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Paleontology and Paleoecology of Pakaurangi Point, Kaipara, New Zealand

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Abstract

DETAILED paleontological studies were carried out on the Lower Miocene (Otaian to Hutchinsonian) Waitemata rocks outcropping between Sandy Bay and Pakaurangi Point, on south-eastern Hukatere Peninsula, Kaipara, with the object of deducing the paleoecological and paleogeographic conditions existing during their deposition. Paleoecological studies indicate that the Pakaurangi Formation was deposited in a warm (23–27°C), agitated- or quiet-water, marine depositional environment. The depth of deposition varied between 20 and 250 metres. The Puketi Formation was rapidly deposited in shallow non-marine water and contains numerous erosional breaks with associated soil and lignite horizons. Paleogeographic considerations suggest a northerly source supplying detritus from pre-existing sediments and a westerly source for contemporaneous volcanic debris.

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INTRODUCTION

The stratigraphy and structure of the area from Sandy Bay to Pakaurangi Point on the south-eastern side of Hukatere Peninsula, in Kaipara Harbour, have been described by the writer (Jones, 1969). In that paper the Waitemata Group in the area has been divided into the Pakaurangi and Puketi formations.

(1) The fossiliferous Pakaurangi Formation consists dominantly of silty sandstones, with occasional "concretionary" limestone bands and andesite-derived hydroclastic grits. This formation has been subdivided into six distinct members (Waiteroa, Tapu, Hollands, Waipukua, Pakaurangi, and Funnel Members in ascending stratigraphic order), each of which has a distinctive lithology and fauna.

(2) The volcanic-derived Puketi Formation consists of a series of shallow-water andesitic and pumiceous tuffs overlying the andesitic Waititi Tuff Breccia and the Yellow Point Sandstone. The Pakaurangi *Miogypsina* Sandstone above the unconformity on Pakaurangi Point has also been included in the Puketi Formation on stratigraphical and petrological grounds.

This paper embodies the results of a detailed paleontological study of the six members of the Pakaurangi Formation, together with a more generalised study of the sparsely fossiliferous Puketi Formation. This is followed by a section giving paleoecological deductions of the conditions of deposition of the Waitemata Group in the Pakaurangi area.

PALEONTOLOGY OF THE WAITEMATA GROUP

Paleontological studies have been concentrated on the Pakaurangi Formation, where the large and extensive fauna has been studied in detail. The resulting faunal lists are given in Table I. Microfaunal identifications were undertaken by Mr G. H. Scott, N.Z. Geological Survey, and his results are given in Table II. Macro- and microfaunas were also obtained from the Pakaurangi *Miogypsina* Sandstone. Lignite seams in the Puketi Formation yielded a good microflora (Table IV), identified by Dr W. F. Harris, N.Z. Geological Survey, and also some identifiable leaf impressions and silicified wood.

Fossil locality numbers refer to New Zealand Fossil Record Sheet Numbers for Sheet N28 (Maungaturoto) of the N.Z.M.S. 1 series (see Appendix for locality grid references). The stratigraphic position of the fossil localities has been indicated previously by the writer (Jones, 1969, fig. 2).

Paleontology of the Pakaurangi Formation

The six members of the Pakaurangi Formation were all subdivided into smaller fossil localities on the basis of lithology and fossil content. The fauna of each of these localities was studied separately and relative specific abundances were noted.

Waiteroa Member

The Waiteroa Member has been subdivided into 12 localities. N28/849–853 represent the upwards succession of Waiteroa beds on the west side of Coates Bay, and N28/855–859 represent the same succession on the east side of Coates Bay. N28/860 and N28/861 represent the Waiteroa outcrops west and east of Hollands Point respectively. The relative abundance of the various faunal elements is given in Tables I, II, and III. (Tables I and II will be found at the end of the text.)

Rare corals occur scattered through most of the localities but they are only abundant in the Upper Waiteroa Shellbed on the east side of Coates Bay. Polyzoans are rare in N28/848–854 but common in N28/855–860—especially *Idmonea, Melicerita,* and *Salicornaria* (terminology follows Stoliczka, 1864). Dominant Foraminifera include *Amphistegina, Cibicides, Alabamina, Astrononion,* and *Nonionella.* The percentage of planktonic Foraminifers varies between 15 and 50. Brachiopods, especially terebratellids, are infrequent but widely scattered through the member. Gastropods are fairly abundant in this member, but most

TABLE III.—Relative faunal abundance within the Pakaurangi Formation.

FAUNA \ MEMBER	Waiteroa (lower)	Waiteroa (upper) Coates Bay	Waiteroa Shellbeds	Waiteroa (upper) Hollands Point	Tapu	Hollands (lower)	Hollands (upper)	Waipukua	Pakaurangi (lower)	Pakaurangi (middle)	Pakaurangi (upper)	Funnel
Distichopora	2	2	12	4	2	2	–	–	17	2	–	–
Oculina	2	4	6	6	2	7	8	–	6	2	2	–
Caryophyllia	–	–	–	6	–	45	26	–	11	–	–	–
Notocyathus	–	–	–	2	2	8	14	–	10	2	2	–
Flabellum	2	4	9	2	6	41	33	4	18	6	2	–
Truncate flabellids	2	4	30	4	2	24	8	2	6	2	–	–
Nucula	24	177	34	4	–	12	2	–	11	44	2	4
Jupiteria	4	2	4	28	2	1	5	–	54	10	9	6
Modiolus	–	–	12	–	2	2	23	–	–	–	–	–
Mesopeplum	10	4	11	8	6	50	23	35	25	2	2	–
Anomia	1	4	29	6	–	4	10	17	38	40	2	6
Crenostrea	–	–	12	–	–	–	–	–	–	–	2	2
Venericardia	1	2	8	50	4	26	38	7	65	16	4	21
Corbulids	4	25	10	108	34	71	29	8	220	59	16	6
Dentalium (heavy shell)	2	2	4	4	–	9	4	4	7	6	4	–
Dentalium (light shell)	6	2	3	28	3	3	4	–	37	41	16	4
Emarginula	–	–	–	–	2	8	–	–	15	6	–	2
Opella	–	2	2	15	2	12	38	–	5	–	–	–
Homalopoma	2	2	–	10	–	–	4	–	72	2	–	2
Zeacolpus	2	4	6	4	2	2	2	–	12	4	6	2
Pareora	178	4	2	580	2	2	2	–	804	14	5	2
Sigapatella	–	2	6	2	2	–	3	–	18	16	–	2
Taniella	–	–	–	4	–	–	1	2	7	59	2	2
Austrofusus	–	–	1	–	–	1	–	–	13	23	–	–
Hima	–	–	–	27	–	–	–	–	53	102	2	–
Baryspira (Spinaspira)	2	–	32	3	–	–	3	–	7	7	3	–
Cylichnania	6	–	2	18	–	6	6	4	78	174	12	2
Balcis	2	–	–	21	–	2	–	–	64	6	2	–
Echinocardium	–	–	–	–	–	–	–	–	2	10	4	3
Phyllacanthus	1	2	3	–	–	6	3	5	–	–	–	–

of them are restricted to N28/860–861. The following gastropods have a general distribution: *Opella, Zeacolpus, Pareora,* calyptraeids, naticids, cassidids, *Falsicolus,* and *Cylichnania. Maoricolpus, Struthiolaria, Cominella, Baryspira, Conus, Conolithus, Austrotoma, Bathytoma, Comitas,* and *Retusa* are most abundant in the Waiteroa Shellbeds, while trochids, *Homalopoma, Zaclys,* triphorids, architectonicids, *Kaiparathina, Balcis, Ellatrivia, Archierato, Zemitrella, Hima,* turrids, *Acteon, Ringicula, Eulimella, Vaginella,* and *Spiratella* are important faunal constituents in N28/860–861. Scaphopods are scattered throughout. Bivales are important members of the fauna and they can be grouped in a similar manner to the gastropods, although only a few (e.g., venerids and corbulids) are common throughout. Small taxodonts, lucinids, and mactrids are restricted in distribution to the finer-grained localities (i.e., not in N28/850, 852, 856, or 858). Heavy-shelled bivalves such as *Crenostrea, Eucrassatella, Chama, Glycymeris, Cucullaea, Venericardia, Lima, Barbatia, Anomia, Septifer,* and *Modiolus* are largely restricted to the Waiteroa Shellbeds. Thin-shelled bivalves, which are most abundant in N28/860–861, include *Ledella, Limopsis,* and *Ryenella.* Annelids are common in N28/860–861, while *Balanus* is common in the Waiteroa Shellbeds. Echinoderms include cidaroids and *Schizaster.* Otoliths occur in N28/850, 860, and 861.

Hornibrook (1952) has identified an ostracod fauna from locality F5730 (N28/861) in the upper Waiteroa Member. He has listed the following species: *Bradleya lactea pakaurangia* Hornibrook, *B. semiarata* Hornibrook, *Trachyleberis clavigera* (Brady), *Quadracythere* sp., *Loxoconcha australis* Brady, *Xestroleberis* sp., *Bairdia* sp., *Cytherelloidea* aff. *auricula* (Chapman), *Cytheresis finlayi* Hornibrook.

Hornibrook has described this fauna as a warm-water assemblage with Australian affinities.

In the Waiteroa Shellbeds oysters and *Eucrassatella* are commonly articulated and often show *Anomia* attachment scars. Most of the other bivalves are disarticulated and many of the gastropods show signs of abrasion. *Nucula* is often abundant in lenses in the silty parts of the Waiteroa Member, as also is *Pareora.* The very fossiliferous lens east of Hollands Point (N28/861) has a higher than average percentage of pelagic molluscs, including *Vaginella, Diacria, Spiratella,* and *Aturia.*

Tapu Member

The Tapu Member has only two fossil localities (N28/862–863) with identifiable faunas—they are lateral equivalents, one occurring on each side of Hollands Point. The localities are faunally similar and have a very restricted number of genera and most of the specimens are in a poor state of preservation. The relative abundance of major faunal elements is given in Table III.

The fauna contains a few widely scattered corals such as *Distichopora* and *Flabellum.* Polyzoans are typically of the more massive variety, i.e., *Melicerita, Spiroporina, and Salicorniaria.* Foraminifera are common in some horizons, and include *Amphistegina, Cibicides, Gyroidinoides,* and *Hoeglundina.* Planktonic Foraminifera constitute about 30 per cent of the total. Gastropods are very rare but include *Emarginula, Maurea, Opella, Zeacolpus, Pareora, Acrilla, Sigapatella, Etremopsis, Austrodrillia,* and *Baryspira.* Scaphopods are thin-shelled (e.g., *Dentalium nanum*). Bivalves are the most abundant faunal constituents and in addition to those listed in Table III include *Ledella, Arca, Glycymeris, Dimya, Chlamys, Lima, Chama, Kuia, Pitar, and Maorimactra.* Most of these bivalves are heavy-shelled, and the few light-shelled members are usually fragmented. The fauna also includes worm tubes and a fragment of *Schizaster.* The whole fauna is widely distributed throughout the respective localities, and hence no fossil associations could be recognised. Broken shell material occasionally occurs in thin gritty lenses (e.g., at N28/802350).

Hollands Member

The Hollands Member has been divided into six localities. N28/864, 867, and 868 represent laterally equivalent basal localities of the Hollands Member, while N28/865 and 866 represent higher laterally equivalent localities west of Pakaurangi Point and N28/869 represents the whole member east of the Point. The relative abundance of genera within these localities is given in Table III.

Corals form an important element in the fauna. They occur throughout the Hollands Member but are especially abundant in N28/866–868. Polyzoans, especially *Melicerita, Salicornaria,* and *Idmonea,* are well represented at all localities. The dominant Foraminifera are *Cibicides* and *Amphistegina,* and they constitute between 35 and 70 per cent of the total Foraminifera. Branchiopods occur at N28/867 and 869, with the latter containing several specimens of *Liothyrella.* Gastropods are not as abundant as bivalves, and their shells are usually heavy and almost unbroken. They include *Emarginula* and *Tugali* especially at N28/867; rare scattered *Maurea* and common *Opella;* minor scattered turritellids, naticids, *Cyclichnania,* and *Vaginella;* rare widely scattered *Serpulorbis, Stephopoma, Balcis badenia, Sigapatella, Archierato, Baryspira,* conids, and *Gemmula.* Scaphopods are heavy-shelled *Dentalium solidum* and *D.* cf. *zelandicum.* Bivalves are abundant, heavy-shelled, often disarticulated, and occasionally broken. In addition to those listed in Table III *Ledella, Barbatia, Cucullaea, Chlamys, Serripecten, Lima, Kuia,* and tellinids are locally quite common. Annelids and *Balanus* are common throughout. Heavy echinoderms are also quite abundant and include numerous cidaroid radioles, *Brissopsis,* and *Schizaster.* Rare otoliths are recorded at N28/869.

Faunal associations are not common in the Hollands Member, with the exception of worm tubes associated with heavy-shelled bivalves (e.g., *Glycymeris*), and polyzoans and smaller molluscs associated in very small lenses and patches of finer-grained sediment. *Modiolus* occurs in pockets within or overlying fine-grained calcite bands near the base of the member. This accounts for their relative abundance in N28/865. There is approximately 35 per cent of the shell material broken (dominantly bivalve) within this member.

Waipukua Member

The Waipukua Member has been subdivided into upper (N28/871) and lower (N28/870) localities. Both localities have essentially similar rich polyzoan and foraminiferal faunas, but the lower locality is characterised by bivalves, especially pectinids, while the upper locality has a progressively more abundant gastropod fauna towards its top. The relative abundance of genera from both localities is combined in Table III.

Corals form a very minor part of the fauna and include *Flabellum, Tethyocyathus,* and *Melithaea.* Polyzoans are extremely abundant and include massive colonies of *"Celleporaria", Retepora, Idmonea,* and *Entalophora.* Large Foraminifera form an important part of the fauna and include *Miogypsina, Heterostegina, Amphistegina,* and the *Cibicides temperata* group. Thirty per cent of the Foraminifera are planktonic. Gastropods are very rare especially towards the base of the member. They include *Crosseola, Zeacolpus, Taniella,* and *Cylichnania.* Scaphopods are heavy-shelled, e.g., *Dentalium solidum.* Bivalves are the dominant molluscs and in addition to those in Table III include *Cucullaea, Glycymeris, Lentipecten, Chlamys, Ostrea, Pinna, Pitar,* and *Kidderia.* The last three only occur near the top of N28/871.

In the Waipukua Member the fossils are generally randomly scattered and show no definite associations. However, many of the pectinid and ostreid valves are still articulated and show attachment areas of polyzoans and annelids. The glycymerids are also often articulated and show occasional worm-bored surfaces. The articulated *Pinna* valves are orientated perpendicular to the bedding, in their typical growth attitude. Broken shell material, other than fragmented slender polyzoans, is rare in this member.

Pakaurangi Member

The Pakaurangi Member has been subdivided into seven faunal localities. N28/873 and 879 represent the upwards sequence north of Pakaurangi Point, while N28/874–878 represent the same succession east-south-east of Waipukua Bay. The relative abundance of genera is given in Tables I and III.

Corals such as *Distichopora, Caryophyllia, Notocyathus,* and *Flabellum* are quite numerous in the basal portion of the Pakaurangi Member (N28/873–875).

Polyzoans are abundant in the basal localities but are fairly common throughout. Slender branching forms are the most common (e.g., *Idmonea*) but *Retepora* and *Salicornaria* are also abundant locally. Dominant Foraminifera include *Bolivina, Parrellina, Amphistegina, Cibicides, Alabamina, Anomalinoides, Gyroidinoides,* and *Hoelundina*. The percentage of pelagic Foraminifera varies between 30 and 55 per cent. Brachiopods occur in the basal localities and include *Liothyrella* and terebratuloids. Gastropods are most common and varied near the base of the member, where the largest and most diversified fauna is found. Gastropods which range through all the localities include *Fautor,* rissoids (especially *Rissoa* near the base), turritellids, *Pareora,* architectonicids, *Balcis,* naticids, eratoids, *Zemitrella, Baryspira, Acteon, Ringicula, Cylichnania,* and pyramidellids. The majority of remaining gastropods are restricted to the lower localities (N28/873–876)—e.g., *Emarginula, Homalopoma, Zaclys, Notosinister,* epitoniids, *Kaiparathina, Zeradina,* calyptraeids, cassidids, *Austrosassia, Chicoreus, Austrofusus, Hima,* mitrids, conids, turrids, cavolinids, and *Spiratella*. Scaphopods are common in all localities, e.g., *Cadulus* and *Dentalium*. Bivalves are less abundant than gastropods and are dominantly thin-shelled. Those occurring throughout all localities include nuculids, arcids, pectinids, limids, *Anomia, Ostrea, Venericardia, Varicardium*, venerids, tellinids, and corbulids. Some bivalves occur most abundantly at the base and top of the member, e.g., nuculanids, *Glycymeris,* and *Chama*. Limopsids, philobryids, mytilids, lucinids, and mactrids are most abundant in the basal localities, while carditids occur at the top. Teredinids, *Pholadomya,* and *Verticordia* characterise N28/876. Annelid tubes and rare otoliths occur throughout, while *Balanus* is restricted to the upper, and *Echinocardium* to the central portion of the sequence.

Most fossils within the Pakaurangi Member are widely distributed and show few associations. Most of the bivalves are in an articulated condition. Polyzoans often occur in pockets associated with pectinids and other large bivalves. Venerids typically occur in small lenses and some of the shells are broken. They are often associated with pyramidellids and *Cylichnania,* and the number of bored shells both in the lenses and scattered throughout all localities indicates that predation was active within the community. *Bankia* is always associated with intensively bored timber fragments, as is *Notocorbula*. Broken shell material is not a common feature within the Pakaurangi Member and is usually restricted to lenses of thin-shelled bivalves.

Funnel Member

The fossiliferous horizon N28/880 is confined to the central portion of the Funnel Member. A characteristic feature of this fauna is the presence of complete *Echinocardium* tests. The relative abundanace of genera is shown in Table III.

Corals are rare in this member, while slender branching polyzoans such as *Idmonea and Filisparsa* are abundant. Dominent Foraminifera include *Amphistegina, Cibicides temperata, C. mediocris, Elphidium,* and *Parrellina*. Planktonic Foraminifera are relatively rare (20 per cent total). Isolated gastropods occur scattered throughout the locality and include *Emarginula, Zeminolia, Conominolia, Homalopoma, Dardanula,* turritellids, *Pareora, Sigapatella, Ellatrivia, Taniella, Baryspira, Turbonilla, Scaphander, and Cylichnania*. Scaphopods are thin-shelled and include *Cadulus, Dentalium nanum,* and *Laevidentalium pareorense*. Thin-shelled bivalves are the dominant faunal elements and in addition to those listed in Table III include *Cuna, Mesopeplum, Pleuromeris, Kuia, Notocallista, Turria, Placamen, Myrtea, Tellinella,* and *Scalpomactra*. Worm tubes, including *Ditrupa,* and the echinoderm *Brissopsis* have also been recorded from this locality.

Faunal associations are rare within this member since most of the fauna is widely dispersed. However, pockets of articulated bivalves such as *Notocallista* are common. *Pareora* and *Cyclichnania* are often associated with *Echinocardium* tests, and *Notocorbula* is most frequently associated with carbonaceous material. *Venericardia* is small and thin-shelled in this member and occasionally occurs as articulated valves. Most of the remaining bivalves are disarticulated. The quantity of broken shell material in this member is small, although occasional lenses of it occur.

Paleontology of the Puketi Formation

Pakaurangi Miogypsina *Sandstone*

The Pakaurangi *Miogypsina* Sandstone, as its name implies, has a dominant foraminiferal fauna including *Miogypsina, Amphistegina, Cibicides temperata,* and *C. mediocris.* It has a very low percentage of planktonic Foraminifera (10 per cent) and no ostracod valves were seen. Fossils other than Foraminifera are rare and include "*Celleporaria*", *Dentalium solidum, Lentipecten, Mesopeplum* and *Notocorbula.* Most of the bivalves are complete but disarticulated.

Lignites of the Puketi Formation

Lignite bands in the Puketi Formation contain abundant leaf impressions, including sedges, grasses, and angiosperm leaves. The lignite also has a good microflora which was identified by Dr W. F. Harris (Table IV). Leaf impressions in muddy sediments overlying the unconformity between the Upper and Lower Puketi Pumiceous Grits were identified by R. H. Ward, Department of Botany, University of Auckland, and they include *Beilschmedia* cf. *taraire* (A. Cunn.) *B.* cf. *tawa* (A. Cunn.), *Geniostoma* cf. *ligustrifolium* A. Cunn., *Grizelinia* cf. *lucida* Forster, *Melicytus ramiflorus* J. R. and G. Forster, and *Rhipogonum* cf. *scandens* Forster. Transverse and longitudinal thin sections of silicified wood from the Upper Puketi Pumiceous Grit have allowed identification of a flora including rata, kauri, manuka, and totara, together with fragments resembling the modern taraire, maire, and a short-grained hardwood resembling teak or karri.

PALEOECOLOGY OF THE PAKAURANGI FORMATION

The paleoecological studies carried out can be subdivided into two major sections: (A) physical and chemical aspects of the environment of deposition, and (B) the nature and paleoecological implications of the faunal elements and communities.

Physical and Chemical Evironment

The nature of the physical and chemical environment determines the biota which it can support.

Nature of the Sediment

The sediments present within the Pakaurangi Formation can vary from andesitic grits to clean or muddy fine-grained sandstones—the latter being the most abundant.

Most beds in the Waiteroa, Waipukua, Pakaurangi, and Funnel Members are massive with indistinct bedding planes or have bedding marked by limestone bands. The generally massive nature of these silty sandstones may be a primary feature, indicating rapid continuous sedimentation, or it may be a secondary feature due to intensive reworking of the sediment by infaunal and marginal epifaunal organisms. The latter explanation is the more plausible and accounts for the mottled appearance of the beds as well as the presence of authigenic pyrite and glauconitic material, which form most abundantly in areas where the rate of deposition is slow.

The Tapu Member and the basal portion of the Funnel Member consist of fairly well-sorted sandstones with a high percentage of andesite grains. The Hollands Member consists of a succession of rather massive moderately-sorted andesitic grits. According to Vella (1962b) these sediment types are typical of the upper neritic zone (0–100m), where current velocities are sufficiently high to remove all fine material and to form occasional ripple marks, as in the Funnel Member.

TABLE IV.—Flora from a lignite seam in the Puketi Formation, N28/796348.

Species	Occurrence	Number Counted	Total
Lycopods			
Lycopodium billardieri Spring	Open clearing	1	
L. volubile Forst. f.	Shady clearing	+	1
Ferns			
Schizaea fistulosa Labill.	Clearings	+	
Trichomanes sp.	Forest	1	
Dicksonia squarrosa (Forst. f.) Swartz	Forest margin	1	
Cyathea dealbata (Forst. f.) Swartz } --	Forest	37	
C. smithii Hook. f. }			
Phymatodes diversifolium (Willd.) Pic. Ser.	Forest	17	
Arthropteris tenella (Forst. f.) Smith	Forest	+	
Pteridium aquilinum (L.) Kuhn	Forest clearing	35	
Histiopteris incisa (Thunb.) Smith	Forest clearing	1	
Pteris comans Forst. f.	Forest	1	
Asplenium shuttleworthianum Kunze	Forest clearing	2	
Blechnum sp.		5	
* Polypodisporites inangahuensis (Couper) Pot.		1	
* P. minimus (Couper) Pot.		+	
unidentified		1260	1361
Conifers			
Dacrydium cupressinum Lamb.	Forest	3	
Phyllocladus sp.	Forest	1	
Podocarpus dacrydioides A.Rich.	Forest	1	
P. spicatus R.Br. ex Mirbel }			
P. sp. totara type } ---	Forest	11	
P. sp. }			16
Dicotyledons			
Araliaceae	Scrub	2	
Nothofagus matauraensis Couper	Forest	2	
N. sp. fusca group	Forest	-	
N. spinosus (?)	Forest	1	
Myrsine sp.	2nd forest	1	
Coprosma sp.	2nd forest	1	
Elytranthe striatus Couper	Parasite	1	
Elaeocarpus sp.	Forest	7	
Ascarina sp.	2nd scrub	1	
Myriophyllum sp.	Water weed	+	
* Tetracolporites ixerboides (?) Couper		+	
* T. sphericus Couper		+	
Leptospermum scoparium Forst.	Scrub	2	
Metrosideros sp.	Coastal/Forest	24	
Myrtus sp.	2nd forest	14	57
Monocotyledons			
Hydrocotyle sp. cf. elongate A.Cunn.	Swamp margin	1	
Rhopalostylis sapida Wendl. & Drude	Open or forest	1	
* Palmae	Open or forest	7	
Cyperaceae	Sedges	13	
Gramineae	Grasses	2	23
Pollen Grains Incertae Sedis			
* Liliacidites waitunaensis Couper		2	
* L. sp.		1	
* Tricolpites alveolatus Couper		1	
* T. variexinus Couper		2	
* T. harrisii Couper		11	
* T. miniscculus McIntyre		1	
* T. cf. waitahuensis Couper		5	
unidentified		18	41
* = extinct species; + = species seen after completion of count.			1449

The sand–silt ratio thus varies considerably through the column, and this is directly reflected by the biota. Suspension feeders predominate on clean sandy substrates, while deposit feeders are largely confined to silty horizons and lenses.

Redox Potential of the Environment

The presence of abundant normal marine fossils and trace fossils indicates that the macro-environment was oxidising throughout the period of deposition, with the exception of the upper portion of the Funnel Member. The lack of fossils in the Tapu Member is probably a function of high velocity traction currents and the consequent rapid deposition of well-sorted sands, rather than due to a change in the redox potential of the macro-environment.

However, within the upper few centimetres of the freshly deposited sediment a reducing micro-environment probably existed, as is indicated by the presence of authigenic glauconitic material, pyrite, and other ferrous-ion compounds. The upper portion of the Funnel Member has no fauna and a high content of pyrite, free sulphur, and carbonaceous material, and this could indicate that the environment of deposition of these beds was a reducing one.

Salinity

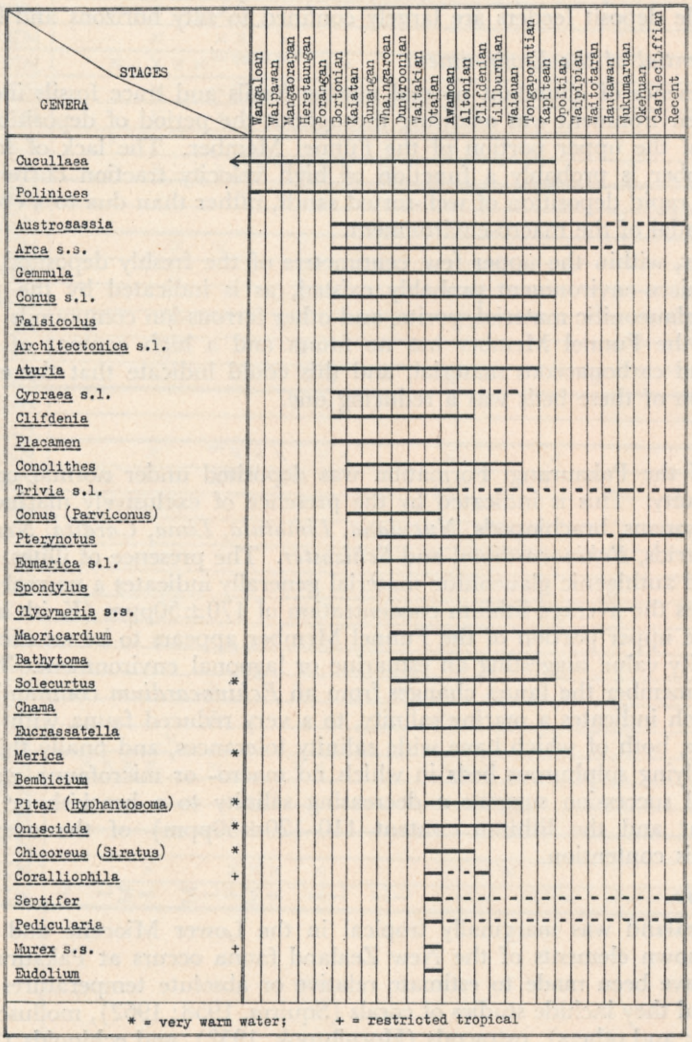
Most of the Pakaurangi Formation was deposited under normal conditions of marine salinity. This is indicated by the presence of exclusively marine organisms such as polyzoans, brachiopods, *Nuculana, Limatula, Lima, Cardita, Nemocardium, Zenatia,* turrids, *Echinocardium,* and *Schizaster.* The presence of illites, montmorillonoids, and authigenic glauconitic material generally indicates a normal marine salinity, as does the average lithium concentration of 170±50ppm (Keith and Degens, 1959). The upper portion of the Funnel Member appears to be an exception with a low salinity value suggesting an estuarine or lagoonal environment. Towards the top of this member the fauna changes from an *Echinocardium* community (Powell, 1937), which indicates a marine salinity, to a very reduced fauna with rare *Ostrea* and *Nucula,* both of which have wide salinity tolerances, and finally this gives way to the overlying sulphurous beds in which no macro- or microfauna was detected. This faunal succession suggests a decreasing salinity to a brackish or fresh-water environment and the lithium content 110–120±50ppm) of the overlying beds supports this contention.

Temperature

New Zealand was marginally tropical in the Lower Miocene and one of the warmest known elements of the New Zealand fauna occurs at Pakaurangi. Many attempts have been made to estimate relative or absolute temperatures during the Tertiary and they include studies of corals (Squires, 1958; 1962), molluscs (Fleming, 1953; 1962; and others), ostracods (Hornibrook, 1952), and echinoids (Fell, 1954).

Table V (after Beu, 1966) shows warm-water representatives of the New Zealand fauna that occur at Pakaurangi, together with their approximate time of migration to New Zealand. Beu has suggested that the numerous new records of tropical and subtropical genera in the Waitakian and Otaian indicate that water temperatures increased to marginal-tropical or even tropical. "The warm water genera *Murex, Merica, Hyphantosoma, Siratus, Oniscidia,* and *Septifer* appear for the first time and in general are short-ranging in New Zealand after the Otaian, and the warm-temperate to tropical genus *Eudolium* is known only from Pakaurangi Point" (Beu, 1966). Fleming (1962) has noted several subtropical forms from the Otaian, including *Spondylus, Coralliophila,* and conidae. Fell (1954) has noted that cidaroids, *Brissopsis,* and *Schizaster* are dominantly warm-water forms, while cidaroids with heavy radioles, such as *Phyllocanthus* and *Eucidaris,* are subtropical to tropical. Hornibrook (1952) has recorded the presence of shallow-water tropical Foraminifera, such as *Miogypsina* and *Heterostegina,* at Pakaurangi, and he has stated that the ostracod fauna indicates a subtropical sea temperature. The species

Table V.—Warm-water genera and their stratigraphic range (after Beu, 1966).



Trachyleberis clavigera and *Loxoconcha australis* are quite common in the Pakaurangi fauna and are at present restricted to areas of the North Queensland coast, New Caledonia, and the mid-Pacific islands. Stenothermal warm-water molluscs such as *Opella, Latirogona, Zeacuminia,* and many of the large pectinids, venerids, naticids, and volutids are endemic lower to middle Tertiary forms. Beu (1966) notes that . . . " The assemblage [at Pakaurangi] is by far the warmest known in New Zealand, but tropical genera are not abundant and the central tropical ornate Cymatiids, Cypraeids, Harpids, and Strombids are not known." Hermatypic corals are good temperature indicators, but only rare fragments are known from the Pakaurangi Formation in this area and in the coeval beds immediately south on Puketotara Peninsula (L. Carter, pers. comm.). They have also been recorded in strata of similar ages at Bushy Point, Hokianga, and Hicks Bay. Squires (1962) considers that the hermatypic genera (12) now known from the " Otaian " of Kaipara and Hokianga indicate that the reefs from which they were derived must have been of a substantial character. He has suggested that the assemblage can be correlated with the Capricorn Group, or more northerly assemblages, on the Great Barrier Reef, Queensland, where the mean annual temperature range is 19° to 28°C. The presence of detrital hermatypic corals and the lack of reefs probably merely indicates that such environments existed in shallower water and were either not preserved or are not exposed. Beu (1966) considers that the presence of hermatypic corals in the Otaian of Hicks Bay, East Cape, indicates that " . . . the 70°F (21°C) isotherm, a convenient biological boundary for the tropical zone, lay across New Zealand in about the vicinity of Rotorua during Otaian time." Ahermatypic corals also show relatively high temperatures, although they have much wider thermal tolerances, e.g., *Balanophyllia* 6.7–27°C, *Carophyllia* 3–26.5°C, *Flabellum* 1.5–27°C, and *Notocyathus* 9–24°C (Squires, 1958).

Oxygen isotope studies on planktonic and benthonic Foraminifera from the Hollands (N28/787) and Waipukua (N28/790) Members have been carried out by Mr I. E. Devereux, Institute of Nuclear Sciences, Lower Hutt. Ten samples from each member were analysed and gave consistent temperature results of planktonic 27±1°C and benthonic 25±1°C (pers. comm., 1966). Devereux considers that the results are reliable and has suggested that the sediment accumulated in a near-shore environment with little contamination from fresh water, i.e., with probable longshore currents.

Very recently published work on Tertiary paleotemperatures by Beu and Maxwell (1968), Devereux (1968), Hornibrook (1968), Keyes (1968), and Squires (1968) lends support to the contention that subtropical to tropical temperatures existed in Northland in the Otaian–Hutchinsonian. Beu and Maxwell have shown that in the Hutchinsonian there is a maximum number of Indo-Pacific Tertiary molluscan genera in New Zealand (32 per cent of the total molluscan fauna) and they have stated: " All molluscan evidence in Northland suggests that temperatures were marginally tropical from at least Bortonian to Waiauan times." On their graph of New Zealand Tertiary sea temperatures (1968, fig. 4) they indicate an Otaian–Hutchinsonian temperatures of 27°C for Northland.

Hornibrook (1968), in a study of the larger Foraminifera of New Zealand, concludes that their presence from Otaian–Hutchinsonian to Waiauan indicates a " fairly continuous warm climate, probably marginally tropical in Northland ". He concludes from the evidence of *Amphistegina* in Southland, allowing for a temperature difference of 5°C between the northern and southern extremities of New Zealand, that the minimum temperature at Wellington in the Otaian-Hutchinsonian would be 22½°C and the actual temperature was probably higher—an estimated 25°C. By extrapolating latitudinal temperature variations, Northland would have had a minimum temperature of 25°C and an estimated temperature of 27°C.

Scleractinian corals provide similar evidence (Keyes, 1968) of marginal tropical temperatures in the Otaian (25°–27°C). This is based on the presence of hermatypic corals, especially reef building genera such as *Porites* and *Turbinaria,* as well as warm-water ahermatypic corals. Keyes suggests that temperatures dropped again in the Hutchinsonian, but the presence of fragments of the hermatypic corals *Turbinaria* and *Plesiastrea* in the Pakaurangi Member on Puketotara Peninsula (Carter, 1967) indicates that temperatures remained relatively high during the Hutchinsonian and that the temperature peak is not as sharp as that shown by Keyes (fig. 1, p. 23).

Squires (1968) considers that coral reefs existed in Northland during the Otaian–Hutchinsonian and that the seasonal temperature range was probably 20° to 28°C. He concludes that the minimum near-shore temperature would be 20°C. This minimum temperature is supported by the oxygen-isotope studies of Devereux (1968). The minimum temperature that Devereux gives for Wellington in Otaian is 20°C and for Hutchinsonian 18°C—corresponding to minimum Northland temperatures of 22°C and 20°C respectively.

Considering the evidence just cited it would appear that the Otaian–Hutchinsonian temperatures in the Kaipara area can be more precisely defined. The minimum temperature of deposition would have been 20°C, and considering the evidence provided by the presence of *Amphistegina* the minimum temperature could be as high as 25°C. Maximum temperatures suggested are marginally tropical in the order of 27° to 28°C. Thus the most probable temperature of deposition of the Pakaurangi Formation would be in the range 23–27°C, which is in excellent agreement with the oxygen-isotope temperatures measured by Devereux (1967) on Pakaurangi material.

Biogenic Paleoecological Factors

Paleoecological deductions based on fossil assemblages cannot be fully comprehensive, since only a small portion of the community is preserved in the fossil record.

Foraminifera

The depth ranges of recent Foraminifera have received some detailed study over the past decade, and wide generic, and even specific, depth tolerances have been brought to light. Depth biofacies cannot be defined now by a single species but rather have to be based on an assemblage with the dominant genera or species recorded (Vella, 1966a). Examples of depth tolerances and abundances of Foraminifera recorded at Pakaurangi are as follows: miliolids are most abundant at depths of 0–50m, but may extend to depths of 200m; *Elphidium* is most abundant in the 6–60m zone but extends down to depths of more than 300m; *Heterostegina* and *Miogypsina* are mid- to upper-neritic forms that are usually anchored to seaweed and are largely restricted to " . . . shallow and warm marine environments " (Drooger, 1963); *Cibicides temperata* is abundant in most neritic environments, but may extend down to 1,000m; *Dyocibicides, Textularia, Cassidulina subglossa,* and *Discorbis* are most abundant above 55m, but their depth ranges extend down to below 300m; *Nonionella* and *Bulimina* are important forms in the 55–183m range; generally deep-water forms such as *Sphaeroidina bulloides* and *Pullenia quinqueloba* were recorded living at 90m outside Wellington Harbour (Hulme, 1964); other deep-water forms such as *Osangularia bengalensis, Cassidulina laevigata,* and *Loxostomum* have all been recorded sporadically from shallower depths. Depths of deposition may also be estimated by considering variance and dominance of genera and species (Table VI, after Walton, 1964), and relative abundance of pelagic Foraminifera (Phleger, 1960):

Percentage of Pelagics	*Depth (metres)*
0–10	0–60m
10–50	60–120m
50–75	120–1,000m

Apart from depth considerations, benthonic Foraminifera may also give an idea of bottom conditions at the time of deposition. The majority of abundant foraminiferal genera within the Pakaurangi Formation are typical sandy-bottom forms, e.g., *Bolivina, Bulimina, Cassidulina, Cibicides, Discorbis, Elphidium, Nonion,* and miliolids.

The Pakaurangi microfaunal assemblage is given in Table II, together with relative abundances of the species. A variability–dominance paleontological log is given in Table VI, and the depths recorded are those of highest probability as given by Walton (1964). The biofacies terminology follows Vella (1966a) and Kennett (1966).

The Waiteroa Member contains abundant *Cribroelphidium, Cibicides temperata, Cibicides* sp., *Dyocibicides, Nonionella,* and *Amphistegina,* which are characteristic forms of the *Elphidium* Biofacies (6–60m). The Tapu Member contains a somewhat similar microfauna but in addition to those listed above contains possible deep-water forms such as *Hoeglundina elegans* and *Robulus* sp. This, together with the decreased abundance of shallow-water forms, suggests that the Tapu Member was deposited in the Lower *Elphidium* or Upper *Haeuslerella* Biofacies, i.e., 50–200m.

TABLE VI.—Foraminifera variability-dominance paleontological log (after Walton, 1964).

MEMBER	FOSSIL record number N28/	VARIABILITY numbers of benthic species	DOMINANCE % abundance of dominant genera	DOMINANCE % abundance of dominant species	% PLANKTONICS	DEPTH after Walton (1964; p220)
PAKAURANGI MIOGYPSINA SANDSTONE	781	28	48A	48A	11	20 m.
FUNNEL	782	34	38A	16·5A	17	20-60 m.
PAKAURANGI	784	42	40C	22·5Ct	36	0-100 m.
	785	44	38C	24·5Ct	56	0-100 m.
	786	37	35C	18A	25·5	20-100 m.
WAIPUKUA	787	36	44C	33·5Ct	30	20-40 m.
	790	39	39C	36Ct	48	0-40 m.
HOLLANDS	788	56	24C	12Ct	65	50-100 m.
	789	41	39C	30·5Ct	35	0-100 m.
TAPU	791	41	50C	28·5Ct	32	20-100 m.
	792	32	40C	29·5Ct	27	20-40 m.
WAITEROA	793	39	41C	31·5Ct	52	0-40 m.
	795	36	32C	19·5Ce	15	40-100 m.

A = Amphistegina spp.; C = Cibicides spp.; Ct = Cibicides temperata; Ce = Cribroelphidium sp.

The Hollands Member has an anomalous foraminiferal depth-range when compared with the macrofaunal evidence of depth. This member contains high percentages of *Robulus* and *Bolivina,* and the most numerous occurrences of deep-water forms such as *Pullenia, Osangularia, Melonis, Hoeglundina,* and *Gyroidinoides.* These Foraminifera all point to a depth of deposition in the Lower *Haeuslerella* or *Karreriella* Biofacies (200–300m). However, this member also contains the highest percentage of miliolids and *Cassidulina subglossa,* as well as reasonably abundant *Cribrorotalia, Elphidium, Amphistegina,* and *Eponides,* all of which indicate shallow waters of the *Elphidium* Biofacies. This latter evidence, together with macrofaunal and sedimentary evidence, is taken to indicate the most probable depositional environment, i.e., 6–60m. The Waipukua Member has a dominantly shallow-water microfauna (*Elphidium* Biofacies, 6–60m) with, as dominant Foraminifera, *Cibicides temperata, Dyocibicides, Cassidulina subglossa, Cibicides mediocris, Amphistegina,* and *Miogypsina.* The basal portion of the Pakaurangi Member has a similar microfauna to the Waipukua Member, but higher in the Pakaurangi Member shallow-water forms become of minor importance and deeper-water forms such as *Gyroidinoides, Hoeglundina,* and *Bolivina* increase in importance. A point to note is that *Robulus* decreases in abundance in the Pakaurangi Member, suggesting that the species present are shallow-water forms. Foriminiferal evidence suggests that the water gradually deepened during the deposition of the Pakaurangi Member, starting in the *Elphidium* Biofacies (6–60m) and rapidly deepening to the Mid- or Lower *Haeuslerella* Biofacies (200–270m). This concept is supported by molluscan and other macrofaunal evidence. The Funnel Member also contains a shallow-water microfauna (*Elphidium* Biofacies, 6–60m) dominated by *Amphistegina, Cibicides, Elphidium* and *Dyocibicides.*

The Pakaurangi Formation, therefore, consists dominantly of a shallow-water *Elphidium* Biofacies, with an increased depth of deposition to Lower *Haeuslerella* Biofacies in the Pakaurangi Member.

Polyzoa

The great majority of living polyzoa inhabit normal-salinity marine environments in waters shallower than 200–400m. Various forms are adapted for environments varying from current-swept rocky or shelly substrates to quiet water. Polyzoans off the Rhone delta (Lagaaij and Goutier, 1965) have a wide temperature tolerance (i.e., from 10°C to 30°C) and are most abundant on relatively quiet bottoms, on silty and sandy marls. The number of polyzoans per unit area increases with a decrease in the rate of deposition, and they are most abundant in areas of slow deposition in the mid-neritic zone (40–100m).

Stach (1936) suggested grouping polyzoans according to their shape and structure, and hence generalised their required environmental conditions. The following types, after Stach with modifications suggested by Lagaaij and Goutier (1965), are found in the Pakaurangi Formation: (1) Membraniporiform (A): Zoarium usually but not necessarily unilamellar, encrusting a solid substrate. " This type is adapted for life in the littoral and sublittoral zones, . . . many forms extend into deeper waters, but are there numerically unimportant" (Stach, 1936). Most occur in areas with a low rate of deposition (Lagaaij and Goutier, 1965).

(2) Celleporiform: Zoecia heaped irregularly in a multilamellar mass of variable shape, usually encrusting on or around a flexible substrate. They are frequently associated with sessile marine plants and hence are especially abundant in the shallow inner neritic zone, where no active transport and resedimentation takes place. They are adapted for life in littoral and sublittoral zones and are numerically unimportant in deeper zones (Lagaaij and Goutier, 1965).

(3) Vinculariiform: Zoarium erect, rigid, firmly attached to a solid substrate by a calcareous base, and with dichotomous subcylindrical branches. They are an important faunal element, with their greatest abundance in deeper water, especially on calcareous sands below 50m. Stach (1936) has suggested that they are " adapted for life in deep or sheltered waters where wave action is absent and currents scarcely active. This group typifies growth in quiet waters ".

(4) Reteporiform: Zoarium erect, rigid, strongly calcified, fenestrate or reticulate, and firmly attached by a calcareous base. Stach (1936) has stated: " This

type is adapted for life in regions where wave action and currents are strong, these factors being overcome by the rigidity and fenestration of the colony. This type is most prolific in sublittoral regions".

Within the Pakaurangi Formation the bulk of polyzoans are of vinculariiform type although in the Hollands and Waipukua Members the other types are also relatively abundant. Hence polyzoan assemblages suggest that most of the Pakaurangi Formation was deposited in quiet and/or deeper waters with a slow rate of deposition. Depths of deposition cannot be determined accurately but are probably within the neritic zone between 50 and 300–400m. The scarcity of polyzoans in the Tapu Member and the basal portion of the Funnel Member is probably due to rapid deposition, while low salinities may account for the lack of Polyzoa in the upper portion of the Funnel Member. The Hollands Member contains membraniporiform (A), viniculariform, and numerous reteporiform types, suggesting that it was deposited in relatively shallow water with strong currents and/or turbulent conditions. The Waipukua Member contains all polyzoan types mentioned, and this suggests that it was deposited in relatively shallow quiet or intermittently turbulent water.

Mollusca

Mollusca are important members of the Pakaurangi Formation fauna but, apart from Marshall (1918) and Grant-Mackie (1965), very little has been mentioned about their ecology. Marshall (1918) concluded that the Pakaurangi Beds accumulated in " offshore waters . . . approaching a depth of 100 fathoms (180m) ". Grant-Mackie (1965) agreed that some of the beds accumulated at such depths but that a depth of 180m cannot be taken as applying to the whole marine sequence.

Information on the ecology of molluscs was obtained from numerous sources, including Dell (1952; 1956), Fleming (1953; 1962), Fretter and Graham (1962), Natland (1957), Nuno (1950), Parker and Curray (1956), Powell (1926; 1927; 1931; 1937; 1938), Thorson (1957), and Zenkevitch (1963).

(1) Waiteroa Member

The molluscan fauna in the silty sandstones of the Waiteroa Member is dominated by infaunal deposit-feeders such as *Nucula, Lincula, Venericardia,* and *Pareora.* This fauna suggests a quiet depositional environment at depths down to 500m, but probably in the upper portion of this range (0–200m). The community is similar to the " normal harbour community " described by Grace (1966) which contains a dominant *Nucula*-polychaete-*Chione* assemblage, *Nucula hartvigiana* being the dominant form present—*N. hartvigiana* is very similar in appearance, and possibly habitat, to *Nucula otamatea.* This community is typical of very shallow waters—shallower than 10m.

The Waiteroa Shellbeds have a distinct fauna with large heavy-shelled epifaunal suspension-feeding bivalves such as *Eucrassatella, Crenostrea,* and *Chama* forming the dominant biomass. Subdominants are also heavy-shelled and include *Notocorbula, Caryocorbula, Baryspira, Maoricolpus, Cominella, Austrotoma, Bathytoma,* and *Gemmula.* Conids have their greatest abundance and mitrids are also well represented within these shellbeds. Infaunal elements are rare (e.g., *Nucula* and *Pareora*). On the eastern side of Coates Bay corals, especially *Distichopora* and truncate flabellids, form an important part of the fauna. The molluscan fauna from these shellbeds suggests that they were deposited by strong currents in shallow water (0–70m). Some of the molluscan remains are worn and show that transportation and concentration of the fauna took place during deposition. However, the large bivalves are generally articulated, and have not been transported. These shellbeds probably were deposited on current-scoured shallow-marine banks. The community present in the Waiteroa Shellbeds is similar to the *Baryspira* community of Powell (1937), and is very similar to that of the Pepper Shellbed in the Wanganui area

(Fleming, 1953). Both these communities have been considered to be typical of shallow-marine (4–15m) turbulent environments.

The Waiteroa Member outcropping around Hollands Point has a richer and more varied fauna with dominants including *Pareora, Gemmula, Vaginella, Venericardia, Chlamys, Notocorbula,* and *Caryocorbula.* It is notable for the relatively high percentage of pelagic molluscs, including *Vaginella, Spiratella, Diacria,* and *Aturia,* which could suggest deeper water, and *Architectonica,* which is typical of warm shallow water (0–40m). However, the dominant infaunal assemblage is similar to the rest of the Waiteroa Member and suggests a similar, although slightly deeper (i.e., 50–300m), environment of deposition.

(2) Tapu Member

The Tapu Member has a very reduced molluscan fauna probably as a result of rapid deposition of these beds. The dominant mollusc present is *Notocorbula,* a shallow infaunal suspension-feeding organism, usually found in the finer portions of the member. Subdominant forms are largely epifaunal suspension-feeders such as *Mesopeplum, Septifer, Arca, Chlamys, Lima, Ostrea, Emarginula, Sigapatella,* etc., whilst several of the gastropods are herbivores, e.g., *Maurea* and *Opella.* This faunal assemblage is typical of high-energy environments where bottom conditions are sandy. Molluscan evidence gives little information as to depth of deposition except that it was probably less than 200m.

(3) Hollands Member

The Hollands Member contains a mixed infaunal (e.g., *Venericardia, Notocorbula,* and *Kuia*) and epifaunal (e.g., *Mesopeplum, Modiolus, Chama,* and *Opella*) assemblage associated with abundant corals, cidaroids, and barnacles in a coarse-grained andesitic sandy grit. The molluscs are dominantly heavy-shelled (e.g., *Cucullaea, Glycymeris, Serripecten,* and *Dentalium solidum*), and their association with *Serpulorbis, Stephopoma, Sigapatella, Archierato,* and *Conus* suggests the assemblage was deposited in a warm shallow-marine environment with current action winnowing out most of the fine sediment. The assemblage is somewhat similar to the *Flabellum–Notocorbula* community of Powell (1937), which was found on coarse-shell and fine-sand substrates at depths of 14–20m. The faunas are similar in dominant and subdominant genera, and the Hollands Member is similarly poor in microfaunal species.

(4) Waipukua Member

The basal portion of this member has a very restricted molluscan fauna of epifaunal suspension-feeders such as *Mesopeplum, Anomia, Lentipecten,* and *Chlamys.* This assemblage suggests that currents were reasonably active and bottom conditions unsuitable for infaunal organisms to exist in any quantity. Depth ranges of these fossils indicate that the sediment must have been laid down in seas shallower than 150m.

The upper portion of the Waipukua Member contains a more varied molluscan fauna with increasing quantities of infaunal bivalves such as *Venericardia, Notocorbula, Cucullaea, Glycymeris,* and *Pinna* towards the top of the member. Gastropods are also more numerous and include *Taniella* and *Cylichnania.* This molluscan assemblage indicates that conditions of deposition became quieter and less turbulent, thus allowing increased quantities of silt, clay, and organic detritus to be deposited with a consequent increase in numbers of infaunal deposit-feeders. The depth of deposition indicated by the molluscs is 4–150m.

(5) Pakaurangi Member

The Pakaurangi Member has the largest and most diverse molluscan fauna within the Pakaurangi Formation. The basal portion of the member grades from the shallow (4–150m) quiet-water sediments of the upper Waipukua Member to the deeper-water mid- and upper portions of the Pakaurangi Member. The lowest beds of the Pakaurangi Member contain infaunal and epifaunal molluscs, often heavy-shelled, e.g., *Cucullaea* and *Glycymeris*. *Pinna, Lentipecten, Notocorbula, Caryocorbula, Myrtea, Baryspira, Chama,* and *Architectonica* are also important elements of the fauna and suggest that the depth of deposition was not greater than 100–150m. The molluscs are dominantly suspension-feeders and this suggests that currents flowed through the area of deposition, removing much of the fine material. However, there was probably very little penecontemporaneous erosion, for most of the burrowing bivalves are still articulated and in their attitude of growth.

In the mid- and upper Pakaurangi Member the fauna loses most of the heavy-shelled bivalves and becomes more diversified, thus possibly indicating deposition in deeper water. The depth of deposition of this part of the member is doubtful because of conflicting evidence from shallow- and deep-water faunas. Marshall (1918) and Grant-Mackie (1965) consider that this member was deposited in water approximately 180m deep. This estimate is based largely on the abundance of turrids and the presence of supposedly deep-water forms such as *Arcoscalpellum*.

Factors pointing to a deep-water environment of deposition include the presence of ornate and light-shelled turrids, rissoids, cerithiids, triphorids, liotiids, scaphandrids, lucinids, and mactrids and the absence or rarity of mytilids and cidaroids. These fossils all point to depths of deposition between 200 and 400m, as does the presence of *Zetella* (150–400m), *Crosseola* (100–280m), *Lodderia* (100–400m), and *Sulconacca* (100–600m). However, many prominent molluscs indicate much shallower depths of deposition, and these include *Xenophora* (50–100m), *Trivia* (0–40m), eratoids (0–60m), *Oniscidia* (0–140m), cassidids (0–100m), *Murex* (0–100m), *Hima* (0–120m), and chitons (0–50m). It is interesting also to note that the majority of turrid genera have relatively shallow members extending up to 5–30m in tropical regions such as the Gulf of Mexico (Keen, 1958). This evidence suggests that deposition may have taken place in quiet shallow water (30–100m), but it must be noted that the majority of these restricted shallow-water genera are epifaunal and there is always the possibility that they may have been transported or that their depth ranges are insufficiently well known.

Hence it may be concluded from molluscan evidence that the depth of deposition was probably greater than 100m and less than 400m, with the highest probability between 150 and 250m.

The molluscan assemblage of the Pakaurangi Member is very similar to that of the Waipipi Formation, Wanganui (Fleming, 1953). However, the latter lacks minutiae or has not had them studied in any great detail. Fleming (1953) considered that the community indicated an environment of rapidly deposited soft-bottom sands and silts at depths of 10–40m; Powell (1931) considered that the same beds were deposited at " a distance from littoral communities in depths shallower than 25 fathoms (50m) ". These depth ranges now need modification because the depth ranges of many of the genera and species have been extended into considerably deeper water by workers such as Dell (1956). The Pakaurangi Member assemblage also shows similarities in the subdominant genera with Powell's (1937) shallow-water *Tawera–Venericardia* community and *Notocorbula–Pleuromeris* community.

(6) Funnel Member

The basal portion of this member contains almost no fauna except for rare oyster valves which appear to have been washed into the environment of deposition. This in itself could suggest a high-energy shallow-water near-shore depositional environment.

The central portion of the Funnel Member contains a high percentage of silt and was probably deposited in a quiet environment. This is reflected in the molluscan fauna by the dominance of infaunal deposit and suspension feeders, e.g., *Noto-*

callista, Venericardia, Notocorbula, Jupiteria, and *Dentalium.* With the exception of the supposedly deep-water genus *Scaphander* all the molluscs in this portion of the member indicate relatively shallow (0–100m) water. The assemblage is similar to the *Echinocardium* community described by Powell (1937) from the Manukau Harbour and the *Echinocardium*–scaphopod community described by Dell (1952) from Marlborough. Both are very similar soft-bottom silt and fine-sand biotopes with the same dominant infaunal elements that are represented in the Funnel Member. These communities are known to exist at all depths down to 50m, and they may extend still lower.

The upper portion of this fossiliferous sequence grades rapidly up into a thin band containing only *Ostrea* and *Notocorbula,* which suggest a shallow-water low-salinity environment. This in turn grades up into the overlying unfossiliferous carbonaceous and sulphurous silty sandstones of the upper portion of the Funnel Member. It may be suggested that these sediments were laid down in a brackish water or lagoonal environment, and this could account for the lack of fossils.

Echinodermata

Echinoderms are good indicators of temperature and normal marine salinity but generally have wide depth tolerances. The majority of echinoderms in the Pakaurangi Formation are warm-water Indo-Pacific genera with the exception of *Goniocidaris,* which originated in Australia (Fleming, 1962). Cidaroids are most abundant in the upper neritic zone on hard or current-scoured substrates, and this accounts for their relative abundance in the coarse-grained Hollands Member. However, *Goniocidaris* is an outer-shelf form and is most abundant in the Pakaurangi Member. Infaunal echinoderms such as *Schizaster, Brissopsis,* and *Echinocardium* inhabit silty sands and muds at all depths on the continental shelf. They are most abundant in the Pakaurangi and Funnel Members where the substrate is of a suitable type.

Coelenterata

The corals in the Pakaurangi Formation are dominantly ahermatypic and this suggests that the temperature was too low, the chemical environment was unsuitable, or the water was too deep for reef corals to become established. Corals occur throughout the Pakaurangi Formation (e.g., *Distichopora, Flabellum planus, Oculina,* and *Notocyathus*) although they are only abundant in the Hollands Member and the Waiteroa Shellbeds, where thick-shelled robust forms such as *Flabellum distinctum,* truncate flabellids, *Caryophyllia,* and *Tethocyathus* are dominant. Corals indicate fairly clean sandy or rocky bottom conditions, although the more robust forms preferentially occur in turbulent conditions or on current-scoured substrates. They do not provide any specific depth limits for sedimentation.

Arthropoda

Balanus is relatively common in the moderately sorted coarse-grained sediments of the Hollands Member and the Waiteroa Shellbeds, which were deposited in an agitated marine environment. They are typically found attached to large shells (e.g., *Crenostrea, Eucrassatella, Cominella,* and *Flabellum*) and to pebbles. *Lepas* and *Arcoscalpellum* are members of a group of almost exclusively bottom-living moderate-depth to deep-sea barnacles, and they are found only in the Pakaurangi Member. The presence of ostracods in the Waiteroa Member suggests that these sediments were deposited at less than 200m in subtropical waters (Hornibrook, 1952).

PALEOECOLOGY OF THE PUKETI FORMATION

Paleoecological deductions concerning the depositional environment of the Puketi Formation are hampered by the lack of fauna and by the limited number of floral identifications available.

The presence of sedimentary features such as laminated and cross-bedding, scour-and-fill structures, graded and reverse graded bedding suggests that the beds were largely deposited in a quiet and occasionally current-scoured aqueous medium. However, the presence of mud cracks, soil horizons, and associated lignite seams indicates that there were numerous environmental fluctuations between terrestrial and shallow-water. The cross-bedding and scour and fill structures may be of fluvial or deltaic origin. The lack of marine macro- and microfauna could be a function of very rapid deposition or it could indicate a non-marine, lagoonal, or brackish-water environment of deposition.

Rare faunal elements have been found in correlatives of the Puketi Formation at Tinopai (e.g., "*Ostrea*", Brothers, 1954) and on the west coast of Hukatere (i.e., the Bushy Point fauna). Hence part at least of the Puketi Formation was rapidly deposited in a shallow-marine environment.

The Yellow Point Sandstone at the base of the Puketi Formation dominantly has finely laminated bedding and only very rare Foraminifera (largely derived from older sediments). Lithium values are low (i.e., 110±50ppm), suggesting that the environment of deposition was brackish or fresh-water.

The abundance of lignite seams (*in situ*), consisting dominantly of sedges, grasses, and occasional angiosperm leaves and timber fragments, suggests that they were deposited in swampy conditions. Lignite seams are less abundant west of Tinopai and this, together with faunal evidence, suggests that the shoreline may have fluctuated between Tinopai and Morgans Point and that the area around Puketi Point was largely low-lying swamp land or lagoon.

A pollen analysis (Table IV), from the lignite seam at N28/796348, near the base of the Puketi Formation, contains a large flora dominated by broadleaf forest and forest-clearing species with a vast predominance of ferns (90 per cent). The climate suggested by this flora is similar to that of Northland today except that warm-temperate to subtropical species are more common, e.g., *Pteris comans, Asplenium shuttleworthianum, Schizaea fistulosa, Nothofagus brassi* group, *Ascarina, Tetracolporites inerboides,* and palms. The presence of palms suggests that the temperature may have been warmer than the present and this agrees well with the findings of Couper (1952) for floras of a similar age from Mangonui, Northland, containing *Cocus zelandicus*. Fleming (1962) considered that the podocarp–palm–fern assemblage of the lower Miocene suggests a marginal-tropical climate with abundant rainfall. *Lycopodium* is typical of poorly drained ground and the presence of *Metrosideros* (rata or pohutakawa), *Hydrocotyle, Myriophyllum, Rhopalostylis sapida* (nikau), Palmae, Cyperaceae, and Gramineae suggests that the lignite accumulated as a lowland swamp deposit with the addition of podocarp and fern pollen from an adjacent coastal broadleaf forest.

The Pakaurangi *Miogypsina* Sandstone was deposited in a shallow, near-shore marine environment. This is indicated by the presence of abundant *Miogypsina* and *Amphistegina* associated with *Dentalium solidum, Mesopeplum,* and massive celleporiform and reteporiform polyzoans. Imbrication of the *Miogypsina* and *Amphisegina* tests suggests that they could have accumulated as a beach or very-near-shore deposit, and this concept is supported by the transgressional onlap sequence shown on the underlying unconformity surface. The conglomerate at Hollands Point probably accumulated as a localised fluvial or deltaic deposit.

PALEOECOLOGICAL CONCLUSIONS

(A) The Pakaurangi Formation was deposited in an oxygenated marine environment of normal salinity with the exception of the uppermost beds of the Funnel Member, which were probably brackish-water or lagoonal deposits formed in a low-salinity, reducing environment. The depth of deposition of almost the whole formation was in moderately shallow water (6–100m) where current action was either marked or almost absent. An increase in the depth of deposition to 150–250m occurs in the Pakaurangi Member. Temperatures were warmer than at present and were probably subtropical to tropical, i.e., in the range 20°C to 27°C. This is suggested by the fauna and is supported by oxygen isotope studies.

(B) The Waiteroa Member was deposited in relatively shallow seas (*Elphidium* Biofacies, 6–60m) and contains a dominantly infaunal, deposit-feeding, muddy-bottom molluscan biotope. The Waiteroa Shellbeds were deposited in a more turbulent and current-scoured environment and contain both infaunal and epifaunal species, the latter predominating. The molluscan and foraminiferal faunas indicate warm-water depositional conditions in depths up to 100m.

(C) The Tapu Member is a poorly fossiliferous moderately-sorted sandstone which was probably rapidly deposited in depths less than 90m.

(D) The dominantly epifaunal, heavy-shelled macrofauna of the Hollands Member suggests that it was deposited in a relatively shallow (25–100m), turbulent or current-scoured warm-water environment. However, the microfauna attains its greatest diversity in this member (56 species), and contains numerous pelagics and *Robulus,* all of which suggest a deeper-water environment. This member also contains the highest percentages of miliolids, *Elphidium,* and *Amphistegina,* all of which indicate deposition in shallow waters. The most probable depth of deposition is in the *Elphidium* Biofacies, between 25m and 60m.

(E) Both macrofaunal and microfaunal evidence indicates that the Waipukua Member was deposited in warm, relatively quiet water at depths anywhere between 10m and 60m.

(F) The Pakaurangi Member has the largest and most diverse molluscan fauna, and it is the deepest-water member of the Pakaurangi Formation. The basal portion of this member shows a gradual change in fauna from the dominantly shallow-water, generically restricted biotope of the Waipukua Member to the more diverse fauna of the Pakaurangi Member. The abundance of turrids and other characteristic deep-water macro- and microfaunal elements in the mid- and upper portions of this member suggests that the beds were deposited at depths between 60m and 300m (*Haeuslerella* Biofacies) and probably largely in the deeper (150–250m) portion of this range.

(G) The lower and middle portions of the Funnel Member were deposited in shallow water (*Elphidium* Biofacies, 6–60m) high and low energy environments respectively. The upper portion of this member is probably a brackish or fresh-water deposit.

(H) The Puketi Formation was deposited in a dominantly non-marine terrestial and shallow-water environment, hence containing abundant lignite seams and virtually no marine fauna. The presence of palms in the flora suggests that the climate was warmer than at present and may have been marginally tropical. Faunal elements were recorded only from the Yellow Point Sandstone (very rare derived Foraminifera) and the Pakaurangi *Miogypsina* Sandstone (molluscs and abundant Foraminifera), which suggests that at least the latter member was deposited under near-shore shallow-marine conditions.

PALEOGEOGRAPHY

The Waitemata sediments in this and adjacent areas lie unconformably on, or in fault contact with, rocks of Landon and earlier Tertiary and Cretaceous age. It may be suggested that a Kaipara " basin " of Waitemata sedimentation transgressed from the south-west on to a north-eastern land mass during the upper Waitakian—the age of basal Waitemata rocks on Puketotara Peninsula (L. Carter, pers. comm., 1966). This shallow-water basin probably extended from Kaukapakapa in the south to Tokatoka or the Tangihua Ranges in the north, with its maximum present exposures on Okahukura, Puketotara, and Hukatere Peninsulas. Its southern extention from Kaukapakapa cannot be determined, although it may have extended south to join the main Auckland trough of sedimentation. Nor can its eastern limits be clearly defined, and the Kaipara basin probably represents a shallow-water facies deposited on the western side of the main Auckland–Bream Tail trough of deep-water Waitemata sedimentation. Its western limits were probably defined by the andesitic chain that extends from Waitakere to Tokatoka, which gave rise to the Manukau Breccia andesites. Its present northern limits extend from Bream Tail to Pahi and Tokatoka, but it possibly extended farther north to Hokianga, Parengarenga, and North Cape. However, the Otaian igneous massif of the Tangihua Ranges (Hughes, 1966) probably separated northern Northland from the Kaipara basin. The Kaipara basin was probably bordered to the north and north-east by a low-lying land mass of early Tertiary and Mesozoic sediments and a schistose and/or acid igneous terrain. Cross-bedding, ripple marks, and pebble imbrication all indicate that depositional currents flowed in a south to south-westerly direction. Derived Foraminifera indicate ages of the source sediments (identifications by G. H. Scott, N.Z. Geological Survey): *Rzehakina* (Mh–Dt) is a siliceous foraminifer which was probably derived from the Mangakahia Group; *Globorotalia crater* group (Dm–Dh) indicates that Dannevirke rocks were exposed in the source area—probably members of the Waiomio Group which are exposed at present in the area between Matakohe and Paparoa; *Globigerinapsis index* (Ab–Ak) is probably the commonest derived foraminifer in the Pakaurangi Formation and, together with abundant allochthonous glauconitic pellets, was probably derived from the Bortonian Pahi Greensand; *Rotaliatina sulcigera* (Ab–Lwh) may have also originated from the Pahi Greensand or it may have come from the Landon argillaceous limestones.

The lower Pakaurangi sediments (Waiteroa to Waipukua Members, uppermost Po to Ph age) are all dominantly of shallow-water origin with depths of deposition generally in the order of 0–100m. Penecontemporaneous erosion produced numerous small unconformities and may indicate slight changes in depth of deposition. This suggests that these members were laid down in relatively near-shore conditions and that, therefore, the shoreline could not have been very far distant to the north. The basin deepened rapidly in the Pakaurangi area during the deposition of the Pakaurangi Member (Ph to Pa age—based on the evolution of *Globigerinoides trilobus,* G. H. Scott, pers. comm., 1966). It is estimated to have reached a depth of 150–250m, indicating that transgression took place and that the shoreline consequently migrated farther from Pakaurangi Point. The depth of deposition then decreased again and reached 0–60m prior to the deposition of the uncomformably overlying Funnel Member. This suggests a regression of the sea with the shoreline again approaching the area of Pakaurangi Point during the time of deposition of the upper portion of the Funnel Member, which is probably a brackish-water or lagoonal deposit.

A major erosion break occurred after the deposition of the Funnel Member, indicating that regression continued and that the Pakaurangi area was exposed to subaerial erosion. This is represented by the marked unconformity on Pakaurangi Point and a less conspicuous one on Puketotara Peninsula (L. Carter, pers. comm., 1966). The Arapaoa Fault and associated smaller faults were probably active during this period of non-deposition and may have coincided with the start or renewal of andesitic volcanicity to the west. Faulting and consequent differential sliding and folding (see Jones, 1969) took place prior to the deposition of the Puketi Formation, since the latter is unaffeced by it.

The Puketi Formation is probably of Pa to Sa age and is a pumiceous phase of the Manakau Breccia deposition. As Arlidge (1955) has suggested, a chain of andesitic volcanoes was probably situated near the western edge of Hukatere Peninsula and extended north to Tokatoka and south at least to Manukau North Head. The Puketi Formation was probably deposited in the very shallow marine or non-marine lagoonal environment enclosed between this chain and the uplifted land

Text continued on page 174

TABLE I.—Macrofauna of the Pakaurangi Formation. Key to first noted occurence of species: L, Laws; P, Park; M, Marshall; F, Ferrar. Key to number of specimens recorded: X, 0-5; 1, 6-10; 2, 11-15; 3, 16-20; 4, 21-25; 5, 26-30; 6, 31-40; 7, 41-50; 8, 51-60; 9, more than 61.

MEMBER	GENERAL			WAITEROA															TAPU		HOLLANDS						WAIPUKUA		PAKAURANGI								FUNNEL
N28 SHEET FOSSIL NUMBER	N28/687	N28/846	N28/847	N28/687	N28/848	N28/849	N28/850	N28/851	N28/852	N28/853	N28/854	N28/855	N28/856	N28/857	N28/858	N28/859	N28/860	N28/861	N28/862	N28/863	N28/864	N28/865	N28/866	N28/867	N28/868	N28/869	N28/870	N28/871	N28/872	N28/873	N28/874	N28/875	N28/876	N28/877	N28/878	N28/879	N28/880
COELENTERATA																																					
Stylaster sp.																	×																				
Distichopora spp.		×			×	×	×		×		×				1	×	×	×		×				×					×	1	×	1	×				
Melithaea cf. hamiltoni (Tenison-Woods)					×													×									×			×							
Alcyonarians																	×	×											×	×						×	
Stylophora pistillata (Esper)	M																																				
Alveopora sp.				×																																	
Rhizangiidae (?Culicia/Cryptangia—D. F. Squires)																																	×				
Oculina virgosa Squires	M	×	×	×	×	×			×		×			×	×		1		×	×		×	1	×	×				1	×	×	×			×	×	
Tethocyathus paliscus Squires			1	×	×								×										×	1				×		×							
Caryophyllia japonica Marenzeller	M	×	4	×	×						×						×	×				×	3	6	2	×			×	2							
Stephanocyathus (Odontocyathus) mantelli Milne Edwards & Haime				×	×						×													×								×					
Notocyathus conicus (Alcock)			×	×													×		×			×	1	×	×				×	1					×		
N. euconicus Squires		×	1		×																		×	×	×					×			×				
N. (Paradeltocyathus) orientalis (Duncan)								×																													
?Idiotrochus n.sp. (—D.F.S.)																									×												
Kionotrochus (Cylindrophyllia) minima (Yabe & Eguchi)		×	×	×																			×						×	×							
Flabellum distinctum Milne Edwards & Haime	M	×	1	×	×		×				×			×	×		×		×	×		×	1	1	×				×	1	×	×			×		
F. planus Squires	F	×	8	×	×						×	×	×	×								×	3	4	1					×							
F. sp.		×	×																	×							×	×		×		×					
Flabellidae n.gen. et spp.	M	×	1	×	×						×	×	×		5	1	×	×	×				1	1	2		×		×	×		×	×				
Guyniidae (?Conosmilia—D.F.S.)																									×												
Balanophyllia (Balanophyllia) alta Tenison-Woods		×	×																							×			×			×					
Dendrophyllia sp.																		×												×							
?Turbinaria sp. (—D.F.S.)																									×												
POLYZOA																																					
Cellepora inermis Stoliczka																							×									×					
Celleporaria sp.		×																									×						×				
Cristina sp.																													×								
Entalophora haastiana Stoliczka		×										×		×			×		×			×		×	×	×	×	×	×	×		×				×	×
Eschara aucklandica Stoliczka																	×																				
Filisparsa orakeiensis Stoliczka																							×	×	×		×		×						×	×	
Flustrella denticulata Stoliczka																							×														
Idmonea giebeliana Stoliczka												×		×			×					×	×		×		×		×	×		×			×	×	×
I. inconstans Stoliczka																							×		×	×	×						×			×	×
I. radians (Lamarck)														×						×		×	×	×	×		×	×	×	×		×			×	×	×
I. serialis Stoliczka						×							×	×									×	×	×				×	×		×			×	×	
Melicerita augustiloba Busk		×												×	×	×	×		×	×		×	×	×	×				×			×					
Porina dieffenbachiana Stoliczka		×											×			×	×		×	×		×		×	×		×		×				×			×	
P. sp.													×		×		×			×			×										×				

Salicornaria marginata (Munster)		×												×	×	×	×		×	×		×		×	×	×	×	×	×	×		×	×		×	×	
Retepora bartrumi Brown																	×					×	×				×	×	×					×			
R. sp.		×														×								×	×								×				
"Retepora" spp.																×							×	×			×									×	
Semiescharipora porosa Stoliczka																	×							×													
Spiroporina vertebralis Stoliczka		×												×		×	×		×						×							×					
S.sp.																								×					×								
BRACHIOPODA																																					
Liothyrella sp.						×			×																	×			×								
cf. Waltonia							×																														
Terebratuloid					×							×						×						×		×			×	×							
MOLLUSCA																																					
BIVALVIA																																					
Solemya sp.																																		×			
Nucula otamatea Laws	L					3	×	9	4	9		×				×	×	×			2		×						×	×		1	6		×	1	×
N. n.sp.	L																																				
Linucula waiaotea (Laws)	L					×	×	1	1	×																			×	×			1				×
Saccella duplicarina (Laws)	L		×		×	×	×	×	×								×	×											×	×						×	
S. sp.		×																×												×						×	×
Jupiteria parleachi (Laws)	L	×				×		×	×								2	2	×						×	×			3	7	×				1	1	1
J. vadosa (Laws)	L					×			×								×	×												1							
Ledella pakaurangiensis Laws	L													×	×	×	2	2	×				×	×					5	9			×		1	2	×
L. n.sp.	L								×									×											×	×							
Ovaleda aucklandica (Marshall)	M																	×											×	×							
Cucullaea (Latiarca) n.sp. aff. australis (Hutton)	M	×	×				×				×				×		×					×		×	×		×	×	×	×	×	×					
C. sp.	L			×							×				×								×				×				×	×					
Arca n.sp.	L	×															1	1	×					×					3	4	×	×	×				
Barbatia mundeformata (Laws)	L	×															×	×						×					1	1							
B. cf. awamoana Finlay	L	×					×		×									×																			
B. sp.	M																									?									×		
Cratis ovata Marwick	L	×			×																								×	×							
C. sp.																	×													×							
Philobrya awamoana (Laws)	L																×																				
P. dupliradiata (Laws)	L																																				
P. zearanea (Laws)	L																	×																			
P. sp.																	?	×																			
Glycymeris (Glycymerita) marshalli Laws	L	×					×		×			×			×	×	×				×		×	×	×			×	×	×		×					×
G. (Grandaxinea) finlayi Laws	L	×	×	×	×				×		×		×		×			×											×				×			×	
G. (Glycymerula) n.sp.	L																					×															
G. sp.	P	×					×		×						×					×				×	×	×	×		×	×	×	×	×				×
Autrosarepta inusitata Laws	L																																				
A. obsoleta Laws	L																																				
Limopsis propeinvalida Laws	L																×	×											×	1					×		
L. sp.												×																		×							
Aulacomya n.sp.																														×							
Trichomusculus n.sp.	L																																				
Ryenella cf. impacta (Hermann)	L	×																×																			
Modiolus sp.													1		×					×		3	×	×		×			×								
Septifer torquatus (Marshall)	M	×	×						×		×	×							×	×				×	×				×	×							
Pinna cf. distans Hutton	P																											×	×		×				×		
Chlamys sp.	M	×		×		×	×					×		×			3	3	×	×		×		×		×	×	×	4	8			×			3	
Mesopeplum costatostriatum (Marshall)	M	×	×	×	×	×					×		×	×				×		×			×	×	2	×	2	×	2	×			×	×			
M. kaiparaense (Finlay)	M	×		×	×	1			×		×	×	×	×	×	×	×	×	×	×			2	4	2	×	3	×	3	1	×	1					×
Serripecten hutchinsoni (Hutton)	M			×											×							×	×	×	×	×			×		×						

MEMBER	GENERAL			WAITEROA															TAPU		HOLLANDS						WAIPUKUA		PAKAURANGI								FUNNEL
N28 SHEET FOSSIL NUMBER	N28/687	N28/846	N28/847	N28/687	N28/848	N28/849	N28/850	N28/851	N28/852	N28/853	N28/854	N28/855	N28/856	N28/857	N28/858	N28/859	N28/860	N28/861	N28/862	N28/863	N28/864	N28/865	N28/866	N28/867	N28/868	N28/869	N28/870	N28/871	N28/872	N28/873	N28/874	N28/875	N28/876	N28/877	N28/878	N28/879	N28/880
Lentipecten hochstetteri (Zittel)	L	×		×	×						×	×	×	×		×								×			1	×	2	1	1	1	1	×	3	×	×
Cyclochlamys shepherdi (Laws)	L																	×											×							×	
Ctenamussium vafer Marwick	L	×	×		×												3	1											2	5					×	×	
Parvamussium sp.																																	×				
Spondylus aucklandicus Marshall	L			×																									×								
Dimya kaiparaensis Laws	L	×			×												×	×	×					×						×							
Anomia poculifera Marshall	M	×	×		×	×	×	×	4						×	×	×	×					1	×	×		2	×	5	3	×	2	3		×	4	1
A. sp.		×	×	×																		×						×	×	×							
Monia n.sp.	L																																				
Lima colorata colorata Hutton	M	×		×		×						×	×				1	2		×	×	×	×	×	×				5	3		×	×	×		1	
L. sp.						×							×																×	×							
Limatula waiaotea Laws	L																×	×						×			×		×	×		×				×	
L.sp.																																×	×			×	
Mantellum sp.	L																×																				
Crassostrea nelsoniana (Zittel)	M																																				
Crenostrea wuellerstorfi (Zittel)	M																																				
C. gittosina (Powell & Bartrum)	F				×		×								2																			×			
Ostrea spp.	M	×			×	×	×	×	×	×	×	×	×			×	1	×	×		×	×	×		×	×	×		1	4		×	×		×	1	×
Chama cf. pittensis Marwick	L	×	×	×	×						×		×		×		1	×	×					×	×	×	×	×	3	2	×			×	×	×	
C. sp.	M				×																×				×				×	×							
Cuna kaipara Laws	L								×												×																×
Salaputium tinopaica Laws	L																																				
Spissatella n.sp.	L																																				
Eucrassatella ampla (Zittel)	M			×	×		1		2			×			1																						
E. sp.																														×							
Cardita kaiparaensis Laws	L																											×		?			?				
Venericardia subintermedia Suter	M	×		×		×					×		1	×	×		5	4	×	×		×	6	1	3		×	×	9	5	×	6	1	×	×	1	4
Pleuromeris instata Laws	L	×					×			×								×					×		×								×		×	×	×
P. otamateaensis Laws	L																																				
P. n.sp.	L										×																										
Divaricella (Divalucina) notocenica King								×	×	×																											
D. sp.	M					×										×																					
Gonimyrtea n.sp.	L																													×							
Myrtea cf. staminifera (Marwick)	L	×				×	×								×	×													×		2	×					×
M. sp.	L								×	?								×											×	×	×						
Pteromyrtea auriculata (Bartrum)	L					×		×		×																							×				
P. disparalis Laws	L					×		×																								×	×				
P. n.sp.A									×	×																			×			×	×				
P. n.sp.B																																	×				
P.sp.						×			×	×							×	×			×								×	×							
Thyasira sp.	M																																				

Diplodonta (Zemysina) n.sp.	L																																	×		
Arthritica ambotruncata Laws	L																																			
A. sp.																		×												×							
Myllitella sp.						×																															
Semeloidea cf. donaciformis Bartrum & Powell																																×					
Rochfortula brevitas Laws	L																																			×	
R. cf. kaawaensis Bartrum & Powell	L																																×				
Mysella apudalpha Laws	L																																			×	
M. sp.	L																													×							
Neolepton sanguineum (Hutton)	L	×								×																											
N. sp.	L						×																														
Costokidderia sp.														×				×																			
Kidderia otamatea Laws	L																													×						×	
K. sp.																												×									
Maoricardium sp.							?																								×						
Varicardium sp.	M			×										×	×		2	2				×	×	×		×			×	×	×		×	?	×	×	
Nemocardium (Pratulum) n.sp.	L																					×							×								
Turria cf pukeuriensis Marwick	L	×						×	×	×																							×				
T. n.sp.	L	×			×		×	×	×	×					×		1							×	×					×	×	1	×		×	×	×
Marama (Hina) pinguis Marwick	L																												×						×		
M. (H.) tumida (Marshall)	M	×	×	×	×													×											×	×							
Kuia macdowelli Marwick	M			×	×					×			×				×			×		×	1	3	×	×				×							×
Bassina sp.																	×	×											×	×							
Pitar (Hyphantosoma) sculpturata (Marshall)	L				×												×	×	×									×	×	1							
Notocallista (Fossacallista) parki (Marwick)	L	×		×				×		×				×			×	×				×		?					×	×		1	×			×	4
"Dosinia" sp.	M								×	×								×						×					×								
Eumarica kaawaensis Marwick	L																																				
Placamen morgani (Marwick)	L	×		×					×									×											×	×			×				×
Maorimactra sp.		×				×				×							×	×	×							×				×							
Scalpomactra cf biconvexa Powell & Bartrum						×	×	×										×											×				×				
S. cf. continua Finlay	L	×				×				×								×															×				×
Zenatia cf cretacea (Woods)																														×			×				
"Macoma" sp.	P																															×	×	×	×		
"Tellina" marshalli (Finlay)	L	×															×													2					×		
Peronidia inflata (Laws)	L				×																				×				×								
Tellinella ferrari Marwick	L			×														×							×				×	×		×					
T. cf. eugonia (Suter)	M	×																																			
T. sp.	L					×		×																×	×				×		×	×					×
Ascitellina cf. protensa Powell	L																																				
Solecurtus cf. bensoni Finlay	L																												×	×		×	×				
S. cf. chattonensis Finlay																																×					
Caryocorbula kaiparaensis (Suter)	M	×	×	×			1	×		1						×	×	×		×								×	1	×	×	1	×		×	×	
C. nitens (Marshall)	M	×	×		×	×				×	×			×			3	2	1	×	×		×	1		×	×		9	×	×	5	×	×	×		
Notocorbula illecta Laws	L	×		×	×		×	×				×		×			8	3	2	2		×	3	8	1			×	3	9	×	3	6		×	1	1
N. innerans Laws	L	×												×			×	×					×			×	×		×	8		×	×				
N. sp.					×					×						×		×					×	×	×			?		×	×		×	×			×
Hiatella cf. australis (Lamarck)	L																													×							
Panopea cf. worthingtoni Hutton	M				×				×									×							×				×	×							
Pholadidea n.sp.	L																									×				×			×				
Bankia aemula Laws	L																																1				
B. cupidia Laws	L																																×				
Teredinid tubes								×															×						×				×				
Pholadomya neozelanica Hutton																																	×				
Offadesma n.sp.	L																																		×		

MEMBER	GENERAL			WAITEROA															TAPU		HOLLANDS						WAIPUKUA		PAKAURANGI								FUNNEL
N28 SHEET FOSSIL NUMBER	N28/687	N28/846	N28/847	N28/687	N28/848	N28/849	N28/850	N28/851	N28/852	N28/853	N28/854	N28/855	N28/856	N28/857	N28/858	N28/859	N28/860	N28/861	N28/862	N28/863	N28/864	N28/865	N28/866	N28/867	N28/868	N28/869	N28/870	N28/871	N28/872	N28/873	N28/874	N28/875	N28/876	N28/877	N28/878	N28/879	N28/880
Thracia sp.						X																											X				
Verticordia cf. setosa Hedley	L																																X				
SCAPHOPODA																																					
Dentalium nanum Hutton						X											1	X	X					X	X				1	1	X	1	2		X	X	X
D. solidum Hutton	M	X		X			X					X			X			X					X	X	X		X	X	X	X	X	X	X	X		X	
D. cf. zelandicum Sowerby																	X						X	X					X					X	X		
D. sp.										X										X				X													
Laevidentalium ecostatum Kirk	M	X				X											X	X	X										X								
L. pareorense (Pilsbry & Sharp)	M	X				X		X	X									2											X	1		2	5		1	1	X
Cadulus zecaninus Laws	L					X		X	X	X							X	X						X					1	X		X	X		X	X	X
C. n.sp.	L																																				
GASTROPODA																																					
Scissurella condita Laws	L																																				
Anatoma miocenica (Laws)	L																X	X											2	6							
A. sp.																							X														
Schismope kaiparaensis Laws	L																	X																		X	
Emarginula kaiparica Laws	L	X																						X	X				1	1		X	X			X	
E. komitica Laws	L																							X					X	X		X				X	
E. sp.	L																		X					X					X								X
Tugali n.sp.	L							X							X																						
"Cellana" sp.												X																									
"Cantharidus" sp.																																	X				
"Micrelenchus" sp.																													?	?							
Maurea gracilis (Marshall)	M		X		X													X				X		X													
M. n.sp.	L	X		X	X																																
M. sp.		X																	X			X	X	X		X						X					
M. (Mauriella) cf suteri (Finlay)												X																					X				
N. gen. ? aff. Maurea																							X			X											
Fautor cf marwicki (Finlay)	L	X															X	X											X	X			X			X	
N. gen. aff Zethalia																							X						X				X				
Antisolarium tricarinatum Laws	L																																				
Conominolia aflexura Laws	L																												X				X				X
C. n.sp.	L	X																																			
C. sp.						X																															
Solariella (Zetela) hutchinsoniana (Laws)	L																	X					X						X	X							
S. (Z.) parvumbilicata (Laws)	L																	X											X	X							
Zeminolia ordo Laws	L																												X	X							X
Opella subfimbriata (Suter)	M		X	X	X		X				X			X			1	X	X		X	1	2	X	1	3			1	X							
Homalopoma (Argalista) aequor (Laws)	L																	X																			
H. (A.) kaiparaensis (Finlay)	L	X										X		X			1	X								X			3	9			X				X
H. (A). sp.																										X				X							

Lissotestella alpha (Laws)	L																																				
Lissotesta beta Laws	L																																				
L. n.sp.	L																																				
Lodderena anceps Laws	L																																				
Lodderia kaiparaensis Laws	L																																				
L. komitica Laws	L																												×								
L. supralevis Laws	L																											×									
Munditia proavita Laws	L																																				
Circonella amplector Laws	L																																			×	
Conjectura congrua Laws	L					×																						×	×								
C. n.sp.	L																																				
Crosseola sinemacula Laws	L																										×	×	×								
C. tenuisculpta Laws	L																																				
C. n.sp.	L																																				
C. sp.	L																							×					×								
Dolicrossea (?) atypica Laws	L																																				
D. clifdenensis Finlay	L	×																																			
Elachorbis n.sp.	L																														×						
Brookula endodonta Finlay	L																																				
Orbitestella praehinemoa Laws	L																												×								
O. praetoreuma Laws	L																×												×								
O. n.sp.	L																												×								
Bembicium sp.																																×					
Eatoniella (Dardanula) praecursor (Laws)	L																×												×								×
E. (D) sedicula (Laws)	L																											×	×								
E. (D.) subexcavata (Laws)	L																															×					
E. (D.) n.sp.	L																																				
Brookesena duplicincta Laws	L																																				
Epigrus pakaurangia Laws	L																																				
Ihungia aequalis Laws	L																																				
Estea asymmetrica Laws	L																																				
Rissoa (Haurakia) onerata (Laws)	L															×	1											×	1			×				×	
R. (H.) sodalis (Laws)	L															×													×								
Scrobs praeco Laws	L																																				
Scalaronoba pristina Laws	L																																				
"Notosetia" bucina Laws	L																																				
"N." epulata Laws	L																												×								
Veterator quadricincta (Marwick)	L																																				
Nobolira inflata Laws	L	×															×												×							×	
Merelina saginata Laws	L																×												×								
"Rissopsis" n.sp.A	L																																				
"R." n.sp.B	L																																				
Rissoidae n.gen. et sp.A	L																×																				
Rissoidae n.gen. et sp.B	L																																				
Nozeba perpava Laws	L																																				
Rissoina heterolira Laws	L																															×					
Zeacolpus aff. pukeuriensis Marwick	L							×														×						×	×			×					
Z. sp.	L	×	×		×	×			×	×					×		×	×	×					×				×	×	1		×	×		1		×
Maoricolpus aff. waitemataensis (Powell & Bartrum)	L	×					×		×				×		×									×					×	×	×	×		×		×	×
M. sp.	L	×									×				×	×													×								
Pareora pinguis Laws	L	×		×	1	9	×	×				×		×			9	9	×		×					×			9	9	×	×	1		×	1	×
Opimilda kaiparaensis (Laws)	L																											×	×								
Architectonica aucklandica (Marshall)	M																												×								

MEMBER	GENERAL			WAITEROA															TAPU		HOLLANDS						WAIPUKUA		PAKAURANGI								FUNNEL
N28 SHEET FOSSIL NUMBER	N28/687	N28/846	N28/847	N28/687	N28/848	N28/849	N28/850	N28/851	N28/852	N28/853	N28/854	N28/855	N28/856	N28/857	N28/858	N28/859	N28/860	N28/861	N28/862	N28/863	N28/864	N28/865	N28/866	N28/867	N28/868	N28/869	N28/870	N28/871	N28/872	N28/873	N28/874	N28/875	N28/876	N28/877	N28/878	N28/879	N28/880
Architectonica spinogula Laws	L																×	×											×								
A. sp.							×											×															×				
Spirolaxis cohaerentia Laws	L																												×								
Zerotula n.sp.	L																×	×															×				
Z. sp.																										×				×						×	
Serpulorbis cf. zelandicus (Quoy & Gaimard)	L																	×						×					×	×			×				
Stephopoma cf rosea (Quoy & Gaimard)																	×								×												
Caecum pertenuis Laws	L																																				
Pakaurangia zelandicus (Marshall)	M																												×								
Zebittium vicinum Laws	L																												?				?				
Ataxocerithium n.sp.	L																												×								
Socienna n.sp.	L																																				
Zaclys propria Laws	L																												×	×		×	×				
Z. violator Laws	L																													×		×					
Z. n.sp.	L																																				
Z. (Miopila) mucro Laws	L																	×												×			×				
Z. (M) simulator Laws	L																	×											×	×		×	×				
Z. sp.	L																×	×														×	×				
Notoseila clifdenensis Laws	L																																				
N. kaiparaensis Laws	L																									×			×								
Triphora neozelanica Laws	L																													×							?
T. zecollata Laws	L																	×																			
T. sp.																		×																			
Notosinister zespina Laws	L																×												×	×			×				
N. n.sp.A	L																	×															×				
N. n.sp.B	L																																				
N.sp.																		×																			
Acrilla kaiparaensis Laws	L	×																	×										×			×	×				
Pliciscala komitica Laws	L																												×								
P. sp.																								×													
Turriscala kaiparaensis Laws	L																	×																			
Cirsotrema firmatum Laws	L																																				
Epitonium sp.																		×																			
Clathroscala tricincta (Marshall)	M														?															×							
C. sp.																		×																			
Notacirsa cf. prisca (Suter)	P																	×												×			×				
Kaiparathina praecellens Laws	L																×	×					×						1	5							
Zeradina aculeata Laws	L																	×												1							
Z. costellata (Hutton)	L																																				
Z. n.sp. aff. costellata (Hutton)	L																																				
Z. (Naridista) esculenta Laws	L																												×								

Z. (N.) jocelynae Laws	L																																				
Z. (Radinista) exilis (Murdoch)																														×							
Z. (R.) vivienneae Laws	L																													×							
Z. sp.	L																																				
Fossaridae n.gen. et sp.	L																×																×				
Cerithioderma sp.	L																												?								
Dalliella neozelanica Laws	L																																				
Maoricrypta wilkensi Finlay	M																													×		×	×				
M.sp.		×			×									×															×			×	×				
Sigapatella novaezelandiae (Lesson)	M	×			×		×		×						×			×								×			×	×		1	1				×
S. otamatea Laws	L	×																											×	×		×	1				
S. sp.	P			×												×	×		×			×							×	×							
Xenophora n.sp.	L																																				
Struthiolaria cincta Hutton	M		×	×																									×	×							
S. cf. prior Finlay	L																																				
S. sp.							×								×														×								
"Cypraea" sp.	L	×													×																						
Trivia aequiflora Laws	L																																				
Ellatrivia kiaparaensis Laws	L	×															×	×												×		×	×				×
Pedicularia n.sp.	L																																				
Atlanta n.sp.	L																													×							
Archierato simulacrum Laws	L																×	×					×						×	×			×				
A. zepyrulata Laws	L																×	×											×	1			×			×	
A. sp.																						×															
Proterato (Cypraeerato) submorosa (Laws)	L	×					?																														
Eratopsis erro Laws	L																														×					×	
Hesperato zevitellina Laws	L																																×				
Tanea socia (Finlay)	M	×																							?				×			×					
Taniella notocenica (Finlay)	L	×			×												×	×					?					×	×	×		×	8		×	×	×
Proxiuber aff. australe (Hutton)	M																	×									×		×		×	×					
Magnatica cf. planispira (Suter)	L								×																												
Sulconacca suturalis (Hutton)	M	×					×				×						×							×					×	×	×	1	2		×		
S. vaughani (Marwick)	M	×		×							×							×					×						1	×			×				
Polinices cf. huttoni Ihering	M			×	×		×								×							×															
P. cf. oneroaensis Powell & Bartrum	M				×			×	×															×	?												
Echinophoria muricata (Hector)	M			×	×																									×		×	×				
E. n.sp.					×																					×				×		×					
E. sp.				×					×				×			×	×	×											×	×							
Galeodea senex (Hutton)	M																																×				
Xenogalea multisecta (Finlay)	M	×																																			
Oniscidea cf. finlayi Laws	L			×	×																											×					
Proxicharonia cf. clifdenensis (Finlay)	L																																				
Austrosassia procera Finlay	L																																				
A. zealta Laws	L	×		×	×												×													×			×				
Eudolium aoteanum Beu					×												×												?	×							
Coluzea sp.	L			×																																	
"Pterynotus" kaiparaensis Fleming	L																	×																			
Poirieria sp.	M			×																																	
Chicoreus (Siratus) komiticus (Suter)	M			×													×												×	×		×	×				
"Murex" n.sp.	L																												×								
Hexaplex n.sp.	L																																×				
Xymenella protocarinata Laws	L																																				
Terefundus n.sp. aff. quadricinctus (Suter)	L																																				
Typhis sp.	L				×																																

MEMBER	GENERAL			WAITEROA															TAPU		HOLLANDS						WAIPUKUA		PAKAURANGI								FUNNEL
N28 SHEET FOSSIL NUMBER	N28/687	N28/846	N28/847	N28/687	N28/848	N28/849	N28/850	N28/851	N28/852	N28/853	N28/854	N28/855	N28/856	N28/857	N28/858	N28/859	N28/860	N28/861	N28/862	N28/863	N28/864	N28/865	N28/866	N28/867	N28/868	N28/869	N28/870	N28/871	N28/872	N28/873	N28/874	N28/875	N28/876	N28/877	N28/878	N28/879	N28/880
Coralliophila turneri Laws	L																																				
C. kaiparaensis (Marshall)	M																																				
Anachis (Costoanachis) problematica Laws	L																																				
Zemitrella inconspicua (Marshall)	F	×			×												×	1											3	9	×	×	×			×	
Z. n.sp.	L																																				
Pyrenidae n. gen. et sp.	L																																				
Penion bartrumi (Laws)	L				×																																
P. parans (Finlay)	L																	×											×	×							
P.sp.																													×				?				
Austrofusus (Neocola) flexuosa (Marshall)	M	×																											×	1	×	×	4				
A. sp.	M						×																		×				×	×			×				
Cominella (Acominia) errata Finlay	M																																				
C. (Paracominia) machphersoni Marwick	F		×	×			×	×	×			×																									
C. sp.							×																														
Kaiparanura spiralis (Marshall)	F																																				
Hima (Mirua) seperabilis Laws	L	×			×												2	3											5	7	×	×	9	×			
Latirogona ornata (Marshall)	M																																				
Falsicolus corrugatus (Marshall)	M																																×				
F. kaiparaensis (Suter)	M	×		×	×						×						1	×						×					×	×		×	×				
F. sp.	M				×		?								?		×	×											×			×	×				
Fusinus n.sp.	L																																				
Austromitra sp.																													×								
Clifdenia turneri inflata Grant-Mackie																													×								
Diplomitra calcar (Marshall)	M																																				
D. masefieldi (Marshall)	M																												×	×		×					
D. nitens (Marshall)	M			×													×												×	×		×	×				
D. sp.																																×					
Uromitra neozelanica Laws	L																																				
Baryspira (Baryspira) sp.	M																																×				
B. (Spinaspira) cincta (Marshall)	M				×		4		×			×					×						×						×		×	×	×				
B. (S.) pakaurangiensis Olson	M								×			×			×								×						×		×	×	1		×		
B. (S.) spinigera (Marshall)	M	×		×			×				×				×		×												1						×		
B. sp.							×	1	3			×		×			×		×				×	×					×		×	1	×		×	×	×
Inglisella pukeuriensis (Suter)	M																																				
I. sp.	L																																				
Bonellitia ovalis (Marshall)	M																																				
Merica kaiparaensis Laws	L																																				
Zeadmete n.sp.	L																																				
Marginella (Kogomea) harrisi Cossmann	M																																				
M. (Glabella) conica Harris	M																																				
Conus armoricus Suter	M			×			×	×																					×								

C. (Parviconus) abruptus Marshall	M																×	×														×				
C. (P.) n.sp. aff. abruptus Marshall																														×						
C. sp.																		×					×						?							
Conolithes marshalli (Finlay)	M		×		×		×								×		×	×											×							
C. thorae (Finlay)	M																																			
Gemmula kaiparaensis (Marshall)	M	×			×												4	1					×	×					1	2			1			
G. lawsi Powell				×																																
G. ornata (Marshall)	M			×	×												×												×	×		×				
G. sp.																		×															×			
Bathytoma bartrumi Laws	L	×		×	×												×												1	×		×	×			
B. finlayi Laws	L																												×	×						
B. sp.	M																																		?	
Comitas kaipara Laws	L			×	×						×						×	×											×	×		×	×			
C. latiaxialis (Marshall)	M		×																											×						
C. sp.							×																	×					×	×						?
Zemacies climacota (Suter)	M	×																												×			×			
Z. ordinaria (Marshall)	M	×		×	×												×												×	×			×			×
Z. sp.																	×												?				×			
Austrotoma excavata (Suter)	M				×	×																	×						×	×						
A. kaiparaensis Powell		×							×																				×	×			×			
A. lawsi Powell					×																															
A. sp.							×																										?			
Inquisitor komiticus Laws	L	×			×						×						×												×	×		1	×			
I. sp.																													×				×	×		
Pseudoinquisitor n.sp.	L																															×				
Tomopleura transenna (Suter)	L																																			
T. n.sp. aff. clifdenica Powell																							×										×			
Microdrillia pakaurangia Powell				×																																
M. n. sp.	L																															?	×			
Austroclavus kaipara (Laws)	L	×															×	×											×	×		×	1			
A. nitens (Marshall)	M	×																											×			×	×			
A. tenuispiralis (Marshall)	M																		×										×							
A. sp.																		×																		
Mitrithara n.sp. A	L																																			
M. n.sp. B	L																																			
Neoguraleus (Fusiguraleus) sp.	L	×																																		
Liracraea dictyota (Hutton)	M																																			
Etremopsis disposita Laws	L																	×											×				×			
E. duospiralis Laws	L																	×											×	×						
E. imperfecta (Suter)	M																																			
E. sp.									?										×										?							
Anacithara axialis (Marshall)	M	×																											×				×			
Nepotilla bartrumi Laws	L																	×												×						
Rugobela tenuilirata (Suter)	M																																			
R. n.sp.	L	×																																		
Maoridaphne clifdenica (Laws)	L																																×			
M. kaiparica (Laws)	L																												×	×		×				
M. n.sp. A	L																												×	×						
M. n.sp. B	L																																			
M. sp.																														×						
Zeacuminia fluctuosa Laws	L																	×												×						
Z. orycta (Suter)	M																												×	×						
Z. n.sp.	L																													×						
Z. sp.																																	×			

MEMBER		GENERAL		WAITEROA															TAPU		HOLLANDS						WAIPUKUA		PAKAURANGI								FUNNEL
N28 SHEET FOSSIL NUMBER	N28/687	N28/846	N28/847	N28/687	N28/848	N28/849	N28/850	N28/851	N28/852	N28/853	N28/854	N28/855	N28/856	N28/857	N28/858	N28/859	N28/860	N28/861	N28/862	N28/863	N28/864	N28/865	N28/866	N28/867	N28/868	N28/869	N28/870	N28/871	N28/872	N28/873	N28/874	N28/875	N28/876	N28/877	N28/878	N28/879	N28/880
Leucotina granulocostata Laws	L																																				
L. sp.						×																															
Acteon otamateaensis Laws	L					×											×												×	×			×				
A. ovalis (Hutton)	M					×																								×							
A. procratericulatus Laws	L	×				×												×											×	×	×	×	×	×		×	
A. sp.							×																			×							×				
Crenilabium zealandicum Marshall	M																												×				×				
Ringicula zecorpulenta Laws	L					×		×	×								×	1								×			×	1	×	×	1	×	×	×	×
Cylichnania bartrumi Marwick	F	×															1	×										×	5	1		7	8	×	1	×	
C. enysi (Hutton)	M	×																×											×	×	×	×	2				
C. plana Laws	L	×			×												×	×					×	×				×	1	3	×	×	9	×		×	
C. sp.						×			×			×										×		×	×	×			×							×	×
Kaitoa recta Laws	L	×				×								×				×											×	3		×	×				
Scaphander komiticus Laws	L																	×											×	2		×	×			×	
S. sp.															×															×					×		×
Limulatys lacrimula (Laws)	L																												×	×							
Atys n.sp. A	L								×																					×							
A. n.sp. B						×																								×							
A. sp.						×		×										×			×									×							
Retusa n.sp. A	L					×																								×					×		
R. n.sp. B	L					×																											×				
R. sp.		×						×																							×						
Turbonilla awasimulans Laws	L																																×				
T. komitica Laws	L																	×															3				
T. separabilis Laws	L																																×				
T. cf. arcana Laws																					×			×													×
T. cf. awamoana Laws	L																																				×
T. cf. bexleyana Laws	L																																				
T. cf. natales Laws	L																																				
T. n.sp.A	L																																				
T. n.sp. B	L																																				
T. sp.										×																			×	×	×		×				
Chemnitzia brevisutura Laws	L																																				
C. granti Laws	L																																				
Pyrgolampros pakaurangiensis Laws	L																																				
Mormula locuples Laws	L																																				
M. tutamoensis Laws	L																																				
Syrnola cf. aclyformis Marwick	L																																				
Finlayola angulifera Laws	L																																				
Eulimella imitator Laws	L																×	×											×	×							
E. komitica Laws	L																	×																			

E. parlimbata Laws	L																	×											×				×			×	
E. waihoraensis (Marwick)	L																																				
E. n.sp.	L																																				
E. sp.																																				×	
Terelimella (?) pravitas Laws	L																																				
Graphis neozelanica Laws	L																																				
G. problanda Laws	L																																				
Odostomia n.sp.	L																																				
Pyrgulina n.sp. A	L																																				
P. n.sp. B	L																																				
N. gen. et sp. aff. Pyrgulina	L																																				
Evelynella cf. doliella Laws	L								×																												
Levipyrgulina n.sp.	L																																				
Linopyrga n.sp.	L																																				
Egila n.sp.	L																																				
Strombiformis aoteaensis (Marshall & Murdoch)	L	×																												×							
Balcis badenia Laws	L																×	1						×					×	5			×				
B. collator Laws	L																×													×			×				
B. kaiparaensis Laws	L	×																×											1	3							
B. lentocontracta Laws	L																																				
B. waikomitica Laws	L																×	×											×	1		×	×				
B. (Vitreolina) waiaotea Laws	L											×					×	×											×	1					×		
B. cf. christyi (Marwick)	L																																				
B. sp.																	×	×											×	×							
Niso sp.	L																																				
Melanella cf. patutahiensis Marwick	L																																				
Vaginella torpedo Marshall	M	×	×		×						×						2	1						×	×				×	2			×			?	
V. n. sp. A																	×													×							
V. n.sp. B																	×	×						×					×	×							
V. n.sp. C	L																×	×				×		×						×							
Diacria n.sp.			×														×												×	×							
Spiratella atypica Laws	L																	×																			
S. ferax Laws	L																×	3											×	2		×					
S. n.sp. A	L																	×																			
S. n.sp. B	L																																				
S. sp.																													×				×				
AMPHINEURA																																					
"Anthochiton" sp.																	×	×																			
"Amaurochiton" sp.																	×													×							
CEPHALOPODA																																					
Aturia cf. australis McCoy	F				×																									×							
ANNELIDA																																					
Ditrupa chapmani Finlay																	1	×											×	1					×		×
D. sp.																	×													×						×	×
Annelid tubes indet		×					×	×									×	×	×		×	×		×	×	×		×	×	×	×	×	×	×	×		
ARTHROPODA																																					
Arcoscalpellum distinctum Grant-Mackie		×																																		×	
Lepas aff. harringtoni Laws																							×						×								
Balanus (Balanus) amphitrite Darwin			×		×		×		×						×						×		1	×		×			×							×	
B. (Chirona) cf. zelandicus Withers							×																×														
B. (Megabalanus) sp.		×																																			
ECHINODERMATA																																					
Regular echinoderm indet			×																					×					×								
Goniocidaris hebe Fell																	×																				

MEMBER	GENERAL			WAITEROA														TAPU		HOLLANDS						WAIPUKUA		PAKAURANGI								FUNNEL
N28 SHEET FOSSIL NUMBER	N28/687	N28/846	N28/847	N28/687	N28/848	N28/849	N28/850	N28/851	N28/852	N28/853	N28/854	N28/855	N28/856	N28/857	N28/858	N28/859	N28/860	N28/861	N28/862	N28/863	N28/864	N28/865	N28/866	N28/867	N28/868	N28/869	N28/870	N28/871	N28/872	N28/873	N28/874	N28/875	N28/876	N28/877	N28/878	N28/879	N28/880
Goniocidaris sp.		×				×																			×				×								
Phyllocanthus aff. titan Fell		×	×									×	×	×									×	×	×		×	×									
P. sp.																								×				×									
Prionocidaris marshalli Fell						×												×								×			×								
Eucidaris sp.											×														×												
Schizaster sp.					×							×							×			×			×				×								
Brissopsis sp.			×									×											×						×					×			×
Echinocardium sp.																																×	1	×			×
BATOIDEA																																					
Myliobatus cf. arcuatus Davis																																×					
TELEOSTEI																																					
Mystriophis cf. obliquum Stinton																	×												×								
Otoliths indet							×										×	×								×				×					×	×	

TABLE II.—Benthic Forminifers of the Waitemata Group, Pakaurangi Point. (Identified by G. H. Scott, New Zealand Geological Survey, Lower Hutt).

MEMBERS	WAITEROA		TAPU		HOLLANDS			WAIPUKUA	PAKAURANGI			FUNNEL	P.Miogyp. Sst.
N28 SHEET FOSSIL NUMBERS	N28/795	N28/793	N28/792	N28/791	N28/788	N28/789	N28/790	N28/787	N28/786	N28/785	N28/784	N28/782	N28/781
Siphotextularia cf. awamoana Finlay		1			3					1		1	
Arenodosaria antipoda (Stache)				1	1							1	
Haeuslerella pukeuriensis Parr s.l.				1	1					2	1		
Textularia cf. subrhombica Stache		1				7	1	1					
Martinottiella communis d'Orb.					1								
Gaudryina convexa (Karrer)		1				3	4						
G. sp.						1							
Quinqueloculina sp. A.											4		
Q. sp. B										2			
Q. sp. C		3					1						
Q. sp. D						2							
Scutuloris?						3							
Pyrgo sp.						1							
Robulus cultratus Montfort		1	4	10	2	10			6	3		1	2
R. loculosus (Stache)		1	1	2									1
R. sp. A					2	9	5						
R. sp. B			1	1	1								
R. sp. C					1								
R. sp. D		2							2		1		
R. sp. E							1	7					
R. sp. F				2	2								
R. sp. G							4						
Saracenaria sp.									1				
Vaginulinopsis sp.													2
Vaginulina elegans d'Orb.				4	1								
V. sp. A				2			1						
V. sp. B										1			1
Amphicoryna scalaris (Batsch)			2						1		2		1
Fissurina?												1	
Glandulina symmetrica Stache											1		
Dentalina?											1		
Stilostomella verneuilii (d'Orb.)				5	1	2		4	1	1			
Nodosaria substrigata Stache								1					
Astacolus sp. A					1								
A. sp. B						1							
Marginulina sp. A				1									
M. sp. B					1								
Sigmoidella kagaensis Cushman & Ozawa							4						
S. sp.	1	4	2		1				2		1		6
Globulina sp.										1			
Guttulina sp. A					1					1			
G. sp. B						1							
Lagena sp.					1								
Sphaeroidina bulloides d'Orb.	2	2	2	1	6	3		1	2	3	2		
Bolivina anastomosa Finlay		6	1	2	7	3	3	1	1	9	9	5	1
B. plicatella Cushman?	1						1						
Baggatella?					1								
Reusella sp.	3	1		1			2	3	3	1	3	5	1
Brizalina finlayi (Hornibrook)	2				1				1				1
B. lapsus (Finlay)		1		1	1		3			3			
B. mahoenuica (Hornibrook)	2												
Loxostomum pakaurangiensis Hornibrook											1	1	
Pavonina aff. triformis Parr	1								1			1	
Siphouvigerina sp.	1												
Uvigerina miozea Finlay s.l.		3		1	7	1	2	2		4	2	1	

MEMBERS	WAITEROA		TAPU		HOLLANDS			WAIPUKUA	PAKAURANGI			FUNNEL	P.Miogyp. Sst.
N28 SHEET FOSSIL NUMBERS	N28/795	N28/793	N28/792	N28/791	N28/788	N28/789	N28/790	N28/787	N28/786	N28/785	N28/784	N28/782	N28/781
Bulimina pupula Stache	1	1		5	6	1		1	5	4	1		
Trifarina bradyi Cushman s.l.	2			1	6	2		3		2	5	5	
Buliminella?								1					
Rectobolivina maoriella Finlay				1									
Rectuvigerina rerensis Finlay?			1										
Neoconorbina sp. A	1	1			2	1		1	2	2			
N. sp. B												3	
N. ?	3							1					1
Discorbinella scopos (Finlay)			1	3	4	2		2		2	1	1	
D. bertheleti (d'Orb.)	2			1	2		1						
D.?					1								
Baggina ampla (Finlay)	1	1			1				3	1			
Eoepidonella?	1				2					1			
Discorbis balcombensis Chap., Parr & Collins	2	9			1	7	1	4					
Bueningia creeki Finlay				3	2		1			2	1	1	
Glabratella crassa Dorreen	1												
Cribrorotalia sp.	1	10		5	2	3	3			6		2	2
Elphidium sp. A	1		9				2	4	1		1	3	4
E. sp. B											1		
"E. ornatissimum"	1	1	6		2	1	2	3	3		4	12	7
Parrellina sp. A.	1	3	4						8	2	6	12	1
P. sp. B			1						1		1	1	
Cribrononion sp.	38				8				2	2	1	3	2
Notorotalia n.sp.		6	4				2						
Miogypsina sp.		2						7					11
Amphistegina sp.	13	18	44	17	3	8	10	9	36	13	8	34	96
Eponides broeckhianus (Karrer)			1										
E. repandus (Fichtel & Moll)		1		1	1	5	2	3					
Victoriella conoidea (Rutten)						1							
Planorbulinella zelandica Finlay		1	1				1	4		1			2
Cibicides mediocris Finlay	20	1	12	1	10	5	10	13	31	16	21	23	27
C. notocenicus Dorreen	3	1					1					17	
C. novozelandicus (Karrer)						1							
C. perforatus (Karrer)		5	3	2	2		2	1		2	1	2	
C. refulgens Montfort		7		1	8	10	12	6	2	2	3		
C. temperata Vella s.l.	3	63	59	57	24	61	70	67	26	48	45	26	17
C. cf. vortex Dorreen	28	1	4	1	2	1	4		7	7	3	11	3
C. sp. A	16		3					1	4	3	8	3	2
C. sp. B							1	1	1			1	
C. sp. C												4	
C. sp. D	1	4			2								
Dyocibicides s.l.	16		7	5	19	2	1	18	21	6	24	3	
Pullenia bulloides (d'Orb.)				1									
P. quinqueloba (Reuss)				1	2								
gen. indet.						1							
Heterostegina sp.								1					
Cassidulina laevigata d' Orb.		4		2	6	2	3			5	1		
C. sp.					2								
Globocassidulina sp.		5	3			7	8	14	4	3	1	1	2
Cassidulinoides orientalis (Cushman)											1		
Ehrenbergina sp.									1	1			
Karreria sp.		3					8				1		
Gyroidinoides prominula (Stache)		2	3		4	1				5	5		
G. zelandica Finlay	3	6	2	11	4	13	6	6	2	8	3	3	
Melonis maoricum (Stache)	1	1			1	1	1						

MEMBERS	WAITEROA		TAPU		HOLLANDS			WAIPUKUA	PAKAURANGI			FUNNEL	P.Miogyp. Sst.
N28 SHEET FOSSIL NUMBERS	N28/795	N28/793	N28/792	N28/791	N28/788	N28/789	N28/790	N28/787	N28/786	N28/785	N28/784	N28/782	N28/781
Melonis cf. dorreeni (Hornibrook)			2			1			1				1
M. ?													1
Alabamina tenuimarginata Chap. Parr & Collins		11	3	5	3	9	5	3	4	9	5	7	1
Astrononion parki Hornibrook s.l.	8	2	2	1	7			2	3	3	1	1	
Anomalinoides fasciatus (Stache)								1					1
A. macraglabra (Finlay) ?	1	3	2	1	8	4	2	3	4	6	8	3	
Cribrononion aoteanum (Vella) ?	2												
Nonion cassidulinoides Hornibrook					1						1		
Nonionella novozealndica Cushman	21									2			
Cerobertina mahoenuica Finlay	1		1	2	1				2	2	2		
Osangularia cf. bengalensis (Schwager)						2							
Stomatorbina ?													1
Hoeglundina elegans (d'Orb.)			9	37	7	1	9		5	1	8	1	2
Planktonic foraminifers	34	208	77	97	380	107	187	86	69	251	113	43	25
Ostracod valves	32	9	12	6	6	10	10	11	13	7	13	13	

mass east of the Arapaoa Fault. The shoreline probably fluctuated in position between Tinopai and Pakaurangi, and the Puketi sediments were periodically exposed to subaerial erosion and the consequent formation of soil horizons and lignite seams. One definite marine intercalation is seen on Pakaurangi Point itself, where there is an onlap sequence of very shallow-water sediments rich in Foraminifera—the Pakaurangi *Miogypsina* Sandstone.

Little or no depositional or tectonic activity has occurred in this area since the Lower Miocene.

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Appendix: Localities of Fossil Collections

The following fossil localities referred to in the foregoing paper are listed with grid references to eight figures. The latter are subdivisions of the standard six-figure grid references for Sheet N28 (Maungaturoto) of the N.Z.M.S. 1 Provisional Series.

Microfauna	*Grid Reference*
N28/781	N28/81523450
782	81433453
784	81263468
785	81513456
786	81133484
787	80993493
788	81463474
789	80603498
790	80903496
791	80713504
792	80043497
795	79763500

Microflora	*Grid Reference*
N28/794	N28/79603480

Macrofauna	*Earlier Workers and Grid References*
N28/687	Cox (1880); Park (1885); Marshall (1916); Vaughan, Marshall, and Marwick (1924); Ferrar (1934); Laws (1939–44).
846	Subsequent general collections from Pakaurangi.
847	Waiteroa to Hollands Members N28/802350–805350, and G.S.3246, Fleming (1944).
687	Waiteroa Shellbeds, Coates Bay, G.S.3247, Fleming (1944).
848	Waiteroa Shellbeds on the west side of Coates Bay; N28/397350.

Macrofauna	*Grid Reference*
N28/849	79753496–79783502
850	79753496
851	79753496–79753495
852	79753495
853	79753495–79743494
854	Waiteroa Shellbeds on east side of Coates Bay; N28/800350.
855	79993499–80013498
856	80013498
857	80013498–80023498
858	80023498
859	80023498–80033498
860	80543502–80663504
861	80663504–80703504
862	80503500–80543502
863	80703504–80763502
864	80243505–80263504
865	80263504–80313504
866	80363502–80433502
867	80433502–80503500
868	80763502–80953496
869	81433482–81483465
870	80953496–81033493
871	81033493–81073488
872	General Pakaurangi Member and G.S.3248, Fleming (1944).
873	81483465–81513455
874	81073488–81113486
875	81113486–81153483
876	81153483–81223474
877	81223474–81263469
878	81263469–81293465
879	81513455–81523452
880	81383457–81503451

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