near Matahiwi (N158), north-west of Masterton, marine conglomerate, sandstone, and limestone breccia in a small outlier on the south-east (downthrown) side of the Mauriceville Fault probably represent the Eringa Cyclothem.

Huangarua Cyclothem (Table 4)

The type section of the Huangarua Cyclothem is in Huangarua River for 400 yards downstream from the junction of the Ruakokopatuna and Makara Streams (N165 977208 to 975213).

TABLE IV.—HUANGARUA CYCLOTHEM TYPE SECTION

(Fig. 3, Column A)

	Feet
(Upper Pleistocene terrace gravels overlie)	
Lignite measures, mostly blue-grey clay, top not seen	50+
Not exposed	c. 50
Beach conglomerate with *Chione*	c. 6
Estuarine mudstone with *Barytellina*	c. 20
Sub-tidal brown free-running cross-bedded sand with *Zethalia*	c. 40
Beach conglomerate with *Tawera* shell-beds	10
(Lignite measures of the Eringa Cyclothem underlie)	

Outcrops are restricted to a belt about twelve miles long, on the western edge of the Windy Peak limestone range and in the Whangaehu Valley to the north-north-east. In Whangaehu Stream (N166), one mile downstream from the junction of Te Ahitaitai Stream (Fig. 3, B), the cyclothem is represented by probably marine rusty-brown conglomerate at the base, blue-grey estuarine fine sandstone with molluscan fossils interbedded with lignite bands in the middle, and probably marine rusty-brown conglomerate at the top.

The northernmost exposure, on the Gladstone–East Coast road five miles east of Gladstone, is calcareous sandstone with conglomerate bands overlying the upper Eringa limestone with a sharp break.

All the exposed Huangarua rocks were deposited close to shore, at a depth of less than 100ft. Deeper-water facies inferred to occur to the west in the Wairarapa Valley are hidden by unconformably overlying middle and Upper Pleistocene deposits.

Mikimiki Formation (Table V)

The name Mikimiki Formation is applied to a group of poorly exposed rocks known only in the eastern foothills of the Tararua Range, north-west of Masterton. The type locality is a cutting on Mikimiki Road (N158 051762) four miles west of the Wellington–Woodville main highway. Only a few feet of sandstone is exposed and no better exposures are known elsewhere. Table V is a composite section compiled from observations made between Mikimiki Road and Kaituna settlement to the south.

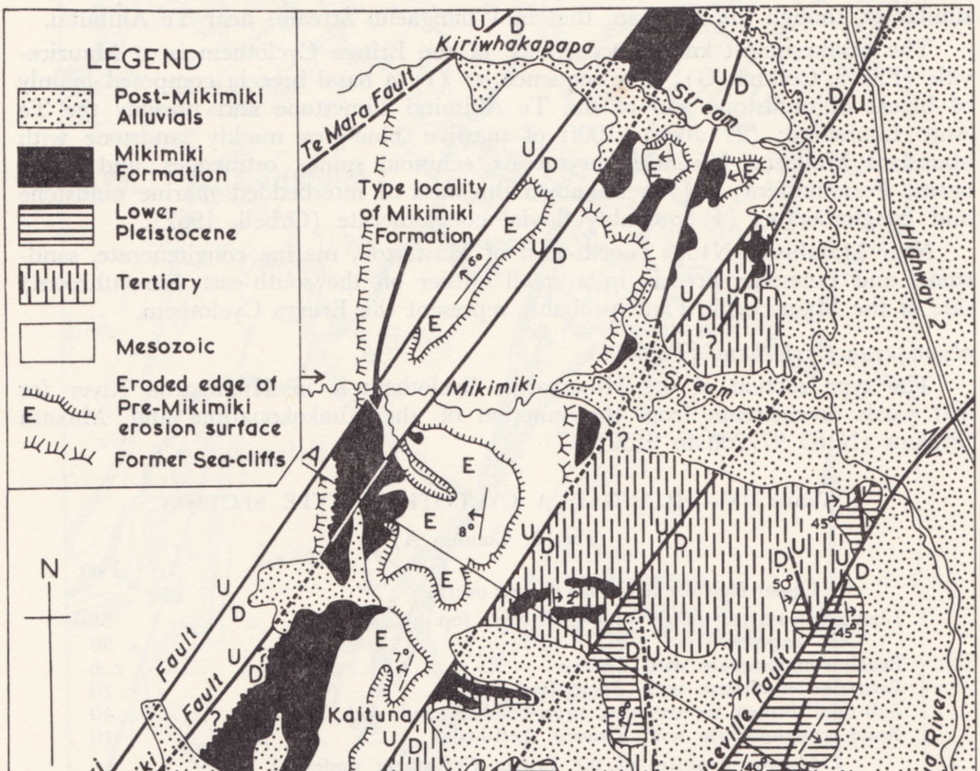

Fig. 6.—Geological Map and section of type locality of Mikimiki Formation and surrounding area. E, fossil erosion surface from which Mikimiki Formation has been stripped.

TABLE V.—COMPOSITE SECTION OF MIKIMIKI FORMATION—MIKIMIKI ROAD TO KAITUNA SETTLEMENT

	Feet
Younger alluvial deposits at Kaituna	?
Conglomerate with large boulders of resistant main-range rocks, unconformity at top	50+
Marine sandstone with conglomerate lenses	20–40
Not exposed	10
Erosion plane cut across medium-rank greywacke (no quartz veins)	

One mile south of Mikimiki Road (054746) the sandstone contains molluscan fossil moulds, and lenses up to 6ft long and 1ft thick of well-rounded pebbles and cobbles. The overlying conglomerate was seen in only one small exposure and is inferred to be extensive mainly from loose pebbles and boulders on the ground surface. Many boulders are more than 2ft in diameter and, like the majority of larger boulders in present-day streams, are composed of exceptionally resistant rocks, such as chert, from the Tararua Range greywackes.

Mikimiki beds are preserved in two fault-angle depressions (Fig. 6), a western one running north-north-east from Waingawa River through the Mikimiki type locality, and an eastern one striking parallel about two miles to the east. In the western fault angle the pre-Mikimiki erosion surface is cut solely on greywacke which has no macroscopic quartz veins and is of lower rank than the main-range greywacke. In the eastern fault angle the erosion surface is cut partly on similar greywacke and partly on lower Pliocene (Opoitian) mudstone. Lower Pleistocene has not been found resting on Opoitian anywhere except at Castle Point, and is almost certainly strongly unconformable to the Mikimiki Formation.

The greywacke is much more resistant than the Opoitian mudstone. Where Mikimiki sediments have been stripped from the greywacke part the erosion surface is still well preserved and dips west-north-west to west at an average of about seven degrees. The erosion surface was originally a valley floor flanked to the west by bluffs, and during the Mikimiki transgression was trimmed by the sea and then covered by the Mikimiki Formation. The bluffs to the west of the Mikimiki type locality are an eroded fault scarp marking the approximate western boundary of the original valley, but have been eroded back since Mikimiki time and are now partly buried beneath thick solifluxion debris. The pre-Mikimiki erosion plane continues north in both fault angles to Kiriwhakapapa Stream. Farther to the north-east and east it has been destroyed, and its original extent is not known.

Excepting Holocene beach deposits and deposits below sea level to the south, the Mikimiki Formation contains the youngest known marine deposits in the Wairarapa Valley.

PALEONTOLOGY

Macrofossils

Well-preserved upper Pliocene and lower Pleistocene macrofossils include molluscs, brachiopods, echinoids, and barnacles. Little attention has been paid to any except the molluscs, which include the most useful correlation fossils. The relationship of *Pelicaria* zones and of the ranges of other key macrofossils to cyclothems is shown in Table VI.

CYCLOTHEMS	*Pelicaria* ZONES	SOME KEY FOSSILS	STAGES
Huangarua	Convexa	*Glycymeris shrimptoni* *Bassina parva*. *Barytellina anomalodonta*	Late Nukumaruan
Eringa	Media	*Austrofusus chathamensis*	Early Nukumaruan
Te Ahitaitai	Acuminata Rotunda Rugosa	*Chlamys delicatula* *Aneator imperator*	Hautawan
Te Aute	Mangaoparia ?	*Phialopecten triphooki* *Mesopeplum crawfordi* *Polinices, Olivella, etc.*	Waitotaran

Table VI.—Stratigraphic Ranges of Key Fossils in Wairarapa.

Palliser Bay fossils have not been studied in detail since they were listed by King (1933). The Castlepoint fauna was listed by Powell (1938). Makara–Mangaopari faunas are being studied by Mrs Dawn Beck, of the University of Canterbury. The lists below give macrofaunas from sheet-districts N162 and N166 collected by research students at Victoria University of Wellington within the last twelve years and recorded in unpublished theses. Determinations for localities N162f501 to f590 and N166f502 to f522 have been checked by the writer; those for localities N162f752 to f762 were made by Dr C. A. Fleming, of New Zealand Geological Survey and have been accepted without checking.

Fossil lists are presented in two tables: VIIA (Maungaraki Range to Gladstone, Sheet District N162); VIIB (near Te Ahitaitai Stream, Sheet District N166 and the southern part of Sheet District N162). Each table represents a composite sequence, the fossil localities being placed in inferred stratigraphic order.

Table VIII gives details of fossil localities.

Table VII.—MACROFOSSILS FROM MAUNGARAKI RANGE TO GLADSTONE.

Localities indicated by Sheet Fossil Numbers in Master File at Geology Department, Victoria University of Wellington—all localities in Table VII are in Sheet District N162.

N.C. = not collected.

	Eringa Cyclothem						Te Ahitaitai Cyclothem									
PELECYPODA	f524	f542	f782	f752	f566	f583	f526	f525	f547	f501	f753	f755	f758	f523	f762	N.C.
Nucula castanea (A. Ad.)	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
Nuculana (*Sacella*) *bellula* (A. Ad.)	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
Neilo aff. *australis* (Q. & G.)	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–
Microcullaea crenulifera Marw.	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–
Clycimeris aff. *laticostata* (Q. & G.)	–	–	x	–	–	–	x	–	–	–	–	–	–	–	–	–
Glycimeris shrimptoni Marw.	–	–	x	x	–	–	–	–	–	–	–	–	–	–	–	–
Glycimeris modesta (Angas)	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–
Limopsis marwicki Pow.	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–
Limatula maoria Fin.	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–
Chlamys delicatula (Hutt.)	x	x	–	–	–	–	x	–	x	x	x	x	–	–	x	x
Chlamys radiata (Hutt.)	–	–	–	x	–	–	–	–	x	x	–	–	–	–	–	–
Mesopeplum aff. *mariae* Fin.	x	x	–	–	x	–	x	–	–	–	–	–	–	–	–	–
Ostrea charlottae Fin.	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–

	Eringa Cyclothem						Te Ahitaitai Cyclothem									
PELECYPODA	f524	f542	f782	f752	f566	f583	f526	f525	f547	f501	f753	f755	f758	f523	f762	N.C.
Ostrea sinuata Lamk.	x	x	–	–	x	x	–	–	–	–	x	x	x	–	–	x
Patro undatus (Hutt.)	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–
Gonimyrtea concinna (Hutt.)	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
Prothyasira peregrina Ired.	–	–	–	?	–	–	–	–	–	–	–	–	–	–	–	–
Amphidesma australe (Gmel.)	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–
Maorimactra acuminella Fin.	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
Scalpomactra scalpellum (Reeve)	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
Zenatia acinaces (Q. & G.)	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–
Myadora striata (Q. & G.)	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–
Pleuromeris hectori Pow.	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–
Pleuromeris cf. *zelandica* (Desh.)	–	–	–	x	–	–	–	x	x	x	–	–	–	–	–	–
Venericardia aff. *purpurata* (Desh.)	–	–	?	–	x	–	x	–	–	–	–	–	–	–	–	–
Notocallista multistriata (Sow.)	–	–	x	–	–	–	–	–	–	x	–	–	–	–	–	–
Chione stutchburyi crassitesta Fin.	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–
Tawera spissa (Desh.)	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–
Tawera subsulcata (Sut.)	–	–	–	–	–	–	?	–	–	–	–	–	–	x	–	–
Dosinia greyi Zitt.	–	–	–	–	–	–	–	–	–	–	x	x	–	–	–	–
Dosinula cf. *zelandica* (Gray)	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
Bassina yatei (Gray)	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–
Bassina parva Marw.	–	–	x	x	–	–	–	–	–	–	–	–	–	–	–	–
Nemocardium pulchellum (Gray)	–	–	–	–	–	–	–	–	x	x	–	–	–	x	–	–
GASTROPODA																
Antisolarium egenum (Gould)	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
Ataxocerithium robustum Fin.	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–
Stiracolpus cf. *symmetricus* (Hutt.)	–	–	–	x	–	–	–	–	x	x	x	–	x	–	–	–
Zeacolpus cf. *vittatus* (Hutt.)	–	–	–	–	–	–	–	x	–	x	–	–	–	–	–	–
Struthiolaria tasmani King	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–
Pelicaria acuminata Marw.	–	–	–	–	–	–	–	–	–	x	–	–	–	–	x	–
Pelicaria acuminata x *rotunda*	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–
Pelicaria rotunda Vella	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–
Pelicaria media Marw.	–	–	x	x	–	–	–	–	–	–	–	–	–	–	–	–
Proxiuber aff. *anteaustralis* Pow.	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–
Austrofusus taitae Marw.	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–
Aneator marshalli (Murd.)	–	–	x	–	–	–	–	–	–	–	–	–	–	–	x	–
Aneator imperator King	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–
Poirieria zelandica (Q. & G.)	–	–	–	–	–	–	–	–	–	x	–	–	–	–	x	–
Coluzea sp.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–
Alcithoe swainsoni (Marw.)	–	–	x	–	–	–	–	–	–	x	–	–	–	–	x	–
Alcithoe aff. *subgracilis* Marw.	–	–	–	–	–	–	–	–	–	x	x	–	–	–	–	–
Baryspira mucronata (Sow.)	–	–	x	x	–	–	–	–	–	–	–	–	–	–	–	–
Micantapex murdochi cf. *prior* Vella	–	–	–	–	–	–	–	–	–	x	–	–	?	–	–	–
Comitas onokeana King	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–
Splendrillia aff. *aoteana* Fin.	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–
S. aff. *lincta* Pow. aff. *otagoensis* Pow.	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–
Aoteadrillia gamma (King)	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–
SCAPHOPODA																
Dentalium nanum Hutt.	–	–	–	–	–	–	x	x	–	–	–	–	–	–	–	–
Dentalium "marwicki" Mestayer	–	–	–	–	–	–	x	x	x	x	–	–	–	–	–	–

	Eringa Cyclothem						Te Ahitaitai Cyclothem									
	f524	f542	f782	f752	f566	f583	f526	f525	f547	f501	f753	f755	f758	f523	f762	N.C.
Fissidentalium aff. *zelandicum* (Sow.)	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–
Cadulus delicatulus Sut.	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–
Cadulus aff. *teliger* Fin.	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–
BRACHIOPODA																
Neothyris aff. *ovalis* (Hutt.)	x	x	–	x	x	–	x	–	–	–	–	–	x	–	–	–

Table VII.—MACROFOSSILS FROM SHEET-DISTRICT N166 AND THE SOUTHERN PART OF SHEET-DISTRICT N162.

In this table faunas from N166f516 and N166f517 have been lumped together under N166f516

	Eringa Cyclothem													Te Ahitaitai Cyclothem									
PELECYPODA	N166f515	N162f508	N162f514	N166f522	N162f516	N162f517	N162f520	N162f521	N162f560	N162f568	N166f504	N162f582	N166f502	N162f587	N166f516	N162f518	N162f590	N162f519	N162f529	N162f586	N162f585	N162f584	N166f520
Nucula castanea (A.Ad.)	–	–	–	x	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–
Nuculana bellula (A.Ad.)	–	x	–	x	–	–	–	–	x	–	–	–	–	–	–	–	–	x	–	–	–	–	–
Nuculana (*Jupiteria*) sp.	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–
Neilo aff. *australis* (Q. & G.)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–
Glycimeris shrimptoni Marw.	–	–	–	–	–	–	x	–	–	–	–	x	x	–	–	–	–	–	–	–	–	–	–
Glycimeris modesta (Angas)	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Chlamys delicatula (Hutt.)	–	–	–	x	–	–	–	–	–	–	–	x	–	x	–	–	x	x	x	x	–	x	x
Chlamys radiata (Hutt.)	–	x	–	x	x	x	x	–	x	x	–	–	x	–	x	–	–	x	–	x	x	–	x
Mesopeplum sp.	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	x
Ostrea charlottae Fin.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x
Ostrea sinuata Lamark	–	–	–	x	–	–	–	–	–	x	x	x	x	x	x	x	x	x	–	–	–	?	–
Patro undatus (Hutt.)	–	–	–	x	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–
Modiolus aff. *fluviatilis* (Hutt.)	x	–	x	–	–	–	–	–	–	–	–	x	x	–	–	–	–	–	–	–	–	–	–
Aulacomya maoriana Ired.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–
Atrina zelandica (Gray)	–	–	–	x	–	–	–	–	x	–	x	–	–	–	–	–	–	–	–	–	–	–	–
Saxicava australis Lamark	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–
Mylitella finlayi Marw.	–	–	–	x	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–
Divaricella notocenica King	–	?	–	x	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pteromyrtea dispar (Hutt.)	–	–	–	x	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–
Taras (*Zemysina*) *globus* (Fin.)	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Prothyasira peregrina Ired.	–	x	–	x	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Amphidesma australe (Gmel.)	–	–	–	–	–	–	–	–	–	–	x	x	x	–	–	–	–	–	–	–	–	–	–
Amphidesma subtriangulata (Wood)	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–
Perionidia edgari (Ired.)	–	–	–	x	–	–	x	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
Maorimactra acuminella Fin.	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
Scalpomactra scalpellum (Reeve)	–	x	–	x	–	–	x	–	x	–	x	–	–	–	–	–	–	–	–	–	–	–	–
Gari lineolata (Gray)	–	–	–	x	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
Zenatia acinaces (Q. & G.)	–	–	–	x	–	–	–	–	x	–	x	–	–	–	–	–	–	–	–	–	–	–	x
Myadora aff. *boltoni* (E. A. Smith)	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Myadora striata (Q. & G.)	–	–	–	x	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–
Pleuromeris cf. *zelandica* (Gray)	–	–	–	–	–	–	–	–	–	–	–	–	x	x	–	–	–	–	–	–	–	–	–
Venericardia aff. *purpurata* (Desh.)	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	?	x
Notocallista multistriata (Sow.)	–	x	–	x	–	x	–	–	–	–	x	–	x	–	x	–	–	–	–	–	–	–	x
Chione crassitesta Fin.	x	–	x	x	–	–	–	–	–	–	–	x	x	–	–	–	–	–	–	–	–	–	–
Talabrica senecta Pow.	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–
Tawera spissa (Desh.)	–	–	–	x	–	–	–	–	x	–	x	–	–	–	–	–	–	–	–	–	–	–	–
Tawera subsulcata (Sut.)	–	–	–	?	–	–	–	–	–	–	–	–	x	x	x	–	x	–	–	–	–	–	–

		Eringa Cyclothem												Te Ahitaitai Cyclothem									
	N166f515	N162f508	N162f514	N166f522	N162f516	N162f517	N162f520	N162f521	N162f560	N162f568	N166f504	N162f582	N166f502	N162f587	N166f516	N162f518	N162f590	N162f519	N162f529	N162f586	N162f585	N162f584	N166f520
Dosinia lambata Gould	–	–	–	x	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
Dosinia greyi Zitt.	–	–	–	x	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–
Dosinia anus (Phillippi)	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–
Dosinia horrida Marw.	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Dosinia spp. indet.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	x	x
Bassina yatei (Gray)	–	–	–	x	–	–	–	–	–	x	–	–	–	x	–	–	–	–	–	–	–	–	–
Bassina parva Marw.	–	x	–	–	–	–	x	–	x	–	x	x	x	–	–	–	–	–	–	–	–	–	–
Eumarcia plana (Marw.)	–	–	–	–	–	–	–	–	–	–	x	x	?	–	x	–	–	–	–	–	–	–	–
Paphirus largillierti (Ph.)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–
Nemocardium pulchellum (Gr.)	–	–	–	x	–	–	x	–	x	–	x	–	–	–	–	–	–	–	–	–	–	–	x
Barytellina anomalodonta Fin.	x	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–
Offadesma angasi (C. & F.)	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Panope zelandica (Q. & G.)	–	–	–	x	–	–	x	–	x	x	–	–	–	–	–	–	–	–	–	–	–	–	–
GASTROPODA																							
Parvacmea sp.	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–
Astraea cf. *heliotropium* Mart.	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Coelotrochus aff. *brownei* Fl.	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Coelotrochus huttoni Cossm.	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Venustas cf. *hodgei* (Hutt.)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–
Zediloma (*Fractarmilla*) sp.	x	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–
Antisolarium egenum (Gould)	–	x	–	x	–	–	x	–	x	–	x	–	–	–	–	–	–	–	–	–	–	–	–
Zethalia zelandica (A. Ad.)	–	–	x	–	–	–	–	–	x	x	–	x	x	–	x	–	–	–	–	–	–	–	–
Zeacumantus lutulentus (Kien.)	x	x	–	–	–	–	–	–	–	–	–	x	x	–	–	–	–	–	–	–	–	–	–
Ataxocerithium robustum Fin.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–
Stiracolpus cf. *symmetricus* (H.)	–	–	–	x	–	–	–	–	x	–	–	–	–	x	–	x	x	x	x	–	–	x	x
Stiracolpus waikopiroensis (Su.)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–
Zeacolpus cf. *vittatus* (Hutt.)	–	–	–	x	–	x	x	–	x	–	x	x	–	–	x	–	x	x	x	–	–	x	x
Cirsotrema zelebori (Dunk.)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x
Struthiolaria tasmani King	–	–	–	x	–	x	x	–	x	–	x	x	–	–	–	–	–	–	–	–	?	–	–
Pelicaria rotunda Vella	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	x	x	x	x	–	–	x	–
Pelicaria rotunda x *acuminata*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	x
Pelicaria media Marw.	–	–	–	x	–	x	x	x	x	x	x	–	–	–	–	–	–	–	–	–	–	–	–
Sigapatella aff. *novaezelandiae* (L.)	–	–	–	–	–	–	–	x	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–
Zegalerus tenuis (Gray)	–	x	–	x	–	–	–	x	x	–	x	–	–	–	–	–	–	–	–	–	–	–	–
Globisinum aff. *venustum* (Sut.)	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Proxiuber cf. *anteaustralis* Pow.	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	x	x	–	–	x
Taniella planisuturalis Marw.	–	x	–	x	–	–	x	–	x	–	x	–	x	–	x	–	x	–	–	–	–	–	x
Uberella cf. *vitrea* (Hutt.)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x
Maoricrypta sp.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–
Cominula aff. *quoyana* (A.Ad.)	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cominista glandiformis (Reeve)	–	–	x	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–
Austrofusus aff. *conoideus* (Zitt.)	–	–	–	x	–	–	x	–	x	–	x	–	–	–	–	–	–	–	–	–	–	–	x
Austrofusus cottoni King	–	–	–	x	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Austrofusus aff. *chathamensis* Fin.	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Austrofusus aff. *marshalli* (Murd.)	–	x	–	–	–	–	x	–	x	x	–	–	–	–	–	–	x	–	–	–	–	x	–
Aneator marshalli (Murd.)	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
Aneator imperator King	–	–	–	–	–	–	–	–	–	–	–	–	–	–	?	–	x	–	–	x	–	–	x
Verconella aff. *mandarina* (Ducl.)	–	–	–	x	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–
Zephos onokeana King	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–
Xymene drewi Hutt.	x	–	x	–	–	–	–	–	–	–	–	x	x	–	–	–	–	–	–	–	–	–	–
Xymene aff. *expansus* Hutt.	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–
Poirieria zelandica (Q. & G.)	–	–	–	x	–	–	x	–	–	–	–	–	–	–	–	–	x	–	x	x	–	–	x
Murexsul cf. *espinosus* (Hutt.)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x
Zeatrophon aff. *bonneti* (Cossm.)	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x
Paratrophon aff. *cheesemani*	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–
Antizafra aff. *pisaniopsis* (Hutt.)	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Alcithoe swainsoni (Marw.)	–	x	–	x	x	x	x	–	x	–	–	x	–	–	–	–	–	–	–	–	–	–	–
Alcithoe aff. *brevis* Marw.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	x	–

	Eringa Cyclothem													Te Ahitaitai Cyclothem									
	N166f515	N162f508	N162f514	N166f522	N162f516	N162f517	N162f520	N162f521	N162f560	N162f568	N166f504	N162f582	N166f502	N162f587	N166f516	N162f518	N162f590	N162f519	N162f529	N162f586	N162f585	N162f584	N166f520
Alcithoe aff. *subgracilis* Marw.	–	–	–	x	–	–	–	–	x	–	–	–	–	–	–	–	x	–	x	x	–	–	x
Alcithoe aff. *gracilis* (Swains.)	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Baryspira mucronata (Sowerby)	–	x	–	x	–	x	x	–	x	x	x	–	x	x	x	–	x	–	–	–	–	x	x
Baryspira erica Olson	–	–	–	–	–	–	–	–	x	–	x	–	–	–	–	–	x	–	–	–	–	x	–
Baryspira aff. *australis* (Sow.)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–
Baryspira depressa (Sow.)	–	–	–	–	–	–	–	–	–	–	x	–	–	–	x	–	–	–	–	–	–	–	–
Alcospira novaezelandiae (Sow.)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	x	–	–	–
Marginella sp.	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Micantapex cf. *prior* Vella	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x
Splendrillia aequistriata (Hutt.)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–
Maoritomella aff. *robusta* Pow.	–	x	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aoteodrillia gamma (King)	–	x	–	x	–	–	x	–	x	–	x	–	–	–	–	–	–	–	–	–	–	–	–
Phenatoma zealandica (Smith)	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Neoguraleus hautotaraensis Vella	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–
Pervicacia tristis (Desh.)	–	–	–	x	–	–	–	–	–	–	–	x	x	–	–	–	x	–	–	–	–	–	–
Amphibola crenata (Martyn)	–	–	–	–	–	–	–	–	–	–	–	x	x	–	–	–	–	–	–	–	–	–	–
Pupa n. sp. aff. *alba* Hutt.	–	–	–	–	–	–	x	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
Potamopyrgus? sp.	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–
SCAPHOPODA																							
Dentalium nanum Hutt.	–	–	–	x	x	–	–	–	–	–	–	–	–	–	x	–	x	–	x	–	–	x	x
Dentalium "marwicki" Mestayer	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	x	x	x	x	x	x	–

TABLE VIII.—MACROFOSSIL LOCALITIES

Fossils from localities N162f501 to f590 were collected by D. M. McBeath in 1949; from N162f752 to f782 by P. McGill in 1954; and from N166f502 to f522 by P. Vella in 1949. Lithologies excepting coquina are given in the code used on the New Zealand Fossil Record Form (Wellman, 1953: 55).

SHEET-DISTRICT N162

Sheet Fossil Number	*Locality*	*Grid Reference*	*Lithology*	*Cyclothem*	*Stage*
f501	Admiral Road	168389	7942c	Te Ahitaitai	Wh
f508	Whangaehu Road	059301	6942f	Eringa	E. Wn
f514	Whangaehu Stream	059301	6942c	Eringa	E. Wn
f516	Whangaehu Stream	058301	7942c0	Eringa	E. Wn
f517	Whangaehu Stream	057301	7942c0	Eringa	E. Wn
f518	Whakarua Stream	072311	9742c	Te Ahitaitai	Wh
f519	Whakarua Stream	073310	9742c	Te Ahitaitai	Wh
f520	Whangaehu Stream	066316	7942c0	Eringa	E. Wn
f521	Whangaehu Stream	066318	7942c0	Eringa	E. Wn
f523	Eringa Peak	139348	coquina	Te Ahitaitai	Wh
f524	Eringa Peak	139351	coquina	Eringa	E. Wn
f525	Eringa Peak	139350	9742d	Te Ahitaitai	Wh
f526	Eringa Peak	139350	9743iS	Te Ahitaitai	Wh
f529	Oreka Stream	108409	coquina	Te Ahitaitai	Wh
f542	Wainuioru Valley	155349	coquina	Eringa	E. Wn
f547	Pukaiaia Peak	176394	7942c	Te Ahitaitai	Wh
f560	Whangaehu Stream	064308	7942c0	Eringa	E. Wn
f566	Wainuioru Valley	157363	coquina	Eringa	E. Wn
f568	Whangaehu Stream	064309	7942c0	Eringa	E. Wn
f582	Whangaehu Stream	065309	5743fS	Eringa	E. Wn
f583	Admiral Road	167378	coquina	Eringa	E. Wn
f584	Whakarua Stream	089310	9742c	Te Ahitaitai	Wh
f585	Whakarua Stream	087309	9742c	Te Ahitaitai	Wh
f586	Whakarua Stream	084309	9742c	Te Ahitaitai	Wh
f587	Whangaehu Road	073325	6942cM	Te Ahitaitai	Wh
f590	Oreka Stream	115402	9742c	Te Ahitaitai	Wh

Sheet Fossil Number	*Locality*	*Grid Reference*	*Lithology*	*Cyclothem*	*Stage*
f752	Kourarau Road	473170	coquina	Eringa	E.Wn
f753	Kourarau Road	480175	9742c	Te Ahitaitai	Wh
f755	Kourarau Road	475185	9742c	Te Ahitaitai	Wh
f758	Kourarau	468187	9742c	Te Ahitaitai	Wh
f762	Maurioho Stream	409184	coquina	Te Ahitaitai	Wh
f848	Gladstone	116437	6543fSS	Eringa	E.Wn
		Sheet-district N166			
f502	Te Ahitaitai Str.	064286	5614fSS	Eringa	E.Wn
f504	Ngarara Stream	046273	7942c	Eringa	E.Wn
f515	Whangaehu Stream	045288	6331eC	Huangarua	U.Wn
f516	Te Ahitaitai Str.	061288	6543dSS	Te Ahitaitai	Wh
f517	Te Ahitaitai Str.	063284	6843dS	Te Ahitaitai	Wh
f520	Te Ahitaitai Str.	074279	7953dS	Te Ahitaitai	Wh
f522	Whangaehu Stream	050276	7942d0	Eringa	E.Wn

Microfossils

Of the microfossils only a few species of Foraminifera have been studied comprehensively. The ranges of three species of *Notorotalia* (Vella, 1957) are correlated with the Pelicaria zones as follows:

Stage	Pelicaria Zone	Notorotalia Species
(Recent)	(post-Convexa)	*Notorotalia zelandica* Fin.
U.Wn	Convexa	
E.Wn	Media	*Notorotalia rotunda* Vella
U.Wh	Acuminata	
E.Wh	Rugosa	*Notorotalia mangaoparia* Vella
U.Ww	Mangaoparia	

The cool-water indicator (Vella, 1957) *Anomalinoides frigindex* Vella makes its first appearance in the Mangaoparia (*Pelicaria*) Zone—i.e., the upper part of the Te Aute Cyclothem or its equivalent. *Hofkeruva* (*Laminiuva*) *rodleyi* Vella, which is probably the "*Uvigerina* of *miozea line*" said to make its last appearance in the Waitotaran (Finlay, in Finlay and Marwick, 1940: 127), is restricted to the Waitotaran and Hautawan stages—i.e., the Te Aute and Te Ahitaitai cyclothems.

Of the many changes in the foraminiferal faunas above the Mangaoparia Zone it is uncertain which are due to depth and related facies changes, which are due to climatic changes, and which, if any, are due to evolution.

Depth Changes

The present account is concerned chiefly with the depth-divisions 1 to 4 given in a table by Vella (1962a). Depth-division 4 is here subdivided into lower neritic (a) (400 to 700ft) and lower neritic (b) (700 to 1,000ft).

The following is the best evidence for absolute depth range of each depth division: Benthic marine fossils may be classed, according to the depth ranges of their present day relatives, into (1) an essentially shallow-water group comprising all the macro-organisms and the micro-organisms Ostracoda and Bryozoa; (2) a depth-tolerant group, comprising the benthic smaller Foraminifera. In New Zealand waters at the present day the ratio of the number of species of group 1 to number of species of group 2 decreases from about 3.0 in water less than 200ft deep to about 0.3 in water 1,000ft deep. A useful though not entirely reliable check is the percentage of foraminiferal shells represented by shells of planktonic species. This planktonic percentage generally increases from near 0.01 in shallowest water to about 0.4 at 1,000ft (cf. Phleger, 1960: 259). These two proportions are assumed to have been the same during the Tertiary and Pleistocene as at present, and are used to determine approximate depth ranges of fossil faunas. The five biofacies representing depths from 0 to 1,000ft now distinguished in the upper Pliocene and lower Pleistocene of Wairarapa are given in Table IX.

Table IX.—Upper Pliocene–Lower Pleistocene Depth Biofacies

R is the ratio of number of species of group 1 (shallow-water group) to the number of species of group 2 (benthic smaller Foraminifera).

Depth Zone	R	Group 1 ("Shallow-water" fauna)	Group 2 (Foraminifera)	Lithology
Estuarine 0–?ft	—	Restricted molluscs and ostracodes	Few species, *Streblus* usually dominant	Estuarine mudstone to conglomerate
Subtidal 0–20ft	—	Restricted molluscs *Zethalia* dominant, many ostracodes	*Notorotalia depressa, Elphidium, Pseudononion*	Beach deposits, cross-bedded sands
Upper Neritic 20–400ft	3/1	All phyla abundant	Abundant *Elphidium,* large *Notorotalia, Astrononion* spp. and Miliolidae	Coquina limestone, well-bedded sandstone, with shell-beds
Lower Neritic (a) 400–700ft	1/1	Many molluscs, few ostracodes, all other taxa rare	Abundant *Haeuslerella parri, Elphid. charlottensis, Notorotalia finlayi, Astrononion* spp.	Muddy sandstone with scattered fossils, no shell-beds
Lower Neritic (b) 700–1,000ft	1/3	Mollusc species few but individuals common in places; all other taxa rare	As above, with species of *Robulus* and other lagenids becoming common	Sandy mudstone with infrequent scattered macrofossils

The probable error of depth determinations is 20 to 30 per cent. Depth faunal change in the sea is proportional to logarithmic depth increase, and depth changes cannot be detected from faunas when they are less than a certain percentage of the average depth of the sea. The maximum depth change (not sea-level change) indicated by Wairarapa cyclothems is about 400ft. Depth change is most easily determined where the average depth was small. Depth changes of 300ft and less had little effect on either faunas or sediments in depths averaging more than 1,000ft.

Inferred depths of deposition are shown on the Wairarapa stratigraphic columns (Fig. 3).

Southern Hawke's Bay Correlatives (Table X)

The upper Pliocene and lower Pleistocene rocks of southern Hawke's Bay were divided by Lillie (1953) by means of fossils, into the following four divisions, which he incorrectly termed formations.

TABLE X.—SOUTHERN HAWKE'S BAY DIVISIONS OF THE UPPER PLIOCENE AND EARLY PLEISTOCENE

" FORMATION "	STAGE CORRELATION (Lillie, 1953)	STAGE CORRELATION (this account)	KEY FOSSILS
Mangatarata	Castlecliffian	Okehuan (and Castlecliffian?)	—
Upper Kumeroa	Upper Nukumaruan	Nukumaruan	*Pelicaria convexa*
Lower Kumeroa	Lower Nukumaruan	Hautawan	*Chlamys delicatula Pelicaria* " *acuminata* "
Te Aute	Waitotaran	Waitotaran	*Phialopecten triphooki, Mesopeplum crawfordi,* " Takapau faunule "

Four key sections (Fig. 7) show consistent cyclic lithological changes. The Te Aute and Lower Kumeroa " formations " each correspond to one cycle, and the Upper Kumeroa to at least two cycles. The base of the Mangatarata Formation is defined by the sudden appearance of abundant pumice, correlated with the pumiceous Makirikiri Tuff (Te Punga, 1952) which marks the base of the Okehuan Stage in Wanganui District (Fleming, 1953: 176). The Mangatarata Formation was not described in sufficient detail to show whether it is cyclothemic.

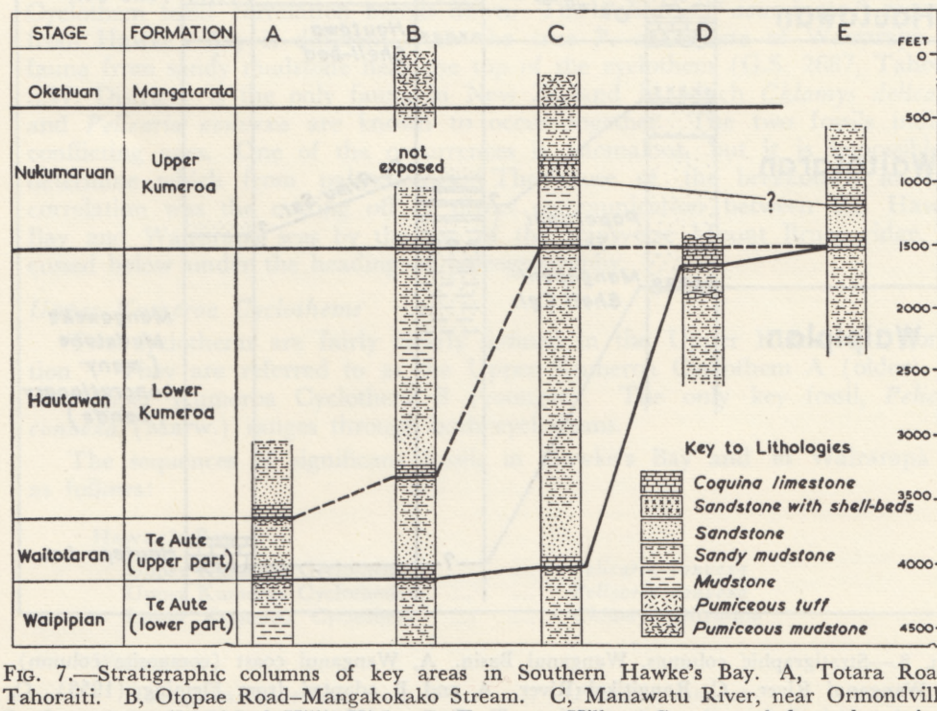

FIG. 7.—Stratigraphic columns of key areas in Southern Hawke's Bay. A, Totara Road, Tahoraiti. B, Otopae Road–Mangakokako Stream. C, Manawatu River, near Ormondville. D, Oruawharo (Woolshed Hill) High. E, Tourerere Hills. Constructed from data given by Lillie (1953).

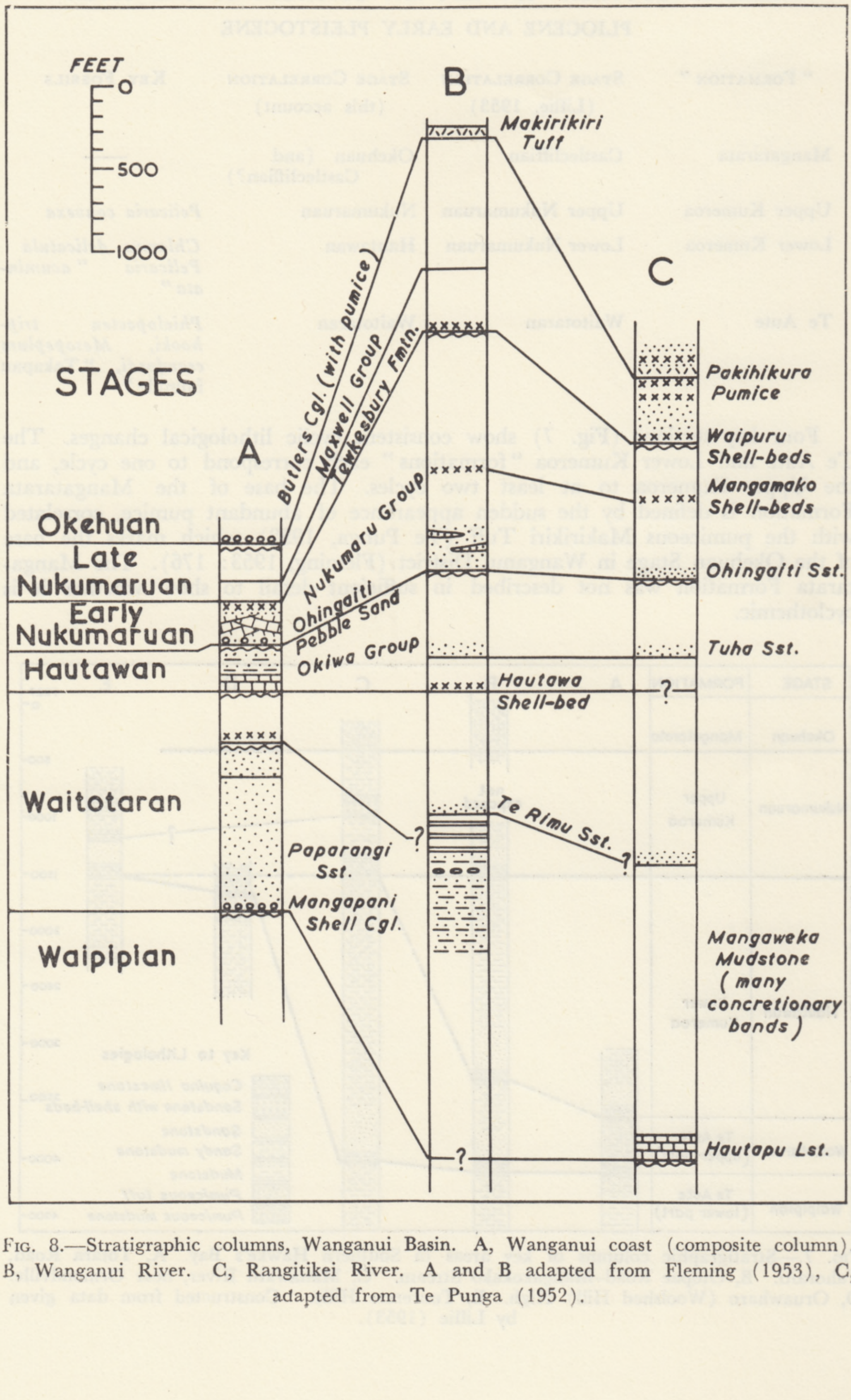

Fig. 8.—Stratigraphic columns, Wanganui Basin. A, Wanganui coast (composite column). B, Wanganui River. C, Rangitikei River. A and B adapted from Fleming (1953), C, adapted from Te Punga (1952).

The Te Aute, Lower Kumeroa, and two Upper Kumeroa cycles are considered as four cyclothems. Like those of Wairarapa, each has an unconformity at its base.

Te Aute Cyclothem

Coquina limestone (Te Aute Limestone) containing *Phialopecten triphooki* (Zitt.) generally forms the base and is followed by medium sandstone containing *Mesopeplum crawfordi* (Hutt.) Blue-grey muddy sandstone and sandy mudstone form the upper part of the cyclothem at most places, and at a number of places contain a distinctive molluscan fauna—the "Takapau faunule" (Lillie, 1953). Deep-water equivalents of the Te Aute cyclothem in Wairarapa contain many species in common with the Takapau faunule, but the faunas are not identical.

The foraminifer *Notorotalia kingmai* Vella is a useful correlation fossil for the sandy-mudstone facies. It occurs with the Takapau faunule in Hawke's Bay, and with Waitotaran faunas containing the warm-water molluscs *Polinices* cf. *waipipiensis* Marw. and *Olivella neozelanica* (Hutt.) in northern Wairarapa. It does not occur above the Te Aute Cyclothem, and probably does not occur below it.

Lower Kumeroa Cyclothem

Chlamys delicatula (Hutt.) makes its first appearance and *Phialopecten triphooki* makes its last appearance in the basal limestone of the Lower Kumeroa Cyclothem of Hawke's Bay, and in the basal limestone of the Te Ahitaitai Cyclothem in Wairarapa. This is good evidence for correlation of the basal limestones. Up to this horizon, fossil correlation agrees with cyclothem correlation between Wairarapa and Hawke's Bay. In the upper part of the Lower Kumeroa Cyclothem fossil correlation breaks down. The *Pelicaria "acuminata"* recorded from Hawke's Bay is different from the true *P. acuminata* of Wairarapa. A fauna from sandy mudstone near the top of the cyclothem (G.S. 2687, Tahoraiti S.W. District) is the only fauna in New Zealand in which *Chlamys delicatula* and *Pelicaria convexa* are known to occur together. The two fossils indicate conflicting ages. One of the occurrences is anomalous, but it is impossible to determine which from paleontology. The cause of the breakdown in fossil correlation was the cutting off of direct communication between the Hawke's Bay and Wairarapa seas by the rise of the transverse Mount Bruce ridge, discussed below under the heading of paleogeography.

Upper Kumeroa Cyclothems

Two cyclothems are fairly clearly defined in the Upper Kumeroa "Formation". They are referred to as the Upper Kumeroa Cyclothem A (older) and the Upper Kumeroa Cyclothem B (younger). The only key fossil, *Pelicaria convexa* (Marw.) ranges through both cyclothems.

The sequences of significant fossils in Hawke's Bay and in Wairarapa are as follows:

HAWKE'S BAY

Upper Kumeroa Cyclothem B	*Pelicaria convexa*
Upper Kumeroa Cyclothem A	*Pelicaria convexa*
Lower Kumeroa Cyclothem	*Chlamys delicatula*

WAIRARAPA

Huangarua Cyclothem	*Pelicaria convexa*
Eringa Cyclothem	*Pelicaria media* and *C. delicatula*
Te Ahitaitai Cyclothem	*Chlamys delicatula*

The occurrence of *Chlamys delicatula* and *Pelicaria convexa* suggest that the base of the Upper Kumeroa Cyclothem A is equivalent to the base of the Huangarua Cyclothem, but they are mutually incompatible species which were controlled by water temperature. The Hawke's Bay sea was cut off by rising land from the Wairarapa sea and, being sheltered from the cold Subantarctic water and exposed across the still submerged Ruahine area to the warm Tasman current, must have been warmer than the Wairarapa sea. The key fossil of the Eringa Cyclothem, *Pelicaria media* (Marw.), is not found outside Wairarapa, and the zone it defines cannot be correlated by fossils with any zone in Hawke's Bay. It was considered to be lower Upper Nukumaruan (Early Nukumaruan of this account) by Vella (1953). The Huangarua Cyclothem cannot be correlated before the Eringa Cyclothem is correlated.

WANGANUI CORRELATIVES

Wanganui district contains the type localities of all the stages covering the age range of the Wairarapa cyclothems and Mikimiki Formation. Fleming (1953) has reviewed the stages and subdivided them into substages. His substages are here given stage rank, and his names for substages which were founded on the same type localities as the original stages (shown in brackets in the table below) are abandoned in favour of the earlier stage names. The divisions relevant to this account are as follows:

STAGES	SYMBOLS	ABANDONED SUBSTAGE NAMES	EUROPEAN EQUIVALENTS
Castlecliffian	Wc	(Putikian)	
Okehuan	Wok		
Nukumaruan	Wn	(Marahauan)	
Hautawan	Wh		Lower Pleistocene
Waitotaran	Ww	(Mangapanian)	
Waipipian	Wwp		Upper Pliocene

Three-letter symbols are needed for the Okehuan Stage because Wo is already in use for the Opoitian Stage and for the Waipipian Stage because Ww is already in use for the Waitotaran Stage.

Regional unconformities occur at the base of each stage (Fig. 8). A more obscure but equally widespread break occurs at the base of the Maxwell Group (Fleming, 1953) in the middle of the Nukumaruan Stage. The Wanganui Basin strata indicate depth changes which are smaller than those of Wairarapa and Southern Hawke's Bay, with shallow phases near the stage boundaries and deep phases near the middles of the stages, excepting the Nukumaruan which has three shallow phases with two intervening slightly deeper phases.

INTER-REGIONAL CORRELATION

The following are the most important inter-regional correlation indicators that occur in the Wanganui Basin:

Okehuan	......	prominent pumice at base
Nukumaruan	......	*Pelicaria convexa* restricted
Hautawan	......	*Chlamys delicatula* restricted
Waitotaran	......	*Crassostrea* and *Phialopecten* without *C delicatula*
Waipipian	......	*Cibicides molestus* last appearance

The Waipipian indicator, *Cibicides molestus* Horni., a foraminifer, is more reliable in Wairarapa and Hawke's Bay than any macrofossil, but its range in Wanganui district has not been fully investigated. All the other index fossils are Mollusca. The Okehuan pumice is ideal for correlation in Wanganui and Hawke's Bay, but has not been found in Wairarapa. Except for the locality in Hawke's

Bay, where *Pelicaria convexa* occurs with *Chlamys delicatula* fossil ranges are consistent relative to one another throughout Wanganui and southern Hawke's Bay.

In any section there are only 10 to 20 useful key stratigraphic species. A typical example is the section in Makara and Mangaopari streams, southern Wairarapa, where there are about 16 useful key stratigraphic species. Of their 32 incomings and outgoings about 15 are useful within the period considered. Of the 15 some 13 occur at unconformities and two between unconformities. Consequently boundaries of stages and other divisions based on paleontology which have been recognised in the past coincide with cyclothem boundaries. This relationship of paleontological zones to cyclothems has recently been noted in the Lias of north-western Europe where ammonites are the dominant fossils (Hallam, 1961). It may be inferred that both cyclic depth change and migration and local extinction of fauna were controlled by the same factor or combination of factors.

There are four regional unconformities within the same time-span in the three regions discussed. From fossil evidence the second lowest unconformity, which may be referred to as the pre-Hautawan unconformity, was coeval throughout the three regions and is assumed to have been caused by an event which affected all three regions. Cyclothems indicate that there were cyclic changes in the depth of the sea, and that the unconformities represent shallow phases. As discussed below under the heading of Geological History, depth changes were caused by apparent sea-level fluctuations of the same order of size as the post-glacial eustatic rise in sea-level. It is therefore assumed that all the unconformities were controlled by the same kind of factor, which was probably glacio-eustatic sea-level fluctuation. In this view, regional unconformities represent time planes, and, together with cyclothems, after ages are broadly delineated by paleontology, can be used for direct stage correlation and for even more detailed correlation (Table XI).

TABLE XI

WAIRARAPA	SOUTHERN HAWKE'S BAY	WANGANUI
Mikimiki Formation	Mangatarata Formation	Okehuan (and younger?)
unconformity	*unconformity* ?	*unconformity* ?
Huangarua Cyclothem	Upper Kumeroa Cycl. B	Late Nukumaruan Stage
unconformity	*unconformity*	*unconformity*
Eringa Cyclothem	Upper Kumeroa Cycl. A	Early Nukumaruan Stage
unconformity	*unconformity*	*unconformity*
Te Ahitaitai Cycl.	Lower Kumeroa Cycl.	Hautawan Stage
unconformity	*unconformity*	*unconformity*
Te Aute Cyclothem	Te Aute Cyclothem	Waitotaran Stage
unconformity	*unconformity*	*unconformity*
Waipipian Stage?	Waipipian Stage?	Waipipian Stage

GEOLOGICAL HISTORY

Apparent Sea-level Changes

Terms to express relative vertical movements of sea level and different kinds of reference points on the lithosphere are defined by Vella (1962a). Gross apparent sea-level changes are local vertical-distance changes between sea level and any reference point fixed relative to the lithosphere, and are caused by vertical tectonic movements and eustatic sea-level changes either singly or together. Deposition usually accompanies apparent sea-level rise, and in shallow marine and terrestrial environments only exceptionally accompanies apparent sea-level fall.

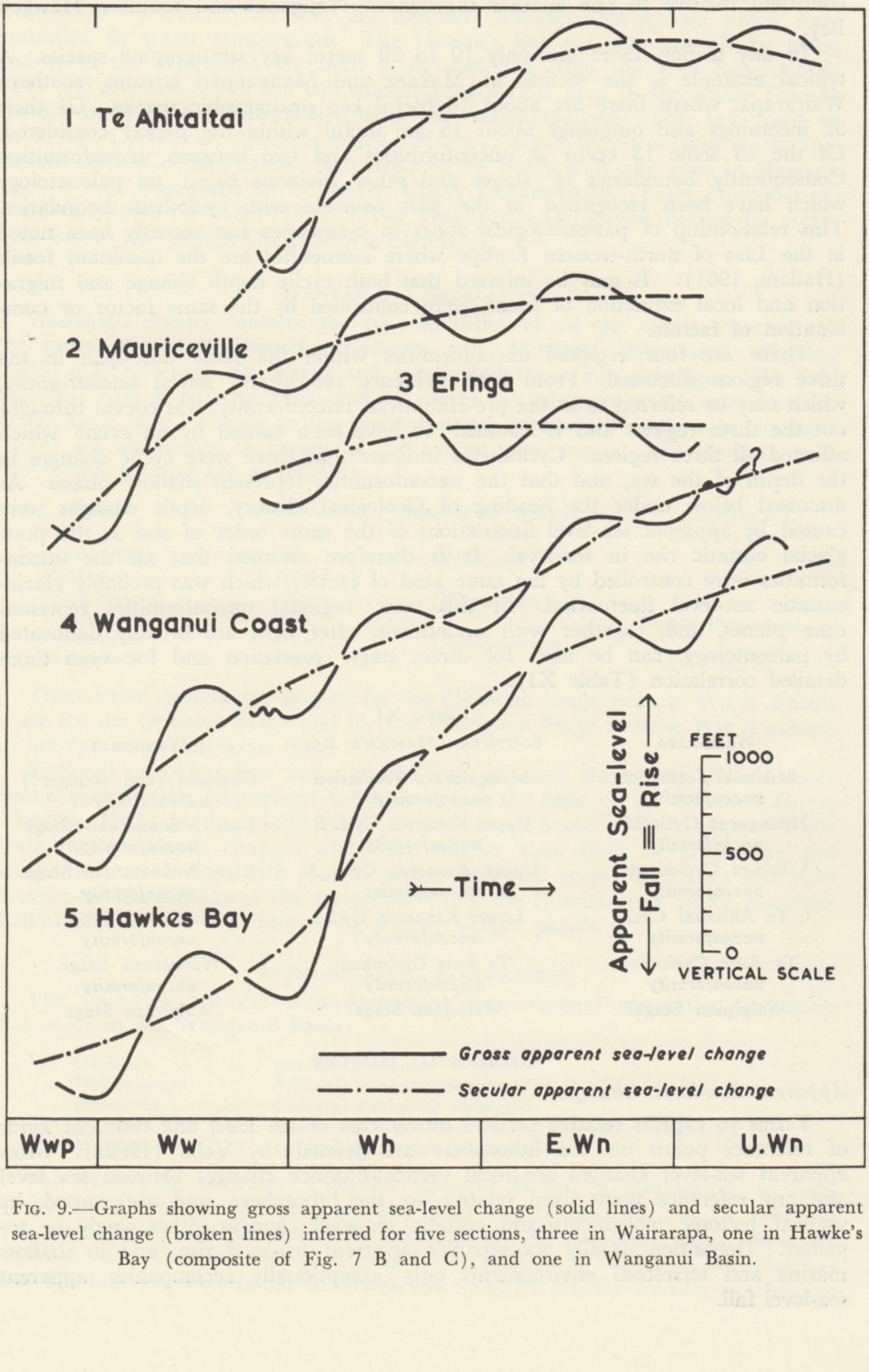

Fig. 9.—Graphs showing gross apparent sea-level change (solid lines) and secular apparent sea-level change (broken lines) inferred for five sections, three in Wairarapa, one in Hawke's Bay (composite of Fig. 7 B and C), and one in Wanganui Basin.

Gross apparent sea-level change can be determined between any two marine horizons in any stratigraphic section, if depth of deposition at each horizon and thickness (and, ideally, compaction) of sediment between the two horizons are known. The method of determination is best explained by considering a hypothetical example:

A is apparent sea-level change between two points in time, the beginning of the Hautawan epoch and the beginning of the Nukumaruan epoch. t is thickness of sediment overlying the base of the Hautawan Stage when deposition of the Nukumaruan Stage commenced, and is assumed to be 1,000ft; ideally this value would be the present thickness of the Hautawan Stage, plus the amount of compaction of the Hautawan Stage that has taken place since the beginning of the Nukumaruan Epoch. d_1 is the depth of deposition at the beginning of Hautawan time, assumed to be 400ft. d_2 is the depth of deposition at the beginning of Nukumaruan time, assumed to be 100ft.

$$\text{Then } A = t + d_2 - d_1 = 1{,}000 + 100 - 400 = 700\text{ft.}$$

A positive value for A indicates an apparent sea-level rise, and a negative value indicates an apparent sea-level fall. A is the sum of apparent sea-level changes within the time interval considered and gives no indication of reversals or changes in rate of apparent sea-level change which may have occurred. Gross apparent sea-level change (A) may be graphed with either the lithosphere or sea-level assumed to be fixed in vertical position.

The cyclothems of southern North Island record a series of oscillatory apparent sea-level changes superimposed on a secular apparent sea-level change—mainly rise. Figure 9 gives gross apparent sea-level change and an inferred secular apparent sea-level change for each of three Wairarapa sections, one Hawke's Bay composite section, and the Wanganui-coast composite section, the lithosphere being assumed fixed in vertical position. The Wanganui-coast graph is based on thicknesses and depths of deposition given by Fleming (1953) and depths of deposition estimated by the writer from fossil lists and lithological descriptions given by Fleming. The Hawke's Bay graph is based on thicknesses given by Lillie (1953) and depths of deposition estimated by the writer from fossil lists and lithological descriptions given by Lillie.

The oscillatory component in each gross apparent sea-level change curve has periods equal to the duration of cyclothems and of most marine stages, and periods of successive oscillations are assumed to be equal. The troughs of oscillations correspond to the boundary unconformities between cyclothems, while the peaks nearly coincide with the deepest phases of the cyclothems. Secular apparent sea-level change in each stratigraphic section is shown by the smoothest curve that lies evenly between peaks and troughs. The rate of secular apparent sea-level change is different for each section, being most rapid where deposits are thickest.

Each curve is similar to a small part of the hypothetical curve presented by Barrell (1917, Fig. 5) to illustrate base-level changes resulting from three combined rhythms of successively smaller amplitude and shorter period. Only two orders of rhythms are represented and of the higher order rhythm only a portion is represented in each of the curves.

The amplitudes of the oscillations are determined by subtracting secular apparent sea-level change from the gross apparent sea-level change. As the amount of compaction is not known it has been ignored when determining gross apparent sea-level changes.

Inferred Eustatic Sea-level Fluctuations

The oscillations are assumed to approximate to sine waves (Fig. 10, 1–5). The order of magnitude of determined amplitudes of successive oscillations in all

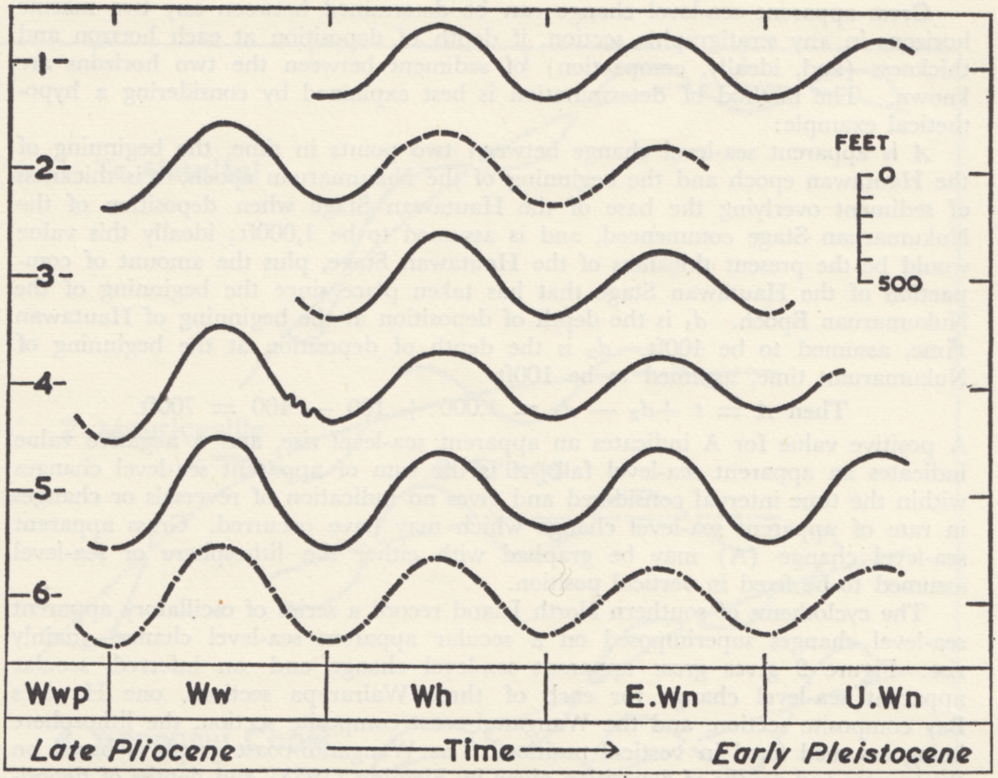

Fig. 10.—Oscillatory apparent sea-level changes. 1–5 derived by subtracting secular apparent sea-level change at successive times from gross apparent sea-level changes (Fig. 9) at corresponding times. 6 derived by averaging 1–5, inferred to represent the best approximation to glacio-eustatic sea-level changes. Cyclothems are assumed to represent equal periods of time. Sea-level fluctuations are arbitrarily represented as sine waves.

sections is the same, ranging from 150 to about 500ft. Oscillations of corresponding age in different sections mostly have nearly the same determined amplitudes. The oscillations have amplitudes of the same order of size as the known post-glacial rise of sea-level and are assumed to represent glacially-controlled eustatic sea-level fluctuations.

Each oscillation, if eustatic, must be equal everywhere, and the averages of all sections will provide the best amplitude values (Fig. 10, 6). The following values, excepting the one in parentheses, have been scaled from the average oscillation curve:

	Wwp	—	Ww	—	Wh	—	E.Wn	—	U.Wn	—	
Rise	—		475		375		250		210		feet
Fall		(350)		475		350		233		200	

A minimum value for the inferred eustatic sea-level fall represented by a disconformity on deep-water sediments is given by the decrease in depth of deposition across the disconformity. Down-drop during the time represented by the disconformity would need to be added to determine the full eustatic fall, but cannot itself be determined because the time represented by the disconformity is not known. A minimum value for the pre-Waitotaran sea-level fall, determined in this way, is given in parentheses in the above table.

Depths of deposition for the Waipipian and Waitotaran of the Hawke's Bay and the Wanganui coast sections and the thickness of Waitotaran in the Mauriceville section are approximate only. Consequently, though there is no doubt as to the existence of a major Waipipian-Waitotaran fluctuation, the values for its amplitude given above may be considerably in error. The evidence for the values of later amplitudes is much sounder, with particularly good control in the Te Ahitaitai–Huangarua, Eringa, and Wanganui coast sections. The successive decrease in amplitudes after the pre-Hautawan fall in sea level is probably significant.

Microcyclothems (Fiege, 1951) in the Eringa Cyclothem at Makara Stream (Fig. 3A) are small scale replicas of cyclothems. Their average depth of deposition decreases upwards, and they represent the regressive phase of the Eringa Cyclothem, unusually fully developed at Makara Stream. They are assumed to have resulted from small glacio-eustatic fluctuations superimposed on the main glacio-eustatic sea-level fall. Presumably only at Makara Stream were rates of down-drop and deposition balanced just right to record the small fluctuations so clearly.

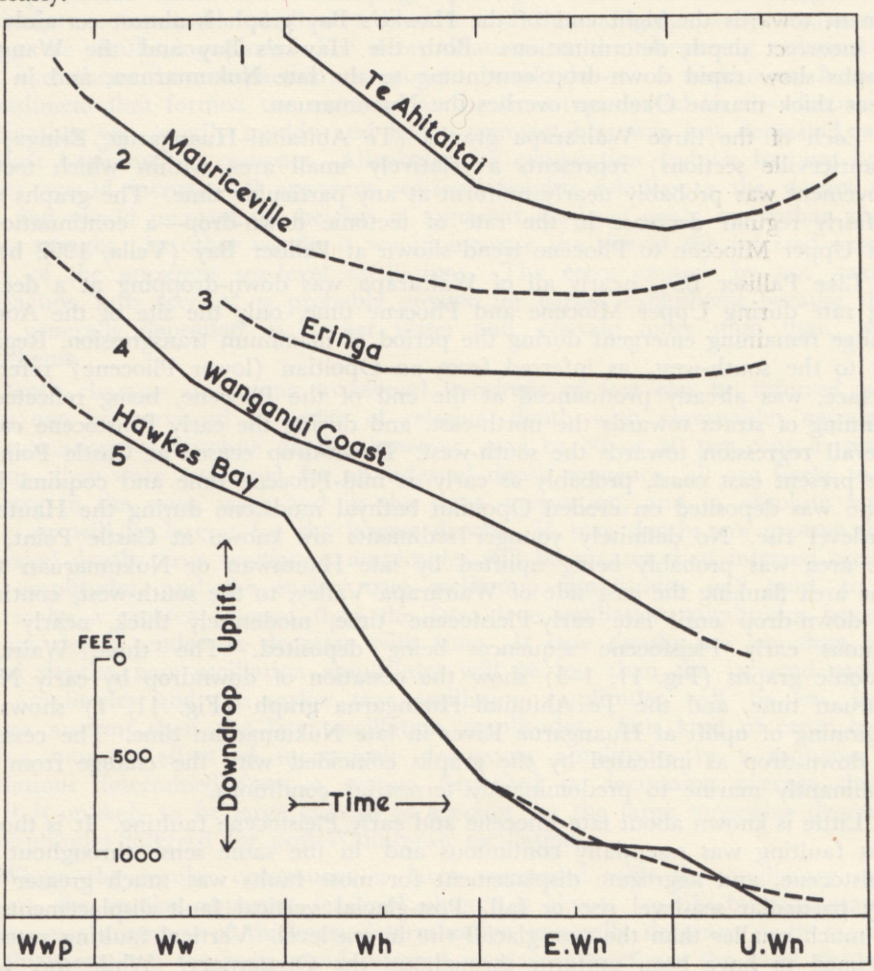

FIG. 11.—Graphs showing direction and rate of inferred vertical tectonic movements, derived by subtracting average oscillatory apparent change (Fig. 10, 6) from gross apparent sea-level change for each section. Broken lines indicate uncertainty.

Tectonic Movements

Secular apparent sea-level change differs from section to section and is assumed to represent vertical tectonic movement. The secular curves shown in Fig. 9 are probably partly in error because they have been constructed from a limited number of points. Long sections show a change in rate of vertical tectonic movement simply because one end of the section sank more rapidly than the other. Composite sections suffer from the same disadvantage, accentuated because they are likely to show discontinuities in the rate of vertical tectonic movement. The Hawke's Bay and Wanganui coast sections are composite, and the smooth curves shown in Fig. 9 are generalisations of the secular movement.

Graphs to show tectonic movement (Fig. 11) were reconstructed by subtracting average oscillation amplitudes (Fig. 10, 6) from the gross apparent sea-level changes. Assuming that the average values are the most nearly correct oscillation amplitudes, the graphs in Fig. 11 show tectonic movement plus most of the errors in determination of stratigraphic thicknesses and depths of deposition. The Wanganui and Hawke's Bay graphs, both derived from composite sections, are less regular than the three Wairarapa graphs. The residual oscillatory component towards the right end of the Hawke's Bay graph is almost certainly due to incorrect depth determinations. Both the Hawke's Bay and the Wanganui graphs show rapid down-drop continuing to the late Nukumaruan, and in both areas thick marine Okehuan overlies the Nukumaruan.

Each of the three Wairarapa graphs (Te Ahitaitai–Huangarua, Eringa, and Mauriceville sections) represents a relatively small area within which tectonic movement was probably nearly uniform at any particular time. The graphs show a fairly regular decrease in the rate of tectonic down-drop—a continuation of the Upper Miocene to Pliocene trend shown at Palliser Bay (Vella, 1962 b).

Like Palliser Bay, nearly all of Wairarapa was down-dropping at a decreasing rate during Upper Miocene and Pliocene time, only the site of the Aorangi Range remaining emergent during the period of maximum transgression. Regional tilt to the south-west, as inferred from an Opoitian (lower Pliocene) reference surface, was already pronounced at the end of the Pliocene, being reflected by thinning of strata towards the north-east, and during the early Pleistocene caused overall regression towards the south-west. Down-drop ceased at Castle Point, at the present east coast, probably as early as mid-Pliocene time and coquina limestone was deposited on eroded Opoitian bathyal mudstone during the Hautawan sea-level rise. No definitely younger sediments are known at Castle Point, and the area was probably being uplifted by late Hautawan or Nukumaruan time. The area flanking the east side of Wairarapa Valley, to the south-west, continued to down-drop until late early-Pleistocene time, moderately thick, nearly continuous early Pleistocene sequences being deposited. The three Wairarapa tectonic graphs (Fig. 11, 1–3) show the cessation of downdrop by early Nukumaruan time, and the Te Ahitaitai–Huangarua graph (Fig. 11, 1) shows the beginning of uplift at Huangarua River in late Nukumaruan time. The cessation of down-drop as indicated by the graphs coincided with the change from predominantly marine to predominantly terrestrial conditions.

Little is known about late Pliocene and early Pleistocene faulting. It is thought that faulting was essentially continuous and in the same sense throughout the Pleistocene, and aggregate displacement for most faults was much greater than any particular sea-level rise or fall. Post-glacial vertical fault displacements are all much smaller than the post-glacial rise in sea level. Vertical faulting rates are assumed to have been uniform throughout the Quaternary. While the whole region was sinking vertical faulting was probably differential down-drop and the topographic expression of the faults would be continuously smoothed off by differential deposition, or, in shallow waters, by differential submarine erosion, or by erosion on the upthrown side and deposition on the downthrown side. Probably depth differed generally by no more than a few feet across faults. Consequently there would be a difference in thickness but no difference in facies across a fault.

Tilting was continuous and in the same sense throughout the Quaternary. Both tilting and fault displacement are of considerable value for interpreting the Quaternary succession and are discussed at greater length by Vella (in press).

Assessment of Accuracy of Inferred Secular and Oscillatory Apparent Sea-level Changes

Datum for each gross apparent sea-level change curve is sea level at the time represented by the oldest unconformity in the section. Apparent sea-level change was determined at the base and at the deepening culmination of each cyclothem. For determinations at the base of a cyclothem the compaction component would generally be small because the most compactable sediments of the previous cyclothem would have been either removed by erosion or covered by coarse, relatively uncompactable shallow sediments and thus already partly compacted, during the shallowing phase. For determinations at the deepening culmination of a cyclothem the compaction component would be at a maximum, because the sediment that formed the sea floor at the time represented by the deepening culmination was usually muddy and hence compactable, was just deposited, and was just beginning to compact. Allowance for compaction (which has not been made) would increase all apparent sea-level heights relative to the datum sea level, but would increase the heights of apparent sea-level peaks more than those of the troughs. In other words, it would increase the size of the inferred amplitudes of the apparent sea-level oscillations. The error caused by not taking compaction into account is probably greater for earlier cyclothems because they were generally deposited in deeper water and contain more mud than later cyclothems.

Depth changes amounting to several hundreds of feet can be inferred, and facies can be arranged in order of relative depth with reasonable certainty. Determinations of absolute depths, however, may be 30 or 40 per cent in error. Because they were estimated for an inferred depth sequence, all are likely to be in error in the same sense and in the same proportion, and in absolute terms the error will be largest for the largest depths. If true depths are greater than estimated depths, true oscillation amplitudes will be greater than inferred oscillation amplitudes, and the earlier true oscillation amplitudes will tend to be greater by a greater amount than the later true oscillation amplitudes because average depth tended to decrease with time. If true depths are less than estimated depths, true oscillation amplitudes will be less than the inferred oscillation amplitudes and the earlier true oscillation amplitudes will be less by a greater amount than the later oscillation amplitudes. This kind of error could give a spurious effect of successively decreasing amplitudes in a sequence of oscillations determined from a section deposited in decreasing average depth, but it is unlikely to be large enough to account for the large successive decreases in amplitudes inferred for post-Waitotaran oscillations.

Where the secular component is large compared with the oscillatory component, the secular apparent sea-level change is shown mainly by stratigraphic thicknesses; accuracy of thickness determination generally decreases with increasing thickness, and the most rapid inferred secular changes are the most liable to error. Where the secular component is of the same order of magnitude as the oscillatory component a large part of the secular apparent sea-level change is inferred from depth determinations, and is subject to the errors in depth determinations.

Paleogeography

The distributions of coquina limestones and deeper-water sediments give directions of deepening and shapes of depressions and highs during Waitotaran, Hautawan and Early Nukumaruan times. Shorelines are difficult to determine because of scarcity of fresh-water deposits, but generally they can be inferred to be a few miles on the shallowing side of the limestone.

The limestones are partly detrital, but are mostly shell reefs. They are inferred to have formed in conditions similar to those now prevailing in Foveaux Strait (Fleming, 1952) in water little deeper than 100ft. In Hawke's Bay there are four main limestones, one in each of the cyclothems; in Wairarapa there are only three, no limestone occurring in the outcropping part of the Huangarua Cyclothem. In places limestone represents an entire cyclothem—Te Ahitaitai Limestone at Castle Point and at Mauriceville—and has evidently grown upward, keeping pace with apparent sea-level rise. Most well-defined cyclothems were

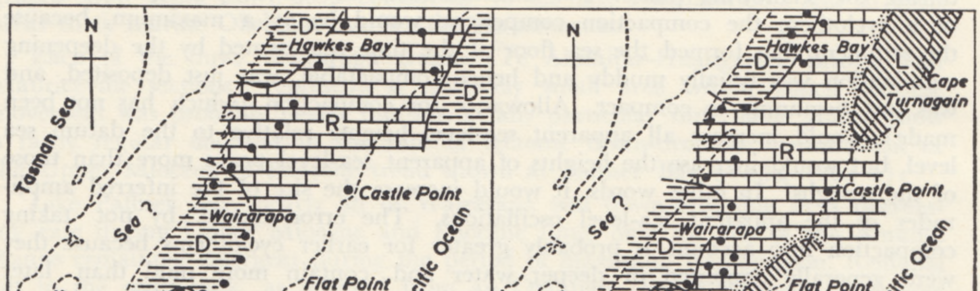

Fig. 12.—Paleogeography of Wairarapa and southern Hawke's Bay at early transgression phases (low but rising sea-level) near beginning of Waitotaran time, Hautawan time Early Nukumaruan time, and Late Nukumaruan time. D, relatively deep water; R, shallow water with shell reefs; L, land.

deposited seaward of the thick massive limestones. The whole of the outcropping part of the Huangarua Cyclothem (Late Nukumaruan), on the other hand, was deposited partly in very shallow water and partly above sea level, landward of the massive limestone zone.

Fig. 12 shows the distribution of shell reefs and the inferred shoreline slightly after the beginning of transgression for each of the four cyclothems representing the Waitotaran, Hautawan, and Nukumaruan in Wairarapa and Hawke's Bay. The Waitotaran limestone appears to have extended over nearly all of southern Hawke's Bay and northern Wairarapa, now outcropping extensively in the west from Ruamahanga River to Takapau, and in isolated outliers in the east, at Te Awaputahi Peak, south of Porangahau, and at Cape Turnagain, east of Pongaroa. Part of this region may have been an island; if not, it was a broad shallow bank, ranging from 100 to 200ft in depth, surrounded by deeper water. Absence of Waitotaran strata at Castle Point probably indicates submarine erosion that resulted from the pre-Hautawan fall of sea level. No Waitotaran or younger strata are known in the East Coast ranges south of Castle Point, but because this area rose above the sea a short time later it is inferred to have been shallow water and possibly already partly above sea level at the height of the Waitotaran transgression. In the far south the site of the Aorangi Range formed an island with fringing shell reefs. Water deepened south of Masterton and west of the present Aorangi Range.

In Wairarapa the two later limestones extend in broad arcuate belts concave to the south-west. The Hautawan limestone belt is offset to the south-west of the Waitotaran limestone, and the early Nukumaruan limestone belt is offset to the south-west of the Hautawan one. In southern Hawke's Bay the pattern of limestone outcrops is similar, with arcuate belts concave to the north-west, but is somewhat more complicated than in Wairarapa owing to overlap of the Early Nukumaruan on to Waitotaran at and north-east of Ormondville.

South of Eketahuna the Mount Bruce High marks an obscurely anticlinal structure transverse to the dominant north-north-east trend of the region. Post-Waitotaran strata do not outcrop on the Mount Bruce High. Except for the appearance of a thin basal conglomerate of greywacke pebbles at Mauriceville, the Hautawan limestone shows no change in facies approaching the high, and is believed to have been originally continuous from Wairarapa to Hawke's Bay. The Early Nukumaruan deposits, on the other hand, show considerable change in facies; the limestone belt lies well to the south of Mount Bruce and near-shore deposits represent the maximum transgression at Mauriceville. The Mount Bruce High almost certainly formed a west-north-west ridge which the Early Nukumaruan sea failed to cover and which from this time onward separated the Wairarapa basin from the Hawke's Bay and Wanganui basins. This separation accounts for marked differences between Wairarapa and Hawke's Bay Early Nukumaruan faunas.

CONCLUSIONS

New Zealand's thick early Pleistocene and Pliocene marine sequences were deposited in three main down-dropping areas: Wairarapa, Hawke's Bay, and Wanganui. Alternate shallowing and deepening of the seas, inferred to have been due to glacio-eustatic sea-level fluctuation, resulted in development of cyclothems in the shallower parts of the seas. Four inter-regional unconformities, inferred to represent low sea levels, are used with some help from fossils for inter-regional correlation of Waitotaran to late Nukumaruan sediments.

In the past the most useful fossils for inter-regional correlation were considered to be *Chalmys delicatula* for the Hautawan and *Pelicaria convexa* for the Nukumaruan. *Chlamys delicatula* indicates cool sea temperatures (Fleming,

1944) and *Pelicaria convexa,* which appears after the disappearance of *C. delicatula,* is inferred to indicate warmer sea temperatures. At the beginning of Hautawan time *Chlamys delicatula* invaded a sea which was continuous from Wairarapa to Wanganui. In Early Nukumaruan time the Wairarapa sea was isolated from the Hawke's Bay–Wanganui sea by rising land along the Mount Bruce transverse high. The Wairarapa sea was still cold and its fauna included *Chlamys delicatula* and the zone species *Pelicaria media,* which is not known outside Wairarapa. The Hawke's Bay–Wanganui sea, on the other hand, was warm during Early Nukumaruan time, and contained *Pelicaria convexa* in abundance, *Chlamys delicatula* having died out at the end of Hautawan time. The difference in temperature of the two seas in Early Nukumaruan time was almost certainly due to their being exposed to different ocean currents which were substantially similar to those of the present day. The Hawke's Bay–Wanganui sea was presumably warmed by the eastward-flowing Tasman Current, whose existence during the later Pleistocene is indicated by molluscs which migrated from Australia (Fleming, 1944). The Wairarapa sea was probably cooled by a forerunner of the northward-flowing Canterbury Current on the eastern side of the country.

In this view *Chlamys delicatula* became extinct in Hawke's Bay and Wanganui during a falling-sea-level phase, and post-glaciation warming could not have been the controlling factor. Indeed, nearly all stratigraphically useful faunal changes took place at cyclothem boundaries—i.e., between one cooling phase and the next warming phase. The controlling factor for the extinction of *Chlamys delicatula* was increase in water temperature due to paleogeographic changes. It is dangerous to infer detailed climatic changes from marine faunas. The Hautawan Stage, until now generally accepted to represent a glacial phase because of its cold-water molluscan fauna, probably represents not a uniformly cold period. but a major world-wide warming followed by a major world-wide cooling.

The boundaries of early Pleistocene marine stages in New Zealand comply with the ideal of Quaternary subdivision envisioned by Suggate 1960: 8) because they coincide with cooling culminations. These coolings represent the sum of coolings throughout the world, and should be distinguishable in marine and partly marine Quaternary deposits throughout the world. Major glacial and interglacial phases may be assumed to have coincided with eustatic sea-level changes, and consequently glacial phases are to be correlated with unconformities and shallow phases in cyclothem sequences.

The Ross glacial deposits of Westland (Gage, 1945) are generally correlated with the marine Hautawan Stage (Fleming, 1955: Gage and Suggate, 1958). They overlie marine strata which in the past were loosely dated as Waitotaran, the Waipipian and Opoitian stages being not recognised anywhere in Westland. Microfaunas recently collected from strata previously referred to the Waitotaran Stage, overlying the Kapitean Stage at Kapitea Creek, Westland, correlate with Opoitian microfaunas from Wairarapa. It is possible that the marine strata underlying the Ross glacial deposits are older than Waitotaran, and the Ross Glaciation may be older than Hautawan. There are at least three possible correlations for the Ross Glaciation, either with the pre-Waitotaran unconformity, or with the pre-Hautawan unconformity, or with the pre-Nukumaruan unconformity, the best provisional correlation, judging from the inferred amount of sea-level fall, being with the pre-Hautawan unconformity.

The possibility that the base of the Waitotaran is the base of the Quaternary must be considered because the inferred pre-Waitotaran fall in sea level indicates a considerable world-wide cooling and glacial advance. An important question, as yet unanswered, is whether the pre-Waitotaran cooling was the first major temperature fluctuation or whether significant temperature fluctuations took place in Pliocene and even in Miocene times. In Wairarapa nearly all pre-Waitotaran and some Waitotaran sediments were deposited too deep to record depth changes caused by glacio-eustatic sea-level fluctuations. New Zealand-wide major changes in foraminiferal faunas at the beginning of the Opoitian Stage (basal Pliocene) and at the beginning of the Waiauan Stage (late mid-Miocene) were probably caused by sudden large coolings, and the pre-Waitotaran cooling was probably not the first. Inferred sea-level fall and change in marine faunas both suggest that the pre-Hautawan cooling was exceptionally severe, and is most likely to be the correlative of the earliest glaciation easily recognised over extensive areas of the now temperate parts of the world—the Günz Glaciation in Europe and the Nebraskan Glaciation in North America. If this is true, the pre-Waitotaran sea-level fall may be the equivalent of the Donau Glaciation of Europe. It seems best to retain provisionally the correlation of the base of the Hautawan Stage with the base of the Quaternary, noting that this implies the occurrence of at least one significant glacial advance in Pliocene time.

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