THE AGE AND PALEOENVIRONMENT OF THE PAKAURANGI FORMATION, WAITAKERE GROUP, NORTHLAND, NEW ZEALAND, BASED ON OSTRACODA

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ABSTRACT

The Early Miocene Pakaurangi Formation, Waitakere Group, have a high diversity of Ostracoda. Key species include *Loxoconcha propunctata*, *Bradleya semiarata*, *Bradleya lactea pakaurangia*, *Hemycythere tarakohensis* and *Bairdia canterburyensis,* and indicate an Altonian age, completely in agreement with foraminiferal ages from this area by other workers.

The species *Trachyleberis zeacristata* Hornibrook is transferred to *Henryhowella. Paijenborchella iocosa* Kingma, and many generic level taxa were also found in a borehole in Bojonegoro, East Jawa, Indonesia.

The previously recorded Clifdenian to Waitotaran range of *Henryhowella probesioides* Hornibrook is extended downwards into the *Altonian*. The Ostracoda also show the paleoenvironment of the Pakaurangi Formation to be littoral to neritic, which is also in agreement with the evidence of foraminifera and molluscs as reported by previous workers.

Keywords: Ostracoda, Pakaurangi Formation, Waitakere Group, Altonian, New Zealand

SARI

Fosil Ostrakoda dari Miosen Awal Formasi Pakaurangi, Kelompok Waitakere sangat beraneka. Fosil penunjuk yang dapat dikenali dari formasi ini antara lain *Loxoconcha propunctata, Bradleya semiarata, Bradleya lactea pakaurangia, Hemycythere tarakohensis* dan *Bairdia canterburyensis*, menunjukkan umur Altonian, sesuai dengan kandungan foraminifera dari daerah yang sama oleh penulis-penulis terdahulu.

Jenis *Trachyleberis zeacristata* Hornibrook disebut sebagai *Henryhowella zeacristata* (Hornibrook). Jenis *Paijenborchella iocosa* Kingma dan tingkat marga juga banyak ditemukan dari inti bor di Bojonegoro, Jawa Timur, Indonesia.

Dahulu kisaran umur *Henryhowella probesioides* Hornibrook yang bebelumnya tercatat dari *Clifdenian* sampai *Waitotaran* diperpanjang ke bawah sampai *Altonian*. Fosil-fosil Ostrakoda menunjukkan lingkungan pengendapan Formasi Pakaurangi antara litoral sampai neritik, yang juga sesuai dengan bukti fosil foraminifera dan moluska oleh penulis-penulis terdahulu.

Kata kunci: Ostrakoda, Kelompok Waitakere, Formasi Pakaurangi, Altonian, Selandia Baru

INTRODUCTION

The study of Ostracoda in Indonesia is still very scarce since McKenzie and Sudijono (1981) described Ostracoda from Sangiran, Central Jawa. Kingma (1948) studied the Ostracoda from a borehole in Bojonegoro, East Jawa, a hopefully of value for age dating by Ostracoda and for regional correlation in future studies.

This study deals with Ostracoda from the northern part of the Waitemata Basin, North Island, New Zealand. The study area and regional setting are shown in Figure 1.

Core samples lodged in the Geology Department of the Auckland University after sampled from bore holes drilled in Tapora Flats, Okahukura Peninsula, Kaipara Harbour by Ministry of Works in 1965 (see locality map and geology of the area, Figure 2). The samples were made available by Dr. G.W. Gibson for this study in the Geology Department, University of Auckland.

Aims

The aims of the study are:

1. to describe or to identify the ostracod faunas of the Tapora Flats bores, Okahukura Peninsula;
2. to determine the ages of the samples based on ostracod faunas;
3. to identify the paleoenvironment of the samples on the basis of ostracod faunas;

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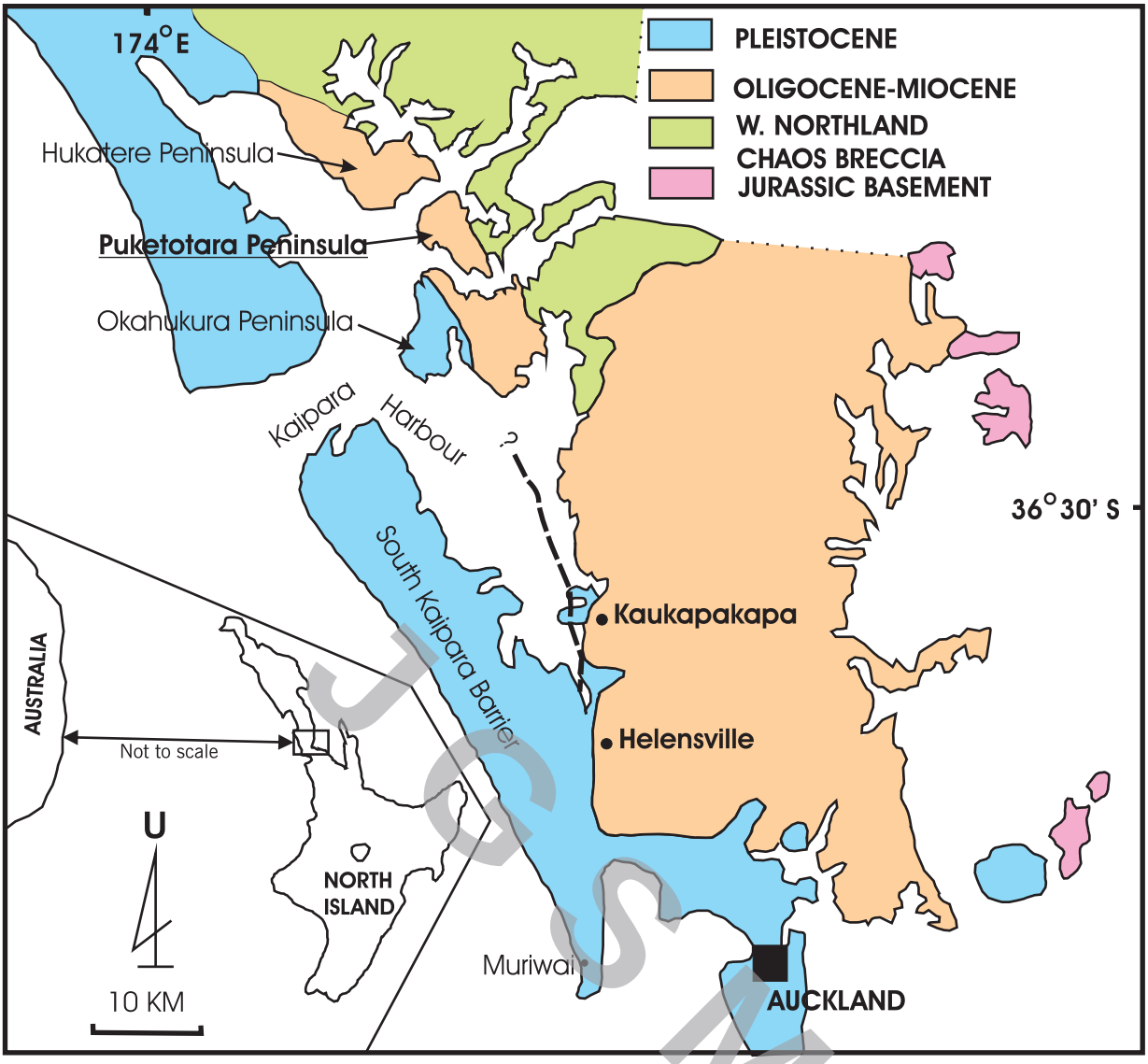


Figure 1. Locality map of study area (Puketotara Peninsula) and regional setting.

Geological setting

The drill holes are located at G.R. (Grid Reference) Q09/266381 on Quaternary sands, on the downthrow side of the major northwest trending Tapora Fault, 1 km west of the escarpment separating Waitakere Group rocks from Quaternary sediments (Ballance and McCarthy, 1975). In the cross section (inset Figure 2), the locality is indicated.

The writers have also studied the drill hole log from the Geological Society of New Zealand Fossil Record Form, which shows the location of the samples and their position in the bore. This is summarized in stratigraphic column I (Figure 3).

The collector (P.F. Ballance) noted that the samples came from Barber's Bay Formation. This formation is equivalent to the Undifferentiated Pakaurangi Formation of Waitakere Group. The age of this formation is Altonian (PI) based on the presence of foraminifera such as *Globigerinoides trilobus trilobus* and *Globorotalia praescitula* from locality Q09/f9568 (Q09/266381).

Previous works

Ferrar (1934) made a general survey of the Dargaville-Rodney Subdivision, which included Okahukura Peninsula. He mapped the Okahukura Peninsula showing the Waitemata Beds (now the Waitemata Group), the Manukau Series (now the Manukau Breccia), the Purua Beds (now Motuoihi Formation) and Pleistocene-Recent sediments which occur on the Tapora Flats.

McCarthy (1972) gave an account of the general geology of Okahukura Peninsula, as a contribution to a more complete geological picture of the Kaipara Harbour. He described in detail the petrography of the Waitemata Group and the Onerahi Chaos-Breccia, determined the nature of the provenance of these rocks and gave a geological history of Okahukura Peninsula.

Ballance and McCarthy (1975) made a detailed study of the geology of the Okahukura Peninsula. They described the petrography and stratigraphic position of the rocks in the Okahukura Peninsula.

Hayward (1975) studied the Early Miocene of the Waitakere Hills, West Auckland including Kaipara Harbour area with emphasis on the paleontology.

Jones (1969, 1970) gave a detailed account of the stratigraphy and structure of Pakaurangi Point, Kaipara, its paleontology and paleoecology.

METHOD

Most of the samples are consolidated rocks, and to obtain Ostracoda from these samples it is necessary to follow washing process as follows:

Method 1: The samples are crushed to pieces 1 to 2 cm in diameter. Each time after crushing the press head and dish equipment have to be cleaned and dipped into methylene blue solution to show up any contamination in the next sample. The surplus blue stain was washed off with thorough rinsing under the tap.

Rock chips from crushing of each sample need drying by placing them into an oven set at 45°C for at least 2 hours to remove pore waters. After cooling for a few minutes the chips have to be covered with 20% by volume of hydrogen peroxide and allowed to stand for up to 30 minutes before wet sieving.

Method 2: Cover the hot rock chips with a hydrocarbon (e.g. petrol, kerosene, etc.) instead of hydrogen peroxide and allow it to stand with lid on for at least one hour in a fume cupboard. Pour the hydrocarbon off for filtering and reuse and cover the chips with water and squeeze with finger before wet sieving. For wet sieving the sieves are of 75 micron aperture and a coarser sieve e.g. 710 or 1680 micron aperture nested above it for protection from coarse fragment and overloading.

The sediments is then washed and put into a pot with a minimum amount of water. Oven-dry the samples. When the sample is dry it is allowed to cool to room temperature. Split it into three size fractions by dry sieving through 150 micron aperture sieve and put into self sealing plastic bags with labeled by catalog number, size fraction etc. The sample is ready to pick.

The specimens of Ostracoda were picked from the samples are as follows:

- Bore Hole 1 from a depth of 47 m is 28 species (± 80 specimens)
- Bore Hole 3 from a depth of 45 m is 35 species (± 140 specimens)
- Bore Hole 3 from a depth of 49 m is 19 species (± 100 specimens)

Following the preparation the faunas are identified and the abundances tabulated (Table 1). This resudue is the basis for later analysis to indicate the age. Table 2 summarizes the paleoecological analysis of the fauna in connection with the environment of the formation.

Photographs in this study were taken under Scanning Electron Microscope (S.E.M.). For this purpose the specimens need to be cleaned for a second time using hydrogen peroxide by dipping them into the solution and brushing carefully. Rinse thoroughly afterwards. Using ultrasonic probe is not adequate for Ostracoda because they have delicate shells. An experiment for only a few second with the ultrasonic probe broke the shell.

Stratigraphy

The rocks of Okahukura Peninsula correlated with the Northland Allochthon, Waitemata Group, Waitakere Group and Quaternary dune and terrace deposits (Ballance and McCarthy, 1975).

The Northland Allochthon was emplaced in the Waitakian Stage (Late Oligocene - Early Miocene). The Waitemata Group here consists of the Timber Bay Formation of Waitakian to Otaian Stages (Late Oligocene to Early Miocene). Rocks of the Waitakere Group on Okahukura Peninsula are divided into three formations: the Okahukura Formation, Pakaurangi Formation and the Motuoihi Formation of Otaian to Altonian age (Early Miocene) (Balance and McCarthy, 1975). The distribution of these formations in the Okahukura Peninsula and their stratigraphic position is shown in Figure 2.

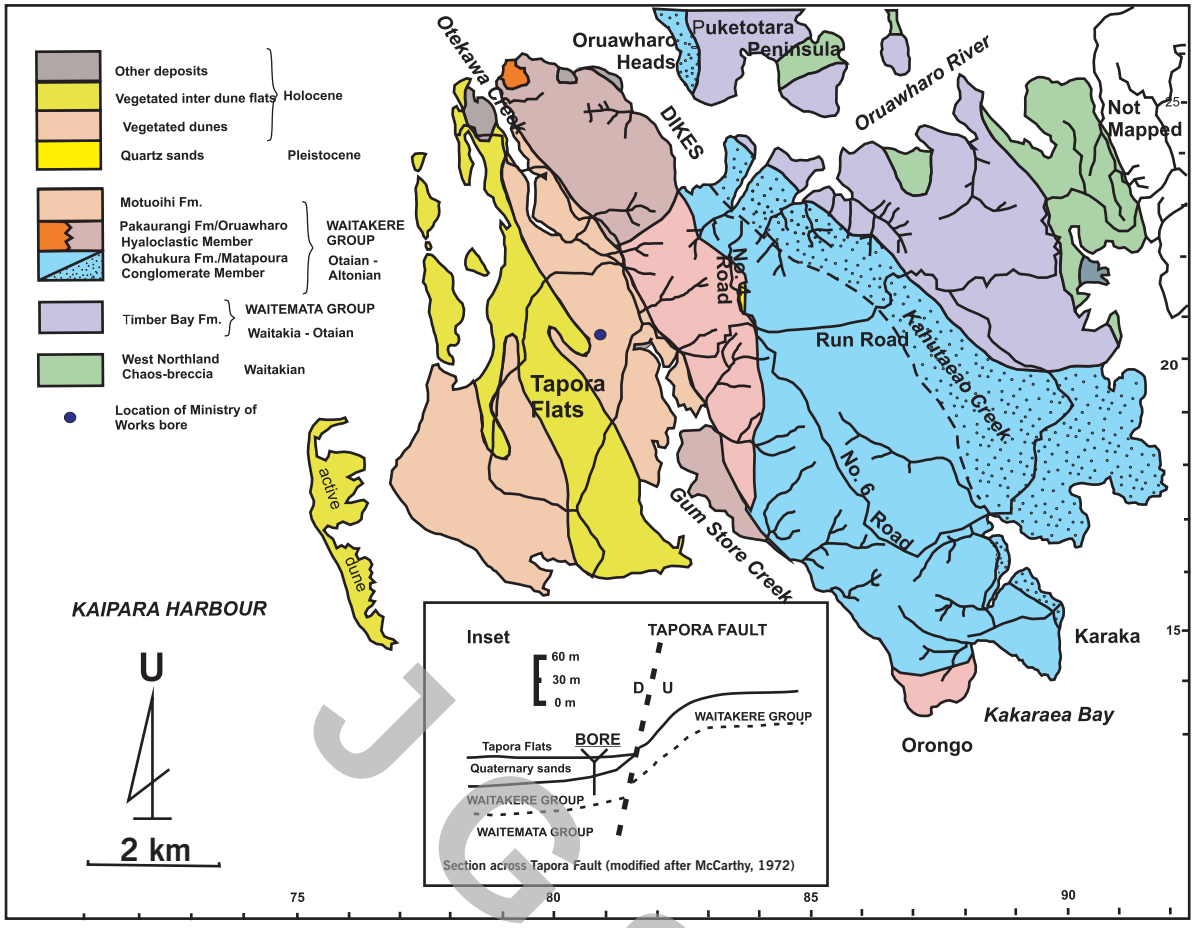


Figure 2. Geological map of Okahukura Peninsula, Kaipara Harbour (after Ballance and McCarthy, 1975).

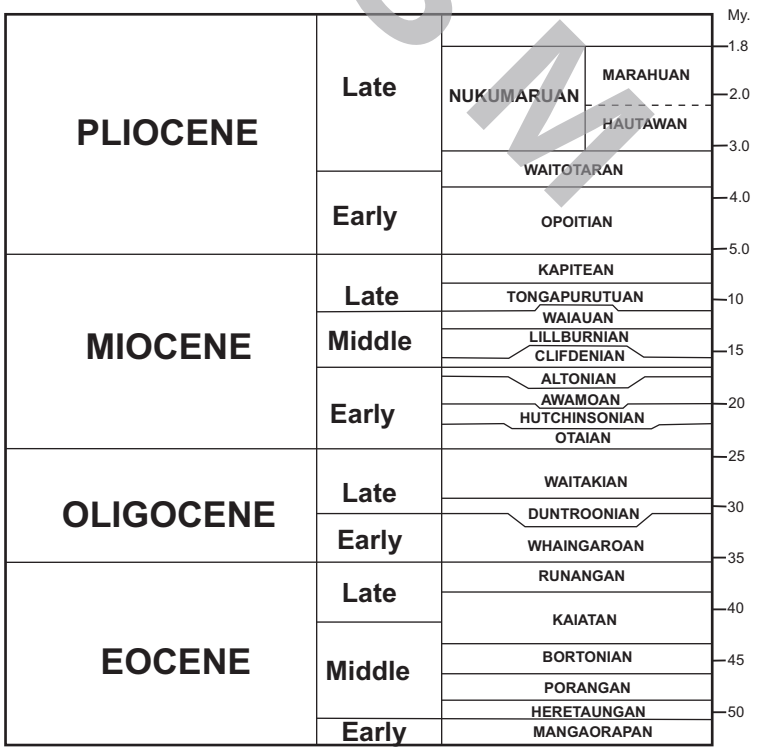


Figure 3. Correlation between New Zealand local stages with Standard Geological Time Scale.

The Pakaurangi Formation (Jones, 1969) belongs to Waitakere Group (Hayward, 1975; Balance and McCarthy, 1975). On Puketotara Peninsula (north of the drill holes) it unconformably overlies the Okahukura Formation and is unconformably overlain by the Motuoihi Formation (Balance and McCarthy, 1975).

There are 2 lithological units in the Okahukura Peninsula:

1. Oruawharo hyoclastic Member of Pakaurangi Formation
2. Pakaurangi Formation.

Oruawharo hyaloclastic Member is in the north, prominent glassy volcaniclastic rocks (hyaloclastic) and along strike in the centre and and the south a variable unit of fossiliferous mudstone and volcanic sandstone (Balance and McCarthy, 1975).

The Pakaurangi Formation is seen in exposures of fine grained fossiliferous rocks on Road No. 4 section (Q09/290389) where thick bedded muddy sandstone with scattered fragmented fossils occur (Balance and McCarthy, 1975). The present study found no lithology like that of the Oruawharo hyaloclastic in the core sample or at the surface.

Systematic Paleontology

The classification used here follows that of Moore (1961), and identification of the species was mostly carried out by A.R. Hasibuan. In this paper we deal only with previously described species, while undescribed forms await future study. All the specimens are stored in the Department of Geology, University of Auckland, New Zealand and numbered in Reference Collection.

Phylum : Arthropoda
Subphylum : Mandibulata Clairville, 1798
Class : Crustacea Pennat, 1777
Subclass : Ostracoda Latreille, 1806
Order : Podocopida G.W. Mueller, 1894
Suborder : Podocopina Sars, 1888

Superfamily : Bairdiacea Sars, 1888
Family : Bairdiidae Sars, 1888
Genus : *Bairdia* McCoy, 1844
Type species : *Bairdia curtus* McCoy, 1844

Bairdia canterburyensis Swanson, 1969
Pl. 1, Figs. 1, 2.

1969, *Bairdia canterburyensis Swanson*. Trans. of the Roy. Soc. of N.Z. Earth Science, 7(3), p.38, Pl. 1, Figs. 17-19.

Remarks: The preservation of this species is poor, but the shape of the carapace and inner margin resembles that of Bairdia canterburyensis Swanson.

Observed Range: Hutchinsonian - Awamoan (= Altonian) (Swanson 1969). The genus ranges from Silurian to Recent, cosmopolitan in shallow marine (neritic) to very deep waters (Van Morkhoven 1963). This species was rare in Tapora Flats Bore Holes.

Superfamily : Cytheacea Baird, 1850
Family : Brachycytheridae Puri, 1954
Genus : *Pterigocythereis* Blake, 1933
Type species : *Cythereis jonesii* Baird, 1850

Pterigocythereis cf. *fimbriata bartonensis* A.J. Keij, 1957.

Pl. 1, Fig. 3

1957. *Pterigocythereis fimbriata bartonensis* Keij. Inst.Roy. Scie. Nat. Belgique, Mem. 136, 210 pp., illus. (incl. maps).
1961 *Pterigocythereis fimbriata* (Munster). Moore, Treatise on Invertebrate Paleontology, p. Q267, Figs. 191, 4e.
1978. *Pterigocythereis fimbriata bartonensis Keij*. Bate and Robinson, A. A stratigraphical Index of British Ostracoda, p. 418, PL. 10, figs. 7-9, Table 4.

Observed Range: The generic range is from Cenomanian - Recent (Van Morkhoven, 1963). Geographical distribution cosmopolitan and ecology is marine, mostly in shallow depth (neritic). This species is very rare in the Tapora Flats Bore Holes and occurs with an Ostracod assemblage of the Altonian Stage (Early Miocene). Anterior part of the specimen is broken, otherwise it is conspecific with *Pterigocythereis fimbriata bartonensis*. The study also observed specimens of this genus which differ from this species and are left for the next study.

Family : Cytherideidae Sars, 1925
Subfamily : Neocytherideidinae Puri, 1957
Genus : *Copytus* Skogsberg, 1939
Type species : *Copytus caligula* Skogsberg, 1939

Copytus novazealandiae (Brady, 1898)

1898, *Cythereis novazealandiae* Brady. Trans. Zool. Soc. 14, p.446, Figs. 1-4.
1967, *Copytus rara* McKenzie. Proc. Roy. Soc. Victoria, 80(1): p.71, Fig. 2j.
1969, *Copytus rara* McKenzie. Swanson, Trans. Roy. Soc. New Zealand, Earth Sciences, 7(3), p. 45, Pl. 5, Figs. 69-71.

Observed Range: Brady (1898) first reported this species as a Recent species from Lyttelton Harbour, New Zealand. Hornibrook (1952) reported that it was already present in New Zealand during Eocene time. Swanson (1969, 1979) noted hat in the Middle Waipara it becomes abundant in Hutchinsonian and Awamoan sediments (Altonian) and very common on Otago Shelf (0-50 m). In the present study, this species was found very rarely in the Tapora Flats Bore Holes where it occurs with Ostracoda assemblage from Altonian Stage.

Family : Cytheruridae G.W. Mueller, 1894
Genus : Cytheropteron Sars, 1866
Type species : *Cythere latissima* Norman, 1865

Cytheropteron alatum Sars, 1963
Pl. 1, Figs. 4-5

1963. *Cytheropteron alatum* Sars. Morkhoven, Post Paleozoic Ostracoda, II, p. 384, Figs. 642-643.

Observed Range: The genus ranges from Liassic to Recent (Van Morkhoven, 1963). Geographical distribution world-wide and marine ecology. Representatives of this genus inhabit practically all depths in modern seas. Deep water species are generally thin shelled and smooth, the present specimen has relatively has thicker shell. In the Tapora Flats Bore Holes it was found commonly in the Altonian Stage.

Subfamily : Cytheropterinae Hanai, 1957
Genus : Oculocytheropteron Bate, 1972
Type species : *Oculocytheropteron praenuntatum* Bate, 1972

Cytheropteron (Aversovalva) aureum Hornibrook, 1952

1952. *Cytheropteron (Aversovalva) aureum* Hornibrook. N.Z. G.S. Pal. Bull. 18, p. 57-58, Pl. 15, Figs. 189-194.
1961. *Cytheropteron (Aversovalva) aureum* Hornibrook. Moore, Treatise on Invertebrate Paleontology p. Q292, Figs. 219, 1b-g.

Observed Range: This species ranges from Bortonian - Recent (Hornibrook, 1952). The generic range is from Late Jurassic - Recent (Moore, 1961). In the Tapora Flats Bore Holes it is very rare in Altonian Stage.

Cytheropteron (Cytheropteron) latiscalpum Hornibrook

1952. *Cytheropteron* (*Cytheropteron*) latiscalpum Hornibrook. N.Z. G.S. Pal. Bull. 18, p. 56-57, Pl. 13, Figs. 181-183.

Observed Range : Known only from Recent (Hornibrook, 1952). In the present study it appears very commonly in Altonian Stage marking a notable extension to its range.

Cytheropteron (Cytheropteron) terecaudum Hornibrook, 1952

1952. *Cytheropteron (Cytheropteron) terecaudum* Hornibrook. N.Z. G.S. Pal. Bull. 18, p. 56, Pl. 12, Figs. 175, 176, 178.

Observed Range: The species ranges from Altonian to Recent (Hornibrook, 1952). It is very rare in the present study in the Altonian Stage.

Cytheropteron (Infracytheropteron) anotum Bate, 1972

Pl. 1, Fig. 6;

1972. *Cytheropteron (Infracytheropteron) anotum* Bate. Pal. Assoc. Spec. Papers, Pal. London, 10, p. 48-49.

Observed Range: Late Cretaceous - Recent (Bate, 1972). Very rare in the present study and occurs in Altonian Stage.

Oculocytheropteron fornix Hornibrook, 1952

1952. *Oculocytheropteron (Cytheropteron) fornix* Hornibrook. N.Z. G.S. Pal. Bull. 18, p. 54, Pl. 11, Figs. 159-161.
1979. *Oculocytheropteron fornix* (Hornibrook). Swanson, N.Z. Oceanog. Inst. Mem. 78, p. 35, Figs. 46a-b.

Observed Range: Bortonian - Recent (Hornibrook, 1952). Very rare in the present study, associated with Ostracod assemblage from the Altonian Stage.

Genus : *Hemicytherura* Elofson, 1941
Type species : *Kangarina quelita* Coryell and Field, 1937

Hemicytherura (Kangarina) cf. *Abysicolla* (G.W. Mueller, 1953)

Pl. 2, Figs. 1-2

1937. *Kangarina quelita* Coryell and Field. Am Museum Novitates, Pl. 13, Figs. 15a-c.
1953a. *Hemicytherura (Kangarina)* cf. *abysicolla* (G.W. Mueller). Ruggieri Atti. Soc. Ital. Sci. Nat., 92, p. 40-56.
1963. *Hemicytherura (Kangarina)* cf. *abysicolla* (G.W. Mueller). Van Morkhoven, Post Paleoz. Ostracoda, II, p. 353, Figs. 575-576.

Observed Range: Ruggiere (1953b) found this species in Plio-Pleistocene strata in Italy. The generic range is Senonian - Recent, geographical distribution is cosmopolitan and ecology is neritic (Van Morkhoven, 1963). In this study the species is very rare and it occurs in the Altonian Stage.

Genus : *Paracytheridea* G.W. Mueller, 1894
Type species : *Paracytheridea depressa* G.W. Mueller

Paracytheridea grignonensis Keij, 1957.
Pl. 2, Figs. 3-5

1894. *Paracytheridea depressa* G.W. Mueller. Naples Sta. Zool. Fauna Flora Golfes Neapel, Monographie, p. 341, Pl. 26, Figs. 16-26, Pl. 29, Figs. 4, 8.
1957. *Paracytheridea grignonensis* Keij. Inst. Roy. Sci. Nat. Belgique, Mem. 136, 210 pp.
1963. *Paracytheridea grignonensis* Keij. Van Morkhoven, Post Paleozoic Ostracoda, II, Elsevier, P. 376-379, Figs. 622-624.

Observed Range: *Paracytheridea grignonensis* Keij is of Eocene age in the Paris Basin, France. The generic range is from Cenomanian to Recent. Its geographical distribution is cosmopolitan and ecology is neritic (Van Morkhoven, 1963). In the Tapora Flats Bore Holes this species appears abundantly in the Altonian Stage.

Remarks: Mueller (1894) regarded that *P. depressa* (type species) was identical with *Cytheropteron bovetensis* Sequenza 1880 but Van Morkhoven (1963) doubted it was synonymous. However, the genera *Vicinia Kuznetsova* 1957 and *Mooreina* Harlton 1933 are possibly synonymous with *Paracytheridea* (Van Morkhoven, 1963).

Genus : *Semicytherura* Wagner, 1957
Type species : *Cythere nigrescens* Baird, 1838

Semicytherura cf. *punctata* (G.W. Mueller, 1963)
Pl. 2, Fig. 6.

1838. *Cythere nigrescens* Baird. Mag. Zool. Bot. 2: p. 143, Pl. 5, Fig.27.
1963. *Semicytherura punctata* (G.W. Mueller). Van Morkhoven, Post. Paleoz. Ostracoda. II, p. 346-349, Fig. 566.

Observed Range : Found Recent in Europe (Ruggieri, 1952 in Van Morkhoven, 1963). The generic range is from Paleocene to Recent, geographical distribution world-wide and ecology is neritic, predominantly littoral (Van Morkhoven, 1963). Most species studied so far appear to be euryhaline and eurythermal. In the Tapora Flats Bore Holes this species was found very rare in the Altonian Stage.

Family : Hemicytheidae Puri, 1953.
Genus : Hemicythere Sars, 1925.
Type species : *Cythereis villosa* Sars, 1866.
Designated by Edwards 1944, p. 517

Hemicythere tarakohensis Hornibrook, 1952
Pl. 3, Figs. 1-3

1952. *Hemicythere tarakohensis* Hornibrook. N.Z.G.S. Pal. Bull. 18, p. 48, Pl. 10, Figs. 141-143.

Observed Range: Known only from Altonian in the type locality, Tarakohe Marl Quarry (Hornibrook, 1952), it is a key fossil for Altonian Stage and provides the evidence for Altonian Stage in this area. In the Tapora Flats Bore Holes this species appears commonly, occurring throughout the Altonian Stage.

Family : Loxoconchidae Sars, 1925.
Genus : Loxoconcha Sars, 1866.
Type species : *Cythere rhomboidea* Fischer 1855, p. 656, non Brady, 1866 (=*Cythere impressa* Baird 1850, non McCoy 1844).

Loxoconcha propunctata Hornibrook, 1952
Pl. 3, Figs. 4-6

1952, *Loxoconcha propunctata* Hornibrook. N.Z.G.S. Pal. Bull. 18,p. 49, Pl. 11, Figs. 148, 149, 153.
1963, *Loxoconcha propunctata* Hornibrook. Van Morkhoven, Post Paleozoic.Ostracoda II, Elsevier, p. 385-389, Figs. 648-650.
1969. *Loxoconcha propunctata* Hornibrook. Swanson, Trans. of the Roy. Soc.of N.Z. 7 (8), p. 47, Figs. 93-95.

Observed Range: This species is a key fossil for Altonian Stage (Hornibrook, 1952). In the middle Waipara it appears in the Otaian where it is rare, gradually increasing in numbers throughout Altonian. The generic range is from Paleocene to Recent, geographical distribution is world-wide while the ecology is mesohaline to littoral (Van Morkhoven, 1963). In the present study, it appears commonly in the Altonian Stage and is the evidence for Altonian Stage.

Loxoconcha semistriata Kingma, 1948
Pl. 4, Figs. 1-3

1948, *Loxoconcha semistriata* Kingma. Kemink Printers, Utrecht, p. 90, Pl. XI, Figs. 4a-4b.

Observed Range: Found from Recent samples from the Malayan region (Kingma, 1948).In this study the species appears rarely in the Altonian Stage.

Family : Pectocytheridea Hanai, 1957.
Genus : *Arcacythere* Hornibrook, 1952.
Type species : *Arcacythere chapmani* Hornibrook, 1952.

Arcacythere chapmani Hornibrook, 1952

1952. *Arcacythere chapmani* Hornibrook. N.Z.G.S. Pal. Bull. 18, p. 31-32, Pl. 2, Figs. 33-35.
1961. *Arcacythere chapmani* Hornibrook. Moore, Treatise on Invert. Pal., p. Q 318, Figs. 246, 2a-c.

Observed Range: Found in New Zealand in Piripauan - Waiauan (Upper Cretaceous - Middle Miocene) (Hornibrook, 1952). In the Tapora Flats Bore Holes, it appears rarely in the Altonian Stage.

Family : Schizocytheridea Howe.
Genus : *Schyzocythere* Triebel, 1950.
Type species : *Schizocythere hollandica* Triebel.

Schizocythere cf. *batjesi* Keij, 1957.
Pl. 3, Fig. 4.

1950. *Schizocythere hollandica* Triebel. Senckenbergiana Laethaea, 31(5-6), p. 320, Pl. 2, Figs. 18-19, Pl. 3, Figs. 12-17.
1957. *Schizocythere batjesi* Keij. Inst. Roy. Sci. Nat. Belgique, Mem., 136; 210 pp.
1961. *Schizocythere batjesi* Keij. Moore, Treatise on Invert. Pal., p. Q 331, Figs. 256, 1a-c.
1978. *Schizocythere batjesi* Keij. Keen in Bate & Robinson, Seel House Press., P. 422, Pl. 12, Figs. 4, 6.

Observed Range: The generic range is Paleocene - Eocene in Europe and North America, and ecologically in marine environment (Van Morkhoven, 1963). Also found in Barton Hampshire of Upper Lutetian - Bartonian (Middle - Late Eocene) (Keen, 1978 in Bate & Robinson, 1978). In this study it is very rare and occurs with an ostracod fauna of Altonian Stage.

Genus : *Paijenborchella* Kingma, 1948.
Type species : *Paijenborchella iocosa* Kingma, 1948.
(= *Paijenborchella Keij*, 1953)

Paijenborchella iocosa Kingma, 1948.
Pl. 4, Fig. 5-6; Pl. 5, Figs. 1

1948. *Paijenborchella iocosa* Kingma. Kemink Printers Utrecht, p. 86, Pl. 5, Fig. 2, Pl. 8, Fig. 12.
1961. *Paijenborchella iocosa* Kingma. Moore, Treatise on Invert. Pal., p. Q 331-332, Figs. 256, 2a-c.

Observed Range: Found from Bojonegoro drilling, Indonesia, in strata of Miocene Age (Kingma, 1948). The generic range is Senonian - Recent, geographical distribution is world-wide and ecologically marine (Van Morkhoven, 1963). In the Tapora Flats Bore Holes this species is very common in the Altonian Stage.

Family : Trachyleberididae Sylvester-Bradley, 1948.
Genus : *Trachyleberis* Brady, 1898.
Type species : *Cythere scabrocuneata* Brady, 1880.

Trachyleberis raynerae Neale, 1975
Pl. 5, Figs. 2-3

1917. *Cythereis rudispinata* Chapman and Scherborn. Chapman, West Austral. Geol. Surv. Bull. 72 (ser. 6, no.11), p. 56, Pl. 14, Fig. 15.
1975. *Trachyleberis raynerae* Neale. Spec. Papers Pal. (Pal. Assoc.), London, 16, p. 62-64.

Observed Range: The generic range is from Eocene to Recent, geographical distribution is cosmopolitan, ecologically mainly found in neritic environment (Van Morkhoven, 1963). Very rare in the Tapora Flats Bore Holes and associated with an Ostracod assemblage of Altonian Stage.

Genus : *Bradleya* Hornibrook, 1952.
Type species : *Cythere arata* Brady, 1880.

Bradleya dyction (Brady, 1952)

1952. *Bradleya dyction* (Brady). Hornibrook, N.Z.G.S. Pal. Bull. 18, p. 39-41, Pl. 6, Figs. 81, 82, 84, 85 (with synonyms).
1963. *Bradleya? Dyction* (Brady). Van Morkhoven, Van Morkhoven, Post Paleozoic. Ostracoda II, Elsevier, p. 162, Fig. 248.

Observed Range: Mangaorapan - Recent (Hornibrook, 1952). The genus ranges from Late Cretaceous to Recent, described from New Zealand and also found in South Atlantic, and doubtful ones (*diction* type) occur cosmopolitan in marine environment (Van Morkhoven, 1963). Found abundantly in the Tapora Flats Bore Holes from Altonian Stage. Very common in New Zealand in very shallow water (Hornibrook, 1952).

Bradleya lactea pakaurangia Hornibrook, 1952
Pl. 5, Fig. 4

1952. *Bradleya lactea* pakaurangia Hornibrook. N.Z.G.S. Pal. Bull. 18, p. 42, Pl. 7, Figs. 95, 97, 98, 102.

Observed Range: Known only from Altonian Stage (Hornibrook, 1952). It has been used as a key fossil by Hornibrook, 1952. Very rare in the Tapora Flats Bore Holes. Occurs with ostracod assemblage consistent with this Altonian age. It is also further evidence for the Altonian Stage in this study. This species resembles the genus *Hermanites* and probably belongs to that genus, but the material is inadequate for further study.

Bradleya semiarata Hornibrook, 1952
Pl. 5, Fig. 5

1952. *Bradleya semiarata* Hornibrook. N.Z.G.S. Pal. Bull. 18, p. 41-42, Pl. 7, Figs. 91, 92, 99.
1963. *Bradleya semiarata* Hornibrook. Van Morkhoven, Post Paleozoic. Ostracoda II, Elsevier, p. 162, Fig. 247.

Observed Range: This species is known only from Altonian Stage (Hornibrook, 1952), and also has been used as a key fossil. In the present study this species was one of the best lines of evidence for the Altonian age and was accompanied by two other key species that support that age.

Genus : Henryhowella
Type species : Cythere evax Ulrich and Basler, 1904.

Henryhowella probesioides (Hornibrook, 1952)
Pl. 5, Fig. 6, Pl. 6, Figs. 1-2

1952. Trachyleberis probesioides Hornibrook. N.Z.G.S. Pal. Bull. 18, p. 34, Pl. 4, Figs. 50, 51, 55.
1969. Henryhowella probesioides (Hornibrook). Swanson, Trans. of the Roy. Soc. N.Z. 7(3), p. 44.

Observed Range: Clifdenian to Waitotaran (Hornibrook, 1952). Van Morkhoven, (1963) regarded *Trachyleberis probesioides* as belonging to the genus *Henryhowella* with a generic range from Eocene to Recent and world-wide distribution in the marine environment, mostly in water over 100 m deep. This species was found from the study area in the Altonian Stage. The species range of Hornibrook (1952), is younger than that indicated by the other ostracod assemblages from this study, and foraminiferal dating (Hayward, 1975). It is therefore concluded that this species here is found for the first time from the Altonian age. The first appearance of the species is extended downwards from Clifdenian to Altonian, and the revised age range therefore is Altonian to Waitotaran.

Henryhowella rugibrevis (Hornibrook, 1952)
Pl. 6, Fig. 3

1952. *Trachyleberis rugibrevis* Hornibrook. N.Z.G.S. Pal. Bull. 18, p. 34, Pl. 4, Figs. 52-54.
1969. *Henryhowella rugibrevis* (Hornibrook). Swanson, Trans. of the Roy. Soc. N.Z. 7(3), p. 44, Pl.4, Figs. 58-60.

Observed Range: Duntroonian - Lillburnian (Hornibrook, 1952). Van Morkhoven, (1963) also regarded *Trachyleberis rugibrevis* as belonging to the genus *Henryhowella*. In this study, this species appears rarely in the Altonian Stage.

Henryhowella zeacristata (Hornibrook, 1952)
Pl. 6, Fig. 4.

1952. *Trachyleberis zeacristata* (Hornibrook). N.Z.G.S. Pal. Bull. 18, p. 35, Pl. 4, Figs. 58, 60, 61.

Remarks: Van Morkhoven (1963) and Swanson (1969) have already transferred *Trachyleberis rugibrevis* and *Trachyleberis probesioides* to the genus *Henryhowella* because of the lack of a large spine and the produced posterior. The present specimen also resembles *Henryhowella* whose lateral ridges do not continue into anterior half of the carapace, where spines are more or less concentrically arranged (Moore, 1961). Based on these features a revised generic placing of the species as *Henryhowella zeacristata* has been made.

Observed Range: Hornibrook (1952) recorded *Trachyleberis zeacristata* from Waitakian to Recent and rare below Altonian. Very rare in the Tapora Flats Bore Holes and occurs with an ostracoda assemblage of Altonian age.

Genus : *Quadracythere* Hornibrook, 1952.
Type species : *Cythere truncula* Brady, 1898, Trans. Zool. Soc. London, 14, p. 444, Pl. 57, Figs. 16-17.

Quadracythere biruga Hornibrook, 1952

1952. *Quadracythere biruga* Hornibrook. N.Z.G.S. Pal. Bull. 18, p. 45, Pl. 9, Figs. 118-120.
1963. *Quadracythere biruga* Hornibrook. Van Morkhoven, Post Paleozoic. Ostracoda II, Elsevier, p.143, Fig. 217.

Observed Range: Stratigraphic range from Duntroonian to Recent (Hornibrook, 1952). The generic range from Paleocene - Recent with world-wide distribution and ecology predominantly in neritic environment (Van Morkhoven, 1963). In this study the species commonly occurs with ostracod assemblages of the Altonian Stage.

Quadracythere mediaruga Hornibrook, 1952

1952. *Quadracythere mediaruga* Hornibrook. N.Z.G.S. Pal. Bull. 18, p. 44-45, Pl. 8, Figs. 115-117.
1963. *Quadracythere mediaruga* Hornibrook. Van Morkhoven, Post Paleozoic. Ostracoda II, Elsevier, p. 143, Fig. 216.

Observed Range: Stratigraphic range from Kaiatan to Recent (Hornibrook, 1952). The generic range, geographical distribution and ecology as above. This species was found commonly in this study in an ostracod assemblage of Altonian Stage.

Family : Xestoleberididae Sars, 1928.
Genus : *Xestoleberis* Sars, 1866.
Type species : *Cythere aurantia* Baird, 1866.

Xestoleberis aurantia (Baird, 1963)
Pl. 6, Figs. 5-6

1963. *Xestoleberis aurantia* (Baird). Van Morkhoven, Post Paleozoic. Ostracoda II, Elsevier, p. 440, Figs. 743-744, (with synonyms).

Table 1. Identified, Abudances an d Range Chart of Ostracoda from Puketotara Peninsula

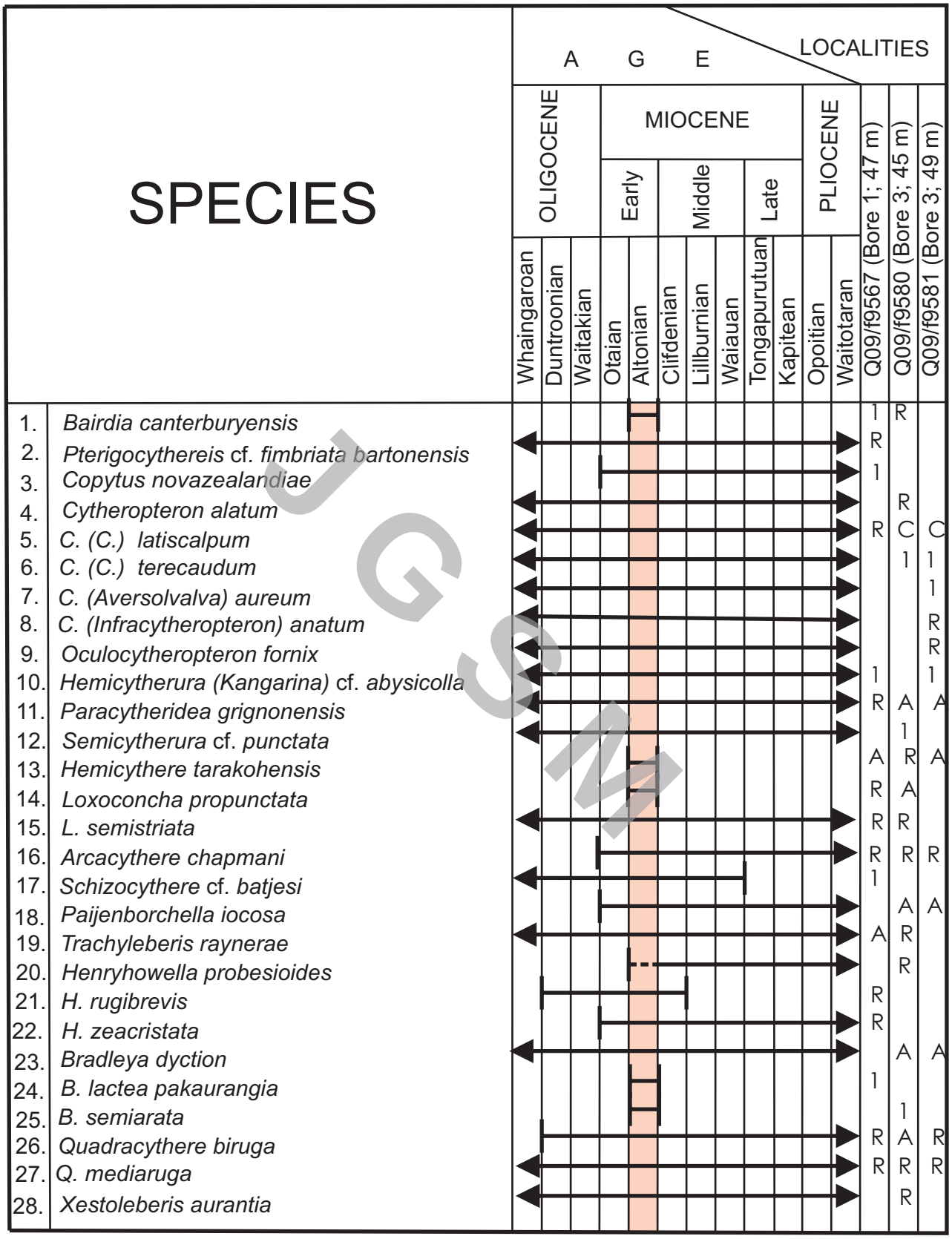


Table 2. Paleoecologic and Geographical Chart of Ostracoda from Pakaurangi Formation

No.	Genus	Recorded ecology and geographical distribution
1.	*Bairdia*	Marine, very shallow and very deep, cosmopolitan
2.	*Pterigocythereis*	Marine, shallow (10 - 150 m), cosmopolitan
3.	*Copytus*	Littoral, cosmopolitan
4.	*Cytheropteron*	Marine, all depths of present seas, cosmopolitan
5.	*Hemicytherura*	Neritic, cosmopolitan
6.	*Paracytheridea*	Neritic, cosmopolitan
7.	*Semicytherura*	Neritic, predominantly littoral, euryhaline and eurythermal, cosmopolitan
8.	*Hemicythere*	Neritic, euryhaline, eurythermal, cosmopolitan
9.	*Loxoconcha*	Mesohaline to littoral, cosmopolitan
10.	*Arcacythere*	Marine, New Zealand
11.	*Schizocythere*	Marine, Europe, North Africa
12.	*Paijenborchella*	Marine, all depths, cosmopolitan
13.	*Trachyleberis*	Marine, neritic, cosmopolitan
14.	*Henryhowella*	Marine, mostly over 100 m, cosmopolitan
15.	*Bradleya*	Marine, shallow water, cosmopolitan
16.	*Quadracythere*	Neritic, cosmopolitan
17.	*Xestoleberis*	Littoral to neritic, some brackish, saline tidal pools, cosmopolitan

Observed Range: The genus ranges from Cenomanian to Recent, with cosmopolitan, most species inhabit littoral to neritic environments. Some forms appear to be able to live in brackish water, others regularly in saline tidal pools (Van Morkhoven, 1963). Mueller (1894) found some species at a depth of 385 m in the Antarctic.

The age of Waitakere Group in the Tapora Flats Peninsula

The biostratigraphic units used in this study are the New Zealand stages of Finlay and Marwick (1948) as emended by Scott (1972). Age determination within the Waitakere Group in the Tapora Flats, Puketotara Peninsula, is made using the ostracod fauna. Standard New Zealand stages and their correlation with the International Standard is shown in Table 3.

Three samples from two bore holes in the Tapora Flats in Puketotara Peninsula yielded Ostracoda. Ostracod assemblages in those samples are shown in Table 1. The samples from Tapora Flats Bore Holes are of Early Miocene age. Ostracoda characteristic of Altonian Stage (Early Miocene) found in the Tapora Flats Bore Hole No. 1, from the depth of 47 m are:

- *Hemicythere tarakohensis* Hornibrook, 1952
- *Loxoconcha propunctata* Hornibrook, 1952
- *Bradleya lactea pakaurangia* Hornibrook, 1952
- *Bairdia canterburyensis* Swanson, 1969

The Ostracod assemblage from drill hole No. 3, from a depth of 45 m and from a depth of 49 m includes only one Altonian index fossil, *Hemicythere tarakohensis* but the assemblage overall is the same as in the other samples. Thus all three samples from bore No, 1 and bore No. 3 are accepted as of Altonian age.

Hayward (1975) recognized three subdivisions of the Altonian Stage in Northern New Zealand, using planktonic foraminifera. Index species for each subdivision are:

Upper Altonian : *Globoquadrina dehiscens* (Chapman, Par, & Collins), *Sphaeroidinella disjuncta* Finlay

Middle Altonia : *Globorotalia* (*Turborotalia*) *praescitula* Blow, *Globorotalia* (T.) *zealandica zealandica* Hornibrook.

Lower Altonian : *Globorotalia* (T.) z. *incognita* Walters, *Globigerina* (*Globigerina*) *woodi connecta* Jenkins, *Globigerinoides trilobus altiaperturus* Bolli, *Globigerinoides t. trilobus* (Reuss), *Globoquadrina dehiscens* (Chapman, Par, & Collins)

According to Ballance and McCarthy (1975) the Pakaurangi Formation contains *Globorotalia* (T.) *praescitula* and *Globigerinoides trilobus trilobus* which indicate an Altonian age (Pl.). The range of *Globigerinoides t. trilobus* is Early to Late Atonian (foraminifral zone of Jenkins, 1967) and on up to Clifdenian (Hayward, 1975). The range of *Globorotalia* (*T.*) *praescitula* is Middle Altonian probably up to Late Altonian (Hayward, 1975). Based on these species the age of the Pakaurangi Formation is most likely Middle to Late Altonian.

Hornibrook (1952) regarded key Altonian species of Ostracoda to include *Hemicythere tarakohensis*, *Loxoconcha propunctata, Bradleya semiarata*, and *Bradleya lactea pakaurangia*. Swanson (1969) has since then added *Bairdia canterburyensis* as another Altonian indicator. This age is entirely consistent with the more accurate dating of the Pakaurangi Formation as Middle to Late Altonian on foraminifera.

Paleoecology

All Ostracod fauna dealt with in this study were obtained from silty fine sandstone, muddy fine sandstone and fine sandy mudstone. The sand/silt ratio is directly reflected by the biota. Suspension feeders are largely confined to silty horizons and lenses. The most abundant sediment type within the Pakaurangi Formation is muddy fine sandstone. The Holland Member (now the Okahukura Formation) consists of a succession of rather massive moderately sorted andesitic grits (Jones, 1970;1972). According to Vella (1962) this sediment type is typical of the upper neritic zone (0 - 100 m), where current velocities are sufficiently high to remove all fine material. This sediment is suitable for a suspension feeding fauna such as Ostracoda, molluscs, etc.

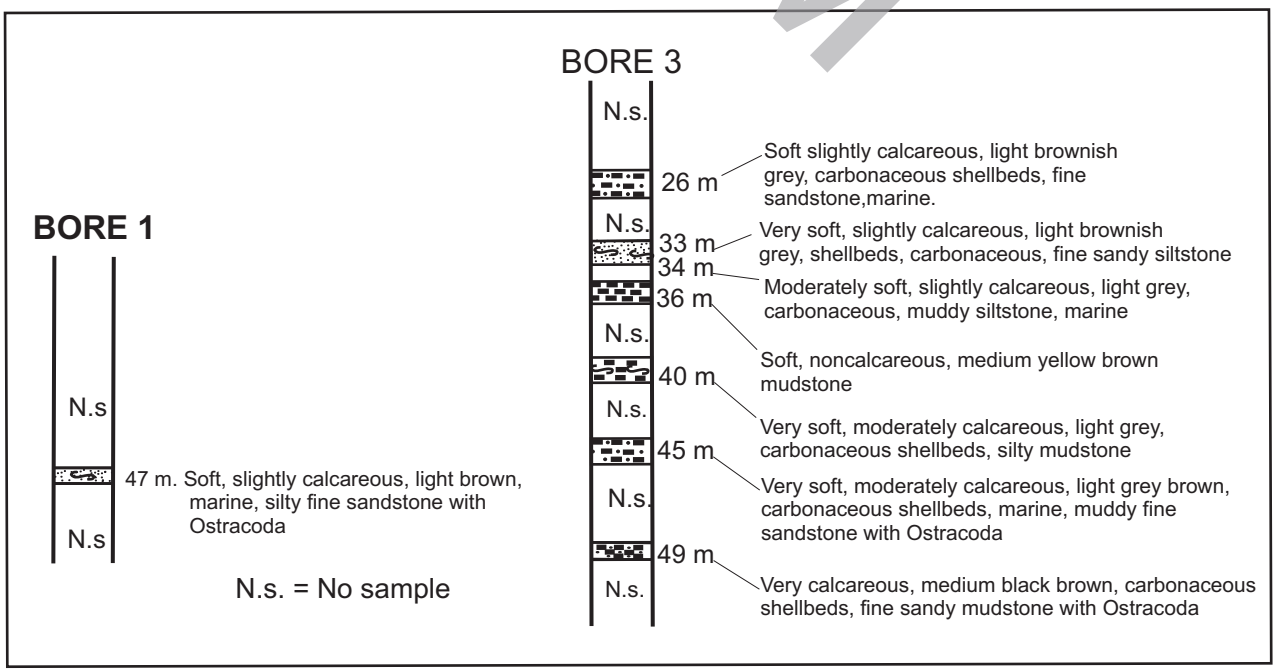
Most Ostracoda from the study area are thick shelled with eye spots, strong sculpture, amphidont hinge and branch pore canals (*Bradleya, Quadracythere, Semicytherura, Hemicytherura* etc.). These genera indicate shallow water. In addition there are few which extend out also into deep water (*Bairdia, Cytheropteron, Paijenborchella, Xestoleberis* etc.).

This is similar to the situation with molluscan faunas in the Pakaurangi Formation studied by workers such as Marshall (1918), Grant-Mackie (1965), Jones (1970) and others.

According to Jones (1970) the Pakaurangi Formation contains infaunal and epifaunal molluscs, often heavy shelled, suggesting that the depth of deposition is not greater than 100 - 150 m.

Molluscs of 200 - 400 m depth are also found in the Pakaurangi Formation. Marshall (1918) and Grant-Mackie (1965) considered that the formation was deposited of approximately 180 m. Based on the molluscan fauna, Jones (1970) concluded that the

Table 3. Stratigraphic Column of the Drillholes from Tapora Flats, Northland, Q09/266381



depth of deposition was probably greater than 100 m and less than 400 m probably 150 - 250 m.

The Pakaurangi Formation generally was deposited under normal marine salinity, although the upper portion appears to be a low salinity deposit suggesting an estuarine or lagoonal environment (Jones, 1970).

Most Ostracoda from the Pakaurangi Formation indicate a shallow marine environment. However, some are brackish water indicators, such as *Loxoconcha* (mesohaline - littoral), *Xestoleberis* (littoral - neritic, some brackish and saline tidal pools), and *Hammatocythere* (brackish) (see Table 2). The presence of brackish water ostracods indicate that the depositional environment of the formation was influenced by brackish or fresh water such as in an estuarine situation.

This conclusion is also confirmed by other workers (e.g. Vella, 1962; Devereux, 1968) who referred to the faunal changes from an *Echinocardium* community (normal marine salinity) upward to *Ostrea* and *Nucula* communities (with very reduced diversity faunas), a succession suggesting decreasing salinity to a brackish (or fresh) water environment. The lithium content of the Pakaurangi Formation is ± 115 ppm (Jones, 1970), and this also suggests reduced salinity.

Devereux (1968), studied the oxygen isotope ratios of planktonic and benthonic foraminifera from the Okahukura Formation and Waipukua Member, and found that the temperatures of the planktonic (27 ± 1°C) and benthonic species (25 ± 1°C), indicate the sediment accumulated in a near shore environment with contamination from fresh water. He considered that the coral reefs existed in Northland during the Altonian - Otaian and that the seasonal temperature range was probably 20° - 28°C. The oxygen isotope study showed that the minimum temperature for the Wellington area in Altonian was 18°C, corresponding to a minimum Northland temperature of 20°C.

The presence of *Semicytherura* and *Hemicythere* (eurythermal forms) indicates that the Pakaurangi Formation accumulated in warm temperate to tropical conditions. Hornibrook (1952) has recorded the presence of shallow water tropical foraminifera in the Pakaurangi Formation, e.g. *Miogypsina*, *Heterostegina*, and has stated that ostracods such as *Bradleya lactea pakaurangia* (also found in this study), *Loxoconcha australis* and *Trachyleberis* (both species found to be common in the Pakaurangi Formation by Jones, 1970), and *Bythoceratina mestayerae* indicate a subtropical sea temperature.

Many attempts have been made to estimate relative or absolute temperature during the Tertiary based on corals, molluscs, and echinoids (Grant-Mackie, 1965 and others), and ostracods (Hornibrook, 1952). Based on observation by many earlier workers and confirmed by the ostracod fauna in this study, the Pakaurangi Formation was deposited in moderately shallow water (0 - 100 m), perhaps even as deep as 150 - 250 m and under the influence of a brackish or fresh water input, giving low salinity environment. Temperatures were warmer than at present and were probably subtropical to tropical, i.e. in the range of 20°C to 27°C.

CONCLUSIONS

- The studied samples came from bore holes in the Pakaurangi Formation with an Altonian age based on the Ostracoda. The key fossils indicating this age include *Loxoconcha propunctata, Bradleya lactea pakaurangia, Bradleya semiarata, Hemicythere tarakohensis*, and *Bairdia canterburyensis*. This age is also in agreement with foraminiferal content of *Globorotalia (T.) praescitula* and *Globigerinoides trilobus trilobus*.
- Part of this work follows Swanson (1969), in which he regards *Trachyleberis rugibrevis* and *Trachyleberis probesioides* belonging to the genus *Henryhowella*. *Trachyleberis zeacristata* which is found in the Pakaurangi Formation is also referred to *Henryhowella* for the same reasons.
- *Bradleya lactea pakaurangia* Hornibrook probably belongs to the genus *Hermanites*, but this taxonomic change would require examination of the type material.
- The previously recorded range of *Henryhowella* is from Clifdenian to Waitotaran. In this study it is associated with unequivocal Ostracods and foraminifera. The range of the genus is therefore extended downwards to Altonian to Waitotaran.
- The environmental requirements of ostracod genera such as *Bradleya, Quadracythere, Xestoleberis, Trachyleberis, Paracytheridea* etc., show that the formation was deposited in shallow marine environments (littoral to neritic), as previously concluded by Jones (1970), Hayward (1975), and Brook (1983).

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PLATE 1

Bairdia canterburyensis Swanson, 1969

Figure 1. Internal view of right valve
Figure 2. External view of right valve

Pterigocythereis cf. *fimbriata bartonensis* Keij. 1957

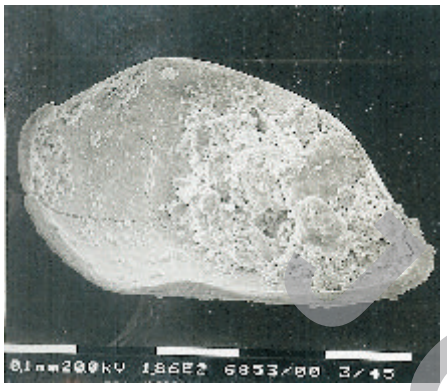
Figure 3. External view of right valve (broken anteroventral part)

Cytheropteron alatum Sars

Figure 4. External view of left valve
Figure 5. Internal view of left valve

Cytheropteron (Infracytheropteron) anotum Bate, 1972

Figure 6. External view of right valve



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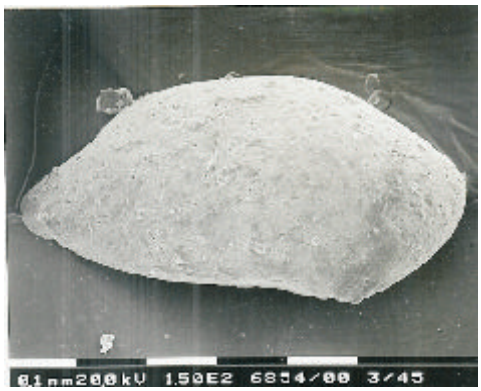

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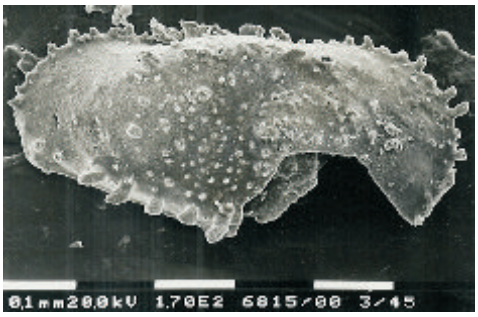

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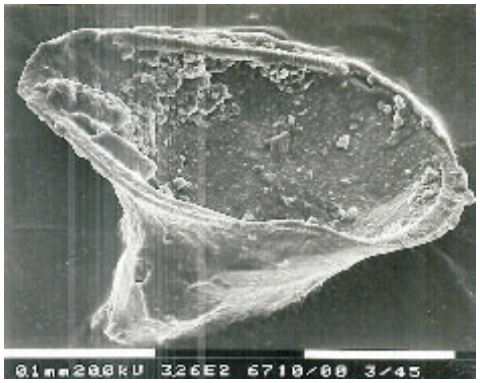

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PLATE 2

Hemicytherura (*Kangarina*) cf. *abysicolla* (G.W. Mueller,1894)

Figure 1. External view of left valve
Figure 2. Dorsal aspect of left valve

Paracytheridea grignonensis Keij, 1957

Figure 3. External view of left valve
Figure 4. Internal view of left valve
Figure 5. Dorsal aspect of left valve

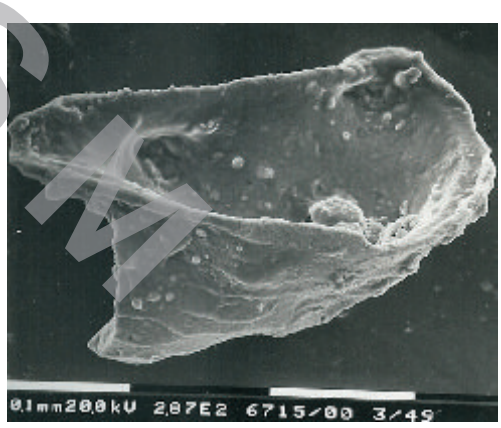
Semicytherura cf. *punctata* (G.W. Mueller, 1894)

Figure 6. External view of right valve (unremoval matrix at postero-ventral)

1

2

3



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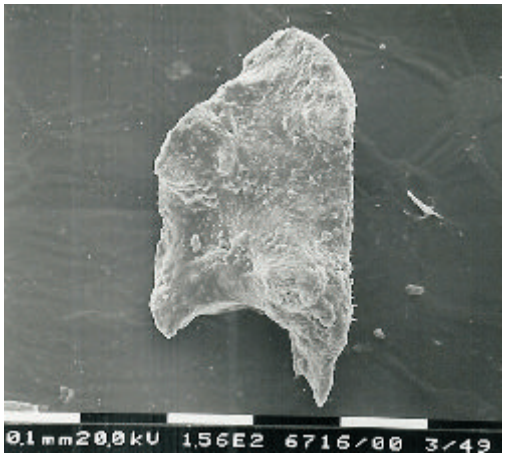

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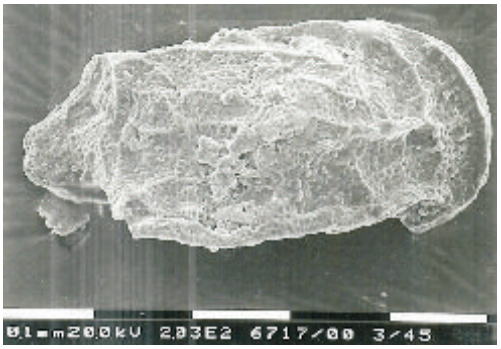

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PLATE 3

Hemicythere tarakohensis Hornibrook, 1952

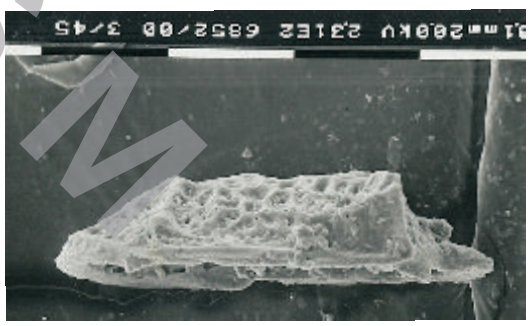
Figure 1. External view of right valve
Figure 2. Internal view of right valve
Figure 3. Dorsal aspect of right valve

Loxoconcha propunctata Hornibrook, 1952

Figure 4. Dorsal aspect of right valve
Figure 5. External view of left valve (broken at posteriodorsally and sticky matrix at dorsal and anterior margin)
Figure 6. Internal view of left valve (sticky matrix inside along the middle)

1

2



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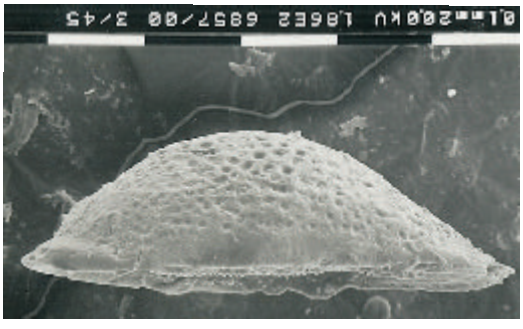

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PLATE 4

Loxoconcha semistriata Kingma, 1948

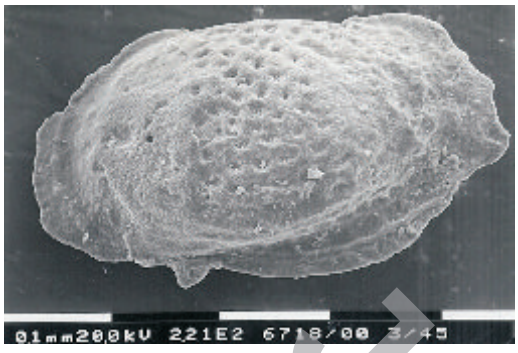
Figure 1. External view of left valve
Figure 2. Internal view of right valve (unremoval matrix inside)
Figure 3. Dorsal aspect of both valves *Schizocythere* cf. *batjesi* Keij, 1957
Figure 4. External view of left valve

Paijenborchella iocosa Kingma, 1948

Figure 5. External view of left valve (broken the middle spine at posterior part)

Paijenborchella iocosa Kingma, 1948

Figure 6. Internal view of left valve (unremoval matrix inside)



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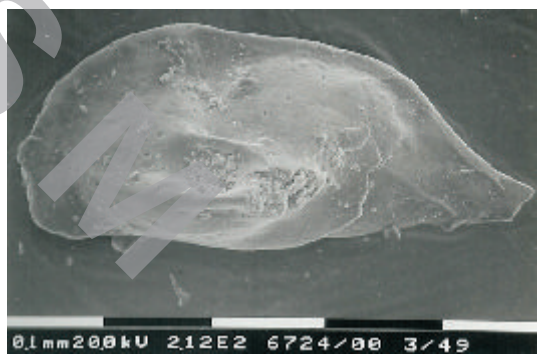

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PLATE 5

Paijenborchella iocosa Kingma, 1948

Figure 1. Dorsal aspect of both valves *Trachyleberis raynerae Neale*, 1975.

Trachyleberis raynerae Neale, 1975

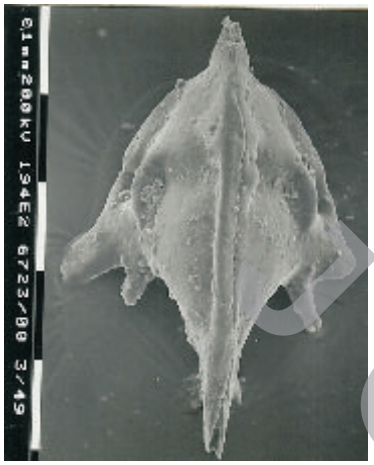
Figure 2. Dorsal aspect of right valve (unremoval matrix inside anterior part).
Figure 3. External view of right valve *Bradleya lactea pakaurangia* Hornibrook, 1952.

Bradleya lactea pakaurangia Hornibrook, 1952

Figure 4. External view of right valve *Bradleya semiarata* Hornibrook, 1952.

Bradleya semiarata Hornibrook, 1952

Figure 5. External view of left valve (unremoval matrix outside) *Henryhowella probesioides* (Hornibrook, 1952)
Figure 6. External view of right valve



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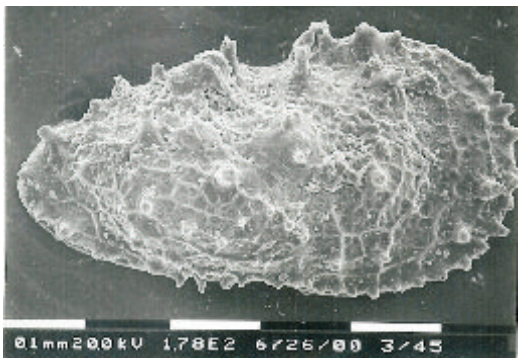

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PLATE 6

Henryhowella probesioides (Hornibrook, 1952)

Figure 1. Internal view of right valve (unremoval matrix inside)
Figure 2. Dorsal aspect of both valves

Henryhowella rugibrevis (Hornibrook, 1952)

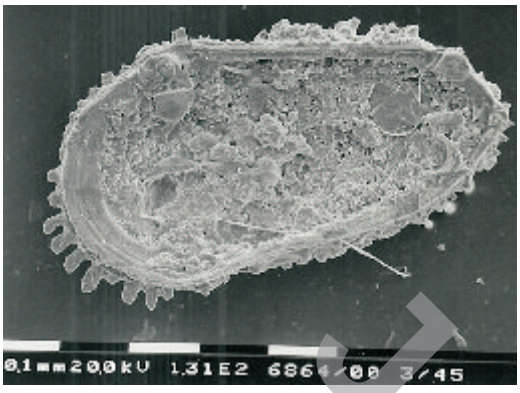
Figure 3. External view of left valve

Henryhowella zeacristata (Hornibrook,1952)

Figure 4. External view of left valve

Xestoleberis aurantia (Baird,1838)

Figure 5. Internal view of left valve (broken specimen at interiorly)
Figure 6. Dorsal aspect of both valve (broken at anteriorly of left valve)



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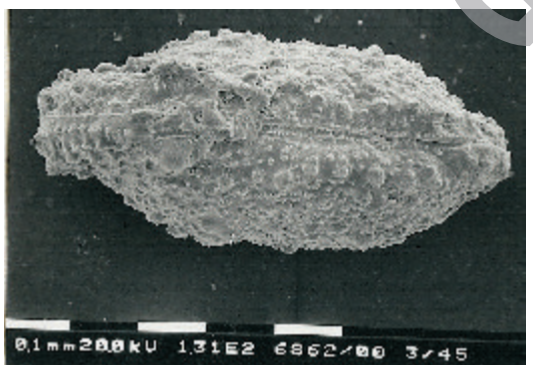

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