STUDIES IN

MIDDLE AND LATE TERTIARY FORAMINIFERA

from

NEW ZEALAND

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CONTENTS

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FOREWORD

Part I of this thesis contains four taxonomic papers; Part II contains five papers on stratigraphic paleontology and paleoecology.

In the first paper of Part I an attempt is made to classify the Uvigerinidae of Raukumara Peninsula phylogenetically instead of in the formerly recognised broad form genera. The second paper outlines several well defined foraminiferal lineages in the New Zealand Tertiary. The third and fourth papers give descriptions needed for the papers presented in Part II; the third paper is furthermore a brief revision of most of the New Zealand species of Nonionidae, while the fourth paper includes descriptions of the Pliocene successors of the Uvigerinidae described in the first paper.

In Part II the first paper (number V) relates stratigraphic paleontology to paleoecology and gives two parallel zonal subdivisions of the uppermost Miocene and Pliocene in Wairarapa, one representing shallow-water facies, the other representing deep-water facies. The next paper sets out a depth sequence of biofacies for the late Tertiary in New Zealand, and suggests depths of deposition for a number of widely distributed facies in the New Zealand Tertiary. In the next two papers (numbers VII and VIII) depth and mode of deposition of Upper Miocene graded alternating sandstone and siltstone strata at Cleland Creek, Wairarapa, are inferred from analysis of the fossil Foraminifera. The final paper gives estimates from associated Foraminifera and other fossils, of the depth and temperature of growth of two fossil coral thickets in Wairarapa.

1

ABSTRACT

Many Uvigerinidae are important zone fossils in deep-water massive sandstones and mudstones of upper Oligocene and Miocene age in Raukumara Peninsula. Twenty-nine species and six subspecies are described, of which nineteen species and three subspecies are new. Subspecific classification is revised, five new genera and four new subgenera being established, partly on morphology and partly on lineage sequences. Time ranges are given in terms of eleven local zones which are correlated approximately with New Zealand stages and with European stages.

I - Upper Oligocene and Miocene uvigerinid foraminifera from Raukumara Peninsula, New Zealand

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INTRODUCTION

This paper is published by permission of Todd Brothers Limited, Wellington, New Zealand. Access to collections at the New Zealand Geological Survey were provided by Mr. N. de B. Hornibrook.

The foraminifera were collected from 1956 to 1958 by geologists of the Todd Brothers Oil Exploration Division from a lease area in Raukumara Peninsula, extending from 50 to 100 miles north of Gisborne and from the coast to about 20 miles inland. The northern part of the area includes the Waiapu and Poroporo valleys; the southern part includes Tokomaru Bay and the Ihungia and middle Mata valleys.

The area contains the type localities of the once well known but now disused Ihungia and Tutamoe "Series" (Ongley and MacPherson, 1928). These are not time divisions but correspond to the transitional (massive mudstone) and redeposited (graded bedded) facies of Wellman (1959).

The upper Oligocene to middle Miocene is represented by 7,000 feet of massive calcareous mudstone in the Waiapu Valley, and about 15,000 feet of graded, bedded alternating sandstones and mudstones in Tokomaru district. The upper Miocene consists of massive mudstones and non-graded alternating sandstones and siltstones (Moore, personal commication) passing into massive shelf sandstone, and ranges in thickness from 200 feet in the west to more than 1,200 feet in the east.

Macrofossils are moderately common near the base of the shelf sandstone. They are extremely rare in the underlying massive mudstone facies. Occasional bands of transported molluscs occur in the graded bedded facies. Foraminifera are abundant in the massive mudstone facies and in the upper Miocene non-graded alternating facies, few in species and individuals in much of the graded bedded facies, and absent, probably owing to weathering, from most of the shelf sandstone. Micropaleontological zones are the only satisfactory detailed mapping units in the upper Oligocene to middle Miocene.

The massive mudstones contain a uniform, somewhat restricted range of benthic foraminifera and abundant individuals of many species of pelagic foraminifera. They contain extremely few Rotaliidae, Discorbiidae, Miliolidae, Elphidiidae, and other groups of foraminifera predominantly restricted to shallow water. Ostracodes, like mollusks, are extremely rare and Bryozoa are absent. The restricted benthic fauna indicates deposition in deep water, beyond the shelf, probably in the lower bathyal depth zone. The sea-floor was uniform, and most benthic species occur persistently within their stratigraphic ranges. Benthic species of restricted stratigraphic range are almost as reliable as pelagic species for zone correlation.

"Zone" is used in the sense recommended by Arkell (1933) for "belts of strata, each of which is characterized by an assemblage of organic remains of which one abundant and characteristic form is chosen as an index" (Marr, 1898). Each zone is named after its most useful guide fossil, the specific name alone being used, with a capital initial letter and not in italics (cf. Mariae Zone, Arkell, 1933).

The zones proposed below are intended to have local application only. Accurate correlation with the New Zealand stages is not possible now but may be possible

Stages		Zones	Characteristic Zone Fossils
Europe	New Zealand	Raukumara Peninsula	
PONTIAN	KAPITEAN	Kapitea	
———	Up.	Compressa	
SARMATIAN	M. TONGAPORUTAN	locally absent due to unconformity.	
———	Low		
TORTONIAN	WAIAUAN	Hurupiensis	
HELVETIAN	Up.	Gladizea	
	Mid. LILLBURNIAN	Mioindex	
———	Low.	Universa	
BURDIGALIAN	CLIFDENIAN	Suturalis	
AQUITANIAN	Up.	Maoria	
	Mid. ALTONIAN	Bispherica	
	Low/ AWAMOAN & HUTCHINSONIAN	Tribola	
		Unconformity?	
CHATTIAN	OTAIAN	Dissimilis.	

(Characteristic Zone Fossils, right column, vertical labels: Catapsydrax dissimilis, Globigerinoides tribola, Globigerinoides bispherica, Rectobolivina maoria, Orbulina suturalis, Orbulina universa, Hopkinsina mioindex, Textularia gladizea, Notorotalia hurupiensis, Bolivinita compressa, Textularia kapitea)

TEXT-FIGURE 1

Correlation of northern Raukumara Peninsula foraminiferal zones with New Zealand and European stages. Characteristic zone fossils and their stratigraphic ranges shown on right. European stage correlations those of Hornibrook (1958, table I) slightly modified.

when foraminiferal zones have been defined at the type localities of the stages. Approximate correlation with New Zealand and European stages is shown in text-figure 1.

The zone ranges of the 32 species and subspecies of Uvigerinidae described are shown in text-figure 2. Species of *Angulogerina* are omitted because this group is being revised by Mr. N. de B. Hornibrook (in press).

CLASSIFICATION

Because their shell characters are few and variable, foraminifera are one of the most difficult animal groups to classify. The have been studied mainly by oil company micropaleontologists using them as a stratigraphic tool, and content to classify them merely as recognisable shapes. Within the last decade the taxonomy of two major groups, the "rotaliform" and the pelagic foraminifera, has been greatly refined by attention to details of shell structure once thought to be of minor significance. Taxonomy of the remainder of the smaller foraminifera has been neglected, except for Hofker's contributions, based on study of internal shell features. A few genera, such as *Haeuslerella* and *Ehrenbergina*, seem truly phylogenetic, but most are acknowledged as being merely form genera. Many are inconveniently large groups; the less bizarre the shape the greater is the number of species per "genus." The writer (1957) used morphology to subdivide certain miliolid "genera" into groups of related species. Probably *Textularia*, *Bulimina*, *Bolivina* and other "genera" could be treated similarly.

	Kapitea	Compressa	(break)	Hurupiensis	Gladizea	Mioindex	Universa	Suturalis	Maoria	Bispherica	Tribola	(break?)	Dissimilis
Neouvigerina plebeja plebeja										X			X
plebeja waiapuensis													X
aotea								X	X	X			
cf. interruptus									X				
toddi						X							
moorei				X	X								
Euuvigerina notohispida	X	X		X	X	X							
Hofkeruva (Hofkeruva) mata mata													
mata zealta				X	X								
taranakia	X	X											
Hofkeruva (Laminuva) tutamoea tutamoea				X	X	X	X	X					
tutamoea altonica									X	X			
zelamina	X	X		X									
Hofkeruva (Tereuva) picki													X
semiteres				X	X	X							
mioschwageri				X									
primigena				X	X								
paeniteres				X									
euteres	X	X											
Hofkeruva (Trigonouva) reacuminata		X		X	X	X	X	X	X	X	X		X
miozea									X	X	X	X	
gargantua				X	X								
Hofkeruva (s.l.) delicatula	X	X											
whakatua									X				
pseudojavana	X												
Norcottia mioindex				X	X	X							
Miniuva minima				X									
Ruatoria ruatoria				X	X	X	X	X					
Rectuvigerina rerensis								X	X	X	X		X
vesca							X	X	X				
pohana		X		X									
Ciperozea ongleyi				X	X	X	X	X	X	X	X		X

TEXT-FIGURE 2

Stratigraphic ranges of Uvigerinidae in Raukumara Peninsula, in terms of zones given in text-figure 1.

A few groups are difficult to subdivide solely on morphologic grounds, and one of these is the uvigerinid group with entirely triserial tests.

The main morphological features available for classifying triserial uvigerinids are size, overall shape, sculpture, and internal structures termed tooth-plates by Hofker (1951).

Tooth-plates are perhaps least subject to variation and hence the most reliable taxonomic guides, but they distinguish only three major groups apart from *Angulogerina*. Hofker's "genera" based solely on tooth-plates are groups of about sub-family rank. In most fossil specimens the tooth-plates are difficult to expose; consequently, a classification based on tooth-plates is impracticable. Fortunately there is a fairly consistent relationship between tooth-plates, sculpture and size. External morphology, used with discretion, distinguishes the tooth-plate groups, and is far more convenient in practice.

Sculpture is of three main types: 1) Costate – having longitudinal ribs. 2) Spinose – entirely covered with scattered, relatively large knobs or spines. 3) Hispid – partly or entirely covered with scattered fine papillae.

Contrary to current opinion, sculpture is particularly useful for defining uvigerine genera. The idea that sculpture is variable and has little taxonomic value is an attitude common in students of foraminifera and results from habits of thought handed down from early systematics. Variability, particularly variability of sculpture, is a bogey which has inhibited advance in taxonomy of many phyla (cf. the discussion of spiriferid brachiopods by Allan, 1947). No species of Uvigerinidae vary greatly in all characters. A few species vary considerably in one character, an extreme example being "*Uvigerina*" *peregrina* Cushman which varies from costate to spino-costate according to its environment. In contrast, the well-defined large genera *Rectuvigerina* and *Siphogenerina* both have consistent sculpture. The well-defined uvigerinid lineages in New Zealand have equally consistent sculpture.

Size is useful, though less consistent than sculpture. Hispid forms are generally small. Spinose and most costate forms are relatively large. Some of the costate lineages described below are remarkably consistent in size.

In areas where rocks were deposited continuously, fossil foraminifera occur in continuous time sequences. They provide lineages which are the surest indicators of evolutionary relationship, because they show progressive changes from species to species.

Advances in classifying pelagic and "rotaliform" foraminifera have not rid modern foraminiferal taxonomy of the "form genus" tradition. Micropaleontologists persist in retaining the generic name *Globigerinoides* for intermediate members of the best established of all lineages, *Globigerinoides triloba* to *Orbulina universa*. Bolli (1957) referred a member of this lineage (*glomerosa* Blow) to the Eocene genus *Porticulasphaera*. Taxonomy should reflect evolution and should take into account sequence of forms in time. Similarity of shape does not always indicate phylogenetic relationship, homeomorphy probably being more common in foraminifera than in higher animal groups. Conversely, difference of shape, as shown by the ancestral lineage of *Orbulina*, does not disprove phylogenetic relationship. Emphasis should be directed to ancestry.

Classification of ammonites, in which stratigraphic position and morphology are considered together, is the best example of the evolutionary approach to taxonomy. Foraminiferal sequences are more certain than those of ammonites and classification of foraminifera by evolution is correspondingly easier.

Established lineages help to confirm or disprove the validity of species, and to show the time range of variation of species. Usually they display some consistent distinctive morphological feature or features. Lineages must not be neglected in any attempt to classify a group, and particularly a large group like "*Uvigerina*" which is difficult to subdivide on morphology alone. Where possible, lineages and groups of related lineages should be the main basis of paleontologists' subgenera and genera, as they are in large groups of Mollusca and other phyla.
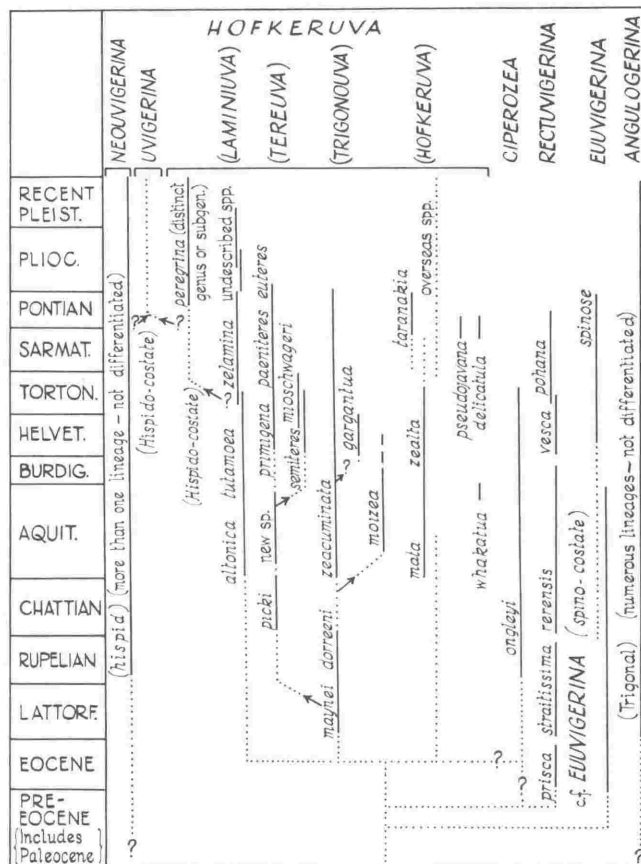
TEXT-FIGURE 3

Inferred phylogeny of main groups of Uvigerinidae. Solid lines denote occurrences within New Zealand. Genera and subgenera shown in upper case italics, subgenera in brackets; species shown in lower case italics; New Zealand species of some genera only are shown.

FAMILY UVIGERINIDAE

The Uvigerinidae are a compact natural group. The siphonate aperture with phialine lip marks them off from the related Buliminidae and from most other calcareous foraminifera.

The form genus *Uvigerina* d'Orbigny was subdivided by Hofker (1951) into three genera, *Aluvigerina*, *Neouvigerina* and *Euuvigerina*, for which Thalmann (1952) subsequently designated *Uvigerina pigmea* d'Orbigny, *U. ampulacea* Brady and *U. aculeata* d'Orbigny respectively, as type species.

Uvigerina, a senior synonym of *Aluvigerina* (*fide* Ellis and Messina, Catalogue of Foraminifera), includes only a small group of Recent and late Tertiary species, and is not known in New Zealand. *Neouvigerina* comprises a large Tertiary and Recent group of finely hispid to smooth species of small to moderate size. Hofker's *Euuvigerina* contains a costate group of numerous species and a spinose group of relatively few species which includes the type species *E. aculeata*. For the costate

~~generations, and tend to become uniserial at the adult stage. A compact Tertiary group with these characters~~ group the new generic name *Hofkeruva* is proposed, with *H. mata*, n. sp., as type species.

The inferred phylogeny of major groups of Uvigerinidae, together with the New Zealand Tertiary species, are shown in text-figure 3. *Hofkeruva* is the dominant genus in New Zealand. Four lineage groups of *Hofkeruva* are named as subgenera. The unnamed *peregrina* lineage, which has typical tooth-plates, but non-typical (spino-costate) ornament, must eventually be separated as a distinct subgenus or genus.

Species that link genera are not known in New Zealand and phylogenetic relationships (text-fig. 3) are inferred from similarities. *Hofkeruva*, *Ciperozea*, *Rectuvigerina* and *Euuvigerina* have the same type of tooth-plate. *Rectuvigerina* almost certainly evolved from a pre-Eocene *Hofkeruva* as it has consistent costate ornament. *Ciperozea* might have diverged from primitive *Rectuvigerina* or directly from *Hofkeruva*. *Euuvigerina* probably developed from *Hofkeruva* through the Eocene to Oligocene spino-costate group represented in New Zealand by *bortotara* and its allies.

Angulogerina and *Neouvigerina* differ from the hofkeruvid group in average size, forms of tooth-plates, shape and ornament. Each group contains several lineages of probable generic or subgeneric rank. The ancestry of the hispido-costate *Uvigerina* may be, as suggested by Hofker, in the Neouvigerinae, which have somewhat similar tooth-plates, or alternatively in the hispido-costate *peregrina* group.

SYSTEMATIC DESCRIPTIONS

Holotypes of new species described below are deposited in the New Zealand Geological Survey, unless stated otherwise. Paratypes of all except rare species are deposited in the United States National Museum, the National Museum of Victoria in Australia, and the Geology Department of Victoria University of Wellington in New Zealand.

LOCALITY NUMBERS

Where possible localities are referred to by the fossil record numbers in universal use in New Zealand, based on the national one-mile map sheet districts.

A few F numbers refer to localities of holotypes of previously described species, and are Geological Survey micropaleontological sample numbers.

Genus Neouvigerina Thalmann, 1952

Type species, by subsequent designation (Thalmann, 1952) *Neouvigerina ampullacea* (Brady) = *Uvigerina ampullacea* Brady, 1884.

The species *ampullacea* (Brady), *interrupta* (Brady), and *porrecta* (Brady) included in this genus by Hofker are
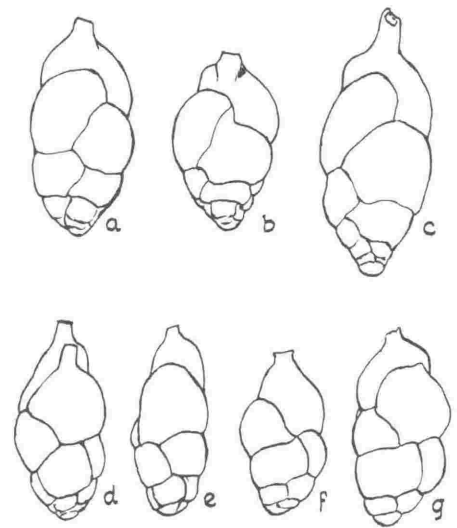
TEXT-FIGURE 4

a, b, c, *Neouvigerina plebeja waiapuensis*, n. sp., n. subsp. a, holotype, b, paratype. N. 72 f. 1562, c, paratype. N.72 f. 1571, × 110. d, e, f, g, *Neouvigerina, plebeja*, n. sp., paratypes N. 80 f. 764, × 110.

relatively small, have only hispid ornament in all generations, and tend to become uniserial at the adult stage. A compact Tertiary group with these characters is clearly separate from the generally larger costate, hispido-costate and spinose uvigerine forms. Some of the forms can be traced more or less continuously through the upper Tertiary to the Recent. Tooth-plates of the New Zealand species could not be examined because the test are infilled with sediment, calcite or marcasite. *Neouvigerina* is a convenient group name for the hispid forms (*aculeata*, *hispida*, *rustica* and *notohispida* are spinose forms and are excluded). Several lineages are represented, but as they have not been closely studied further subdivision of the group is not attempted here. Some of the species appear to be widespread and to have long Tertiary ranges.

Neouvigerina plebeja Vella, new species
Plate 2, figure 19, text-figure 4d–g

Test very small, elongate, fusiform, solid; apex rounded; sutures moderately impressed, giving regularly lobulate outline; chambers inflated, slightly broader than high, increasing regularly in size, and coiled regularly so that sutures on successive whorls are usually in line, giving a characteristic neat appearance; sculpture, a few papillae, usually on the apex only; remainder of shell smooth and matt; apertural neck narrow, thin, often broken off.

Dimensions: Holotype 0.36 × 0.14 mm.

Age: Dissimilis to? Universa zones (Otaian to Lower Lillburnian, Chattian to Helvetian).

Locality of holotype: N.80 f. 764, 1¼ miles up Makara Stream, Mata Survey District, 4 miles 70 chs. at 282 degrees from Trig. 186 (Triloba zone).

Variation: Some specimens referred to this species are broader and generally about 30 percent larger than the type and may represent a different species. Papillae vary slightly in size and extent. Megalospheric and microspheric forms were not distinguished.

Remarks: Nondescript small shells of this type, common in New Zealand post-Eocene rocks have generally been classed as *Uvigerina* cf. *canariensis* d'Orbigny. *N. plebeja* is rare in the Oligocene (Dissimilis zone), common in the lower Miocene.

Neouvigerina plebeja Vella waiapuensis Vella, new subspecies
Text-figure 4a–c

Test small, solid, broad, with acuminate conical apex; sutures more deeply impressed between later chambers which become progressively more inflated and lobulate; maximum width usually above the middle; papillae largest and most numerous at the apex, but extending over most of the test.

Dimensions: Holotype 0.43 × 0.21 mm.

Age: Dissimilis zone (Otaian, Chattian).

Locality of holotype: N.72. f. 1562, east bank Waiapu River two miles north-east of Ruatoria township.

Remarks: A few specimens of *N. plebeja plebeja* occur with *N. plebeja waiapuensis* in some Dissimilis zone faunas. The two forms seem not to intergrade and possibly represent distinct species.

Neouvigerina aotea Vella, new species
Plate 2, figure 20

Test small, rather thin, elongate, subcylindrical, with bluntly rounded apex and depressed chambers; sutures impressed; early chambers ornamented with numerous scattered papillae; later chambers with papillae tending to become aligned longitudinally, usually coalescing to form continuous, fine, somewhat irregular ribs on adult chambers, reaching to the base of the neck on the terminal chamber; apertural neck short with a thin phialine lip.

Dimension: Holotype 0.51 × 0.23 mm.

Age: Triloba to Maoria zones (Altonian, Aquitanian).

Locality of holotype: N.80 f. 1429, Mata River, between Ihungia Road and Waikopiro Stream.

Variation: Shape is constant. Size varies about 20 percent; the development of costae is extremely variable, some specimens having only scattered papillae on all chambers, and some, like the holotype, having costae on all except the earliest chambers. Costae are never present on the initial quarter of the test.

Remarks: Pliocene and Recent hispido-costate groups such as *Uvigerina s.s.* and *Hofkeruva peregrina* have costae on the juvenile which become dissected into spines on the adult, and are larger than *N. aotea*. Ontogeny suggests that *N. aotea* had a hispid ancestor and its costae are secondary. *N. aotea* superficially resembles the New Zealand lower Tertiary spino-costate *bortotara-*group, but is more like *Neouvigerina* in its small, neat, compact shell and fine papillae. It is probably a branch of the *N. plebeja* lineage.

N. aotea is a useful index species, being known only from the Altonian Stage. It is persistent and common in the massive mudstone facies of Waiapu, and has been found to the south in Wairarapa and Nelson districts.

Neouvigerina cf. interrupta (Brady)
Plate 2, figure 7

Test small, elongate tending to become uniserial; sculpture of numerous scattered, tiny, elevated, rounded papillae; apex narrowly rounded; apertural neck long.

Dimensions: Hypotype 0.55 × 0.20 mm.

Age: Bispherica zone (Mid-Altonian, Aquitanian).

Locality of hypotype: N.80 f. 1300, 2¼ miles up Ihungia Stream, 20 chains at 360 degrees from Trig. Wharekia 181, Tokomaru Survey District.

Remarks: Only one specimen was found. It is distinct from all other species in the lease area but agrees closely with Brady's (1884, pl. 75, figs. 12–14) illustrations of Recent *interrupta*.

Neouvigerina? toddi Vella, new species
Plate 2, figure 15

Test large for the genus, elongate, subcylindrical, solid; chambers numerous, slightly broader than high, subquadrate to irregular in shape; sutures deeply incised outline slightly lobulate; apex broadly rounded; surface matt; nearly smooth with a few scattered, small, low, rounded tubercles concentrated near the sutures; neck short with prominent phialine lip.

Dimensions: Holotype 0.68 × 0.27 mm., paratype 0.51 × 0.27 mm.

Age: Suturalis zone (Clifdenian, Burdigalian).

Locality of holotype and paratype: N.80 f. 1758, grid. ref. 561, 513, headwaters of Mangara Stream.

Remarks: Though based on only two specimens, this species is clearly distinct, in its large, nearly smooth, subcylindrical test. Inclusion in *Neouvigerina* is provisional.

Neouvigerina moorei Vella, new species
Plate 2, figure 17

Test of moderate size, fusiform, broadest slightly above the middle; sutures incised between adult slightly lobulate chambers, flush and obscured by callous on early chambers; apex acute with small glassy terminal spine; sculpture of scattered, distant, tiny, rounded tubercles, more numerous near the apex and close to the sutures; apertural neck not distinctly marked off from the terminal chamber, tapered, surmounted by a solid phialine lip.

Dimensions: Holotype 0.64 × 0.30 mm.

Age: Gladizea to Hurupiensis zones (Upper Lillburnian to Waiauan, Tortonian).

Locality of holotype: N.80 f. 738, grid. ref. 561513, headwaters of Mangarara Stream (Gladizea zone).

Variation: Megalospheric and microspheric forms were not distinguished. Size varies about 20 percent; shape is fairly consistent but the apical cone varies from moderately convex to regularly tapering. The apical spine is missing from many specimens, probably having been broken off. The calloused conical apex and the relatively large size are typical.

Remarks: Though known only from the middle Miocene in the lease area this species almost certainly ranges up into the upper Miocene elsewhere in New Zealand. The lower limit of its range has not been established definitely but is probably close to the base of the Gladizea zone.

N. moorei is similar to, possibly conspecific with, the form illustrated by Bermudez (1949, pl. 13, fig. 48) as *U. mantaensis* Cushman and Edwards, from the "middle and upper Oligocene" (the lower part of the range of *Orbulina;* Burdigalian or Helvetian) of the Dominican Republic, but appears to be distinct from the type of *U. mantaensis.*

The species is named after W. R. Moore, formerly geologist for Todd Brothers Ltd.

Genus Euuvigerina Thalmann, 1952

Type species by subsequent designation (Thalmann, 1952) *E. aculeata* (d'Orb.) = *Uvigerina aculeata* d'Orbigny, 1846.

Tooth-plates of "*Uvigerina*" *notohispida* are simple twisted ribbon-like calcareous structures, running along the longitudinal axis of the test, passing through the aperture of each chamber and attached to the inner side of the rim of each aperture. They match the tooth-plates of *Euuvigerina aculeata* as described by Hofker. The costate "a2 generation" of *E. aculeata* described by Hofker was not found in New Zealand Tertiary faunas containing *notohispida* and has not been described for *rustica* or *hispida*. Nevertheless, the large spines of these species are characteristic and

distinguish them from all other species. They form a compact group, commencing with *notohispida* and *rustica* in the middle Miocene. The ancestral stock is probably the spino-costate group represented in New Zealand by the Eocene–Oligocene *bortotara* lineage which like *notohispida* has strikingly different megalospheric and microspheric forms. The *bortotara* lineage is provisionally classed in *Euuvigerina.*

It is not certain that the Tertiary group is phylogenetically related to *E. aculeata*, and it may need a new generic name. It would be unwise, however, to erect a new genus without further investigation of the Recent species.

Euuvigerina notohispida (Finlay)
Plate, 2, figures 16, 18

Hopkinsina notoshispida FINLAY, 1939, Roy. Soc. New Zealand, Trans., vol. 69, no. 1, p. 105, pl. 12, figs. 10–11. – FINLAY AND MARWICK, 1947, New Zealand Jour. Sci. Technol., sec. B, vol. 28, no. 4, p. 234.
Uvigerina notohispida (Finlay). – FINLAY, 1947, Roy. Soc. New Zealand, Trans., vol. 76, no. 3, p. 341. – HORNIBROOK, 1958, Micropaleontology, vol. 4, no. 1, p. 32.

The spines on later chambers are mostly low flat-topped cones; a few may be irregular in shape, but most are circular. On early chambers the spines are reduced in height with tops rounded, apparently by secondary deposits of shell on top of and between them. They are irregularly scattered with interspaces varying in width on individuals and from one individual to another, but generally not exceeding the width of the spines. The apertural neck is cylindrical, smooth and thin, frequently broken off.

Microspheric forms taper to an acute apex while the megalospheric forms are subcylindrical with a broadly rounded apex due to a very large proloculum. Microspheric forms tend to be slightly larger than the megalospheric.

Dimensions: Megalospheric hypotype 0.84 × 0.43 mm.; microspheric hypotype 0.91 × 0.43 mm.

Age: Mioindex zone to Kapitea zone (Middle Lillburnian to Kapitean, Helvetian to Pontian).

Localities of types: Holotype, F.3141, Kaiti Beach, Gisborne (Tongaporutuan, Sarmatian); hypotypes, N.72 f. 1259, grid. ref. 715393, Paoruku Stream, 1½ miles east of Waiapu River (Hurupiensis zone).

Remarks: *E. notohispida* is a useful stratigraphic index species at the top and bottom of its range, throughout New Zealand, but in the lease area its value is reduced because it is relatively rare.

Genus Hofkeruva Vella, new genus

Type species: Hofkeruva mata, n. sp.

Because of the similarity of tooth-plates Hofker grouped a costate form which he identified as *tenuistriata* (Reuss)

with *Euuvigerina aculeata*. Costate and spinose groups have been distinct since the latter appeared (as *E. rustica* and *E. notohispida*) in the middle Miocene. The partly uniserial costate genus *Rectuvigerina* has the same kind of tooth-plates and is phylogenetically closer to the costate group, having clearly developed from an unknown pre-Eocene costate uvigerinoid form. Costate uvigerinoid species first appear in the lower Oligocene in New Zealand. These and species of *Rectuvigerina* do not intergrade with the spino-costate "*Euuvigerina*" *bortotara* group.

The hispido-costate *peregrina* group, which appeared in New Zealand in the Pliocene, has entirely costate juveniles, suggesting a costate ancestor. The evolution of hispid ornament from costate ornament is a rare event, not common as has been inferred by students of foraminifera. Furthermore, in the hispid form of *peregrina* the costate character is not entirely lost because the papillae are never scattered at random but are aligned longitudinally. It may be desirable later to separate the *peregrina* group as a distinct genus, but provisionally it is classed in *Hofkeruva, sensu lato*.

Uvigerina pigmea though mainly costate is clearly distinguished from *Hofkeruva* by its tooth-plates. *Uvigerina* is a small group, probably confined to the Recent, and taxonomically isolated.

Costate species are the dominant Uvigerinidae of the Oligocene to Pliocene of New Zealand and apparently of most other parts of the world. The many lineages represented must eventually be grouped into several genera. Meanwhile, as a compromise, the entire group is separated as the genus *Hofkeruva* and four lineages are recognised as subgenera in New Zealand.

Though many tests were opened or sectioned, owing to infillings few tooth-plates could be examined. Toothplates of *Hofkeruva (Hofkeruva) mata* and *taranakia, Hofkeruva (Tereuva) picki* and *paeniteres, Hofkeruva (Trigonouva) mioschwageri* and *Hofkeruva (Laminiuva) tutamoea* were found to be identical with those of *Euuvigerina aculeata* and *Hofkeruva* "*tenuistriata*" as described by Hofker (loc. cit.), i.e., simple, transversely curved, twisted, ribbon-like plates passing through the apertural necks and joined to the top interior of each apertural neck.

The type species, *H. mata*, is an elongate form, similar and almost certainly related to *H. tenuistriata* (Reuss). The type figure of *tenuistriata* is poor and diverse forms have been described under the name of *tenuistriata*. This species therefore is not suitable to be nominated as type species.

Subgenus Hofkeruva Vella, new subgenus

Elongate tests of moderate size with ornament of narrow axial ribs, typically extending to the base of the apertural neck; compactly coiled and neat.

The subgenus is represented in New Zealand by the Miocene lineage *mata – zealta – taranakia*.

Hofkeruva (Hofkeruva) mata Vella, new species
Plate 2, figures 3–4

Test small, elongate, elliptical, rather solid, with moderately impressed sutures; adult chambers slightly undercut in some specimens; outline somewhat lobulate; sculpture, numerous narrow, crisp, steeply bevelled, sharp-crested ribs, narrower than interspaces, usually stopped at the sutures, less commonly continous from one chamber to the next; ribs on initial chamber commencing with tiny spinose projections on a few specimens, but usually not spinose, increasing in height gradually from the apex to the sides of the terminal chamber, then tapering rapidly, generally extending to the base of the neck, but on a few fully grown tests not reaching the neck; apertural neck rather narrow, short, with thin phialine lip; apex bluntly acuminate not differing perceptibly in microspheric and megalospheric individuals.

Dimensions: Holotype 0.54 × 0.24 mm., paratype 0.51 × 0.26 mm.

Age: Triloba to Suturalis zones (Altonian to Clifdenian, Aquitanian – Burdigalian) grading up to the middle Miocene chronological subspecies *zealta*.

Variation: Tests do not approach the uniserial condition as do specimens illustrated under the name of *Uvigerina tenuistriata* by Cushman (1918, pl. 22, fig. 7) and by Dieci (1959, pl. 6, figs. 8–9, as varieties *gaudryinoides* Fornasini and *siphogenerinoides* Fornasini). Size varies about 50 percent.

Remarks: *H. mata* is similar to the form figured as *U. bifurcata* d'Orbigny from the lower Miocene of Sumatra by Leroy (1944, pl. 5, fig. 28).

H. mata is rare in the massive siltstone facies but abounds in partly graded bedded sediments with a few transported Mollusca on the western side of the Tutamoe Syncline (Ongley and MacPherson, 1928). It is probably a transported shallow-water species.

Hofkeruva (Hofkeruva) mata Vella zealta Vella, new subspecies
Plate 2, figure 2

Test more solid than typical *mata* with thicker ribs, less lobulate outline, and usually more acute apex.

Dimensions: Holotype 0.53 × 0.26 mm.

Age: Universa to Hurupiensis zones (Lower Lillburnian to Waiauan, Helvetian to Tortonian).

Locality of holotype: N.80 f. 738, Mata River 1¼ miles downstream from Waikopino Stream junction, Tutamoe Survey District, 50 chains at 075 degrees from Trig. 177A.

Variation: Size, shape and strength of ribs are fairly constant.

Remarks: H. *mata* and *zealta* form a temporal cline, grading apparently continuously from one form to the other. An arbitrary boundary is taken at the base of the Universa zone.

Hofkeruva (Hofkeruva) taranakia Vella, new species
Plate 2, figure 1

Test small, solid, elongate usually tapered to bluntly acuminate apex; sutures slightly impressed, hardly interrupting the outline; ribs few, widely spaced, strongly raised thick flanges, most of them continuous from the apex to the terminal chamber, usually reaching to the base of the neck; apertural neck short, broad, with thin phialine lip.

Dimensions: Holotype 0.63 × 0.33 mm.

Age: Compressa to Kapitea zones (Upper Tongaporutuan to Kapitean, Pontian).

Locality of holotype: N.81 f. 643, grid ref. 373512, Te Puia, Compressa Zone.

Variation: Shape varies a good deal. Many specimens are ovate rather than regularly tapered, and irregularities in growth are common. The sculpture is the most consistent feature.

Remarks: The marked difference in sculpture suggests that this is probably not a lineal descendant of H. *mata zealta*. Because of an unconformity in the lease area, it is not known whether or not the two forms intergrade.

Subgenus Laminiuva Vella, new subgenus

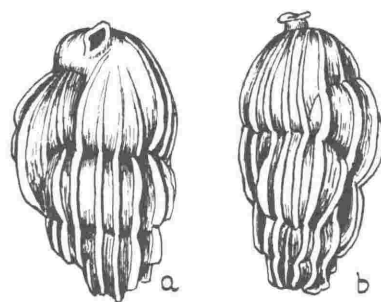*Type species: Hofkeruva (Laminiuva) tutamoea* Vella, n. sp.

Test of moderate to large size, with numerous thin, elevated, flange-like axial ribs, usually continuous from apex to terminal chamber, typically reaching the base of and even encroaching on the neck; profile irregular owing to deeply impressed sutures and inflated chambers.

Laminiuva is proposed for a New Zealand Miocene to Pliocene lineage. No comparable overseas species are known and this subgenus is probably endemic. The lineage appears as a small form, close to the type species, in the Bispherica zone of the lease area and in the lower Altonian or Awamoan of east Wellington. The antecedents of this small species are not known. The type species *tutamoea* ranges from the Suturalis to the Hurupiensis zone, and is replaced by *zelamina* in the Compressa and Kapitea zones. *Laminiuva zelamina* is known in the upper Miocene of east Wellington where it is in turn replaced by an undescribed species in the lower Pliocene.

Hofkeruva (Laminiuva) tutamoea Vella, new species
Plate 1, figure 4

Test of moderate size, widest near the middle, with irregularly lobulate outline and truncated apex; numerous flangelike ribs, thin and hyaline at their

TEXT-FIGURE 5

Hofkeruva (Laminiuva) tutamoea altonica, n. subsp. a, paratype, b, holotype, × 110.

outer edges, irregularly serrated by breakage, produced to tiny spines at the apex; interspaces wider than the ribs; apertural neck short, broad, with thin upward-curving phialine lip.

Dimensions of holotype: 0.68 × 0.39 mm.

Age: Suturalis to Hurupiensis zones (Clifdenian to Waiauan, Burdigalian to Tortonian.

Locality of holotype: N. 80 f. 1426, Mata River, north of Waikopiro Stream junction (Gladizea zone).

Variation: Slight; size, lobulation and sculpture are consistent.

Hofkeruva (Laminiuva) tutamoea Vella altonica Vella, new subspecies
Text-figure 5a, b

Smaller than typical *tutamoea* with lower, thicker ribs.

Dimensions of holotype: 0.53 × 0.31 mm.

Age: Bispherica and Maoria zones (middle to upper Altonian, Aquitanian). In east Wellington, lower Altonian or Awamoan, lower Aquitanian.

Locality of holotype: N. 159 f. 592, grid ref. 570781, middle Tinui Valley, East Wellington (lower Altonian or Awamoan).

Repository: Geology Department, Victoria University of Wellington.

Remarks: This subspecies grades up to typical *tutamoea*. Maoria zone specimens are generally distinctly smaller than *tutamoea* but are sometimes difficult to separate.

Hofkeruva (Laminiuva) zelamina Vella, new species
Plate 1, figure 3

Test large, subcylindrical, gently tapering to bluntly rounded apex; impressed sutures obscured by sculpture of numerous heavy longitudinal flangelike ribs with crests not serrated by breakage, not indented at the sutures, continuous from apex to summit of terminal chamber, thicker than those of *tutamoea*, not produced to apical spines; aperture as in *tutamoea*.

Dimensions of holotype: 0.85 × 0.37 mm.

Age: Hurupiensis to Kapitea zones (Waiauan to Kapitean, Tortonian to Pontian).

Locality of holotype: N. 80 f. 1368, Mata River near Waikopiro Stream junction (Hurupiensis zone).

Variation: Size varies about 50 percent. Sculpture is consistent and the most diagnostic feature. Microspheric and megalospheric forms were not distinguished.

Subgenus Tereuva Vella, new subgenus

Type species: Hofkeruva (Tereuva) paeniteres (Finlay) = *Uvigerina paeniteres* Finlay, 1939.

Tests of moderate to large size with lobulate outline, apertural neck sunken in a shallow depression; sculpture of longitudinal ribs or flanges, generally continuous on successive chambers, strongest on early chambers, decreasing toward adult chambers, and always absent from the upper surface of the terminal chamber.

Tereuva is probably endemic to New Zealand. The earliest species which can be included definitely in the lineage is *Hofkeruva (Tereuva) picki*, n. sp., known from as early as the Waitakian stage (middle Oligocene) (Hornibrook, personal communication). The latest species is the almost completely smooth *Hofkeruva (Tereuva) euteres* of the Compressa and Kapitea Zones (Pontian). The group almost certainly developed in New Zealand from the lower Oligocene plexus of *Hofkeruva (Trigonouva) maynei* (Chapman), which includes varieties whose adult tests tend to become smooth. The group is not a linear evolutionary sequence but is distinguished by progressive retreat of the costae from the adult part of the test.

Hofkeruva (Tereuva) picki Vella, new species
Plate 1, figure 10

Test of moderate size, obese, solid, ovate to subcylindrical, with broadly rounded or obtusely angled apex, sutures impressed, chambers moderately inflated; sculpture of about 14 primary ribs with broad interspaces, strongly raised, sometimes produced to small spines at the apex, continuous over sutures, tapering towards the adult, obsolete by the penultimate chamber, very faint on the lower part of the terminal chamber, not reaching the upper surface; a few weak interstitial ribs on post-juvenile chambers; apertural neck short, broad with usually broken thin phialine lip, sunken in a shallow depression.

Dimensions of holotype: 0.85 × 0.45 mm.

Age: Dissimilis zone (Otaian, Chattian).

Locality of holotype: N. 72 f. 590, Poroporo River beside main highway (Dissimilis zone).

Variation: The ribs of the holotype coalesce at the apex, but in many specimens, possibly the microspheric form, they commence discretely and are produced to minute spines near the apex. The degree of smoothness of the terminal chamber is variable.

Remarks: This species does not occur in the shelf facies of the Otaian in the South Island and is assumed to be a deep water form. It is confined to the Dissimilis zone in the lease area, but has been identified by Hornibrook (personal communication) in the Waitakian Stage (Rupelian—Chattian) elsewhere in New Zealand.

Care is needed to distinguish *Tereuva picki* from two later forms – an undescribed Altonian (Aquitanian) species which has a more conical shape in the juvenile test, more acute apex, and less regular, often twisted sculpture; and the Lillburnian (Helvetian) *primigena*, which has consistently weaker sculpture.

Hofkeruva (Tereuva) semiteres Vella, new species
Plate 1, figures 13, 14

Test of moderate size, stout, solid, with deeply impressed sutures and irregular lobulate outline; sculpture of few irregular flangelike ribs, some dying out quickly on the juvenile part of the shell, some persisting on to the penultimate chamber; apex profile irregular owing to sudden termination of rib-flanges at different levels, more or less acuminate in the microspheric form, bluntly truncated in the megalospheric; apertural neck short, broad, situated in a shallow depression, and furnished with a thin phialine lip upturned at the rim. *Dimensions of holotype:* 0.89 × 0.45 mm.; paratype 0.86 × 0.46 mm.

Age: Universa to Gladizea zones (Lillburnian, Helvetian).

Locality of holotype and figured paratype: N. 80 f. 1406 Mata River, north of Waikopiro Stream junction (Universa or Mioindex zone).

Remarks: H. (Tereuva) semiteres is smaller than *mioschwageri* and has shorter, fewer rib-flanges and a less acuminate apex. No other species of *Tereuva* has similar flangelike ribs.

Hofkeruva (Tereuva) mioschwageri (Finlay)

Uvigerina mioschwageri FINLAY, 1939, Roy. Soc. New Zealand, Trans., vol. 69, pt. 1, p. 103.

Test large, sub-conic, widest near the adult end, with elongate acuminate early test; elevated flangelike ribs on the early shell, dying at about the penultimate chamber. Adult end of shell smooth; apertural neck short with flaring phialine lip.

Age: Gladizea zone (upper Lillburnian, upper Helvetian or Tortonian).

Locality of holotype: N. 97 f. 498, Waikura Stream, Poverty Bay.

Variation: The costae of *mioschwageri* are consistently flangelike. Generally they are continuous from one chamber to the next and somewhat twisted. In some specimens they are discrete on each chamber and not in line, forming irregularly disposed, flattened finlike projections.

Remarks: T. mioschwageri is rare in the lease area.

T. mioschwageri and *T. semiteres* seem to be closely related species and are considered to have diverged from the main line of *Tereuva*. The acuminate shape and twisted costae suggest that *mioschwageri* developed from the unnamed Altonian species (noted in text-fig. 3).

Hofkeruva (Tereuva) paeniteres (Finlay)

Uvigerina paeniteres FINLAY, 1939, Roy. Soc. New Zealand, Trans., vol. 69, pt. 1, p. 103.

Test large, with somewhat inflated chambers and lobulate outline; sculpture of obsolete axial ribs visible on juvenile chambers only.

Age: Hurupiensis zone (Waiauan, Tortonian).

Locality of holotype: F. 3132, Kaiti Beach, Poverty Bay (probably Waiauan).

Remarks: Tereuva paeniteres is preceded by an ancestral form with heavier sculpture in the Mioindex and Gladizea zones and followed by a virtually smooth descendant in the Compressa and Kapitea zones. The early form grades up to typical *paeniteres*. The hiatus between the Hurupiensis and Compressa zones in the lease area obviates grading from *paeniteres* to the smooth form there, but from scattered lower Tongaporutuan faunas elsewhere a gradational relationship appears to exist. The group appears to be a temporal cline, which evolved from moderately costate to smooth. Three chronospecies are recognised with arbitrary boundaries defined as follows:

Kapitea zone	... *euteres*
Compressa zone	... *euteres*
(Zones missing)	
Hurupiensis zone	... *paeniteres*
Gladizea zone	... *primigena*
Mioindex zone	... *primigena*

Hofkeruva (Tereuva) primigena Vella, new species
Plate 1, figure 12

Large, obese, widest above the middle, with rounded apex; sculpture distant low axial ribs, continuous from the apex, very weak on adult chambers, but most reaching the terminal chamber.

Dimensions of holotype: 1.0 × 0.57 mm.

Age: Mioindex and Gladizea zones (middle and upper Lillburnian, Helvetian—Tortonian).

Locality of holotype: N. 80 f. 1448, Mata River north of Waikopiro Stream junction.

Remarks: This species is most useful at its first appearance. It enters at about the same horizon as *Euuvigerina notohispida* and *Norcottia mioindex,* marking the base of the Mioindex zone.

Hofkeruva (Tereuva) euteres Vella, new species
Plate 1, figures 6-7

Test of moderate size with impressed sutures and lobulate outline, entirely smooth, or with faint traces of longitudinal ribs on the initial part of the shell only.

Dimensions of holotype: 0.75 × 0.38 mm., paratype 0.63 × 0.37 mm.

Age: Compressa and Kapitea zones (upper Tongaporutuan and Kapitean, Pontian).

Locality of holotype and figured paratype: N. 80 f. 705, near main highway, Tokomaru Survey District, 3 miles 5 chains at 265 degrees from Trig. K. 62, Compressa zone.

Variation: Shape varies from squat and globose to broadly elliptical.

Subgenus Trigonouva Vella, new subgenus

Type species: Hofkeruva (Trigonouva) zeacuminata, n. sp.

Tests of moderate to large size with moderate to strong axial costae; juvenile and usually also the adult roughly triangular in cross section.

Costate uvigerinoid tests of triangular habit seem to occur in the Miocene of many countries, but it is unlikely that all are phylogenetically closely related. In New Zealand *Trigonouva* appears first near the base of the Oligocene (Whaingaroan Stage) as *maynei* (Chapman), is followed in the middle Oligocene (Waitakian Stage) by *dorreeni* (Finlay), and in the upper Oligocene and Miocene (Pareora, Southland and Taranaki Series) by *zeacuminata,* n. sp. These three species probably constitute a direct lineage. *Trigonouva miozea* (Finlay) is considered to be a short-lived offshoot of the main lineage. The extraordinarily large species *gargantua* appears suddenly at the base of the Universa zone apparently without ancestors in New Zealand.

Hofkeruva (Trigonouva) zeacuminata Vella, new species
Plate 1, figures 15, 16

Test of moderate to large size, solid, broadest near the adult end, tapering with lightly convex profile, little indented by weakly impressed sutures, and acutely pointed not spinose apex; sculpture, moderately high, steeply bevelled, longitudinal ribs with narrowly rounded crests continuous from apex to adult chambers, some bifurcating, increasing in height from the apex to the first third, then diminishing gradually towards the adult end, usually dying on the terminal chamber shortly below the base of the neck; apertural neck variable in length, rather broad with thick phialine lip.

Dimensions of holotype: 0.86 × 0.44 mm.; paratype 0.82 × 0.46 mm.

Age: Triloba to Compressa, possibly Kapitea zones (lower Altonian to ?Kapitean, Aquitanian to Pontian).

Locality of holotype and figured paratype: N. 71 f. 1160, grid. ref. 689347, stream north of Willow Stream, Rotokautuku (Universa zone).

Variation: Size varies about 50 percent. Many specimens (megalospheric form?) have a slightly truncated apex with a few ribs produced to small spines.

Remarks: This species is readily distinguished by its trigonal early test, tapering form, usually acutely pointed apex, strong mostly continuous axial ribs and small smooth area at the summit of the terminal chamber. It is the commonest, most widely distributed species in the Miocene rocks of the lease area and occurs extensively in upper Oligocene and Miocene elsewhere in New Zealand.

Hofkeruva (Trigonouva) miozea (Finlay)
Plate 1, figures 5, 8–9; plate 2, figure 6

Uvigerina miozea FINLAY, 1939, Roy. Soc. New Zealand, Trans., vol. 69, pt. 1, p. 102, figs. 12–14.

Supposed microspheric and megalospheric forms require separate descriptions.

Microspheric: Ovate varying from stout to narrow, with moderately impressed sutures and slightly lobulate profile; subtrigonal in transverse section; apex narrowly rounded without spines at the ends of the ribs.

Megalospheric: Subcylindrical with truncate apex usually bearing spines formed by prolongation of the ends of ribs; sutures deeply impressed; profile very lobulate; trigonal shape obscure.

Common features: Test rather small, with short broad apertural neck and heavy phialine lip; sculpture of low broadly rounded longitudinal ribs not crossing sutures, heaviest on early chambers, becoming progressively finer on later chambers, finally becoming hair-thin.

Dimensions of hypotypes: Microspheric, 0.55 × 0.34 mm.; megalospheric, 0.61 × 0.40 mm. (pl. 1 fig. 8), 0.59 × 0.32 mm. (pl. 1 fig. 9).

Age: Triloba to Suturalis zones (lower Altonian to Clifdenian, Aquitanian to Burdigalian).

Localities of types: Holotype: F. 5389 North Bank, Mangaoporo River, Waiapu district (Suturalis zone); hypotypes: microspheric, N. 80 f. 1765, grid. ref. 555512, Kouetumarae Stream (Triloba zone), megalospheric N. 72 f. 520 Poroporo River, Waiapu district (Bispherica zone); N. 71 f. 645, Whakatu Stream, Waiapu district (Maoria zone).

Remarks: The name *miozea* has been applied loosely to several upper Miocene and Pliocene species. The range of variation is much less than has been supposed. Many

Triloba and Bispherica zone populations have obsolescent sculpture. The illustrated megalospheric test (pl. 1 fig. 5) has very fine distant riblets even on the juvenile chambers and has no apical spines. It is possible that this early form is separable from *miozea s.s.*

The holotype of *miozea* is the form here described as microspheric. It is not firmly established that the form described as the megalospheric is not a distinct species. The two forms seem to have the same stratigraphic range, but they are not found together at all places, and their morphologic differences are greater than is usual between alternate generations of *Hofkeruva*.

Hofkeruva (Trigonouva) gargantua Vella, new species
Plate 1, figure 11

Test very large, solid, broadly conic, widest near the adult end, tapering to narrowly rounded apex; the three initial angles accentuated by heavy broadly rounded ribs; other ribs obscured by callous on early test, appearing on later chambers then diminishing to become obsolete by the final chamber; sutures slightly impressed on adult test, obscured by callous on juvenile test.

Dimensions of holotype: 1.07 × 0.60 mm.

Age: Universa to Mioindex zones (lower to middle Lillburnian, Helvetian).

Locality of holotype: N. 80 f. 719, Mangahoui Stream, Mata Survey District, 6 miles 10 chains at 262 degrees from. Trig. Puketite (Mioindex zone).

Variation: The three initial angles are sometimes less accentuated and the intervening ribs less obscured by callous than on the holotype.

Remarks: This species is conspicuous because of its size. It is rare but widespread in the massive mudstone facies. In some respects it resembles *zeacuminata* and may be a derivative of the local lineage. It appears suddenly at about the same horizon as *Orbulina universa*, without any known ancestors and is most likely and emigrant.

Hofkeruva, sensu lato

Three species of doubtful and unknown affinities are described under the generic name *Hofkeruva*, but are not allocated to a subgenus.

Hofkeruva delicatula Vella, new species
Plate 2, figure 5

Small, subcylindrical, with slightly inflated chambers and slightly undercut sutures; sculpture of crisp, narrowly rounded costae not continuous over sutures tending to form prickles at the base of each chamber, and prolonged to small spines at the truncate apex.

Dimensions of holotype: 0.41 × 0.25 mm.

Age: Compressa zone (upper Tongaporutuan, Sarmatian or Pontian).

Locality of holotype: N. 80 f. 1304, grid. ref. 590510, Mata Road, one mile east of Fernside Road junction.

Variation: Size, shape and ornament are quite constant in seven paratypes from the type locality. Prickles are not always present at the base of each chamber.

Remarks: This tiny, elegant species is not unlike lower Miocene tests referred to *Trigonouva miozea* and may be a derivative of that species. It is not transversely trigonal. A similar form has been seen in the Waiauan of Hawkes Bay.

Hofkeruva whakatua Vella, new species
Plate 2, figure 11

Shell of moderate size, broadly ovate, with lightly impressed sutures scarcely visible on the early part of the test; sculpture of few, widely spaced, strong flange-like ribs with thin outer edge serrated by breakage, generally extending from apex to just below the summit of the final chamber; apertural neck short, broad, with phialine lip thin and seldom preserved.

Dimensions of holotype: 0.73 × 0.50 mm.

Age: Maoria zone (upper Altonian, upper Aquitanian).

Locality of holotype: N. 71 f. 645, Whakatu Stream, Waiapu District.

Remarks: Known only from the type locality where 30 specimens were found.

Though it has ribs like those of *Laminiuva tutamoca*, *H. whakatua* is distinguished from all the *Laminiuva* group by its squat shape, the smooth upper surface of its terminal chamber, and the wide spacing of its ribs. It is probably related to the Javanese species figured as *Uvigerina crassicostata* Schwager by Boomgaart (1949, pl. 12, fig. 8).

Hofkeruva pseudojavana Vella, new species
Plate 1, figures 1–3

Test of moderate size, squat, broadly ovate, with lightly impressed sutures indistinct on the early part; megalospheric form with bluntly truncated apex, microspheric with an acute apex with a prominent spine; sculpture of strong narrowly rounded ribs continuous from apex to penultimate chamber or lower part of final chamber; greater part or all of terminal chamber smooth; apertural neck short, rather narrow; phialine lip not seen.

Dimensions of holotype (microspheric): 0.58 × 0.40 mm., figured paratype (megalospheric) 0.67 × 0.45 mm.

Age: Compressa zone (upper Tongaporutuan, Pontian).

Locality of holotype: N. 80 f. 1258, grid. ref. 547508, Pauariki Stream, Tokomaru District.

Remarks: *H. pseudojavana* is known only from the type locality, represented by 10 specimens.

It resembles *H. whakatua* but is easily distinguished by its smaller size, lower, more rounded ribs, smoother terminal chamber, and prominent apical spine on the microspheric form. The megalospheric test is similar to the form illustrated as *Uvigerina javana* Koch by Boomgaart (1949, pl. 12, fig. 10).

Genus **Norcottia** Vella, **new genus**

Type species: *Norcottia mioindex* (Finlay) = *Hopkinsina mioindex* Finlay, 1947.

Small, narrowly lanceolate, neat, with elevated chambers, strongly incised sutures; triserial throughout; ornament of close fine longitudinal costae made faintly gemmulate apparently by microscopic transverse riblets; apertural neck slender, well developed with a thin flaring phialine lip.

In placing *mioindex* in *Hopkinsina*, Finlay was evidently influenced by its elongate ovate shape and fine regular ornament. The type of *Hopkinsina* (the Louisiana Eocene *H. danvillensis* Howe and Wallace) has a triserial initial stage forming one-quarter to one-third of the test, followed by a slightly twisted but essentially biserial stage. The outline is nearly smooth, sutures being hardly impressed. The apertural neck is rudimentary and oval in shape. No related species are known in New Zealand. *Norcottia* has more in common with the uvigerinoid group than with *Hopkinsina*. Most specimens have an obscurely trigonal juvenile stage. Tooth-plates were not

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PLATE 1
All figures × 70

1, 2　*Hofkeruva pseudojavana* Vella, n.sp.
　　　1, holotype, microspheric; 2, paratype, megalospheric.

3　*Hofkeruva (Laminiuva) zelamina* Vella, n. sp., holotype.

4　*Hofkeruva (Laminiuva) tutamoea* Vella, n. sp., holotype.

5, 8, 9　*Hofkeruva (Trigonouva) miozea* (Finlay)
　　　5, megalospheric N.72 f. 520 Bispherica Zone; 8, 9, microspheric N. 80 f. 1765 Triloba Zone.

6, 7　*Hofkeruva (Tereuva) euteres* Vella, n. sp.
　　　6, holotype; 7, paratype.

10　*Hofkeruva (Tereuva) picki* Vella, n. sp., holotype.

11　*Hofkeruva (Trigonouva) gargantua* Vella, n. sp., holotype.

12　*Hofkeruva (Tereuva) primigena* Vella, n. sp., holotype.

13, 14　*Hofkeruva (Tereuva) semiteres* Vella, n. sp.
　　　13, holotype; 14, paratype.

15, 16　*Hofkeruva (Trigonouva) zeacuminata* Vella, n. sp.
　　　15, paratype; 16, holotype.

PLATE 1
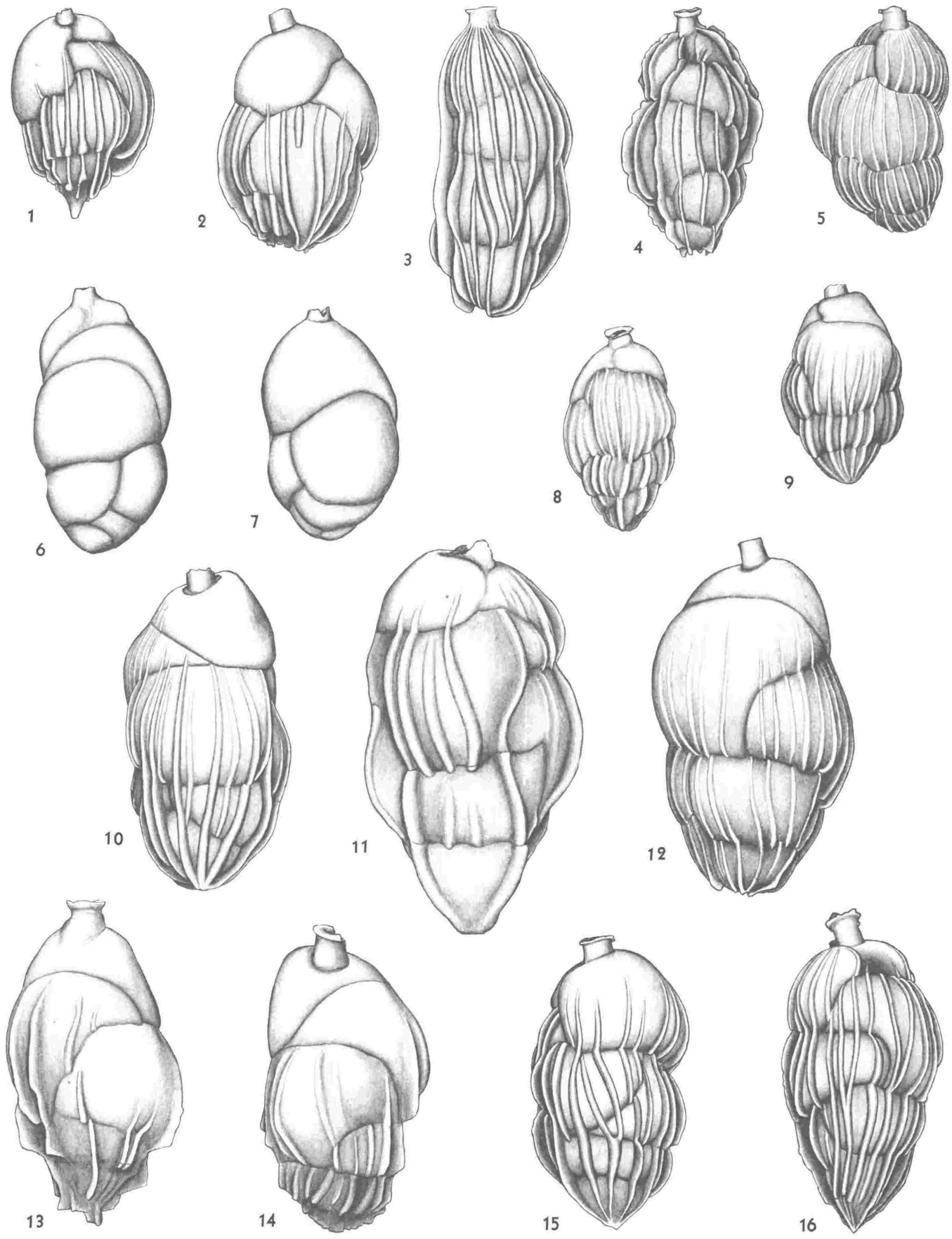
seen, all specimens opened having been filled with matrix or secondary deposits, but the small size and regular placing of chambers suggest relationship to *Angulogerina*.

The species is taxonomically isolated.

Norcottia mioindex (Finlay)
Plate 2, figure 14

Hopkinsina mioindex FINLAY, 1947, New Zealand. Jour. Sci. Technol., sec. B, vol. 28, no. 5, pp. 282–283, pl. 5, figs. 80–82.

Dimensions of hypotype: 0.59 × 0.19 mm.

Age: Mioindex to Hurupiensis zones in the lease area, Lillburnian to Kapitean elsewhere (Helvetian to Tortonian).

Localities: Holotype, F. 5305, Porangahau Survey District, Hawkes Bay (Lillburnian?); hypotype, N 81, f. 609, Tokomaru Bay (Hurupiensis zone).

Remarks: N. mioindex is a fairly persistent species throughout New Zealand. It appears suddenly in abundance at the base of the Mioindex zone, and disappears suddenly, without descendants, at the top of the Kapitea zone. Being distinctive and abundant, it is an invaluable index fossil.

Genus Miniuva Vella, new genus

Type species: *Miniuva minima*, n. sp.

Tiny, triserial, tending to uniserial, moderately elongate, with somewhat irregular lobulate habit; sculpture of irregular longitudinal costae not continuous over sutures; apertural neck very short with slightly reflexed lip.

Like *Norcottia mioindex* this species is taxonomically isolated. Its aperture is distinctive. Its habit is too irregular for *Norcottia* and its minuteness excludes it from *Hofkeruva*.

Miniuva minima Vella, new species
Plate 2, figures 8–10

For description see generic diagnosis above.

Dimensions of holotype: 0.29 × 0.10 mm., figured paratypes 0.31 × 0.12, 0.25 × 0.09 mm.

Age: Mioindex zone (Lillburnian, Helvetian).

Locality: N. 72 f. 1349, Waiapu River, near Ruatoria.

Remarks: Known definitely only from the type locality.

Genus Ruatoria Vella, new genus

Type species: *Ruatoria ruatoria*, n. sp.

Small, narrow, elongate, initially triserial, last two or three chambers staggered uniserial, irregularly lobulate with deeply impressed sutures; sculpture narrow distant costae not continuous over sutures, not reaching the upper part of the final chamber; apertural neck broad, slightly constricted at the middle expanding to somewhat irregular flaring lip.

Ruatoria ruatoria Vella, new species
Plate 2, figures 12–13

For description see generic diagnosis.

Dimensions: Holotype 0.45 × 0.13 mm.; paratype 0.43 × 0.11 mm.

Age: Bispherica to Mioindex zones (mid-Altonian to mid-Lillburnian, Aquitanian to Helvetian).

Locality of holotype and figured paratype: N. 72 f. 1429, Bispherica zone, Waiapu River, near Ruatoria.

Remarks: No related New Zealand species are known but *Siphogenerina panggoensis* Leroy from the Telisa formation (Miocene) of Sumatra is similar. *Ruatoria* is easily distinguished from *Rectuvigerina* by its smaller size, irregular profile, staggered terminal chambers and rather distinctive aperture.

Genus Rectuvigerina Mathews, 1945

Type species: By original designation, *Siphogenerina multicostata* Cushman and Jarvis, 1929.

The New Zealand Oligocene to Miocene sequence *striatissima* (Stache)—*rerensis* (Finlay)—*vesca* (Finlay)—*pohana* (Finlay) shows progressive change from coarse-ribbed to fine-ribbed. The change is not gradual, successive species invading suddenly and replacing the pre-existing species. Being widespread and easy to recognize, they are superlatively useful index species. All are most common in the massive calcareous mudstone facies.

R. vesca is probably close to the Java Miocene species figured as *Siphogenerina striata* (Schwager) by Boomgaart (1949, pl. 9, fig. 2). Other New Zealand species are possibly related to contemporaneous overseas species.

Rectuvigerina rerensis (Finlay)
Plate 2, figures 22–23

Uvigerina tenuistriata Reuss. – CHAPMAN, 1926, New Zealand, Geol. Survey, Pal. Bull., no. 11, pl. 14, fig. 9.
Siphogenerina rerensis FINLAY, 1939, Roy. Soc. New Zealand, Trans., vol. 69, no. 1, p. 110, pl. 11, fig. 8.
Rectuvigerina rerensis (Finlay). – MATHEWS, 1945, Jour. Pal., vol. 19, no. 6, p. 596, pl. 82, fig. 15.

Dimensions of Hypotypes: N. 72 f. 1562, 0.82 × 0.22 mm., N. 72 f. 1245 0.72 × 0.22 mm.

Age: Dissimilis to Suturalis zones (Otaian to Clifdenian, Chattian to Burdigalian).

Localities of types.: Holotype, F. 3029 Whangara Beach, Poverty Bay. Hypotypes N. 72 f. 1562, Waiapu River,

Dissimilis Zone; N.72 f. 1245, grid. ref. 728393, Maramatoitoi Stream (Triloba Zone).

Remarks: Distinguishing characters are the relatively heavy, strongly raised, rather widely spaced costae, depressed chambers with flattened ribs and slightly incised sutures. The microspheric form has a single apical spine, the megalospheric has costae produced to form a number of smaller apical spines.

Rectuvigerina vesca (Finlay)
Plate 2, figures 24–25

Siphogenerina vesca FINLAY, 1939, Roy. Soc. New Zealand, Trans., vol. 69, no. 1, p. 109, pl. 13, figs. 46–47.
Rectuvigerina vesca (Finlay). – MATHEWS, 1945, Jour. Pal., vol. 19, no. 6, p. 598, pl. 81, fig. 7.

Dimensions of hypotypes: 0.85 × 0.19, 0.69 × 0.20 mm.

Age: Universa to Gladizea zones (lower to upper Lillburnian, Helvetian).

Localities: Holotype F.5105, Citrini's Area, near Kumara, Greymouth. hypotypes, N.71 f. 1160 grid. ref. 689347, Willow, near Rotokautuku (Universa Zone).

Remarks: R. vesca is distinguished from *rerensis* by its more slender, more delicate test, more elevated, subglobular adult chambers, and finer sculpture. The microspheric and megalospheric forms each have a single large apical spine.

Rectuvigerina pohana (Finlay)
Plate 2, figure 26

Siphogenerina pohana FINLAY, 1939, Roy. Soc. New Zealand, Trans., vol. 69, no. 1, pp. 109–110, pl. 13, figs. 44–45.
Rectuvigerina pohana (Finlay). – MATHEWS, 1945, Jour. Pal., vol. 19, no. 6, p. 395, pl. 82, figs. 10–11.

Dimensions of hypotype: 0.69 × 0.20 mm.

Age: Hurupiensis to Compressa, or Kapitea zones (Waiauan to upper Tongaporutuan or Kapitean, Tortonian to Pontian).

Localities: Holotype F.3099, Uawa Survey District, east of Trig. 166, Poverty Bay, Compressa Zone (upper Tongaporutuan, Sarmatian or Pontian).

Remarks: Smaller than *vesca*, with very fine close ribs. Found in great numbers, but in relatively few samples. In the Mata River, in Tutamoe district, hybrid populations of *Rectuvigerina pohana* × *vesca* and of *Plectofrondicularia pohana* Finlay × *parri* Finlay mark the base of the Hurupiensis Zone.

Genus Ciperozea Vella, new genus

Type species: *Ciperozea ongleyi* (Finlay) = *Siphogenerina ongleyi* Finlay, 1939 (upper Oligocene to Miocene, New Zealand).

In *Rectuvigerina* the adult chambers become rectilinear immediately above the triserial stage which is usually less than half the test; the longitudinal ribs are prominent and extend from suture to suture, a high proportion extending across the sutures from one chamber to the next. In contrast *Siphogenerina ongleyi* has a large triserial portion, does not become truly rectilinear, and has ornament of low ribs tending to become very finely prickly in well preserved specimens, dying on the upper surface of the terminal chamber, and stopped abruptly and neatly in line, slightly above the suture at the base of each chamber.

The New Zealand lower Eocene species *S. prisca* Finlay is similar but smaller and may be an early member of the group.

Siphogenerina seriata Cushman and Jarvis closely resembles *ongleyi*. Specimens in the New Zealand Geological Survey collection, No. 12 from the Cipero Marl of Trinidad, have finer ribs tending to become obsolete, with more pronounced prickliness, but stopped in the same way, neatly in line at the base of each chamber. Another similar form occurs in the Suva Soapstone, having very fine obsolete ribs on later chambers, an apical spine and a number of small spines at the beginnings of ribs on the initial chambers.

The relatively weak ribs stopped above the sutures to give the chambers an undercut appearance, the large triserial stage and staggered uniserial adult chambers distinguish the group from *Siphogenerina* and *Rectuvigerina*.

Ciperozoa ongleyi (Finlay)
Plate 2, figure 21

Siphogenerina ongleyi FINLAY, 1939, Roy. Soc. New Zealand, Trans., vol. 69, no. 1, p. 111, pl. 13, figs. 42–43.
Rectuvigerina ongleyi (Finlay). – MATHEWS, 1945, Jour. Pal., vol. 19, no. 6, p. 594, pl. 81, fig. 18.

Dimensions of hypotype: 0.80 × 0.37 mm.

Age: Dissimilis to Hurupiensis zones (Otaian to Waiauan, Chattian to Tortonian). First appears in Waitakian (Rupelian) elsewhere in New Zealand.

Localities: Holotype, F.5093 Porangahau – Wimbledon Road, Hawkes Bay (Waitakian, Rupelian). Hypotype, N. 72 f. 1565, Waiapu River (Dissimilis Zone).

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PLATE 2
All figures × 70

 1   *Hofkeruva (Hofkeruva) taranakia* Vella, n. sp., holotype.

 2   *Hofkeruva (Hofkeruva) mata zealta* Vella, n. subsp., holotype.

3–4   *Hofkeruva (Hofkeruva) mata* Vella, n. sp., holotype.

 5   *Hofkeruva delicatula* Vella, n. sp., holotype.

 6   *Hofkeruva (Hofkeruva)* cf. *miozea* (Finlay) N.71, f.645 (Maoria Zone).

 7   *Neouvigerina* cf. *interrupta* (Brady) N.80, f.1300 (Bispherica Zone).

8–10   *Miniuva minima* Vella, n. sp. 9, holotype; 8, 10, paratypes.

 11   *Hofkeruva whakatua* Vella, n. sp., holotype.

12–13   *Ruatoria ruatoria* Vella, n. sp. 12, holotype; 13, paratype.

 14   *Norcottia mioindex* (Finlay) N.81, f.609, Hurupiensis Zone.

 15   *Neouvigerina toddi* Vella, n. sp., holotype.
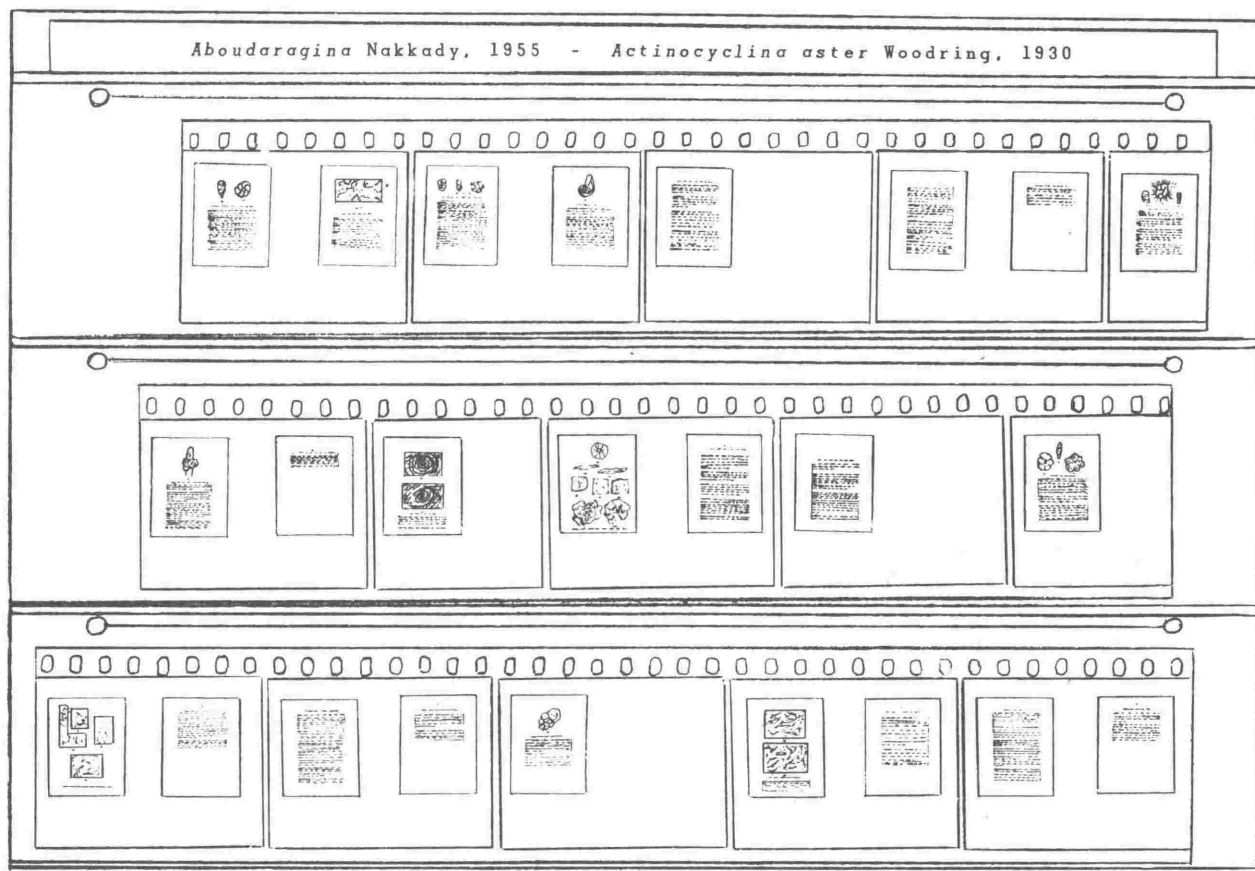
16, 18   *Euuvigerina notohispida* (Finlay). 16, microspheric; 18, megalospheric N. 72, f.1259 (Hurupiensis Zone).

 17   *Neouvigerina moorei* Vella, n. sp., holotype.

 19   *Neouvigerina plebeja* Vella, n. sp., holotype.

 20   *Neouvigerina aotea* Vella, n. sp., holotype.

 21   *Ciperozea ongleyi* (Finlay) N.72, f.1565 (Dissimilis Zone).

22–23   *Rectuvigerina rerensis* (Finlay) 22, megalospheric N. 72, f. 1245 (Triloba Zone); 23, microspheric N. 72, f. 1562 (Dissimilis Zone).

24–25   *Rectuvigerina vesca* (Finlay) N. 71, f. 1160 (Universa Zone); 24, microspheric; 25, megalospheric.

 26   *Rectuvigerina pohana* Finlay N. 81, f. 617. (Compressa Zone).

PLATE 2
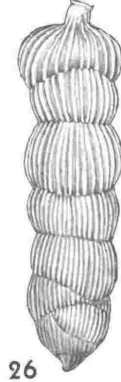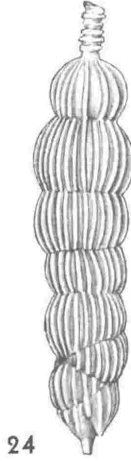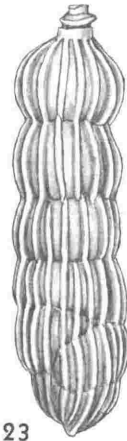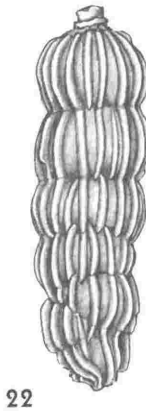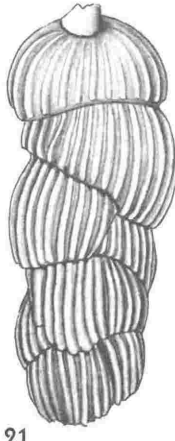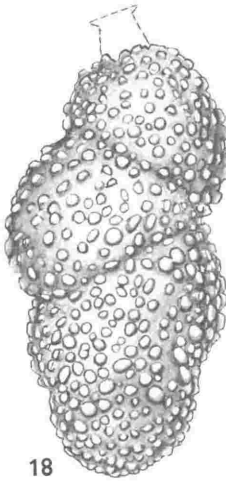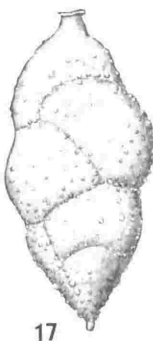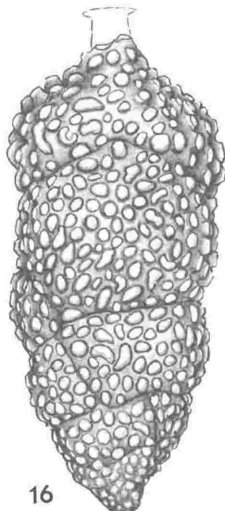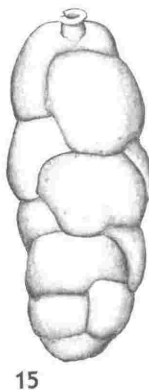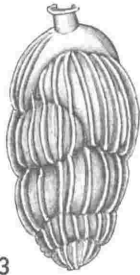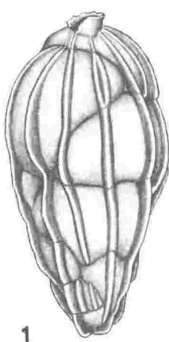
The Catalogue of Foraminifera in microfilm

Aboudaragina Nakkady, 1955 — Actinocyclina aster Woodring, 1930

TEXT-FIGURE 1

The printed edition of the Catalogue of Foraminifera was exhausted in 1958. A new printing cannot be undertaken because of the great cost. The demand for the Catalogue continues, however, and a microfilm edition has been prepared to meet this demand.

The microfilm edition consists of thirty-three 100 foot rolls of 35 mm. film on which the Catalogue, complete through 1958, has been reproduced. More than 1580 genera and 25,275 species are included in this edition.

The rolls of film can be used as issued or cut into strips of four or five frames each and filed in transparent plastic holders (text-figure 1) supplied with each microfilm copy of the Catalogue. These holders can accommodate a total of fifteen frames each, and each frame can be viewed individually in a special flat-bed viewer. Space in which to file supplementary frames can be provided by not filling the holders to capacity initially.

Supplements to the microfilm edition are issued annually and consist of a roll of 35 mm. film. If the transparent holders are being used for the original copy, the supplements should be cut into individual frames and interfiled in the proper places to maintain the alphabetic arrangement. The supplementary frames can be interspliced in the original rolls if a conventional type reader is to be used.

The Catalogue, filed in the transparent holders, can be accommodated in four $5 \times 8 \times 24$ inch file drawers. Self-adhering labelling strips are also supplied with the plastic holders.

This microfilm edition of the Catalogue of Foraminifera is now available on a subscribing membership basis. Inquiries and applications should be directed to the Department of Micropaleontology, The American Museum of Natural History, Central Park West at 79th Street, New York, N. Y.   THE EDITORS.

II - SOME FORAMINIFERAL LINEAGES IN

NEW ZEALAND.

This account has been submitted for
inclusion in a review of foraminiferal
lineages to be presented at the
Congress on the Stratigraphy of the
Mediterranean Neogene, to be held at
Berne, in 1963.

SOME FORAMINIFERAL LINEAGES IN NEW ZEALAND.

By Paul Vella, Victoria University of Wellington, New Zealand.

ABSTRACT.

Twenty-nine species of Foraminifera are described and illustrated. They represent the following eight lineages: Karreriella cylindrica lineage, Plectofrondicularia pohana lineage, Bolivina affiliata lineage, Trigonouva lineage, Tereuva enteres lineage, Tereuva mioschwageri lineage, Laminiuva lineage, and Rectuvigerina pohana lineage. Five of the lineages belong to the Family Uvigerinidae. All the species are abundant and widespread, and are important stratigraphic index fossils in New Zealand.

KARRERIELLA CYLINDRICA LINEAGE (Table I)

The Karreriella cylindrica Lineage includes three described species which appear in succession through the Tertiary. The first to appear is Karreriella novozealandica Cushman (Eocene-Oligocene), the second is Karreriella cushmani Finlay (Miocene) and the third is Karreriella cylindrica Finlay (Upper Miocene - Pliocene). All the species are abundant and widespread in strata of their particular age range, and are useful correlation fossils.

The chief characteristics of the lineage are the moderate to large size, elongation, relatively small multiserial stage, and slightly rough surface finish of the shell. The progressive

Table I. 17

		KARRERIELLA	PLECTO-FRONDICULARIA	BOLIVINA
RECENT				
PLEISTOCENE				
PLIOCENE	Waitotaran	cylindrica		
	Waipipian.	cylindrica		
	Opoitian.			affiliata
UPPER MIOCENE	Kapitean.	hybrid populations.	pohana	affiliata
	Tongaporutuan.	hybrid populations.	pohana	
	Waiauan			
MIDDLE MIOCENE	Upper Lillburnian	cushmani	n. sp.?	
	Middle Lillburnian.	cushmani	n. sp.?	
	Lower Lillburnian.			
LOWER MIOCENE	Clifdenian.		parri	
	Altonian.		parri	
	Awamoan.			anastomosa
OLIGO-CENE	Otaian	intermediate form.	proparri	
	Waitakian		proparri	
	Duntroonian.		proparri	
	Whaingaroan.	novozealandica		
EOCENE				ʀpontis.
PALEOCENE		primitive form.		
DANIAN				

evolutionary trends appear to be increase in size, increase in relative length, decrease in the relative size of the multiserial stage, and a change from a lateral placement of chambers, as in Textularia, to a more terminal though never uniserial placement of chambers. The last trend results in a less compressed and more cylindrical shell, and is the most important for distinguishing the three species.

Karreriella novozealandica is quite distinct from the other species, but a form intermediate between it and Karreriella cushmani occurs in the Pareora Series - Upper Oligocene. The intermediate form is generally classed as Karreriella novozealandica, but it and a primitive form which occurs in the Paleocene (Hornibrook, 1961) may be separable as distinct species. Karreriella cushmani and Karreriella cylindrica closely resemble each other. Both occur in the Upper Miocene (Taranaki Series) and intermediate forms from this part of the column, which have been regarded as intermediate in evolutionary development, are probably hybrids (Vella, 1962, fig. 4)

Karreriella novozealandica Cushman (Plate I, fig. 4)
1936 Karreriella novozealandica Cushman, Contr. Cushm. Lab. Spec.
            Publ. 6, p. 37, pl. 5, figs. 18a, b.
1937 -----------------------; Cushman, ibid, 8, p. 133, pl. 15,
            fig. 9.
1940 -----------------------; Finlay, Trans. Roy. Soc. N.Z. 69
            (4), p. 451, pl. 63, figs. 35 - 37.

The stubbiest member of the lineage; multiserial part about one third to one half of the shell and slightly bulbous; biserial part moderately compressed, usually slightly tapered, with 3 to 5 pairs of short chambers. Length 1-1.5 mm.

Type locality, Motutara Point, Kawhia (Whaingaroan: lower Oligocene). Stratigraphic range of typical form Porangan to Waitakian (Eocene and Oligocene).

Karreriella cushmani Finlay (Pl. I, fig. 5)
1940 Karreriella cushmani Finlay, Trans. Roy. Soc. N.Z. 69 (4),
p. 452, pl. 63, figs. 38 - 42.

Much longer than novozealandica, with markedly lobulate periphery; multiserial part narrower, less bulbous, and a much smaller proportion of the shell; biserial part slightly compressed generally of uniform width throughout, consisting of up to 6 pairs of chambers. Length may exceed 2 mm.

Type locality, F11661, Island Creek, upper Waipaoa Valley, Raukumara Peninsula (Clifdenian - Suturalis Zone). Stratigraphic range, Awamoan to Kapitean (Miocene - about Aquitanian to Pontian).

Karreriella cylindrica Finlay (Pl. I, fig. 6.)
1935 Karreriella siphonella (Reuss); Parr, Trans. Roy. Soc. N.Z.
65 (2), p. 84, pl. 20, fig. 3.
1940 Karreriella cylindrica Finlay, Trans. Roy. Soc. N.Z.
69 (4), p. 452, pl. 63, figs. 43 - 46

Similar to cushmani, but differing in being almost perfectly cylindrical, with scarcely lobulate profile, and multiserial part merging imperceptibly in to the biserial part. Length may exceed 2 mm.

Type locality, F5557A, Cheviot district, North Canterbury (Tongaporutuan).

Stratigraphic range, Waiauan to Waitotaran (about Tortonian to Upper Pliocene).

Forms with a strongly lobulate periphery (like cushmani) occur even in the Opoitian (lower Pliocene), but always in populations predominantly like typical cylindrica.

PLECTOFRONDICULARIA POHANA LINEAGE (Table I)

Four New Zealand species belong to Plectofrondicularia in the strict sense (Vella, in press), proparri (Oligocene), parri (Lower and Middle Miocene), pohana (Upper Miocene) and turgida (Lower and Middle Miocene). Plectofrondicularia turgida Hornibrook is thicker than the other species and appears to belong to a different line of which no other species occur in New Zealand. The other three species are closely related and are considered to represent a single lineage.

The shell is fairly large, elongate, pointed at the initial end, rapidly increasing to maximum width so that the edges are sub-parallel for most of the length. Each edge is furnished with

three flange-like longitudinal keels, each side is flat or slight-
ly concave and is ornamented with usually two spaced costae of
varying length. The initial part of the shell is biserial, but
most of the shell is uniserial with chevron-shaped (inverted
V-shaped) chambers.

The progressive evolutionary change which is most important
for distinguishing species is an increase in the internal angle
of the chevron-shaped chambers, from strongly acute in proparri
to strongly obtuse in pohana. Other trends are a slight increase
in thickness of the shell, and increase in convexity of the edges,
so that on later species the middle keel on each edge projects
further beyond the lateral keels than on the earliest species.

Finlay (1939A) noted that successive North American species
show a similar increase in the angle of the chevron-shaped
chambers Plectofrondicularia floridana Cushman being equivalent
to Plectofrondicularia parri, and Plectofrondicularia californica
Cushman and Edwards being equivalent to Plectofrondicularia pohana.
This strongly suggests that the New Zealand and American species
belonged to the same lineage, that each evolutionary stage of
the lineage was spread at least throughout the Pacific, and that
during particular periods, slightly different forms arose at
different places because of geographic separation. It is unlikely
that the New Zealand species evolved in New Zealand. Each appears
suddenly and disappears suddenly, and shows little change from

from the bottom to the top of its stratigraphic range. Hornibrook (1961) states that parri passes into pohana through intermediate forms in the Lillburnian, but the intermediate forms are probably a distinct species which appears abruptly at the base of the Lillburnian Stage and disappears at the top of the Lillburnian Stage. Plectofrondicularia pohana appears, usually in abundance, at the base of the Waiauan Stage, and no pre-Waiauan shells have the typical chamber shape of Plectofrondicularia pohana, not even members of large populations.

Plectofrondicularia proparri Finlay (Pl. I, fig. 7)

1947 Plectofrondicularia proparri Finlay, N.Z. Jour. Sci. Tech.
        28B (5), p. 276, pl. 4, figs. 46 - 48.

1961 ---------------; Hornibrook, N.Z. Geol. Surv. Pal. Bull.
        34 (1) p. 81, pl. 12, fig. 246.

Shell elongate with a very short biserial stage followed by 12 or more chevron-shaped uniserial chambers with sutures at angles ranging from 70 degrees on early part of shell to 45 degrees terminally. Length 1.5 mm.

Type locality: F6560 Tengawai River, South Canterbury (Otaian Stage).

Plectofrondicularia parri Finlay (Pl. I, fig. 8.)

1939 Plectofrondicularia parri Finlay, Trans. Roy. Soc. N.Z. 68
        p. 516, pl. 68, fig. 4.

1961 ---------------; Hornibrook, N.Z. Geol. Surv. Pal. Bull.

34 (1), p. 82, pl. 12, figs. 244 - 5.

Similar in shape to proparri with similar very short bis-erial stage followed by up to 12 chevron-shaped uniserial chambers. Sutures of chevron-shaped chambers bisigmoid, hori-zontal near the edges of the shell then bent up on either side to the apex of the chevron, the angle of which varies from 110 degrees on the early part of the shell to about 60 degrees terminally. Usually, on each side, two longitudinal costae commence near the apex and extend about $\frac{3}{4}$ of the length of the shell. Length up to 1.4 mm.

Type locality, F5273, All Day Bay Mudstone, Kakanui Beach, Otago, (Awamoan).

Plectofrondicularia pohana Finlay (Pl. I, fig. 9.)

1939 Plectofrondicularia pohana Finlay, Trans. Roy. Soc. N.Z. 68,

p. 516, pl. 68, fig. 3.

Similar to parri, and usually possessing two similar long-itudinal costae, differing in that the chevron-shaped uniserial chambers are much less strongly arched, the angle remaining much greater than 90 degrees right to the terminal chamber. Length up to 1.5 mm.

Type locality, Cheviot, Marlborough (Jedburgh Marls - Taranaki Series).

In the Stratigraphic Lexicon (Fleming, ed. 1959) Plectofrond-icularia pohana is recorded as occuring for the last time in the Nukumaruan Stage, but Nukumaruan and all other Pleistocene

specimens are considered by the writer to be reworked. The species occurs abundantly in the Waiauan, Tongaporutuan, and Kapitean stages then cuts out abruptly at the base of the Opoitian Stage (basal Pliocene).

BOLIVINA AFFILIATA LINEAGE (Table I).

The Bolivina affiliata lineage includes three species, of which the first appeared in the upper Eocene, and the last became extinct in the Pliocene. The lineage may be still surviving as Bolivina robusta Brady which Finlay (1939C, p. 320) considered to be related to Bolivina affiliata.

All the species have broad, ovate, depressed, subcarinate bolivine shells, with reticulate ornament connecting raised sutural ribs. The characters which change with time are the texture of the anastomosing sculpture, and the thickness of the early part of the shell.

Bolivina pontis Finlay (Pl. I, fig. 10)
1939 Bolivina pontis Finlay, Trans. Roy. Soc. N.Z. 69 (3), p. 320.
1961 ---------------- Hornibrook, N.Z. Geol. Surv. Pal. Bull.
34 (1), p. 71, pl. 10, fig. 189.

Shell small, at first thick and somewhat rounded, but adult part compressed with carinate periphery. Sculpture of relatively widely-spaced sometimes discontinuous reticulate raised ribs on all but the last two chambers. Length, up to 0.5 mm.

Type locality, F5244, Bridge Point, Otago (Runangan Stage).

Bolivina anastomosa Finlay (Pl. I? fig. 11.)

1939 Bolivina anastomosa Finlay, Trans. Roy. Soc. N.Z. 69 (3),

p. 320, pl. 27, figs. 75 - 7, 103, 111.

Distinguished from pontis by more closely spaced reticulate ribs. The last four or five chambers may be nearly smooth. Length up to 0.5 mm.

Type locality, F5273, All Day Bay Mudstone, Kakanui Beach, Otago (Awamoan - Triloba Zone).

Finlay considered this species to be related to Bolivina byramensis Cushman (America), B. reticulata Hantken (Europe), and B. retiformis Cushman (Egypt), Hornibrook (1961) noted that pontis-like forms occur with anastomosa in the Whaingaroan, and apparently there is a gradual change from pontis to anastomosa during the early Oligocene, but anastomosa then persists without appreciable change up to at least the Clifdenian Stage, and according to Hornibrook up to the Waiauan Stage.

Bolivina affiliata Finlay (Pl. I, fig. 12)

Distinguished from anastomosa mainly by shape: the initial part of the shell is not thick and rounded, but is compressed and carinate from the apex to the adult. Sculpture is generally a little finer and still more closely spaced than on anastomosa. Length, about 0.5 mm.

Type locality, F5703 Westland (Taranaki Series).

Bolivina affiliata makes its first appearance in the Clifdenian
Stage (Hornibrook, in Fleming, ed. 1959, p. 76), and its last
appearance in the Waitotaran Stage (upper Pliocene). Bolivina
robusta appears just above the base of the Pleistocene.

UVIGERINID LINEAGES (Table II)

Uvigerinidae occur in New Zealand from Middle Eocene to
Recent. Eocene and Oligocene species are not numerous, and were
mostly described by Finlay (1939b). Species described from
Raukumara Peninsula (Vella, 1961) are fairly representative for
the Upper Oligocene and Miocene in New Zealand, and further
species described from Wairarapa district (Vella, in press) are
likewise fairly representative for the Pliocene. A number of
present day species are yet to be described, but most of them
appear to be late Pleistocene or Recent immigrants not closely
related to Tertiary species.

Some Tertiary forms are probably endemic, others are closely
related to forms elsewhere in the world. The widespread genus
Siphogenerina (as emended by Mathews, 1945) is not represented.
Seven main Uvigerinid groups have been recognised in New Zealand.

1. "Uvigerina" bortotara Finlay group: Spino-costate triserial
    forms, restricted to the Eocene and Oligocene.

2. Euuvigerina: Large, triserial, with heavy spines. Repres-
    ented in New Zealand by only notohispida (Finlay) which
    ranges from Lillburnian to Kapitean and is closely related

		TRIGONOUVA	TEREUVA euteres line	TEREUVA Mioschwageri line	LAMINIUVA	RECTUVIGERINA
RECENT						
PLEISTOCENE						
PLIOCENE	Waitotaran.				rodleyi	
	Waipipian.	pliozea				
	Opoitian.				tutamoides	
UPPER MIOCENE	Kapitean.		euteres			
	Tongaporutuan.				zelamina	pohana
	Waiauan		paeniteres			
MIDDLE MIOCENE	Upper Lillburnian		primigena	mioschwageri	tutamoea	
	Middle Lillburnian.	zeacuminata		semiteres		vesca
	Lower Lillburnian.					
LOWER MIOCENE	Clidenian.		not			
	Altonian.	miozea	represented	n. sp.	altonica	
	Awamoan					rerensis
OLIGOCENE.	Otaian		picki			
	Waitakian	dorreeni				
	Duntroonian					
	Whaingaroan	maynei				
EOCENE						

to the overseas Tertiary species _rustica_ (Cushman and Edw,)
and _hispida_ (Schwager).

3. _Neouvigerina_: Small, triserial, with sculpture of fine
spines (hispid). A number of New Zealand species have
been described but the stratigraphic range of most of them
has not been determined, and their relationships to one
another and to overseas species are not fully understood.
In New Zealand the group ranges from Lower Oligocene to
Pliocene, and is probably represented at the present day.

4. _Hofkeruva_: Of moderate to large size, triserial, with
costate sculpture. This is by far the most prolific
uvigerinid group in the New Zealand Neogene, as it appears
to be elsewhere in the world. A number of lineages, and
a number of discrete species have been distinguished. The
well-defined lineages have been named as subgenera of
Hofkeruva. The longest ranging lineage is _Trigonouva_
which appears first at the base of the Oligocene, and
continues up to the Pliocene. Four other lineages –
Tereuva 1, _Tereuva_ 2, Hofkeruva (s. Str.) and _Laminiuva_
– appear at successive horizons in the upper Oligocene and
early Miocene. The _Tereuva_ lineages probably evolved in
New Zealand from _Trigonouva_, whereas _Hofkeruva_ and _Laminiuva_
commenced as immigrant species without ancestors in New
Zealand. The group as a whole increases in diversity of
species towards the middle and upper Miocene, then decreases
in diversity towards the top of the Pliocene.

5. <u>Noviuva</u>: Of moderate to large size, triserial, with sculpture
   of costae partly dissected into spines; rather similar to
   the "<u>Uvigerina</u>" <u>bortotara</u> group but larger and separated by
   a time break ranging from Upper Oligocene to Middle Miocene.
   <u>Noviuva</u> is based on the Recent species <u>peregrina</u> (Cushman)
   and includes one described New Zealand Tertiary species,
   <u>zelandica</u>.   It appears in the top Miocene and is common in
   the Pliocene.

6. <u>Rectuvigerina</u>: Slender shells of moderate size, with a small
   triserial stage, followed by typically retilinear uniserial
   chambers, with sculpture of longitudinal costae which are
   generally continuous from one chamber tô the next.   Six
   New Zealand species are classed as <u>Rectuvigerina</u>. Three
   of them constitute a simple lineage commencing in the
   upper Oligocene, and ending at the top of the Miocene.
   Two of the other species - <u>prisca</u> (Finlay) and <u>postprandia</u>
   (Finlay) are not typical, having non-rectilinear uniserial
   chambers, are restricted to the Eocene, and are considered
   by the writer not to be ancestral to the Oligocene-Miocene
   lineage.

7. <u>Ciperozea</u>: Large with a large triserial stage followed by
   two or three uniserial but not rectilinear chambers, with
   a distinctive sculpture of low longitudinal ribs which
   stop abruptly and neatly in line just above the lower
   suture of each chamber; on well-preserved shells the ribs
   have minute prickles on their crests.   Represented in New

Zealand by one species - ongleyi (Fin.) - which is closely related to "Siphogenerina" seriata Cushman and Jarvis, and t to an undescribed species in the Suva Formation of Fiji.

8. Angulogerina: Eight mid-Tertiary species of Angulogerina (and two of Trifarina) were described by Hornibrook (1961). Late Tertiary forms are yet to be described.

Norcottia and Miniuva are other groups represented by single species in the Miocene, and are possibly endemic.

The five best defined lineages are described below.

TRIGONOUVA LINEAGE

Trigonouva is distinguished by its obscurely tricarinate juvenile shell, followed by inflated rounded adult chambers. Adult sizes of different species range from 0.6 mm. to more than 1.0 mm. Costae are heavy and regular, but generally die out on the upper surface of the terminal chamber, leaving a smooth area around the base of the apertural neck.

Trigonouva maynei (Chapman) (Pl. II, fig. 18.)

1926 Uvigerina maynei Chapman, N. Z. Geol. Surv. Pal. Bull. 11, p. 70, pl. 14, fig. 6.

1939 ------------------; Finlay, Trans. Roy. Soc. N.Z. 69 (1), p. 100, pl. 11, fig. 6, pl. 12, figs. 18, 19.

1961 ----------------; Hornibrook, N.Z. Geol. Surv. Pal. Bull. 34 (1), p. 64.

1961 Hofkeruva (Trigonouva) maynei (Chapman); Vella, Micropaleon-

-tology 7 (4), p. 476.

Small for the lineage, trigonal habit of juvenile scarcely developed, ribs strong and tending to be flange-like on early chambers, tending to become obsolete on adult chambers. Apex blunt, jagged due to produced outer edges of rib terminations. Type locality, North Canterbury - Oxford Chalk (Whaingaroan).

The earliest Hofkeruva in New Zealand, this species arrived here at the beginning of the Oligocene, but its overseas antecedents are not known. Although classed as Trigonouva, it has characters which ally it to Tereuva, and it is probably ancestral both to the Trigonouva lineage and to the Tereuva lineage.

Trigonouva dorreeni (Finlay) (Pl. II, fig. 19)
1939 Uvigerina dorreeni Finlay, Trans. Roy. Soc. N.Z. 69 (1),p. 101
1961 Hofkeruva (Trigonouva) dorreeni (Finlay): Vella,

Micropaleontology, 7 (4), p. 476.

Close to maynei, but with more pointed apex, more distinctly trigonal juvenile. Costae rather variable, tending to become obsolete so that generally most of the shell is smooth, only the apex having strong flange-like longitudinal plates.
Type locality, F5363, 100 ft. above Cobden Limestone, Westland (Waitakian Stage).

The nearly smooth forms classed in this species are probably the fore-runners of the Tereuva lineage, and a case might be made for separating them as a distinct species. More careful study is needed, however, and it is better in the meantime to

regard all Waitakian specimens as members of one variable pop-
ulation which was on the point of diverging into the two evol-
utionary lines.

Trigonouva zeacuminata, Vella (Pl. II, fig. 20)
1961 Hofkeruva (Trigonouva) zeacuminata, Vella, Micropaleontology
                7 (4), p. 476, pl. 1, figs. 15, 16.

     Shell fairly large, with acuminate apex and strong, rounded
regular costae mostly continuous over sutures, tapering to the
apex where they coalesce to form a point, and tapering on the
upper surface of the final chamber, dying before reaching the
apertural neck.
Type locality, N71f1160, Rotokautuku, Raukumara Peninsula (Lower
Lillburnian Stage - Universa Zone).

     Similar to the strongly ribbed extreme forms of dorreeni,
but distinguished by the regularity of the ribs, and the neatly
pointed apex. Trigonouva zeacuminata was reported to range from
Awamoan to Upper Tongaporutuan in Raukumara Peninsula. It def-
initely does not occur below Awamoan at Raukumara Peninsula, but
has been found in the Otaian Stage elsewhere. The Tongaporutuan
form is probably a distinct species.

Trigonouva pliozea Vella (Pl. II, fig. 21)
1962 Hofkeruva (Trigonouva) pliozea Vella, Trans. Roy. Soc. N.Z.
                Geol. 2 (1), p. 8 , pl. 2 , figs. 22-25.

     Similar to zeacuminata, but generally slightly larger, and

the microspheric form sharply acuminate with a prominant spine at the apex. Megalospheric form with a blunter apex usually with two or three costae projecting slightly as apical spines. Costae generally extending right to the base of the apertural neck.

Type locality, N153 fq16, Hawera Road, Eketahuna (Opoitian Stage – Lower Pliocene).

The last of the lineage in New Zealand, restricted to the Pliocene.

<u>Trigonouva miozea</u> (Finlay) (Pl. II, fig. 23)

1939 <u>Uvigerina miozea</u> Finlay, Trans. Roy. Soc. N.Z. 69 (1), p. 102
          figs. 12 - 14.

1961 ---------------------; Hornibrook, N.Z. Geol. Surv. Pal. Bull.
          34 (1), p. 65, pl. 8, fig. 144.

1961 <u>Hofkeruva (Trigonouva) miozea</u> (Finlay); Vella, Micropaleont-
          ology, 7 (4), p. 477, pl. 1, figs. 5,8,9, pl. 2.
          Fig. 6.

Small for the lineage, whole shell usually subtrigonal, costae low and rounded, tending to become very thin on the adult chambers, apex bluntly rounded with or without tiny spines formed by prolongation of costae.

Type locality, F5389, Mangaoporo River, Raukumara Peninsula (Clifdenian Stage).

Although the name <u>Uvigerina miozea</u> has been used for many records up to Pleistocene in age, the species is really a short-lived offshoot of the <u>Trigonouva</u> lineage, restricted to the Lower

Southland Series.

Trigonouva gargantua Vella   (Pl. II, fig. 22)

1961 Hofkeruva (Trigonouva) gargantua Vella, Micropaleontology

7 (4), p. 477, pl. 1, fig. 11.

Very large, trigonal early shell accentuated by heavy costae
on the angles. Other costae covered by smooth callous on early
shell but emerging on middle chambers. All costae obsolescent on
final chamber. Apex narrowly rounded.
Type locality, N80f719 Mangahoui Stream, Raukumara Peninsula
(Middle Lillburnian Stage - Mioindex Zone)

This species has no obvious ancestor in New Zealand and
is probably an immigrant but because of its trigonal shape is
considered to be genetically related to the Trigonouva lineage.
It is restricted to the lower two thirds of the Lillburnian Stage.

TEREUVA LINEAGES

Tereuva is distinguished by shells of moderate to large size
having adult chambers smooth, and exceptionally all chambers
smooth. Typically the apertural neck is set in a shallow circular
depression at the top of the terminal chamber. The group appears
to be endemic and consists of two lineages.

The main lineage is named the Tereuva euteres Lineage and
consists of a succession of four species which show progressive
reduction of the costae until, in the final species - euteres

- they completely disappear. The other lineage is named the
Tereuva mioschwageri Lineage and in it the costae become reduced
in number, restricted to the lower parts of the chambers, and
extended to form fin-like flanges, but this trend is not strictly
progressive.

The Tereuva euteres Lineage is represented from the upper
Oligocene (Otaian Stage) to the Upper Miocene (Kapitean Stage).
The Tereuva mioschwageri Lineage is represented by an undescribed
species in the Lower Miocene (Altonian Stage) and by two described
species in the Middle Miocene (Lillburnian Stage). The fin-like
flanges are strongly reminiscent of the flange-like costae of
Trigonouva maynei, and the mioschwageri line probably diverged
from the euteres line before the Miocene.

1. Tereuva euteres Lineage:

Tereuva picki Vella (Pl. II, fig. 26)
1961 Hofkeruva (Tereuva) picki Vella, Micropaleontology 7 (4), p.
475, pl. 1, fig. 10.

Of moderate size, stout, ovate to subcylindrical, with
broadly rounded or obtusely angled apex. Costae strong on the
early part of the shell, tapering to die or almost die by the
terminal chamber.

Type locality N72f590, Poroporo River, Raukumara Peninsula (Otaian
Stage).

Tereuva primigens Vella (Pl. II, fig. 27)

Tereuva primigena Vella (Pl. II, fig. 27)

1961 Hofkeruva (Tereuva) primigena Vella, Micropaleontology

7 (4), p. 476, pl. 1, fig. 12.

Large, obese, similar to picki, but with much lower, thinner costae, very weak on adult chambers, but generally reaching the terminal chamber.

Type locality, N80f1448, Mata River, Raukumara Peninsula (Lillburnian Stage).

Tereuva paeniteres (Finlay) (Pl. II, fig. 28)

1939 Uvigerina paeniteres Finlay, Trans. Roy. Soc. N.Z. 69 (1),

p. 103.

1961 Hofkeruva (Tereuva) paeniteres (Finlay); Vella, Micropaleontology, 7 (4), p. 476.

Large with deeply impressed sutures, costae weak, restricted to the early part of the shell.

Type locality, F3132 Kaiti Beach, Poverty Bay (probably Waiauan Stage.)

Tereuva euteres Vella (Pl. II, fig. 29)

1961 Hofkeruva (Tereuva) euteres Vella, Micropaleontology 7 (4),

p. 476, pl. 1, figs. 6,7.

Shell of moderate size, with deeply impressed sutures. Surface entirely smooth or rarely with faint traces of costae at the apex.

Type locality, N80f705, Tokomaru district, Raukumara Peninsula (Upper Tongaporutuan Stage).

2. _Tereuva mioschwageri_ Lineage:

Tereuva semiteres Vella (Pl. II, fig. 24)

1961 _Hofkeruva (Tereuva) semiteres_ Vella, Micropaleontology 7 (4),

p. 475, pl. 1, figs. 13, 14.

Of moderate,size, stout, with deeply incised sutures and irregular profile. Costae few, irregular in size, flange-like, some dying out on the early part of the shell, some persisting to the penultimate chamber.

Type locality, N80fl406, Mata River, Raukumara Peninsula (Lower or Middle Lillburnian).

Tereuva mioschwageri (Finlay) (Pl. II, fig. 25)

1939 _Uvigerina mioschwageri_ Finlay, Trans. Roy Soc. N.Z. 69 (1),

p. 103.

1961 _Hofkeruva (Tereuva) mioschwageri_ (Finlay); Vella,

Micropaleontology, 7 (4), p. 475.

Larger than _semiteres_, with a more tapering apex, and with more numerous costae, some of which are flange-like, some weaker, all generally extendingto the penultimate chamber.

Type locality, N97f948, Waikura Stream, Poverty Bay (Upper Lillburnian).

An undescribed species in the Altonian is more like _mioschwageri_ than _semiteres_, but is distinguished by lower, twisted costae. It is the first known species of the _mioschwageri_ lineage, and is probably derived from _Tereuva picki_.

LAMINIUVA LINEAGE

Laminiuva is characterised by shells of moderate size with typically flange-like longitudinal costae that extend strongly from apex to the base of the apertural neck. As originally described there were three species, two of which were sub-divided into chronological subspecies, but all five forms are here treated as species. The species are distinguished chiefly by differences in shape and in the thickness and regularity of the costae. The trends, if any, are towards a narrower shell and thicker, lower, more regular costae.

Size ranges from 0.5 mm to 0.85 mm.

The lineage appears first in the Awamoan Stage, as an immigrant form without fore-runners in New Zealand, and continues up to the Pleistocene. It is not yet known in present day faunas.

Laminiuva altonica Vella (Pl. I, fig. 13)

1961 Hofkeruva (Laminiuva) tutamoea altonica Vella, Micropaleontology, 7 (4), p. 474, text - fig. 5.

Small for the lineage, with thick, raised, narrowly flange-like costae which extend generally unbroken the full length of the shell. Type locality, N159f592, Tinui Valley, Wairarapa (Awamoan Stage).

This is considered to be the ancestral form. Altonian specimens are a little larger, and possibly are intermediate between altonica and tutamoea.

Laminiuva tutamoea Vella   (Pl. I, fig. 14)

1961 *Hofkeruva (Laminiuva) tutamoea tutamoea* Vella, Micropaleont-
ology, 7 (4), p. 474, pl. 1, fig. 4.

Of moderate size, with irregular lobulate outline and trunc-
ated apex. Numerous flange-like costae serrated by breakage of
their hyaline-thin outer edges. Type locality, N80f1426, Mata
River, Raukumara Peninsula (Upper Lillburnian Stage).

Laminiuva zelamina Vella   (Pl. I, fig. 15)

1961 *Hofkeruva (Laminiuva) zelamina* Vella, Micropaleontology 7 (4)
p. 474, pl. 1, fig. 3.

Large, subcylindrical, with rounded apex. Costae regular,
continuous from apex to apertural neck, flange-like but thick and
not serrated by breakage. Type locality, N80f1368, Mata River,
Raukumara Peninsula (Waisuan Stage).

Laminiuva tutamoides Vella   (Pl. I, fig. 16)

1962 *Hofkeruva (Laminiuva) rodleyi tutamoides* Vella, Trans. Roy.
Soc. N.Z. Geol. 2 (1), p.9

Of moderate size, narrow, with rather irregular thin flange-
like ribs generally serrated by breakage of the edges like those
of tutamoea. Type locality, N153 f953, Ngaturi Creek, Eketahuna
district (Waipipian Stage).

Laminiuva rodleyi Vella   (Pl. I, fig. 17)

1962 *Hofkeruva (Laminiuva) rodleyi rodleyi* Vella, Trans. Roy. Soc.
N.Z. Geol. 2 (1), p.9, pl.2, figs. 28, 29.

Of moderate size, narrow; acuminate, with regular, rather thick raised costae.

Type locality, N158/583, near Mauriceville, Wairarapa (Waitotaran Stage).

This form is hardly recognisable as Laminiuva, but the relationship is shown by the earlier species tutamoides which grades into rodleyi through intermediate populations in the Waipipian Stage.

RECTUVIGERINA POHANA LINEAGE

Elongate cylindrical shells with a small triserial stage ($\frac{1}{3}$ the total length in rerensis, relatively smaller in other species). The change from triserial to uniserial is fairly abrupt, and the uniserial chambers, usually four or five in number, are perfectly rectilinear. Sculpture consists of regular longitudinal ribs extending from suture to suture on each chamber.

The species of Rectuvigerina in New Zealand have generally been regarded as a linear evolutionary series. Three kinds of progressive evolutionary change are considered to occur: (1) decrease in relative size of the triserial stage, (2) straightening of the uniserial stage to a perfectly rectilinear condition, (3) change in the sculpture from relatively coarse to fine. The New Zealand Eocene forms, prisca and postprandia are primitive in having relatively large triserial stages and non-rectilinear uniserial stages. The early Oligocene species R. striatissima has an extremely small triserial stage and perfectly rectilinear

uniserial chambers, and is the most advanced species we have in New Zealand. Later species have larger triserial stages, and R. striatissima can not be regarded as intermediate between them and the Eocene species. It is extremely unlikely that R. striatissima is a descendant of postprandia (Finlay), and much more likely that it is one of the numerous immigrant species that appeared in New Zealand at the beginning of the Oligocene and that its ancestor was a perfectly rectilinear overseas Eocene species.

The younger three species show only slight changes in structure and shape of the shell, but show the progressive fining of sculpture and probably constitute a linear evolutionary succession - here named the Rectuvigerina pohana lineage. The oldest New Zealand species of the lineage is Rectuvigerina rerensis which is unlikely to be a descendant of the previous R. striatissima and was probably one of numerous immigrants from overseas which arrived in New Zealand at the beginning of Waitakian time. It was followed by R. vesca in the Middle Miocene and R. pohana in the Upper Miocene.

The biozones of the species of the lineage form a continuous succession apparently without any time gaps, but they overlap only slightly or not at all. The change in the sculpture though progressive is not gradual, taking place abruptly at biozone boundaries. Gradational forms, known to the writer for only the two later species - vesca and pohana, are confined to a small thickness of strata which represents a very small proportion of the biozones of each species, and probably are hybrids, not intermediate evol-

utionary stages.

Rectuvigerina rerensis (Finlay) (Pl. I, fig. I)

1939 Siphogenerina rerensis Finlay, Trans. Roy. Soc. N.Z. 69 (1),

p. 108, pl. 11, fig. 8.

1945 Rectuvigerina rerensis (Finlay); Mathews, Jour. Pal. 19 (6),

p. 596, pl. 82, fig. 15.

1961 -------------------------; Hornibrook, N.Z. Geol. Surv. Pal. Bull

34 (1), p. 66, pl. 8, fig. 146.

1961 ----------------------; Vella, Micropaleontology, 7 (4), p.480

pl. 2, figs. 22 - 23.

Triserial stage about $\frac{1}{3}$. Costae relatively thick and widely
spaced. Apex of microspheric form with single rudimentary spine,
that of megalospheric form with several tiny prickles. Length
up to 0.9 mm.

Type locality, F3029 Whangara Beach, Poverty Bay (Awamoan or Alt-
onian).

Rectuvigerina vesca (Finlay) (Pl. I, fig. 2)

1939 Siphogenerina vesca Finlay, Trans. Roy. Soc. N.Z. 69 (1),

p. 109, pl. 13, figs. 46 - 47.

1945 Rectuvigerina vesca (Finlay) Mathews, Jour. Pal. 19 (6), p.598

pl. 81, fig. 7.

1961 -------------------; Vella, Micropaleontology, 7 (4), p. 481,

pl. 2, fig. 24 - 25.

More slender and delicate than rerensis, with more elevated
and globular adult chambers, and finer sculpture. Triserial stage
about $\frac{1}{4}$. Microspheric and megalospheric forms both have a single

prominant apical spine. Length up to 0.9 mm.

Type locality, F5105, Kumara, Westland (Lillburnian).

Rectuvigerina pohana (Finlay) (Pl. I, fig. 3)

1939 Siphogenerina pohana Finlay, Trans. Roy. Soc. N.Z. 69 (1),

     p. 109, pl. 13, figs. 44 - 45.

1945 Rectuvigerina pohana (Finlay); Mathews, Jour. Pal. 19 (6),

     p. 598, pl. 81, fig. 7.

1961 -------------------; Vella, Micropaleontology, 7 (4), p. 481,

     pl. 2, fig. 26.

   Slightly smaller than vesca, with very fine, dense ribs.

Apex slightly pointed but not spined.

Type locality, F3099, Poverty Bay (Upper Tongaporutuan Stage).

   This species occurs abundantly in appropriate facies up to

the top of the Taranaki Series but disappears before the Wanganui

Series and is not replaced by any related species.

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and Pliocene of Wairarapa, New Zealand. <u>Trans. Roy.</u>
Soc. N.Z. Geol. 2 (1), pp. 1—14.

PLATE I

(all figures X 75)

1. _Rectuvigerina rerensis_ (Finlay), holotype.

2. _Rectuvigerina vesca_ (Finlay), holotype.

3. _Rectuvigerina pohana_ (Finlay), holotype.

4. _Karreriella novozealandica_ Cushman, F5382, Bortonian (Middle Eocene).

5. _Karreriella cushmani_ Finlay, holotype.

6. _Karreriella cylindrica_ Finlay, holotype.

7. _Plectofrondicularia proparri_ Finlay, holotype.

8. _Plectofrondicularia parri_ Finlay, holotype.

9. _Plectofrondicularia pohana_ Finlay, holotype.

10. _Bolivina pontis_ Finlay, holotype (after Hornibrook, 1961).

11. _Bolivina anastomosa_ Finlay, holotype (after Hornibrook, 1961).

12. _Bolivina affiliata_ Finlay, Opoitian Stage (lower Pliocene), Wairarapa - somewhat diagrammatic.

13. _Laminiuva altonica_ Vella, holotype.

14. _Laminiuva tutamoea_ Vella, holotype.

15. _Laminiuva zealamina_ Vella, holotype.

16. _Laminiuva tutamoides_ Vella, holotype.

17. _Laminiuva rodleyi_ Vella, holotype.
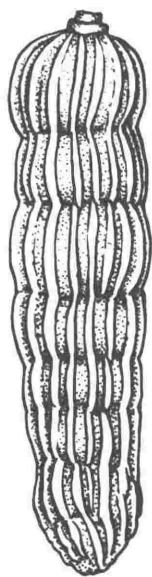
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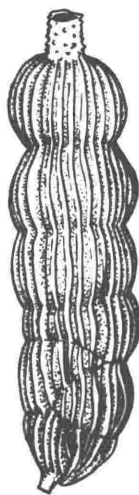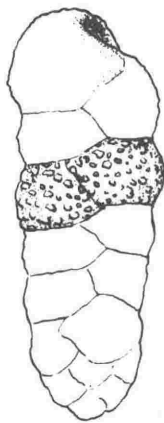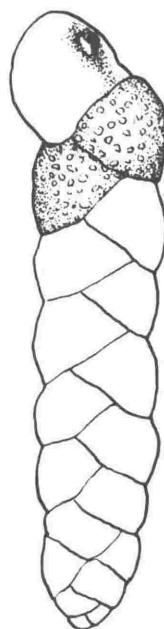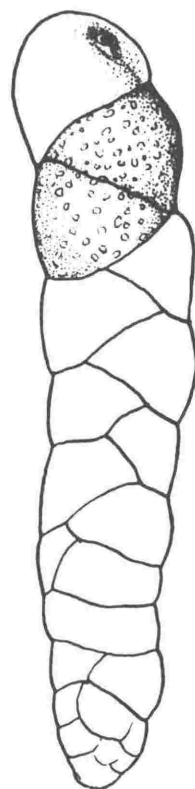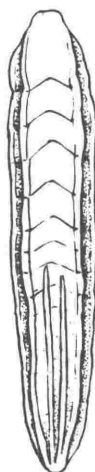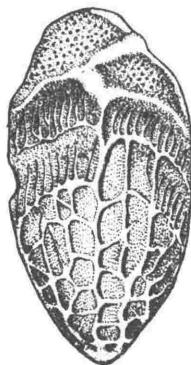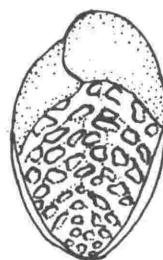
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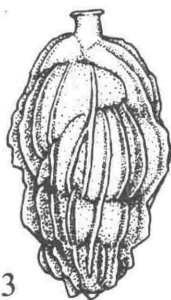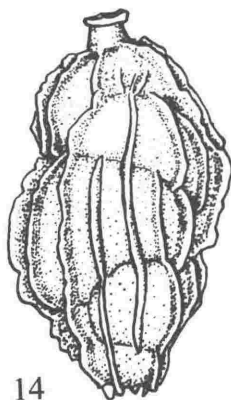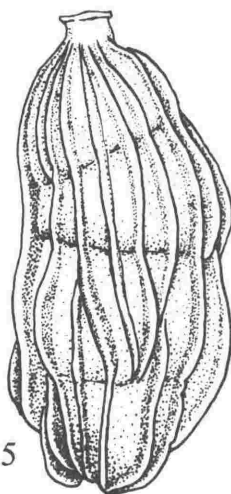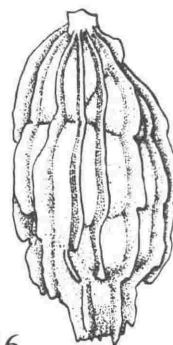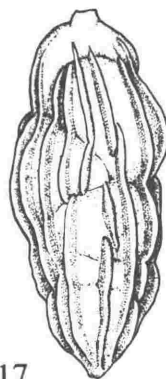
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PLATE II

(all figures X 75)

18. _Trigonouva maynei_ (Chapman), topotype.

19. _Trigonouva dorreeni_ (Finlay), holotype.

20. _Trigonouva zeacuminata_ Vella, holotype.

21. _Trigonouva pliozea_ Vella, holotype.

22. _Trigonouva gargantua_ Vella, holotype.

23. _Trigonouva miozea_ (Finlay), N80f1765, Triloba Zone, Awamoan Stage (lower Miocene).

24. _Tereuva semiteres_ Vella, holotype.

25. _Tereuva mioschwageri_ (Finlay), holotype.

26. _Tereuva picki_ Vella, holotype.

27. _Tereuva primigena_ Vella, holotype.

28. _Tereuva paeniteres_ (Finlay), paratopotype.

29. _Tereuva euteres_ Vella, holotype.
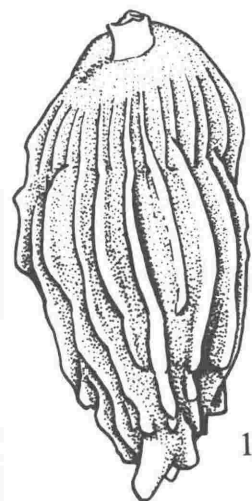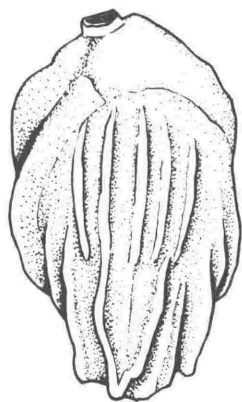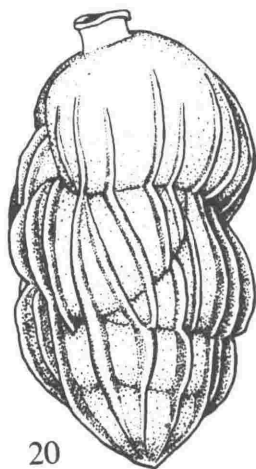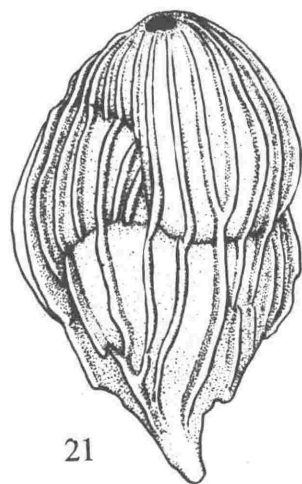
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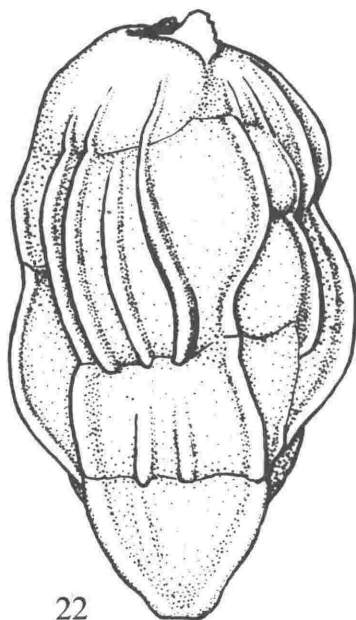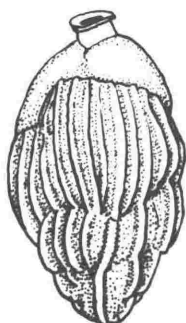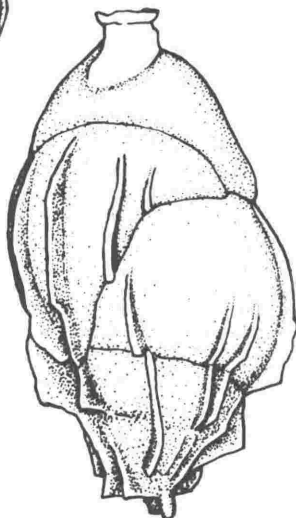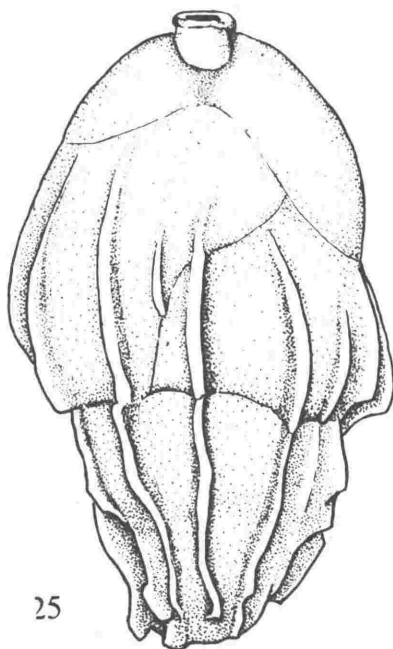
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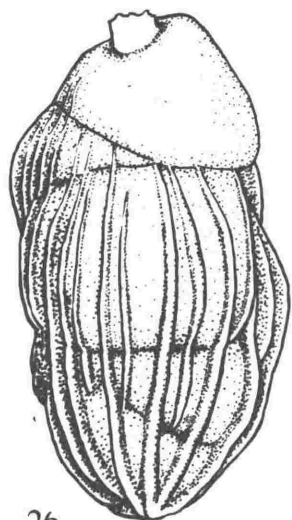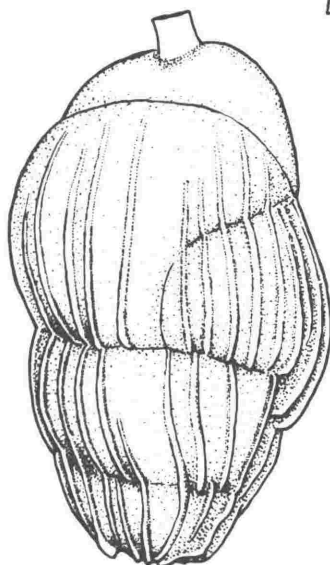
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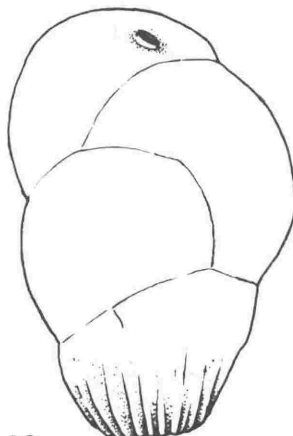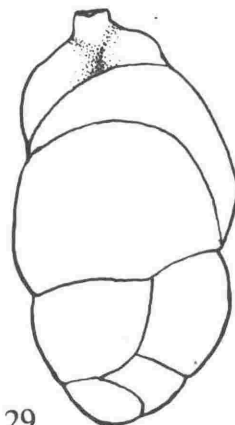
TRANSACTIONS

OF THE

ROYAL SOCIETY OF NEW ZEALAND

GEOLOGY

III – Late Tertiary Nonionid Foraminifera from Wairarapa, New Zealand

By Paul Vella

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Abstract

Wairarapa upper Miocene and Pliocene marine sediments have yielded twelve species of Nonionidae representing six genera—*Melonis* Montfort, *Florilus* Montfort, *Zeaflorilus* nov., *Nonionella* Cushman, *Astrononion* Cushman and Edwards, and *Pacinonion* nov. Species are of little value for stratigraphic correlation, but are useful depth indicators.

The new genus *Pacinonion*, which is related to the widely distributed *Astrononion*, was restricted to the New Zealand region during the Tertiary, and is now probably restricted to the western Pacific. The new genus *Zeaflorilus* includes as type species *Nonionella parri* Cushman (since 1940, known as *Pseudononion parri* in New Zealand). Two new species of *Melonis*, two of *Pacinonion*, and one of *Astrononion* are described.

Introduction

The name Nonionidae is used here in its restricted sense (Sigal, 1952), excluding *Elphidium* and related genera which are now grouped in the family Elphidiidae. Two long disused generic names—*Florilus* Montfort, and *Melonis* Montfort—were recently revived by *Voloshinova* (1958) for distinctive groups of species which up till now have been lumped in the genus *Nonion* Montfort. The genus *Nonion* in its restricted sense comprises species with prominent umbones

	ZEAFLORILUS BIOFACIES	ELPHIDIUM BIOFACIES	HAEUSLERELLA BIOFACIES	KARRERIELLA BIOFACIES	ROBULUS BIOFACIES	SEMIPELAGIC BIOFACIES	EUPELAGIC BIOFACIES
Inferred depth in ft. 0 20 400 900 1,100 2,000 4,000							
ASTRONONION vadorum							
PACINONION poriensis							
novozealandicum							
cf. parki							
neefi							
MELONIS lutorum							
zeobesus							
FLORILUS flemingi							
ZEAFLORILUS parri							
NONIONELLA zenitens							
magnalingua							
NONIONELLA? sp.							

Fig. 1.—Approximate depth ranges of Nonionidae in the late Tertiary of Wairarapa; occurrences in biofacies with inferred depth ranges of biofacies. Broken lines indicate either uncertain occurrence or rare occurrence.

bathyal mudstones, and a variety of coarse to fine shallow-water sediments. Biofacies are varied, representing a considerable range of depths. Fossil Foraminifera include twelve species of Nonionidae; only three other species of Nonionidae—*Melonis maoricum* (Stache), *Nonionella novozealandica* Cushman, and *Nonionella ? gemina* Hornibrook—have been reported from upper Miocene or Pliocene rocks elsewhere in New Zealand.

Within the Upper Miocene and Pliocene the Nonionidae are of little use as stratigraphic index fossils, but nearly all are useful ecological indicators. Depth ranges of the Wairarapa species (Fig. 1) are inferred mainly from occurrences in biofacies which were defined by Vella (1962a, 1962b) and Kennett (in press). The name Pseudononion Biofacies is now changed to Zeaflorilus Biofacies because of the generic name change in this account.

The Wairarapa species of *Melonis, Astrononion,* and *Pacinonion* are fully described and illustrated in this account. Those of *Florilus, Zeaflorilus* and *Nonionella* (except *Nonionella ? sp.*) are already well described and illustrated elsewhere.

Holotypes of new species and all figured specimens are in the collection of the Geology Department, Victoria University of Wellington. Paratypes of new species have been presented to the New Zealand Geological Survey.

Locality numbers are New Zealand fossil record numbers based on the national one-mile topographic-sheet district grid. The master files for fossil record numbers of Wairarapa Sheet districts are in the Geology Department, Victoria University of Wellington.

Subfamily NONIONINAE Schultze, 1854

Genus ASTRONONION Cushman & Edwards, 1937

TYPE SPECIES: by original designation, *Nonionina stelligera* d'Orbigny; Recent, Canary Islands.

Cushman (1948) recognised that the genus *Astrononion* included two kinds of shells, one with "rhomboid" supplementary chambers, the other with "tubular" supplementary chambers. These two different kinds of shells are here separated as distinct genera, *Astrononion* and *Pacinonion*.

The type species of *Astrononion* could hardly have been less happily chosen. Cushman (1939, p. 36) remarked: "The types of this species came from shallow water off the island of Teneriffe, Canary Islands, where d'Orbigny recorded it as very rare. There have been many records referred to this species . . . but . . . none of them are identical with the species figured and described by d'Orbigny". Presumably the type cannot be found, and the only indication that we have of the generic characters is an indifferent illustration by d'Orbigny which has been reproduced by Cushman (1939, Pl. 10, fig. 1).

D'Orbigny's drawing is highly idealised, but fairly certainly indicates overlapping triangular supplementary chambers. The angle near the umbilical ends of the last two supplementary chambers, remarked on by Cushman (1939, p. 36) is probably incorrectly drawn owing to d'Orbigny's incorrect observations of the way in which one supplementary chamber overlaps another. Each of the earliest four visible supplementary chambers is shown overlapping the one subsequent to it, an improbable condition, and the reverse of that in all other species with triangular supplementary chambers. With the overlap of these early supplementary chambers reversed, and the angle taken out of the anterior margin of the latest two supplementary chambers, d'Orbigny's figure looks very similar to *Astrononion gallowayi* Loeblich and Tappan (= *stellatum* Cushman and Edwards, not *Nonionina stellata* Terquem) from off Iceland, as was suggested by Parker (1952).

Only *Astrononion galkowayi* Loeb. & Tap., *tumidum* Cush. & Ed., and *viragoense* Cush. & Ed. have supplementary chambers that are approximately rhomboid in shape. On many other species supplementary chambers described by Cushman as "rhomboid" are triangular, though overlap of the broad umbilical ends gives a rhomboid appearance on some. Both rhomboid and triangular forms of supplementary chambers taper narrowly to their peripheral ends, and typically are soldered to the shell only on the anterior and umbilical margins. On any shell each of the later-formed supplementary chambers normally has the whole of its posterior margin free and raised slightly above the shell wall to leave a long slit-like supplementary aperture. In many species the earlier-formed supplementary chambers, however, have their posterior edges soldered to the shell for some distance out from the umbilicus by callous, and are beginning to assume the appearance of tubular supplementary chambers. In one species, *Astronion italicum* Cush. & Edw. even the latest-formed supplementary chambers are subtubular with very oblique low, slit-like apertures at their peripheral ends.

Astrononion is here restricted to species with triangular or rhomboid supplementary chambers which have apertures along their posterior margins, and which

contrast with the parallel-sided tubular supplementary chambers of the new genus *Pacinonion*. *Astrononion* differs further from *Pacinonion* in having the umbilicus covered by the inner ends of the supplementary apertures, in usually having fewer chambers per whorl, and in having somewhat irregularly shaped chambers.

The writer examined the types of *A. impressum* Hornibrook, and *A. pusillum* Hornibrook. *A. impressum* is definitely an *Astrononion*, having long slit-like openings along the posterior margins of triangular supplementary chambers. The supplementary chambers of *A. pusillum* are difficult to see clearly, but appear to be parallel-sided tubes like those of *Pacinonion*. The umbilicus of the shell is closed, however, and the apertures of the supplementary chambers are quite long and very oblique like those of *A. italicum*. *A. pusillum* is therefore typical of neither *Astrononion* nor *Pacinonion* and is provisionally left as a member of *Astrononion*.

Astrononion cf. *fijiense* Cushman & Edwards, with short supplementary chambers like those of the Fijian species, occur in a N.Z. Geological Survey sample from Hobson's Bay, Auckland (lower Miocene). It has not been recorded previously.

Astrononion now has a world-wide distribution, and occurs in the Eocene of Europe and New Zealand, the Oligocene of New Zealand, the Miocene of Australia and New Zealand, and the Pliocene of Australia, New Zealand, Japan and Europe. It was widely distributed during much of the Tertiary and is probably the stock from which *Pacinonion* arose. Species of emended *Astrononion* are:

> *stellatum* (Terquem), Eocene France
> *italicum* Cushman & Edwards, Pliocene Italy (?)
> *sidebottomi* Cushman & Edwards, Recent, Mediterranean
> *stelligerum* (d'Orbigny), Recent, Canary Islands
> *gallowayi* Loeblich & Tappan, Recent, Iceland and Alaska
> *tumidum* Cushman & Edwards, Recent, Ascension Island
> *viragoense* Cushman & Edwards, Recent, British Columbia
> *aomoriense* Asano, Pliocene, Japan
> *hamadaense* Asano, Pliocene, Japan
> *australe* Cushman & Edwards, Miocene and Pliocene, Australia
> *fijiense* Cushman & Edwards, Recent, Fiji
> *impressum* Hornibrook, Eocene to Lower Miocene, New Zealand
> (?) *pusillum* Hornibrook, Eocene to Lower Miocene, New Zealand
> cf. *fijiense* Cush. & Edw., Lower Miocene, New Zealand
> *vadorum* n. sp., Pliocene, New Zealand
> *antarcticum* Parr, Recent, off Enderby Land and off Leopold and Astrid Coast,
>   Antarctica

Astrononion vadorum n. sp. (Pl. 1, figs. 4, 5)

Shell of moderate size, moderately compressed, with subparallel sides and rounded periphery. Sutures flush to slightly depressed, linear, distinct, 7–9 per whorl. Primary aperture an arched slit at the base of the terminal face. Supplementary chambers formed by narrow transversely arched plates broadest about quarter of their length from the umbilicus, tapering to the peripheral end, with posterior edges free for almost their full length on last three chambers, soldered to the shell by callous for part of their length on earlier chambers.

Estimated maximum diameter: 0.425 mm; thickness: 0.19 mm (holotype).

TYPE LOCALITY. N153f937, Tiraumea River, Eketahuna District, holotype and 5 paratypes. Twelve additional paratypes from N153f943, Pori Limestone (Waipipian ?).

STRATIGRAPHIC AND ECOLOGIC RANGE.   Known only from the two localities mentioned, probably both Waipipian or Waitotaran (middle or upper Pliocene). N153f937 is a Zeaflorilus Biofacies, and N153f943 is an Elphidium Biofacies, and the inferred depth range of *Astrononion vadorum* is 0 to c200ft.

REMARKS.   *Astrononion vadorum* is distinguished from other described species by the narrowness of the supplementary chambers. Chambers tend to be irregular in shape, inflation varies, and shells tend to be slightly assymetrical.

Genus PACINONION

TYPE SPECIES.   *Astrononion novozealandicum* Cushman & Edwards, Recent (and Plio-Pleistocene), New Zealand.

Similar to *Melonis* and *Astrononion*, but with supplementary chambers consisting of parallel-sided tubes along the inner parts of the sutures on both sides of the shell. Apertures of supplementary chambers small, round to ovate, situated at the peripheral end, and usually normal to the longitudinal axis of the tubes. Umbilicus typically open, chambers numerous, shell of regular shape.
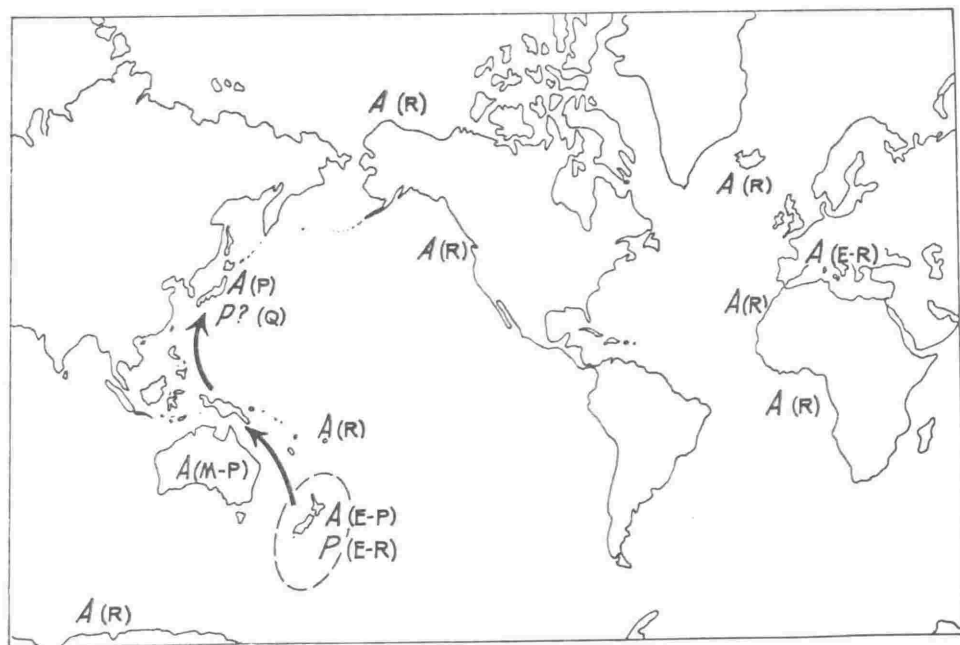
FIG. 2.—Geographic and stratigraphic distribution of *Astrononion*, A, and *Pacinonion*, P. Letters in parentheses: E. Eocene; M, Miocene; P, Pliocene; Q, Quaternary; R, present day. Arrows indicate inferred late Tertiary or Quaternary migration of *Pacinonion* from the New Zealand region (shown by broken line).

The history of *Pacinonion* is different from that of *Astrononion* (Fig. 2). *Pacinonion* is well represented from the Oligocene to the Recent in New Zealand and appears to have been endemic to the New Zealand region to the end of the Tertiary. Judged from the type description (Ellis & Messina, Catalogue of Foraminifera), *Astrononion umbilicatulum* Uchio from the lower *Pleistocene* of Japan is fairly certainly a species of *Pacinonion*. *Astrononion italicum* Cushman & Edwards. from the Pliocene of Italy, might also be considered a species of *Pacinonion*, but has distinctly tapering (narrow triangular) supplementary

chambers with essentially posterior apertures, and is here regarded as a species of *Astrononion* which is convergent to *Pacinonion.* No other species which might belong to *Pacinonion* have been described from beyond New Zealand.

During middle and late Tertiary time New Zealand, being situated to leeward of a continent, received many migrant species of marine organisms, and being situated to windward of a wide expanse of deep ocean, was well adapted to the fostering of endemic and nearly endemic groups, the best known examples among Foraminifera being *Haeuslerella* and *Notorotalia.* The occurrence of *Pacinonion ? umbilicatulum* in Japan may indicate late Tertiary or Quaternary migration like that of *Notorotalia* (see list in Hornibrook, 1961, p. 134). Such migrations of Foraminifera may have had the same basic cause as the extensive Quaternary migrations of the gastropods *Typhina* and *Siphonochelus* (Vella, 1961) and that of the pelecypod *Pecten,* which Fleming (1957) explained as almost certainly controlled by Pleistocene cooling.

SPECIES OF *PACINONION*

	Early to middle Tertiary	Late Tertiary and Quaternary	Recent
New Zealand	*parki* (Hornibrook)	*novozealandicum* *parki* *poriensis* n. sp. *neefi* n. sp.	cf. *novozealandicum* (Cush. & Edw.)
Japan		*umbilicatulum* (Uchio)	

Pacinonion novozealandicum (Cushman & Edwards) (Pl. 1, figs. 10, 11)

> 1937. *Astrononion novozealandicum* Cushman and Edwards, Contr. Cush. Lab. 13, p. 35, Pl. 3, figs. 18a, 18b.
> 1939. *Astrononion novozealandicum* Cushman, U.S. Geol. Surv. Prof. Paper 191, p. 37, Pl. 10, figs. 12a, 12b.

Adult shell large, with deep umbilicus and rounded periphery, the final whorl being nearly circular in cross-section, with 10–12 visible primary chambers. Supplementary chambers distinct, extending from lightly calloused umbilical rim about two-thirds of the distance to the periphery; supplementary apertures, terminal, normal, subcircular, sunken in small pits on the suture lines immediately beyond the peripheral ends of the supplementary chambers. Juvenile more compressed than the adult, with narrowly rounded periphery.

Maximum diameter, 0.60 mm; thickness, 0.31 mm (hypotype, Pl. a, fig. 11).

LOCALITY OF HYPOTYPES. N153f943, Pori Limestone (Waipipian ?).

STRATIGRAPHIC AND ECOLOGIC RANGE. Known only in friable sandy phases of shell limestones of middle and upper Pliocene age and in a few very shallow-water sands of indeterminable age; Zeaflorilus and Elphidium Biofacies, inferred depth range 0 to *c.* 200ft. The full stratigraphic range is not known because of lack of shallow-water biofacies from the uppermost Miocene and lower Pliocene.

Pacinonion cf. parki (Hornibrook) (Pl. 1, figs. 8, 9)

Similar to the Awamoan (Lower Miocene) types of *P. parki* (= *Astrononion parki* Hornibrook, 1961, p. 95, Pl. 12, figs. 230, 237), with typical convexly bevelled sides and narrowly rounded periphery, but with very heavy callous around the umbilicus, tending to spread completely over the supplementary chambers so that only the supplementary apertures are visible as tiny round openings situated in small pits on the sutures about half way between the umbilicus and the periphery. The specimen figured in side view (Fig. 8) is deformed, lacking the eighth to last supplementary chamber.

Maximum diameter, 0.39 mm; thickness, 0.125 mm (hypotype Pl. a, fig. 9).
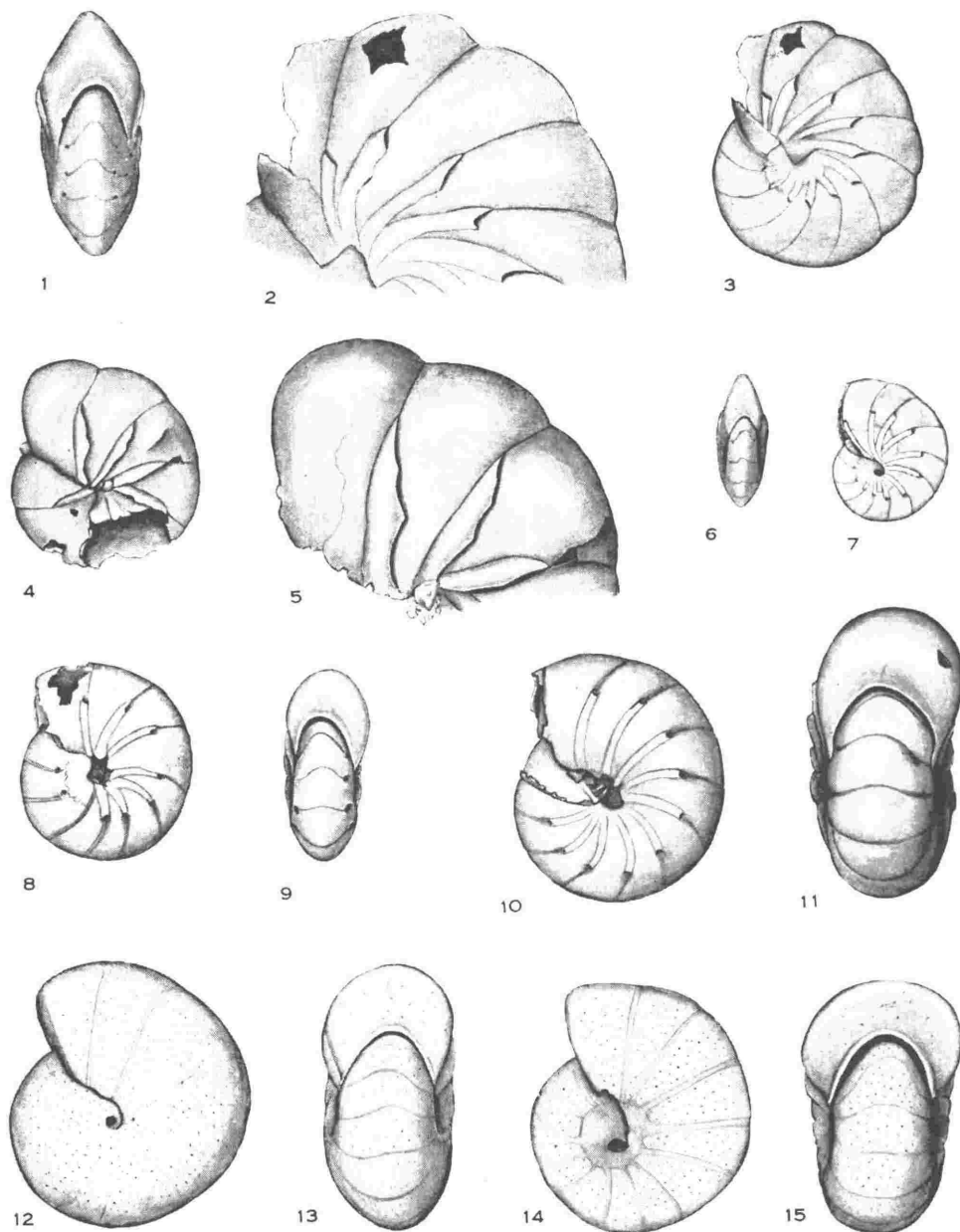
(All figures × 70 unless stated otherwise)

Figs. 1–3.—*Pacinonion poriensis* n. gen., n. sp. 1, holotype; 3, topotype-paratype; 2, detail of same topotype-paratype × 140.

Figs. 4, 5.—*Astrononion vadorum* n. sp., holotype. 5, detail × 140.

Figs. 6, 7.—*Pacinonion neefi* n. gen., n. sp. 6, holotype; 7, topotype-paratype.

Figs. 8, 9.—*Pacinonion* cf. *parki* (Hornibrook) n. gen., N.153f888, upper Pliocene, Eketahuna district.

Figs. 10, 11.—*Pacinonion novozealandicum* (Cushman and Edwards) n. gen., N153f943, mid-Pliocene(?) Pori limestone, Eketahuna district.

Figs. 12, 13.—*Melonis lutorum* n. sp., holotype.

Figs. 14, 15.—*Melonis zeobesus* n. sp. 14, topotype-paratype; 15, holotype.

Locality of Hypotypes.   N153f888, Eketahuna District (Waitotaran ?).

Stratigraphic Range.   The stratigraphic range of *P. parki* was given by Hornibrook (1961) as Runangan to Taranaki Series (Upper Eocene to Upper Miocene). In Wairarapa *P.* cf. *parki* occurs at least as high as Waitotaran (upper Pliocene).

Ecologic Range.   Elphidium Biofacies to Robulus Biofacies, inferred depth range *c*. 200 to 2,000 ± 1,000ft.

Remarks.   Easily distinguished from other late Tertiary species of *Pacinonion* by moderate size and convexly bevelled sides.

Pacinonion poriensis n. sp. (Pl. 1, figs. 1-3)

Shell large for the genus, discoidal, with slightly lobulate subcarinate periphery. Sutures lightly impressed to flush, gently curved, oblique, swept back from the umbilicus. Supplementary chambers tubular, essentially parallel-sided but slightly irregular in shape, and varying somewhat in size, extending about half the distance or less from the umbilicus to the periphery. Supplementary apertures narrowly ovate, terminal, oblique to the tubes. Umbilicus closed, covered with callous which extends out to obscure the inner ends of early supplementary chambers.

Maximum diameter, 0.49 mm; thickness, 0.21 mm (holotype).

Type Locality.   N153f943, Pori Limestone, Eketahuna District (Waipipian or Waitotaran).

Stratigraphic Range.   Like that of *P. novozealandicum* uncertain because of poor sampling of appropriate facies. So far known only from the Middle or

Ecologic Range.   *Zeaflorilus* Biofacies to Elphidium Biofacies, inferred Upper Pliocene.
depth range 0–*c*. 200ft.

Remarks.   *Pacinonion poriensis* differs from all other species referred to *Pacinonion* in having closed umbilici, and oblique openings to the supplementary chambers. The supplementary chambers are furthermore somewhat irregular in size, and not perfectly parallel-sided as are those of the type species. The features may indicate that *poriensis* is not a true *Pacinonion*, but, like *italicum*, an *Astrononion* convergent to *Pacinonion*.

Pacinonion neefi n. sp. (Pl. 1, figs. 6, 7).

Shell tiny, discoidal with slightly lobulate subcarinate periphery. Sutures flush, linear, fairly strongly curved, directed forward from the umbilicus, but curving backwards towards the periphery. Supplementary chambers tubular, regular, extending slightly more than half way across the whorl, with round, normal, terminal apertures. Umbilicus narrow but deep, with rim of callous which extends out to obscure most of each supplementary aperture on the early part of the visible whorl.

Maximum diameter, 0.30 mm; thickness, 0.13 mm (holotype).

Type Locality.   N153f896, Tiratahi Stream, Eketahuna District (Upper Tongaporutuan or Kapitean), holotype and four paratypes.

Stratigraphic Range.   Kapitean (uppermost Miocene) to Opoitian (Lower Pliocene).

Ecologic Range.   Robulus Biofacies to Semipelagic Biofacies, inferred depth range 2,000 ± 1,000ft to 4,000 ± 2,000ft. Infrequent to rare, rather sporadic.

Remarks.   At first sight *P. neefi* might be considered a juvenile of *P. poriensis* because of its discoidal shape, but *neefi* has more nearly radial sutures, normal (not oblique) supplementary apertures, deep open umbilicus, and different inferred depth range.

Summary of Distinctive Features of Late Tertiary Species of
Pacinonion

P. novozealandicum. Large, with convex adult whorl, broadly rounded periphery; supplementary apertures normal to long axes of supplementary chambers, sunken in small pits on the sutures.

P. cf. parki. Of moderate size; with obscurely bevelled flanks and narrowly rounded periphery; supplementary chambers tending to be hidden beneath callous; supplementary apertures normal, sunken in well-defined pits on the sutures.

P. poriensis. Large, discoidal with bevelled flanks and subcarinate periphery; sutures strongly oblique; supplementary apertures oblique to supplementary chambers; umbilicus closed.

P. neefi. Small, discoidal, with bevelled flanks and subcarinate periphery; sutures directed forward from the umbilicus but curving back towards the periphery; supplementary apertures normal to long axes of supplementary chambers; umbilicus open, narrow, deep.

Subfamily MELONISINAE Voloshinova, 1958
Genus Melonis Montfort, 1808

Type species, by original designation, *Nautilus pompilioides* Fichtel & Moll.

Shell coarsely perforate, involute, with broadly rounded periphery, flush sutures and open umbilicus.

Melonis lutorum n. sp. (Pl. 1, figs. 12, 13)

Shell moderately large, subcircular, almost perfectly smooth, with flush, linear, almost radial, slightly backward curving sutures. Aperture a narrow slit at the base of the terminal face, extending along the inner margin of the whorl and apparently into the neat, narrow, deep umbilicus on each side. Flanks of shell convexly bevelled, periphery rather narrowly rounded. Dense perforations of moderate size in all external shell walls. Early part of external whorl apparently varnished with secondary shell deposit making sutures almost invisible.

Maximum diameter, 0.54 mm; thickness, 0.275 mm (holotype).

Type Locality. N153f1016, Bowen Road, Eketahuna district (Opoitian Stage) holotype and three paratypes.

Stratigraphic and Ecologic Range. Rare to infrequent in Semipelagic Biofacies (and Eupelagic Biofacies ?) indicating an inferred depth range greater than 2,000ft. Known only in the Opoitian Stage (lower Pliocene) but its non-occurrence above Opoitian is possibly due to decreasing sea depth.

Remarks. Distinctive features are the flush sutures obscured on early part of whorl, bevelled flanks, and neat smooth appearance of the shell. Karrer's figure of the type of *Nonionina simplex* (reproduced by Cushman, 1939, Pl. 4, figs. 1a, 1b) resembles *Melonis lutorum*, but the resemblance is probably accidental, the shell represented being almost certainly *Melonis maoricum* (Stache) (see *Nonion maoricum*, Hornibrook, 1961, p. 91). *Melonis maoricum* has prominent plates extending into the umbilicus from the inner margin of the whorl.

Melonis zeobesus n. sp. (Pl. 1, figs. 14, 15)

Shell moderately large, subcircular with slightly inflated adult chambers (13 to 15 per whorl), and with distinct, flush, limbate, nearly radial, usually slightly backward curving sutures which coalesce with a broad rim of callous around the wide umbilicus. Aperture

a rather wide slit extending around the base of the terminal face from umbilicus to umbilicus. Juvenile shell somewhat compressed with bevelled flanks and narrowly rounded periphery; adult with strongly convex flanks and broadly rounded periphery. Dense perforations slightly coarser than those of *M. lutorum* in all but the limbate areas of the external whorl.

Maximum diameter, 0.50 mm; thickness, 0.34 mm (holotype).

TYPE LOCALITY. N153f866, Makuri River, Eketahuna District (Waipipian), holotype and 6 paratypes.

STRATIGRAPHIC RANGE. Tongaporutuan (upper Miocene), or earlier, to Waipipian (mid-Pliocene).

ECOLOGIC RANGE. Sporadic but commonly abundant in Robulus Biofacies and possibly in Semipelagic Biofacies. Inferred depth range 2,000 ± 1,000ft to 3,000 ± 2,000ft.

REMARKS. Distinguished from *M. lutorum* by the less compressed adult chambers, broadly rounded periphery, and limbate sutures and umbilical margin. The shell is generally assymetrical, as shown in Fig. 15, but not more so than that of *M. lutorum* and of species of *Astrononion* and *Pacinonion*. The assymetry makes *M. zeobesus* similar to *Anomalinoides subnonionoides* (Finlay), but the two sides of *M. zeobesus* are equally involute. *Nonion halkyardi* Cushman (Eocene, France) is smaller, has only 10 to 12 chambers per whorl, and judged from Cushman's figure has a wider umbilicus without a broad limbate area surrounding it.

<div align="center">Subfamily NONIONELLINAE Voloshinova, 1958</div>

<div align="center">Genus FLORILUS Montfort, 1808</div>

Type species, by original designation, *Nautilus asterizans* Fichtel & Moll, Recent, Adriatic.

Shell symmetrical to slightly assymetrical, chambers rapidly increasing in size, umbilici closed, typically with small glassy nodules clustered on the umbilical area, periphery subangular, walls finely perforate.

Florilus includes at least two species groups; one consists of shells like the type species—large, with subangular periphery, chambers increasing in size moderately rapidly, and umbilical nodules well developed; the other consists of shells like *Florilus grateloupi* (= *Nonionina grateloupi* d'Orbigny)—smaller than the type species, with periphery more rounded, chambers more rapidly increasing in size, and umbilical nodules usually absent or poorly developed.

Nonionellina Voloshinova, 1958 (type species *Nonionina labradorica* Dawson) has a symmetrical adult shell but a *Nonionella*-like juvenile shell and may include some species like *grateloupi*.

Florilus flemingi (Vella)

1957. *Nonion flemingi* Vella, N.Z. Geol. Surv. Pal. Bull. 28, p. 37, Pl. 9, figs. 183, 184.

STRATIGRAPHIC RANGE. Tongaporutuan (Upper Miocene) to Recent.

ECOLOGIC RANGE. Zeaflorilus Biofacies to Karreriella Biofacies, inferred depth range o to *c.* 1,000ft; abundant from 50ft down in Cook Strait.

REMARKS. This species probably belongs to the *grateloupi* group. It may be a *Nonionellina*, but no *Nonionella*-like juveniles have been seen.

Genus ZEAFLORILUS nov.

TYPE SPECIES. *Nonionella parri* Cushman, Recent, New Zealand.

Shell large, trochoid, one side completely involute, convex, with depression in the centre but closed umbilicus, other side completely or nearly completely evolute, flatly domed; sutures limbate; chambers numerous, moderately rapidly increasing; periphery sharply angled; aperture a slit at the base of the terminal face, restricted to the involute side.

Nonionella parri Cushman and *Nonion stachei* Cushman were referred to *Pseudononion* Asano, 1936 by Finlay (in Finlay and Marwick, 1940) and by Hornibrook (1961). The type species of *Pseudononion—P. japonicum* Asano— is a delicate shell, about half the size of *Zeaflorilus parri*, has chambers very rapidly increasing in size, and is close to species of *Nonionella* such as *turgida* (Williamson) and *zenitens* Finlay on the one hand and to *Florilus grateloupi* (d'Orb.) on the other. It lacks the tongue extending from the final chamber over the umbilicus on the more involute side of the type species of *Nonionella* (*N. miocenica* Cushman). Despite this difference *Pseudononion* was synony-mised with *Nonionella*, not without some justification, by Cushman (1948). Both *Pseudononion* and *Nonionella* appear to be derived from the *grateloupi* group of *Florilus*.

The New Zealand early Tertiary species *stachei* is only slightly assymetrical, and is close to *Florilus asterizans* (F. & M.) and especially close to the two European Miocene species *Florilus lamarcki* (d'Orb.) and *Florilus boueanus* (d'Orb.) (Chapman, 1926). *Nonion stachei* Cushman is therefore reclassed as *Florilus stachei* (Cushman).

The size, rate of increase in chamber size, and subangular periphery indicate that *Zeaflorilus*, unlike *Pseudononion* and *Nonionella*, arose from the typical group of *Florilus*. Finlay and Hornibrook both appear to have regarded *stachei* as the ancestor of *parri*. Another Recent species, however, *Nonionella chiliensis* Cushman & Kellett, from off South America, appears to be referable to *Zeaflorilus*, and the ancestor of the genus is not necessarily a New Zealand species but may have been any early Tertiary species of *Florilus*.

Zeaflorilus parri (Cushman)

> 1936. *Nonionella parri* Cushman, Contr. Cush. Lab. 12, p. 89, Pl. 13, figs. 17a–c.
> 1939. *Nonionella parri* Cushman, U.S. Geol. Surv. Prof. Paper 191, p. 34, Pl. 9, figs. 12a–c.
> 1940. *Pseudononion parri* (Cushman), Finlay & Marwick, Trans. Roy. Soc. N.Z. 70(1), p. 122.

STRATIGRAPHIC RANGE.   Lillburnian (mid-Miocene) (Hornibrook, 1961, p. 93) to Recent.

ECOLOGIC RANGE.   Abundant in the Zeaflorilus Biofacies; infrequent, possibly transported specimens only, in the Elphidium Biofacies. Cushman's types came from the sandy beach at Timaru, and the species is common at Island Bay beach, Wellington. Shells occur abundantly from 30 to 1,300ft in Cook Strait (Vella, 1957), but probably nearly all have been transported from shallower water. To-gether with abundant large *Notorotalia* spp. (Foraminifera) and *Zethalia zelandica* (Q. & G.) and *Chemnitzia* sp. (Gastropoda), *Zeaflorilus parri* is extremely abundant in loose cross-bedded sand of Nukumaruan (lower Pleisto-cene) age in southern Wairarapa. These sands are similar to the Shakespeare Cliff Sand (mid Pleistocene) of Wanganui, and were probably deposited in normally saline water at a depth of 6 to 12ft. Abundant *Zeaflorilus parri* usually indicates the Zeaflorilus Biofacies (formerly known as the Pseudononion Bio-facies), which is considered to indicate depths from 0 to about 20ft.

Genus NONIONELLA Cushman, 1926

Type species, by original designation, *Nonionella miocenica* Cushman, Miocene, California.

Nonionella zenitens Finlay

> 1940. *Nonionella zenitens* Finlay, Trans. Roy. Soc. N.Z. 69 (4), p. 457, Pl. 65, figs. 145, 152–6.
> 1961. *Nonionella zenitens* Hornibrook, N.Z. Geol. Surv. Pal. Bull. 34 (1), p. 93, Pl. 12, figs. 225, 231.

STRATIGRAPHIC RANGE. Given by Hornibrook (1961) as Waipawan to Kapitean (Paleocene to Upper Miocene). Shells occurring throughout the Pliocene—Opoitian to Waitotaran (for example N153f888)—in Wairarapa are not significantly different from *N. zenitens*.

ECOLOGIC RANGE. Sporadic and infrequent to common, possibly in part of the Haeuslerella Biofacies, definitely in the Karreriella Biofacies and the Robulus Biofacies. Inferred depth range shallower than 900ft to 2,000 ± 1,000ft.

Nonionella magnalingua Finlay

> 1940. *Nonionella magnalingua* Finlay, Trans. Roy. Soc. N.Z. 69 (4), p. 456, Pl. 65, figs. 144, 146.
> 1961. *Nonionella magnalingua* Hornibrook, N.Z. Geol. Surv. Pal. Bull 34 (1), p. 94, Pl. 12, figs. 226, 232–3.

STRATIGRAPHIC RANGE. Lower Oligocene to Pleistocene (Hornibrook, 1961).

ECOLOGIC RANGE. Nearly the same as, but probably extending to somewhat shallower depth than, that of the less common *N. zenitens*.

Nonionella ? sp.

Shell of small to moderate size with rapidly increasing chambers and narrowly rounded periphery; juveniles apparently bilaterally symmetrical, adults slightly asymmetrical, occasional specimens with a small tongue extending over the umbilicus from one side of the final chamber. Not unlike *Nonionella novozealandica* Cushman, but lacking nodules in the umbilical area; possibly more closely related to the *grateloupi* group of *Florilus*.

LOCALITIES. N153f884, Eketahuna district (Kapitean); N153f877, Mangaone Valley, Eketahuna district (Opoitian).

STRATIGRAPHIC AND ECOLOGIC RANGE. Kapitean (uppermost Miocene) to Opoitian (lower Pliocene). Robulus Biofacies, inferred depth range between 1,000 and 3,000ft; rare.

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TRANSACTIONS

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GEOLOGY

IV - # Some Foraminifera from the Upper Miocene and Pliocene of Wairarapa, New Zealand.

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Abstract

TWELVE new species of fossil Foraminifera are described and illustrated, and three new genera are proposed. The new species are: *Haeuslerella finlayi, Sigmoilopsis zeaserus, Buliminoides missilis, " Bolivina " turbiditorum, Bolivinita pliobliqua, Parafrondicularia wairarapa, Hofkeruva (Trigonouva) pliozea, Hofkeruva (Tereuva) lutorum, Hofkeruva (Laminiuva) rodleyi rodleyi* and *rodleyi tutamoides, Noviuva zealandica, Neouvigerina bellula, Neouvigerina eketahuna.* The species formerly known as *Bigenerina pliocenica* Finlay is transferred to the genus *Haeuslerella* Parr; *Nodosaria sinalata* Finlay, and *subtetragona* Finlay, to the new genus *Awhea* (Lagenidae); *Plectofrondicularia advena* Cushman, *whaingaroica* (Stache) and *vaughani* Cushman to the new genus *Proxifrons* (Lagenidae); *Uvigerina peregrina* and allied spino-costate species to the new genus *Noviuva* (Uvigerinidae).

Known stratigraphic ranges and inferred depth ranges are given for each species.

INTRODUCTION

MOST of the species described below were collected from Eketahuna and Mauriceville districts, in northern Wairarapa, by G. Neef and G. E. Orbell, research students in geology at Victoria University of Wellington. Three new genera and twelve new species are described to validate names for stratigraphic and paleoecological studies.

Over much of Wairarapa slightly indurated marine sediments of Upper Miocene to lower Pleistocene age rest unconformably on a basement of Mesozoic rocks. They form a sedimentary cycle best illustrated by the section exposed in the sea-cliffs at the north-east side of Palliser Bay in southern Wairarapa (Vella, 1962a). Generally the transgressive phase of the cycle indicates rapid deepening and the regressive phase indicates slow shallowing. The Upper Miocene and lower and middle Pliocene sediments are generally several thousand feet thick, and except for the lower few hundred feet are mainly muddy sandstones, mudstones, and

turbidites which were deposited at depths greater than 1,000ft. The upper Pliocene and lower Pleistocene sediments are generally much thinner and coarser, and were mostly deposited in depths less than 1,000ft. Upper Miocene and lower Pliocene shallow-water sediments occur in limited areas and define near marginal parts of the main basin of deposition.

In the deep-water sediments Foraminifera are the only useful age correlation fossils, because other fossils are rare. Correlation of deep- and shallow-water facies is difficult because of differences in foraminiferal faunas (Vella, 1962b). Shallowing during middle and late Pliocene time caused the disappearance of many species from the area. Deep-water species such as *Robulus costatus* (F. and M.), *R. echinatus* (d'Orb.), *Lenticulina mammiligera* (Karr.), and "*Nodosaria*" *multicostales* (Fin.), which are generally considered to have become extinct in lower Pliocene time (Fleming, 1959), may have disappeared because of shallowing, and may have disappeared from different areas at different times. Sediments which have been classed as lower Pliocene solely because they contain one or more of these species may actually be middle or even late Pliocene in age. Stage correlation is not reliable and the stratigraphic range of each species is therefore given in terms of stratigraphic zones of either a deep-water or a shallow-water series, depending on the depth range of the particular species, as well as in terms of New Zealand stages. The stratigraphic zones (defined by Vella, 1962b) and their provisional correlation with New Zealand and European stages are as set out in Table I.

TABLE I.—STRATIGRAPHIC ZONES.

SHALLOW-WATER ZONES	DEEP-WATER ZONES	NEW ZEALAND STAGES	EUROPEAN STAGES
Zelandica Zone	—	Nukumaruan	?
Rotunda Zone	—	Hautawan	Sicilian
Kingmai Zone	—	Waitotaran	Calabrian
—	Molestus Zone	Waipipian	Astian
Olssoni Zone	Inflata Zone	Opoitian	Plaisancian
Kapitea Zone	Zeaserus Zone	Kapitean	Pontian
—	Compressa Zone	Upper Tongaporutuan	Upper Sarmatian

The depth biofacies originally recognised in the Opoitian and Waitotaran stages in northern Wairarapa (Vella, 1962b, 1962c) seem to represent substantially the same inferred depths from the Upper Tongaporutuan to the Hautawan. Depth ranges of species are given in terms of biofacies and inferred depths as follows:

Streblus Biofacies	estuarine
*Zeaflorilus Biofacies	$0 - c$ 20ft
Elphidium Biofacies	200 ± 100ft
Haeuslerella Biofacies	600 ± 300ft
*Karreriella Biofacies	$1,000 \pm 100$ft
Robulus Biofacies	$2,000 \pm 1,000$ft
Semipelagic Biofacies	$4,000 \pm 2,000$ft
Eupelagic Biofacies	$8,000 \pm 4,000$ft

SYSTEMATIC DESCRIPTIONS

All holotypes of new species are in the collection of the Geology Department, Victoria University of Wellington. Paratypes of all except rare species have been presented to the New Zealand Geological Survey.

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* Due to a taxonomic name change the former Pseudononion Biofacies (Vella, 1962b) is now known as the Zeaflorilus Biofacies (Vella, 1962d). The Karreriella Biofacies was first defined by Kennett (in press) in the Kapitean Stage at Cape Foulwind, Westland.

Family TEXTULARIIDAE

Genus HAEUSLERELLA

Haeuslerella finlayi n. sp. (Pl. 1, fig. 11)

Shell large, solid, juvenile two-fifths biserial like *Textularia,* changing fairly suddenly to adult three-fifths which is uniserial but not quite rectilinear. Juvenile part broader than adult part, compressed with narrowly rounded periphery, and with fairly smooth surface cement covering all but the largest sand grains and obscuring the obtusely angled, chevron-shaped flush sutures. Adult part consisting of 3 to 5 hemispheroidal chambers, each except the terminal one half-embraced by the succeeding one; terminal chamber generally slightly produced to the simple, round, terminal aperture; adult sutures impressed and fairly clearly defined; surface of terminal chamber rough, constructed of irregularly-shaped moderately coarse grains, and lacking finishing surface cement; surface of penultimate chamber partly smoothed, and surface of earlier adult chambers almost as smooth as the juvenile shell.

Length: 1.37mm; breadth of juvenile: 0.44mm; breadth of adult: 0.35mm (holotype).

TYPE LOCALITY. N153f907, Eketahuna District (Opoitian), 10 paratypes.

STRATIGRAPHIC RANGE. Compressa Zone?, Zeaserus Zone, Inflata Zone (Upper Tongaporutuan? to Opoitian); deep enough facies are probably lacking above the Inflata Zone.

ECOLOGIC RANGE. Semipelagic Biofacies and probably Eupelagic Biofacies (4,000 ± 2,000ft to greater depth).

REMARKS. Similar to *Haeuslerella pliocenica* (Finlay) but distinguished by the relatively smooth surface of all but the last two chambers. A similar, but smaller and still smoother *Bigenerina*-like form in rocks of similar age but shallower facies, especially at Palliser Bay is a distinct species which is not yet described. Some specimens of *Haeuslerella morgani* Finlay in the Taranaki Series have nearly rectilinear adult chambers, but are smaller than *finlayi,* and have a fairly even cement finish over the whole shell.

Haeuslerella pliocenica (Finlay).

1939. *Bigenerina pliocenica* Finlay, Trans. Roy. Soc. N.Z. 69 (3), p. 311, Pl. 24, fig. 15.

This species was classed as *Bigenerina* by Finlay because of the sudden transition from its biserial juvenile to its rectilinear uniserial phase. Most species of *Haeuslerella* change gradually from the biserial to the uniserial phase, but the late Tertiary species *H. parri* Finlay and *H. finlayi* n. sp. both change suddenly. In its almost rectilinear adult stage and in the roughened surface of its final chambers *finlayi* is intermediate between *pliocenica* and *morgani.* Hence despite its superficial resemblance to the European species *Bigenerina nodosaria* d'Orbigny, *pliocenica* is almost certainly a member of the supposedly endemic New Zealand genus *Haeuslerella* and represents the culmination of the main trend of evolution of the group from completely biserial *Textularia*-like forms (early Tertiary) to predominantly uniserial forms (late Tertiary). The western Java species *Bigenerina speciosa* Yabe and Asano is possibly related to *pliocenica,* as was suggested by Finlay, but if so should be reclassified as *Haeuslerella.*

STRATIGRAPHIC RANGE. Finlay (1939) gave the range as Opoitian to Waitotaran, but for many years it has been considered to extend from Upper Tongaporutuan to Hautawan. The writer, and possibly other micropaleontologists, however, has hitherto misidentified *H. finlayi* as *pliocenica.* The stratigraphic range of true *H. pliocenica* therefore may need to be reassessed.

ECOLOGIC RANGE. Karreriella Biofacies and Robulus Biofacies (c 900 to 2,000 ± 1,000ft).

Family MILIOLIDAE

Subfamily SIGMOILOPSINAE

Genus Sigmoilopsis Finlay

Sigmoilopsis zeaserus n. sp. (Pl. 1, figs. 14, 15).

> 1959. *Sigmoilopsis* aff. *schlumbergeri* (Silv.), Fleming, Lexique Strat. Internat. 6 (4), p. 281.
> 1962. *Sigmoilopsis* n. sp. aff. *schlumbergeri* (Silv.), Vella, Trans. Roy. Soc. N.Z. Geol. 1 (—), *passim*.

Shell large for the genus, broadly ovate, moderately compressed, obscurely sigmoid in end view, with narrowly rounded acute periphery. Aperture circular, situated on a short neck with thin phialine lip seldom preserved, and with a simple internal tooth on the inner side. Surface of shell rough with fine to medium sand grains lacking a finishing layer of cement.

Length: 0.76mm; breadth: 0.575mm; thickness: 0.40mm (holotype).

Type Locality. N153f916, 1½ miles north-east of Hawera Road, Eketahuna District (Opoitian); 7 paratypes.

Stratigraphic Range. Zeaserus Zone to Inflata Zone (Kapitean to Opoitian). *S. zeaserus* replaces *S. schlumbergeri* at or near the base of the Kapitean Stage, thus defining the base of the Zeaserus Zone. Shallowing may account for the absence of *S. zeaserus* from the Molestus Zone, which immediately overlies the Inflata Zone.

Ecologic Range. Robulus Biofacies to Semipelagic Biofacies (2,000 ± 1,000ft to 4,000 ± 2,000ft); fairly persistent, but uncommon.

Remarks. Distinguished from *Sigmoilopsis schlumbergeri* by rougher surface, larger size, and usually greater relative width.

Family LAGENIDAE

Subfamily FRONDICULARIINAE

Apertures of many *Frondicularia*-like species of Foraminifera, even when well-preserved, are difficult to see clearly, and cannot be considered diagnostic of any particular family. Many species have been placed in the Heterohelicid genus *Plectofrondicularia* for no better reason than that they have a biserial initial stage. Well defined radiate apertures show that the *Frondicularia*-like genera *Kyphopyxa* Cushman, *Parafrondicularia* Asano, and *Dyofrondicularia* Asano are definitely Lagenidia, and by common consent these genera are classed as Lagenidae. Some of the species which up till now have been classed as *Plectofrondicularia* are here considered to be *Parafrondicularia*, and others are classed in a new genus *Proxifrons*.

Neanic shells are conservative in many Foraminifera, and prolocula, where visible, appear to be even more conservative. Though the proloculum has not been mentioned by Foraminiferal taxonomists, such as Cushman (1948) and Sigal (1952), if it has some peculiarity of shape or ornament or size, as in many lagenidae, it may be just as useful for determining relationships of foraminiferal species as the protoconch is for determining relationships of gastropod species. Each of the two new genera of Frondiculariinae described below has a distinctive proloculum.

Genus Parafrondicularia Asano, 1938

> Type species, by original designation, *Parafrondicularia japonica* Asano, Pliocene, Japan.

In New Zealand at least three groups of species have been included in *Plectofrondicularia* Liebus, 1903:

(1) Species like the type (*P. concava* Liebus, subsequent designation, Cushman, 1928)—elongate, with concave sides, subparallel margins, quadrate cross-section emphasised by longitudinal keels at the four angles and an additional keel at each peripheral margin—*proparri* Finlay (Oligocene), *parri* Finlay (Lower-Mid Miocene), *turgida* Hornibrook (Lower Miocene), and *pohana* Finlay (Upper Miocene). These species, as noted by Finlay (1939) are closely related to the American *floridana* Cushman (Miocene) and *Californica* Cushman and Stewart (Pliocene). Restricted to species like these, *Plectofrondicularia* forms part of a compact group of Heterohelicid genera which includes *Bolivinita* Cushman, 1927, *Amphimorphina* Neugeboren, 1850 (= *Nodomorphina* Cushman, 1927) and *Staffia* Schubert, 1911. Quadrate cross-section, four primary keels, and usually two peripheral keels are characteristic of these genera, though lost in the adult stage of *Amphimorphina,* and are strongly conservative shell features.

(2) Species similar in outline to typical *Plectofrondicularia,* but with flat (not concave) sides usually ornamented with dense, fine, longitudinal ribs, and with a narrowly rounded or acute periphery lacking the three keels—*fyfei* Finlay, *pellucida* Finlay, possibly *awamoana* Finlay. The adult chambers of these shells are almost invariably broken because they are so delicate; the writer has seen one specimen of *pellucida* with the final chamber and aperture intact. The aperture is round, situated on a short cylindrical neck, and has an irregularly denticulate margin, rather similar to that on *advena* figured by Bready (1884; pl. 66, fig. 9), and could well be a modified radiate aperture. *Parafrondicularia japonica* closely resembles these species (except *advena*) in its overall shape and ornament, and its aperture is radiate though it lacks the neck which occurs on *pellucida*. *Plectofrondicularia fyfei* Finlay and *Plectofrondicularia pellucida* Finlay are therefore reclassed as *Parafrondicularia* in the family Lagenidae. *Plectofrondicularia awamoana* Finlay is reclassed as *Parafrondicularia?*

(3) The third group of species is described below as the new genus *Proxifrons.*

Parafrondicularia wairarapa n. sp. (Pl. 1, figs. 4-6)

Shell fairly large, moderately broad, tapering to acute or narrowly rounded initial end, initially biserial in microspheric, uniserial in megalospheric. Uniserial chambers at first chevron-shaped, but becoming progressively more embracing and more strongly curved at the periphery. Sculpture of 2 to 6 fine longitudinal more or less continuous riblets near the middle of each face, and narrow thin peripheral flange. Proloculum globular with two peripheral flanges.

Length: 0.725mm; breadth: 0.275mm (holotype).

TYPE LOCALITY. N153f971, near Alfredton, Eketahuna District, Middle Tongaporutuan; 2 paratypes; 5 additional paratypes from N153f916, 1½ miles north-east of Hawera Road (Opoitian).

STRATIGRAPHIC RANGE. Below Compressa Zone to Inflata Zone (Tongaporutuan to Opoitian).

REMARKS. Incomplete nearly adult chambers on holotype and figured paratype are pathological deformities. *Parafrondicularia goharai* (= *Plectofrondicularia goharai* Kuwano) from the Pliocene of Japan is the most similar species, but has more numerous ribs which are evenly distributed on the early part of the shell and die out on the adult part. *P. wairarapa* is intermediate in form between *Parafrondicularia* and the new genus *Proxifrons* in its width and its embracing adult chambers. It is intermediate between each of these genera and *Frondicularia* in its development of biserial chambers, the megalospheric form having the essential characters of *Frondicularia.*

Genus PROXIFRONS nov.

Type species: *Plectofrondicularia advena* Cushman, Recent.
Shell extremely compressed, broad and mucronate in side view, with small initial biserial

stage followed by inverted V-shaped chambers extending far back along the periphery towards the apex. Aperture typically round and obscurely radiate. Proloculum typically subspherical and ornamented with a single strong longitudinal rib on each side.

In addition to the type species this genus includes *Frondicularia whaingaroica* Stache (Eocene to Lower Miocene), *Plectofrondicularia vaughani* Cushman (late Tertiary) and similar broad leaf-like species. As noted by Hornibrook (1961, p. 81) *whaingaroica* appears to grade into *advena* in the late Tertiary in New Zealand. *Proxifrons vaughani*, which is distinguished by its great width, appears to be an offshoot of the *whaingaroica-advena* lineage. Both *advena* and *vaughani* occur fairly persistently in late Tertiary bathyal mudstones in New Zealand.

Genus AwHEA nov.

Type species: *Nodosaria sinalata* Finlay, late Tertiary, New Zealand.
Compressed or cylindrical nodosarioid shells with ornament of strong longitudinal ribs, and with sub-oval bluntly pointed large proloculum.

This genus includes two New Zealand species, *sinalata* (Finlay, 1939, p. 452, pl. 63, fig. 49), Upper Miocene to Pliocene, and *subtetragona* (Finlay, loc. cit. fig. 47), Miocene. Finlay noted that *subtetragona* closely resembles "*Nodosaria tetragona* Costa" from Trinidad as figured by Cushman and Jarvis (1930, p. 360, pl. 33, fig. 1).

Hornibrook (1961, p. 83) placed *subtetragona* in *Staffia* Schubert, of which *Nodosaria tetragona* Costa is the type species. Costa's figure of the holotype of *tetragona* shows a shell very different from *subtetragona*—compressed, with only four keels which are disposed like the four primary keels of *Bolivinita* and *Plectofrondicularia*. The six longitudinal ribs of *subtetragona* lend a superficial resemblance to the heterohelicid genera grouped around *Plectofrondicularia*, but are disposed differently. The perfectly cylindrical juvenile of *subtetragona* probably indicates a non-heterohelicid ancestor, and the large peculiarly-shaped proloculum suggests relationship with some species of *Frondicularia*. The most likely interpretation is that the genus *Awhea* is a Frondicularian group which is convergent to *Nodosaria*.

Finlay considered *Nodosaria tosta* Schwager (Pliocene, Indo-Pacific) to be related to *sinalata*.

Family BULIMINIDAE

Subfamily TURRILININAE

Genus BULIMINELLA Cushman

Buliminella missilis n. sp. (Pl. 1, fig. 3)

A small, compact, cigar-shaped helicoid spiral of narrow chambers with raised limbate sutures subparallel to the coiling axis. Initial end narrowly rounded, adult end broadly rounded. Spiral suture obscure, ascending steeply and making little more than one revolution of the shell. Aperture comma-shaped, situated in a depression to one side of the adult end of the shell, apparently an umbilical chink and not an opening into the last formed chamber.

Length: 0.56mm; breadth: 0.17mm (holotype).

TYPE LOCALITY. N158f624a, sandstone phase of a turbidite rhythm, Clelands Road, Mauriceville district (Kapitean Stage). Four paratypes in the type sample, 2 paratypes in the mudstone phase of the same rhythm (N158f624b) and 7 paratypes in a turbidite rhythm at another Clelands Road locality (N158f630).

STRATIGRAPHIC RANGE. Known only from the turbidites at Clelands Road; Kapitea-Zeaserus Zone (mixed shallow- and deep-water faunas), Kapitean Stage.

ECOLOGIC RANGE. In the turbidites *B. missilis* is associated with *Buliminella elegantissima* (d'Orb.) and *Buliminoides williamsonianus* (Brady) which are unequivocally very shallow-water species (see Natland, 1957, etc.). None of the

three has been found in numerous samples from very deep- to moderately shallow-water non-turbidite facies. *B. missilis* was therefore probably restricted to very shallow water.

REMARKS. *Buliminella missilis* is probably closely related to *B. gracilis* Collins (1953) from the Pleistocene of western Victoria, Australia, but is shorter, and more pointed at the initial end. The relationship to *Buliminoides* suggested by Collins is supported by the almost longitudinal sutural ribs, and by the apertural characteristics of *B. missilis*.

Subfamily BOLIVININAE

Genus BOLIVINA d'Orbigny

" Bolivina " turbiditorum n. sp. (Pl. 1, figs. 1, 2)

Shell small, solid, with rounded periphery, tapering from adult to rounded initial end, biserial apparently throughout (initial few chambers obscured by secondary callus). Each chamber produced to form a carina which lies just above the suture at and near the periphery of the shell, but curves sharply up about two thirds of the distance in towards the middle line of the shell, leaving a depressed area where the chamber overlaps the previous chamber; the inner parts of carinae are almost in line on successive alternate chambers, and the two series, one on each side of the middle line, define a longitudinal concave area on each side of the shell; within each concave area limbate sutures (really the thick rims of previous apertures) between the overlapping parts of the chambers form a zig-zag line. Aperture large, subtriangular, surrounded by a heavy glassy rim.

Length: 0.44mm; breadth (side view): 0.25mm; thickness (peripheral view): 0.175mm (holotype).

TYPE LOCALITY. N158f624b, mudstone phase of turbidite rhythm, Clelands Road, Mauriceville district, 10 paratypes.

STRATIGRAPHIC RANGE. Known with certainty only from the turbidites at Clelands Road; Kapitea-Zeaserus Zone, Kapitean Stage.

ECOLOGIC RANGE. As for *Buliminella missilis*.

REMARKS. One of a group of closely related species in the late Tertiary and Pleistocene which have generally been referred to loosely as *Bolivina* cf. *parri* Cushman. Typical *Bolivina parri* has the concave areas developed weakly and only on the early part of the shell. The rounded periphery and transversely carinate chambers characterise a group of Bolivinid shells which are now classed in various genera, for example *Loxostomum pakaurangiensis* Hornibrook and *Bifarina fimbriata* (Millet). These features indicate closer relationship than do the stages between the biserial and uniserial condition which are the main basis of the present generic classification. As yet there is no generic name for species of the *parri-turbiditorum* group, and they are provisionally classed as "*Bolivina*."

Family HETEROHELICIDAE

Genus BOLIVINITA Cushman

Bolivinita pliobliqua n. sp. (Pl. 1, figs. 12, 13)

Shell similar to *pliozea* Finlay, but rhomboid in transverse section, and generally narrower and longer; slightly twisted, tapering gently from the adult end to the bluntly rounded initial end. Sides smooth, concave, each bounded by its own pair of prominent longitudinal keels. Periphery separated from sides by the keels, gently convex, ornamented by two to four longitudinal ribs which are continuous across the sutures.

Length: 0.575mm; width (side view): 0.20mm; thickness (peripheral view): 0.15mm; width of concave area between keels on one side: 0.14mm (holotype).

TYPE LOCALITY. N153f910, Makakahi River, Eketahuna District (Kapitean); 35 paratypes.

67

STRATIGRAPHIC RANGE. Compressa Zone to Kingmai Zone (Upper Tonga-porutuan to Waitotaran).

ECOLOGIC RANGE. Not established with certainty, but about Haeuslerella Biofacies to Robulus Biofacies, a moderately shallow to moderately deep water species, and the most common *Bolivinita* in the late upper Miocene and the Pliocene of Wairarapa. Several other species occur within the same stratigraphic range but each appears to have a different ecology. *Bolivinita compressa* Finlay is relatively infrequent in Wairarapa and appears to have been a very deep-water species. *Bolivinita pohana* Finlay occurs in the semipelagic Biofacies with an estimated depth range of 4,000 ± 2,000ft—greater than the probable maximum depth range of *pliobliqua*. *Bolivinita pliozea* Finlay occurs in shallow-water Kapitean (uppermost Miocene) sediments, becomes common in the late Pliocene, and completely replaces *pliobliqua* in the Pleistocene, this replacement being probably due to shallowing of the sea in the Wairarapa Basin.

REMARKS. In the past *B. pliobliqua* has been misidentified as *B. pohana* and possibly also as *B. pliozea*. *B. pohana* is more compressed and more obliquely rhomboid, and typically has keels only at the two acute angles of the rhomb. *B. pliozea* is quadrate, not rhomboid, in section.

<div align="center">

Family UVIGERINIDAE

Genus HOFKERUVA Vella

Subgenus TRIGONOUVA Vella

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Hofkeruva (Trigonouva) pliozea n. sp. (Pl. 2, figs. 23-25)

Shell large, tapering, heavily costate, megalospheric with blunt apex bearing several small spines formed by produced ends of costae, microspheric with acutely pointed apex bearing a single large spine. Costae raised with rounded crests, some continuous over sutures, on final chamber extending to the base of the apertural neck.

Length: 0.80mm; breadth: 0.39mm (holotype).

TYPE LOCALITY. N153f916, $1\frac{1}{2}$ miles north-east of Hawera Road, Eketahuna district (Opoitian), 15 paratypes.

STRATIGRAPHIC RANGE. Inflata Zone (Opoitian) and possibly Molestus Zone (Waipipian).

ECOLOGIC RANGE. Not yet determined absolutely; persistent and abundant in the Robulus Biofacies, estimated depth range c 1,000 to 2,000ft, not in deeper biofacies, but probably present in shallower biofacies.

REMARKS. The large size, and the apical spine of the microspheric form, are the main distinguishing characters. This species is fairly certainly a derivative of the Miocene species *Hofkeruva (Trigonouva) zeacuminata* Vella. An undescribed species which is possibly intermediate has been recognised by Mr G. W. Gibson in the Taranaki Series (Upper Miocene). *Trigonouva pliozea* has been found by Mr J. P. Kennett in the Opoitian Stage in Westland, South Island, and appears to be a widespread and useful stratigraphic index fossil.

<div align="center">

Subgenus TEREUVA Vella

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Hofkeruva (Tereuva) lutorum n. sp. (Pl. 2, figs. 26, 27)

Shell of moderate size, ovate, with blunt apex, microspheric and megalospheric not obviously different in shape. Longitudinal costae strong, raised, rounded, closely spaced on early part of shell and produced to form numerous small spines at the apex, becoming weaker and more distant towards the adult part of the shell and dying before reaching the base of the apertural neck, some in line on successive chambers, but increasing in size at the base of each chamber so as to give an undercut appearance. Chambers most inflated
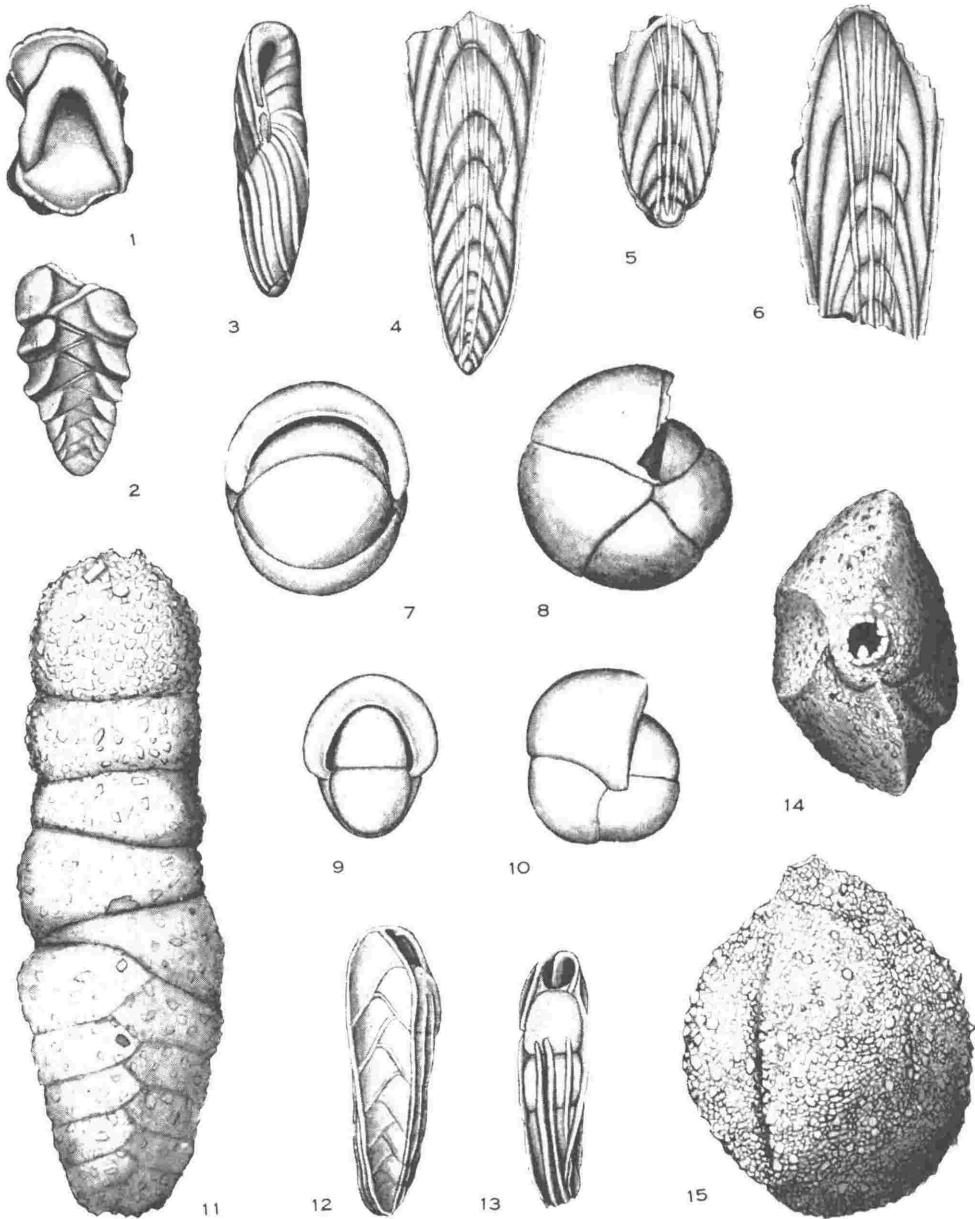
P. Vella del.

(All figures are ×75 unless stated otherwise. All paratypes are from type localities unless stated otherwise.)

Figs. 1, 2.—" *Bolivina* " *turbiditorum* n. sp.; 1, apertural view of paratype ×150; 2, holotype.
Fig. 3.—*Buliminella missilis* n. sp., holotype.
Figs. 4–6.—*Parafrondicularia wairarapa* n. sp.; 4, holotype; 5, 6, paratypes.
Figs. 7, 8.—*Pullenia bulloides* (d'Orbigny), N153f916 (Opoitian) ×150.
Figs. 9, 10.—*Pullenia quadriloba* Reuss, N158f610 (Opoitian) ×150.
Fig. 11.—*Haeuslerella finlayi* n. sp., holotype.
Figs. 12, 13.—*Bolivinita pliobliqua* n. sp.; 12, holotype; 13, paratype.
Figs. 14, 15.—*Sigmoilopsis zeaserus* n. sp.; 14, paratype; 15, holotype.

PLATE 2.　　　　　　　　　TRANS. ROYAL SOCIETY OF N.Z., GEOLOGY, VOL. 2, NO. 1.
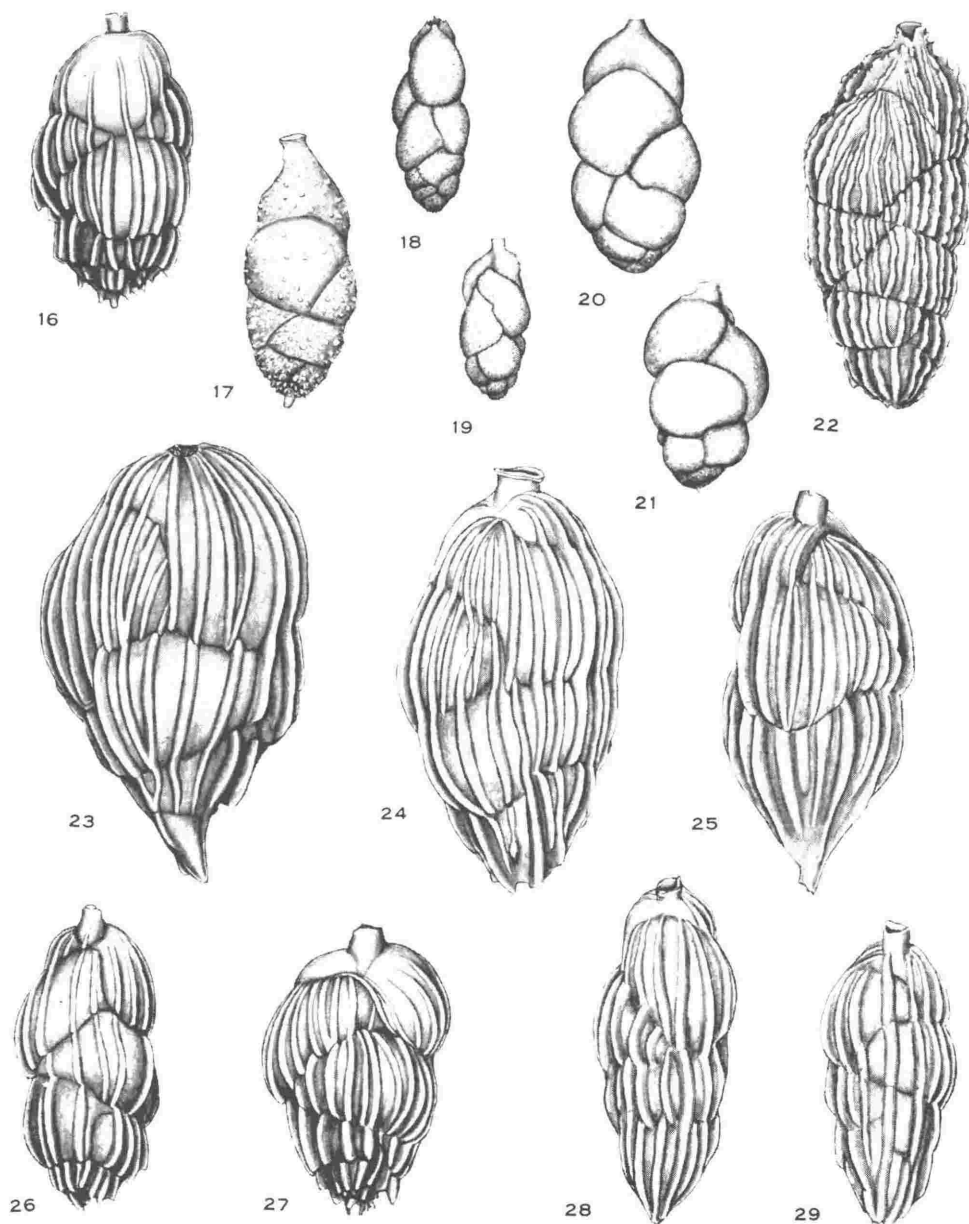
P. Vella del.

(All figures are ×75. Paratypes are from type localities unless stated otherwise.)

FIG. 16.—*Hofkeruva* (s.l.) *delicatula* Vella, N158f610 (Opoitian).

FIG. 17.—*Neouvigerina vadescens* (Cushman), N158f609 (Opoitian).

FIGS. 18, 19.—*Neouvigerina bellula* n. sp.; 18, paratype; 19, holotype.

FIGS. 20, 21.—*Neouvigerina eketahuna* n. sp.; 20, holotype; 21, paratype.

FIG. 22.—*Noviuva zelandica* n. gen., n. sp.; holotype.

FIGS. 23–25.—*Hofkeruva (Trigonouva) pliozea* n. sp.; 23, 24, paratypes; 25, holotype.

FIGS. 26, 27.—*Hofkeruva (Tereuva) lutorum* n. sp.; 26, holotype; 27, paratype.

FIGS. 28, 29.—*Hofkeruva (Laminiuva) rodleyi* n. sp.; 28, holotype; 29, paratype.

at the base, giving a peculiar obese appearance, overhanging the sutures below. Apertural neck set in a slight depression on the top of the terminal chamber.

Length: 0.625mm; breadth: 0.30mm (holotype).

TYPE LOCALITY. N153f910, Makakahi River, Eketahuna District (Kapitean); 150 paratypes.

STRATIGRAPHIC RANGE. Zeaserus Zone to Inflata Zone (Kapitean to Opoitian).

ECOLOGIC RANGE. Robulus Biofacies, inferred depth range *c* 1,000 to *c* 2,000ft.

REMARKS. The illustrated paratype has unusually strong costae. Many specimens are less fully grown than the holotype, and consequently are more squat. The strong inflation of chambers, weak sculpture, and slight depression at the base of the apertural neck are the distinctive characters, and suggest that this species is a rather primitive representative of the *Tereuva* group. It is not a derivative of the Waiauan and Tongaporutuan (middle and upper Miocene) species of *Tereuva*.

Subgenus LAMINIUVA Vella

Hofkeruva (Laminiuva) rodleyi n. sp.

Hofkeruva (Laminiuva) rodleyi rodleyi (Pl. 2, figs. 28, 29)

Shell of moderate to large size, heavily costate, narrowly fusiform, microspheric with acutely pointed apex, megalospheric with narrowly rounded apex. Costae raised, bevelled with narrowly rounded crests, mostly continuous from end to end of the shell, reaching and even encroaching on to the apertural neck.

Length: 0.69mm; breadth: 0.30mm (holotype).

TYPE LOCALITY. N158f583, near Mauriceville (Waitotaran); 15 paratypes.

STRATIGRAPHIC RANGE. Kingmai Zone? (Waitotaran), Mangaoparia Zone (late Waitotaran) to Rotunda Zone (Hautawan). May range up into Nukumaruan and Castlecliffian.

ECOLOGIC RANGE. Elphidium Biofacies to Haeuslerella Biofacies, inferred depth range *c* 20 to less than 900ft.

REMARKS. This subspecies shows little resemblance to most of the species of the *Laminiuva* group but relationship is indicated by the subspecies described below. The distinguishing characters of the species are the long, narrow, fusiform shape and the strong, continuous ribs, and of the subspecies *rodleyi* are the rounded crests of the ribs.

Hofkeruva (Laminiuva) rodleyi tutamoides n. subsp.

Crests of costae thin flanges often slightly serrated by breakage as in *Laminiuva tutamoea* Vella. Shell tending to be a little broader than that of *rodleyi rodleyi*.

Length: 0.63mm; breadth: 0.32mm (holotype).

TYPE LOCALITY. N153f953, Ngaturi Creek, Eketahuna district (Waipipian), 28 paratypes; 22 additional paratypes from N153f990, Waipori Stream, Eketahuna district (Opoitian).

STRATIGRAPHIC RANGE. Olssoni Zone to Kingmai Zone (Opoitian to Waitotaran).

ECOLOGIC RANGE. As for *rodleyi rodleyi*.

REMARKS. The Flange-like ribs of this subspecies clearly indicate the relationship to *tutamoea* the type species of the subgenus. The subspecies is easily distinguished from *tutamoea*, however, by its narrow acuminate shape, and somewhat lower, stronger, more continuous costae. *Laminiuva zelamina* Vella is more closely related than *tutamoea*, but has a bluntly rounded apex and subcylindrical shape.

HOFKERUVA (sensu lato)

Hofkeruva delicatula Vella (Pl. 2, fig. 16)

    1961. *Hofkeruva delicatula* Vella, Micropaleontology 7 (4), p. 477, Pl. 2, fig. 5.
    Somewhat larger than the types from Raukumara Peninsula, but otherwise similar, with
the characteristic broad truncate apex covered with small spines, and with the distinctly
undercut chambers each with crisp, neat costae produced to tiny prickles at the base.

    Length: 0.56mm; breadth: 0.325mm (figured hypotype).

    LOCALITY. N158f610, mudstone overlying Kapitean turbidite at Clelands Road,
Mauriceville district (Basal Opoitian). Not yet known from any other localities in
Wairarapa.

    STRATIGRAPHIC RANGE. The lower part of the Inflata Zone, distinguished by
several species lingering from the Miocene, and provisionally called basal Opoitian
(see Kennett, in press).

    ECOLOGY. Semipelagic Biofacies, inferred depth between *c* 2,000 and *c* 4,000ft.

    REMARKS. Might be confused with *Tereuva lutorum*, but has a wider, more
truncate base, more distinctly undercut chambers, and subcylindrical rather than
ovate or tapering overall shape.

Genus NOVIUVA nov.

    Type species: *Uvigerina peregrina* Cushman.
    Large uvigerinid shells with main sculpture of irregular or serrated longitudinal costae
which tend to become dissected into spines on the adult part of the shell. Interspaces and
sometimes the costae themselves granulose or covered with fine papillae or spines. Tooth-
plates as in *Euuvigerina* and *Hofkeruva.*

    The hispido-costate *peregrina* group of shells which comprise *Noviuva* was
provisionally classed as *Hofkeruva* in the broad sense and was thought to have
probably evolved from one of the *Hofkeruva* lineages during the Miocene (Vella,
1961, p. 473, and text-fig. 3). It may, however, have a much longer history and
include Eocene species like "*Uvigerina*" *bortotara* Finlay.
    Noviuva should be restricted to species with spines developing or developed
from costae, and arranged in longitudinal more or less linear series, and should
not include species with costae developing from spines or with spines scattered at
random. Species which appear to meet these conditions are *Uvigerina ciperana*
Cushman and Stainforth (Cipero Marl, Trinidad), *Uvigerina hispido-costata*
Cushman and Todd (Miocene, Jamaica), *Uvigerina interrupto-costata* Leroy
(L. Miocene, Sumatra), *Uvigerina joaquinensis* Kleinpell (Up. Miocene,
California).
    Uvigerina shiwoensis Asano (Recent and Pliocene, Japan) is regarded as a
doubtful species of *Noviuva.*
    Uvigerina dirupta Todd (Recent, California) has spines scattered at random,
and appears to be close to *Euuvigerina aculeata* (d'Orb.).

Noviuva zelandica n. sp. (Pl. 2, fig. 22)

    Shell large, elongate, subcylindrical, with only slightly depressed, but distinct sutures,
heavily sculptured with irregular, serrated, somewhat sinuous costae, produced to irregular
spines on top of the final chamber, extending on to the apertural neck. Apex broadly
rounded.

    Length: 0.79mm; breadth: 0.35mm (holotype).

    TYPE LOCALITY. N153f916, 1½ miles north-east of Hawera Road, Eketahuna
district (Opoitian); 7 paratypes.

    STRATIGRAPHIC RANGE. Inflata Zone (Opoitian).

    ECOLOGIC RANGE. Semipelagic Biofacies, inferred depth range 4,000 ± 2,000ft.

REMARKS. Close to *peregrina*, but consistently has a broader apex, and no spines on the apex.

Genus NEOUVIGERINA Hofker

Neouvigerina vadescens (Cushman) (Pl. 2, fig. 17)

1933. *Uvigerina proboscidea* Schwager var. *vadescens* Cushman, Contr. Cush. Lab. 9 (4), p. 85, Pl. 8, figs. 14–15.

The New Zealand shells included in *vadescens* are of moderate size, elongate, ovate, with slightly inflated chambers, distinct but little impressed sutures, broad tapering apertural neck with solid reflexed lip, and ornament of small distant raised spines and dense minute papillae.

Length: 0.55mm; breadth: 0.225mm (hypotype).

LOCALITY OF HYPOTYPE. N158f609, Mauriceville district (Opoitian).

STRATIGRAPHIC RANGE. Inflata Zone, Opoitian.

ECOLOGIC RANGE. Robulus Biofacies? (2,000 ± 1,000ft).

REMARKS. About half the specimens bear an apical spine as on the paratype figured by Cushman. Shape and size agree well with the types, but the type description and figure are not good enough for comparison of the ornament.

Neouvigerina bellula n. sp. (Pl. 2, figs. 18-19)

Shell tiny, elongate, ovate, with rounded apex, adult and near adult chambers higher than wide, with distinct depressed sutures. Wall thin and delicate, covered with fine hair-like spines.

Length: 0.31mm; breadth, 0.15mm (holotype).

TYPE LOCALITY. N153f1016, Bowen Road, Eketahuna district (Opoitian).

STRATIGRAPHIC RANGE. Inflata Zone, Opoitian.

ECOLOGIC RANGE. Robulus Biofacies to Semipelagic Biofacies, inferred depth range 2,000 ± 1,000ft to 4,000 ± 2,000ft.

REMARKS. Size, shape, and ornament are fairly consistent and readily distinguish *N. bellula* from other late Tertiary species. *N. plebeja* Vella is possibly the mid-Tertiary ancestor of *bellula,* comparable in size, but with more conic apex and smoother surface. There appears to be no similar species described from beyond New Zealand. According to d'Orbigny's description and figure *Uvigerina canariensis* attains a length of 2/3mm and is an acuminate shell with subglobular chambers. *Uvigerina auberiana* is comparable in size (1/3mm) to *N. bellula,* but has subglobular chambers, and ornament of costae in addition to papillae or spines.

Neouvigerina eketahuna n. sp. (Pl. 2, figs. 20, 21)

Shell large for the genus, short, solid, with swollen subglobular chambers and deeply impressed sutures giving a lobulate outline; subovate or somewhat tapering; apex broadly rounded. Wall thick, covered with dense low rounded papillae.

Length: 0.54mm; breadth, 0.275mm (holotype).

TYPE LOCALITY. N153f896, one mile west of Rongomai Valley Road, Eketahuna district (Kapitean).

STRATIGRAPHIC RANGE. Below Compressa Zone to Kapitea Zone, Tongaporutuan to Kapitean.

ECOLOGIC RANGE. Haeuslerella Biofacies to Robulus Biofacies, inferred depth range *c* 500 to 2,000 ± 1,000ft.

REMARKS. Easily distinguished from all other New Zealand species by the large size, swollen chambers, and regular papillate ornament. The most similar species is *N. mantaensis* (Cushman and Edwards) from the Tertiary (Oligocene?) of Ecuador, which is broader, more compact, with less inflated chambers.

Family CHILOSTOMELLIDAE

Genus PULLENIA Parker and Jones

Pullenia quinqueloba (Reuss)

> 1851. *Nonionina quinqueloba* Reuss, Zeitschr. Deutsch. Geol. Ges. 3, p. 71, Pl. 5, fig. 31.
> 1867. *Pullenia compressiuscula* Reuss, var. *quinqueloba* Reuss, Sitz. Akad. Wiss. Wien 55, p. 87.
> 1884. *Pullenia quinqueloba* (Reuss), Brady, Rep. Voy. *Challenger,* Zool. 9, p. 617, Pl. 84, figs. 14–15.
> 1961. ————————— Hornibrook, N.Z. Geol. Surv. Pal. Bull. 34 (1), p. 90, Pl. 11, figs. 207–208.

New Zealand late Tertiary specimens closely match the Italian Pliocene specimen figured by Cushman and Todd (1943, Pl. 3, figs. 8a-b).

ECOLOGIC RANGE. Haeuslerella Biofacies to Karreriella Biofacies (possibly Robulus Biofacies), inferred depth range *c* 400 to *c* 1,000ft. The common species of moderately shallow- to moderately deep-water sediments. Shells occur sporadically from 60 to 750ft in Cook Strait (Vella, 1957).

Pullenia quadriloba Reuss (Pl. 1, figs. 9, 10)

> 1867. *Pullenia compressiuscula* Reuss, var. *quadriloba* Reuss, Sitz. Akad. Wiss. Wien 55, p. 87, Pl. 3, fig. 8.
> 1943. *Pullenia quadriloba* Reuss, Cushman and Todd, Contr. Cush. Lab. 19 (1), p. 15, Pl. 2, figs. 20, 21.

The Wairarapa specimen illustrated is not fully grown, and no other well preserved specimens have been obtained. It is less compressed than the European specimens illustrated by Reuss and by Cushman and Todd, having the final chamber expanding suddenly from the umbilicus, but it is uncertain whether this difference is significant.

STRATIGRAPHIC RANGE. The type is from the Miocene of Galicia. Cushman and Todd recorded the species from the Miocene of the Vienna Basin, and living in the Western Atlantic. Bermudez illustrated a form like it as *P. quinqueloba,* from the Miocene of the Dominican Republic. In Wairarapa it occurs from the Compressa Zone (Upper Tongaporutuan), and possibly lower, to the Inflata Zone (Opoitian).

ECOLOGIC RANGE. Robulus Biofacies? to Semipelagic Biofacies, inferred depth range deeper than 1,000ft to *c* 4,000ft.

Pullenia bulloides (d'Orbigny) (Pl. 1, figs. 7, 8)

> 1946. *Pullenia bulloides* (d'Orb.) Finlay, Trans. Roy. Soc. N.Z. 76 (2), p. 243.
> 1948. *Pullenia sphaeroides* (d'Orb.) Dorreen, J. Pal. 22 (3), p. 298.
> 1957. *Pullenia bulloides* (d'Orb.) Vella, N.Z. Geol. Surv. Pal. Bull. 38, p. 10.
> 1961. ————————— Hornibrook, N.Z. Geol. Surv. Pal. Bull. 34 (1), p. 90, Pl. 11, figs. 205, 206.

Shells referred to *Pullenia bulloides* are considered to be good indicators of abyssal depths (below 5,000ft) off California (see Natland, 1957, Phleger, 1960). The Cook Strait form (Vella, 1957) occurs sparsely at a depth of 72ft and in greater number at a depth of 294ft. The form illustrated here is restricted to

bathyal sediments in the late Tertiary of Wairarapa. These major differences in depth range at different times and places are difficult to explain without assuming differences in the genetic make-up of the forms at different times and places. Differences in genetic make-up would imply the existence of different subspecies, or species which might be closely related or might not be closely related but homeomorphic. Single large samples of *"Pullenia bulloides"* from Wairarapa show less variation than is generally allowed for the species. The shells illustrated here, and the one illustrated by Hornibrook are similar to the topotype of *bulloides* illustrated by Cushman and Todd (1943, Pl. 2, figs. 18a-b). Wairarapa shells in some other samples closely resemble the Recent specimen (from 10,000ft) illustrated by Cushman and Todd (1943, Pl. 2, figs. 16a-b), having only 4 chambers showing, and this may be a distinct species.

Maximum diameter: 0.34mm; thickness: 0.30mm (hypotype, Pl. 1, fig. 8).

ECOLOGIC RANGE. Robulus Biofacies to Semipelagic Biofacies, possibly Eupelagic Biofacies, inferred depth range deeper than 1,000 to deeper than 4,000ft.

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PART   TWO

STRATIGRAPHY AND PALEOECOLOGY

𝒱 – Biostratigraphy and Paleoecology of Mauriceville District, New Zealand

By Paul Vella

Abstract

Animals that live on the sea-floor are different at different depths. Faunal changes from shallow to deep are gradual, but particular depth faunas can be defined by dominant and depth-restricted taxa (species to phyla) to give a depth sequence. Similar sequences of faunas, assumed to be depth-controlled, can be determined for any particular time in the past, and their approximate depths can be determined.

In Mauriceville district rocks of about the same age were deposited in very different depths, contain few species in common, and are thus difficult to correlate.

Temperature change is an important factor in depth and time correlation. Temperature decreases with depth in the ocean, and at any one depth decreased with time from the Miocene to the Pleistocene. Non-depth-tolerant species would appear earlier in the south than in the north and depth-tolerant species would appear earlier in deep water than in shallow water. Some key species now used for time correlation in New Zealand are merely temperature indicators.

Local bio-stratigraphic divisions are essential for detailed stratigraphy. More than one sequence of facies-restricted bio-stratigraphic divisions may be required for contemporaneous deep- and shallow-water deposits.

Relationship of Time Divisions to Depth Divisions

Temperature and pressure are among the most important ecological factors in the sea. Only pressure is solely controlled by depth. But the other marine ecological factors—average temperature, range of temperature variation, light intensity, salinity, type of bottom, turbidity—are generally directly related to depth in any particular area. Variation in ecological factors at any particular depth is greatest in shallow water (less than 150ft) and decreases with increasing depth. The faunas reflect this, varying most in shallow water and becoming increasingly uniform with increasing depth. Furthermore, the effects of depth decrease with increasing depth, and the rate of faunal change downwards is more closely related to logarithmic than to direct depth increases

The need to recognise facies changes when attempting time correlation is universally accepted. But facies changes generally have been regarded merely as a hindrance to time correlation and not as an essential part of the geological record. As most present marine ecological factors are depth-dependent, it is inferred that lateral changes in past faunas generally indicate changes in relative depth.

Most marine sedimentary successions are essentially cyclic. The following sequence, represented by the curve in Fig. 1, is a simple example:

(1) Transgression (subsidence commences).
(2) Deepening of the sea (subsidence more rapid than deposition).
(3) Culmination (subsidence balances deposition).
(4) Shallowing (subsidence less rapid than deposition).
(5) Regression.
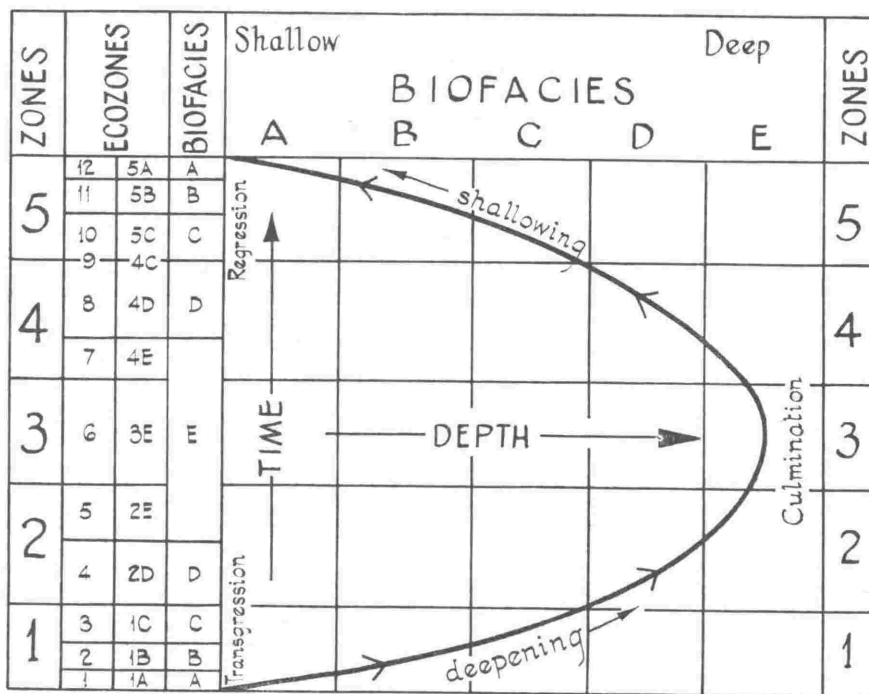
FIG. 1.—Diagram to show the chief causes of vertical faunal changes in marine sediments. The curve shows change in depth during a hypothetical simple sedimentary cycle. Observed faunal divisions (ecozones) 1 to 12 are combinations of time divisions: zones 1 to 5, and depth divisions: biofacies A to E. Biofacies may reappear in time; zones appear only once.

The directly observable (objective) faunal divisions in such a succession are controlled partly by time and partly by depth. They are distinguished as ecozones and from them zones and biofacies must be abstracted. These three kinds of basic paleontological divisions may be defined as follows:

(1) Ecozones: purely objective faunal divisions in any stratigraphic section.
(2) Zones: time-stratigraphic faunal divisions for any restricted area, in some cases for a restricted facies within a restricted area.
(3) Biofacies: Ecological (usually depth) faunal divisions for any particular age.

Biofacies change both laterally and vertically. They are best determined from lateral faunal changes, and are tested by consistency of sequence in both vertical and horizontal directions. If a facies-transgressive horizon marker (such as an

ash shower) is available, biofacies for one time can be determined objectively from lateral variation. Usually such markers are not available and biofacies must be determined, like zones, by trial and error proceeding in a possibly infinite series of steps as follows:

(1) Determination of crude time divisions.
(2) Determination of ecological (lateral) faunal divisions within each time division.
(3) Refinement of time divisions in the light of ecological divisions.
(4) Refinement of ecological divisions within refined time divisions . . . etc.

Zones are usually determined by trial and error through comparison of several sections. The acid test is always consistency of sequence in separate sections. Once depth changes are known it should be possible to separate objectively depth biofacies from an ecozone sequence to leave an essentially zone sequence. For this purpose it is not necessary to know absolute depths represented by each biofacies, but only the correct order from shallowest to deepest.

Absolute Depth of Deposition

Table I shows seven depth-faunal divisions recognised in Wairarapa Upper Miocene and Pliocene rocks, with their characteristic lithologies. Associations of depth faunas and lithologies are constant. The absolute depth ranges of shallow water divisions can be judged more accurately and with more confidence than those of deep-water divisions. The depth range of divisions increases approximately logarithmically from shallowest to deepest.

TABLE I.

Depth Range	Fauna	Lithology
(1) Estuarine	Restricted molluscs, ostracodes, Foraminifera	Silts and conglomerates
(2) Sublittoral *c.* 20ft	Restricted molluscs, ostracodes, Foraminifera	Sands and conglomerates
(3) Upper Neritic 20 to c. 200ft	Abundant molluscs, ostracodes, barnacles, brachiopods, echinoids, bryozoans, Foraminifera	Sands, shell beds, reef and detrital limestone
(4) Lower Neritic *c.* 200 to *c.* 1,000ft	Common molluscs, infrequent ostracodes, abundant Foraminifera.	Massive to poorly bedded sandstone and siltstone; macrofossils scattered
(5) Upper Bathyal 1,000 to 2,000ft	Infrequent deep-water molluscs, abundant Foraminifera	Massive muddy siltstone; macrofossils scattered.
(6) Mid Bathyal 1,000 to ? 4,000ft	Extremely rare molluscs, abundant Foraminifera (pelagics 40 to 60 per cent)	Massive mudstone.
(7) Lower Bathyal to Abyssal ? ? 4,000ft plus	Extremely rare molluscs, Foraminifera: 70 to 90 per cent pelagics; benthic species few, individuals numerous	Massive mudstone

Foraminiferal Biofacies

Foraminifera are considered the most useful group for paleoecological study. They are the best known microfossils, easy to collect in large numbers, and abundant throughout a wide range of marine facies. Recent Foraminifera have distributions limited by temperature, pressure, or other ecological factors, and many species range far back into the Tertiary. Some controlled by temperature

but tolerant to other ecological factors related to depth have different depth ranges at different latitudes. Others have the same depth range in spite of temperature differences over a wide range of latitudes. Thus the order of appearance of species in depth varies from latitude to latitude. As the late Tertiary was a period of cooling it may be inferred that in any particular place the order of appearance in depth of persistent species changed from time to time. To use Foraminifera by themselves to determine absolute depths of deposition it is necessary to know the temperature of the surface water at the time of deposition and to have studied depth distributions of nearby Recent Foraminifera in a latitude with the same average surface-water temperature. In New Zealand neither condition is fulfilled. Foraminiferal biofacies can, however, be determined for each age and can be related to the depth divisions based on total fossil faunas outlined above, and then can be used by themselves to infer absolute depths of deposition.

Seven Pliocene (Opoitian and Waitotaran) biofacies are listed in Table II.

TABLE II

Biofacies	Inferred Depth Division	Approximate Depth Range in feet
1. Streblus	Estuarine (hyposaline)	0 to ?
2. Pseudononion	Sublittoral	20
3. Elphidium	Upper Neritic	20 to 200
4. Haeuslerella	Lower Neritic	200 to 1,000
5. Robulus	Upper Bathyal	1,000 to 2,000
6. Semipelagic	Mid Bathyal	2,000 to 4,000
7. Eupelagic	Lower Bathyal to ?Abyssal	4,000 plus
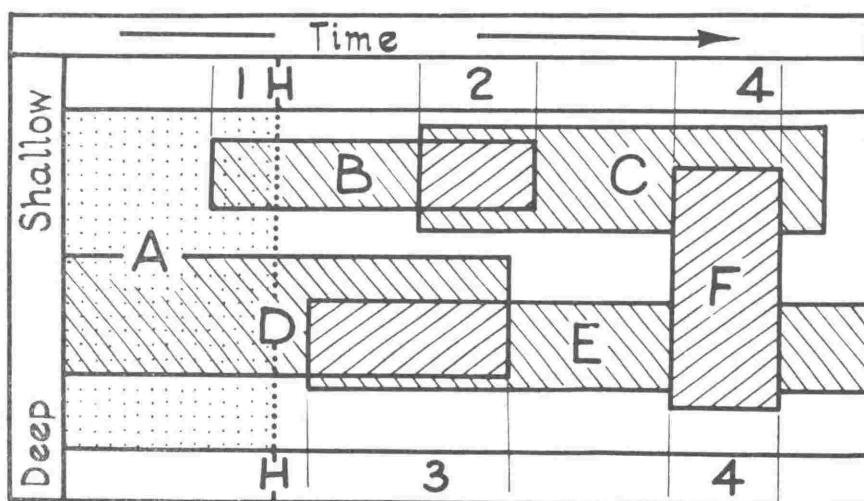
Fig. 2.—Idealised diagram showing time ranges of species B and C restricted to shallow water, D and E restricted to deep water, a depth tolerant benthic species F, and the upper time limit of a pelagic species A whose remains are found in both shallow- and deep-water deposits. Zones 1, 2 and 3 are defined by the overlapping ranges of species (overlap zones); zone 4 is defined by the total local time-range of a short-lived species (Teilzone). The outgoing of the previously abundant ubiquitous pelagic species A defines the time horizon H. The diagram illustrates the difficulty of correlating shallow- and deep-water deposits in the absence of pelagic species such as A or of depth-tolerant species such as F.

78

Depth-restricted key-forms enable equivalent depth biofacies of different ages to be correlated with each other in the same way as time divisions are correlated by time-restricted key-forms. Biofacies of the Pleistocene and the upper Miocene are similar to and fairly easily correlated with those of the Pliocene. The chief difficulty in depth correlation is the progressive shift of temperature-restricted species from deeper to shallower water during the regional cooling prior to the Pleistocene.
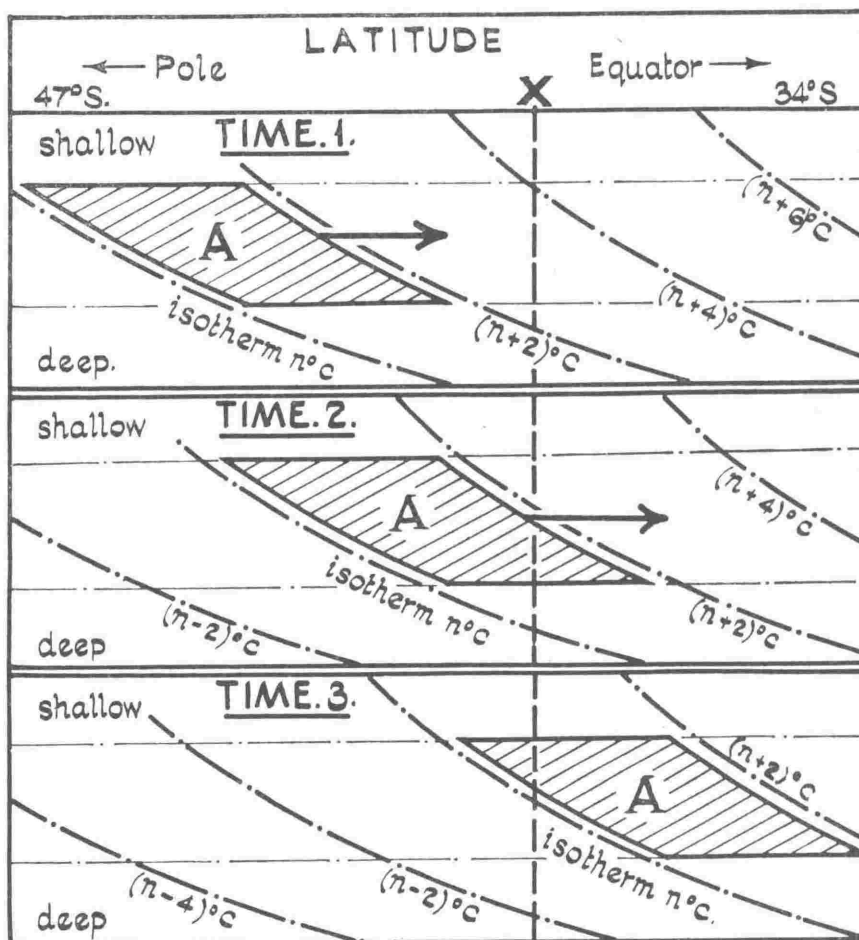
Fig. 3.—Idealised diagram illustrating migration of a depth- and temperature-controlled species A during a period of cooling. Latitudes and temperatures approximately as for New Zealand at the present day. The species migrates northward within its restricted depth range, indicated by the horizontal broken lines. At latitude X it is absent at time 1, occurs only in deep water at time 2, and occurs only in relatively shallow water at time 3.

Time Divisions

Of the few species common to very deep- and very shallow-water microfaunas most are long-ranging and useless for correlation. Time correlation is effected mainly through intercorrelation of faunas of intermediate depths. Mixed deep and shallow faunas in turbidites can provide direct correlation. Most correlations are defined by overlaps of the ranges of species. Overlap zones have complex interrelationships, each having peculiar time and depth ranges (Fig. 2).

Time changes result either from evolution or from regional change in some physical condition. Cooling presaging glaciation is the only known regional physical change of the upper Tertiary, and is considered to account for a large proportion of the faunal changes now used for New Zealand stage correlation. Regional cooling resulted in migration towards the equator of equatorward dipping isothermal surfaces. Of the temperature controlled species, those that were depth controlled moved towards the equator, those that were not depth-controlled moved upwards or towards the equator (Fig. 3).

All faunal changes due to cooling are time-transgressive, and "stages" based on them are younger towards the equator than away from the equator. On the other hand, in any small area such faunal changes are depth-transgressive in time and "stages" based on them are younger in shallow-water sediments than in deep-water sediments. An example of a depth-time transgressive faunal change is shown in Fig. 4.
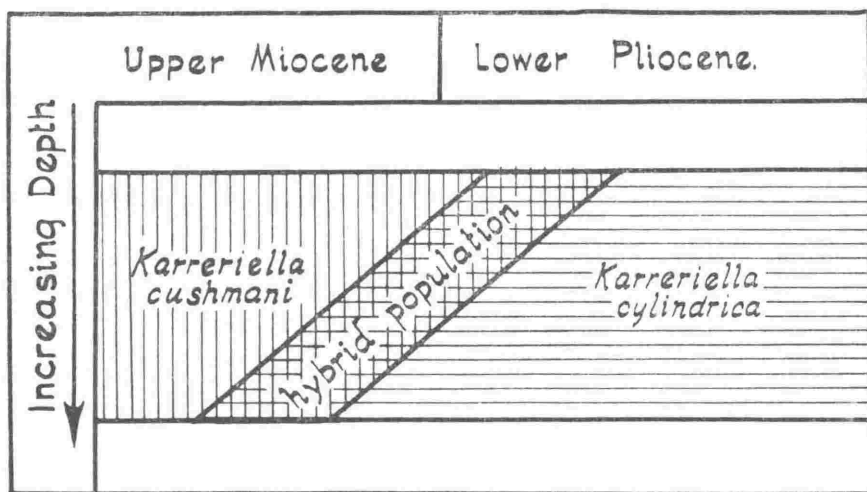
FIG. 4.—Chart showing possible explanation of the observed sequence of *Karreriella cushmani* Fin., *K. cushmani cylindrica* and *K. cylindrica* Fin. in Wairarapa. The sequence, previously regarded as evolutionary, is here considered to be due to the effect of ante-Pleistocene cooling on two species separated by an isothermal surface. Temperature increases to the top left, normal to the species boundary.

This theoretical difficulty in correlating adjacent deep- and shallow-water sequences is borne out in practice. Lower bathyal mudstone with a restricted benthic fauna at first thought to be Tongaporutuan in age was later found to overlie turbidites with the shallow water Kapitean key species *Bulimina aculeata* d'Orb. On the other hand, upper neritic strata later proved to be Waitotaran were at first correlated with the Opoitian because they contain *Norcottia mioindex* (Fin.) a common Miocene bathyal species previously thought to make its last appearance in lower Opoitian bathyal sediments.

Correlation with the type localities of the New Zealand stages is still more difficult because latitude differences are added to depth differences. In order to have valid time divisions which will not be subject to change with increase in knowledge it is necessary to set up separate local zone sequences for different depths of deposition.

For the area described a shallow-water and a deep-water succession have been set up. Their approximate correlations with the New Zealand stages are shown in Table III.

Table III

Shallow-water and deep-water zone sequences and their inferred correlation with one another and with the New Zealand stages.

N.Z. Stage (approx.)	Shallow-water zones and main correlation fossils (Foraminifera and Mollusca)	Deep-water zones and main correlation fossils (Foraminifera only).
Wn	Zelandica Zone: *Notorotalia zelandica; Tawera subsulcata, Stiracolpus waikopiroensis*	——
Wh	Rotunda Zone: *Notorotalia rotunda, Chlamys delicatula*	——
Ww–Wh	Mangaoparia Zone: *Notorotalia mangaoparia, Anomalinoides frigindex*	——
Ww	Kingmai Zone: *Notorotalia kingmai, Polinices, Olivella*	——
Wwp	(Zone missing)	Molestus Zone: *Cibicides molestus*
Wo	Olsoni Zone: *Notorotalia olsoni*	Inflata Zone: *Cibicides ihungia, Turborotalia inflata*
Tk	——	Zeaserus Zone: *Sigmoilopsis* n. sp. *Bulimina aculeata* (in turbidites)
Up.Tt	——	Schlumbergeri Zone: *Sigmoilopsis schlumbergeri, Bolivinita compressa*

The substages of the Waitotaran (Waipipian and Mangapanian) and Nukumaruan (Hautawan and Marahauan) erected by Fleming (1953: 102–103) are here accorded stage rank. The Marahauan and Mangapanian substages have the same type localities as the Nukumaruan and Waitotaran stages respectively and are thus abandoned. The following symbols are used to indicate the stages in Table III.

Wanganui Series (Pliocene to lower Pleistocene)
Wn Nukumaruan
Wh Hautawan
Ww Waitotaran
Wwp Waipipian
Wo Opoitian
Taranaki Series (Upper Miocene)
Tk Kapitean
Tt Tongaporutuan

Time Zones for Shallow-water Strata

Five shallow-water time zones—Olsoni, Kingmai, Mangaoparia, Rotunda, and Zelandica—shown in Table III are named from large species of *Notorotalia*. *Notorotalia olsoni* Vella is restricted to its zone in the area described, but has been recorded from Opoitian (possibly Kapitean) to Recent (Vella, 1957: 50) elsewhere. A hiatus is likely between the Olsoni and Kingmai zones. Strata placed in the Rotunda Zone are hard shell limestone and were not sampled for Foraminifera. They are correlated by the pelecypod *Chlamys delicatula* (Hutton) which occurs with *Notorotalia rotunda* Vella between the Mangaoparia and Zelandica zones elsewhere in Wairarapa. Stage correlation of the Olsoni and Kingmai zones is based

mainly on stratigraphy established by G. Neef in Eketahuna Sheet District to the north. The Kingmai Zone contains typical Waitotaran macrofaunas including the warm-water forms *Polinices* cf. *waipipiensis* (Marwick) and *Olivella* (*Lampro-domina*) *neozelanica* (Hutt.). An unconformity underlies. The Olsoni Zone seems equivalent to poorly fossiliferous strata unconformably underlying the Kingmai Zone at Eketahuna and considered upper Opoitian to lower Waitotaran from their stratigraphic position. Stage correlation of the Mangaoparia, Rotunda, and Zelandica zones is based on ages for the *Notorotalia* species given by Vella (1957: 56) and on the occurrence of the molluscs *Tawera subsulcata* (Sut.) and *Stiracolpus* cf. *waikopiroensis* (Sut.) in the Zelandica Zone and *Chlamys delicatula* (Hutt.) in the Rotunda Zone.

Time Zones for Deep-water Strata

Four deep-water zones are shown in Table III. The Inflata Zone is the best defined, the base by the incoming of the pelagic *Turborotalia inflata* (d'Orb.) and the top by the outgoing of *Cibicides ihungia* Fin., a ubiquitous benthic species of wide bathymetric range. The overlying Molestus Zone is distinguished by the presence of *Cibicides molestus* Horni. and absence of *Cibicides ihungia*. *Cibicides molestus* is abundant in moderately-shallow to moderately-deep water deposits. The top of the Molestus Zone is not defined because of the absence of deep-water beds, but would be placed at the outgoing of *C. molestus* believed to be near the top of the Waipipian elsewhere in Wairarapa and in Hawke's Bay.

The Zeaserus Zone takes its name from a manuscript new species of *Sigmoilopsis* related to *Sigmoilopsis schlumbergeri* (Silv.). The top is well defined by the incoming of *Turborotalia inflata*. The base is marked by the incoming of the *Sigmoilopsis* n. sp. and by a stage in evolution of the *Bolivinita pliozea* Fin. lineage, but is poorly defined because the *Sigmoilopsis* is generally rare except within narrow bathymetric limits. The Schlumbergeri Zone, next lower, does not outcrop in the area described but has been distinguished in adjacent areas.

Correlation. The base of the Inflata Zone is the best reference horizon. The pelagic *Turborotalia inflata* is probably temperature-controlled and hence its incoming is likely to be time-transgressive with latitude, but within a small area it gives reliable time correlation through deposits of all except upper neritic depths. It is generally accepted as the base of the Opoitian Stage. Foraminifera are not known well enough to define the top of the Opoitian Stage—i.e., the base of the Waipipian Stage, even at type localities. For convenience the top of the Inflata Zone is assumed to be the top of the Opoitian and the top of the Molestus Zone is assumed to be the top of the Waipipian.

The Zeaserus Zone cannot be dated by its depth-restricted fauna, because this includes no accepted " key " species. Graded-bedded sandstones and mudstones, however, contain redeposited shallow-water Foraminifera, including the Kapitean key *Bulimina aculeata* (d'Orb.). In adjacent areas the underlying Schlumbergeri Zone contains an immediately older fauna including *Bolivinita compressa* Fin. and *B*. aff. *pliozea* Fin., lacking *B. aculeata*, and considered about Upper Tongaporutuan in age.

Microsamples from Mauriceville District

The name Mauriceville District is used for Sub-Sheet District 2 of N.Z.M.S.1, Sheet District N158. All 72 microsamples from this district were collected by G. E. Orbell during a recent geological survey (Orbell, in press). An index of microsample localities, a list of key Foraminifera, with age and depth ranges, and age and depth determinations with key species for each microsample, are given below.

The following abbreviations are used: Ps, Pseudononion Biofacies; El, Elphidium Biofacies; Ha, Haeuslerella Biofacies; Ro, Robulus Biofacies; Sp, Semipelagic Biofacies; Ep, Eupelagic Biofacies; N.F., no fauna; N.D., not determined.

Standard symbols are used for New Zealand Stages.

Lithologies are given in the code of the N.Z. Fossil Record Form (Wellman, 1953: 55) with an additional supplementary letter (R) to indicate graded bedding (redeposited).

INDEX OF FOSSIL LOCALITIES

[Full locality details are recorded in the Sheet Fossil Master-file for Wairarapa region at the Geology Department, Victoria University of Wellington.]

Sheet Fossil Number	Locality	Grid Reference	Lithology	Macro-fauna	Foram. fauna	Age
f551	**Mauriceville**	181831	7723dS	Comm.	Comm.	Wn
f552	Mauriceville	181832	8723d	Comm.	Rare	Wn
f553	Dreyers R. Rd	233843	7722d	Rare	Comm.	Wwp
f554	Dreyers R. Rd	245828	9722d	Rare	Sparse	Wwp–Wh
f555	Whangaehu Rd	252828	9722c	Broken	Comm.	Wh?
f556	Mt Bruce	148867	9842c	None	Comm.	Wwp
f557	Mauriceville	181832	9852d	Comm.	Sparse	Wn
f558	Mauriceville	196853	5564iCC	Sparse	Rare	Wn
f559	Dreyers R. Rd	209858	5553iCC	Coquina	Rare	Wh
f561	Mauriceville	192831	7942dSC	Sparse	Comm.	Ww–Wh
f565	Mauriceville	194844	9742dBC	Sparse	Comm.	Ww–Wh
f566	North Rd	171874	9843d	None	Comm.	Wo
f567	North Rd	164890	7741cCT	None	None	?
f568	Ihuraua	255863	9842cC	None	Abund.	Wo
f569	Mt Bruce	159893	7741dCW	None	None	?
f570	Snowden Hill	202830	7642d	Sparse	Comm.	Ww–Wh
f571	Mauriceville	171829	9842d	None	Abund.	Tk
f572	Mangamahoe Rd	214883	9741cC	Comm.	Sparse	Wh?
f573	Mangamahoe St	199894	7771cC	None	None	?
f574	Paikakako	202879	8752cC	None	Abund.	Wwp
f575	Mangamahoe Rd	223889	8752cC	Rare	Abund.	Ww
f576	Paikakako	201881	8752cC	None	Comm.	Wwp
f577	Rioux Hill	230876	8742c	None ?	Abund.	Ww
f578	Sweep Hill	256905	9742c	None	Abund.	Wo
f579	Sweep Hill	271903	9852c	Rare	Abund.	Wo
f580	Sweep Hill	261891	9852c	None	Abund.	Wo
f581	Ihuraua	269891	9940h	None	None	?
f582	Ihuraua	272890	9842c	None	Abund.	Wo
f583	Daggs Rd	295882	7742c	None	Abund.	Wwp
f584	Daggs Rd	296863	9842cW	None	Rare	?
f585	Ihuraua Valley	269858	6652cSR	Fragile	Fragile	Wo
f586	Ihuraua Valley	260861	9942c	None	Abund.	Wo
f587	Ihuraua Valley	250863	9942cW	None	None	?
f588	Ihuraua Valley	249856	9742cR	None	Abund.	Wo
f589	Ihuraua Valley	259861	9842cT	None	Abund.	Wo
f590	Dreyers R. Rd	217856	9742c	Sparse	Abund.	Ww
f591	Mangamahoe St	206897	9731cW	None	None	?
f592	Rioux Hill	228881	9742cT	Sparse	Sparse	Ww–Wn
f593	Rioux Hill	230874	9740hT	None	None	?
f594	Paikakako Hill	205882	9742cTR	None	Comm.	Wo
f596	Mauriceville	184862	9741cTR	None	Comm.	Tk
f597	Jacksons Line	156832	9742cTR	None	Abund.	Wwp
f598	Jacksons Line	161825	9742cT	None	Abund.	Wo
f599	Mauriceville	172829	9742cTR	None	Abund.	Tk
f600	Mauriceville	176828	7842c	Broken	Comm.	Ww
f601	Snowden Hill	203833	7842c	Sparse	Comm.	Ww–Wh
f602	Snowden Hill	205831	7942c	Rare	Sparse	?

Sheet Fossil Number	Locality	Grid Reference	Lithology	Macro-fauna	Foram. fauna	Age
f603	Dreyers R. Rd	219849	8742cT	Rare	Abund.	Ww
f604	Dreyers R. Rd	242835	8741cT	None	Rare	?
f605	Dreyers R. Rd	249831	7742cTO	None	Abund.	Wo
f606	Dreyers R. Rd	253830	9742cT	None	Comm.	Wo
f607	Whangaehu Rd	252820	9742cT	None	Abund.	Wo
f608	Clelands Rd	257812	9842cTR	None	Abund.	Wo
f609	Clelands Rd	260814	9842cT	None	Abund.	Wo
f610	Clelands Rd	265814	9742cT	None	Abund.	Wo
f611	Clelands Rd	271813	9942c	None	Abund.	Tk
f612	Mauriceville	170816	7942c	Fragile	Abund.	Ww–Wh
f613	Whangaehu Val.	234806	7942cT	None	Comm.	?
f614	Whangaehu Val.	238806	7942cT	None	Abund.	Wwp–Ww
f615	Limebrook	228803	7952cT	Sparse	Comm.	Ww
f616	Limebrook	215806	7952cT	None	Comm.	Ww
f617	Ihuraua Rd	257840	7942cT	Rare	Sparse	Wo
f618	Ihuraua Rd	257841	7942cT	None	Rare	?
f619	Ihuraua Rd	258841	7942cT	None	Rare	?
f623	Clelands Rd	272811	9742cR	Broken	Abund.	Tk
f624a	Clelands Rd	276811	6954jR	Broken	Abund.	Tk
f624b	Clelands Rd	276811	9742cR	None	Abund.	Tk
f625a	Clelands Rd	278811	7954iR	Broken	Abund.	Tk
f625b	Clelands Rd	278811	9742cR	Rare	Abund.	Tk
f626a	Clelands Rd	282808	7954iR	Broken	Abund.	Tk
f626b	Clelands Rd	282808	9742cR	Broken	Abund.	Tk
f627	Mangamahoe	204897	9832cT	None	Abund.	Wo
f628	Clelands Rd	261813	9732cTR	Worn	Abund.	Wo
f629	Mauriceville	169811	7841cS	Comm.	Comm.	?
f630	Ihuraua	294900	7942cS	Comm.	Sparse	Wo

KEY SPECIES OF FORAMINIFERA

	Time Range	Depth Range
Angulogerina sp.	———	Ps?–El–Ha?
Anomalinoides frigindex Vella	Up. Ww–Rec.	———
Anomalinoides spherica Finlay	Tk–Ww	———
Astrononion sp.	———	El–Ha?
Astrononion novozealandicum Cushm. & Edw.	———	Ps–El
Bigenerina pliocenica Finlay	Up. Tt–Wh	Ro–sp?
Bolivina affiliata Finlay	———	Ha–Ro
Bolivina albatrossi Cushman	———	Ha?–Ro
Bolivina aff. *fyfei* Hornibrook	———	El–shallow Ha
Bolivinita cf. *elegantissima* Boomgart	Sw–Wo	———
Bolivinita pliozea Finlay	Ww–Wc	———
Bolivinita aff. *pliozea* Finlay	Wo?–Ww	———
Bolivinita n. sp. aff. *pliozea* Fin.	Up. Tt–Ww?	———
Bulimina aculeata d'Orbigny	Tk–Rec.	Ha–Ro
Bulimina bremneri Finlay	S–Wo	Ro–?
Bulimina marginata d'Orbigny	———	El–Ha
Bulimina senta Finlay	?–Tk	———
Bulimina cf. *striata* d'Orbigny	Tk–?	Ha?–Ro
Buliminoides williamsoniana (Brady)	———	El–Ha?
Cassidulina laevigata d'Orbigny	———	El–Ha?
Cibicides deliquatus Finlay	Sw–Ww	Ha?–Ro
Cibicides n. sp. aff. *deliquatus* Fin.	Ww–Rec.	El–Ha
Cibicides ihungia Finlay	Lw–Wo	El?–Ha–Ep
Cibicides marlboroughensis Vella	Ww?–Rec.	El
Cibicides molestus Hornibrook	?–Wwp	Ha–Ro
Ehrenbergina mestayerae Finlay	———	El
Elphidiononion aoteanum Vella	———	Ps–El
Elphidium sp.	———	El
Elphidium charlottensis (Vella)	———	Ps–El–(rare)Ha

	Time Range	Depth Range
Elphidium novozealandicum Cushman	——	El
Gavelinopsis cf. *hamatus* Vella	——	Ps–El
Haeuslerella parri Finlay	Tt–Wh	El–Ha
Hofkeruva n. sp. cf. *paeniteres* (Finlay)	?–Tk	Ro–?
Hofkeruva n. sp. aff. *tutamoea* Vella	Ww–?	——
Hofkeruva cf. *tutamoea* Vella	Wwp–Ww	——
Karreriella cylindrica Finlay	——	Rp–Ep
Lenticulina mammiligera	Lw–Wo	Ro
Migros medwayensis (Parr)	?–Tk	Ha
Nonion flemingi Vella	——	Ps–Ha–(rare) Ro
Notorotalia depressa Vella	——	Ps–El?
Notorotalia finlayi Vella	Ww–Rec.	Ps–Ha–Ro?
Notorotalia hurupiensis Vella	Sw–Wo	El–Ha
Notorotalia hurupiensis x *finlayi*	Wwp	El–Ha
Notorotalia inornata Vella	——	Ps–El?
Notorotalia kingmai Vella	Ww	El?–Ha
Notorotalia mangaoparia Vella	Up. Ww–L. Wh	El–Ha?
Notorotalia olsoni Vella	Wo	El?–Ha
Notorotalia pliozea Vella	Tk–Ww	El?–Ha
Notorotalia pristina Vella	Sw–Tk	El
Notorotalia taranakia Vella	——	Ro–Ep
Notorotalia tenuissima (Karrer)	——	El
Notorotalia zelandica Finlay	Wn–Rec.	El
Oolina hexagona (Williamson)	——	Ps–El
Oolina squamosa (Montfort)	——	Ps–El
Pileolina radiata Vella	——	El
Pileolina zelandica Vella	——	El
Plectofrondicularia pohana Finlay	Sw–Tk	——
Plectofrondicularia cf. *advena* Cushm.	——	Ro–?
Pseudononion parri (Cushman)	——	Ps–(rare) El
Pseudogaudryina crespinae Parr	——	El
Quinqueloculina spp.	——	El
Quinqueloculina (*Lachlanella*) sp.	——	El
Rectobolivina sp.	——	El–Ha?
Rectobolivina striatula Cushman	——	El–Ha?
Robulus spp.	——	Ro
Robulus calcar (Linn.)	——	El?–Ha
Robulus costatus (F. & M.)	?–Wwp?	Ha?–Ro
Robulus echinatus (d'Orbigny)	?–Wo	Ro
Rosalina cf. *bradyi* (Cushman)	——	El–Ha?
Saracenaria italica Defrance	——	Ha?–Ro
Sigmoilopsis wanganuiensis Vella	Wn–Rec.	El–Ha?
S. n. sp. aff. *schlumbergeri* (Silv.)	Tk–Wo	(rare) Ro–Sp–Ep?
Sigmomorphina cf. *lacrimosa* Vella	——	El–Ha?
Siphotextularia ihungia Finlay	?–Wo	——
Siphotextularia wairoana Finlay	Wo–Wn?	El?–Ha
Siphotextularia subcylindrica Finlay	Sw–Wo?	——
Staffia multicostales (Finlay)	Wo	Ro
Streblus aoteanus Finlay	——	(rare) El
Textularia ensis Vella	——	El
Turborotalia inflata (d'Orbigny)	Wo–Rec.	——

SAMPLE DETERMINATIONS

f551:   Wn Zealandica Zone 20–200ft. Elphidium Biofacies; overlies Rotunda Zone.
Age: *Bigenerina pliocenica, Haeuslerella parri, Notorotalia zelandica, Sigmoilopsis wanganuiensis.*
Depth: *Ehrenbergina mestayerae, Notorotalia zelandica Textularia ensis.*

f552:   Wn Zealandica Zone 20–200ft. Elphidium Biofacies; shell-bed at f551.
Age: *Notorotalia zelandica.*
Depth: *Notorotalia depressa.*

f553: Wwp Kingmai Zone? 200–1,000ft. Haeuslerella Biofacies.
       Age: *Cibicides molestus, Notorotalia finlayi, Hofkeruva* cf. n. sp. aff. *tutamoea*.
       Depth: *Bulimina aculeata, Haeuslerella parri, Elphidium charlottensis*.

f554: Wwp–Wh zone indeterminate 200–1,000ft. Haeuslerella Biofacies.
       Age: *Bolivinita pliozea, Notorotalia finlayi*.
       Depth: *Robulus calcar, Haeuslerella parri*.

f555: Wh? zone N.D. 200–1,000ft. Haeuslerella Biofacies. Base of Hautawan limestone.
       Age: *Anomalinoides frigindex* ?, *Hofkeruva* n. sp. aff. *tutamoea*.
       Depth: *Notorotalia* large sp., *Robulus calcar, Haeuslerella parri*.

f556: Wwp Molestus Zone 200–1,000ft Haeuslerella Biofacies?
       Age: *Cibicides molestus*, absence of *Cibicides ihungia*.
       Depth: *Cibicides molestus, Haeuslerella parri*.

f557: Wn Zelandica Zone 20–200ft. Elphidium Biofacies.
       Age: *Notorotalia zelandica*.
       Depth: *Cibicides marlboroughensis*.

f558: Wn Zelandica Zone 0–200ft mixed Elphidium and Pseudononion Biofacies; many
       worn specimens.
       Age: *Notorotalia zelandica*.
       Depth: *Pseudononion parri*.

f559: Age and depth N.D.

f561: Up. Ww–L. Wh. Mangaoparia Zone 20–200ft. Elphidium Biofacies.
       Age: *Notorotalia mangaoparia, Anomalinoides frigindex, Hofkeruva* n. sp. aff.
       tutamoea.
       Depth: *Elphidium* sp. *Notorotalia inornata, Notorotalia depressa*, **Elphidiononion**
       aoteanum.

f565: Up. Ww–L. Wh. Mangaoparia Zone 20–200ft. Elphidium Biofacies; near base of
       Hautawan limestone.
       Age: *Notorotalia mangaoparia ? Anomalinoides frigindex, Hofkeruva* n. sp. aff. *tuta-
       moea*.
       Depth: *Angulogerina* sp., *Quinqueloculina* spp., *Quinqueloculina (Lachlanella)* **sp.**,
       Textularia ensis.

f566: Wo Inflata Zone 2,000–4,000ft. Robulus-Semipelagic Biofacies.
       Age: *Hofkeruva* n. sp. aff. *zelamina, Turborotalia inflata*.
       Depth: *Hofkeruva* n. sp.

f567: N.F.

f568: Wo Inflata Zone 2,000–4,000ft. Semipelagic Biofacies.
       Age: *Hofkeruva* n. sp. aff. *zelamina, Turborotalia inflata*.
       Depth: 50% planktonics.

f569: N.F.

f570: Top Ww-basal Wh Mangaoparia Zone? 20–200ft. Elphidium Biofacies.
       Age: *Notorotalia mangaoparia, Hofkeruva* n. sp. aff. *tutamoea*.
       Depth: *Quinqueloculina* spp., rare *Siphotextularia wairoana*.

f571: Tk, Zeaserus Zone 1,000–2,000ft. Robulus Biofacies?
       Age: *Bulimina aculeata, Bulimina* cf. *striata, Sigmoilopsis* n. sp. aff. *schlumbergeri*.
       (*Turborotalia inflata* absent).
       Depth: *Sigmoilopsis* n. sp., *Bulimina aculeata, Cibicides deliquatus*.

f572: Age N.D. 20–200ft. Elphidium Biofacies.
       Depth: *Astrononion novozealandicum*, abundant *Elphidium charlottensis*, badly
       preserved macrofossils.

f573: N.F.

f574: Wwp Molestus Zone 1,000–2,000ft. Robulus Biofacies. Age: *Cibicides molestus,
       Sigmoilopsis* n. sp. aff. *schlumbergeri, Turborotalia inflata, Cibicides ihungia* absent.
       Depth: *Bigenerina pliocenica, Karreriella cylindrica*.

f575: Ww Kingmai Zone 200–1,000ft. Haeuslerella Biofacies.
       Age: *Notorotalia kingmai, Bolivinita pliozea, Hofkeruva* cf. n. sp. aff. *tutamoea*.
       Depth: *Robulus calcar, Haeuslerella parri, Siphotextularia wairoana*, fragments of
       Mollusca, lacks *Elphidium*, miliolids, etc.

f576: Wwp Molestus Zone 1,000 plus ft. Robulus Biofacies or deeper fauna. Age: *Cibicides molestus, Turborotalia inflata, Cibides ihungia* absent.
Depth: *Bigenerina pliocenica.*

f577: Ww Kingmai Zone 200–1,000ft. Haeuslerella Biofacies?
Age: *Anomalinoides spherica, Cibicides* n. sp. aff. *deliquatus, Notorotalia finlayi, Hofkeruva* n. sp. aff. *tutamoea.*
Depth: *Haeuslerella parri,* lacks *Elphidium,* etc.

f578: Wo Inflata Zone 1,000–2,000ft. Robulus Biofacies.
Age: *Bulimina bremneri, Robulus costatus, Turborotalia inflata.*
Depth: *Bigenerina pliocenica, Karreriella cylindrica, Sigmoilopsis* n. sp. aff. *schlumbergeri, Robulus costatus.*

f579: Wo Inflata Zone 2,000–4,000ft. Semipelagic Biofacies.
Age: *Cibicides ihungia, Turborotalia inflata.*
Depth: *Karreriella cylindrica,* 50% planktonics, very rare small Mollusca.

f580: Wo Inflata Zone 2,000–4,000ft. Semipelagic Biofacies.
Age: *Cibicides ihungia, Turborotalia inflata.*
Depth: *Bolivina albatrossi,* ca. 50% planktonics, possibly some transported shallower-water spp.

f581: N.F.

f582: Wo Inflata Zone 2,000–4,000ft. Semipelagic Biofacies, almost identical with f580.

f583: Wwp Molestus Zone? 200–1,000ft. Haeuslerella Biofacies.
Age: *Cibicides molestus, Turborotalia inflata, Cibicides ihungia* absent.
Depth: *Siphotextularia wairoana, Haeuslerella parri,* lacks *Elphidium,* etc.

f584: Age and depth N.D.

f585: Wo Olsoni Zone 1,000–4,000ft. Robulus or Semipelagic Biofacies with transported spp. of the Haeuslerella Biofacies.
Age: *Hofkeruva* n. sp. aff. *zelamina, Notorotalia olsoni.*
Depth: *Hofkeruva* n. sp., *Notorotalia olsoni.*

f586: Wo Inflata Zone 1,000–2,000ft. Robulus Biofacies.
Age: *Staffia multicostales, Cibicides ihungia, Turborotalia inflata.*
Depth: *Robulus* spp., *Staffia multicostales, Bigenerina pliocenica, Karreriella cylindrica,* 20–30% planktonics.

f587: N.F.

f588: Wo Inflata Zone 1,000–2,000ft. Robulus Biofacies with transported spp. of the Haeuslerella Biofacies.
Age: *Cibicides ihungia, Turborotalia inflata.*
Depth: *Robulus* spp., *Notorotalia taranakia, Haeuslerella parri.*

f589: Wo Inflata Zone 1,000–2,000ft. Robulus Biofacies.
Age: *Staffia multicostales, Bolivinita* cf. *elegantissima, Cibicides ihungia, Lenticulina mammiligera, Robulus echinatus, Siphotextularia ihungia, Turborotalia inflata.*
Depth: *Lenticulina mammiligera, Robulus echinatus, Staffia multicostales.*

f590: Ww Kingmai Zone? 200–1,000ft. Haeuslerella Biofacies.
Age: *Notorotalia hurupienses* x *finlayi, Bolivinita pliozea, Hofkeruva* cf. n. sp. aff. *tutamoea.*
Depth: *Robulus calcar, Siphotextularia wairoana, Elphidium charlottensis, Haeuslerella parri, Nonion flemingi,* lacks abundant *Elphidium,* large *Notorotalia,* etc.

f591: N.F.

f592: Ww–Wn zone indeterminable 20–1,000ft. Elphidium or Haeuslerella Biofacies.
Age: *Bolivinita pliozea, Notorotalia finlayi.*
Depth: *Elphidium charlottensis.*

f593: N.F.

f594: Wo Inflata Zone graded-bedded.
Age: *Cibicides ihungia, Turborotalia inflata.*
Depth: N.D.

f596: Tk Zeaserus Zone 2,000–4,000ft. Semipelagic Biofacies with transported Haeuslerella Biofacies species.
Age: *Hofkeruva* cf. *paeniteres,* abundant *Plectofrondicularia pohana, Siphotextularia subcylindrica, Sigmoilopsis* n. sp. aff. *schlumbergeri.*

Depth: Abundant *Sigmoilopsis* n. sp., *Karreriella cylindrica, Bigenerina pliocenica* absent, *Rectobolivina striatula.*

f597: Wwp Molestus Zone 1,000–2,000ft. Robulus Biofacies, with transported Haeuslerella Biofacies species.
Age: *Cibicides molestus, Cibicides ihungia* absent, *Turborotalia inflata.*
Depth: *Bigenerina pliocenica, Karreriella cylindrica, Plectofrondicularia* cf. *advena, Saracenaria italica, Rectobolivina striatula.*

f598: Wo Inflata Zone 1,000–4,000ft. Robulus or Semipelagic Biofacies.
Age: *Cibicides ihungia, Turborotalia inflata.*
Depth: *Bigenerina pliocenica, Karreriella cylindrica,* 30–40% planktonics.

f599: Tk Zeaserus Zone 2,000 plus ft. Semipelagic or Eupelagic Biofacies with transported Haeuslerella Biofacies species.
Age: *Hofkeruva* cf. *paeniteres,* abundant *Plectofrondicularia pohana, Siphotextularia subcylindrica, Sigmoilopsis* n. sp. aff. *schlumbergeri.*
Depth: *Karreriella cylindrica, Sigmoilopsis* n. sp., *Rectobolivina striatula, Bolivina* aff. *fyfei.*

f600: Ww Kingmai Zone 200–1,000ft. Haeuslerella Biofacies.
Age: *Notorotalia kingmai, Cibicides deliquatus, Hofkeruva* cf. n. sp. aff. *tutamoea, Notorotalia finlayi.*
Depth: *Notorotalia kingmai, Siphotextularia wairoana, Haeuslerella parri.*

f601: Ww-Wh zone indeterminable 20–200ft. Elphidium Biofacies, 120ft below Hautawan limestone.
Age: *Hofkeruva* n. sp. aff. *tutamoea, Notorotalia finlayi.*
Depth: *Pileolina zelandica.*

f602: Age and depth N.D.

f603: Ww Kingmai Zone 20–200ft. Elphidium Biofacies?
Age: *Anomalinoides spherica, Cibicides deliquatus, Notorotalia pliozea, Hofkeruva* n. sp. aff. *tutamoea.*
Depth: *Notorotalia pliozea, Elphidiononion aoteanum,* abundant *Elphidium charlottensis, Haeuslerella parri, Rectobolivina striatula.*

f604: Age and depth N.D.

f605: Wo Olsoni Zone 20–1,000ft. Elphidium or Haeuslerella Biofacies.
Age: *Notorotalia olsoni, Cibicides molestus.*
Depth: *Bulimina marginata, Cassidulina laevigata, Rectobolivina striatula, Notorotalia olsoni.*

f606: Wo Olsoni Zone 20–1,000ft. Elphidium or Haeuslerella Biofacies.
Age: Indicators as for f605.
Depth: *Bolivina* aff. *fyfei, Rectobolivina striatula, Gyroidinoides stineari.*

f607: Wo Inflata Zone 1,000–2,000ft. Robulus or deeper Biofacies, tuffaceous matrix, possibly some transported species.
Age: *Cibicides ihungia, Lenticulina mammiligera, Turborotalia inflata.*
Depth: *Lenticulina mammiligera, Karreriella cylindrica.*

f608: Wo Inflata Zone 1,000 plus ft. Robulus or deeper Biofacies, with transported Haeuslerella or Elphidium Biofacies species.
Age: *Notorotalia olsoni, Staffia multicostales, Turborotalia inflata.*
Depth: *Staffia multicostales, Karreriella cylindrica, Notorotalia olsoni.*

f609: Wo Inflata Zone 1,000–4,000ft. Robulus or Semipelagic Biofacies.
Age: *Bulimina bremneri, Cibicides ihungia, Turborotalia inflata.*
Depth: *Bigenerina pliocenica, Karreriella cylindrica, Sigmoilopsis* n. sp. aff. *schlumbergeri,* less than 40 per cent planktonics.

f610: Wo Inflata Zone 4,000 plus ft. Eupelagic Biofacies.
Age: *Cibicides ihungia, Turborotalia inflata.*
Depth: Small number of benthonic spp., 70 per cent planktonics.

f611: Tk Zeaserus Zone 4,000 plus ft. Eupelagic Biofacies.
Age: Abundant *Plectofrondicularia pohana, Sigmoilopsis* n. sp. aff. *schlumbergeri.*
Depth: *Sigmoilopsis* n. sp. rare, low number of benthonic spp., more than 70 per cent planktonics.

f612: Upper Ww–Lower Wh Mangaoparia Zone 20–200ft. Elphidium Biofacies.
Age: *Notorotalia mangaoparia, Cibicides* n. sp. aff. *deliquatus, Hofkeruva* n. sp. aff. *tutamoea, Notorotalia finlayi.*
Depth: *Notorotalia mangaoparia, Siphotextularia wairoana.*

f613: Age N.D. 20–1,000ft. Elphidium or Haeuslerella Biofacies, tuffaceous.
Age: *Bolivinita* aff. *pliozea, Notorotalia finlayi?*
Depth: *Elphidium charlottensis, Rectobolivina* sp., *Robulus,* siliceous sponge spicules and Radiolaria.

f614: Wwp–Ww zone indeterminable 20–200ft. Elphidium Biofacies.
Age: *Cibicides molestus ?, Notorotalia pliozea, Hofkeruva* cf. n. sp. aff. *tutamoea.*
Depth: *Astrononion* sp., *Bolivina* aff. *fyfei, Elphidium charlottensis,* siliceous sponge spicules.

f615: Ww basal? Kingmai Zone 20–1,000ft. Elphidium or Haeuslerella Biofacies.
Age: *Notorotalia kingmai, Notorotalia hurupiensis* x *finlayi, Cibicides* n. sp. aff. *deliquatus.*
Depth: *Notorotalia kingmai,* siliceous sponge spicules.

f616: Ww basal? Kingmai Zone 200–1,000ft. Haeuslerella Biofacies.
Age: *Hofkeruva* n. sp. aff. *tutamoea, Notorotalia hurupiensis* x *finlayi.*
Depth: *Astrononion* sp., *Haeuslerella parri, Nonion flemingi.*

f617: Wo Olsoni Zone 20–1,000ft.   Elphidium or Haeuslerella Biofacies.
Age: *Notorotalia olsoni.*
Depth: *Haeuslerella parri, Siphotextularia wairoana.*

f618: Age and depth N.D. Radiolaria.

f619: Age and depth N.D. Radiolaria and siliceous sponge spicules.

f623: Tk Zeaserus Zone 1,000 plus ft. Robulus or deeper Biofacies with transported Elphidium Biofacies species, graded-bedded with mollusc and echinoid fragments.
Age: Abundant *Plectofrondicularia pohana, Bulimina aculeata, Notorotalia pliozea, Sigmoilopsis* n. sp. aff. *schlumbergeri.*
Depth: *Bigenerina pliocenica, Karreriella cylindrica, Hofkeruva* cf. *zelamina,* abundant planktonics, *Notorotalia pliozea, Notorotalia tenuissima, Oolina squamosa, Rectobolivina striatula, Rosalina* cf. *bradyi.*

f624: Tk Zeaserus Zone 2,000 plus ft. Semipelagic or Eupelagic Biofacies, with transported Elphidium Biofacies (upper neritic) species, graded-bedded with worn fragments of molluscs, echinoids, and bryozoans, and chipped ostracodes.
Age: *Bulimina senta, Hofkeruva zelamina, Migros medwayensis, Notorotalia pristina, Bulimina aculeata.*
Depth: *Bigenerina pliocenica, Karreriella cylindrica,* 70 per cent planktonics in mudstone bands; *Elphidium* sp., *Notorotalia pristina, N. tenuissima, Buliminoides williamsoni, Migros medwayensis, Oolina hexagona, Pileolina radiata, P. zelandica, Pseudogaudryina crespinae, Quinqueloculina* spp., *Rosalina* cf. *bradyi, Sigmomorphina* cf. *lacrimosa.*

f625: Tk Zeaserus Zone 2,000 plus ft. Semipelagic or Eupelagic Biofacies, with transported Elphidium Biofacies species graded bedded.
Age: Common *Plectofrondicularia pohana, Bulimina aculeata.*
Depth: Faunas similar to those in f624.

f627: Wo Inflata Zone 1,000–2,000ft. Robulus Biofacies?
Age: *Cibicides ihungia, Turborotalia inflata.*
Depth: *Bigenerina pliocenica, Karreriella cylindrica, Bulimina aculeata, Bolivina albatrossi, Cibicides deliquatus.*

f628: Wo–Wwp zone indeterminable 2,000–4,000ft. Semipelagic Biofacies with transported Haeuslerella Biofacies species, graded bedded, tuffaceous with worn gastropod apices and some ostracodes.
Age: *Cibicides molestus, Turborotalia inflata.*
Depth: *Bigenerina pliocenica,* abundant *Notorotalia taranakia,* common *Sigmoilopsis* n. sp. aff. *schlumbergeri,* abundant planktonics; *Haeuslerella parri, Robulus calcar.*

f629: Age N.D. 0–200ft. Pseudononion or Elphidium Biofacies.
Depth: *Elphidium novozealandicum, Gavelinopsis* cf. *hamatus,* infrequent *Streblus aoteanus.*

f630:   Wo Olsoni Zone 20–200ft.   Elphidium Biofacies.
        Age: *Notorotalia olsoni.*
        Depth: *Bolivina* aff. *fyfei, Rectobolivina striatula.*
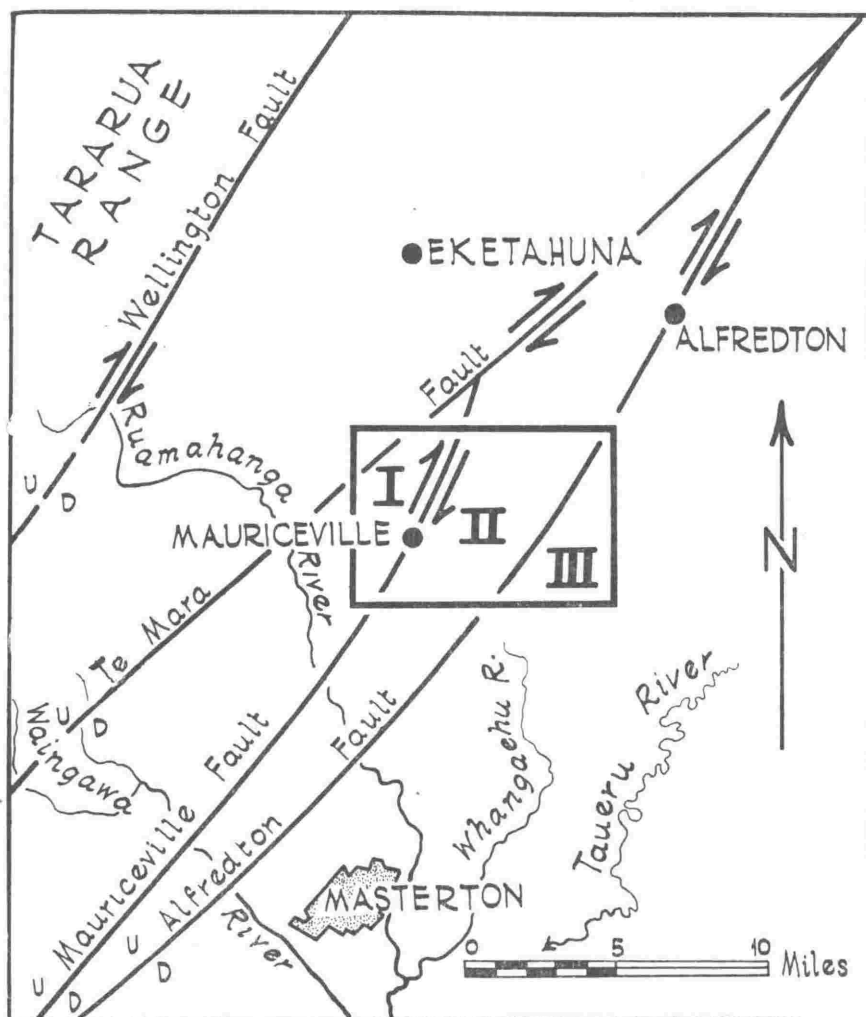
FIG. 5.—Main faults in north-west Wairarapa. The rectangle delineates the Mauriceville District; I, western belt, west of the Mauriceville Fault; II, central belt between the Mauriceville and Alfredton Faults; III, eastern belt, east of the Alfredton Fault.

DISCUSSION

The main faults in the north-western part of Wairarapa are shown on Fig. 5. The Mauriceville Fault and the Alfredton Fault (Orbell, in press) cross the Mauriceville District and converge to the south-west. They join and become the Wairarapa Fault near Carrington, west of Carterton. The north-east part of the Te Mara Fault has been mapped by G. Neef, the south-west part by the writer. Near Mount Bruce it has brought Opoitian mudstone into contact with Mesozoic greywacke, and to the north-east it displaces the Tertiary rocks and shows some evidence of recent dextral movement (G. Neef, pers. comm.). To the south-east it runs obliquely into the Tararua Range at Te Mara Bush. The Mauriceville

Fault abuts against the Te Mara Fault five miles north-north-east of Mauriceville.

The Alfredton Fault is continuous with the Wairarapa Fault to the south-west and with the Makuri Fault to the north-north-east. Between Carrington and the Mauriceville District it has not been active since the last glaciation, and all postglacial movement has been concentrated on the branch Mauriceville Fault. The 1855 Earthquake trace (Ongley, 1943) and prominent postglacial scarplets have directed attention to the Mauriceville Fault, giving the erroneous impression that it is the main fault.

The Mauriceville Fault and the Alfredton Fault divide the Mauriceville District into three north-north-east-trending belts (Orbell, in press)—numbered I, II, and III on Fig. 5. The sequence of depth-facies changes in the Kapitean and Opoitian of each belt is shown in the following table:

BELT I	BELT II	BELT III
Wo: (not preserved)	Lower neritic	(Not preserved)
Wo: Mid to upper bathyal	Mid to upper bathyal	Lower to mid-bathyal
Tk: Neritic	Neritic	Lower bathyal
Tk: Non-marine	(Not exposed)	Turbidites, probably lower bathyal

The neritic Kapitean of Belt II is exposed just west of the Alfredton Fault about four miles south-west of Alfredton (G. Neef, pers. comm.).

Present-day slopes on muddy sea-beds do not exceed two or three degrees. If strike-slip displacement of facies is not assumed, the inferred slope of the sea-bed across the Alfredton Fault in Kapitean time—over 20°—is impossibly high. A postglacial terrace sequence at Waiohine River, in southern Wairarapa, cut by the Wairarapa Fault, shows that strike-slip displacement of at least 400 feet took place after the last glaciation, and was about six times greater than the vertical displacement. Orbell (in press) notes that streams near Mauriceville are dextrally displaced 60ft by the Mauriceville Fault. Lower-bathyal Opoitian matching that to east of the Alfredton Fault in Mauriceville District occurs to the west of the fault about ten miles to the north in Eketahuna District. A dextral strike-slip movement is indicated, but its amount cannot be determined without mapping of depth-facies belts over a much larger area.

That the Mauriceville Fault is a major tectonic feature is shown by the apparent vertical displacement of 8,000ft at Mauriceville (Orbell, in press). But the similarity of the depth-facies sequences on the two sides suggests a small displacement of facies belts—i.e., relatively small strike-slip displacement compared with that at the Alfredton Fault to the east.

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Determining Depths of New Zealand Tertiary Seas

An Introduction to Depth Paleoecology

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Abstract

PALEOECOLOGY is the study of past environmental conditions. It is based chiefly on fossils, but also on lithologies and inferred geological history. Marine paleoecology has two primary aims: firstly to determine former surface water temperatures and secondly to determine former sea depths. Until now little effort has been made to determine depths of former New Zealand seas, even though the information is vital for geological history, and particularly for tectonic history.

Depth paleoecology is best carried out in three steps. The first is to determine fossil biofacies by noting consistent taxonomic associations. The second step is to determine the order of relative depths of the fossil biofacies from their space-time distribution. The third step is to determine absolute depths by depth-correlating each fossil biofacies with its equivalent present-day biofacies. Depth-correlation of biofacies that represent a particular depth at different times is carried out by application of methods and principles analogous to those applied to time-correlation of stratigraphic zones that represent the same time at different places. A series of biofacies for any particular age is easier to depth-correlate than an isolated biofacies.

The determination of absolute depths of former New Zealand seas is hampered by lack of data on the depth ranges of present-day organisms (especially Foraminifera) in seas around New Zealand. But a basic framework of world-wide depth biofacies is defined by progressive change with depth of relative proportions of the main groups of marine organisms represented by fossils, and can be applied to paleoecology in New Zealand. This framework is supported by some well established changes with depth in molluscan and foraminiferal faunas.

The Status of Paleoecology in New Zealand

THE TWO MOST IMPORTANT AIMS of paleoecology are to estimate sea-level temperatures at successive times during the past, and depth of deposition of ancient sediments. Temperatures indicate climatic history; depths indicate paleogeography and much of tectonic history.

19

Various animal groups have been used to estimate temperature changes at sea-level during the Cenozoic. Temperatures are generally considered to have risen during the early Tertiary, reaching a maximum at the beginning of the Miocene, and to have fallen during the late Tertiary, reaching a minimum in the Pleistocene. No attempts have been made to define temperature-controlled zoogeographic provinces for any time within the Tertiary. From the distribution of reef-building corals (Squires, 1957), however, it is clear that temperature zonation existed during the Miocene, and temperature zonation may be assumed to have existed throughout the Cenozoic. Determination of past temperature zones is vitally necessary for both depth determination and inter-regional stratigraphic correlation.

Depth paleoecology is virtually an unexploited field of research in New Zealand, and is still seriously hampered by lack of data on the depth ranges of present-day organisms in New Zealand seas. Previously only two serious attempts have been made to determine depths of deposition of New Zealand Tertiary sediments by paleoecological methods. The first (Fleming, 1953) dealt mainly with Pleistocene marine sediments deposited within a small range of shallow depths. The second (Vella, 1962) dealt with Upper Miocene and Pliocene sediments near Mauriceville, Wairarapa, deposited between 0 ft. and c5,000 ft. In a large range of depths such as that determined in Wairarapa, certain general features of the faunas can be used as criteria for broad depth divisions which are useful for a reconnaissance of New Zealand Cenozoic sea depths.

The physical factors which probably account for these depth criteria are discussed below and a practical method for applying the criteira to paleoecology is outlined. The method is based on total fossil content of rocks, and can be used by a geologist with an elementary knowledge of paleontology. It is limited in that it will give only broad and rather indefinite depth ranges, but these depth ranges can serve as a firm basis for more detailed studies by specialist paleontologists. Some additional notes are given on particular Mollusca, Echinoidea, and Foraminifera which appear to be useful depth indicators.

First Principles of Paleoecology

The primary assumption of paleoecology is that ' the present is the key to the past '. Paleoecology is essentially the reverse of ecology. The ecologist seeks to determine the inter-relationships of living plants or animals to their environment, and is able to measure physical factors of the environment directly. The paleoecologist uses ecological data to attempt to infer physical factors of the environments of fossils. His inferences are liable to be considerably in error because the fossil record is fragmentary, and because the ecology of present-day organisms is as yet imperfectly understood.

The plant and animal community is itself one of the most characteristic features of any environment because it is extremely sensitive to any change in the environment. Fossils are a partial record of past communities, and are the best index we have of past environments. They are not so reliable, however, that the paleoecologist can afford to neglect any other lines of evidence. All fossils occur in some kind of rock, and the physical and chemical characters of the rock may be diagnostic of a particular environment or range of environments. The sequence of events inferred from the stratigraphic succession is also invaluable for the paleoecologist.

The term ' facies ' which commonly appears in geological literature strictly means general appearance. It is used in several special senses, one of which is the rock or group of rocks characteristic of a particular environment. For example we may speak of the turbidite facies meaning the kind of rock deposited by submarine turbidity currents; or the estuarine facies meaning a particular suite of rocks varying in some characters, but all exhibiting the peculiar characters of estuarine deposits. The term lithofacies specifies the physical and chemical characters of the rock of a particular range of evinronments. The term ' biofacies ' specifies the biological assemblage of a particular range of environments. A particular marine lithofacies of one age within a limited area is generally accompanied by its own particular biolfacies. This is partly because many benthonic animals prefer to live on a particular type of sea-bottom — a hard bottom, sandy bottom, or mud bottom. But more generally it is because biofacies and lithofacies are both controlled by physical and chemical factors related to depth in the sea.

Dominant Physical Factors in Oceanic Environments

Conditions on the shallowest parts of present-day seas are strongly affected by local fatcors including the air temperature, the strength and direction of the prevailing wind, the physical and chemical nature of sediment supplied from the land, the distance from river mouths, the velocity of tidal and wave generated currents, and the morphology of the sea-bed. These produce local variations in the type of sea-bed and in the physical and chemical nature of the sea-water. As a result a number of widely different biofacies occur each with a localised though recurrent distribution. The associated lithofacies are equally variable. At the present time these variable shallow-water biofacies extend down to about 400-500 feet, although there is reason to believe that they did not extend so deeply during much of the Tertiary.

At greater depths the factors controlling the environment show much less variation from place to place. At a given depth physical and chemical conditions are relatively uniform and this results in relatively uniform biofacies and lithofacies. The main variations in

conditions take place vertically as the sea tends to be stratified with regard to temperature, salinity, oxygen content, and other chemical variables. In addition depth controls hydrostatic pressure and exerts a dominant influence on light intensity. Depth is therefore a master factor which gives rise to a series of biofacies, each being characteristic of a particular depth range.

Sunlight is the ultimate source of energy for all life in the sea as on the land. The limit of effective light penetration and hence of photosynthesis is thought to be about 500 feet in temperate seas (Holmes, 1957). The quantity of growing plants available to herbivorous animals must decline rapidly with increasing depth. A decrease in variety of animals and a radical change in the composition of faunas takes place between 500 and 1,000 feet, and is inferred to be related to the availability of living plant food. Biological communities from 0 to 500 feet includes photosynthesising plants, herbivores, carnivores, and scavengers; communities from 500 to 1,000 feet are probably transitional with decreasing numbers of photosynthesising plants and herbivores; communities below 1,000 feet probably include only scavengers and carnivores.

Temperature is an important physical factor affecting plant and animal distributions in every part of the ocean, and is possibly the most important factor in depths greater than 1,000 feet. Except locally in polar regions temperature decreases with increase in depth. At the same time temperature of the surface water generally decreases with increase in distance from the equator, but this horizontal temperature gradient may be locally reversed as a result of ocean currents. The deepest parts of the ocean have a uniform temperature from equator to polar regions of about 1-2° C. The vertical temperature gradient is steepest at the equator. It is much lower and may actually be reversed in polar seas. Isothermal surfaces in the oceans are thus generally inclined, dipping towards the equator; shallower isotherms are more steeply inclined than deeper isotherms. Furthermore, at any particular place temperatures gradually changed during the past, and the space-time pattern of temperature change is highly complex. Consequently paleoecological interpretation of a temperature controlled organism is difficult and requires a knowledge of either the depth at which the organism was living or the sea-level temperature where and when the organism was living. It is believed (cf. Natland, 1957) that distributions of many deep-water Foraminifera are controlled mainly by temperature and present-day biofacies occur in zones which tend to be bounded by isothermal surfaces and thus deepen towards the equator (Fig. 4).

Little is known of the direct effects of the hydrostatic pressure gradient on animal distributions, but at least a few Foraminifera appear to occur in restricted depth ranges while tolerating large temperature ranges. Such forms are of very great value for determining past depths, but not many are known because they are

detected only by ecological study over a large range of latitudes and ecological studies tend to be localised.

Carbon dioxide concentration is assumed to be related to temperature and hydrostatic pressure, and increases with depth. Below a certain depth the CO_2 concentration becomes sufficient to ensure that all forms of calcium carbonate (including shells of Foraminifera) are dissolved. This depth is referred to as the $CaCO_3$ solution boundary, and is about 15,000 feet off California, but may be shallower in polar regions. In the Ross Sea, Antarctica, from distributions of Foraminifera examined by the writer, there is a $CaCO_3$ solution boundary at about 1,400 feet. Certain animals

DEPTH	ENVIRONMENT	TYPICAL SEDIMENTS	PHYSICAL + CHEMICAL FACTORS		FORAMINIFERA	OTHER GROUPS IMPORTANT AS FOSSILS
0 feet	Littoral	variable, well sorted, including sands & shell-beds	Light decreases	Photic zone	number of species increases	number of species decreases
	Neritic		Temperature decreases			
300 / 600	Transition from neritic to bathyal	muddy sand / sandy mud.				
1,200						
3,000	(inner bathyal)	massive blue mud	Temperature increases	Pressure increases	at maximum	characteristic Mollusca
6,000	Bathyal	Globigerina ooze	Light nil			number of individuals insignificant geologically
9,000	(outer bathyal)	Turbidites			decreases (Globigerina ooze fauna)	
12,000			Temperature at minimum 1-2°C			
15,000	Abyssal	siliceous ooze		CaCO₃ solution boundary	no calcareous species	
18,000	Hadal	red clay				
33,000						

Fig. 1: Conventional arbitrary depth divisions of the ocean floor, showing main changes with depth of sediments, physical and chemical factors, and animals represented as fossils.

(e.g. a few species of Mollusca) are able to extract calcium carbonate for their shells from the water below the solution boundary, and live at very great depths in oceanic trenches. Foraminifera seem to to be unable to do so, and where the solution boundary is deep the ratio of calcareous to non-calcareous Foraminifera gradually

23
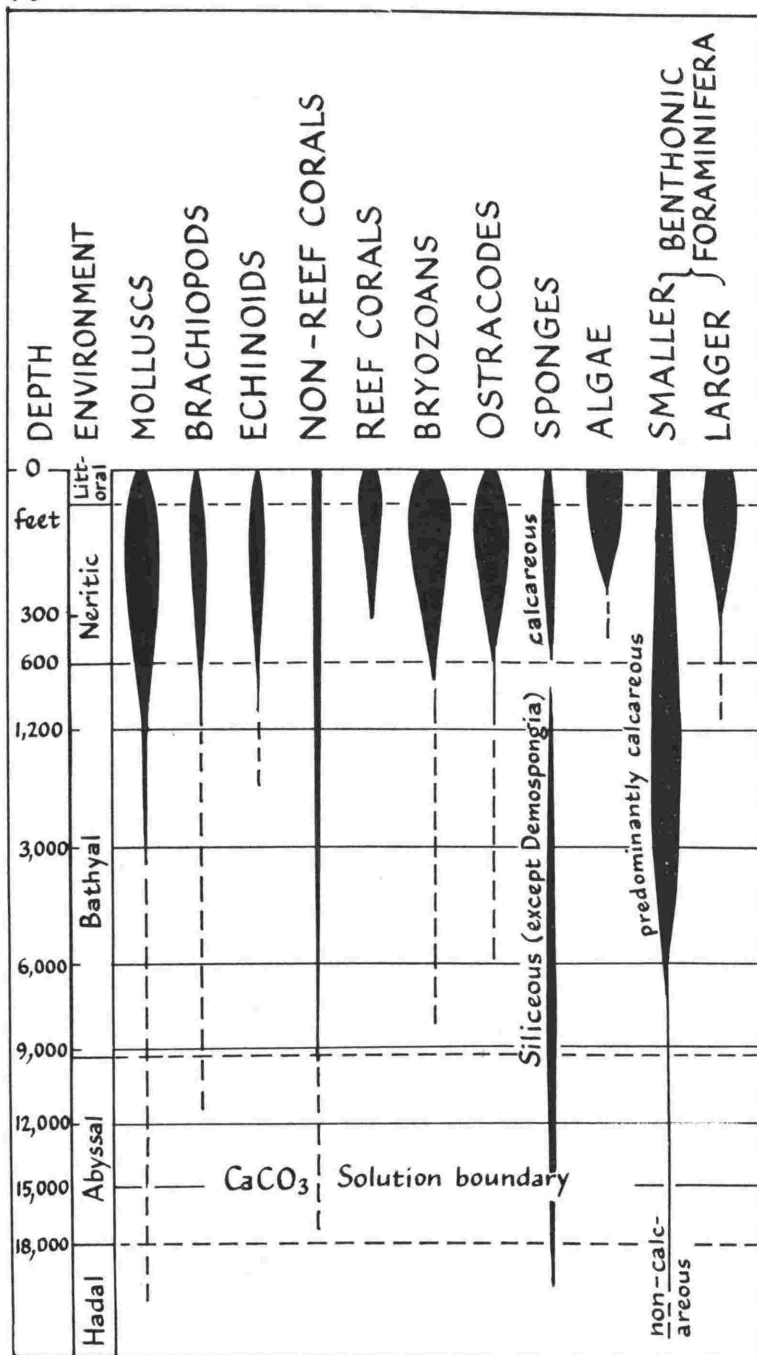
Fig. 2: Depth distribution of main present-day groups of marine organisms represented as fossils, based mainly on data in the Annotated Bibliographies in the Treatise of Marine Ecology and Paleoecology (Hedgpeth and Ladd, editors, 1957, Geol. Soc. America Mem. 67). Relative abundance of species and specimens roughly indicated by the width of the range line; insignificant numbers of specimens

decreases with increasing depth to become nil at the solution boundary. Globigerina ooze does not accumulate below the solution boundary because the shells of pelagic Foraminifera falling from the surface are dissolved before they reach the bottom.

Conventional Names for Oceanic Depth-environments

The ocean floor has been divided according to arbitrarily chosen depths into five main depth environments — littoral (intertidal), neritic (continental shelf), bathyal (continental slope), abyssal (deep-sea-floor), and hadal (deep oceanic trenches). Figure 1 shows the conventional depth-environments, the physical factors affecting distribution of plants and animals, and the probable depth range of the main lithofacies occurring in New Zealand. The physical factors form a basic framework for the pattern of depth faunas which can be used for estimating depths of former seas.

Depth Distribution of Present-day Marine Organisms

Generalised Distribution of Main Taxa:

The most useful depth indicators are benthonic organisms. The planktonic Foraminifera and Radiolaria are also useful because they are essentially pelagic (inhabitants of the high seas) and their remains generally accumulate most abundantly in deep water.

The overall depth distributions of main benthonic marine taxa represented as fossils are shown in Figure 2. Most taxa have a large depth range, but all except the benthonic smaller Foraminifera are poorly represented in, and for paleoecological purposes are virtually absent from deeper waters. The abundance of species and specimens of most groups or organisms falls off rapidly below 500 feet, becoming very small by about 1,000 feet, suggesting that light intensity is the essential controlling factor for most organisms.

Benthonic smaller Foraminifera are most abundant between 500 and 1,000 feet (Bandy and Arnal, 1960) and presumably are mostly scavengers, their primary energy supply being organic material drifted down from above. They are well represented down to the $CaCO_3$ solution boundary.

Present-day faunas can thus be divided into two groups: An essentially shallow-water group, virtually absent below 1,000 feet, comprising all benthonic groups represented as fossils except the smaller Foraminifera, and an essentially depth tolerant group, comprising the benthonic smaller Foraminifera only. The best indication of depth down to 1,000 feet is the ratio of the number of species of the shallow-water group to the number of species of benthonic smaller Foraminifera (S/F). Approximate ratios are as follows:

DEPTH RANGE	S/F
0-400 feet	greater than 3/1-2/1
400-600 feet	2/1-1/1
600-1,000 feet	1/1-1/3

25

The decrease in the ratios with increase in depth is well established but statistical work on recent faunas is needed to determine ratios for each depth more accurately.

Mollusca in New Zealand:

Powell (1957) listed slightly over 2,000 species of Mollusca living in New Zealand with the depth range and geographic distribution known for each at the time of writing. Nearly all are littoral or neritic. What we know of deeper water Mollusca is due mainly to Dell (1956) who listed 595 species and subspecies from 48 stations (sampling positions) between 600 and 1,800 feet. Dell called this the achibenthic fauna of New Zealand. Only 165 species were recorded at 1,800 feet. Of these 27 are typical shallow-water species found in deep water close to the continental shelf only, and are inferred to have been swept down from the shelf by vigorous currents. The typical 1,800-feet fauna thus includes 138 known species. Within it Dell distinguished three important elements:

(1) Species with a large bathymetric range, extending from shallow water down to 1,800 feet — 36 spp. (includes *Neilo australis, Nemocardium pulchellum* and Scaphopoda which occur in the massive calcareous mudstone facies of the Pliocene in Wairarapa).

(2) Species occurring in shallow water (0-100 feet) at the Subantarctic Islands — 9 spp. These species are depth-tolerant but are apparently temperature-controlled.

(3) Species restricted to deep water — 93 spp., representing 71 genera. This group is distinctive and of prime importance for paleoecology. It includes 13 genera which occur in the Cenozoic and are useful bathymetric indicators. Ten of these — *Pectunculina, Parvamussium, Manawatawhia, Pleia, Waipaoa, Teremelon, Micantapex,* or the *murdochi* group, *Comitas* of the *fusiformis* group, *Scaphander,* and *Planipyrgiscus* — have no known shallow-water species. The other three — *Galeodea, Ellicea,* and *Iredalina* — are known only rarely above 600 feet. Dell included in his list of archibenthic Mollusca 14 species recorded from 4,000 feet most occurring at one station collected by the 'Challenger' Expedition, and 3 species from 6,600 feet at another station collected by the 'Challenger' Expedition. Seven of these species are also recorded from 1,800 feet or less.

Apart from the rapid decrease in number of species with increasing depth between 500 and 1,000 feet (Fig. 3), shells tend to become smaller and thinner. The absolute depth range of individual species, and the geographic range of genera tend to become larger. A large proportion of the genera represented at 1,800 feet are not endemic to New Zealand.

Figure 3 is based on New Zealand occurrences down ot the depth of 6,600 feet. The number of species in hadal depths is filled in from data given for the Kermadec Trench by Bruun (1957).

Data on the number of species on a typical fauna of any particular depth has not been analysed. It is assumed that the number of species at any place will show approximately the same relationship to depth as the total New Zealand fauna, and experience with fossil depth-biofacies supports this assumption.
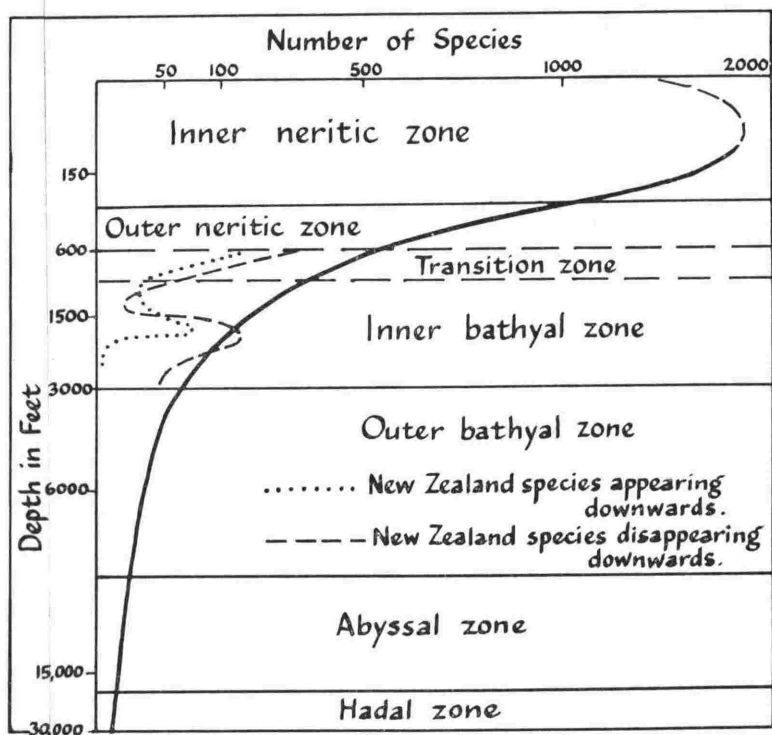
Fig. 3: Graph showing number of species of Mollusca at different depths in New Zealand seas down to about 6,000 feet, and in the Kermadec Trench at hadal depths. Main curve generalised.

Deep-water Mollusca of the New Zealand Tertiary are comparatively little known. They are generally rare and poorly preserved and have been neglected by paleontologists in favour of neritic fossils which are at many places abundant and well preserved. They offer a fertile and undeveloped field of research as they promise to be the most reliable indicators for depths between 1,000 and 2,000 feet. Sediments deposited within this depth range form a large volume of New Zealand Tertiary rocks.

Of the genera of Echinoidea which occur in the New Zealand Tertiary, a number are still represented in Recent seas, either in New Zealand itself or, in the case of the warm-water genera which no longer occur here, in north-eastern Australian waters.

Goniocidaris ranges the outer part of the shelf, apparently on both hard and soft bottom, but the slender-spined species also enter the archibenthal fauna. *Ogmocidaris* is at present unknown from the Tertiary, but it may be expected to occur in the deeper-water facies of the Castlecliffian; it appears to be mainly archibenthal. Of the genera now extinct in New Zealand, notable cidarids are *Phyllacanthus* and *Eucidaris*; both are indicative of shallow-water hard-bottom, especially the outer parts of reefs (including coral reefs), in waters not cooler than those of Norfolk Island and the Kermadecs.

Of the other regular genera, *Pseudechinus* is the only important one in the Tertiary; most species prefer hard bottom, on the outer two-thirds of the shelf (30 to 100 fathoms), though dead immature tests are constantly encountered in muds. Similar immature tests are common in the Castlecliffian, and are thought to indicate specimens which have been overcome by muds, whilst originally living on some temporary hard-bottom, such as shell-beds would provide. One species which occurs in the Castlecliffian, *P. flemingi*, is otherwise known only as living specimens in about 30 to 300 fathoms, east of the South Island; this is evidently a deeper-ranging form than the other members of the genus. *Evechinus chloroticus* is a eurythermal, strictly littoral speices, ranging at present from the Kermadecs to Stewart Island; typical of reefs and rock-platforms in the extant fauna, it occurs fossil in the same inferred facies in the Nukumaruan.

Of the irregular genera, all indicate a moderately soft bottom (such as shell-grit), and most require a mud, or sandy mud, bottom. The commonest is *Echinocardium*, which tolerates all depths. The sand-dollars inhabit shallow water on the upper part of the shelf, below low-tide, resting on sand or sandy mud. Other genera, such as *Brissopsis* and *Spatangus*, among the heart-urchins, are soft-bottom indicators, occupying most of the shelf; they avoid rough water, and do not come into the uppermost 10 fathoms or so, but may extend well into the archibenthal zone.

Summaries of data referring to the bottom ecology of extant and fossil echinoderms in New Zealand will be found in Fell 1952, pp. 3-4; 1954 *(passim)*; 1958 (complete checklists for species occurring in the ranges 1,000 fathoms or deeper, 300-1,000 fathoms, and 100-300 fathoms).

The only account of distributions of Recent Foraminifera in New Zealand (Vella, 1957) describes faunas from 0 to 1,500 feet in Cook Strait. There strong bottom currents have transported shallow-water shells into deeper waters, and only the upper limit of the depth range of each species is useful for paleoecology. Data from ecological studies carried out in other parts of the world must be used with caution for two reasons: In the first place there is good evidence that many Foraminifera are depth-tolerant but temperature-restricted, and have different depth ranges in different parts of the world. In the second place many Foraminiferal species have few distinguishing characters and there may be more homeomorphs than we now realise. Homeomorphs are different species which are morphologically similar and therefore difficult to distinguish. For example, a form called *Pullenia bulloides* is characteristic of abyssal depths off the coast of California, while a form with a similar shell known by the same name occurs in quite shallow water in New Zealand. Hitherto paleontologists have recognised homeomorphs of different ages (heterochronous); it may also be necessary for ecologists to recognise homeomorphs of different depths (hetrobathyal).

In the United States use of fossil Foraminifera by oil companies has stimulated all phases of research on Foraminifera, including their ecology. The Gulf of Mexico and the coast of California are probably the most throughly examined areas in the world. The biofacies distinguished off the west coast of the North American continent from Alaska to Panama, summarised by Natland (1957, pp. 554-8), give a good idea of faunal variation with depth and with latitude (Fig. 4).

Biofacies I, that of lagoons and estuaries, includes only species capable of tolerating a large range of temperatures and shows no significant change with latitude. Biofacies 2 — intertidal and near-shore (upper neritic) — includes a greater number of species, all of which are capable of tolerating a moderate range of temperatures; this biofacies also shows little change with latitude. Biofacies 3 — 125-900 feet — is divided into sub-facies 3A and 3B; light penetration seems to be the depth-controlling factor; the boundary between the sub-biofacies 3A and 3B is a latitude, and the difference between them is due to temperature difference. The five depth biofacies from 900 to 15,000 feet (the $CaCO_3$ solution boundary) are controlled by temperature, their boundaries corresponding to isothermal surfaces. The depth ranges of biofacies increase approximately logarithmically with increasing depth.

The value of pelagic (planktonic) Foraminifera for depth determintation has been a controversial subject, and is still contested by some micropaleontologists. The number of pelagic Foraminifera living in the surface water generally increases with distance from the

29

shore, and as depth generally increases with the distance from the shore there is usually a relationship between depth and the number of shells of pelagic Foraminifera falling to the bottom. Pelagic oozes (including Globerina ooze) as their names indicates, are essentially restricted to the deep sea floor. The number of shells of pelagic Foraminifera falling to the bottom generally decreases towards land becoming very small near the shore. Pelagic shells may accumulate abundantly near the shore in two kinds of exceptional circumstances. Phleger (1960) notes that they may be abundant along coasts where the run-off of fresh water is extremely low, thus suggesting that the pelagic Foraminifera are sensitive to a slight decrease in salinity; it is unlikely that run-off from New Zealand was low at any time during the Cenozoic. On high run-off coasts on-shore winds may periodically blow pelagic water masses towards the shore causing local abundant accumulations of pelagic shells in shallow water and this may well have happened on former westward continental shelves of New Zealand.

Abundance of pelagic Foraminifera is expressed as the percentage of pelagic foraminiferal shells (%P) in the total number of foraminiferal shells, benthonic and pelagic. The number of pelagics increases fairly regularly from 0% in the littoral biofacies to 90% or more in Globigerina ooze on the deep sea floor.

Phleger (1960) described seven generally applicable foraminiferal depth biofacies (Fig. 5), using the following 'Population characteristics': (1) Number of benthonic species. (2) Number of benthonic genera. (3) Percentage of arenaceous specimens. (4) Characteristic benthonic genera. (5) Percentage of pelagic shells. (6) Other features.

Phleger's depth biofacies are defined in much more general terms than those of Natland. They are more useful to us than Natland's because they are controlled solely by depth; they can be recognised in the New Zealand Cenozoic, but are not as reliable for depth determination as biofacies based on total fossil faunas.

Depth Restricted Groups of Benthonic Smaller Foraminifera:

The following groups of benthonic smaller Foraminifera are restricted in depth range except for a few species, and appear to have been restricted to the same depth range throughout the Cenozoic.

MILIOLIDAE: Most genera are restricted to above 400 feet. Some genera, for example *Biloculina*, are locally abundant between 400 and 1,000 feet. Only a few species live or lived in deeper water, probable Tertiary examples being *Sigmoilopsis schlumbergeri* and *Praemassilina tenuis*.

NONIONIDAE: Mostly restricted to above 1,000 feet. *Pseudononion parri* is dominant in the intertidal zone, but is infrequent in deeper water. *Astrononion novozealandicum*, from its Tertiary distribution,

ALASKA	CALIFORNIA	PANAMA

Biofacies I - Lagoons, estuaries, tidal mud flats 24°C - 5°C
   Trochammina inflata
   Buliminella elegantissima
   Streblus beccarii

Biofacies 2 - Littoral & upper neritic   21°C - 13°C   0 to 10 ft.
   Elphidium poeyanum   Elphidium cf. articulatum
   Elphidium hannai   Eponides frigidus
      (abundant Mollusca)

125 ft.

Biofacies 3 A   13°C - less than 8·5°C ! Biofacies 3 B   13°C - 11°C
Cassidulina limbata   Lower neritic
C.   tortuosa | Bolivina striatella   Uvigerina incila
C.   californica | Virgulina bramlettei   Cancris panamensis
Eponides repandus | Bulimina marginata   Cibicides cf. basiloba
Polymorphina charlottensis | B.   pulchella

900 ft.

Biofacies 4-A   8·5°C - 5°C   Biofacies 4 B   11°C - 8·5°C
                    Upper bathyal   Bolivina plicata
                                         Angulogerina carinata
        Bolivina argentea   8·5°C Isotherm Cancris inflata
            Bolivina interjuncta   Gyroidina, Suggrunda
   ?   Epistominella
            Bolivina spissa

            Uvigerina peregrina
Biofacies 5   Epistominella pacifica
Mid bathyal 5°C-3°C   5°C Isotherm
                                                      2,000 ft.

   ?   Bulimina subacuminata
                Uvigerina pygmea

Biofacies 6   3°C Isotherm   4,000 ft.
Lower bathyal 3°C-2°C
   (probably world-wide)   Bulimina rostrata   Pullenia bulloides
                           Uvigerina senticosa   Nonion pompilioides

   ?   2°C Isotherm   7,500 ft.
Biofacies 7
Abyssal less than 2°C   Osangularia bengalensis

         Approximate CaCO₃ Solution boundary   15,000 ft.

Fig. 4: Diagram to show foraminiferal biofacies from Alaska to Panama in relation
to depth and temperature; constructed from data summarised by Natland (1957).
Slope of isotherms diagrammatic.

DEPTH (feet)	ENVIRONMENT	No. of BENTHONIC SPECIES	No. of BENTHONIC GENERA	% ARENACEOUS SPECIMENS	CHARACTERISTIC BENTHONIC GENERA	% PELAGICS
	MARINE MARSH	5 - 8	3 - 8	100% or dominant	*Miliammina* *Trochammina* *Jadammina etc.*	nil
	COASTAL LAGOON	10 - 20	5 - 10	5 - 75%	*Ammotium* *Streblus* *Elphidium*	nil
0-60	NEARSHORE TURBULENT ZONE	—	—	low	*Textularia* large spp. *Elphidium* *Streblus* *Miliolidae*	nil
60-200	INNER CONTINENTAL SHELF	10 - 25	5 - 15	10 - 25%	*Buliminella* *Rosalina* *Rotalia* *Elphidium*	10%
200-400	OUTER CONTINENTAL SHELF	30 - 40	20 - 30	5%	*Bigenerina Virgulina* *Cassidulina Cibicides* *Nonionella Nonion* *Uvigerina*	up to 50%
400 - 3,000	UPPER CONTINENTAL SLOPE	30 - 40	20 - 30	5%	*Bolivina Pullenia* *Bulimina Uvigerina* *Cassidulina*	up to 75%
deeper than 3,000	LOWER SLOPE + DEEP SEA	10 - 25	5 - 15	10 - 20%	*Bulimina Epistominella* *Glomospira Pullenia* *Gyroidina* *Haplophragmoides*	up to c 100%

Fig. 5: Chart showing main features of foraminiferal biofacies described by Phleger 1960).

appears to have been restricted to intertidal and nearshore environments but other species of *Astrononion* occurred down to about 1,000 feet.

ELPHIDIDAE: Large ornate species of *Elphidium* are restricted to intertidal and nearshore environments. *Elphidium charlottensis* and related Cenozoic forms appear to have occurred down to about 1,000 feet. *Elphidium* is not as common in New Zealand as elsewhere, being largely replaced in both Recent and Cenozoic faunas by *Notorotalia*. *Notorotalia depressa* and *inornata* are essentially intertidal. Other large species are restricted to depths less than 400 feet. *Notorotalia finlayi* occurs abundantly in estuaries and in the open sea from 0 to about 1,000 feet. *Notorotalia taranakia* occurs from about 1,000 feet down to an undetermined depth. Corresponding Cenozoic species occur in the same order relative to the shore-line, and probably lived in similar depths.

ROTALIIDAE: The genus *Streblus* is abundant in estuaries in New Zealand and other parts of the world.

DISCORBIDAE: This family includes a host of genera and species. From Tertiary occurrences most appear to have lived in less than 400 feet.

PLANISPIRAL LAGENIDAE: Many species occur between 1,000 and 2,000 feet (Brady, 1883). *Robulus calcar* seems to be the only species which occurs abundantly in late Cenozoic sediments containing abundant macrofossils, and is probably limited to depths less than 1,000 feet. Most species of *Robulus, Lenticulina,* and *Sarecenaria* are abundant in massive calcareous mudstone with rare Mollusca such as *Neilo, Parvamussium,* etc. They define the Robulus biofacies which is considered to indicate depths between 1,000 and 2,000 feet.

LITUOLIDAE: *Cyclammina cancellata* and a large *Haplophragmoides* are common in New Zealand Tertiary calcareous mudstones without macrofossils. Phleger (1960) noted that *Cyclammina cancellata* is common in Tertiary mudstones (presumably in the United States). *C. Cancellata* now lives deeper than 6,000 feet (Akers, 1954) and is probably a good world-wide deep water indicator.

Paleoecological Method

A simple method of depth determination which may be called ' depth range analysis ' makes direct use of depth ranges of Recent species that occur as fossils or are closely related to fossil species. This method works fairly well for Pleistocene and perhaps Pliocene faunas, but is ineffective for older faunas because of their small number of Recent species. Other limitations are that some Recent species have different depth ranges at different places, that closely related Recent species commonly have different depth ranges, and that until depths of past faunas are determined we have no means of knowing whether any particular species has maintained the same depth range with time.

Bandy (1956, pp. 189-191), working in Miocene and Pliocene sediments of Florida, estimated water temperatures from fossil benthonic Foraminifera, and scaled off depths from the present day bathythermal gradient in the adjacent north-eastern part of the Gulf of Mexico. This method is subject to the same kinds of limitations as the depth range analysis method, and is further complicated by the decrease in sea-level temperatures which took place all over the world in the late Tertiary, and which Bandy did not take into account.

The method suggested here is carried out in three stages: First, determine biofacies; second, determine the order of relative depth of the biofacies; third, attempt to determine absolute depth range of each biofacies by comparison with present day biofacies.

Determination of Fossil Biofacies and Their Depth Order:

Biofacies are simply natural biological assemblages distinguishable by taxonomic content from other natural biological assemblages. The biofacies may be defined by either the total or part of the

total biological assemblage. All fossil biofacies are only partial assemblages, and even these may be defined by reference to only one taxonomic group — say Foraminifera, or Mollusca. They are recognised by noting consistent associations of species or other taxa. Generally innumerable biofacies can be recognised in extensive fossiliferous rocks and the paleoecologist must sort out the significant associations by experience.

Two methods are available for determining the depth order of fossil biofacies — that is the relative depth represented by each — without reference to present-day biofacies: (1) by considering the change of biofacies with distance at one time; (2) by considering the change of biofacies with time at one place.

The first method is ideally the same as that used for present-day ecology, but in practice is limited by the difficulty of precise dating. Unless redeposited the fossils in lateral geological sections (sections exposing rocks representing one time) have approximately their original aerial distributions, except where they are displaced by transcurrent faults. The faunal changes in the section can be mapped, and the position of the shore-line and direction of deepening can usually be determined fairly easily.

BIOFACIES	LITHOLOGY	GENERAL FEATURES of BIOFACIES	SOME DIAGNOSTIC SPECIES + GENERA
Streblus	mudstone sandstone conglom.	Limited number of species of molluscs, ostracodes + Foraminifera. Diagnostic species in each biofacies.	Streblus aoteanus (F) (in abundance)
Pseudononion	well-sorted well-bedded sandstone,		Pseudononion parri (F) Notorotalia depressa (F) Zethalia, Amphidesma (M)
Elphidium	reef and detrital limestone sandstone	All kinds of fossils abundant, but patchy in distribution	Elphidium spp. (F) Notorotalia large spp. (F) Glycymeris, Phialopecten etc. (M)
Haeuslerella	massive sandy mdst. scattered macroff.	Abundant Foraminifera frequent molluscs infrequent ostracodes	Notorotalia Kingmai (F) Robulus calcar. (F) Micantapex aff. murdochi (M)
Robulus	massive mudst. rare scattered macroff. Turbidites with mixed biofacies	Very abundant Foraminifera infrequent to rare molluscs	Robulus spp. abundant (F)
Semipelagic		Abundant Foraminifera 40-60% pelagics very rare molluscs	Karreriella cylindrica Bigenerina pliocenica Notorotalia taranakia
Eupelagic		70-90% pelagic Foram. decreasing benthonic Foram. very rare molluscs	

Fig. 6: Chart showing main features of biofacies in the Pliocene of Wairarapa, New Zealand (modified from Vella, 1962).

The second method of determining the depth order of fossil biofacies may be limited by difficulty in separating the faunal changes which are due to depth change from those irreversible faunal changes which are due to evolution and ante-Pleistocene cooling (cf. Vella, 1962, Fig. I). At various times during the Tertiary large areas of land in the New Zealand region dropped down very rapidly to become deep-water basins. First, shallow-water, then progressively deeper-water facies were deposited. Many Tertiary basins deepened so rapidly that shallow to deep transitions are represented within one stage. As the stage is generally the smallest time division that can be recognised time-controlled faunal changes are non-existent or negligible in these sections.

In Wairarapa many well-exposed vertical sections through the Hurupi Formation and overlying sediments (Upper Miocene) show progressive facies changes due to progressive deepening (Vella, 1954). The Hurupi Formation rests uncomformably on older rocks and its deposition commenced as the sea transgressed over an area that was previously land. The generalised sequence with oldest rocks at the bottoms is as follows:

	THICKNESS
Massive blue-grey calcareous mudstone with rare macrofossils grading down to	2,000 ft.
Massive blue-grey muddy sandstone with abundant scattered macrofossils grading down to	c500 ft.
Well-bedded, well-sorted sandstones with shell-beds — many kinds of macrofossils	c300 ft.
Basal Conglomerate	c2 ft.
Angular unconformity; erosion surface on Mesozoic greywacke.	

The basal conglomerate, at some places barren of fossils, at others containing broken shells, is the littoral facies of the advancing sea. The well-bedded sandstone with shell-beds is the inner neritic facies deposited in shallow water just off-shore. The massive muddy sandstone and massive calcareous mudstone represent successively greater depths. There is considerable difference of opinion as to the absolute depths represented by all except the littoral facies.

Generalised descriptions of the faunas of each facies are as follows:

Basal Conglomerate: Fauna not known.

Shell-beds in well-bedded sandstone: Abundant Mollusca including Pelecypoda, Gastropoda, Scaphopoda, and a Nautiloid, rare Brachiopoda, locally abundant Scleractinian corals, fragments of Echinoidea, abundant Cirrepedia, locally abundant Bryozoa, abundant Ostracoda, relatively infrequent benthonic Foraminifera,

but locally abundant *Notorotalia* and *Elphidium*, rare pelagic Foraminifera. The dominant fossil is generally the thick-shelled gastropod *Callusaria callosa*. No other facies contains so many phyla or so many species.

Massive muddy sandstone: Abundant Pelecypoda, gastropoda, and Scaphopoda, moderately abundant benthonic Foraminifera, infrequent pelagic Foraminifera, and rare Ostracoda. Dominant molluscs in the shallower phase are *Cucullaea* n. sp., *Dosinia cottoni, Kuia macdowelli,* and *Marama hurupiensis,* and in the deeper phase are *Limposis lawsi* and many species of Turridae.

Massive calcareous mudstone: Rare Mollusca, mainly small and delicate gastropoda, and thin-shelled Pelecypoda such as *Neilo, Myrtea* and *Parvamussium;* abundant benthonic and pelagic Foraminifera, the pelagic percentage increasing upwards from about 30 to about 90%.

A similar but more complete series of biofacies determined for the Pliocene in northern Wairarapa (Vella, 1962) is shown in Fig. 6. This series was determined during the examination of some hundreds of fossil faunas, mainly microfaunas, from a large area, and is based on many vertical and many lateral sections.

Estimation of Depths Represented by Fossil Biofacies:

Estimation of the absolute depth range of each fossil biofacies is a process of faunal matching akin to age-correlation, and may be called depth-correlation. Faunas of several different consecutive ages are always easier to age-correlate than an isolated fauna. Similarly faunas of several different consecutive depths are easier to depth-correlate than an isolated fauna. Depth correlation is easiest when a complete series of depth biofacies for a particular age is available. Depth correlation of the Wairarapa Upper Miocene (Hurupi Formation and overlying sediments) and Pliocene facies is shown in Fig. 7 together with some important isolated facies in the early Tertiary.

In each of the upper four biofacies of the Pliocene about 90% of the genera and 70% of the species of Foraminifera are the same as in equivalent present-day biofacies. When the possibility of transportation of shells from shallow to deep water is allowed for Foraminiferal index genera are useful. Not enough is known about Foraminifera deeper than 1,000 feet in present-day New Zealand seas to allow a comparison to be drawn with equivalent Pliocene faunas.

The shallower Upper Miocene biofacies contain many different genera (such as the Mollusca *Cuculaea* and *Conospirus* and the Foraminifer *Amphistegina*) due to the sea-level temperatures being appreciably warmer than at present. Deeper Upper Miocene biofacies are generally similar to deeper Pliocene and present-day biofacies.

WAIRARAPA (Up. Mioc. (Hurupi Sequ.)	Biofacies	Isolated Tertiary Facies	S/F	% P.	PRESENT DAY FEATURES — Lithologies/Foraminifera	Other groups	Best Depth indicators in Cenozoic	DEPTH in feet
	Streblus Biofacies		?	nil	Streblus	restricted Molluscs + Ostracods	Streblus + molluscs	0 - 50 (estuarine)
Basal Conglomerate	Pseudononion Biofacies		3/1	nil	Pseudononion Discorbis Notorotalia	Molluscs, Echinoids, Brachiopods, Ostracods	Pseudononion and spp. of Notorotalia	0 - 20
well-sorted sst. with shell-beds	Elphidium Biofacies	Algal reefs Miocene eastern N.I.	3/1	10%	Miliolidae Elphidium Notorotalia	Ostracodes, Bryozoa etc., all abundant	sorting of sediments; abundance of all fossils	220 ± 200
massive muddy sst.	Haeuslerella Biofacies		3/1 to -1/3	10% to 30%	massive sandy mud. ?	Abundant Infrequent molluscs	Massiveness; scattered molluscs	600 ± 400
massive calcareous mudstone	Robulus Biofacies		1/3 to nil	30% to 50%	massive blue mud. (Robulus) Notorotalia profunda	rare; small delicate molluscs	characteristic molluscs (if found)	2,000 ± 1,000
	Semipelagic Biofacies	— ? — Amuri Limestone (Paleocene-Oligocene Globigerina ooze)	nil	40% to 70%	Glob. ooze or turbidites — pelagic shells dominant in sediments	extremely rare		3,000 ± 1,000
	Eupelagic Biofacies	Flinty phase of Amuri Lst.	nil	60% to c100%	various lithologies typically well-sorted		% P.	8,000 ± 4,000
		Red clayst. (Paleocene)	nil	?	Siliceous ooze red clay	non-calcareous	increasingly siliceous microfauna non-calcareous microf. and manganese nodules	c 15,000
								deeper than 15,000

Fig. 7: Depth correlation of various New Zealand Cenozoic sedimentary facies and biofacies with present-day biofacies.

Lower Miocene shallow water biofacies are markedly different, including reef building calcareous algae, locally reef building corals, and larger benthonic Foraminifera, because sea-level temperatures at the time ranged from subtropical in the south to tropical in the north.

Pelagic biofacies are best represented in the early Tertiary. The Amuri Limestone is white, fine-grained, locally muddy and locally highly siliceous, ranges in age from Paleocene to lower Oligocene, and extends from northern Canterbury through Marlborough to Southern Wairarapa. Thin sections generally show abundant globigerinid shells, and siliceous phases contain many Radiolaria. As pointed out long ago by Marshal (1916) the Amuri Limestone is a fossil Globigerina ooze, and the siliceous phases probably were deposited near the $CaCO_3$ solution boundary and are transitional to Radiolarian ooze. The siliceous phases are mostly Paleocene in age; surface temperatures at the time may have been subglacial (Squires, 1957, Fig. 5), and the solution boundary may not have been as deep as 15,000 feet.

Bands of red clay up to 20 feet thick occur in red and green mottled fine-grained mudstones ('bentonite') of Paleocene age in Raukumara Peninsula. The red clay contains entirely non-calcareous microfaunas including Radiolaria and siliceous and arenaceous Foraminifera. The association of red clay with siliceous faunas is known at present on only the deepest parts of the ocean floors.

Conclusion

In New Zealand during each stage of the Cenozoic, sediments were deposited in a large range of depths. Broad depth divisions can be differentiated in them without a detailed knowledge of the depth distributions of present-day organisms. Depth divisions are defined essentially by biofacies, though lithofacies are also useful depth indicators. Fossil biofacies should be determined from the space-time distribution of fossil species without reference to present-day biofacies. Methods of recognising fossil biofacies are described by Imbrie (1955).

At this stage fossil biofacies for each age can be placed in order of increasing depth, and can be used as indicators of relative depth in the same way that fossil zones are used as indicators of relative ages. Relative depth determinations can be extremely useful to the geologist for paleogeographic reconstruction, and for determining some kinds of tectonic events. In the light they may shed on faunal succession they may prove to be of considerable value to the ecologist.

Once fossil biofacies are defined absolute depth determination may be attempted by depth-correlation with prsent-day biofacies.

Absolute depths are better determined from total fossil biofacies than from single taxonomic units, such as Mollusca or Foraminifera, within the fossil biofacies. They can not yet be determined with great precision, and consequently it is essential that fossil biofacies be defined and named as distinct units from present-day biofacies. To this may be applied the principles and rules already laid down for defining and naming fossil (biostratigraphic) zones.

Two neglected lines of research needed for depth determination in the New Zealand Tertiary are studies of distribution of Recent Foraminifera in New Zealand, and taxonomic studies of Tertiary deep-water Mollusca.

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VII- FORAMINIFERA FROM UPPER MIOCENE TURBIDITES,

WAIRARAPA, NEW ZEALAND.

FORAMINIFERA FROM UPPER MIOCENE TURBIDITES, WAIRARAPA, NEW ZEALAND.

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ABSTRACT.

Abundant and well preserved Foraminifera in turbidites of Upper Miocene (Kapitean) age, at Cleland Creek, were compared with Foraminifera in four different depth biofacies of about the same age. The turbidites were deposited in depths certainly greater than 2,000 ft, and probably between 4,000 and 6,000 ft, and were derived from all shallower depths up to about 300 ft or less. Fragile shells and large shells are less common in turbidites than in non-turbidites, and many shells are considered to have been destroyed during transport. The basal layer of each turbidite rhythm is considered to consist of "slumped" neritic sediment with little intermixed deep-water sediment, the intermediate layer to have been deposited by a swift turbidity current, and the upper layer to have been deposited from suspension after the turbidity current ceased flowing. No trace of autochthonous sediment was found between turbidite rhythms.

INTRODUCTION.

~~Turbidites~~ Strata with well-defined graded rhythms at Cleland Creek, about five miles east of Mauriceville township, were mapped and described ∧as turbidites by Orbell (1962). For turbidites they contain extraordinarily abundant and well-preserved Foraminiferal shells which are considered to represent mixed biofacies (Vella, 1962a), similar to the mixed biofacies found in the Ventura Basin, California, in turbidites of about the same age (Natland and Kuenen, 1951). Like the clastic sediment, the Foraminiferal shells are size-sorted, with large shells concentrated in the lower part of each rhythm (Vella, in press).

Generally at the top of each rhythm in the Ventura Basin is an autochthonous layer of mudstone described by Natland and Kuenen as lithologically and faunally distinct from the mudstone forming the upper part of the rhythm below. At Cleland Creek no lithologically distinct layers were found, and samples from the tops of two rhythms yielded mixed deep- and shallow-water faunas showing that no autochthonous layers are present.

BIOFACIES ANALYSIS.

Natland and Kuenen were able to use known depth distributions of present day Foraminifera. This data is not yet known for New Zealand, and the writer is forced to use an inferred sequence of fossil depth biofacies (Vella, 1962b). This method has both disadvantages and advantages, for, while absolute depths represented by biofacies are uncertain, confusion due to possible
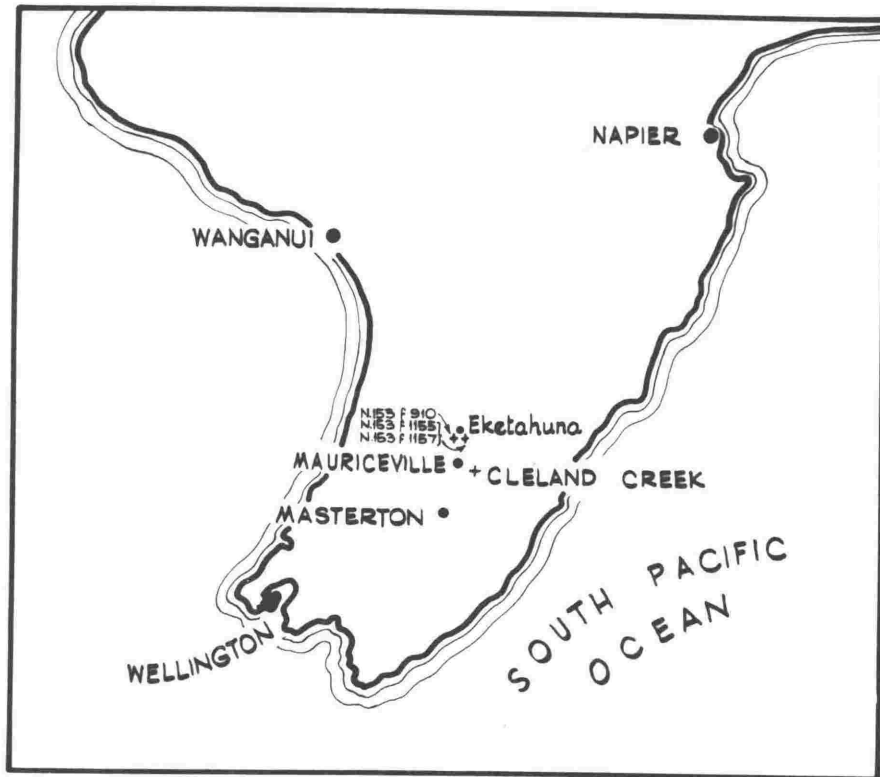
Fig. 1: Map of the southern part of North Island, showing
location of Cleland Creek, and the approximate
localities of three non-turbidite samples which
are not from Cleland Creek but are described in
the text.

changes in depth range of species and genesa with time is obviated.

Fossil depth biofacies are determined in three steps. The first is to determine assemblages of species which lived together (biofacies). The second is to arrange the biofacies in order of depth. The third is to use known ranges of present day organisms to estimateabsolute depth ranges of the biofacies. The first two steps are based on direct observation of fossil distributions. The third step is a subjective process offaunal matching, similar to age correlation, and is subject to progressive revision in about the same measure as age correlation. Only the first two steps are required to show that turbidites contain a mixture of biofacies.

Foraminifera from the turbidites are compared with the Foraminifera in a depth series of four biofacies.

SAMPLE LOCALITIES AND CHART OF FOSSIL OCCURRENCES.

Twelve turbidite samples were examined - all from Cleland Creek, a small stream flowing parallel to Cleland Road, Sheet District N158 (Fig. 1). Four were average samples collected by a field geologist, Mr. G. Orbell, to represent the upper and lower parts of two rhythms. The other eight were a series of closely spaced samples which were collected by the writer for the purpose of determining faunal changes within a rhythm and at rhythm boundaries.

Three of the non-turbidite samples used for comparison are

from Sheet District N153 immediately to the north of N158, and are on the opposite side (north-west) of the Alfredton Fault from Cleland Creek. The sample furthest from Cleland Cree, is about nine miles to the north-west. They represent different stages of deepening between nil and several thousand feet which took place in the area during Kapitean time (G. Neef, pers. comm.). The fourth comparative sample - N158f610 - is from basal Opoitian (basal Pliocene) massive mudstone overlying the Kapitean turbidites at Cleland Creek. It was previously determined as Kapitean in age (Vella, 1962a; Orbell, 1962), but rare specimens since found of the pelagic species Turborotalia inflata (d'Orb.) indicate an age slightly younger than Kapitean.

Full details of the fossil localities are recorded in the New Zealand Fossil Record master file for the Wellington region at the Geology Department, Victoria University of Wellington. Abbreviated details are given in Table I. Lithology symbols in this table are those proposed by Wellman (1953, p. 55) with the addition of the symbol R (redeposited) for turbidite facies. Age symbols are Tk (Kapitean) uppermost Miocene, and Wo (Opoitian) lower Pliocene.

TABLE I.

FOSSIL LOCALITIES

Fossil Record No.	Locality	Grid ref.	Lithology	Macro-fossils	Age
N153					
f910	Makakahi Riv.	179952	932c	nil	Tk
f1155	Mangaoranga	206972	6631c	abundant	Tk
f1157	Mangaoranga	205975	8942d	common	Tk
N158					
f610	Cleland Creek	260814	9842cMM	nil	Wo
f624a	Cleland Creek	276811	7954jCSSR	comminuted	Tk
b	''	''	9851CCSR	comminuted	''
f626a	Cleland Creek	282808	79641CQSR	comminuted	Tk
b	''	''	9851cCR	comminuted	''
f630a-h	Cleland Creek	279810	----	comminuted	Tk

(Lithologies and positions in rhythms of f630a-h shown by Fig. 2)

All non-turbidite samples used for comparison, and the four turbidite samples collected by Orbell were selected for the study because of their relatively good foraminiferal faunas. The series of eight closely spaced samples at locality f630 were taken close to where a good sample had been collected by Orbell.

Occurrences of Foraminifera are shown in Table II. The four columns on the left give species in non-turbidite samples and are arranged from left to right in order of inferred deepening. Relative abundances are based on counts of specimens on mounted faunal slides. The slides do not contain all the specimens in each sample, but give reasonably true relative abundances of more common species. They probably give greater than true relative abundances of rare species because a special search was made for these in each sample.

- 6 -

TABLE II.

DISTRIBUTION CHART OF FORAMINIFERA

Figures 1 to 9 give actual numbers of specimens, c indicates 10 to 20, a indicates more than 20, and a dash (-) indicates nil. Samples i-iv are from non-turbidite facies; i = N153f1155, ii = N153f1157, iii = N153f910, iv = N158f610. Corresponding numerals to left of table indicate species restricted to each of these samples or inferred to be restricted to equivalent biofacies; v indicates species restricted to an inferred fifth biofacies. x indicates species not restricted to one biofacies.

	Species	i	ii	iii	iv	a	b	c	d	e	f	g	h	a	b	a	b
						N158f630								f624		f626	
iv	Rhabdammina? sp.	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
iv	Haplophragmoides? sp. (crushed)	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-
ii	Textularia kapitea Finlay	-	a	-	-	-	-	-	-	-	-	-	1	-	-	-	-
ii	T. aff. ensis Vella	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-
x	Haeuslerella parri Finlay	?	a	-	-	-	-	?	-	-	-	2	-	-	-	-	2
iii	H. morgani Finlay	-	-	c	-	-	9	9	-	6	9	2	2	c	c	4	6
iii	H. finlayi Vella	-	-	2	-	-	-	2	-	-	?	?	-	-	?	?	2
x	H. pliocenica (Finlay)	-	-	?	?	-	-	-	-	-	-	-	-	1	-	?	-
x	Siphotextularia ihungia Finlay	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-
x	S. subcylindrica Finlay	-	3	7	-	-	-	7	-	2	1	1	1	7	-	-	-
i	S. aff. mestayerae Vella	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
i	Gaudryina crespinae Cushman	-	-	-	-	-	1	-	-	-	-	-	-	9	-	-	-
x	Karreriella cylindrica Finlay	-	-	a	a	?	4	2	-	3	9	c	2	4	5	4	8
iii	K. bradyi (Cushman)	-	-	c	-	-	-	1	-	-	3	1	-	-	-	-	1
x	Martinottiella sp.	-	8	?	-	-	1	-	-	-	4	3	-	1	1	-	3
iii	Sigmoilopsis zeaserus Vella	-	-	4	-	-	-	-	-	?	1	6	-	-	-	-	1
i	Quinqueloculina triangularis d'Orb.	-	-	-	-	-	3	1	-	1	-	-	c	c	-	?	-

Table II continued.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
i Quinqueloculina cf. lata Terquem	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
i Q. kapitiensis Vella	-	-	-	-	-	-	1	-	-	-	-	-	2	-	-	-
i Q. (Lachlanella) n. sp.	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-
x Biloculina sp.	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
x Pyrgo sp.	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-
ii Robulus calcar Linne	-	a	-	-	-	-	-	-	-	-	-	-	-	-	-	-
x R. cf. calcar Linné (small)	-	-	9	-	-	-	-	-	-	-	-	-	-	-	-	-
i R. cultratus Montfort	c	-	-	-	-	1	-	-	-	-	-	2	-	-	-	-
iv R. dicampylus (Franzenau)	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
x R. gyroscalprus (Stache)	-	5	8	-	-	-	-	-	-	-	-	-	-	-	-	-
x R. loculosus (Stache)	-	1	4	-	-	-	-	-	-	-	-	-	1	-	-	-
x R. spp.	-	-	-	2	-	-	2	-	3	-	3	2	3	2	2	2
ii Lenticulina peregrina (Schwager)	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
x Saracenaria italica Defrance	-	2	8	-	-	-	-	-	-	-	-	-	-	-	-	-
x Marginulina subbullata Hantken	-	2	2	-	-	-	-	-	-	-	1	-	-	-	-	-
x Vaginulina sp. A	-	1	7	4	-	-	-	-	-	1	-	-	-	?	-	1
iii Vaginulina sp. B	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-	1
iv Dentalina soluta Reuss	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
x D. substrigata Stache	1	1	9	-	-	-	-	-	-	1	3	-	-	-	-	-
x Dentalina sp.	-	3	-	-	-	-	-	-	-	-	-	-	1	-	-	1
ii Nodosaria affinis Reuss	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
iii N. cf. calomorpha Reuss	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	?
iii N. catenulata Brady	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-
x N. holoserica Schwager	-	-	4	4	-	-	-	-	-	-	-	1	-	-	-	1

Table II continued.

	Species																
iii	Nodosaria lamnulifera Boomgaart	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-
x	N. longiscata d'Orb.	-	1	7	c	-	-	3	-	2	1	-	-	1	1	1	1
x	Chrysalogonium verticale (Stache)	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
iii	Amphicoryne cf. scalaris (Batsch)	-	-	7	-	-	-	-	-	-	1	-	-	7	-	-	-
x	A. hirsuta (d'Orb.)	-	-	c	2	-	-	2	-	-	1	-	-	2	-	-	-
iii	A. hirsuta var. (smooth)	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-
iii	Stilostomella antipoda (Stache)	-	-	a	-	-	-	-	-	1	-	-	-	2	-	-	-
iv	S. cf. verneuilii (d'Orb.)	-	-	-	1	-	-	-	-	2	7	1	-	1	-	2	2
x	Stilostomella sp. (spinose)	-	-	4	1	-	-	2	-	-	-	1	-	2	3	-	1
x	Stilostomella spp. indet.	-	-	8	-	-	-	2	-	-	-	-	-	-	-	-	-
x	Parafrondicularia pellucida (Fin.)	-	-	5	3	-	-	-	-	-	-	-	-	-	-	1	1
iii	P. wairarapa Vella	-	-	3	-	-	-	1	-	-	2	3	-	-	1	-	-
iii	Proxifrons vaughani (Cushman)	-	-	2	-	-	-	-	-	-	2	-	-	-	-	-	-
iii	Awhea subtetragona (Finlay)	-	-	4	-	-	-	-	-	-	2	-	1	-	-	-	-
iii	Lagena distoma Parker & Jones	-	-	2	-	-	-	-	-	-	-	-	-	1	?	-	1
x	L. cf. laevis (Montagu)	-	1	?	-	-	-	-	-	-	-	-	-	1	?	-	-
iv	L. hispida Reuss	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1
x	L. cf. sulcata Walker & Jacob	-	-	1	c	-	-	-	-	-	-	-	?	3	-	-	-
ii	Oolina globosa (Montagu)	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
i	O. hexagona (Williamson)	-	-	-	-	-	-	2	-	-	-	-	-	7	-	-	-
i	Oolina melo d'Orbigny	-	-	-	-	-	4	3	-	1	-	-	3	2	-	2	1
i	O. costata (Williamson)	-	-	2	-	-	-	-	-	-	-	-	-	6	1	-	-
x	Fissurina orbignyana Seguenza	-	-	-	-	-	-	-	-	-	-	2	-	6	3	1	2
i	F. yokoyamae (Millett)	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-

Table II continued.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
x	Fissurina sp.	-	4	1	-	-	-	8	-	-	-	2	-	-	-	-	-
i	Guttulina yabei Cushman & Ozawa	?	-	-	-	-	-	-	-	-	-	-	1	3	1	-	-
i	Sigmomorphina cf. lacrimosa Vella	-	-	-	-	-	2	?	-	-	-	-	3	7	1	?	1
i	Laryngosigma williamsoni (Terquem)	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
i	Sigmoidella cf. elegantissima (P. & J.)	1	-	-	-	-	-	-	-	-	-	2	4	-	-	-	-
iv	Glandulina symmetrica Stache	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
iii	Ramulina sp.	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
x	Plectofrondicularia pohana Finlay	-	6	a	-	-	2	8	-	2	4	3	-	2	5	3	c
x	Bolivinita pliobliqua Vella	-	5	a	-	-	-	5	-	2	6	7	-	3	?	-	6
iii	B. cf. elegantissima Boomgaart	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-
iv	B. pohana Finlay	-	-	-	c	-	-	1	-	-	4	?	-	-	-	-	-
iii	Bolivina albatrossi Cushman	-	-	2	-	?	-	2	-	1	-	-	-	3	1	-	2
x	B. affiliata Finlay	-	-	a	1	-	-	-	-	-	-	3	1	6	7	3	a
x	B. numerosa Vella	-	1	1	-	-	-	3	-	-	-	-	-	2	3	1	2
iii	B. cf. pacifica Cushman	-	-	a	-	-	-	-	-	1	-	-	-	-	-	1	6
x	Bolivina spp.	-	2	6	-	-	1	-	-	-	1	1	-	2	4	1	2
i	"Bolivina" turbiditorum Vella	-	-	-	-	-	1	-	-	1	2	-	1	c	c	1	3
i	Rectobolivina sp.	1	-	-	-	-	-	1	-	-	-	-	2	6	1	2	-
iii	Virgulina aff. rotundata Parr	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-
i	Virgulopsis cf. pustulata Finlay	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
i	Buliminella elegantissima d'Orb.	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-	?
i	B. missilis Vella	-	-	-	-	-	1	2	-	2	-	-	4	5	2	-	-
i	Buliminoides williamsonianus (Brady)	-	-	-	-	-	1	-	-	-	-	-	1	6	-	-	-
x	Bulimina aculeata d'Orbigny	4	8	-	-	-	4	6	-	3	3	1	2	c	7	2	4

Table II continued.

	Species	Counts
x	Bulimina cf. australis Vella	- 3 c 1 - 1 c - 1 8 2 - 9 6 - 1
V	B. truhcanella Finlay	- - - - - - - - - - - - 2 - -
i	Bulimina sp. (smooth)	- - - - - - - - - 1 - - - 3 1 c
ii	Bulimina notovata Chapman	- 2 - - - - - - - - - - - - - -
x	Globobulimina pacifica Cushman	- 4 c - - - - - - - - - - - -
x	Neouvigerina vadescens (Cushman)	- - - - - - - - - - - - - 3
iii	N. bellula Vella	- - a - - 1 c - 4 5 - - - - - -
iii	N. eketahuna Vella	- - a - - - - - 2 - - 8 5 - 5
x	Hofkeruva (H.) taranakia Vella	- - - - - 1 - - - - - 3 - 2 ?
x	H. (Trigonouva) cf. zeacuminata Vel.	- - - - - - - - - - - - - 5 c
ii	H. (Laminiuva) zelamina Vella	- a - - - 5 c - 7 8 5 c a 6 - -
iii	H. (Tereuva) lutorum Vella	- - a - - 3 1 - - c 5 5 2 8 2 -
iv	Hofkeruva s.l. delicatula Vella	- - - c - - ? - - - - - - - 3
x	Hofkeruva sp. indet.	1 7 - - 1 - - - - - - - - - - -
iv	Euuvigerina notohispida (Finlay)	- - - 1 - - - - - 1 1 - 1 - - -
V	Norcottia mioindex (Finlay)	- - - - - - - - - 3 - - 1 - - -
x	Trigarina bradyi Cushman	- - - - - 4 - - 2 1 1 2 c c c 6
x	Angulogerina spp.	- - - - - - - - - - - 7 5 1 2
x	Pleurostomella sp.	- - 4 1 - - 2 - - - - 1 - - 2
iii	Ellipsoglandulina subconica (Kreutz.)	- - 3 - - - - - - - - - - - -
iv	Ellipsoglandulina sp.	- - - 4 - - - - - - - 1 - -
x	Cassidulina alevigata d'Orb.	- - - - - - 1 - ? - - - 2 - 1
x	C. neocarinata Thalmann	- - - - 1 2 - - - - 3 c 1 2
iii	C. subglobosa Brady	- - 4 - 1 - 2 - 2 1 - - 8 3 1 4

Table II continued.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
x	Cassidulina sp.	-	-	2	1	-	-	-	-	-	-	1	-	3	4	-	1
x	Cassidulinoides orientalis (Cushm.)	-	c	5	-	-	1	5	-	-	-	-	-	4	1	1	2
x	Chilostomella ovoidea Reuss	-	9	6	-	-	-	-	-	-	-	-	-	-	1	-	-
x	Spheroidina bulloides d'Orbigny	-	3	a	c	1	1	-	1	-	7	6	-	4	2	-	4
iii	Pullenia cf. bulloides d'Orbigny	-	-	a	-	-	-	-	-	-	4	2	1	4	-	-	3
x	Pullenia quinqueloba (Reuss)	-	4	2	-	-	-	-	-	-	-	-	-	-	-	-	2
iv	P. quadriloba (Reuss)	-	-	-	7	-	-	-	-	-	-	-	-	-	-	-	-
vi	Florilus flemingi (Vella)	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
iv	Melonis lutorum Vella	-	-	-	9	-	1	-	-	-	-	-	-	-	-	-	-
vi	Melonis zeobesus Vella	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
iii	Nonionella magnalingua Finlay	-	-	c	-	-	-	-	-	-	-	-	-	-	2	-	1
iii	N. zenitens Finlay	-	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-
iii	Nonionella? sp.	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-
i	Zeaflorilus parri (Cushman)	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	p
x	Pacinonion cf. parki Hornibrook	6	2	-	-	-	4	5	-	-	?	-	-	4	1	-	-
iii	P. neefi Vella	-	-	4	-	-	-	-	-	-	-	-	1	1	-	-	-
iii	Pacinonion n. sp.?	-	-	7	-	-	-	?	-	-	-	-	-	c	c	1	2
x	Anomalinoides parvumbilia (Finlay)	-	c	a	c	-	-	3	-	3	1	3	1	7	2	?	3
ii	A. cf. spherica (Finlay)	-	3	-	-	-	3	1	-	1	-	-	2	7	-	2	1
x	Cibicides deliquatus Finlay	?	a	c	2	2	-	2	-	2	1	-	2	4	2	-	-
x	C. ihungia Finlay	-	8	a	1	2	-	2	-	-	-	-	-	-	2	-	1
x	C. mediocris Finlay	-	-	-	-	3	2	2	-	6	c	8	5	7	a	4	7
x	C. molestus Hornibrook	-	a	a	a	-	2	8	1	1	8	c	3	3	1	2	c
iv	C. aff. robertsonianus (Brady)	-	-	-	a	-	-	-	-	-	-	-	-	-	-	-	-

Table II continued.

i	Dyocibicides primitiva Vella	-	-	-	-	-	1	-	-	-	-	-	-	3 ?	-	-
i	Rosalina cf. bradyi (Cushman)	-	-	-	-	-	2 ?	-	-	?	-	4	a 8	- ?
i	Pileolina radiata Vella	-	-	-	-	-	-	-	-	-	▲	-	2	-	-	-
i	Pileolina zealandica Vella	-	-	-	-	-	5 3	-	4	▲	1	3	3 1	- -
x	Discopulvinulina bertheloti (d'Orb.)	- ?	-	-	- ?	1	-	1	-	-	-	-	- 1
x	Eponides tenera (Brady)	- 2	c	c	-	-	1	-	-	1	-	-	2 1	1 1
iv	E. cf. schreibersi (d'Orb.)	-	-	- 1	1	-	-	-	-	-	-	-	- -	- -
x	Gyroidina prominula (Stache)	- 1	8	-	-	1	-	-	1	-	-	-	2 1	- -
ii	Gyroidinoides zealandica Finlay	- a	-	-	-	4 5	-	4	1	-	-	a 4	4 5
x	Gyroidinoides sp. (tiny umbilicus)	-	- 3	6	-	-	-	-	-	1	-	- 1	- -
iii	Valvulinaria sp.	-	- 7	-	-	-	-	-	-	-	-	-	- -
iii	Parvicarinina altocamerata (H-A. & E.)	-	- 1	-	-	-	-	-	-	1 1	1	- -	- -
iii	Laticarinina halophora (Stache)	-	- 1	-	-	-	-	-	-	-	1	-	- -	- -
x	Epistomina elegans d'Orb.	- c	4	6	-	-	-	-	5 2	2 1	-	-	1 -
iii	Epistominella sp.	-	- 3	-	-	-	-	-	-	-	-	- 1
i	Elphidium charlottensis Vella	-	-	-	-	4 1	-	2	1	-	-	7 2	1 3
i	E. cf. crispum (Linne)	-	-	-	-	-	-	-	1	-	1 2	4	-	2 ?
i	E. novozealandicam Cushman	-	-	-	1 6	1	-	-	2 1	-	9 2	6 8
i	Notorotalia cf. depressa Vella	a	-	-	-	1 6	6	-	6	- ?	8	a c	7 7
i	N. olssoni Vella	-	-	-	-	-	-	-	-	-	1 1	- -	- -
x	N. taranakiasVella	- ?	a	-	?	-	4	-	2	-	c	-	- 1	2 3
i	Amphistegina sp.	-	-	-	-	-	-	-	1	-	-	-	- -	- -
	Globorotalia inflata (d'Orb.)	-	-	- a	-	-	-	-	-	-	-	- -	- -
	Globorotalia n. sp. aff. miozea Fin.	-	-	- c	-	-	-	-	1	-	-	- -	- -

Table II continued.

Globorotalia aff. menardii (d'Orb.)	1	1	-	2	-	2	3	-	-	1	-	-	1	6	1	1
Globigerina bulloides d'Orbogny	3	c	a	a	2	6	c	-	7	6	7	?	a	a	1	6
G. semivera Hornibrook	-	6	c	a	-	-	c	-	5	3	2	-	c	c	-	4
Globigerinita sp.	-	-	8	c	-	-	-	-	-	-	-	-	1	6	-	-
Orbulina universa d'Orbigny	-	-	-	a	-	-	3	-	-	-	-	-	4	1	-	-

BIOFACIES CONTAINED IN TURBIDITES.

A. BIOFACIES REPRESENTED BY THE FOUR NON-TURBIDITE SAMPLES.

Each of the four non-turbidite samples contains several
species which do not occur in the other three. The great maj-
ority of these species are facies-restricted and define the biofac-
ies. Absolute depths are best estimated by comparison with the
named Pliocene biofacies (Vella, 1962a) which have a larger
number of Recent species. Diagnostic features and estimated
depth ranges are as follows:

i. N153f1155: Sandstone with shell-beds containing abundant
Mollusca; the microfauna includes ostracodes and echinoid spines.
The Foraminifera Guttulina, Sigmoidella, Zeaflorilus, and Notor-
otalia cf. depressa indicate the "Zeaflorilus Biofacies" or the
"Elphidium Biofacies" - as Zeaflorilus is not abundant, probably
the "Elphidium Biofacies". Depth 0 to c400 ft.

ij. N153f1157: Sandy mudstone with infrequent scattered Mollusca;
the microfauna includes a few ostracodes: Abundant Haeuslerella
cf. parri and Robulus calcar, and the absence of persistent very

shallow-water species such as those above and of persistent deep-water species such as Karreriella cylindrica, and Haeuslerella finlayi indicates the "Haeuslerella Biofacies". Depth 600 ± 400 ft.

iii. N153f910: Massive calcareous mudstone with rare Mollusca, no Ostracods. Haeuslerella pliocenica, Karreriella cylindrica, and Sigmoilopsis zeaserus indicate a biofacies of greater depth than the "Haeuslerella Biofacies". The great number of benthonic species (76); relative abundance of Robulus and Saracenaria, and paucity of pelagic specimens (c25%) indicate the "Robulus Biofacies". Depth 2,000 ± 1,000 ft.

iv. N158f610: Massive calcareous mudstone, no Mollusca or Ostracoda found. Rhabdammina?, Haplophragmoides?, Euuvigerina notohispida, and Cibicides aff. robertsonianus, and the absence of many species which occur at N153f910, indicate a biofacies which is distinct from the "Robulus Biofacies". Pelagic species make up 50% of the shells abd indicate the "Semipelagic Biofacies". Depth 3,000 ± 1,000 ft.

B. BIOFACIES CONTAINED IN TURBIDITES BUT NOT REPRESENTED BY
    NON-TURBIDITE SAMPLES:

The turbidite samples contain 39 species of benthonic Foraminifera which do not occur in any of the non-turbidite samples. Most of them are assumed to belong to biofacies different from any of the four comparative non-turbidite samples. The 39 species can be divided into three depth classes; probably shallow-water species, probably deep-water species, and species of uncertain depth.

The first class contains: Siphotextularia aff. mestayerae, Gaudryina crespinae, Quinqueloculina triangularis, Q. cf. lata, Q. kapitiensis, Q. (Lachlanella) n. sp., Oolina hexagona, O. melo, Sigmomorphina cf. lacrimosa, Laryngosigma williamsoni, Virgulopsis cf. pustulata, "Bolivina" turbiditorum, Buliminella elegantissima, B. missilis, Buliminoides williamsonianus, Dyocidicides primitive, Rosalina cf. bradyi, Pileolina radiata, P. zealandica, Elphidium charlottensis, E. cf. crispum, Elphidium novozealandicum, Notorotalia cf. olsoni, Amphistegina sp.

Many of these species are common in shallow water in Cook Strait at the present day, but comparable fossil faunas are seldom found in Wairarapa. Depth ranges of nearly all probably lie between 0 and 400 ft. Biofacies at these shallow depths are extremely variable, and the shallow-water non-turbidite sample N153-f1155 represents only one of a probably large number of localised shallow-water sub-biofacies.

The second class, deep-water species, includes only Bulimina truncanella and Norcottia mioindex. Bulimina truncanella is closely related to the present day species Bulimina rostrata Brady which is widespread and restricted to very deep water (Brady, 1884; Natland, 1957; Bandy and Arnal, 1960). Norcottia mioindex has no close present day relative. Both species generally occur together in massive calcareous mudstones without macrofossils and with pelagic Foraminifera as the dominant microfossils. They probably represent a biofacies of greater depth than any of those represent

ed by the four comparative non-turbidite samples.

OCCURRENCES OF FACIES RESTRICTED SPECIES IN TURBIDITES:

For brevity in Table II facies-restricted species of each biofacies are identified by the following numbers:

i. Species restricted to N153f1155, and the class of probably shallow-water species contained in turbidites but not in any of the comparative non-turbidites samples, as listed above.

ii. Species restricted to N153f1157

iii. Species restricted to N153f910

iv. Species restricted to N158f610

V. Probably deep-water species contained in turbidites but not in any of the comparative non-turbidite samples.

Restricted species of all five biofacies occur in two of the turbidite rhythms, and species from four biofacies occur in the other rhythm (Table II). ~~The number of facies-restricted species occurring in each rhythm, and~~ For comparison the total number of facies-restricted species in each biofacies ~~(N) is given in Table~~ is given in the column headed N, and the ~~III. The~~ approximate total number of specimens examined in each sample or rhythm is given in brackets (the figure given in brackets for shallow-water biofacies is the number of specimens examined in sample N153f1155, but the number of restricted species (30) includes only 6 from this sample the other 24 being found only in the turbidites.).

TABLE III.

FACIES-RESTRICTED SPECIES IN TURBIDITES.
(data abstracted from Table II).

N: Number of restricted species in each biofacies.

BIOFACIES (inferred depth increasing downwards)			RHYTHMS N158 f624 f624	f626 (350)	f630 (900)
i. Shallow-water biofacies	(50)	30	21 spp.	14 spp.	25 spp.
ii. Haeuslerella Biofacies	(350)	15	6	4	4
iii. Robulus Biofacies	(650)	37	19	18	20
iv. Semipelagic Biofacies	(300)	14	3	2	5
v. Deep-water biofacies	(-)	2	2	-	1

The mixing of biofacies indicates that the turbidite fossils were displaced from the depths in which they originally lived. The non-turbidite samples contain 32 species which were not found in the turbidite samples, but these are rare species, fragile species, and large species. All species are less common in turbidite turbidites than in non-turbidites, and this could be largely due to dilution resulting from mixing of sediments from different environments, with different assemblages of species.

Species with fragile shells which are not represented in the turbidites include Virgulina aff. rotundata, Globobulimina pacifica, Florilus flemingi, Nonionella zenitens, and Nonionella? sp. An equally fragile species, Nonionella magnalingua, which is common in one of the non-turbidite samples, is represented by rare damaged shells in two of the turbidite samples. Large forms not

represented in turbidites include _Pyrgo_ and _Robulus_. Remains of mo
molluscan shells in the turbidites are all finely comminuted,
echinoid shells are represented by spines and broken plates only,
and ostracode shells are generally damaged. It is likely that,
in general, large foraminiferal shells and fragile shells were
not sufficiently protected by the surface tension of water to
prevent their destrction during transport, though a few specimens,
such as _Nonionella magnalingua_ in f624b and f626b, have survived.

Preferential destruction of weaker and larger shells probably
accounts for the generalised kind of fauna usually found in Tert-
iary turbidites in which the species are all small and strong-
shelled and are mostly common in non-turbidite facies. In some
turbidites which are completely barren of fossils all shells
which were originally present in the sediments must have been
destroyed.

A few species, for example _Oolina costata_, are small and
strong-shelled, and are common in one turbidite rhythm, yet are
absent from others. They tend to be sporadically distributed in
non-turbidite facies and suggest that different turbidite rhythms w
were not all derived from the same set of environments.

VARIATIONS WITHIN RHYTHMS.

A. GENERAL:

Although the total number of species in each of the three
rhythms is relatively constant, there is considerable variation
in the number of species in different parts of each rhythm (Table
IV).

TABLE IV.

NUMBER OF SPECIES IN EACH TURBIDITE SAMPLE.

RHYTHMS	SAMPLES IN EACH RHYTHM							TOTAL FOR RHYTHM				
	a	b	c	d	e	f	g					
N158f624	82	70	--	-	-	-	-	97 (incl. 6 pelagic spp.)				
N158f626	43	68	-	-	-	-	-	73 ("	4	"	"	)
N158f630	-	40	60	3	42	48	45	100 ("	5	"	"	)

The foraminiferal shells in all three rhythms are size-sorted as in the rhythm at locality N158f625 (Vella, in press), with larger shells concentrated towards the base and smaller shells concentrated towards the top of each rhythm.

The proportions of shallow-water species and specimens decrease from the bottom to the top of each rhythm. This change is probably not related to size-sorting because large species are generally represented by juveniles in the upper parts of rhyth rhythms, and the proportions of large and small species appear to be about the same in shallow- and deep-water facies.

The vertical faunal changes are most clearly shown by the series of closely spaced samples, N158f630a-h.

B. RHYTHM SAMPLED IN DETAIL - N158f630a-h.

At locality N158f630 rhythms average about 3 ft and range from about 2 ft to 4 ft thick. The basal sandstone is generally about 6 inches thick, and consists predominantly of medium sand with abundant fragments of molluscan shells, is sufficiently permeable to act as an aquifer, and is mottled with rusty brown limonite stain. Between the sandstone and overlying mudstone is

Rusty-stained blue-grey muddy sst. as below.

Irregular, bored surface — disconformity between two rhythms.

Blue-grey mudstone with some minute fragments of molluscan shells.

Poorly developed microbedding Zone of most rapid gradational change.

Rusty-stained blue-grey muddy sst. with abundant comminuted molluscan shells.

Irregular surface, as above.

Mudstone, as above.

Scale of inches

40

30
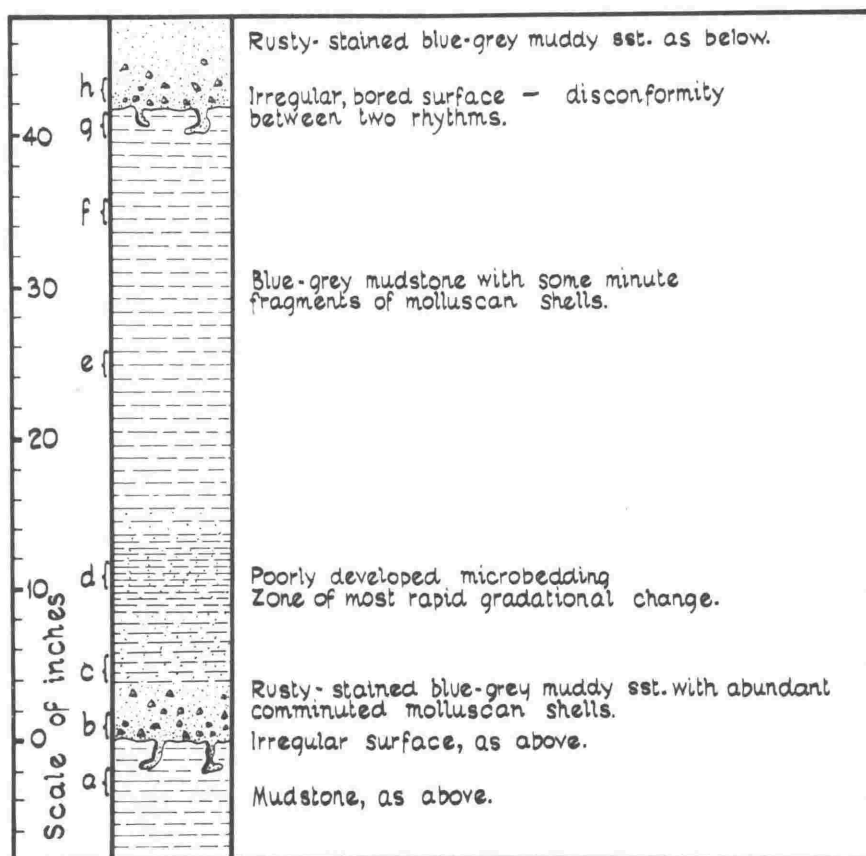
20

10

0

h

g

f

e

d

c

b

a

Fig. 2: Diagrammatic columnar section of turbidite rhythm which was sampled in detail at locality N158f630, Cleland Creek. Relative vertical positions of samples a to h are shown at the left side of the column.

Table V continued.

		N	a	b	c	d	e	f	g	h
ii.	Haeuslerella Biofacies	15	0	3	3	0	2	2	1	3
iii.	Robulus Biofacies	37	3	3	10	0	8	10	11	4
iv.	Semipelagic Biofacies	14	1	2	2	0	1	3	3	0
v.	Deep-water Biofacies	2	0	0	0	0	0	1	0	0
Total number of benthonic specimens			18	93	192	2	91	146	127	93
Total number of pelagic specimens			2	8	35	0	13	10	9	1

Every sample except "d", which is almost barren, contains Foraminifera from at least three different biofacies, most contain Foraminifera from four biofacies, and one contains Foraminifera from all five. Sandstone samples ("b", "c", and "h") contain a high proportion of shallow-water species, whereas most mudstone samples ("a", "e", "f", "g") contain a high proportion of deep-water species. This unequal distribution of species is paralleled by a more marked difference in the relative numbers of specimens (Table VI, and Fig. 3).

TABLE VI.

NUMBER OF SPECIMENS OF RESTRICTED SPECIES OF EACH BIOFACIES IN

EACH SAMPLE - N158f630.
(data abstracted from Table II).

SPECIMENS FROM:		SAMPLES a-h.							
i.	Shallow water	2	39	24	0	20	7	7	46
ii.	Haeuslerella Biofacies	0	12	17	0	12	9	7	13
iii.	Robulus Biofacies	2	10	30	0	16	41	25	9

Fig. 3: Bar diagram to show differences in relative proportions of shallow-water shells and deep-water shells at different levels in the turbidite rhythms sampled at N158f630. Specimens of restricted species of each biofacies (numbered as in table II) are shown as a percentage of total shells. Non-diagnostic species are marked x in Table II. Each bar represents one of the samples a to h and is placed horizontally at its correct level against the columnar section of the rhythms at the left side of the diagram. The proportion of shallow-water shells relative to deep-water shells abruptly increases at the base of each rhythm and decreases somewhat irregularly from the base to the top of each rhythm. Sample d represents a fairly thin zone that is almost barren of fossils.

LEGEND	NERITIC SPECIES		NON-DIAGNOSTIC SHELLS	BATHYAL + ?ABYSSAL SPECIES		
	Biofacies 1	Biofacies 2		Biofacies 3	Biofacies 4	Biofacies 5

Shells per cent 0 20 30 40 50 60 70 80 90
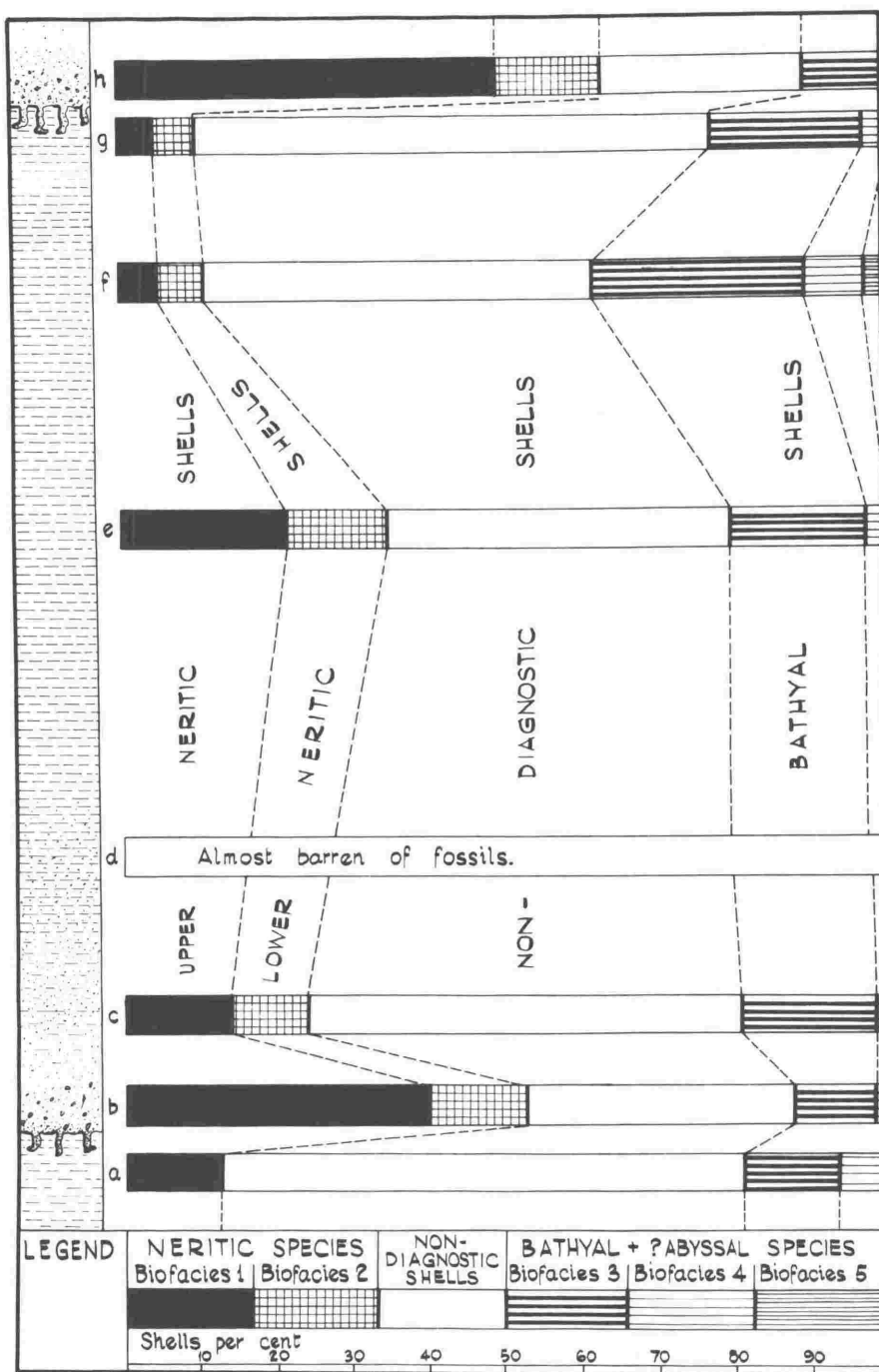
Table VI continued.

IV. Semipelagic Biofacies	1	1	2	0	2	12	3	0
V. Deep-water	0	0	0	0	0	3	0	0
Non-diagnostic specimens	11	31	96	2	41	74	85	25
Pelagic specimens	2	8	26	0	13	10	99	1
Total specimens	18	101	195	2	104	156	136	94

Figure 3, a graphical pepresentation of Table VI, shows
rhythmic fluctuation in relative proportions of shallow- and
deep-water shells which coincides more or less with the rhythmic
fluctualtion in relative proportions of sand and mud. That
shallow- and deep-water shells were not completely intermixed
indicates that the shallow- and deep-water sediments were not
completely intermixed.

Besides the change in proportions of shallow- and deep-water
shells there is a change in the total number of shells. The
basal sandstone and the mudstone generally have abundant shells,
but the gradational zone between the sandstone and the mudstone
has very sparse shells. This change is due to difference in the
number of shells destroyed during transport and deposition of the
sediment forming different modes of transport and deposition.

The basal sandstone is mostly shallow-water sediment with
shallow-water fossils, and is considered to have been transported
as a unit ~~single mass or as an aggregation of clots of sediment.~~ It
was dense, ~~probably viscous, and too cohesive to mix freely with
water,~~ and essentially a watery slump ~~rather than a true turbidity~~

current, and that slid rather than flowed turbulently from the upper part of the continental shelf down into much deeper water. During its transit down the slope internal movement was sufficient to thoroughly intermix Foraminifera and sediment picked up on the way, and to partially separate coarser sediment from finer sediment and larger shells from smaller shells, but it was not sufficient to destroy more than the largest and most fragile shells.

The intermediate zone between the basal sandstone and overlying mudstone, which is nearly barren of fossils, is the only part of the rhythms at Cleland Creek that shows any microbedding. Mr. S. Kustanovich and the writer found that much thicker and usually convoluted microbedded layers in Oligocene (Otaian) turbidites at Ekenui Stream, Tinui, Wairarapa, are invariably barren of fossils, though fossils are generally present in underlying non-microbedded sandstone and overlying non-microbedded mudstone. The microbedding indicates sorting and suggests deposition by fairly rapidly moving water in which abrasion may have been strong. This part of the rhythm is considered to have been deposited by the muddy after turbidity, current which was generated by the initial slump.

Massive mudstone overlying the barren layer was probably deposited essentially from suspension after water movement had slowed down. Foraminiferal shells would have been subjected to wear and tear during transport, and probably the number of shells destroyed would vary from one turbidite rhythm to another, but no shells would be broken during deposition.

No faunal evidence was found for an autochthonous layer of

the kind which occurs between rhythms in the Ventura Basin (Natland and Kuenen, 1951). Samples N158f630a and g were taken as close to the top of rhythms as ~was~ possible without contamination from the overlying rhythms, and both contain mixed biofacies. Either no autochthonous sediment was deposited in the time interval between deposition of rhythms, or more probably autochthonous sediment was stripped off by each slump preceeding a turbidity flow. The borings in the top of each rhythm are probably merely the lower ends of burrows which originally extended up through the autochthonous sediment, and which were still occupied by living animals after the new rhythm had been laid on top. Sand probably was emplaced in the truncated burrows by the buried animals boring upwards in a futile effort to ~reopen their burrows~ escape.

DEPTH OF DEPOSITION OF THE TURBIDITES.

In the absence of autochthonous layers a minimum depth of deposition is the best that can be determined for the turbidites at Cleland Creek. This is the minimum depth of the deepest biofacies represented.

The Semipelagic Biofacies is the deepest recognised with reasonable certainty, the evidence for the Eupelagic Biofacies being only the two benthonic species Bulimina truhcanella and Norcottia mioindex. The chief evidence of the depth ranges of the Semipelagic and Eupelagic Biofacies (discussed more fully by Vella, 1962a, 1962b) are the almost total absence of Mollusca, Brachiopoda, Echinoidea, Bryozoa and Ostracoda, and the relative

abundance of Foraminifera, and especially, a high proportion of pelagic foraminiferal shells. When freed of sediment the Eupelagic fossil biofacies is similar to Globigerina ooze, with pelagic shells up to more than 90% of all foraminiferal shells. The Semipelagic fossil biofacies has from 40% to 60% of pelagic shells. In geographic distribution for any particular time, and in strati-graphic sequences, the Robulus Biofacies ~~invariably~~ usually intervenes between the Semipelagic Biofacies and the Haeuslerella Biofacies. The Robulus Biofacies has from 30% to 50% of pelagic shells, and a highly diagnostic molluscan fauna which is similar to the deep-est present day archibenthal faunas described by Dell (1956) from depths of 1500 to 1800 ft. This archibenthal molluscan fauna marks the greatest well-documented depth in the depth sequence defined by biofacies in the late Tertiary rocks of Wairarapa. The Semi-pelagic and Eupelagic biofacies both represent considerably greater depths, but the actual depth ranges attributed to them are ~~little better than guesses,~~ tentative, being based mainly on data given by Phleger (1960).

The minimum depth of the Semipelagic Biofacies is conservat-ively estimated to be 2,000 ft., and this is the least possible depth at which the Cleland Creek turbidites could have been deposted. The best estimate that can be made with the present data is between 4,000 and 6,000 ft.

CONCLUSIONS.

Turbidites at Cleland Creek contain mixed deep-water and

shallow-water Foraminifera. A typical rhythm consists of three poorly differentiated but highly distinctive layers: a basal sandstone with abundant fossils representing slumped shallow-water sediment with a small proportion of intermixed deep-water sediment; an intermediate layer which is commonly microbedded and barren of fossils, representing sediment deposited by the turbidity current which was generated by the slump; massive mudstone with abundant fossils, forming the upper part of the rhythm, representing sediment which was thrown up in the cloud above the turbidity current and deposited from suspension after the turbidity current had ceased to flow.

No known mode of deposition, other than by submarine slumping and turbidity current accounts for the simultaneous mixing of deep- and shallow-water shells, size-sorting of shells, and destruction of shells. The turbidites wereddeposited at great depth, probably between 4,000 ft. and 6,000 ft, and the sediments which compose them were derived from all shallower depths up to about 400 ft or less.

This study was commenced with the purpose of testing faunal mixing and the existence of autochthonous layers, and determining depth of deposition. The results exceeded expectations, ~~including~~ and gave positive evidence of the different modes of deposition of different parts of the rhythms. Study of well-exposed Tertiary turbidites can supplement ~~yield~~ data ~~not~~ obtainable by oceanographic methods. A more statistical approach is needed, but was not warranted by the methods of sampling and of determining relative proportions of specimens used in

the present study. More rhythms should be closely sampled at
Cleland Creek to test how consistent are faunal changes and
layering, and turbidites other than those at Cleland Creek
should be examined in the same way.

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(N153f1155 and f1157) which had been collected and prepared by
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VIII - SIZE-SORTING OF FORAMINIFERA IN A TURBIDITE

RHYTHM, CLELAND CREEK, WAIRARAPA, NEW ZEALAND.

SIZE-SORTING OF FORAMINIFERA IN A TURBIDITE RHYTHM, CLELAND CREEK, WAIRARAPA, NEW ZEALAND.

By Paul Vella, Victoria University of Wellington.

ABSTRACT

Two microsamples were taken, one from sandstone and one from mudstone, in a rhythm in Upper Miocene turbidites at Cleland Creek. All the specimens of two species of Foraminifera were measured. Small specimens predominate in the mudstone, large specimens in the sandstone. The maximum size is about the same in both sandstone and mudstone, but the minimum size is much smaller in the mudstone. The shells of Foraminifera are size-sorted in the same way as the clastic grains.

INTRODUCTION

The preceeding paper gives Foraminifera in Upper Miocene turbidites at Cleland Creek, Wairarapa, and discusses vertical changes in taxonomic composition of faunas within individual rhythms. The following account describes a preliminary investigation of vertical change in average size of foraminiferal shells within one rhythm at Cleland Creek. The location is shown in the preceeding paper (Vella, 1963, Fig. 1).

Orbell (1962) collected microsamples from the sandstone and mudstone phases of several rhythms. During examination for age determination it was noticed that the average size of the Foraminifera in the sandstone samples is greater than in the mudstone samples. This applies to samples as a whole, as can be easily seen by comparing mounted slides, and to individual species. For a more quantitative investigation of the size distribution of foraminiferal shells two of Orbell's samples from one rhythm were used. They were not prepared especially for the purpose, and serve merely to indicate that the shells are definitely size-sorted and that a more thorough investigation would be warranted.

SIZE FREQUENCY DISTRUBUTIONS OF INDIVIDUAL SPECIES

Only a few samples contain enough specimens of an individual species to show statistically significant differences in size-frequency distribution. A useful species must have a reasonably large adult shell and a small juvenile shell, and must be abundant in both the sandstone phase and the mudstone phase of one rhythm. Generally only a small proportion of species are abundant in any non-turbidite sample, and any species is generally less common in turbidite samples than in non-turbidite samples. Furthermore, species which are common or abundant in one phase of a turbidite rhythm may be infrequent or rare in the other phase.
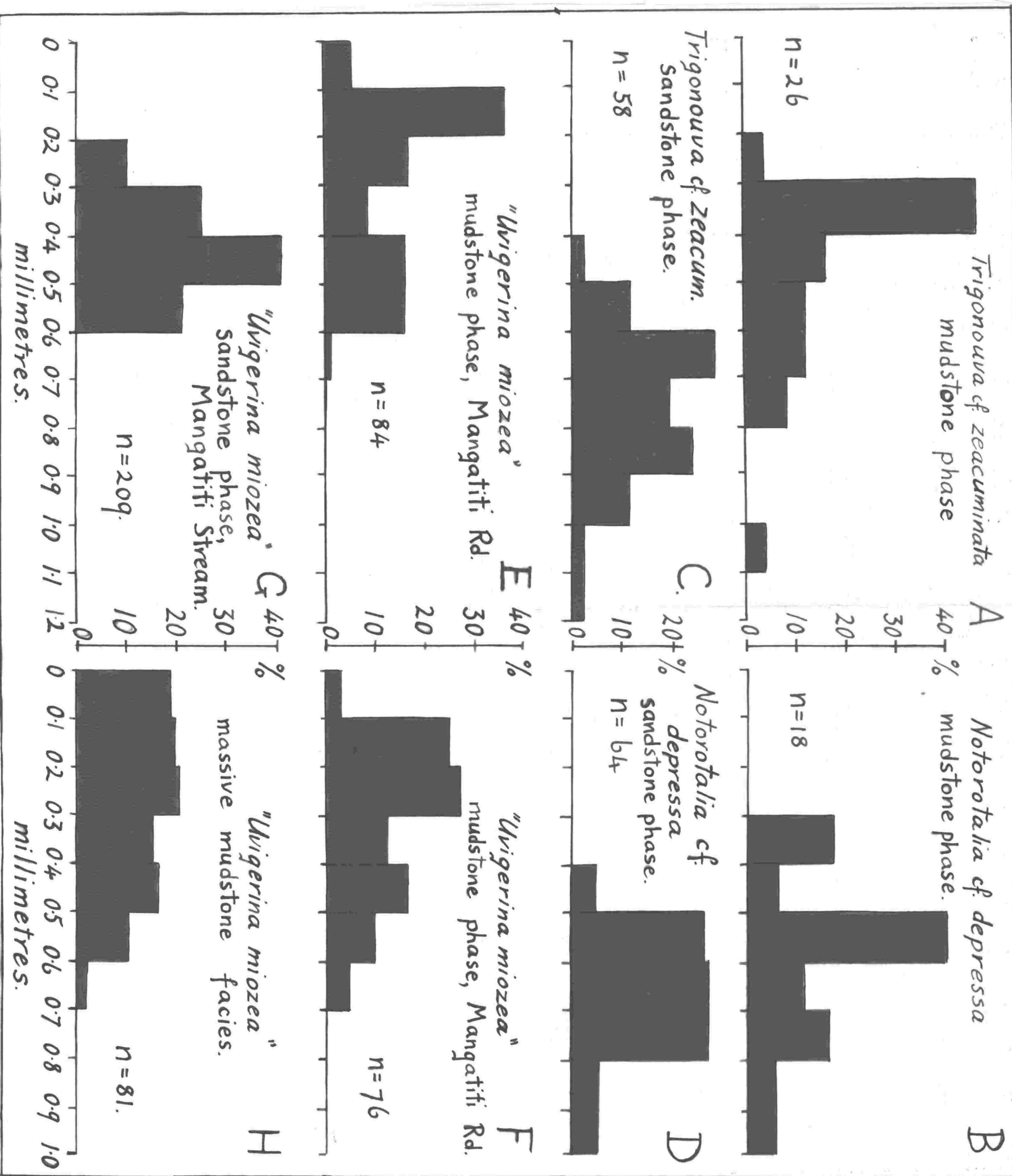
Fig. 1. Histograms showing percentages of specimens of particular species of Foraminifera plotted against linear increases in size: A - D, Cleland Creek; E - H, Mangatiti area, adapted from Scott (1961).

The species which most obviously shows the size difference between sandstone and mudstone phases is <u>Karreriella cylindrica</u> Finlay, a large arenaceous species with distinctive juvenile and adult stages, which is generally represented mostly by juveniles in the mudstones and mostly by adults in the sandstones. Unfortunately it is too infrequent at Cleland Creek for statistical study without much larger samples than those available.

The most satisfactory examples found were <u>Hofkeruva</u> (<u>Trigonouva</u>) cf. <u>zeacuminata</u> Vella and <u>Notorotalia</u> cf. <u>depressa</u> Vella in sandstone and mudstone samples of a rhythm at locality N158f625. The two samples were of the size usually collected as spot samples, weighing approximately one pound *and were washed by a routine method over a 240 mesh screen.* All specimens of both species were picked, and reasonably large numbers were obtained from the sandstone sample, but rather small numbers from the mudstone sample. Using an ocular scale, specimens of <u>Hofkeruva</u> were measured between the apex and the apertural end, and specimens of <u>Notorotalia</u> were measured along the maximum diameter. Measurements and numbers of specimens are given in table I, and are plotted as histograms showing numbers of specimens as percentage against linear increases in size in figure 1 A-D.

TABLE I

DIMENSIONS OF TWO SPECIES OF FORAMINIFERA IN SANDSTONE AND MUDSTONE OF A TURBIDITE RHYTHM

Locality: N158f625, Cleland Creek, grid reference

Size	Number of Specimens			
	Trigonouva cf. zeacuminata		Notorot*alia* cf. depressa	
Mm.	Sst.	Mdst.	Sst.	Mdst.
0.26	–	1	2	–
0.28	–	–	–	–
0.30	–	–	–	–
0.32	–	2	–	–
0.34	–	1	–	–
0.36	–	3	–	–
0.37	–	4	–	–
0.39	–	2	–	3
0.41	–	–	–	–
0.43	–	2	–	–
0.45	–	1	1	–
0.47	–	1	2	1
0.49	1	–	–	–
0.51	1	–	2	1
0.52	1	1	2	1
0.54	1	–	2	1
0.56	2	1	5	3
0.58	2	–	6	–
0.60	3	1	3	1
0.62	3	2	2	2
0.64	2	–	2	–
0.65	2	–	3	–
0.67	3	–	6	–
0.69	3	1	2	–
0.71	4	1	5	1
0.73	–	–	2	–
0.75	2	1	4	2
0.77	3	–	6	–
0.79	2	–	1	–
0.80	4	–	1	–
0.82	1	–	2	1
0.84	3	–	–	–
0.86	2	–	1	–

Mm.	Sst.	Mdst.	Sst.	Mdst.
0.88	4	-	-	-
0.90	-	-	1	-
0.92	2	-	-	-
0.94	4	-	-	-
0.96	-	-	3	-
0.97	-	-	-	1
0.99	1	-	-	-
1.01	-	-	-	-
1.03	1	-	-	-
1.05	-	1	-	-
#—1.07	-	-	-	-
1.18	1	-	-	-

Total Specimens: 58   26   64   18

The three main features of the size frequency distributions
are: (1) Juveniles predominate in the mudstone while adults
predominate in the sandstones; (2) Specimens with a measured
dimension less than 0.45 mm. occur only in the mudstone phase;
(3) A greater range of sizes occurs in the mudstone than in
the sandstone, the maximum size being about the same in both
mudstone and sandstone. Larger samples from the mudstone
could not upset these conclusions.

In general all sizes of shells , from proloculum stage
to adult, are represented in any unsorted sample of Foramin-
ifera. The absence of specimens less than 0.45 mm. (which is
considerably larger than the proloculum of either species)
in the sandstone phase therefore indicates mechanical sorting
of the shells. The high proportion of small specimens in the
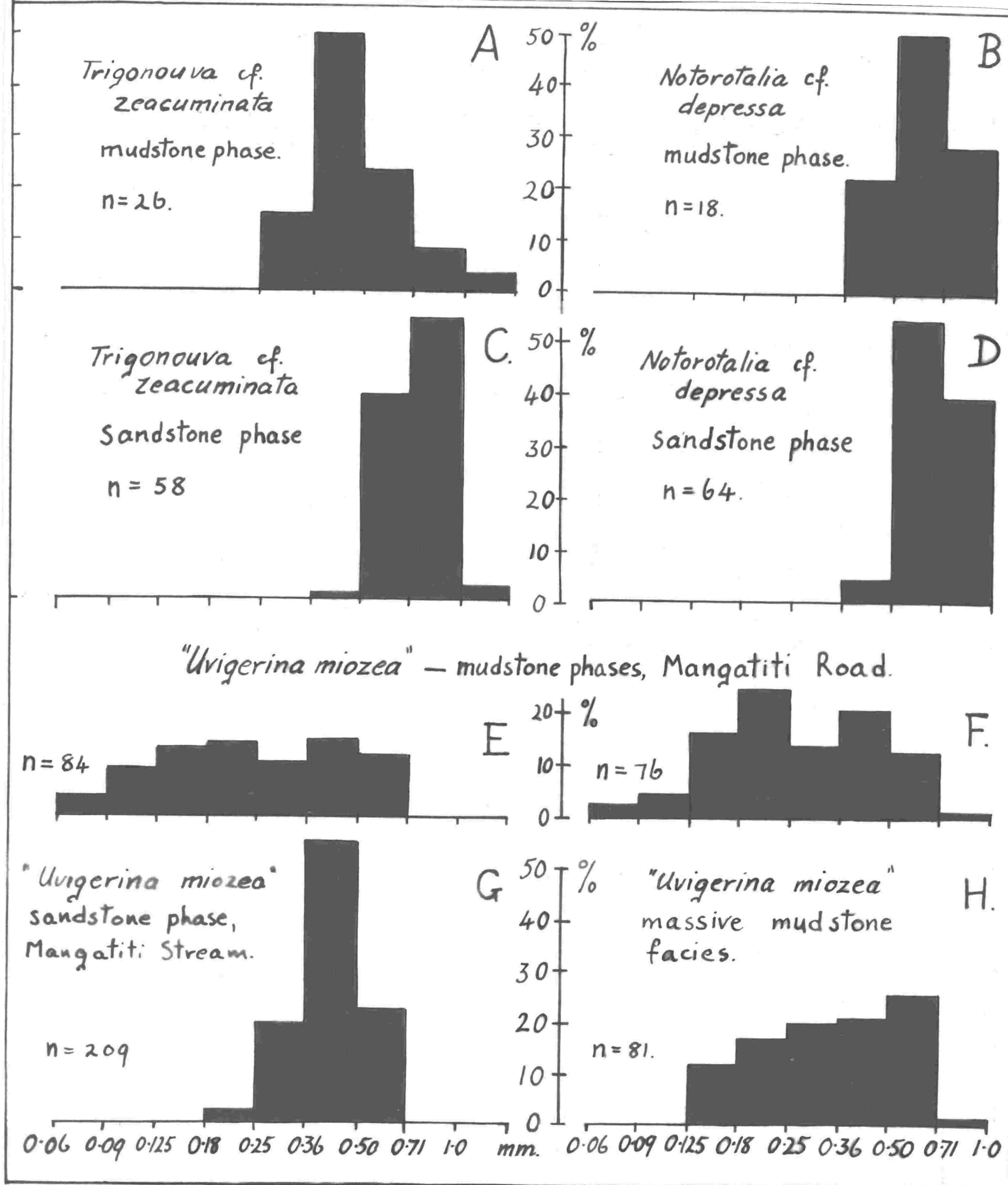mudstone is almost certainly to be correlated with the high

Fig. 2. Size-frequency histograms from same data as those in figure 1, but showing percentages of specimens plotted against logarithmic increases in size (Wentworth Scale with double the usual number of intervals): A - D, Cleland Creek; E - H, Mangatiti area, adapted from Scott (1961).

proportion of large specimens in the sandstone, and is due to
mechanical sorting.

In their sorted condition the foraminiferal shells are
not *representative* samples of ~~fossil~~ *the original living* populations and should be regarded as
sedimentary particles. Histograms showing percentages of
specimens plotted against linear increases in size are approp-
riate for studying foraminiferal populations but not for
studying sediments. Histograms were therefore replotted to
show percentages of specimens against a Wentworth Scale with
double the usual number of divisions (Fig. 2 A - D). This has
the effect of compressing the larger sizes into a smaller
number of classes, making the right hand end of each histogram
more compact.

The strongly unimodal size-frequency distribution and sharp
cut-off of the small sizes suggests fairly good sorting in the
sandstone, but clastic particles of much larger size than the
largest measured Foraminifer also occur abundantly in the sand-
stone. The lack of small specimens is the most significant
feature.

The occurrence of much smaller specimens, and the predom-
inance of small specimens in the mudstone are the most signif-
icant differences between size frequencies in mudstone and
sandstone. ~~Nevertheless~~, The smaller sizes cut off sharply
in the mudstone, as in the sandstone, ~~and the smallest possible~~
but in this case the cut off is
controlled by the 60 micron opening size of the sieve used for washing the samples.
~~sizes are still not represented~~. The larger range of sizes in
the mudstone does not indicate poorer sorting than in the sand-

stone because the maximum size of shells is less than the maximum size of clastic grains in the sandstone. The maximum size of shells in the mudstone is about the same as the maximum size of shells in the sandstone. Viewed as particles which have settled from suspension, the shells in the mudstone can be interpreted as a poorly sorted fraction which settled later than the sandstone fraction, but earlier than the fraction containing the smallest juveniles. Adult specimens (and large clastic grains) in the mudstone may have been carried in by the waning turbidity current after the deposition of the lower part of the rhythm, or may have settled late due to their having been carried exceptionally high above the sea floor by eddies generated above the turbidity current.

Scott (1961) discussing the mode of formation of Upper Miocene graded-bedded strata at Mangatiti Road, 25 miles northeast of Cleland Creek gave size frequency histograms for "Uvigerina miozea", a species similar to Trigonouva aeacuminata, in the upper parts of two mudstone phases. For comparison he gave three other histograms, one for "Uvigerina miozea", in nearby massive siltstone facies of about the same age; one for "Uvigerina miozea" (undoubtedly different from the upper Miocene species) in a sandstone phase of nearby late Oligocene strata; and one inferred from published data on Elphidium crispum living in natural conditions. All except the one for Elphidium crispum are replotted here (figures 1 E - H and figures 2 E - H) to show numbers of specimens as percentages

against linear increases in size and against logarithmic
(modified Wentworth Scale) increases in size. Size freq-
uencies in the mudstone phases of the graded beds are similar
to those inferred for Elphidium crispum in being bimodal, and
Scott thought this likely to be due to a high mortality rate
of very young individuals and to indicate that the fossil
populations in the mudstone phases were not sorted. This
conclusion would imply either that the graded beds at Mang-
atiti Road are not turbidity current deposits, or that the
upper part of each mudstone is a distinct layer not part of
the graded bed deposited by each turbidity current.

The massive mudstone facies is generally an extremely
poorly sorted sediment (Orbell, 1961) and probably contains
unsorted fossil populations. The size frequencies of
"Uvigerina miozea" in the massive mudstone (Figs. 1H, 2H)
are not bimodal, but on the contrary show nearly uniform
percentages of nearly all except the largest sizes of shells.
The bimodal size frequencies of Elphidium crispum therefore
cannot be taken as typical of unsorted dead populations of
all species.

In their extraordinarily high content of juvenile shells
the mudstone phases of the graded beds at Mangatiti Road differ
from Scott's other examples. They resemble the mudstone phase
at Cleland Creek, but the size range of shells is larger, the
minimum size is smaller, and the peak frequency size is smaller
(shown most clearly by Fig. 1E, F) because a finer screen was used in
preparation of the samples.

If Scott's samples (which were taken from the topmost

parts of two rhythms) were from turbidites they could well
represent that final stage when the finest material in the
cloud formed by the turbidity current was settling. The
secondary peaks of larger sizes of shells (Figs. 1E, F,
Fig. 2E, F) which are not found in the Cleland Creek mud-
stone phases, are not explained, and they may indicate a
somewhat different mode of deposition. Alternatively, these
secondary peaks may be subjective because "Uvigerina miozea"
might include more than one species. Furthermore figures
1F and 2F (Scott's Fig. 3) were based on specimens from two
samples.

The lack of statistical samples of "Uvigerina miozea"
from the sandstones in the graded beds at Mangatiti Road ~~vit.~~
weakens
~~lates~~ the conclusions drawn by Scott from the mudstone sam-
ples. Scott stated that juveniles and adults occur in
(Mangatiti Road.)
sample 4 from the sandstone at locality N154f521, but gave
no indication of relative frequency or of minimum size. The
size frequencies of "Uvigerina miozea" in the sandstone phase
of upper Oligocene graded beds (Fig. 1G, Fig. 2G) are remark-
ably similar to those in the sandstone phase at Cleland Creek.
So far from representing "an entirely different set of sedim-
entary conditions" as remarked by Scott (p. 87), this kind of
size frequency is probably the complement of that in the mud-
stone phases at Mangatiti Road, and strongly suggests similar
conditions of deposition.

CONCLUSIONS

Difference in the average sizes of foraminiferal shells between the sandstone and mudstone phases of a turbidite rhythm at Cleland Creek indicates mechanical sorting. The sorting is imperfect like that of the clastic sediment of the rhythm. Further work is required to determine the constancy of size frequencies in different parts of turbidite rhythms, and to determine the full sequence of vertical changes in a rhythm. Large ~~raw~~ samples may be required to obtain statistical samples of a particular species.

A high frequency of adult shells, unimodal size frequency, and absence of small juvenile shells is probably diagnostic of sandstone phases of turbidites. A high frequency of juvenile shells and large size range is probably diagnostic of mudstone phases of turbidites. The late Oligocene graded-bedded strata sampled by Scott at Mangatiti Stream are turbidites. The Upper Miocene graded-bedded strata sampled by Scott at Mangatiti Road are probably also turbidites.

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IX - FORAMINIFERA AND OTHER FOSSILS FROM UPPER

TERTIARY DEEP-WATER CORAL THICKETS,

WAIRARAPA, NEW ZEALAND.

INTRODUCTORY NOTE

The following paper was prepared at the request of Dr. D.F. Squires of the Smithsonian Institution, Washington, D.C., U.S.A., and is intended to follow his paper on fossil coral thickets of Wairarapa, in the Journal of Paleontology.

Small "reefs" built by "ahermatypic" corals have been known in cold, mostly deep, waters for nearly 100 years, but suitable equipment for studying them has only recently been devised. In 1956 the Woods Hole Oceanographic Institution charted by echo soundings more than 200 ridges within an area of 1,200 square miles at the northern end of the Blake Plateau, off the south-east coast of North America. A few of the ridges have since been studied by means of dredging, underwater photography, detailed echo soundings, and seismic profiles, and have been identified as banks of coral (Stetson, Squires and Pratt, 1962*). They are up to a mile long and 150 meters high. The northern part of the Blake Plateau ranges from 550 to 1,000 meters deep. Assuming that all the ridges on this part of the

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* Stetson, T.R., Squires, D.F., and Pratt, R.M., 1962: Coral Banks occurring in Deep-Water on the Blake Plateau. American Museum Novitates 2114, pp. 1-39.

Blake Plateau are built by corals, Stetson, Squires and Pratt pointed out that deep-water coral reefs are more extensive than was formerly realised, and probably were equally extensive in the past. This is of considerable importance to geologists because fossil coral reefs have generally been accepted as good evidence of tropical shallow seas.

While working on the Blake Plateau reefs Dr. Squires recalled two fossil coral structures which he had seen in Wairarapa in 1959. On revisiting New Zealand in 1962 he was able to re-examine the Wairarapa structures, and was satisfied that they are essentially similar to those of the Blake Plateau. The Wairarapa structures are the first to be recognised as fossil deep-water coral reefs, and like their modern counterparts they were sites of "high density marine populations" and harboured many organisms that did not live on the surrounding sea floor. Fossils other than corals from within the coral reefs, and from the surrounding sediments indicate cold deep water, and are discussed in the following paper.

Squires distinguishes four developmental stages of the coral structures, taking the "colony" as the first stage. Both of the Wairarapa reefs have reached only the second stage, and are known as thickets. They are relative-ly small, consist of a number of colonies with closely interwoven branches, and have no layer of coral debris at

the base. The third and fourth stages, known as coppices and banks, are generally larger, and are distinguished by layers of debris at the base.

The dominant coral in the Blake Plateau reefs is Dendrophyllia profunda, and the next in importance is Lophelia prolifera. At least two other species occur sparingly. The Wairarapa fossil thickets contain only one species of coral, Lophelia parvisepta, an extinct species known only in New Zealand, but closely related to Lophelia prolifera. All known present day thickets, coppices and banks are composed of more than one species of coral, and occur in waters ranging in temperature between $6^{\circ}C$ and $10^{\circ}C$. The known temperature tolerance of Lophelia prolifera is from $2.5^{\circ}C$ to $12^{\circ}C$.

A map of the southern part of the North Island from Squires' account is given here to show the locations of the two coral thickets (Fig. 1).
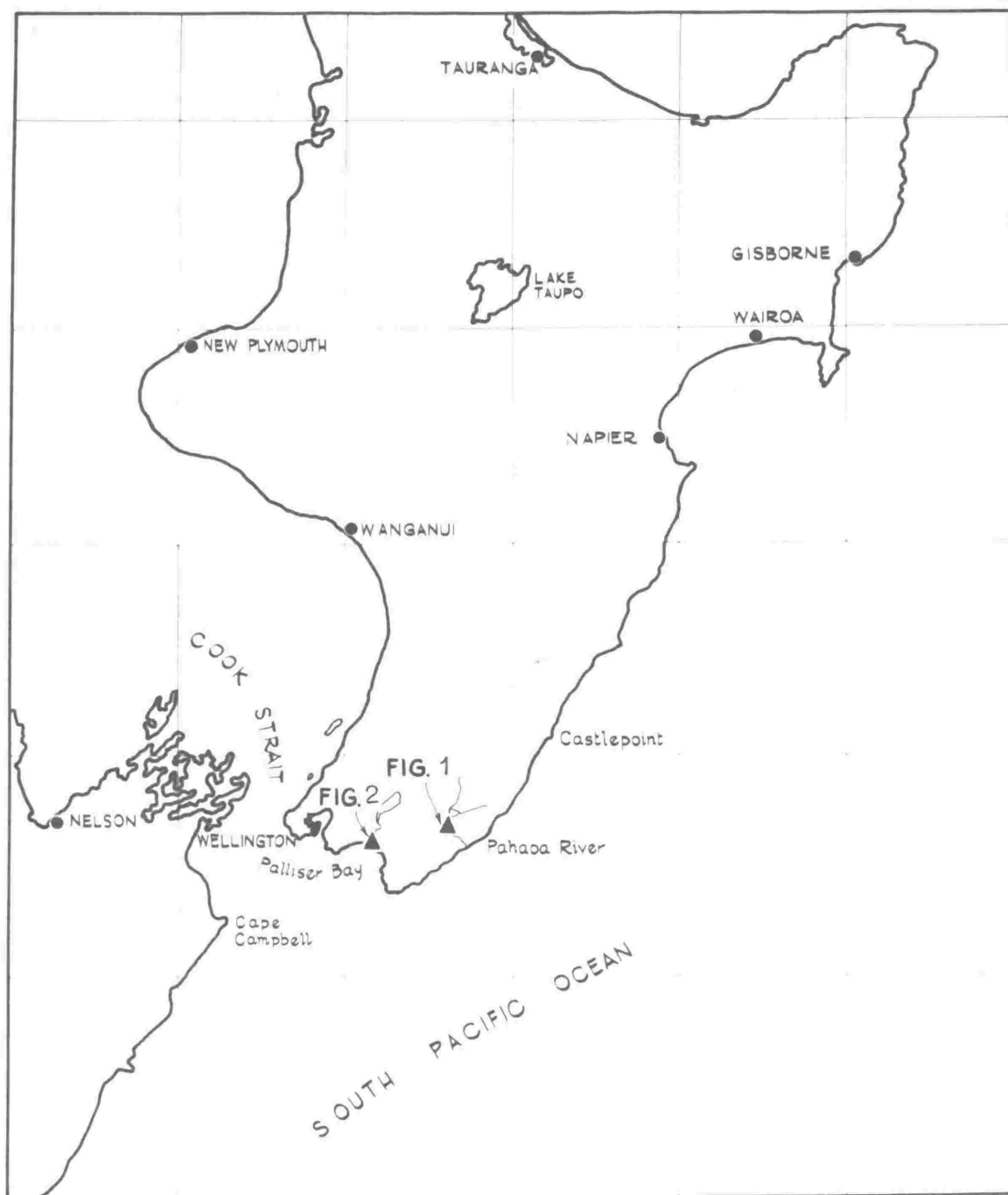
Fig. 1: Map showing location of Hinakura Coral Thicket (Fig. 1) and Lake Ferry Coral Thicket (Fig. 2).

Abstract

Two fossil coral thickets are known in Wairarapa, one late Miocene, the other late Pliocene in age.

Foraminifera from the late Miocene coral thicket, and the underlying and overlying mudstones indicate a sea depth probably not less than 1,500 meters, and a temperatue of about 2°C. Species of Mollusca, Ostracoda, Echinodermata, and Foraminifera are restricted to the thicket.

Foraminifera and Mollusca from the late Pliocene coral thicket and the underlying and overlying mudstones indicate depths between 200 and 300 meters, and uncertain but fairly cold temperatures. Several Foraminifera, a few attached Pelecypods, a free-swimming Pelecypod, and a Brachiopod are restricted to the thicket.

Introduction

The coral _Lophelia parvisepta_ has been found at four places in New Zealand and ranges in age from lower or middle Miocene to upper Pliocene. At two localities, both in Wairarapa, the coral forms thickets described by Squires (1963) who gives locality numbers and full locality details. Foraminifera and other fossils

associated with the two thickets are discussed below with special reference to the geological age of the thickets and the depth and temperature of the water in which they grew.

Each thicket is underlain and overlain by mudstone, and lies on a disconformity (Squires, 1963, p. 00). In each case the corals are assumed to have commenced growing on a firm bottom formed by minor erosion, and it can not be assumed that the mudstones were formed at the same depth as the thickets. Consequently microsamples were collected from within each thicket, from underlying and overlying mudstones, and from sediments to one side, in order to determine vertical and lateral changes in biofacies. Depths were determined by a method described in two previous accounts (Vella, 1962a, 1962b), using a relative scale of late Tertiary depth biofacies.

A generalised locality map is given by Squires (1963, fig. 1). The main locality numbers and locality details are as follows:

1. Hinakura Coral Thicket: N166f716, grid reference 154247, 100 meters west of Pahaoa River, $1\frac{1}{4}$ miles north of first road bridge north of Hinakura Post Office (fig. 1).
2. Lake Ferry Coral Thicket: N165f491, grid reference 682081, $\frac{3}{4}$ mile south-east of Lake Ferry Hotel, in sea cliffs north-east side of Palliser Bay (fig. 2).
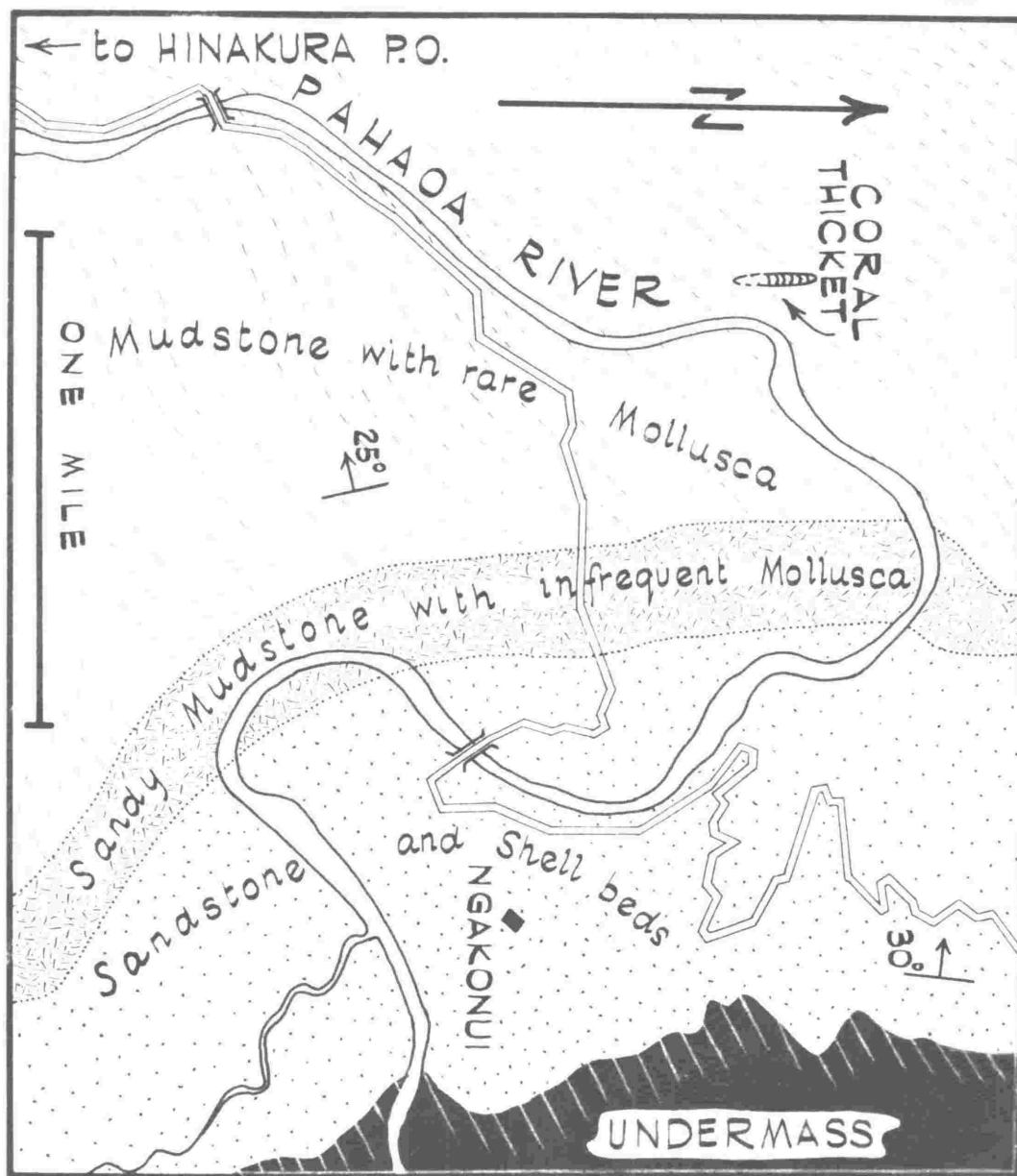
Fig. 1: Geological sketch map of northern end of Hinakura Valley showing lithological sequence, and location of Hinakura Coral Thicket. Drawn from air photograph.
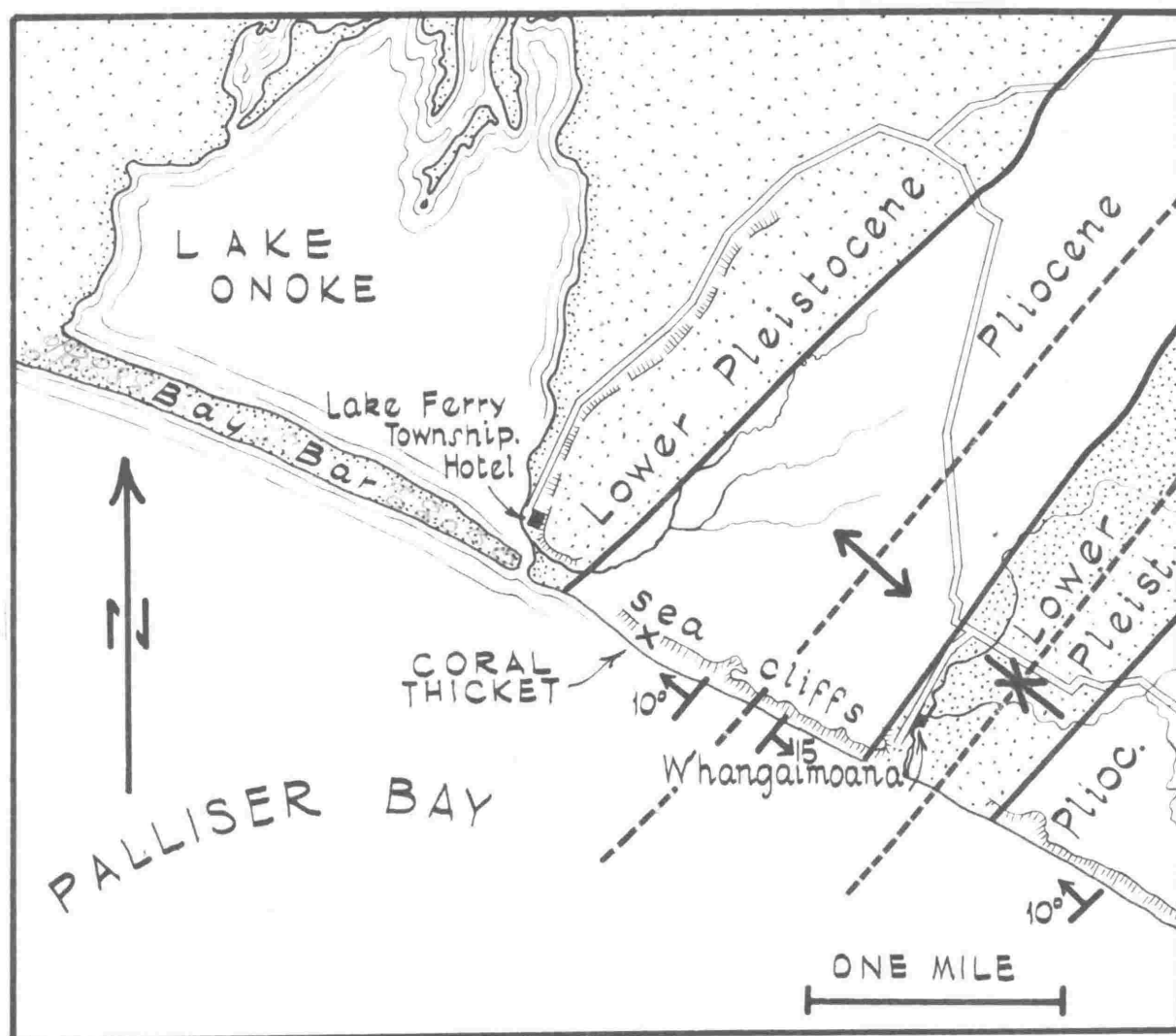
Fig. 2: Geological sketch map of coastal area near Lake Ferry, north-east side of Palliser Bay, showing location of Lake Ferry Coral Thicket. Pliocene and lower ~~Pliocene~~ Pleistocene strata shown without upper Pleistocene gravel cover.
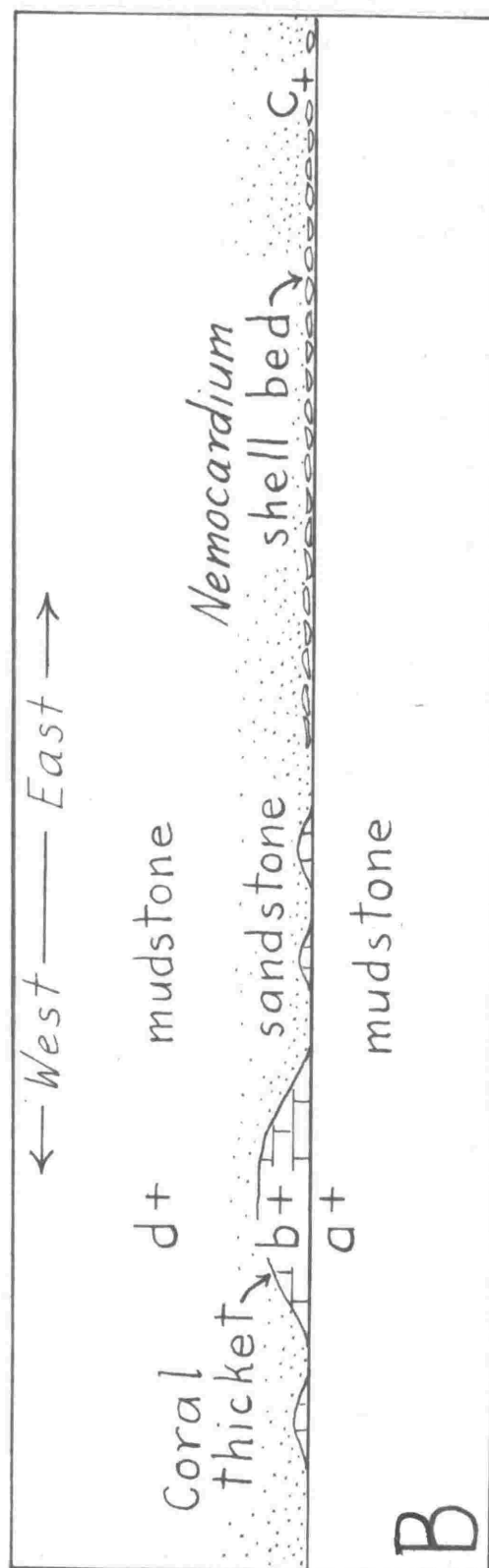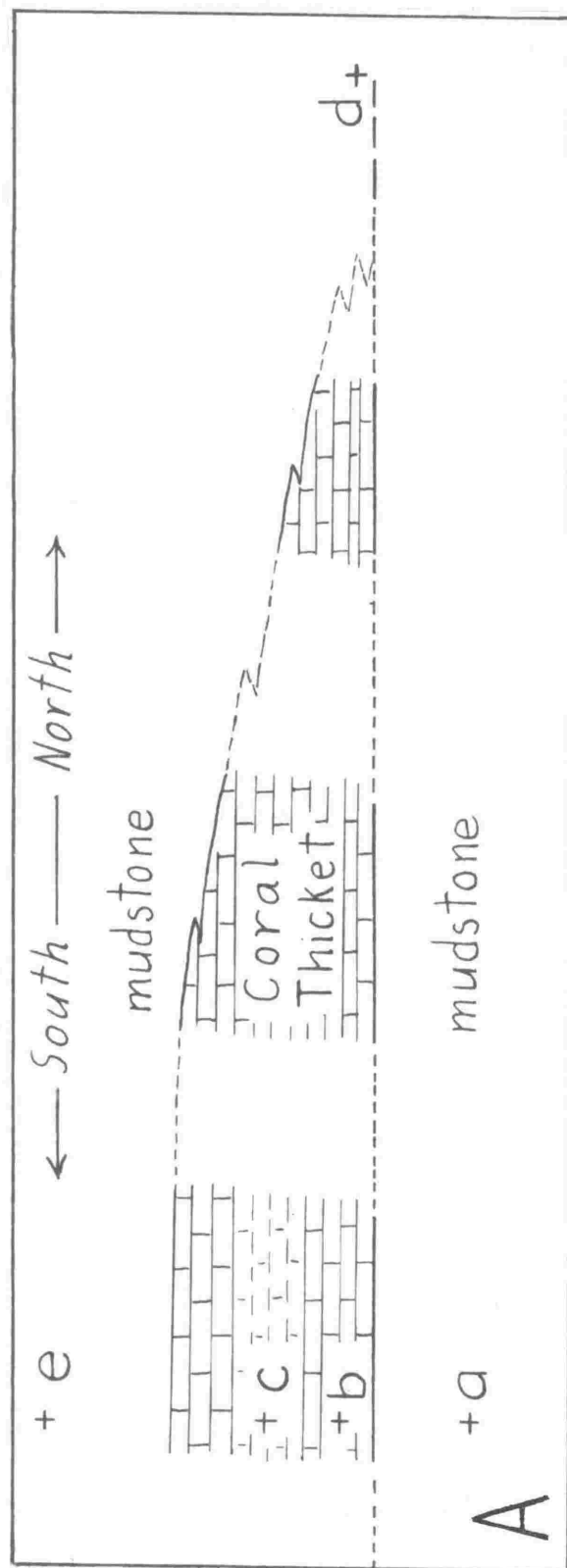
Fig. 3: Diagrammatic sections of fossil coral thickets in Wairarapa; vertical scale of each twice the horizontal, total width of A 60 meters, and of B 30 meters. A: Hinakura Coral Thicket showing positions of samples N166f716a-e; blank areas not exposed. B: Lake Ferry Coral Thicket showing positions of microsamples N165f491a-d.

Relative abundances of benthonic species of Foramimi-
ifera in each microsample were determined by covering a
3 x 2 inch tray with a thin layer of washed sample and
counting the number of visible specimens for each
species. The rare species were picked out by sorting
through the complete sample in the usual way. In tables
1 and 2, which show distributions of Foraminifera at the
two localities, relative abundances are shown by the
following symbols: a (abundant), more than 20 specimens
counted; c (common), between 10 and 20 specimens counted;
f (frequent), between 1 and 9 specimens counted; r (rare),
no specimens found when counting.

The precise identities of planktonic species are not
relevant to this study and were not determined critically.
The proportions of planktonic specimens in foraminiferal
samples were determined approximately.

Hinakura Coral Thicket

Five microsamples were collected, all of which were
given the same locality number (N166f716) and are dis-
tinguished ~~by~~ from one another by suffixed letters.
Samples a, b, c, and d were taken in vertical line at
the southern end of the exposure of the thicket. Details
~~of the~~ of the sample positions (fig. 3A) are as follows:
a: mudstone 2 meters below base of thicket; thicket 1
meter above base; c: thicket near middle, layer with

relatively little coral; d: mudstone 7 meters north of northernmost exposure of thicket, vertical position relative to thicket uncertain, but probably slightly above base of thicket; e: mudstone 2.5 meters above top of thicket. The five samples yielded a total of 107 benthonic species and 12 planktonic species of Foraminifera (table 1). In all samples more than 90% of shells are of planktonic species.

A search was made at the outcrop for macrofossils, and the few traces found are mentioned briefly below. They are extremely rare, and painstaking collecting will be required to deal with them adequately.

Table 1 goes here.

Table 1

Foraminifera Associated with Hinakura Coral Thicket

Samples: a, mudstone below thicket; b and c, within coral thicket; d, mudstone by north side of thicket; e, mudstone above thicket.

Benthonic species:

1. restricted to thicket.	Samples: a	b	c	d	e
Amphimorphina sp.		-	r		
Bolivina A (short, striate)		-	f		
Cassidulina sp.		-	f		
Cibicides novozelandicus		r	-		
Dentalina consobrina		f	-		
Discopulvinulina sp.		r	r		
Ellipsoglandulina subconica		-	r		
Ellipsoidina sp.		-	r		
"Eponides" cf. punctulatus		r	-		
Gavelinopsis sp.		f	-		
Glandulina symmetrica		f	-		
Globobulimina pacifica		r	-		
Haeuslerella cf. finlayi		f	-		
Laminiuva zealamina		f	-		
Massilina subaequalis		f	-		
Neouvigerina vadescens		f	-		
Nodosaria hochstetteri		f	-		
Nodosaria (large, striate)		r	-		
Oolina costata		f	r		

Table 1 - continued

	a	b	c	d	e
Oolina melo		f	-		
Pacinonion cf. neefi		-	f		
Planulina wüllerstorfi		f	f		
Proxifrons vaughani		?	r		
Pyrgo murrhina		f	-		
Quinqueloculina sp.		f	f		
"Sigmoilina" tenuis		-	f		
Siphotextularia ihungia		r	f		
Trigonouva cf. zeacumunata		f	f		

2. present in thicket and mudstone

	a	b	c	d	e
Angulogerina sp. (tiny)	f	-	f	-	f
Awhea sinalata	f	f	f	c	f
Bolivina affiliata	f	f	f	f	f
Bolivina albatrossi	r	f	f	f	f
Bolivina pacifica	-	-	f	f	f
Bolivina sp. B	f	c	c	c	-
Bolivinita aff. quadrilatera	f	f	-	-	-
Bulimina notovata	f	c	f	c	f
Bulimina aff. striata	r	f	c	c	f
Bulimina truncanella	-	f	f	f	-
Bulimina sp.	-	-	r	r	-
Cibicides bradyi	f	f	f	c	c
Cibicides aff. deliquatus	f	f	f	f	f
Epistomina elegans	f	c	-	-	-

Table 1 - continued

	a	b	c	d	ee
Epistominella sp.	-	r	-+	-	r
Eponides tenera	-	f	f	f	f
Fissurina orbignyana	f	f	f	f	f
Fissurina spp.	f	ff	f	f	-
Gyroidinoides neosoldanii	f	f	f	f	f
Haeuslerella cf. morgani	-	f	f	f	f
Karreriella bradyi	c	c	c	a	c
Lagena meridionalis	f	f	f	f	-
Lagena striata	-	f	f	f	f
Laticarinina halophora	f	f	f	-	f
Melonis lutorum	f	f	f	a	f
Melonis pompilioides	-	f	f	f	-
Neouvigerina bellula	f	f	f	f	f
Nodosaria filiformis	f	f	f	c	f
Nodosaria holoserica	f	f	f	f	f
Nodosaria longiscata	f	c	-	c	c
Nodomorphina sp.	f	f	-	-	f
Norcottia mioindex	f	f	f	f	a
Oolina globosa	-	f	-	f	-
Osangularia bengalensis	f	f	c	a	c
Parafrondicularia wairarapa	f	f	f	f	f
Plectofrondicularia pohana	f	c	f	c	c
Pleurostomella alternans	f	f	f	c	r
Pleurostomella brevis	-	-	f	f	-
Proxifrons advena	f	f	f	f	f
Psammosphaera cf. fusca	a	r	-	-	-

Table 1 - continued

	a	b	c	d	e
Pullenia bulloides	f	f	f	c	c
Pullenia cf. subcarinata	-	-	c	-	?
Quinqueloculina venusta	-	a	f	f	f
Ramulina sp.(fragments)	r	-	r	-	-
Robulus sp.	-	f	-	-	r
Sigmoilopsis schlumbergeri	f	a	c	f	c
Sphaeroidina bulloides	f	f	f	c	c
Stilostomella dentaliniformis?	r	f	f	c	f
Stilostomella sp. A	f	f	r	f	c
Stilostomella sp. B	f	-	r	f	-
Stilostomella sp. C	f	-	f	f	f
Tereuva lutorum	-	c	f	f	-
Textularia sp.	-	-	r	-	r
Virgulina aff. rotundata	r	f	-	f	-
Virgulopsis n. sp.(smooth)	f	f	c	a	c

3. restricted to mudstones

	a			d	e
Amphicoryne scalaris	-			-	f
Bolivina sp. C (minute)	f			-	-
Bolivinopsis cubensis	r			-	-
Bulimina senta	f			-	f
Cassidulina subglobosa	-			f	-
Chrysalogonium verticale	f			f	-
Dentalina soluta	f			-	-
Dentalina substrigata	-			-	f
Euuvigerina notohispida	-			-	f

Table 1 - continued

	a	b	c	d	e
Gyroidina prominula	-			-	f
Karreriella cushmani	-			f	f
Martinottiella n. sp.	f			f	-
Miniuva minima	f			-	c
Oolina hexagona	-			-	r
Oolina sp.	-			-	r
Parafissurina spp.	-			f	f
Robulus iotus	f			f	-
pyritic casts of tubular arenaceous spp.?	c			a	c

Planktonic Species:

	a	b	c	d	e
Globigerina bulloides	x	x	x	x	x
Globigerina dubia	-	?	?	-	x
Globigerina euapertura	x	?	x	x	x
Globigerina nepenthes	x	x	x	x	x
Globigerina subcretacea	x	-	-	x	x
Globigerinita sp.	x	?	x	x	x
Globigerinoides cf. rubra	-	x	x	x	-
Globigerinoides triloba	x	x	x	x	x
Globorotalia canariensis	x	x	x	x	x
Globorotalia menardii	-	x	x	x	x
Globorotalia aff. miozea	x	x	x	x	x
Orbulina universa	x	x	x	x	x

The Hinakura Coral Thicket lies well above the base
of a thick massive blue-grey mudstone (fig. 1) and is
near the middle of the Upper Miocene which at Hinakura
is about 1,200 meters thick. All five samples from in
and near the thicket appear to be about the same age and
give no evidence of a significant time break at the dis-
conformity immediately below the thicket. The presence of
Bolivinita aff. quadrilatera and Bolivina albatrossi,
and the absence of Upper Tongaporutuan species such as
Haeuslerella pliocenica (Finlay), Bolivinita compressa
Finlay, Bolivina barnwelli Finlay, indicate a Middle
Tongaporutuan age (middle Upper Miocene).

The very high percentage of planktonic Foraminifera
indicates the eupelagic environment. In the late Tertiary
of Wairarapa more than 60% of planktonic shells is
considered to indicate depths greater than 1,200 meters
(Vella, 1962a, 1962b), but percentage of planktonic shells
is not accepted by all micropaleontologists as a reliable
indication of depth of deposition.

Depth distributions of present day benthonic
Foraminifera in New Zealand are not known, and depths
indicated by fossil benthonic biofacies must be judged
from their position within the relative scale of late
Tertiary biofacies (Vella, 1962a, 1962b), and by com-
parison with present day foraminiferal faunas described
from elsewhere in the world.

The biofacies of the mudstones probably represents
a greater depth than any ~~any~~ sample previously examined
by the writer. It includes five species which are not
found in previously recognised biofacies - Bulimina
truncanella, Miniuva minima, Euuvigerina notohispida,
Melonis pompilioides, and Osangularia bengalensis. Two
other species, Norcottia mioindex and Melonis lutörum,
are abundant and persistent in the Hinakura mudstone, but
are rare and sporadic in semipelagic biofacies, and absent
from all shallower biofacies. On the other hand, two im-
portant genera, Nonionella and Notorotalia, are not repre-
sented in the Hinakura mudstones. Notorotalia taranakia
Vella is a dominant species in semipelagic biofacies of
late Miocene and early Pliocene age, and other species of
Notorotalia are dominant in shallower biofacies. Nonionella
is common in upper bathyal biofacies and becomes less
common in the deeper-water semipelagic biofacies.
Karreriella cylindrica (or cushmani) is a dominant species
in deep neritic to semipelagic biofacies, but is sporadic
and subsidiary in the Hinakura mudstones. The biofacies
of the thicket is somewhat different from that of the
surrounding mudstones, but it includes essentially the
same assemblage of key depth species, and probably
lived at a similar depth.

In the sequence of late Tertiary depth biofacies the
greatest reliable depth is at the upper limit of the

semipelagic biofacies, and is determined from associated
Mollusca to be about 600 meters. The upper limit of the
eupelagic biofacies is assumed to be considerably deeper,
perhaps as much as 1,200 meters.

In present day faunas off the coast of California
Natland (1957) distinguished seven depth-temperature
biofacies. The Hinakura faunas have diagnostic species
in common with Natland's deepest faunas, biofacies 6
and 7. The diagnostic species of biofacies 6 at California
are <u>Bulimina rostrata</u>, <u>Uvigerina senticosa</u>, <u>Pullenia</u>
<u>bulloides</u>, and <u>Melonis pompilioides</u> (= <u>Nonion pompili-
oides</u>). The only diagnostic species of biofacies 7 is
<u>Osangularia bengalensis</u>. The Hinakura include <u>Bulimina</u>
truncanella (closely related to <u>Bulimina rostrata</u>),
<u>Melonis pompilioides</u>, <u>Pullenia bulloides</u>, and <u>Osangularia</u>
<u>bengalensis</u>, and would appear to represent a depth
approximately at the boundary between Natland's biofacies
6 and 7. This boundary is defined by the $2^{o}C$ isotherm,
and is at a depth of about 2,000 meters off California,
though it shallows to the north.

Neritic fossils from elsewhere in New Zealand, and
planktonic Foraminifera, indicate that the climate at
sea level in New Zealand during late Miocene time was
sub-tropical, and the surface water temperature would
have been not less than that off California at the present
day. The depth of the 2° isotherm was probably related

to the ~~semipelagic~~ temperature, and assuming a similar
                surface water

vertical temperature gradient, was probably not less or

little less than it is off California at present.

Possible additional evidence for cold temperature are

Lagena meridionalis, Pullenia subcarinata, and the

primitive arenaceous forms, which are common in present

day Antarctic faunas. Additional evidence for the depth

is Quinqueloculina venusta which occurs only between

1,500 and 2,500 meters in the northeastern Gulf of Mexico

(Parker, 1954).

The three independent lines of evidence - percentage

of planktonic shells, the relative depth sequence of

fossil biofacies, and the analogy with present day

faunas - all indicate that the Hinakura mudstones

and coral thicket originated in deep water. Though

each line of evidence is somewhat uncertain by itself,

the agreement of all three makes the conclusion almost

certain, and it is reasonable to accept that the water

temperature was near 2° and the water depth was between

say 1,500 and 2,500 meters. The inferred temperature

is considerably lower than the 6° to 10° considered

likely for coral thickets by Squires (1963), but the

minimum temperature tolerance of present day Lophelia

(the sole coral genus identified in the Wairarapa

fossil thickets) is given as 2.5^o by Squires (1963,

table 3).

Differences between Thicket Fauna and
Mudstone Faunas

The samples from the thicket gave 83 species of benthonic Foraminifera, and those from the mudstones gave 79 species. Of these species, 28 are restricted to the thicket, and 24 are restricted to the mudstones. A Pelecypod, probably a large Nucula, and a fragment of a moderately large Gastropod were found in the thicket, and unidentifiable remains of a number of Mollusca, a number of broken echinoid spines, and well-preserved shells of several species of Ostracoda, were found in the microsamples from the thicket. Only extremely rare Turrid Gastropods were found in the mudstones, and no molluscan remains, rare echinoid spines, and one species of Ostracode were found in the microsamples from the mudstones. The thicket thus contains a distinctive biofacies somewhat richer in species of Foraminifera, Mollusca, Ostracoda, and possibly also Echinodermata, than the biofacies of the surrounding mudstones.

All samples were approximately the same size, and those from the thicket contain many times more specimens of Foraminifera than those from the mudstones. This indicates a difference in the relative proportions of fossils and clastic sediment, and is considered to be related to the disconformity at the base of the thicket.

Coral began to grow shortly after the disconformity
was formed, the thicket grew up while the rate of
deposition of clastic sediment was still relatively
low, and was finally smothered when the rate of depos-
ition of clastic sediment increased again.

Lake Ferry Coral Thicket

Four microsamples were collected, and like those
from the Hinakura thicket, were given a single locality
number and distinguished by suffixed letters. Samples
N165f491a, b, and d were taken in vertical line near the
middle of the thicket. Details of the sample positions
(fig. 3B) are as follows: a: mudstone 30 centimeters
below base of thicket; b: thicket 20 centimeters above
base; c: Nemocardium shell bed 17 meters to south-east
of thicket, on same disconformity; d: mudstone 2 meters
above top of thicket. The four samples yielded a total
of 49 benthonic species and 6 planktonic species of
Foraminifera (table 2).

Macrofossils were collected from abovexxand the mud-
stones above and below the thicket, and from the
thicket itself. Those in the mudstone are scattered
sparsely, and the species appear to be, in the main,

randomly distributed; in order to obtain representative samples, collections were made from considerable thicknesses below and above the thicket. The macrofossils in the thicket are chalky and difficult to extract, and the list of species given below is likely to be incomplete. The macrofossil samples were given the same locality number as the microsamples, and are distinguished by a different series of suffixed letters. Details of the macrofossil sample horizons are as follows: x: mudstone 2 to 30 meters below coral thicket; y; within coral thicket; z: mudstone 2 to 30 meters above coral thicket. The three samples gave a total of 27 species (table 3).

_____ _____

Table 2 goes here, followed immediately by table 3.

Table 2

Foraminifera Associated with Lake Ferry Coral
Thicket

Samples: a: mudstone below thicket; b: thicket;
c: Nemocardium shell bed; d: mudstone above thicket.

Benthonic Species:

	Samples:			
1. restricted to thicket	a	b	c	d
Angulogerina sp.		r		
Biloculina sp.		r		
Bolivina decussata		f		
Dyocibicides biserialis		c		
Gyroidinoides sp. indet.		r		
Hofkeruva cf. tenuistriata		f		
Lenticulina variabilis		f		
Oolina caudigera		f		
Parafrondicularia pellucida		r		
Quinqueloculina aff. delicatula		f		
Quinqueloculina sigmoilinoides		c		
Stilostomella sp. indet.		f		
Textularia sp.		r		
2. common to thicket and mudstones				
Anomalinoides parvumbilia	c	f	f	c
Anomalinoides cf. spherica	c	c	f	f

Table 2 - continued

	a	b	c	d
Bolivina subspinescens	-	f	f	f
Bolivina sp. (minute)	f	f	-	a
Bolivinita pliobliqua	a	a	a	a
Bulimina aculeata	c	f	a	a
Cassidulina neocarinata	f	c	a	a
Cassidulina subglobosa	..	f	f	f
Cassidulinoides orientalis	f	f	c	f
Cibicides deliquatus	c	c	c	c
Elphidium charlottensis	c	f	c	c
Epistomina elegans	-	c	-	f
Eponides tenera	f	f	f	f
Florilus flemingi	f	f	f	f
Globobulimina pacifica	c	f	f	f
Haeuslerella parri	a	a	a	a
Laminiuva tutamoides	a	a	a	a
Marginulina sp.	-	f	f	-
Notorotalia finlayi	c	c	a	a
Notorotalia kingmai	a	c	f	-
Pacinonion cf. parki	c	c	c	a
Pullenia quinqueloba	c	f	f	f
Pyrulina sp.	f	f	f	f
Robulus sp.	-	r	-	f
Siphonaperta macbeathi	-	c	f	-
Siphotextularia wairoana	f	f	c	f

Table **2** - continued

	a	b	c	d
Sphaeroidina bulloides	f	f	f	c
Trigonouva aff. pliozea	f	f	f	?

3. restricted to mudstones and
      Nemocardium shell bed.

	a	b	c	d
Chilostomella ovoides	r		-	-
Epistominella sp.	-		f	f
Fissurina clathrata	-		-	f
Lagena striata	f		-	-
Nonionella magnalingua	-		-	c
Notorotalia mangaoparia	-		-	f
Oolina costata	r		-	-
Virgulina schreibersiana	f		-	f

Planktonic Species:

	a	b	c	d
Globigerina bulloides	x	x	x	x
Globigerina cf. dubia	-	-	-	x
Globigerinita sp.	x	-	-	-
Globigerinoides rubra	x	x	x	-
Globorotalia inflata	x	x	x	x
Orbulina universa	-	-	-	x

Table 3

Macrofossils Associated with
Lake Ferry Coral Thicket

Collections:- x; mudstone below thicket; y, thicket; z, mudstone above thicket.

Samples:

	x	y	z
1. restricted to thicket.			
Pelecypoda			
Ctenoides sp.	x		
Lima sp.	x		
Ostrea sinuata (small)	x		
Gastropoda			
Murexsul cf. espinosus	x		
Brachiopoda			
Tegulorhynchia nigricans	x		
2. common to thicket and mudstones.			
Pelecypoda			
Chlamys cf. delicatula	x	x	-
Chlamys gemmulata	?	x	-
Nemocardium pulchellum	x	x	x
Pleuromeris cf. zelandica	-	x	x
Gastropoda			
Alcithoe aff. subgracilis	x	x	x

Table 3 - comtinued

	x	y	z
Baryspira novaezelandiae	x	x	x
Comitas onokeana	x	x	x
Scaphopoda			
Dentalium nanum	x	x	x

3. restricted to mudstones

Pelecypoda

Marama murdochi	x	-	x
Nucula sp.	-	-	x

Gastropoda

Austrofusus sp.	x	-	-
Baryspira cf. mucronata	x	-	-
Cominula hamiltoni	x	-	x
Ellicea carinata	x	-	x
Iredalina finlayi	x	-	x
Micantapex cf. murdochi	-	-	x
Pelicaria mangaoparia	-	-	x
Poirieria zelandica	-	-	x
Proxiuber sp.	x	-	-
Stiracolpus cf. symmetricus	-	-	x
Zemitrella sp.	x	-	-
Zephos onokeana	x	-	x

About 150 meters stratigraphically above the Lake
Ferry Coral Thicket the Mollusca Pelicaria rugosa and
Chlamys delicatula (in abundance) mark the Rugosa Zone
which is considered to be the lowest division of the
Pleistocene in Wairarapa (Vella, 1953, 1963). The mud-
stone between the coral thicket and the base of the
Rugosa Zone contains Pelicaria mangaoparia which indicates
the Mangaoparia Zone, and also contains the Foraminifer
Notorotalia mangaoparia which ranges through the Mangao-
paria and Rugosa Zones. The mudstone below the coral
thicket contains no Pelicaria, and instead of Notorotalia
mangaoparia has Notorotalia kingmai which is restricted
to the Waitotaran Stage in Wairarapa. Notorotalia finlayi
which is also present indicates that the lower mudstone
is not older than Waitotaran.

As the Mangaoparia Zone represents the upper part
of the Waitotaran Stage the mudstone overlying the
thicket is late Waitotaran in age and the mudstone under-
lying the thicket is probably early Waitotaran in age.
The Waitotaran Stage is generally considered to be
upper Pliocene.

The coral thicket contains Notorotalia kingmai but
neither N. mangaoparia nor any Pelicaria, but it is
separated from the lower mudstone by disconformity, and
the sediment in which it is enclosed grades up to the
overlying mudstone. The thicket is therefore regarded as

part of the Mangaoparia Zone, and late Waitotaran in age.

Two of the Mollusca, Chlamys delicatula which is represented by slightly atypical specimens in and below the thicket, and Murexsul espinosus which is represented by a slightly atypical specimen from the thicket, are considered to be restricted to the lower Pleistocene elsewhere in Wairarapa. Chlamys delicatula is a cool water species that migrated northward at the end of Plio- cene time, and occupied seas covering much of the southern part of the North Island of New Zealand during early Pleistocene time (Fleming, 1944). It is considered to range down to the Waitotaran Stage in the northern part of the South Island (Fleming, in Fleming ed., 1959), and its occurrence at Lake Ferry Coral Thicket probably represemts about the northernmost limit of its range in Waitotaran time. Murexsul espinosus is assumed to be a cool water species for it normally accompanies Chlamys delicatula in early Pleistocene faunas.

Environment of Thicket

Lithological changes suggest that the Lake Ferry thicket formed during a temporary shallowing of the sea, but the paleontological evidence for this is uncertain. The environment in which the thicket grew is difficult to assess because it is not known to what extent species

in the thicket were controlled by ecological conditions
peculiar to the thicket and not by depth. The mudstones
are more like other Tertiary sediments, representing
more normal conditions, and their depth of deposition
can be determined with more certainty.

The mud stone overlying the thicket has almost the
same microfauna and macrofauna as the mudstone under-
lying the thicket, and the depth of deposition was about
the same for both mudstone units. The low percentage
of planktonic Foraminifera suggests a neritic environment.
Among the benthonic Foraminifera, the occurrence of
Haeuslerella parri, large Notorotalia, Elphidium
charlottensis, and Anomalinoides cf. spherica, and the
absence of shallow neritic forms such as Elphidiononion,
Zeaflorilus, Bolivinita pliozea, and large species of
Elphidium, indicate the Haeuslerella Biofacies (Vella,
1962a, 1962b) the inferred depth range of which is from
slightly over 100 meters to about 300 meters. Four of
the Mollusca, Ellicea, Iredalina, Comitas, and Micantapex,
which are closely related to present day archibenthal
species, were considered by Dell (1956) to indicate
depths probably between 300 and 600 meters. The first
three are common in both mudstone units; the Micantapex
is restricted to the overlying mudstone, but this may
well be due to age difference in age of the two mudstones.

The Mollusca in the mudstones thus suggest somewhat
greater depths than do the Foraminifera, but both
fossil groups are compatible with a depth of about
300 meters.

Turning now from the mudstones to the thicket itself,
the Mollusca from within the thicket give little indica-
tion of water depth. The small size of the specimens of
Chlamys cf. delicatula and Ostrea indicates conditions
far from optimum for these species and obviates their
use as depth indicatess. Some of the restricted species
of Foraminifera, chiefly the Miliolidae, suggest that
the thicket was formed in somewhat shallower water than
the mudstone, but it is not known whether these species
are controlled by depth or by type of sea-bottom.

The best indication of the depth at which the coral
thicket formed is given by the Nemocardium shell bed at
the same horizon to the south-east of the thicket.
Nemocardium pulchellum is a present day Pelecypod with
a bathymetric range from 1 to 600 meters (Dell, 1956)
and occurs in facies ranging from shallow neritic to
upper bathyal in the Pliocene and Pleistocene. As a fossil
in shallow-water shell beds it is generally only a minor
constituent of a large fauna; in bathyal sandy mudstones
at many places it is the dominant macrofossil, and
usually forms nests either by itself or with the
Gastropod Stiracolpus, and sometimes with infrequent

specimens of another Pelecypod, _Marama murdochi_. The

bed and the coral thicket, suggests a depth of deposition less than that of the mudstones. There is but little paleontological evidence that the thicket was formed during a temporary shallowing of the sea, and the depth probably was at no, less than about 250 meters.

The Pelecypod Chlamys delicatula in the thicket and underlying mudstone, and probably the Gastropods Stiracolpus aff. symmetricus and Zephos onokeana in both mudstone units, indicate cool temperatures (Fleming, 1944). The lack of genera with subtropical affinities, especially Polinices, Olivella, and Typhis (Neotyphis), that are characteristic of Waitotaran faunas as little as 50 miles to the north-east of Lake Ferry, indicates that the water temperature was lower than the normal shallow water temperature of Waitotaran times. The benthonic Foraminifera give no indication of temperature. The assemblage of planktonic Foraminifera is about the same as that which now lives in the adjacent Cook Strait, and the lack of Globorotalia of the miozea line, which occurs in the Waitotaran at some places, may indicate that the surface water itself at Lake Ferry was colder than normal for Waitotaran times.

Differences Between the Thicket
Fauna and Associated Faunas

The benthonic foraminiferal assemblages in the four
samples examined are rather uniform. The coral thicket
gave the richest fauna with 41 species. The mudstones
together gave 36 species, nearly all of which occur in
the thicket, and the Nemocardium shell bed gave only 26
species all of which occur in the thicket. The relative
paucity of species in the shell bed gives an indi-
cation of the number of species that depended on the
thicket, and hence of the powerful ecological effect
of the thicket.

The macrofauna of the thicket is markedly different
from that of the mudstone, and includes a large proportion
of attached forms, also one free-swimming Pelecypod
(Lima) which do not occur in the mudstones. In each of
the mudstone units 16 species were found, whereas in
the thicket only 13 were found, but these figures are
not strictly comparable. The species in the thicket
were recorded from only one or two square meters of
exposure, were difficult to discern amongst the coral
branches, and are poorly preserved, and they are
probably not fully representative. Those from the two
mudstone units on the other hand, were recorded from
some hundreds of square meters of exposure, were easy

to discern as white shells in blue-grey sediment, and were fairly well preserved, and probably are nearly fully representative. Excepting nests of Nemocardium, and more rarely of Stiracolpus, the Mollusca of the mudstone are sparsely scattered, and must have lived at a concentration of one per several square meters of sea bottom. The concentration of Mollusca in the thicket was probably several orders higher.

As at Hinakura, the coral commenced to grow after erosion had formed a firm bottom, and before deposition recommenced, continued to grow while deposition was relatively slow, and was finally smothered when deposition speeded up.(Squires, 1963, p.00).

Conclusions

The Hinakura Coral Thicket was built up immediately after a brief interval of erosion and during a temporary phase of slow deposition, in late Miocene time. The Foraminifera suggest that the sea depth was between 1,500 and 2,500 meters, and the temperature was about 2°C. The temperature at sea level was subtropical. The events which caused erosion and slow deposition are not known. Differences between the fauna in the thicket and that in the surrounding mudstones are probably almost

entirely due to the special habitat created by the thicket.

The Lake Ferry Coral Thicket was similarly built immediately after a brief interval of erosion, and during a phase of slow deposition of sand and probably by-passing of mud, in late Pliocene time. From Foraminifera and Mollusca the sea depth is considered to have been much shallower than that inferred for the Hinakura thicket, probably between 200 and 300 meters. The water temperature is uncertain, but was relatively low. The events which caused erosion and slow deposition may have been changes of climate above sea level, and eustatic changes of sea level. Differences between the fauna in the thicket and that in the surrounding sediments are certainly largely due to the special habitat created by the thicket, but may be in part due to slight shallowing of the sea immediately before the thicket commenced to grow.

At each locality more detailed sampling is required to determine possible variations of the microfauna from one part of the thicket to another, and in the clastic sediment laterally from the thicket. The Ostracoda, though not numerous, should be examined critically. Ecological studies of present day organisms in New Zealand seas,

with particular reference to depth and temperature
tolerances, will be needed to make a more satisfactory
assessment of the physical environment of each thicket.

Acknowledgements

Check List of Species.

All the species named in tables 1, 2, and 3 are
listed in alphabetic order of genera. Each generic name
is followed by its author's name, date, and family.
Each species with author's name in parentheses is followed
by the generic name under which it was originally de-
scribed.

Foraminifera:

Amphicoryne Schlumberger 1881, Lagenidae

    scalaris (Batsch) Nautilus 1791.

Anomalinoides Brotzen, 1942, Anomalinidae

    parvumbilia (Finlay) Anomalina 1940

    spherica (Finlay) Anomalina 1940

Awhea Vella 1963, Lagenidae

    sinalata (Finlay) Nodosaria 1940

Bolivina d'Orbigny 1839, Virgulinidae

    affiliata Finlay 1939

    albatrossi Cushman 1922

    decussata Brady 1881

    subspinescens Cushman 1922

    pacifica Cushman and McCulloch 1942

Bolivinita Cushman 1927, Heterohelicidae

    pliobliqua Vella 1963

    quadrilatera (Schwager) Textilaria 1866

Bolivinopsis Yakovlev 1891, Textulariidae?

    cubensis (Cushman and Bermudez) **Spiroplectoides** 1937

Bulimina d'Orbigny 1826, Buliminidae

    aculeata d'Orbigny 1826

    notovata Chapman 1941

    senta Finlay 1940

    striata d'Orbigny 1843

    truncanella Finlay 1940

Cassidulina d'Orbigny 1826, Cassidulinidae

    neocarinata Thalmann 1950

    subglobosa Brady 1881

Cassidulinoides Cushman 1927, Cassidulinidae

    orientalis (Cushman) **Cassidulina** 1922

Chilostomella Reuss 1850, Chilostomellidae

    ovoidea Reuss 1850

Chrysalogonium Schubert 1907, Lagenidae

    verticale (Stache) **Dentalina** 1865

Cibicides Montfort 1808, Anomalinidae

    bradyi (Trauth) **Truncatulina** 1918

    deliquatus Finlay 1940

    novozelandicus (Karrer) **Rotalia** 1865

Dentalina d'Orbigny 1826, Lagenidae

    consobrina d'Orbigny 1846

    soluta Reuss 1851

    substrigata (Stache) **Nodosaria** 1865

Dyocibicides Cushman and Valentine 1930, Anomalinidae

   biserialis Cushman and Valentine 1930

Ellipsoglandulina Silvestri 1900, Ellipsoidinidae

   subconica (Kreuzberg) Nodosaria 1930

Elphidium Montfort 1808, Elphidiidae

   charlottensis (Vella) Elphidiononion 1957

Eponides Montfort 1808, Discorbiidae

   punctulatus (d'Orbigny) Rotalia 1826

   tenerus (Brady) Truncatulina 1884

Epistomina Terquem 1883, Epistominidae

   elegans (d'Orbigny) Rotalia 1826

Euuvigerina Thalmann 1952, Uvigerinidae

   notohispida (Finlay) Hopkinsina 1939

Fissurina Reuss 1850, Lagenidae

   orbignyana Seguenza 1862

   clathrata (Brady) Lagena 1884

Florilus Montfort 1808, Nonionidae

   flemingi (Vella) Nonion 1957

Glandulina d'Orbigny 1826, Polymorphinidae

   symmetrica Stache 1865

Globigerina d'Orbigny 1826, Orbulinidae

   bulloides d'Orbigny 1826

   dubia Egger 1857

   euapertura Jenkins 1960

   nepenthes Todd 1957

subcretacea Lomnicki 1901.

Globigerinoides Cushman 1927, Orbulinidae

    rubra (d'Orbigny) Globigerina 1839

    triloba (Reuss) Globigerina 1850

Globobulimina Cushman 1927, Buliminidae

    pacifica Cushman 1927

Globorotalia Cushman 1927, Globorotaliidae

    canariensis (d'Orbigny) Rotalina 1839

    inflata (d'Orbigny) Globigerina 1839

    menardii (d'Orbigny) Rotalia 1826

    miozea Finlay 1939

Gyroidina d'Orbigny 1826, Discorbiidae

    prominula (Stache) Rotalia 1865

Gyroidinoides Brotzen 1942, Discorbiidae

    neosoldanii (Brotzen) Gyroidina 1936

Haeuslerella Parr 1935, Textulariidae

    finlayi Vella 1963

    morgani (Chapman) Spiroplecta 1926

    parri Finlay 1939

Hofkeruva Vella 1961, Uvigerinidae

    tenuistriata (Reuss) Uvigerina 1870

Karreriella Cushman 1933, Valvulinidae

    bradyi (Cushman) Gaudryina 1911

    cushmani Finlay 1940

    Cylindrica Finlay 1940

Lagena Walker and Jacob 1798, Lagenidae

    meridionalis Wiesner 1931

    striata (d'Orbigny) Oolina 1839

Laminiuva Vella 1961, Uvigerinidae

    tutamoides Vella 1963

    zealamina Vella 1961

Laticarinina Galloway and Wissler 1927, Discorbiidae

    halophora (Stache) Cristellaria 1865

Lenticulina Lamarck 1804, Lagenidae

    variabilis (Reuss) Cristellaria 1850

Massilina Schlumberger 1893, Miliolidae

    subaequalis (Parr) Spiroloculina 1935

Melonis Montfort 1808, Nonionidae

    lutorum Vella 1962

    pompilioides (Fichtel and Moll) Nautilus 1798

Miniuva Vella 1961, Uvigerinidae

    minima Vella 1961

Neouvigerina Thalmann 1952, Uvigerinidae

    bellula Vella 1963

    vadescens (Cushman) Uvigerina 1933

Nodosaria Lamarck 1812, Lagenidae

    filiformis d'Orbigny 1826

    hochstetteri Schwager 1866

    holoserica Schwager 1866

    longiscata d'Orbigny 1846

Nonionella Cushman 1926, Nonionidae

   magnalingua Finlay 1940

Norcottia Vella 1961, Uvigerinidae

   mioindex (Finlay) Hopkinsina 1947

Notorotalia Finlay 1939, Rotaliidae

   finlayi Vella 1957

   kingmai Vella 1957

   mangaoparia Vella 1957

Oolina d'Orbigny 1839, Lagenidae

   caudigera (Wiesner) Lagena 1931

   costata (Williamson) Entosolenia 1858

   globosa (Montagu) Vermiculum 1803

   hexagona (Williamson) Entosolenia 1848

   melo d'Orbigny 1839

Orbulina d'Orbigny 1839, Orbulinidae

   universa d'Orbigny 1839

Osangularia Brotzen 1940, Discorbiidae

   bengalensis (Schwager) Anomalina 1866

Pacinonion Vella 1962, Nonionidae

   neefi Vella 1962

   parki (Hornibrook) Astrononion 1961

Parafrondicularia Asano 1938, Lagenidae

   pellucida (Finlay) Plectofrondicularia 1939

   wairarapa Vella 1963

Plectofrondicularia Liebus 1903, Heterohelicidae

   pohana Finlay 1939

Planulina d'Orbigny 1826, Anomalinidae

    wüllerstorfi (Schwager) Anomalina 1866

Plectofrondicularia Liebus 1903, Heterohelicidae

    pohana Finlay 1939

Pleurostomella Reuss 1860, Ellipsoidinidae

    alternans Schwager 1866

    brevis Schwager 1866

Proxifrons Vella 1963, Lagenidae.

    advena (Cushman) Frondicularia 1923

    vaughani (Cushman) Plectofrondicularia

Psammosphaera Schulze 1875, Saccamminidae

    fusca Schulze 1875

Pullenia Parker and Jones 1862, Chilostomellidae

    bulloides (d'Orbigny) Nonionina 1826

    quinqueloba (Reuss) Nonionina 1851

    subcarinata (d'Orbigny) Nonionina 1839

Pyrgo Defrance 1824, Miliolidae

    murrhina (Schwager) Biloculina 1866

Quinqueloculina d'Orbigny 1826, Miliolidae

    delicatula Vella 1957

    sigmoilinoides Vella 1957

    venusta Karrer 1868

Robulus Montfort 1808, Lagenidae

    iotus (Cushman) Cristellaria 1923

Sigmoilina Schlumberger 1887, Miliolidae

    tenuis (Czjzek) Quinqueloculina 1848

Sigmoilopsis Finlay 1947, Miliolidae

    schlumbergeri (Silvestri) Sigmoilina 1904

Siphonaperta Vella 1957, Miliolidae

    macbeathi Vella 1957

Siphotextularia Finaly 1939, Textulariidae

    ihungia Finlay 1940

    wairoana Finlay 1939

Sphaeroidina d'Orbigny 1826, Chilostomellidae

    bulloides d'Orbigny 1826

Stilostomella Guppy 1894, Lagenidae

    dentaliniformis (Cushman and Jarvis) Ellipsonodosaria 1934

Tereuva Vella 1961, Uvigerinidae

    lutorum Vella 1963

Trigonouva Vella 1961, Uvigerinidae

    pliozea Vella 1963

    zeacuminata Vella 1961

Virgulina d'Orbigny 1826, Virgulinidae

    rotundata Parr 1950

    schreibersiana Czjzek 1848

Mollusca

Pelecypoda

Chlamys Roeding 1798, Pectinidae

   gemmulata (Reeve) Pecten 1853

(Zygochlamys) Ihering 1907

   delicatula (Hutton) Pecten 1873

Marama Marwick 1927, Veneridae

   murdochi Marwick 1927

Nemocardium Meek 1876, Cardiidae

(Pratulum) Iredale 1924

x pulchellum (Gray) Cardium 1843

Ostrea Linné 1758, Ostreidae

   sinuata Lamarck 1819

Pleuromeris Conrad 1867, Carditidae

   zelandica (Deshayes) Cardita 1854

Gastropoda

Alcithoe H.& A. Adams 1853, Volutidae

   subgracilis Marwick 1926

Baryspira Fischer 1883, Olividae

   novaezelandiae (Sowerby) Ancillaria 1859

   mucronata (Sowerby) Ancillaria 1830

Comitas Finlay 1926, Turridae

   onokeana King 1933

Cominula Finlay 1926, Cominellidae

(Procominula) Finlay 1926

    hamiltoni (Hutton) Clathurella 1885

Ellicea Finlay 1928, Buccinulidae

    carinata Powell 1929

Iredalina Finlay 1926, Volutidae

    finlayi King 1933

Micantapex Iredale 1936, Turridae

    murdochi (Finlay) Bathytoma 1930

Murexsul Iredale 1915, Muricidae

    espinosus (Hutton) Murex 1886

Pelicaria Gray 1857, Struthiolariidae

    mangaoparia Vella 1953

Poirieria Jousseaume 1879, Muricidae

    zelandica (Quoy and Gaimard) Murex 1833

Stiracolpus Finlay 1927, Turritellidae

    symmetricus (Hutton) Turritella 1873

Zephos Finlay 1926, Cominellidae

    onokeana King 1933

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