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The Crespin Volume: Essays in honour of Irene Crespin

Compiled by

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The name of Irene Crespin has been synonymous with micropalaeontological studies in a distinguished professional career extending from 1927 to 1961. Although her main interest was the foraminifera, she was required, at a time when there were few professional palaeontologists in Australia, to turn her attention to many groups, and also produced publications on ostracods, diatoms, conodonts, and radiolarians. In recognition of her work her name has been commemorated in the foraminiferal genera *Crespinella* and *Crespinina*, and has also been given to many species.

One of us (D.J.B.) has been associated with Dr Crespin during most of his professional career; the other (V.S.) has continued Dr Crespin's pioneering studies on Lower Cretaceous foraminifera in Australia. We feel honoured in being associated with the collection of papers in this volume, which is a tribute to Dr Crespin, from her friends and colleagues.

D. J. Belford *V. Scheibnerová*

FOREWORD

Irene Crespin, O.B.E., B.A., D.Sc., has both pioneered her field of study and become an internationally accepted specialist—a goal of many scientists. Therefore it is most appropriate to honour such a distinguished Australian micropalaeontologist with a commemorative volume of special papers in this, her eighty-first year; and it is a pleasure and honour for me to be associated with this volume, which was initiated and organized by her colleagues and foraminiferal specialists Dr D. J. Belford, who has carried on her work in the Bureau, and Dr Viera Scheibnerová.

I first met Irene Crespin when I was a vacation student with the Bureau in 1946; and when I joined the organization as a young geologist in 1950 I was privileged to be part of her research group studying microfossils collected by a field party (of which I was a member) in the Fitzroy Basin, Western Australia. It soon became obvious that Irene was quite a special person; those who have known her personally or have worked with her cannot help but be impressed by her drive, her enthusiasm, her wide range of interests, her ability to succeed (in many fields) against daunting odds and frustrations, her cheerfulness and humour, and her ability to get things done and get work published. Some autobiographical snippets were produced in a limited edition entitled *Ramblings of a Micropalaeontologist*, which gives an absorbing account of the problems that confronted palaeontologists in the early days of science in Australia; these were formative years for geology—particularly the role of women in geology—and for the Bureau of Mineral Resources.

Irene Crespin was born in Melbourne on 12 November 1896; she attended the Mansfield (State) Primary School and then, as one of its first students, the Mansfield High School (or as it was then known, Mansfield Agricultural High School) in northeast Victoria. It was here that her interest in geology and palaeontology was aroused by her headmaster, Dr Charles Fenner, an Australian geographer and geologist who searched for fish remains and fossil plants in the Carboniferous mudstones of the Mansfield district. She entered the Faculty of Arts at Melbourne University in 1915, and planned to be a teacher, having decided against a musical career—in spite of her success in higher music examinations.

Her interest in geology was further stimulated by the lectures of Professor Skeats, and her earlier interest in palaeontology was developed by Mr Frederick Chapman, palaeontologist at the National Museum, Melbourne, who was also lecturer in Palaeontology at the university. The influence of both Skeats and Chapman diverted her objective from teaching to geology, with special interest in palaeontology.

As one might expect, her ability and character were recognized at the university and she was elected the first woman President of the Student's Representative Council in 1918; other distinguished students at Melbourne University at the time were (later titles) Dame Mary Herring, Sir Robert Menzies, Professor Sir Keith Hancock, Sir Philip D. Phillips, and Professor Sir Kenneth Bailey.

After graduating B.A. in 1919 with special interest in the science subject of geology, she spent some years doing part-time research with the Victorian Geological Survey as well as teaching, before being appointed Assistant Commonwealth Palaeontologist to Frederick Chapman in 1927 in the newly created Geological Branch of the Department of Home Affairs; she succeeded him as Commonwealth Palaeontologist in 1936. Her appointment in 1927 started a memorable career in the Public Service, until her retirement in 1961 as chief micropalaeontologist and supervisory geologist in the Bureau of Mineral Resources. During her early professional career she provided (almost single handed) fundamental and important fossil expertise for companies and government involved in the search for petroleum in Australia and Papua New Guinea. She was closely associated with Dr W. G. Woolnough, the Commonwealth Geological Adviser from 1927-41 who, with Dr Wade, had such influence on petroleum exploration throughout Australia and New Guinea at that time. In these early years, a palaeontologist could not become too specialized as there were so few such scientists in Australia to study and advise on the wide variety of fossils received for examination—a task now shared by many specialist palaeontologists.

Even early in her career, Irene became well known for her work, and this, together with her drive and pursuit of information, enabled her to get out of the laboratory and into the field where geological problems originate; I wonder how many palaeontologists would have descended the old Gippsland oil shaft by bucket to collect samples—she was the first and only woman micropalaeontologist to do so. She travelled widely, both locally and overseas, financing these trips from both public and personal funds. There would be few palaeontologists, particularly micropalaeontologists, who would not know her, either personally or through her scientific publications; she made the effort to get out into the world and meet other distinguished scientists. Her resourcefulness and initiative were evident in the way she obtained seabed samples before the advent of JOIDES and the deep sea drilling techniques—by gently persuading a ship's captain that dropping anchor could become a scientific exercise; she would then carefully monitor the resultant 'catch' when it was hauled up!

Her move to Canberra from Melbourne in 1936, to substandard accommodation and poor equipment, was an epic experience in itself, and not many would have the humour and flexibility to endure the same conditions today. Staff numbers, finance, equipment and conditions improved, and shortly after the BMR was established in 1946, palaeontology became one of the pillars of the Bureau's program. Presently, with 15 palaeontologists, it covers all the main groups of fossils used in exploration for petroleum and minerals, and includes publication of the many and necessary stratigraphic and fossil descriptions for the international audience.

The fire the Bureau suffered in 1953 was a major blow to the organization and to many individuals, particularly to Dr Crespin, who lost priceless possessions, technical research papers, type collections, and photos. But as with other dedicated and determined scientists, it was a case of making the best of a bad situation, getting on with the job at hand, and rebuilding for the future. She has always been one who could commit herself quickly and clearly on paper, and her numerous publications in local and overseas journals attest to her great ability—87 papers as a single author, 23 as a joint author, and over 100 open file reports and notes, are monuments themselves to her ability in science during nearly 40 years of research.

As one might expect of someone with such character and activity, her life did not revolve entirely around science. She was always interested in people and sport; it was therefore not surprising to see her public spirit manifested in her appointment as an office-bearer on various social, sporting and technical committees. She was Secretary of the Royal Society of Canberra for 12 years and then President (the first woman to hold that office); she was Secretary, and later Chairman in 1957, of the Geological Society of Australia (Territories Division), and she has been very active in Soroptomists International as a charter member of the Canberra Club of Soroptimists, becoming its president in 1957.

Not only was she a tough competitor and top grade player in her prime, she still retains an active interest in all types of sporting endeavours. She played competition tennis and golf while at the university and is an Honorary Member of Kew Golf Club, Melbourne; on arriving in Canberra she transferred to the Royal Canberra Golf Club; with a handicap of 15, she was a forceful player and a well known personality on the greens. The Crespin Cup is annually contested for cricket supremacy between the local geologists—the 'hard' rocks and the 'soft' rocks; and woe betide her favoured 'soft' rocks if they don't perform creditably!

Irene's distinguished scientific and social careers are studded with Honorary positions, awards and titles; in 1960 she was made an honorary fellow of the Royal Microscopical Society, London (the only honorary fellow in Australia); she was given an honorary membership of the Geological Society of Australia in 1964, and is a life member of the Royal Society of Victoria and the Royal Society of Canberra; she was made an honorary member of Soroptimists in 1971, and an honorary member of ANZAAS in 1973—she is the only honorary member of ANZAAS living in Canberra. She was awarded the Coronation Medal in 1953, and then the Clarke Medal in 1956 from the Royal Society of New South Wales, for scientific research in Australia and its Territories—the first woman to receive this award. She was awarded the Degree of Doctor of Science by Melbourne University in 1960, and obtained the award of merit from the Commonwealth Professional Officers Association in 1961. Dr Crespin's career was highlighted by the award of the Order of the British Empire (OBE) in 1969, by Her Majesty Queen Elizabeth II, for public service.

This distinguished Australian, a leader in science as well as in other endeavours, is a dynamic personality who has, by her example and achievement, reached the highest levels in her profession. The motto of a sign adorning her office desk for many years—"Label today, tomorrow you will have forgotten"—typifies her ability to do things now, not put them off for another day.

2 November 1976

J. N. Casey

The Genus *Triplasia* (Foraminiferida) from the Miocene of Papua New Guinea

by

D. J. Belford

Three species of the genus *Triplasia*—*T. polymorpha* sp. nov., *T. dekkeri* sp. nov., and *T. rotundata* sp. nov.—are described from a lower Miocene sequence in the Yangi Beds, Wabag area, Papua New Guinea; another species is placed in open nomenclature.

The wall structure of *Triplasia* is considered to be simple, and the reported pseudolabyrinthic structure is considered to result from pyrite replacement of calcareous cement in the test wall.

INTRODUCTION

The species of *Triplasia* described here were first found in samples from the Yangi Beds, Wabag area, Papua New Guinea, collected by a Bureau of Mineral Resources geological field party in 1963. The geology of this area was given by Dekker & Faulks (1964), and by Dow, Smit, Bain & Ryburn (1972). Additional specimens were later found in a sample from the same formation collected during a geological survey of the Wabag 1:250 000 Sheet area in 1972; this sample is outside the area of the locality map given here (Fig. 1).

Because of different interpretations of the wall structure of species of the genus *Triplasia* given in published papers the specimens were first examined to determine the nature of the test wall. As the specimens could not be referred to any described species it was then decided to record the fauna and discuss the nature of the test wall for comparison with that of species described from other areas and other stratigraphical levels.

I wish to express my thanks to Dr R. Cifelli for enabling me to examine species of the genus *Flabellammina* deposited in the National Museum of Natural History, Washington, D.C.; to Dr J. Malecki and Dr S. Geroch for forwarding specimens of *Flabellamminopsis* from the Middle Jurassic of Poland; to Dr W. Koch for forwarding topotype specimens of *Triplasia murchisoni* Reuss, and also specimens of *T. murchisoni* from the 110 m level in the Lathwehren 11 borehole; and to Dr P. J. Jones and Mr G. C. Chaproniere of the Bureau of Mineral Resources who read and commented on the manuscript.

Figured specimens and thin sections are deposited in the Commonwealth Palaeontological Collection (CPC), Bureau of Mineral Resources, Canberra, Australia, except for one thin section of *Triplasia murchisoni* Reuss, deposited in the collection of the Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover, FRG, under type number 10174. Additional specimens are deposited in the ESCAP Fossil Reference Collection (E) held at the Bureau of Mineral Resources. All dimensions in this paper are given in millimetres.

Genus **TRIPLASIA** Reuss, 1854

Type species: Triplasia murchisoni Reuss, 1854; original designation (monotypy).

Loeblich & Tappan (1952) gave a detailed discussion of the genus *Triplasia* and produced an extensive synonymy list; earlier, Bartenstein & Brand (1951) had placed *Frankeina* in the synonymy of *Triplasia*. Ziegler (1959) and Lindenberg (1967) also gave a detailed discussion of *Triplasia*, and each placed the genera *Flabellammina* Cushman, 1928 and *Flabellamminopsis* Malecki, 1954 in the synonymy of *Triplasia*. I am in full agreement with the comments made by Ziegler and Lindenberg concerning *Flabellamminopsis*, and cannot add anything to their discussions. However, after examination of *Flabellammina alexanderi* Cushman in the National Museum of Natural History, Washington, D.C., and of *F. magna* Alexander & Smith in the collections of the Bureau of Mineral Resources, I would retain *Flabellammina* as a distinct genus. *Flabellammina*

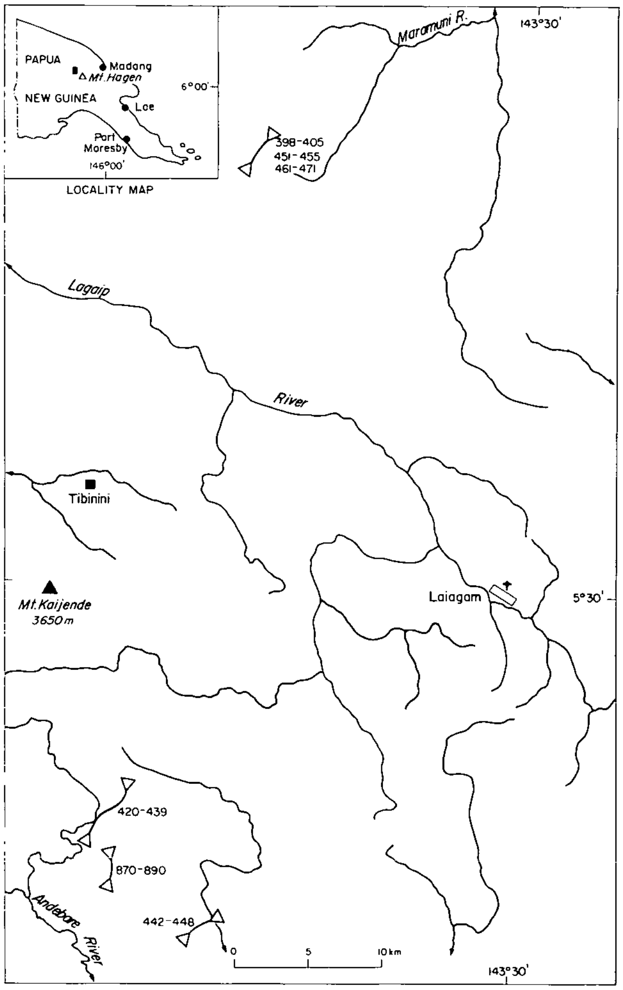

Figure 1. Locality map.

is a compressed agglutinated genus with simple test walls; no triangular or quadrate forms have been recorded. The aperture of *Flabellammina* is terminal, rounded to elongate, but is not produced, or at the end of a short apertural neck, as in species of *Triplasia*.

Triplasia polymorpha sp. nov.

Plate 1, figs. 1-12

Material examined: 73 specimens.

Derivation of name: From the Greek *polys,* many and *morphe,* form or shape, referring to the variation in test shape.

Diagnosis: A large species of *Triplasia,* compressed and flabelliform, or triangular throughout, or initially compressed and developing a low median ridge which results in an irregular triangular cross-section. Test wall coarsely agglutinated, of quartz grains with calcareous cement; aperture terminal, elongate, slightly produced, or with a short neck.

Description: Test large, compressed and flabelliform throughout, or becoming triangular in cross-section; some specimens initially compressed, later chambers developing a raised median ridge which results in a low irregular triangular cross-section. Specimens triangular throughout range in cross-section from almost equilateral forms to forms in which two sides are much longer than the third side. Early chambers coiled, later uniserial, chambers in uniserial portion broad and low, test widening slowly with growth or of almost uniform width throughout. Sutures narrow, slightly depressed, arched. Proloculus of compressed tests large, globular, that of triangular specimens not observed. Wall coarsely agglutinated, consisting mainly of quartz grains with large amount of calcareous cement, simple in structure. Aperture terminal, a narrow elongate opening, slightly produced, or at end of a short neck.

Dimensions:	*Length*	*Maximum width*
Holotype (CPC 15772)	1.93	1.47
Paratype A (CPC 15773)	2.16	1.33
Paratype B (CPC 15774)	3.33	1.47
Paratype C (CPC 15775)	2.51	1.60
Paratype D (CPC 15776)	2.36	1.40
Paratype E (CPC 15777)	1.76	1.05

Occurrence: Holotype (CPC 15772), paratypes A to C (CPC 15773 to 15775) and thin sections CPC 15778 and 15779 from sample F.435, Kindan section, Wabag 1:250 000 Sheet area, Papua New Guinea; paratype D (CPC 15776) from sample F.434, in the same section; paratype E (CPC 15777) from sample F.448 in a section southwest of Laiagam, Wabag 1:250 000 Sheet area, for which no details are available. Occurs also in sample 7152-8049, from the headwaters of Wage River, Wabag 1:250 000 Sheet area. Unfigured paratypes are deposited in the Commonwealth Palaeontological Collection under number CPC 15780. Additional specimens and thin sections are deposited in the ESCAP Fossil Reference Collection held at the Bureau of Mineral Resources under numbers E579 to E583.

Type level: Top of early Miocene, associated with a planktic foraminiferal fauna indicating zone N.8.

Remarks: Of the 73 specimens examined, 23 are compressed throughout, 44 are triangular throughout, 5 develop a low irregular triangular cross-section in later chambers, and one weakly quadrilobate specimen has been found. The largest specimens are triangular throughout and may be microspheric forms; those which are compressed throughout occur only in one sample and are the most abundant form (23 of 33 specimens or 70%). In the other samples from which *T. polymorpha* sp. nov. has been recorded most specimens are triangular throughout. The holotype is a large specimen with an irregular triangular cross-section. Triangular specimens from other assemblages are generally more regularly formed, but do contain specimens with an irregular cross-section; all specimens from assemblages containing only triangular forms are therefore referred to *T. polymorpha* sp. nov.

Thin-sections, polished surfaces, and test fragments of calcite-filled tests do not show any evidence of labyrinthic structure; irregular wall structure has been seen only in rare specimens infilled by pyrite (Plate 1, figs. 11-12). *T. polymorpha* sp. nov. is considered to have a simple wall structure and to be distinct from other described species of *Triplasia.*

Triplasia dekkeri sp. nov.

Plate 1, figs. 13-17; plate. 2, figs. 1-2

Material examined: 27 specimens.

Derivation of name: For F. E. Dekker, formerly of the Bureau of Mineral Resources, who led the geological party which collected the samples containing this species.

Diagnosis: A large species of *Triplasia,* compressed or triangular throughout, uniserial portion of triangular specimens with rounded angles and some specimens almost circular in section; wall smoothly finished, simple in structure; aperture terminal, slightly produced.

Description: Test large, compressed and triangular throughout. Compressed specimens almost uniform in width; triangular specimens uniform in width and slightly tapering towards last chamber, angles rounded, some specimens almost circular in section. Initial chambers planispirally coiled, later chambers uniserial; on compressed specimens low and broad, on triangular specimens becoming more equidimensional with growth, last chamber often higher than wide. Sutures indistinct on spiral chambers; on uniserial chambers narrow, depressed, arched. Test wall agglutinated, smoothly finished, consisting of quartz grains and calcareous fragments with high proportion of calcareous cement; structure simple. Aperture terminal, narrow, elongate, slightly produced.

Dimensions:	*Length*	*Maximum width*
Holotype (CPC 15781)	1.85	1.02
Paratype A (CPC 15782)	1.67	0.95
Paratype B (CPC 15783)	3.10	1.00

Occurrence: Holotype (CPC 15781) paratypes A and B (CPC 15782 and 15783) and thin section (CPC 15784) from sample F885 in a section southwest of Laiagam, near the Andebare River, Wabag 1:250 000 Sheet area, Papua New Guinea; known only from this sample. Unfigured paratypes are deposited in the Commonwealth Palaeontological Collection under number CPC 15785. Additional specimens and one thin section are deposited in the ESCAP Fossil Reference Collection held at the Bureau of Mineral Resources under numbers E584 and E585.

Type level: Top of early Miocene; associated with a planktic foraminiferal fauna indicating zone N.8.

Remarks: Of the 27 specimens examined, 18 are compressed throughout and 9 triangular throughout. As with *T. polymorpha* sp. nov., the larger specimens are triangular throughout.

T. dekkeri sp. nov. is distinct from other described species of *Triplasia.*

Only calcite-filled specimens of *T. dekkeri* sp. nov. have been observed; no irregular wall structure has been seen, and the test wall is regarded as simple, non-labyrinthic.

Triplasia rotundata sp. nov.

Plate 2, figs. 3-10

Material examined: 10 specimens.

Derivation of name: From the Latin *rotundus,* round, circular, referring to the circular cross-section of uniserial chambers.

Diagnosis: A large species of *Triplasia* with coiled compressed initial chambers, later uncoiled; subtriangular to circular in section, uniserial chambers uniform in width; test wall smooth, simple in structure; aperture terminal, produced.

Description: Test large, elongate, early chambers coiled, laterally compressed, later uncoiled, uniserial; uniserial portion of compressed specimens oval in outline, of other specimens subtriangular, elongate oval, or circular in outline. Uniserial chambers of compressed specimens uniform in width throughout, wider than high; on other specimens becoming equidimensional or last chamber higher than wide. Sutures indistinct on spiral chambers, on uniserial chambers horizontal, narrow, moderately to strongly depressed, margin of test of some specimens lobate on final chambers. Test wall agglutinated, smoothly finished, consisting mainly of quartz grains; pyrite grains also common, with large proportion of calcareous cement, structure simple. Aperture terminal, produced, narrow, elongate.

Dimensions:	*Length*	*Maximum width*
Holotype (CPC 15786)	2.41	1.02
Paratype A (CPC 15787)	2.66	1.06
Paratype B (CPC 15788)	2.86	0.97

Occurrence: Holotype (CPC 15786), paratypes A and B (CPC 15787 and 15788) and thin section (CPC 15789) from sample F399 near the base of a section at Burgers Mountains, Wabag 1:250 000 Sheet area, Papua New Guinea; known only from this sample.

Unfigured paratypes are deposited in the Commonwealth Palaeontological Collection under number CPC 15790. Additional specimens are deposited in the ESCAP Fossil Reference Collection held at the Bureau of Mineral Resources under number E586.

Type level: Top of early Miocene, associated with a planktic foraminiferal fauna indicating zone N.8.

Remarks: T. rotundata sp. nov. is distinguished by the less compressed and oval cross-section of the uniserial chambers of flabelliform tests, and by the subtriangular to circular cross-section of other specimens. The test wall of *T. rotundata* contains a high proportion of pyrite, seemingly as an original constituent of the wall; pyrite grains occur only rarely in one other species of *Triplasia* recorded from Papua New Guinea. It is not known if this is due to specific selectivity, or to limitations on the material available and suitable for test formation.

Only calcite-filled tests of *T. rotundata* have been observed, and no irregular test wall has been observed; the wall is regarded as simple in structure.

Triplasia sp.

Plate 2, figs. 11-13

Rare large specimens compressed throughout are placed here. The early chambers are coiled and the later chambers uniserial, very broad and low. The test wall is smoothly finished, consisting mainly of quartz grains, with pyrite grains and a high proportion of calcareous cement. The aperture is terminal, narrow and elongate.

Only four specimens are available and are insufficient for description and naming of this species; it is distinct from other described species in the present material.

Dimensions:	*Length*	*Maximum width*
CPC 15791	2.06	1.17
CPC 15792	3.33	1.76

Occurrence: Figured specimens CPC 15791 and 15792 from sample F399, near the base of a section at Burgers Mountains, Wabag 1:250 000 Sheet area, Papua New Guinea; known only from this sample.

COMMENTS ON WALL STRUCTURE OF *TRIPLASIA*

Bartenstein (1952) first applied the term pseudolabyrinthic to the test wall of agglutinated foraminifera, referring to forms in which the wall is strongly lobed and dissolved, with large spaces between the grains constituting the wall. He did not consider this wall type to have anything in common with true labyrinthic wall structure, which does not depend only on "solution of the wall". He later (Bartenstein, 1955) used the term pseudolabyrinthic for the test wall of species of the genus *Flabellamminopsis* Malecki, 1954. Malecki had described the wall as labyrinthic. Hagn & Ziegler (1957) and Ziegler (1959) discussed wall structure of agglutinated foraminifera, and concluded that the pseudolabyrinthic appearance depends on preservation and becomes distinct only by replacement of the calcareous cementing material by pyrite. Lindenberg (1967, p. 14) also considered agglutinated wall structure and gave a review of the literature to that time. In calcite-infilled specimens of *Haplophragmium* and *Triplasia,* Lindenberg observed a chitinous inner lining of the test wall, and small stolons forming perpendicular to the wall; these dichotomise, and were compared by Lindenberg to alveolinid canals. Pyrite-infilled tests showed the same structure. Discussing the genus *Triplasia,* Lindenberg (p. 35) also noted that labyrinthic structure was shown only in tests infilled by pyrite and that therefore the opinion of Hagn & Ziegler (1957) that this was a replacement structure could not be definitely excluded. Hofker (1957) illustrated a labyrinthic structure in specimens of *Triplasia murchisoni* Reuss (incorrectly referred by Hofker to *Flabellammina; murchisoni* is the type species of *Triplasia* and this name antedates *Flabellammina*). However, topotypes of *T. murchisoni* which I have examined, and which are infilled by pyrite, do not show any well-developed labyrinthic wall structure. A specimen from the 110-m level in the Lathwehren 11 borehole also does not have a well-developed labyrinthic structure (see Plate 3, fig. 6-7); specimens from this level in this borehole were figured by Hofker (1957).

Dr J. Malecki and Dr S. Geroch forwarded topotype specimens of species of *Flabellamminopsis* Malecki from the Middle Jurassic in the vicinity of Czestochowa, Poland; these specimens have been polished and examined under a scanning electron microscope (see Plate 3, fig. 1-5). These illustrations, particularly figures 2 and 3, show an irregular wall structure, variation in the size of the grains incorporated into the wall, and irregular spaces between the grains. The irregularity of the wall does not seem to me to be a labyrinthic structure, but to result from the differing grain sizes and perhaps also from partial solution of the test wall.

In Papua New Guinea specimens this apparent labyrinthic structure has been observed only in those rare forms infilled with pyrite (see Plate 1, figs. 11-12). As can be seen from the plates, specimens infilled with calcite show only a simple wall structure. These sections are very similar to the section of *Triplasia loeblichi* figured by Hagn (1953). Murray (1973) investigated the wall structure of some agglutinated Foraminifera. He found, among other characteristics, that the pores in several species with calcareous cement end blindly just beneath the outer wall and are normally developed mainly in the chamber walls on the sides of the test, being less well developed or absent in the apertural face and the septa. The forms with pores seem to be of stenohaline marine or hypersaline species. No definite pores have been observed in Papua New Guinea specimens; some of the tubular openings in the wall of species of *Flabellamminopsis* (Plate 3, figs 2-3) may be pores of the kind described by Murray. The stolons recorded by Lindenberg (1967) in specimens of *Haplophragmium* and *Triplasia* may also be part of a pore system.

On the basis of published discussion of wall structure in agglutinated foraminifera, particularly the genera *Halpophragmium* and *Triplasia,* and also from my own observations, I would agree with the opinion of Hagn & Ziegler (1957), and would interpret the labyrinthic appearance as not being a primary wall structure, but as resulting from solution of the test wall and from replacement of calcareous cement by pyrite.

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PLATE 1


1


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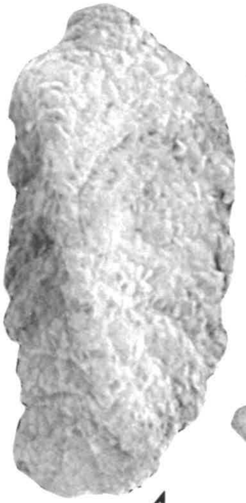
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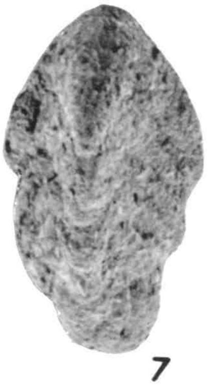
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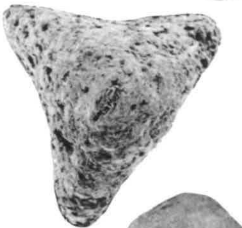
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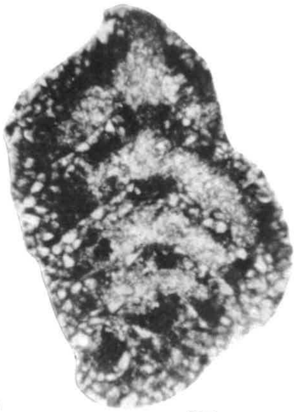
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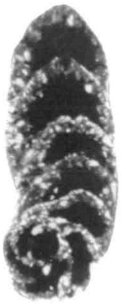
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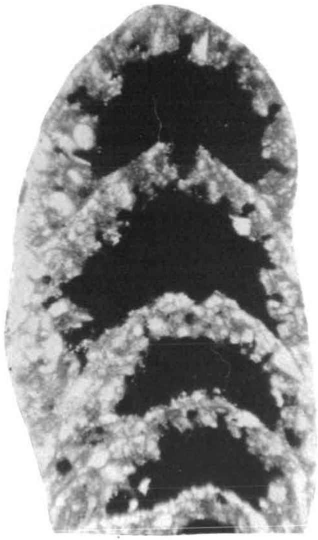
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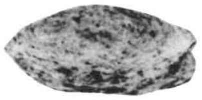
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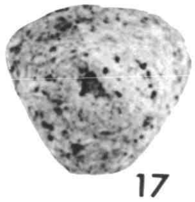
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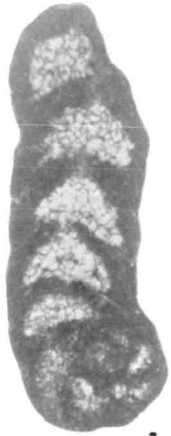
Triplasia polymorpha sp. nov.

Figs.	
1, 2	Holotype, CPC 15772. —1. Side view, x20. —2. Top view, x20.
3	Paratype A, CPC 15773, side view, x20.
4, 5	Paratype B, CPC 15774. —4. Side view, x20 . —5. Top view, x20.
6	Paratype C, CPC 15775, side view, x20.
7, 8	Paratype D, CPC 15776. —7. Side view, x20. —8. Top view, x20.
9	Paratype E, CPC 15777, top view, showing weakly quadrilobate test; x20.
10	Thin section of flabelliform specimen, CPC 15778, showing simple wall structure; x20.
11, 12	Thin section of triangular specimen infilled with pyrite, CPC 15779, showing irregular wall structure. —11. x20. —12. x52.

Triplasia dekkeri sp. nov.

Figs.	
13, 14	Holotype, CPC 15781. —13. Side view, x20. —14. Top view, x20.
15	Paratype A, CPC 15782, side view, x20.
16, 17	Paratype B, CPC 15783. —16. Side view, x20. —17. Top view, x20.

PLATE 2



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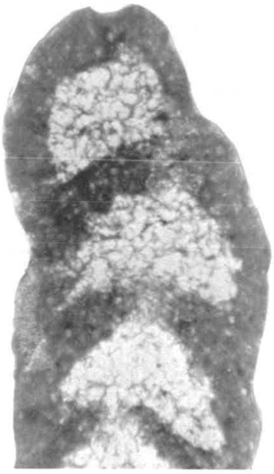

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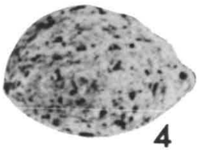

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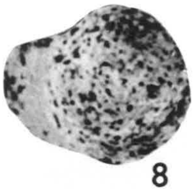

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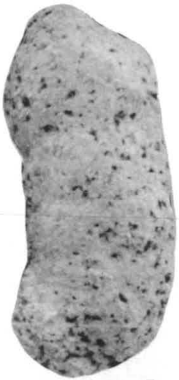

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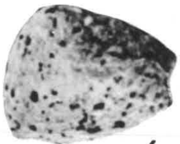

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Triplasia dekkeri sp. nov.

Figs.

1, 2 Thin section of triangular specimen, CPC 15784, showing simple wall structure. —1. x24. —2. x52.

Triplasia rotundata sp. nov.

Figs.

3, 4 Holotype, CPC 15786. —3. Side view, x20. —4. Top view, x20.

5, 6 Paratype A, CPC 15787. —5. Side view, x20. —6. Top view, x20.

7, 8 Paratype B, CPC 15788. —7. Side view, x20. —8. Top view, x20.

9, 10 Thin section, CPC 15789, showing simple wall structure. —9. x24. —10. x52.

Triplasia sp.

Figs.

11, 12 CPC 15791. —11. Side view, x20. —12. Top view, x20.

13 CPC 15792, side view, x20.

PLATE 3

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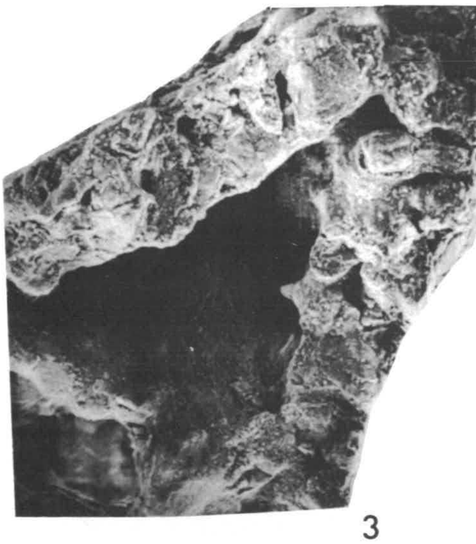

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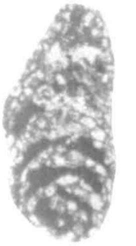

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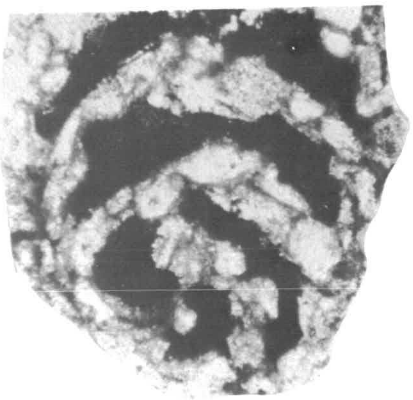

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Triplasia tricarinata (Malecki)

Figs. 1–3 CPC 15793, specimen from Czestochowa, Poland, *P. parkinsoni* Zone Middle Jurassic. —1. Top view of broken specimen, showing irregular wall structure; x40. —2, 3. Enlarged areas of photograph of fig. 1, x160.

Triplasia crassa (Malecki)

Figs. 4, 5 CPC 15794, specimen from Czestochowa, Poland, *P. parkinsoni* Zone Middle Jurassic. —4. Polished surface, x40. —5. Enlargement of fig. 4, showing irregular wall structure; x88.

Triplasia murchisoni Reuss

6, 7 Thin section of specimen from borehole Lathwehren No. 11 at 110 m (Upper Cretaceous), showing simple wall structure. —6. x24. —7. x62. Deposited in the collection of the Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover, F.R.G., under type number 10174.

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Notes on the geology of eastern Timor

by

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Current interpretations of the geology of Timor present a simplistic picture that fails to reflect the island's position astride the alpinotectonic thrust front which forms the eastern Indonesian sector of the circum-Cathay orogene opposite Australia. Recent offshore seismic surveys have clearly re-established the original concept of Timor representing the top part of a pile of southward thrusted nappes.

The oversimplified picture arose from incomplete and/or incorrect reading of the complex stratigraphic-palaeontologic record and possibly also from too much reliance on airphoto interpretation.

The only published map and description of eastern Timor shows e.g. too much Permian, too little Mesozoic, completely omits important occurrences of Upper Jurassic and Senon-Eocene formations, also of mid-Tertiary volcanic necks, and lumps extensive Tertiary block-clay masses of different ages into one single formation.

The problems presented by the alpine-style tectonics of Timor are still far from being resolved and this paper can only hope to assist in finding the direction in which further studies have to proceed.

INTRODUCTION

The contents of this paper are based on observations made from August 1957 to September 1958 when the author was Chief Geologist/Exploration Manager for Timor Oil Ltd (Sydney) and directed the work of a team of six young Australian geologists whose task it was to map the southern slopes of eastern Timor between the Indonesian border in the west and the meridian of the Mata-Bien Range in the east.

The western sector, with base in Suai-Cumnassa, was mapped by S. Rowe and B. Quinn, the central part around Same by G. Swindon and B. Boyd, and the eastern party, based in Viqueque, consisted of I. Freytag and P. Tetlow. In 1957 the writer was also assisted by A. Gourlay. The regular and rapid identification of microfossils was carried out in Adelaide by Prof. M. F. Glaessner, while macrofossils were determined by the author. This arrangement worked very efficiently, and the exploration team always knew the age of a formation immediately or within a very short time.

From October 1958 the team was redeployed and for a few months directed by an American consultant, Dr G. Downs. Thereafter it carried on without a senior resident Chief Geologist until mid-1959, when it broke up. A single professional, M. G. Audley-Charles, remained in place from 1959 with some interruptions until the end of 1961, and it is due to his efforts that an overall geological map and description of Portuguese Timor (Audley-Charles, 1968) ever came into print.

It seems, however, that he was not given access to technical reports written by this writer (e.g. the Quarterly Progress Report July-September 1958) which regularly summarized the advancing knowledge of the intricacies of east Timor's geology as gradually unveiled by the work of the three regional parties. The only report Audley-Charles (1968, p. 2) claims to have seen is one by I. Freytag (1959) which was concerned solely with parts of the eastern sector. It is evident that a lot of accumulated knowledge got lost because Audley-Charles remained unaware of many discoveries his predecessors had made.

Some concepts advocated in recent papers by Crostella & Powell (1975) and Grady (1975), which seem to be at variance with our 1957/58 observations, have finally prompted this author to unearth his notes, sketches, correspondence, etc. dealing with his Timor work in order to re-open the discussion on some important aspects of Timor's geology which, the writer believes, have been misinterpreted.

The invitation to contribute this paper to a volume which honours Dr Irene Crespin gives the writer particular pleasure not only because of his long association with Dr Crespin and her work, but also because she has made significant contributions to the knowledge of Timor's microfaunas—a matter of premier importance to the arguments presented here.

STRATIGRAPHIC NOTES

All stratigraphic observations are summarized in a comprehensive table (Table 1).

1. DISTRIBUTION OF PERMIAN AND TRIASSIC

The deepest visible tectonic element of the Timor nappe pile, commonly assumed to be autochthonous (but see below under Tectonic Notes), exposes a substantial Lower to early Upper Permian sequence (over 1000 m) as its oldest part. It comprises the Atahoc (below) and the Cribas (above) Formation (Audley-Charles, 1965, 1968). Both occur also on the north side of the eastern tip of Timor, at Loiquero.

In the southern slopes of the island only the Cribas Formation appears at the surface, and Audley-Charles (1968) mentions four areas, viz. along the south coast of the eastern tip of the island, then some 40 km to the west in the Afolita valley south of the overthrust Legumau Range, then again 40 km farther west along the

TABLE 1: STRATIGRAPHIC TABLES—COMPARISON OF INTERPRETATIONS

STRATIGRAPHIC TABLES COMPARISON OF INTERPRETATIONS 1953-1957			Audley-Charles 1968				Brunnschweiler (1957/58) this paper			Grunau 1953 and 1957	
			Autochthonous	Allochthonous			Pseudoautochthonous	Allochthonous		Pseudoautochthonous	Allochthonous
				Lolotoi Complex	Aileu Formation	Maubisse Formation		Lolotoi Complex	Aileu and Maubisse Complex		Nappe Complex
TERTIARY	PLIO-PLEISTOCENE		26/25/24				26/25/24			26/23	
	PLIOCENE		23/22				23/22/21			22/14?	
	MIOCENE	U	22/3				22/3			22/14?	
		M			×	×21			×	14?	×
		L	20				20		20*	14?	20/14*
	OLIGOCENE		19/2				19/3			14?	14*
	EOCENE	U	18				18			14?	14*
		M	18					×		14?	
		L	15	×			17/15/14		16	14	16/14*
	PALEOCENE		15				15/14		16	14	16/14*
CRETACEOUS	MAESTRICHTIAN		15/13			13	15/141		13	14	14*/13
	CAMPANIAN		15/13/12			13	14/12		13	14	14*/13
	SANTONIAN		13/12			13	14/12		13	14	14*/13
	CONIACIAN		12				12				
	TURONIAN		12				12				
	CENOMANIAN		12				12				
	ALBIAN		12						11?		
	APTIAN								11?		
	NEOCOMIAN								11?		
JURASSIC	MALM						10		10		
	DOGGER		9				9				
	LIASSIC		9				9			9	
TRIASSIC	RHAETIC										
	NORIAN		8				8		7	8	7
	CARNIAN		8				8		7	8	7
	LADINIAN		8				8			8	
	ANISIAN										
	SCYTHIAN										
PERMIAN	UPPER		5/3			6/2	5/3		6/2	5/3	6/2
	MIDDLE		5/3			6/2	5/3		6/2	5/3	6/2
	LOWER		4			6/2	4		6/2	4	6/2
PRE-PERMIAN				1/2	1/2			1/2	1/2		1/2

26 Baucau Limestones
25 Dilor Conglomerates
24 Seketo Block Clay
23 Lari Guto Limestone
22 Viqueque Formation
21 Bobonaro Scaly Clay
20 Cablac/Aliambata Limestone
19 Barique Formation
18 Dartollu Limestone

17 Coinassa Limestone
16 Globorotalia-Globigerina Limestone
15 Seical Formation
14 Bibilui Formation
13 Borolalo Limestone
12 Wai Bua Formation
11 Aileu Flysch
10 Buchia-Belemnopsis Shales
9 Wai Luli Formation

8 Aitutu (Mota Bui) Limestone
7 "Tutuala Limestone"
6 Maubisse Formation
5 Cribas Formation
4 Atahoc Formation
3 Minor volcanics
2 Major volcanics
1 Metamorphics

× Time of nappe emplacement (orogenic paroxysm)

* Marginally and only locally involved in thrust tectonics (e.g. in the Mata Bian Range)

River Cua north of Viqueque ('Viqueque Inlier'), and finally near the Indonesian border in the valleys of the Lomea and Bazol south of Bobonaro ('Bazol Anticline').

While the two easternmost south-slope occurrences are not contested because our 1957/58 work did not cover these regions (but note differences with Grunau, 1957), the Permian age of the presumably non-fossiliferous shales in the 'Viqueque Inlier' is certainly wrong. The sequence along the River Cua and in the steep slopes to the west and northwest of it is, in fact, fossiliferous. It contains *Halobia* and is Upper Triassic.

The westernmost Permian in the 'Bazol Anticline' is also suspect. For one thing the foraminiferal faunule found there (Audley-Charles, 1968, p. 8) could be Triassic as well as Permian, and for another it seems that the absence of *Atomodesma,* which elsewhere in the Cribas Formation is quite common, makes the case for a Permian age of the Bazol sequence rather unconvincing. It ought also to be remembered that Gageonnet & Lemoine (1958) must have had some good reasons for establishing a 'Flysch inférieur (?Ladinien)' as basal part of their 'Complexe triasico-jurassique' in these western parts of eastern Timor, reasons which we found to be well founded.

Audley-Charles's (1968) case is further weakened by the astonishingly young age (Norian) for what is said to be the basal part (Tallibelis Member) of the Aitutu Formation in this 'Bazol Anticline'. Since the presence of Ladinian is proven for the Cribas Anticline itself, and since the Aitutu Formation quite generally covers the Carnian and the Norian, one cannot but wonder where all the Carnian has gone here. Its sudden absence is all the more suspect when one knows that well-bedded limestones farther south along the lower reaches of the rivers Raiquetta and Fohra, shown on the map (Audley-Charles, 1968) as Jurassic, contain in fact Upper Triassic *Monotis.* The very fact that substantial areas of Triassic have been mapped as Jurassic, or even as Tertiary block clays ('Bobonaro Scaly Clay'), leads one to suspect that wishful thinking about the tectonics has resulted in loose interpretations. In any event, to claim there is an unconformity (mid-Permian to Norian!) between Cribas Formation and Tallibelis Member of the Aitutu Formation here, while at the same time admitting that the contact cannot be seen (Audley-Charles, 1968, p. 13), is rather too risky in view of the chaotic plasticity of most Mesozoic formations in Timor.

The south to southwest dipping sequence along the hill crest road from Zumalai to Bobonaro, which is supposed to traverse the Bazol 'Permian' before one arrives at the Lomea River crossing below Bobonaro, never reminded us in any way of the Cribas Formation. This all the less as in the critical area around the rocky hilltop called Loroba the grey flysch-like shales contain interbeds of radiolarian limestones (unknown in the Permian), and the conformable (with the shales and radiolarian limestones) overlying mass of non-fossiliferous well-bedded grey limestones of Loroba Hill itself can in no way be likened to the fossiliferous limestone intercalations of the Cribas Formation. This whole sequence is best regarded as Triassic or Triasso-Jurassic.

This contention is further supported by the observation that, compared with our detailed work of 1957/58, Audley-Charles's map (1968, Pl. 13) of these southwestern slope areas presents not only an oversimplification in general, but that in some areas it is downright wrong.

For example, the mountain of Tilomar near the Indonesian border west of Suai is shown on the map as consisting of Bobonaro Scaly Clay (Tertiary block clays) covered by a couple of small patches of Viqueque Formation and, to the south, by a large southward-dipping terrace of young coral limestone (Baucau Limestone). In fact, Tilomar mountain is built up of a conformable, gently southward dipping, sequence with well-bedded blue-grey limestone as oldest exposed formation, grading upward into a sandstone (brown) formation with some limestone interbeds in its lower part, and this is overlain by radiolarian limestone with interbedded shale. That most likely Triassic sequence is finally capped right at the top of the mountain, around the Administration Post building, by well-bedded white and red crinoidal limestones which we regarded as a thrust sliver of Permian connected possibly with the north-dipping big slab of overthrust basic igneous rocks (with melaphyres, diabases) on the mountain's northeast flank. Tertiary block clays we found slapped on only over the lower north-northeast slope of Tilomar mountain.

Substantial areas of Triassic and/or Jurassic are shown as Tertiary block clays also on the Carar Ulo River (Baulella-Fatulor area northwest of Debos) and farther east in the foothills between the rivers Raiquetta and Lomea. Every one of these rivers and their tributaries has been walked up and mapped in detail by Messrs Rowe and Quinn in 1958 (several times in the writer's company) and it is quite obvious that also along the northern limb of the Beco Syncline the local development of the Viqueque Formation rests unconformably on Triassic-Jurassic shale-sandstone series. If there are any block clays at all in this area they may occur at best in the form of high-level erosional remnants on some watersheds.

It is interesting to note that Kutassy (1931) described Triassic fossils 'from the Suai area', collected by L. von Loczy, and this writer does not think they came from floaters in block clays (not, of course, recognized as such then) but from the very substantial 'autochthonous' Triassic exposures in that foothill region.

Still another area where too much Tertiary block clay is mapped at the expense of certain Triassic is in the upper reaches of the Lomea River east of Bobonaro.

On a joint exercise in May 1958 with the centre party from Same (G. Swindon, B. Boyd) we walked the Lomea gorge from the road crossing below Bobonaro upriver to the last main fork about 5 km due east of Bobonaro, and then climbed out northward to where the Bobonaro-Atsabe-Dili road turns northward across the slope of the western spur of the Ramelau (Tata Mailau) Range. Apart from being the best place to demonstrate the nature of the young block clays themselves, this part of the gorge also displays the rough erosional relief of the surface on Mesozoic rocks upon which the block clays rest.

At the road crossing, the clays rest on 20° southwest dipping limestone of the Loroba Flysch type (see above). From there northward and then east to a small northern tributary 1.5 km east of Bobonaro the surface of the Mesozoic base is not exposed, the river running in block clays. The Mesozoic appears again north of the river just before one arrives at this tributary, and it consists of 7° southwest dipping green sandstone with thin pebble layers. From there eastward reappear successively dark *Halobia*-shales (Tallibelis type?) on the north side and radiolarian limestone south of the river, then well-bedded grey sandstone with a 35° west dip, thereafter up to the end of the traverse at the river fork 5 km east of Bobonaro highly contorted thin-bedded radiolarian limestones overlain south of the river by more gently south-dipping *Halobia*-shales which are interbedded with radiolarian limestones. Above this latter sequence follows in the south flank of the gorge a flysch-like sandstone-shale-limestone series very much resembling what is a little farther south called Permian by Audley-Charles (1968). The contorted radiolarian limestone continues in the steep slope northward up to the Bobonaro-Atsabe road and eastward into the southern limb of the Aitutu Anticline. As already shown by Gageonnet & Lemoine (1958) this anticline passes to the north of the upper Lomea to continue as the island's structural backbone towards the Indonesian panhandle between Lolotoi and Balibo.

A fourth area where substantial outcrops of Triassic have been interpreted as floaters in young block clays (Audley-Charles, 1968) is the valley of the Mota Bui near Aliambata. The contorted thin-bedded radiolarian limestones here were, in fact, taken as type locality for the autochthonous Triassic carbonate facies (now Aitutu Formation) by the Shell Company geologists Escher and Grunau, i.e. their Mota Bui Formation.

Unlike the big exotic floaters of different, massive Triassic limestone in the Ossulari region, 15 km to the southwest, the Mota Bui Triassic presents no obvious aspects which would force one to regard it as block clay component. For one thing, large masses of such tectonized thin-bedded, and often shale-parted, limestones are not likely to remain together. In fact, although being common components in the block clays, they are regularly found broken down into small angular fragments. It is even less likely that substantial series of soft clayey shales, e.g. the Triassic conodont shales on the road 1.5 km west of Aliambata (apparently not known to Audley-Charles), will stick together or remain attached to a mass of radiolarian limestone during the process of being dumped into a deep marine trough in front of the growing Timor nappe pile. It is a different matter, however, when such masses become involved in nappe tectonics; in such structures they may well remain coherent in spite of the deforming tectonic stresses. The structural complexity of much of the Aliambata-Mota Bui area is in our opinion more likely due to thrust tectonics than to olistostromic phenomena, however important the latter may be in some other regions of Timor.

According to our observations as well as those of Gageonnet & Lemoine (1958), and of Grunau (1957), there is a wider spread of remnants of the overthrust Maubisse Formation than shown on the map of Audley-Charles (1968). For example, peaks of massive fossiliferous Permian limestone, as isolated outliers of the two western lobes of the Ramelau thrust mass, rest on the northwest-dipping Triasso-Jurassic sequence also to the west of the Bobonaro-Atsabe road, i.e. on the slopes which fall away to the valley of the Be Bai River. One of them forms the craggy summit (inhabited by mountain natives) immediately to the west of the narrow watershed saddle from which the road begins to descend over the steep north slopes of the main Ramelau ridge.

Near Atsabe itself (which appears to be placed too far to the west on the map of Audley-Charles, 1968), a short distance down the Lete Foho-Dili road eastward into the majestic gorge of the Bandeira River, which is bridged at the hair-pin curve shown on the map, one can see the classic Lochseiten-type (from the famous locality in the Helvetic Nappes in eastern Switzerland) thrust plane between Mesozoic shale (below) and massive Permian limestone (above) right along the road which is cut obliquely through the outcrop. The Maubisse Formation ought therefore to be shown as coming right down to the road there, which implies either a twin anticline as suggested by Gageonnet & Lemoine (1958) under, or a secondary (pli-faille?) thrust through, the north slope of the Ramelau Range.

It is also to be noted that the two tiny outcrops, shown on the map as belonging to the Lolotoi Complex along the Maubisse-Same road 3 km east of Aitutu village, consist of massive unfossiliferous limestone of unknown age (coralline Permian or Triassic?) which rest on Jurassic Wai Luli rocks well below the Lolotoi thrust plane. They are as enigmatic a phenomenon as a number of similar unfossiliferous, evidently tectonically emplaced, limestone masses farther east (e.g. Fatu Calau-Foho Feho), but they certainly do not belong to the metamorphic Lolotoi Complex or to some Tertiary block clay sequence.

That the overthrust and largely epimetamorphosed Aileu Formation (Formation?) is in part Permian (Gageonnet & Lemoine, 1958) is indicated by an occurrence of mildly recrystallized crinoidal limestone of the Maubisse type along the north coast road between Hera and Hetenaro. Much of it, however, may be flysch of early Cretaceous age (see below, p. 13).

2. PRESENCE OF UPPER JURASSIC

According to Audley-Charles (1968) the Wai Luli Formation does not extend beyond the Middle Jurassic, and it is claimed that Upper Jurassic formations are absent.

That is not so. The characteristic Oxford-Kimmeridgian *Buchia-Belemnopsis* fauna, widespread in Australasia, is also present in eastern Timor. This should already have been evident from the literature (Wanner, 1956; Grunau, 1957), and our observations confirmed it.

In the lowest tectonic element, i.e. the autochthonous, the fauna occurs along the Bobonaro-Lete Foho-Dili road (a) in reddish and yellowish shales in the north flank of the Aitutu Anticline (see also Wanner, 1956), then (b) on the north slope of the Ramelau Range spur which forms the northern wall of the Bandeira Valley. At this locality the shales are tectonically stressed, the *Buchia* specimens being squashed and the *Belemnopsis* stretched. This repetition of the Upper Jurassic is due either to the existence of an Aitutu 'Twin Anticline', as advocated by Gageonnet & Lemoine (1958), or to an upthrust (pli-faille?) striking along the Bandeira which would result in a doubling of the Ramelau thrust sheet (Maubisse Formation) across the summit region of the Ramelau Range.

The *Buchia-Belemnopsis* fauna occurs also in the higher tectonic elements, for instance again along the Bobonaro-Lete Foho-Dili road 2-3 km south of Lete Foho, where red sericitized slate contains *Buchia* (barely recognizable) and *Belemnopsis* overstretched, i.e. invariably torn into axially aligned fragments separated by empty and/or calcite-filled cylindrical voids.

This occurrence opens an interesting new vista on the age of substantial parts of the mostly epimetamorphic mass of flysch known as Aileu Formation (Audley-Charles, 1968). If one draws a line from this area near Lete Foho northeastward along the strike of these basal parts of the Aileu element one arrives in the region south of Sarin in the upper reaches of the Laclo River before the final climb of the road from Dili to Maubisse. Not far after the beginning of this climb we found in purplish calc-schists slightly tectonized (flattened and oval shaped) Permian ammonites which the writer identified as *Propinacoceras* cf. *P. transitorium* Haniel, *Paralegoceras* cf. *P. sundaicum* Haniel, *Adrianites* sp., and *Parapronorites* sp. and/or *Medlicottia* sp. The question arises how much of this Aileu element consists of northward increasingly dynamometamorphosed Mesozoic flysch of post-Oxford/Kimmeridge age rather than Permian and, furthermore, whether the Aileu and Maubisse sequences are in fact separated by a thrust plane at all.

The apparent absence of Triassic and Lower Jurassic in this higher tectonic element is not surprising if one considers that the thrust mass came from a region quite some distance (120-200 km) away in the north, i.e. from a region which may well have had a sedimentary history rather different from that of the Timor Island area itself (Grunau, 1953, 1957; Wanner, 1931, 1956; Audley-Charles, 1968).

Another locality where the *Buchia-Belemnopsis* fauna occurs has already been mentioned by Grunau (1957). In the Aliambata area (Duro Uato Uai Creek) we too found it in calc-shales participating in a pile of thrust slivers which simulate an autochthonous anticline ('Aliambata Anticline'). *Buchia malayomaorica* (Krumbeck) is also known from near Pualaca (Wanner, 1956; Grunau, 1957).

3. UPPER CRETACEOUS, PALEOCENE, AND EOCENE

Numerous disconnected occurrences together with facies and faunal variety and tectonic complications make the reading and interpretation of the record contained in eastern Timor's Upper Cretaceous to late Eocene rocks very difficult, but the complexity of this record is rather played down in the formationological and nomenclatorial treatment by Audley-Charles (1968).

The Upper Cretaceous is represented by three formations: (1) the autochthonous, largely radiolarian, and strongly tectonized Wai Bua Formation, restricted to the south slope area between the rivers Sui and South Laclo; (2) the also largely radiolarian and equally if not more tectonized Seical Formation (Upper Cretaceous to mid-Eocene), restricted to a small area on the north coast just east of Baucau; (3) the Borolalo Limestone (Upper Senonian) which is said to occur in both autochthonous and allochthonous situations.

This subdivision replaces an earlier one that recognized only one authochthonous Upper Cretaceous-to-Lower Eocene formation for which we (1957/58) used the name 'Bibiliu Series' after Grunau (1953, 1957), although the latter author was uncertain about the formation's upper age limit (Pliocene?). However, numerous carefully collected samples—there is always danger of pollution of a sample's foraminiferal fauna from the overlying Mio-Pliocene Viqueque Formation—gave always the same result as to age: Senonian to Paleocene/early Eocene. Another trap to be avoided was to label as 'Bibiliu Series' samples which, in fact, had been collected in the occasionally red (ferromanganiferous material reworked from Bibiliu clays) basal beds of the Viqueque Formation. Grunau (1957) had drawn attention to this, and it appears that some current oversimplified concepts would not have arisen if such observations had been kept in mind.

Our 'Bibiliu Series' therefore included Audley-Charles's (1968) Wai Bua and Seical Formations, as well as all block clays (commonly red, and rather shale than clay) which are older than the Upper Miocene-Pliocene Viqueque Formation, i.e. are overlain by the latter unconformably. By the same token it did, of course, not include block clays of Viqueque or post-Viqueque age such as those of the Bobonaro area, i.e. the type for the Bobonaro Scaly Clay of Audley-Charles (1965). This matter and its consequences will be further discussed later in this paper. Equally important is that the 'Bibiliu Series' always underlies the 'Fatu Limestones' of old, whatever the age of the latter may be, whereas the Viqueque and post-Viqueque formations lap onto them. In other words, if all the 'Fatus' were (not all are) of Lower Miocene age (Cablac Limestone of Audley-Charles, 1968) it is evident that the 'Bibiliu Series', including its block clay facies, cannot be younger than Oligocene. Furthermore, since the volcanic Barique Formation commonly seems to be interposed between 'Fatus' and Bibiliu block clays, e.g. at Mount Bibiliu itself, the age becomes even pre-Oligocene.

All this ties in very well with the Upper Cretaceous-Lower Eocene microfaunas of *Globotruncana*, small *Globorotalia* and *Globigerina* and, occasionally, nummulitids (Seical) which characterize the 'Bibiliu Series'. The term 'fauna of small *Globorotalia-Globigerina*' conforms, of course, to the pertinent concepts micropalaeontologists held in the late 1950s, before the taxonomic revisions which began to appear in the mid-1960s.

The conclusion is that the original concept of a 'Bibiliu Series', in terms of regional stratigraphy, was perfectly valid and need not have been discarded because some Mio-Pliocene elements had been erroneously included, and certainly not simply in favour of only two of its three aspects (Wai Bua and Seical Formations), thereby neglecting its block clay facies which, incidentally, does not contain post-Eocene components, whereas Viqueque and post-Viqueque block clays, of course, do.

The Borolalo Limestone, as Grunau (1953, 1957) already noticed, is quite certainly an allochthonous element, most of all at its type locality. What is said about Aliambata No. 1 well (Audley-Charles, 1968, p. 19) is not correct. The records of that well do exist and are perfectly reliable. Set at the foot of the big rock face of the type section of the Senonian Borolalo Limestone it first entered Paleocene-early Eocene *Globorotalia-Globigerina* limestone, below which were again Boralalo Limestone beds with *Globotruncana*. Then followed an overturned Senon-Eocene limestone sequence characterized by the already mentioned foraminiferal faunas. At about 550 m the drill entered a different, grey, type of limestone; a core was taken, and it contained *Halobia*. After about 25 m this Triassic again gave way to *Globotruncana* limestone, at which point this writer recommended by cable to the Company to abandon the well as it was all too obviously located on a complex pile of allochthonous elements. The Company decided to carry on and continued the well, later at times under great technical difficulties (large losses of drilling mud into broken rock and cavities, fishing jobs), to a total depth of 1355 m without reaching the base of that overthrust complex ('multiple faulting' in Audley-Charles, 1968).

The Borolalo type *Globotruncana* limestones, commonly associated with similar but slightly younger *Globorotalia-Globigerina* limestones, have a much wider distribution than Audley-Charles (1968) indicates. In the west, apart from floaters up to house-size in the block clays between the rivers Tafara and Raiquetta, there is also an outcrop (floater?) in the little creek below the Ranuc oil seep near Debos. Several large Borolalo blocks occur in the Wai Luli gorge jammed into the contact between south-dipping metamorphics (here altered basic tuffs) of the Lolotoi Complex and from the south steeply onlapping basal conglomerates ('Nagel-fluh'-type gompholite) of the Viqueque Formation. Whether these blocks are independent thrust slivers or represent evidence of a thin wedge of pre-Viqueque (Bibiliu) block clays cannot be decided.

Significant occurrences of Borolalo facies limestone are those in the watershed area between Cribas and Pualaca. The road into Laclubar, shortly after the turnoff from the Cribas-Pualaca road, passes immediately below a small group of timbered limestone hills. These limestones are folded and contain the typical Senon-Paleocene faunas of small foraminifera of that facies. Their folding is disharmonic against the underlying, regionally southwest-dipping, Triassic-Jurassic which, incidentally, contains red *Cyzicus* (*'Estheria'*)-shales in the exposures a little north of the turn-off. Because there is no evidence at all here of the presence of block clays these limestones must be overthrust elements.

Another thrust sliver of such limestone, found by F. Weber in this area, has been mentioned in Grunau (1957, p. 89). To the south still another one sits on Triassic just west of the village of Fatu Berliu (Grunau, 1957, p. 90). From this region eastward there are other allochthonous Borolalo elements (Grunau, 1953, 1957), and there is no reason to assume that even the largest contiguous Borolalo Limestone outcrop on the island, that of Iliomar, is autochthonous.

It would in any event seem to be suspect that the Borolalo Limestone, which was laid down in the period shortly before and into the early stages of the first of the two major Tertiary paroxysms, should display identical facies in both its presumably autochthonous and allochthonous occurrences. Such a concept introduces complications into the palaeogeography of the region which are very difficult to resolve. Audley-Charles (1968, p, 19 under Environment) seems to have become aware of that, e.g. when he tries to explain why that other Upper Cretaceous sequence on Timor, the radiolarian Wai Bua Formation, is entirely dissociated from the distribution pattern of the Borolalo Limestone. All this is more satisfactorily explained through the notion that the Borolalo Limestone is an allochthonous element wherever it occurs in eastern Timor.

Audley-Charles (1974, pp. 360-61, fig. 7) has since suggested that the Wai Bua Formation may also be an allochthonous element which was thrust onto Timor at the same time as, i.e. together with, the Borolalo Limestone. While this is not impossible, it still fails to satisfactorily explain the dissociation of the two formations.

Thus, to conclude the discussion on the Upper Cretaceous, the *Globorotalia-Globigerina* carbonate facies of the latest Cretaceous to Paleocene, as does the Senonian Borolalo Limestone, characterizes the allochthonous elements in Timor, whereas the autochthonous complex displays the radiolaritic, in places detritic *Globorotalia-Globigerina* facies (with rare *Globotruncana*) with associated block clays. In the area surveyed by us (1957/58) we were able to confirm all of the allochthonous Senon-Paleocene elements shown as 'Te' on the sections in Grunau (1957), e.g. Mount Builo, Mount Ossu, Mundo Perdido (Wei Nete), Loi Una, Mount Bibiliu, and, as seen above, we found some more. On the map of Audley-Charles (1968) they are unfortunately not indicated at all, and the text takes their significance rather too lightly.

The records of the Eocene are also very complex, and their interpretation depends very much on accurate age determination of foraminiferal faunas. However, even from the approximate identifications for the 'Dartollu Limestone', published by Audley-Charles (1968, pp. 22-23), it is evident that it may be highly pertinent whether a fauna is of late Paleocene to earliest Eocene (Ilerdian/Cuisian) or of late Middle Eocene (Biarritzian?) age. It seems to have been overlooked that this age difference goes with geographic separation. The older fauna is known only from the 'Série de Same' (Gageonnet & Lemoine, 1958), whereas the type locality at Dartollu, and the material from Fehuc Reen, yield only the younger fauna. In other words, they do not represent two facies of the same limestone development and should not have been described under one and the same name 'Dartollu Limestone'.

While the limestones at Dartollu and Fehuc Reen are perhaps coeval and correlatable, it is advisable to treat the 'Série de Same' separately. After the name of the river along which it is exposed it may be called Coinassa Limestone. Its age, relying on the association of *Orbitolites* cf. *O. douvillei* (NUTTALL) with *O.* cf. *O. complanatus* LAMARCK and *Alveolina* sp. aff. *A. oblonga* D'ORBIGNY, is late Ilerdian/early Cuisian, i.e. very earliest Eocene (Hottinger, 1960; Lehmann, 1961), or earliest Ta_2 in the East Indian time scale.

The significance of making this distinction emerges when the topographic location and the geologic environment of the Coinassa Limestones is considered. With their basal grit and shale/sandstone they are found along and east of the Coinassa right up into the narrow depths of the gorge below the Same-Maubisse road. The northernmost outliers there are surrounded and surmounted (topographically) to the west, north, and east by high and steep mountain slopes consisting of phyllite and metabasalt of the Lolotoi Complex. In spite of diligent search by Messrs Swindon and Boyd we failed to find any occurrences of Coinassa Limestone in these slopes, i.e. earliest Eocene resting on the Lolotoi Complex. Our conclusion had to be that erosion has re-exposed the Coinassa sequence in a south-facing half-window after it had been covered by the overthrust metamorphics.

Since the Dartollu Limestone in its type area rests on top of the Lolotoi Complex, the Coinassa Limestone below, one can now conclude that the Lolotoi Complex was emplaced in the time interval represented by the age difference between the Coinassa and the Dartollu Limestones, i.e. in Lower to Middle Eocene times. In this context it is interesting to note that an early Eocene *Globorotalia-Globigerina* fauna was also found in the upper part of the series of tough dark shales and hard sandstones exposed in the creek just west of the Raimera coffee plantation (2 km west of Same). This sequence (shown as Jurassic on the map) dips at 60° north beneath the Lolotoi Complex of the Cablac group and is overlain downslope by the south-dipping Viqueque Formation.

4. THE TERTIARY CHAOTIC BLOCK CLAYS

The stratigraphic problems created by the ubiquity of Tertiary block clays are numerous, though not peculiar to Timor. These problems have not been satisfactorily resolved by lumping all the clays (except the Seketo variety) together under the concept 'Bobonaro Scaly Clay—Middle Miocene". Audley-Charles's (1968, pp. 47-48) reasoning for giving a Middle Miocene age to this formation is not at all convincing, and his subsequent attempts to find a better explanation have not improved the situation (Audley-Charles & Carter, 1972; Audley-Charles, 1974). While admitting that the microfauna in the clays is not older than Upper Miocene he still maintains that the age for both the formation itself and for the time of its emplacement by submarine sliding or slumping is Middle Miocene (Tf).

The critical questions which must be asked under such circumstances are:

I. How does a formation of Upper Miocene age arrive in place here during the Middle Miocene?
II. Why are there truly late Miocene and/or Pliocene block clays, but also block clays which are obviously older (unconformity!) than the Upper Miocene to Pliocene Viqueque Formation?
III. How old are the pre-Viqueque block clays really, since they can certainly not be Middle Miocene where they contain an Upper Miocene fauna?
IV. Do in fact all block clays contain an Upper Miocene and/or Pliocene fauna?

The very young age of large block clay masses in the hinterland of Suai, especially those of Bobonaro, was discovered in mid-1958 when the report of Prof. M. F. Glaessner on a sample from the basal clays at the Lomea River road crossing below Bobonaro described the microfauna as 'early Pliocene—deepwater fauna'. About the same time the east party geologists found similarly young block clays, including the very youngest (Seketo Block Clay), in the region between the rivers Mota Cua and Mota Bui, most of them south of Mount Builo near Fatu Dara, a klippe of early Eocene and early Miocene limestones. Subsequently a few small occurrences were also located in the Same region. Obviously, after these discoveries one had to be doubly careful when mapping block clays—while previously we had known of only one generation of them, we now had several. Consequently our mapping tried thereafter to distinguish between pre-Viqueque 'Bibiliu') and late (Bobonaro) or post-Viqueque (Seketo) block clays. Where this could not be done by direct observation of superposition, we used as preliminary indicators the difference in colour of clays or shales and the presence or absence of blocks of Lower Miocene Cablac Limestone. Eventually the decisive factor was, of course, the report on the microfaunas.

The regional picture, which emerged during the second half of 1958, was that the oldest block clay generation ('Bibiliu') was dominant east of a line Dili-Rai Mean, the Upper Miocene-Pliocene generation west of it, and that the youngest generation appeared to be restricted to the region east of Viqueque.

In trying to answer the questions posed above one must, to begin with, keep in mind that:

1. The pre-Viqueque block clays do not contain a Middle Miocene fauna.
2. Nobody has ever found any evidence for the presence of Middle Miocene formations in eastern Timor.
3. The Lower Miocene (Te) is represented by the Bahama-type (Audley-Charles, 1968) carbonate facies of the Cablac Limestone, and the Oligocene by the volcanic Barique Formation. Neither of these shows any evidence of genetic association with block clays.

This then leaves us with the choice between the following two conclusions:

Either (A) the block clays and the molasse-type Viqueque sequences are contemporaneous, side-by-side co-existing facies of one and the same Upper Miocene to Pliocene marine sedimentary story; i.e. the Bobonaro Scaly Clay is a member of the Viqueque Formation —or vice versa

or (B) the pre-Viqueque block clays are significantly older than Upper Miocene, in fact older than Oligocene, though younger than Senonian; but in this case there are also much younger, viz. Upper Miocene and/or Pliocene, block clays which must be mapped separately from the early Tertiary ones.

For this writer that is a Hobson's choice. The key to the solution lies evidently in question IV above, and how it is to be answered has already been indicated in the discussion on the validity of a 'Bibiliu Series' in the sense of Grunau (1953, 1957). During the 1957/58 exploration work it was found that, unless there was pollution from above (also in wells), the microfauna in pre-Viqueque block clays was always the early Tertiary *Globorotalia-Globigerina* assemblage. We were well aware of the possibility of conclusion (A) but, in the end, it had to be rejected, even in the face of the fact that it was near impossible to map clays of different age separately wherever the younger one was lying directly on the older.

Accepting Audley-Charles's (1965, 1968) interpretation means a return to point zero which, in view of his faulty argument for a Middle Miocene age of the formation, is not justified. It may also be mentioned that geologists with worldwide experience, such as H. R. Grunau and E. F. Escher (1953, 1957), who were also well versed in Alpine geology, would hardly fail to observe an onlap of pre-Viqueque block clays on 'Fatu limestone' (all older than Middle Miocene), if that were indeed so. Only the younger, post-Middle Miocene block clays do that (of which these two geologists were not then aware), and Audley-Charles (1965, p. 272; 1968, p. 49) is mistaken in stating: 'In the field the Bobonaro Scaly Clay is always found overlying the thrust sheets and never below them', if this statement means to include also the pre-Viqueque block clays.

It is also interesting to consider Audley-Charles's (1965, 1968) explanation of the genesis and emplacement of these block clays in the light of Prof. M. F. Glaessner's characterization of the Pliocene foraminifera from the base of the Bobonaro sequence as 'deepwater fauna'. This may well mean that the clays themselves have been laid down directly in deep water, and were not carried into this environment by sliding and slumping from higher levels of the submarine slope. Exotic materials, however, would have constantly arrived in the latter manner and, in so doing, might have enduringly disturbed the quiet sedimentary environment of the deepwater clays. In other words, while gravity slides and slumping are certainly important agents in the genesis of such chaotic formations, the conclusion that the whole mass was emplaced in the form of one or just a few large gravity slides, and that it is therefore entirely an allochthonous formation, does not necessarily follow. In this context it is well to remember that the 'Bibiliu' (pre-Viqueque) block clays are also associated with a deepwater facies, viz. the radiolarian and ferromanganiferous sediments of the Wai Bua and the Seical types.

One agrees with Audley-Charles (1965, 1968) in that a complex advancing thrust front must have been responsible for the creation of these exotic block clays. The analogous facies in the Alps, incidentally, is the 'Exotic Flysch', not the Wildflysch (Audley-Charles, 1965, pp. 271-72; 1968), as this author has tried to make clear elsewhere (Brunnschweiler, 1966). It is also clear that there are two phases of major thrusting discernible in Timor, one in the Lower and the other in the Upper Tertiary. Audley-Charles (1968) has called them Timorean and Ramelauan. It is perfectly reasonable to assume that the Lower Tertiary Timorean thrust front, as did later the Ramelauan, brought about its own block clay facies. Where is it? In the Lower Tertiary block clay facies of Grunau's (1953, 1957) 'Bibiliu' Series', of course.

Wherewith it would appear that everything has fallen in its proper place.

5. TERTIARY VOLCANICS

Tertiary volcanism in the Timor region is manifest in the Oligocene Barique Formation and to a lesser degree in the minor tuffaceous beds in the Viqueque Formation.

Whether the Barique Formation is really so prominent and widespread as shown on Audley-Charles's map (1968, Pl. 13) is another question. Its common association with the epimetamorphics of the Lolotoi Complex, which contains quite similar basic and ultrabasic rocks, must often make it very difficult to distinguish between the two.

The large patch of Oligocene shown around the eastern end of Mount Cablac and, in fact, topographically infilling the deep valley of the Coinassa (Cunhaca) River, is an example where parts of the Lolotoi Complex may have been wrongly assigned to the Barique Formation.

In the first week of July 1958 the steep flanks of Cablac's eastern spur were climbed in two traverses by G. Swindon and B. Boyd from the Coinassa River up to the base of the Cablac Limestone. They found nothing but generally SE-dipping (40-70°) dark grey to grey-green phyllonites (schistes lustrés) and greenish phyllite, which have surely nothing to do with the Barique Formation. Down in the Coinassa gorge and up the slopes east and north of the river they reported phyllonite and phyllite interbedded with altered basalt, greenstone (diabase), and probably basaltic tuff, but found it impossible to meaningfully subdivide the sequence. The same type of sequence is found northward up to the watershed between Coinassa and Wai Luli, where it rests overthrust upon a Jurassic limestone-shale series belonging to the south limb of the Aitutu Anticline. Altered basalts occur also in the Cablac south slope. They are, in fact, the first rocks of the Lolotoi Complex one encounters on the climb up the south face. The Lolotoi metamorphics surrounding and topographically surmounting the northernmost outcrop of the Coinassa Limestone (Dartollu Limestone of Audley-Charles, 1968) consist also of phyllite and altered basalt.

For what reasons is a substantial part of this typically Lolotoi sequence assigned to the Barique Formation? Anybody who knows the Coinassa Valley area will regard this Oligocene, which Audley-Charles (1968) depicts on the map as if it were infilling a modern valley—although overlain to the west by the Cablac Limestone—as very suspect, to say the least. Such an odd situation called for a well argued explanation which, unfortunately, was not given.

The statement in Audley-Charles (1968, p. 25), claiming there are no volcanic necks nor possible feeder-dykes which could have served as vents for the extrusion of the lava and tuff of the Barique Formation, is also not quite correct.

There are four prominent trachytic plugs 3 km north of Hatu Udo, the largest west and three smaller ones east of the road to Ainaro. They have penetrated pre-Viqueque ('Bibiliu') block clays and may have been mistaken for large exotic blocks by Audley Charles (1968) if, in fact, he has had a look at them. That they are not floaters is indicated by the observation that in all four the cooling jointing is vertical, i.e. they all stand upright, which could surely not be expected if they were exotic blocks. Moreover, there ought to be more of such trachytic exotics elsewhere in the block clays of Timor. Yet so far they are unique. Neither have igneous rocks of that type ever been noticed in the allochthonous complexes whence the exotics came.

It is not claimed here that there is a genetic relashionship between the Hatu Udo plugs and the Barique Formation, although this is theoretically possible because, as shown before, the pre-Viqueque block clays are pre-Oligocene. However, considering the modest size of these trachytic plugs, it is perhaps more likely that they have something to do with the thin vitric tuff beds in the lower part of the Viqueque Formation (Audley-Charles, 1968, p. 29).

TECTONIC NOTES

1. THE QUESTION OF TIMOR'S AUTOCHTHONEITY

Ever since the first geologist traversed eastern Timor 70 years ago along its axis (Hirschi, 1907) there have been contrasting interpretations of its structure. On reading the brief summary of the exploration history in Grunau (1953) one realizes that the co-existence of drastically opposed concepts such as are found again in recent papers by Grady (1975) and Crostella & Powell (1975) are nothing new.

The reason for the persistence of contrasting interpretations is the simple fact that geologists have as yet spent far too little time on the island. Some studied only a small area while others did little more than a few motorized traverses along the main roads. Even Escher and Grunau did not come farther west than the South Laclo River (Grunau, 1953, 1957), and Gageonnet & Lemoine (1958) did not see much of the geology to the east of that river. Yet the keys to the solution of a problem in the east are commonly found in the west, and vice versa. The most concerted and prolonged effort ever was Timor Oil Ltd's 1957-59 campaign, but even that was limited to less than half of the territory of eastern Timor, i.e. to the southern slope areas with suspected petroleum potential, although a number of excursions into 'forbidden' territories were carried out. Thus, no geologist before Audley-Charles (1968) has ever had the chance to see the whole of eastern Timor.

One ought to see the regional geology in an appropriate perspective. The distance from the Indonesian border to the eastern tip of the island near Tutuala is about 270 km. This means that eastern Timor alone compares directly with the length of the whole Swiss Alps from Lake Geneva to the Austrian border. Over much of its length the island is also just about as wide as the Central Alps.

A comparison with Switzerland is quite justifiable because the tectonic style seen in Timor immediately recalls that of the Central Alps to anybody who knows them. It took a century and a half and the work of hundreds of geologists to unravel the story of the Alpine Orogene, and even today some of its chapters remain hotly disputed. Timor may well be an even more difficult case, not only on account of its remoteness, but also because one suspects that what one sees is merely the top part of a very big pile of nappes which has just begun to emerge from the sea. Escher and Grunau (Grunau, 1953) already made it clear enough that they were uncertain about the autochthonous nature of the tectonically lowest element in eastern Timor by using the term 'pseudo-autochthonous'.

That the fundamental structure of the outer Indonesian Arc from the Andaman Sea (Weeks et al., 1967) to the Timor Sea is indeed an advancing pile of nappes has in recent years been well demonstrated by offshore seismic work (Beck & Lehner, 1974; Crostella & Powell, 1975). The overall picture indicates a considerable amount of crustal foreshortening which reflects an orogenic development going back to the end of the Cretaceous. Important parts of the earlier chapters of the story may be read in the mountains of Timor itself, but the records of the latest thrust movements are still hidden beneath the sea and can only be surmised from the interpretation of seismic profiles and offshore drilling.

Whatever the details of the current thrust-tectonic interpretations may be (Audley-Charles, 1968, 1974; Crostella & Powell, 1975), one must now certainly accept that there are no truly autochthonous structural elements exposed on Timor. At best there are what Gageonnet & Lemoine (1958) called neo-autochthonous formations ('post-orogenic' in part in Crostella & Powell, 1975). Even these must since the Pliocene have been riding southward on the back of the thrust front although they have not themselves moved from the place where they were deposited on the nappe pile.

In the light of the additional evidence from offshore seismic surveys it may seem superfluous to deal with the concepts of Grady (1975) who suggests that neither the Ramelau-Maubisse Permian nor the Lolotoi Complex is overthrust. It seems he cannot see the wood for the trees. One look at the deep re-entrant exposure of the Mesozoic in the Bandeira Valley between the Permian-capped western spurs of the Ramelau Range east of Atsabe should be enough to convince anybody of the correctness of the thrust notion. Moreover, there is no Triassic on the north-dipping back of the Maubisse Formation toward its contact with the Aileu element although Upper Jurassic beds occur in the basal part of the latter.

The occurrence of patches of Aitutu type Triassic within the Ramelau thrust mass itself near Maubisse (Grady, 1975)—even if proven by fossils, which is not the case—would not at all do away with the thrust theory. It has already been mentioned (p. 12) that the Maubisse Permian is probably doubled across the Ramelau Massive by a secondary thrust (pli-faille?), an interpretation which, incidentally, goes back to some of the earliest observers, e.g. F. Weber. Along this split, which may well strike out through the Maubisse area, slivers of Aitutu type Triassic could well have been dragged up. Considering all other complexities in Timor's tectonics, such drag-slivers are in no way unusual, even if they are no longer obviously overlain by Permian. In this context it is rather interesting to see that Grady (1975, fig. 3) in his section C-D shows a fault on the slope-side contact between Triassic and Maubisse Formation.

The Lolotoi Complex is quite definitely allochthonous. This can be seen perfectly in the steep north slope (along the 'new road') of the watershed ridge between the rivers Wai Luli and Coinassa where the Lolotoi sequence rests on the Mesozoic (here interbedded limestone and shale) of the south limb of the Aitutu Anticline and dips away to the south too at 40-50°. Because of the considerable relief of the surface on which the Lolotoi Complex rests (Grunau, 1957, p. 89) it must vary considerably in thickness, and a single gravity traverse near Mount Cablac (Grady, 1975) can hardly establish the Lolotoi's autochthoneity. It only indicates that Audley-Charles's (1968, Pl. 12) estimate of its local thickness was off the mark.

There is no future in denying the nappe tectonics of Timor and, as shown in this paper, one cannot always rely, as Grady (1975) does, on the observations and interpretations of Audley-Charles (1968). The fact that many 'Fatu limestones' are not simply Lower Miocene Cablac Limestone, but include Eocene, Upper Cretaceous, and older elements (Grunau, 1953, 1957) shows that e.g. point (f) of Grady (1975, p. 224) has not gone away through 're-interpretation in different ways'. Neither will his point (d) disappear. The differences in sequence and facies between the pseudo-authochthonous and the allochthonous elements are all too obvious.

2. TIMING OF OROGENIC MOVEMENTS

In the absence of any information about internal structures in the Palaeozoic of the allochthonous complexes nothing can be said about respective older orogenic events. Moreover, if there had been any subsequent, Mesozoic, orogenic movements before the latest Cretaceous, one would have to expect their records to be strongly overprinted by the Tertiary orogenies, and therefore very hard to find.

There are nevetheless significant gaps in the stratigraphic record in both the pseudo-autochthonous and the allochthonous units. In the former there is a break from the late Permian to the Ladinian, then again from the Kimmeridgian to the Cenomanian. In the allochthonous elements the hiatus is between the Permian and the Oxford-Kimmeridgian although there may have been a meagre and patchy development of reefal carbonates at some time during the Triassic, e.g. Tutuala (Grunau, 1957), Fatu Calau-Foho Fehuc, and similar mostly unfossiliferous limestones elsewhere. Whether such stratigraphic gaps are due to orogenic or epeirogenic events is not known.

The earliest of the alpidic thrust movements began probably at the end of the Cretaceous, so that by the Upper Eocene the Lolotoi Complex had been emplaced from the north onto Timor. Much of the chaotic deformation of the more plastic members of the Mesozoic to Eocene sequence—including the pre-Viqueque ('Bibiliu') block clays—would have taken place in this early Tertiary phase (Timorean, in Audley-Charles, 1968). There is an intriguing, but as yet unsolved, problem as to what the Lolotoi Complex carried on its back in terms of exotic formations from the north as well as of sediments deposited on it during its march southward.

The latest thrust movements recorded on Timor itself took place during the Middle Miocene (Ramelauan, in Audley-Charles, 1968). They involved derivates from the Maubisse Formation and from an as yet unnamed reefal ?Triassic limestone facies, as well as Borolalo Limestone (*Globotruncana* and *Globorotalia-Globigerina* carbonates) and Cablac Limestone (*Spiroclypeus*). Grunau (1953, 1957) already demonstrated that not all occurrences of Cablac Limestone (Tertiary e) are in situ, i.e. neo-autochthonous in the sense of post-Timorean. It is unfortunate that this situation is not evident on the map of Audley-Charles (1968), because he omits to show the tectonic 'interbedding' of the mentioned limestones.

After the Ramelauan paroxysm the upper-level thrust tectonics must have shifted southward into the present offshore front of the eastern Banda Arc, while the completed structure of what is now Timor Island—although further affected by mild folding and uplift—moved as a whole farther southward on a deeper-seated and still invisible detachment surface. Crostella & Powell (1975), in their generalized cross-section figure 7, claim overthrusting of what they call 'Undifferentiated Plastic Allochthonous' on the Viqueque Formation in the south slope of the Bobonaro Hills north of Suai. This seems to be an unwarranted extrapolation of situations (e.g. their figure 9) which may occur at depth offshore because on the island itself such young (Pliocene or later) thrust tectonics are not observable, neither in the Bobonaro area nor elsewhere. The Viqueque Formation on land is entirely an onlapping neo-autochthonous sequence, i.e. laid down after the Ramelauan thrust phase. Olistostromic material may occur on top of it, but not overthrusted elements.

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Foraminifera from the Mitchellian Stage

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Twenty-two species of foraminifera are recorded from the glauconitic clay facies of the Tambo River Formation in Gippsland, Victoria. Sixteen species are figured by stereoscan photographs; one is recorded from the Tertiary for the first time. This association is characteristic of the local Mitchellian Stage and also indicative of the internationally recognized *Globorotalia mayeri* Zone of Middle Miocene age. The age of the Mitchellian Stage, formerly thought to be Late Miocene, is revised accordingly.

INTRODUCTION

By this study of the Mitchellian Stage, a tribute is paid to the work of Dr Irene Crespin and one of her many contributions to Australian geology. The Mitchellian Stage was first proposed by Dr Crespin in 1943. Interest in this Stage continues and recent work on internationally applicable time-rock units in the Late Tertiary has prompted this search in the Bairnsdale district of Gippsland, Victoria, for the criteria of the currently recognized zones.

In the vicinity of Bairnsdale, the local "bedrock" is the Bairnsdale Limestone, a somewhat irregularly-cemented and, for the most part, poorly-stratified formation, though bedding is more clearly seen near its base and top. Overlying the Bairnsdale Limestone is a less abundantly calcareous rock unit known as the Tambo River Formation. This relatively unconsolidated formation has few good natural exposures, a circumstance which is responsible for the poor regional knowledge of it; furthermore, throughout the Bairnsdale/Tambo River area, outcrop sections of the Tambo River Formation are always truncated by unconformable or disconformable younger deposits of entirely different character. (Carter, 1964, pp. 23-31).

Crespin (1943) designated the Mitchellian Stage as being represented by a section of Tambo River Formation, about three metres in thickness, overlying the Bairnsdale Limestone at the Bairnsdale Pumping Station. Subsequent usage of the Mitchellian Stage has included all outcropping occurrences of the Tambo River Formation. The passage of the Tambo River Formation upwards into strata representing younger time-rock units cannot be seen in outcrops, but discussion of this sequence in bores and also of some components of its fauna has been given by Crespin (1943) and Wilkins (1963).

A widespread feature of the Tambo River Formation as a whole is its conspicuous content of glauconite, which may be seen at Moormurng, Nicholson River, Salt Creek, Swan Reach, Tambo River downstream from Swan Reach, and in the Toorloo Arm road cutting, Lake Tyers (Wilkins, 1963; Carter, 1964). At two localities which have figured prominently in previous discussions of the Mitchellian Stage, namely the Bairnsdale Pumping Station and Rose Hill (Crespin, 1943; Wilkins, 1963), the glauconitic facies is either not present or concealed within covered intervals. The glauconitic clay, being the most constant and widespread facies of the Tambo River Formation, has been chosen as the source of the foraminifera for the present paper. The preservation of this material makes it suitable for study by scanning electron microscope. Furthermore, there is some justification for regarding the widespread glauconitic facies of the formation as being representative and a third consideration has been the desirability of describing this Mitchellian assemblage from outcrops in the type area of the Stage, even if not from the nominated type locality at the Bairnsdale Pumping Station. The two localities sampled for this paper are Swan Reach and Allotment 15A, Parish of Moormurng (see Carter, 1964, pp. 23, 28).

ANNOTATED LIST OF FIGURED SPECIES

Massilina lapidigera (Howchin & Parr) 1938
Plate 1, fig. 1

Massilina lapidigera (Howchin & Parr) 1938. Carter, 1964, pp. 58, 59; pl. 1, figs. 1, 2.

Remarks: This species may achieve a large size of 2 mm or more. In the Bairnsdale district hornblende crystals, derived from granitic rocks to the north, frequently provide the "jewelling" of the test, alluded to by the trivial name.

Discorbinella biconcava (Jones & Parker) 1862
Plate 1, figs. 2, 3

Discorbinella biconcava (Jones & Parker) 1862. Carter, 1964, p. 86; pl. 5, figs. 97-100.

Remarks: The stereoscan photographs of this species show the character of the apertural flaps and the discreteness of the umbilical foramina, which are distinctive features of *Discorbinella*.

Cibicides mediocris Finlay, 1940
Plate 1, figs. 4, 5

Cibicides mediocris Finlay, 1940. Carter, 1964, pp. 97, 98; pl. 7, figs. 133-135.

Cibicides cygnorum Carter, 1964
Plate 1, figs. 7, 8

Cibicides cygnorum Carter, 1964. Ibid. p. 98; pl. 7, figs. 139-141. Albani, 1968, p. 30.

Remarks: The range of this species, formerly known only from the Bairnsdale Limestone and Tambo River Formation, has been extended to the Holocene by Albani (*Ibid.*).

Baggina philippinensis (Cushman) 1921

Plate 1, fig. 6

Baggina philippinensis (Cushman) 1921. Carter, 1964, p. 85; pl. 5, figs. 94-96.

Rosalina australis (Parr) 1932

Plate 1, fig. 9

Rosalina australis (Parr) 1932. Carter, 1964, p. 73; pl. 3, figs. 51-53.

Globigerina bulloides d'Orbigny, 1826

Plate 2, figs. 10-12

Globigerina bulloides d'Orbigny, 1826. Carter, 1964, p. 104; pl. 9, figs. 174-176; Kennett & Vella, 1975, pl. 1, figs. 1-4.

Globigerina falconensis Blow, 1959

Plate 2, figs. 13-18

Globigerina falconensis Blow, 1959. Parker, 1962, p. 264; pl. 1, figs. 14, 16-19; Blow, 1969, p. 319; pl. 16, fig. 1; Kennett, 1973, pl. 2, figs. 3, 4; Kennett & Vella, 1975, pl. 1, fig. 5.

Remarks: The figured specimens are comparable with those figured by Kennett (1973) but differ in surface texture from that figured by Blow (1969).

Globigerina woodi Jenkins, 1960

Plate 3, figs. 25, 26

Globigerina woodi Jenkins, 1960. Jenkins & Orr, 1972, pl. 11, figs. 10-12; Kennett, 1973, pl. 2, figs. 5-8; Kennett & Vella, 1975, pl. 1, figs. 9-12.

Globorotalia mayeri Cushman & Ellisor, 1939

Plate 3, figs. 19-24

Globorotalia mayeri Cushman & Ellisor, 1939. Kennett, 1973, pl. 13, figs. 12-16.

Remarks: Specimens of this species have five chambers in the last whorl and a slightly enlarged last chamber, thus distinguishing it from *G. continuosa* Blow, which has four chambers in the last whorl and also from *G. mayeri nympha* Jenkins, which has a diminutive last chamber. The five-chambered last whorl of the figured specimens agrees closely with specimens figured by Kennett (1973, pl. 13), Jenkins (1966, pl. 2, figs. 12a-c) and Jenkins (1971, pl. 11, figs. 297-299). Jenkins (*Ibid.* figs. 300-302) and Bolli (1957, pl. 28) have figured *G. mayeri* with six chambers in the last whorl. The significance of this difference is not clear.

Globorotalia miozea conoidea Walters, 1965

Plate 4, figs. 28-32

Globorotalia miozea conoidea Walters, 1965. Kennett, 1973, pl. 16, figs. 4-11; pl. 17, figs. 4-13; Kennett & Vella, 1975, pl. 7, figs. 6-8.

Remarks: Although agreeing with the description of the subspecies in degree of biconvexity, width of aperture, degree of pustulation of the area in front of the aperture and smoothness of the margin, all specimens from Swan Reach are more elliptical in marginal outline and more coarsely perforated dorsally than the typical form.

Nonion victoriense Cushman, 1936

Plate 3, fig. 27

Nonion victoriense Cushman, 1939. Carter, 1964, pp. 109-110; pl. 10, figs. 201, 202.

Cribrononion hawkesburiensis Albani, 1974

Plate 4, fig. 31

Cribrononion hawkesburiensis Albani, 1974. p. 38; pl. 1, figs. 12-14.

Remarks: This species is recorded from Tertiary deposits for the first time.

Elphidium parri Cushman, 1936

Plate 4, figs. 33, 36

Elphidium parri Cushman, 1936. Carter, 1964, p. 122; pl. 13, figs. 250, 251.

Elphidium crespinae Cushman, 1936

Plate 4, fig. 34

Elphidium crespinae Cushman, 1936. Carter, 1964, p. 121; pl. 12, figs. 240, 241.

Notorotalia howchini (Chapman, Parr & Collins) 1934

Plate 4, fig. 35

Notorotalia howchini (Chapman, Parr & Collins) 1934. Carter, 1958, p. 65; pl. 10, figs. 104-106; Carter, 1964, pp. 125, 126.

DISCUSSION

The foraminifera recorded here, plus additional records of pelagic foraminifera from the stratotype of the Mitchellian Stage (Carter, 1964) give an association of:

Globigerina bulloides
Globigerina falconensis
Globigerina woodi
Globigerinoides rubra
Globigerinoides triloba
Globigerinoides obliqua
Globigerinoides glomerosa curva
Orbulina universa
Globorotalia mayeri
Globorotalia miozea conoidea
Notorotalia howchini

This association of species occurs approximately 25 metres above the entry of *Orbulina universa* in the sequence near Bairnsdale (Carter, 1964) which was formed by slow, rather than rapid, deposition. The presence in the fauna of *Globorotalia mayeri* places an upper limit of Middle Miocene on its age and it does not represent a younger Zone than N.14 of Blow (1969). Study of this association and the age determination deduced from it has been conditioned by the prevailing scarcity of pelagic foraminifera in the Tertiary rocks of Gippsland and many species which might permit a finer zoning of the sequence have not yet been found. Nevertheless, there is no reason to doubt the precision of this upper limit to the age of the Mitchellian Stage even though a more accurate assignment within Blow's Zones N.9 to N.14 is not yet possible. Consequently, the former allocations of a Late Miocene age to the Mitchellian Stage by virtually all previous authors, must be revised in favour of a Middle Miocene age.

Kennett (1973) has defined a *Globorotalia mayeri* Zone on the basis of a species assemblage, to which the association listed above is regarded as being equivalent in age, although by no means all of Kennett's index species have been found in the present material. Kennett considers *Orbulina universa* to make its appearance within his *Globorotalia mayeri* Zone, which would therefore include Zones N.9 to N.13 of Blow (1969) and Zones N.9 to N.14 as identified by Jenkins (1971) and Kennett (1973). However, the full extent of that Zone is determined by the range of *Orbulina universa,* which ranges downwards throughout the Bairnsdalian Stage, represented in the area under discussion by the Bairnsdale Limestone and the upper part of the underlying Wuk Wuk Marl (Carter, 1964). If the *Globorotalia mayeri* Zone of Kennett (1973) is accepted as a Zone of type (iv) of Carter (1964, p. 45), no semantic problems need arise from the inclusion of both the Bairnsdalian and Mitchellian Stages within this Zone. Jenkins (1966) recognized a *Globorotalia mayeri* Zone in the Lakes Entrance oil shaft sequence, but did not relate it to outcropping formations or to the Australian Stage Classification, and since he recognised an *Orbulina universa* Zone below it, it would appear to represent only the upper part of the *Globorotalia mayeri* Zone of Kennett (1973) and also of the *Globorotalia mayeri mayeri* Zone of Jenkins (1971).

Elsewhere in Victoria, *Orbulina universa* occurs unaccompanied by *Globorotalia miozea conoidea,* thus suggesting that, at least locally, there may exist two subzones of the *Globorotalia mayeri* Zone, identified by the presence or absence of *G. miozea conoidea.*

The inclusion of *Notorotalia howchini* in the association listed above is in recognition of the potential stratigraphical value of the upper limit of the range of this species. *N. howchini* does not extend far above the level of the samples studied here.

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PLATE 1

Massilina lapidigera (Howchin & Parr) 1938

Figs.

1 Swan Reach. Side view; x38.

Discorbinella biconcava (Jones & Parker) 1862

2 Swan Reach. Oblique dorsal view; x160.

3 Swan Reach. Ventral view; x160.

Cibicides mediocris Finlay, 1940

4 Moormurng. Ventral view; x80.

5 Swan Reach. Dorsal view; x110.

Baggina philippinensis (Cushman) 1921

6 Swan Reach. Dorsal view; x110.

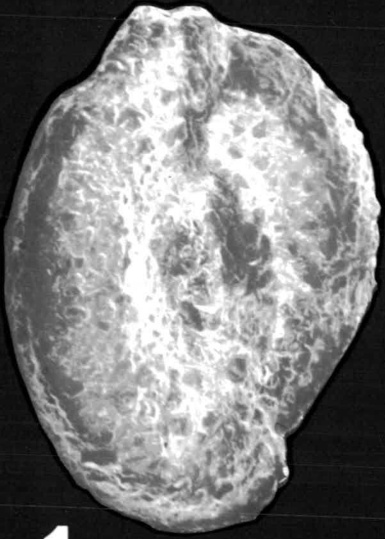
Cibicides cygnorum Carter, 1964

7 Moormurng. Ventral view; x110.

8 Swan Reach. Dorsal view; x110.

Rosalina australis (Parr) 1932

9 Swan Reach. Dorsal view; x190.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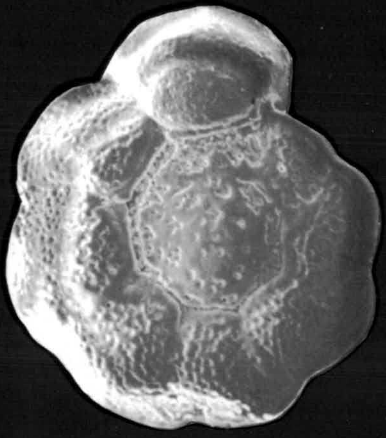
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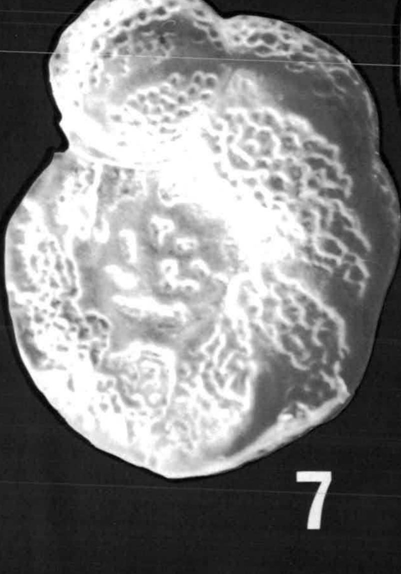
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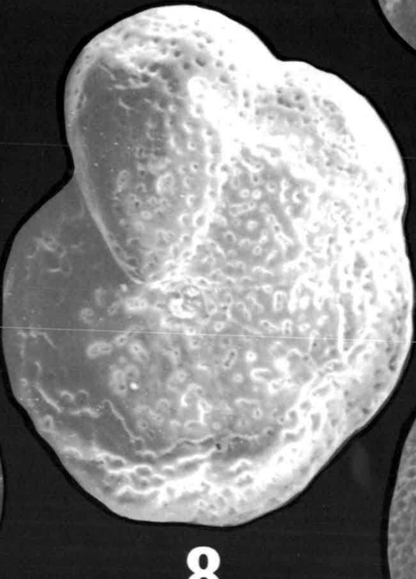
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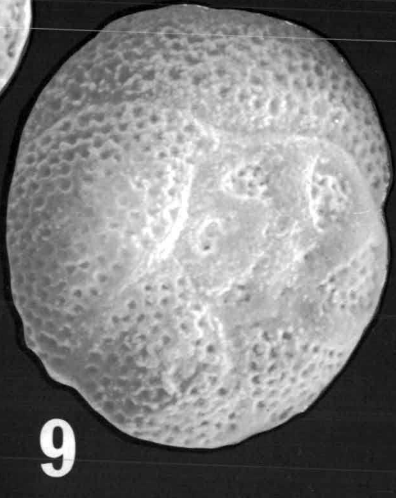
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PLATE 2

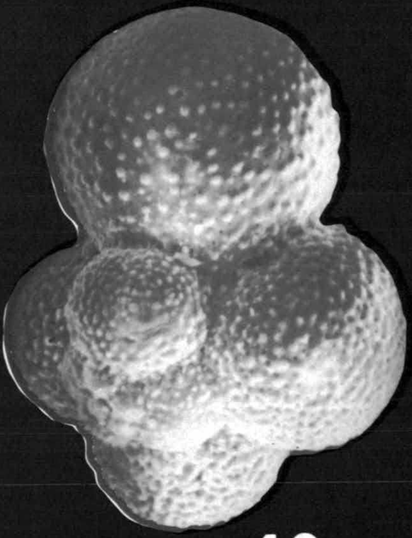
Globigerina bulloides d'Orbigny, 1826

Figs.

10 Swan Reach. Dorsal view; x160.
11 Moormurng. Side view; x125.
12 Moormurng. Ventral view; x160.

Globigerina falconensis Blow, 1959

13 Swan Reach. Oblique ventral view; x160.
14 Swan Reach. Oblique ventral view; x160.
15 Moormurng. Side view; x160.
16 Moormurng. Dorsal view; x160.
17 Moormurng. Side view; x160.
18 Moormurng. Oblique ventral view; x160.



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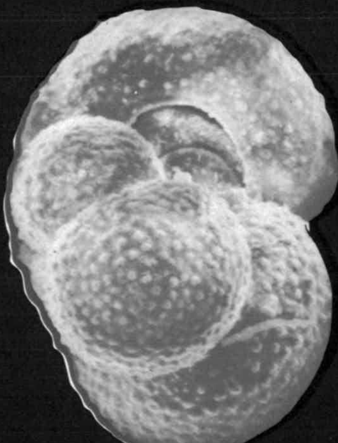

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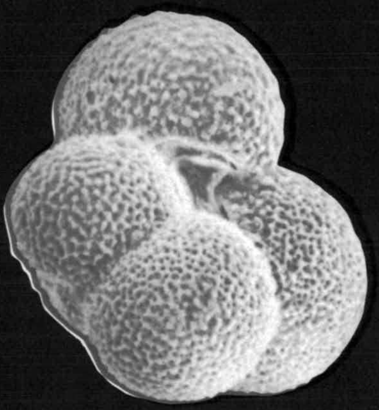

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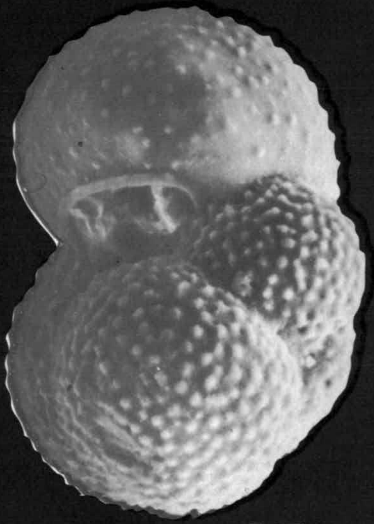

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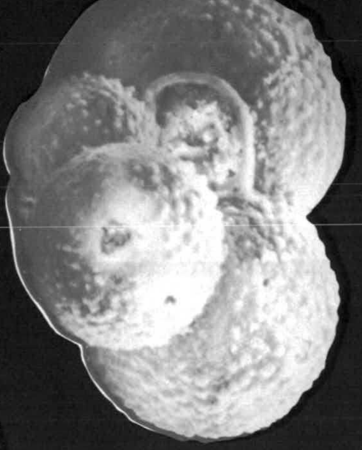

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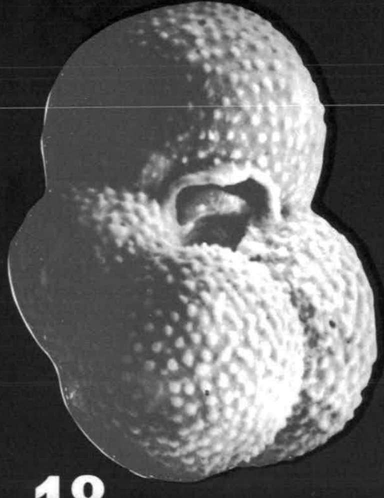

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PLATE 3

Globorotalia mayeri Cushman & Ellisor, 1939

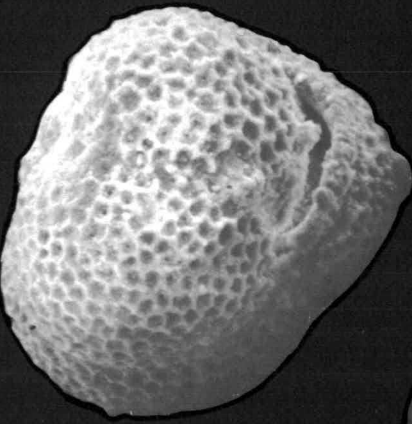
Figs.
19 Swan Reach. Side view; x190.
20 Swan Reach. Ventral view; x190.
21 Swan Reach. Side view; x190.
22 Swan Reach. Dorsal view; x190.
23 Swan Reach. Side view; x190.
24 Swan Reach. Oblique ventral view; x190.

Globigerina woodi Jenkins, 1960

25 Moormurng. Oblique ventral view; x190.
26 Swan Reach. Oblique ventral view; x120.

Nonion victoriense Cushman, 1936

27 Swan Reach. Side view; x140.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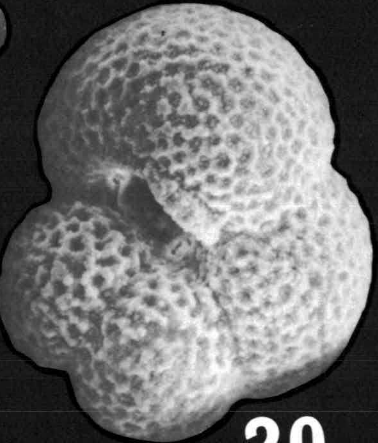
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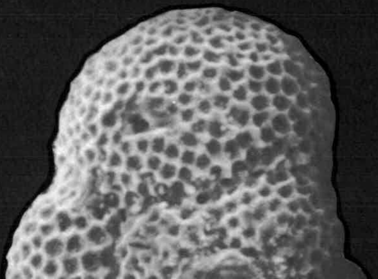
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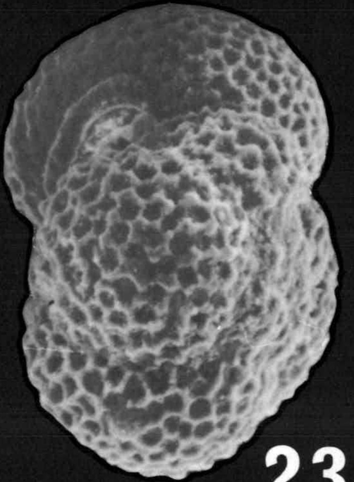
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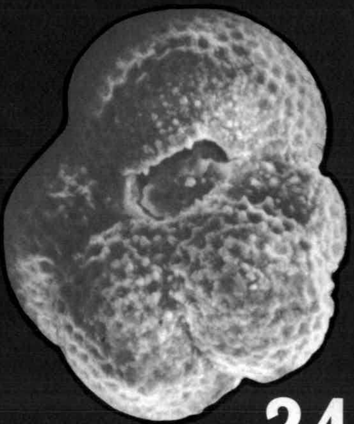
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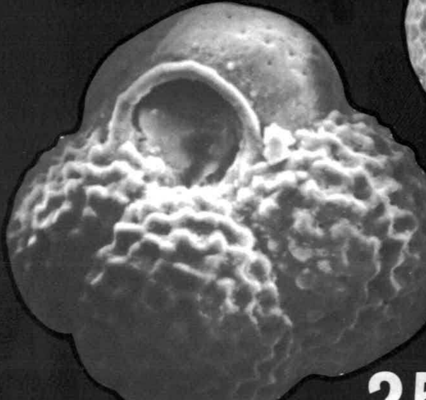
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PLATE 4

Figs.

Globorotalia miozea conoidea Walters, 1965

28 Swan Reach. Part of dorsal surface; x320.
29 Swan Reach. Oblique dorsal view; x160.
30 Swan Reach. Dorsal view; x250.
32 Swan Reach. Dorsal view, same specimen as Figs. 28 and 29; x160.

Cribrononion hawkesburiensis Albani, 1974

31 Moormurng. Side view; x220.

Elphidium parri Cushman, 1936

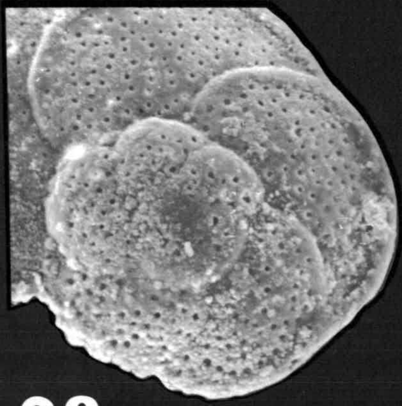
33 Moormurng. Side view; x95.
36 Moormurng. Apertural area; x190.

Elphidium crespinae Cushman, 1936

34 Moormurng. Side view; x100.

Notorotalia howchini (Chapman, Parr & Collins) 1934

35 Swan Reach. Dorsal view; x145.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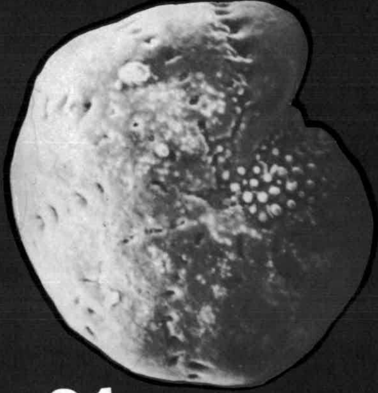
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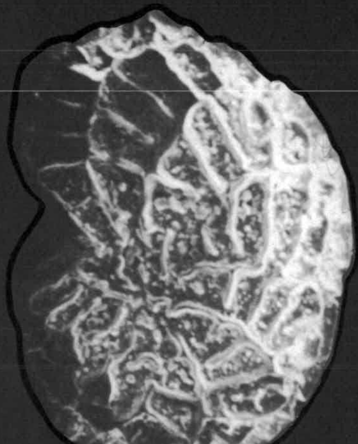
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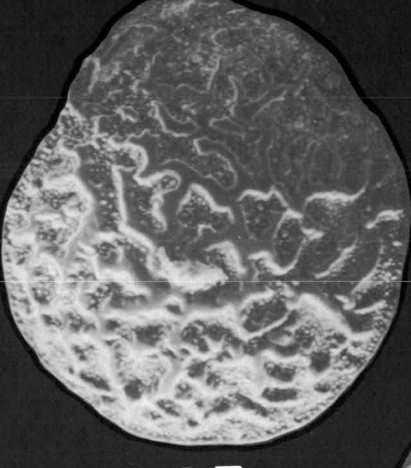
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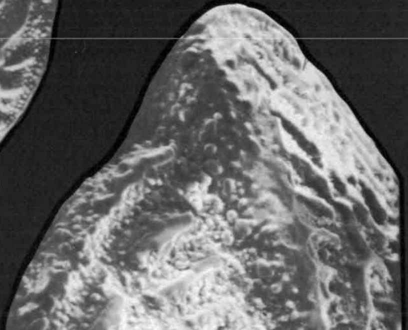
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Reflections on outer Melanesian Tertiary larger foraminifera

by

P. J. Coleman

Four major faunas of Tertiary larger foraminifera are found within Outer Melanesia (north-coastal New Guinea-Bismarck Archipelago-Solomons-New Hebrides-Fiji). The oldest (Late Eocene) consists of species of the principal genera *Nummulites, Asterocyclina, Spiroclypeus, Discocyclina, Pellatispira.* It has an extremely large area of distribution extending far outside Outer Melanesia. The second (Late Oligocene-Early Miocene) has as dominant species *Lepidocyclina* (*Eulepidina*) *ephippioidies, L. sumatrensis, Miogypsinoides dehaarti, Spiroclypeus margaritatus,* and *Cycloclypeus eidae,* and occurs on all of the major islands. The third (Early-Middle Miocene) is dominated by *L. japonica, L. ferreroi, L. martini, Cycloclypeus* (*Katacycloclypeus*) *martini, C.* (*C.*) *indopacificus, Miogypsina polymorpha,* and *M.* sp. cf. *M. neodispansa.* This fauna has a comparatively spotty but yet widespread distribution. The fourth fauna ranges into the Late Miocene and is dominated by multilepidine *L. radiata, Cycloclypeus* (*C.*) *indopacificus* and *Operculina complanata.* Species of *Lepidocyclina* within Outer Melanesia support the notion of the subgenus *Eulepidina* but not of *Trybliolepidina* nor of *Multilepidina* nor, possibly, of *Nephrolepidina.* Study of *Lepidocyclina*-species (and those of other genera) shows that extremely wide variation is the normal condition; it may be linked to the cultivation of symbiont algae. Study of such variation, along with further bioseries studies and the effort to obtain tighter time controls by use of associated planktic foraminifera, should enhance the use of individual species and of species-assemblages. An explanation for the unusually wide areal distributon of some species may lie in the reconstruction of ocean current systems throughout the Tertiary, now made possible under seafloor spreading theory.

In 1947 I was an Honours student trying to come to grips with foraminifera. The appeal they had for me was a combination of aesthetics and utility. The aesthetic aspect predominated: it was then, and still is, a source of wonder that protozoans, even complicated ones, could manufacture such a variety of elegant solid structures, seemingly engineered for specific if unknown functions.

Towards the end of that year I met Irene Crespin for the first time. She was a leader in the field, I was a tyro. At the end of an hour we had shared our appreciation of the beauty of the little beasts and without any change in style on her part I had been led gently into a greater realisation of the use of foraminifera as a precision tool in geology. At that and subsequent meetings she instructed and inspired me at the same time, apparently without effort and, I am sure, without realising that she was exercising a great gift.

After that first meeting I went to Papua New Guinea, where I was further instructed by Martin Glaessner, and soon after to the Solomons, as a member of the first University of Sydney expedition. Thus began an enduring interest in the geology and the foraminiferal faunas of Outer Melanesia. Outer Melanesia stretches from north coastal New Guinea east through the Bismarck Archipelago (New Britain and New Ireland) to the Solomons, New Hebrides and so on to Fiji. The geologies of these essentially Cainozoic areas are similar and so too are their foraminiferal faunas, especially those of the larger foraminifera. As a tribute to Irene, I am privileged to offer over the next few pages some reflections which have arisen from my study of Outer Melanesian larger foraminifera.

There are at least four major faunas of larger foraminifera which can be found at localities over most parts of Outer Melanesia. The first and oldest is of Late Eocene age. It is an *Asterocyclina-Spiroclypeus-Discocyclina* fauna found in shallow-water, poorly sorted calcarenites which only rarely include small amounts of volcanic material, but which nearly always have a strong algal and/or bryozoan content. Commonly occurring species of this fauna include *Asterocyclina matanzensis* Cole, *A. praecipua* Cole, *Spiroclypeus vermicularis* Tan, *Discocyclina* sp. cf. *D. omphala* (Fritsch), *Nummulites pengaronensis* (Verbeek), *Pellatispira madaraszi* (Hantken), *P. hoffmeisteri* Whipple, and *Halkyardia* spp. The relative proportions of these species and, indeed, the presence of the principal genera may vary locally from sample to sample within a single formation. The cause of this is unknown but as a variable feature it is common throughout the area of distribution. This is extremely large, extending far outside Melanesia to include parts of Indonesia to the west, the Marianas and Marshall groups in the north, and Tonga to the east; *Asterocyclina* occurs in New Zealand and Chatham Island to the south and in the Tuamotu group, French Oceania, still farther east (Cole, 1970 with refs.; Coleman, 1969); oddly enough, this fauna has not been found so far in the Solomons. I know of no other fauna of Tertiary larger foraminifera which has as great an area of distribution in the western Pacific. It poses problems in the sheer mechanics of distribution over so large an area and of the environment which permitted these; the environmental aspect has special significance within the plate tectonics' framework.

Following the Late Eocene most of the areas of Outer Melanesia experienced a vigorous submarine igneous episode so that the Oligocene part of the general column is marked by a lava pile with some pyroclastics but little in the way of fossiliferous sediment. In the Late Oligocene, however, these areas shoaled and were settled by shallow-water benthos in which algae and foraminifera together are a major component. Reef corals are decidely rare. Epiclastic volcanic debris is generally a pervasive element even in sediments with a high biogenic carbonate content. Flysch-type sediments are prevalent, both turbiditic and shallow-water, but may nevertheless contain numerous larger foraminifera. This style of varied sedimentation, marked by rapid facies changes lateral and vertical, persisted with minor breaks into the mid-Miocene, that is, from about 25 m.y. to 12 m.y. B.P.

The second major fauna is then of Late Oligocene to Early Miocene age, and is even more widespread within Outer Melanesia, covering larger areas of deposition than the Late Eocene one. It is a *Spiroclypeus-Eulepidina* fauna in which the most common constituent species are *Lepidocyclina* (*Eulepidina*) *ephippioides* (Jones & Chapman), *L.* (*Nephrolepidina*) *sumatrensis* (Brady), *L.* (*N.*) *parva* (Oppenoorth) (close to *sumatrensis*), *Spiroclypeus margaritatus* (Schlumberger) (often identified as *S. leupoldi* (van der Vlerk)), *Miogypsina thecideaeformis* (Rutten), *Miogypsinoides dehaarti* (van der Vlerk), *Cycloclypeus*-species of Tan's *eidae* type, and *Heterostegina borneensis* (van der Vlerk). A muted version of this fauna is younger, Early Miocene (roughly N.4-N.5) and is equally wide-ranging. *Spiroclypeus* is absent or extremely rare. *Eulepidina* individuals are larger, and tend to be more heavily pillared and twisted and saddle-shaped (sellate). *Cycloclypeus* is of Tan's *posteidae* type (with fewer heterostegine chambers). Conical forms of *M. dehaarti* (= *Conomiogypsinoides* Tan) are common. *Lepidocyclina verbeeki* (Newton & Holland), *Miogypsina neodispansa* (Jones & Chapman) and *Austrotrillina*-species intermediate between *striata* and *howchini* are new elements. This version is indeed muted by today's criteria and is hence not clearly demarcated from the main fauna.

The third fauna is clearcut. It is of late Early to Middle Miocene age (roughly N.7-N.14) and lacks both *Eulepidina* and *Spiroclypeus; M. dehaarti* is absent or extremely rare. The most common species include *Lepidocyclina japonica* Yabe (transitional from *L. verbeeki*), *L. ferreroi* Provale, *L. martini* (Schlumberger), *L. radiata* (Martin), *Miogypsina polymorpha* (Rutten), *M.* sp. cf. *M. neodispansa, Cycloclypeus* (*C.*) *indopacificus* Tan, *C.* (*Katacycloclypeus*) *martini* van der Vlerk and/or *C.* (*K.*) *annulatus* Martin and *Operculina complanata* (Defrance). *Flosculinella* sp., *Borelis* sp., *Miolepidocyclina* sp. (probably new), and *Austrotrillina howchini* (Chapman) are sometimes present, but their distribution is spotty and very much facies-controlled.

A still younger fauna, rather more restricted areally, ranges into the Late Miocene (N.15-N.16). It occurs in the Solomons, New Hebrides, and Fiji, but I have no firm records from western Outer Melanesia. It is dominated by *Lepidocyclina radiata* (markedly 'multilepidine'), *Cycloclypeus* (*C.*) *indopacificus* and *Operculina complanata; Borelis* sp. cf. *B. pygmaeus* Hanzawa is rare and unevenly distributed. Almost invariably, the sediment containing this fauna is rich in volcanic debris.

Younger, Late Miocene through Holocene, assemblages exist but are not ranked as faunas because they lack the degree of persistence and uniformity in distribution which is a feature of the faunas so far outlined, and the component species fluctuate greatly in numbers over small areas and sequences. It is true, however, that the presence in a sample of *Marginopora vertebralis* Quoy & Gaimard (often in swarm proportions), *Alveolinella quoii* (d'Orbigny) and large, heavily ornamented rotaliids is strongly indicative of a post-Middle Miocene age; the presence of *Cycloclypeus carpenteri* (Brady) has similar age connotations but is indicative also of a deeper-water environment of deposition. Although they tend to be mutually exclusive and are only debatably 'larger' foraminifera, the presence of *Calcarina spengleri* (Gmelin) and *Baculogypsina sphaerulata* (Parker & Jones) is a fairly sure indication of Quaternary age and of shallow-water, near-beach deposition.

The successions on most areas of Outer Melanesia are strongly faulted and characterised by marked facies changes both lateral and vertical; on the ground, the vegetation is often thickly tropical and the weathering is deep; good outcrops are comparatively rare, and unbroken sequences even more so. These features in combination make it difficult to establish correct local sequences and, once this is done, to correlate such sequences within an island and from one island to another. In the early days of exploration of Outer Melanesia, the major faunas outlined previously made, and still make, this task much easier; the use of them has enabled reasonably detailed stratigraphies of most of the island groups to be built up. More recently (e.g. McTavish, 1966), this biostratigraphic contribution has been complemented (and with greater accuracy) by the use of planktic foraminifera. Probably because most of the depositional areas of Outer Melanesia had ready access to open ocean, even strongly terrigenous sediments may often have an unusually high content of planktic foraminifera.

The further study of such associations of larger and planktic forms (see Coleman & McTavish, 1964, 1966) would be worthwhile. The rigorous dating which is now provided by planktics would not only refine the age limits of particular species (as we presently conceive them) of the larger foraminifera, and of whole assemblages of such species, but also permit the more refined use of the bioseries concept, as exemplified by the work of van der Vlerk & Postuma (1967) and Schipper & Drooger (1974). The use of planktics is stressed because of the rarity of thick, unbroken and easily sampled sequences in any area with which I am familiar. An upgrading of the stratigraphic value of the larger foraminifera would be an advantage, for these forms are much more common than planktics, and are more easily extracted and studied.

Apart from the proven use of larger foraminifera as the means of swift and broad correlations within Outer Melanesia and the promise of more refined use which would be conferred by study of associated planktics, there are other aspects more generally palaeontological which have arisen from my long-term study of the larger foraminifera of this region. I discuss a few which I find to be of special interest and relevance to the genus and species concepts, the notion of bioseries, problems of biodistribution, and palaeoclimatology (especially within the framework of plate tectonics).

To start with, we might consider the conceptual validity of those groups of species of the genus *Lepidocyclina* (s.l.) which can be loosely described as eulepidine, nephrolepidine, trybliolepidine, and multilepidine, and which are traditionally differentiated on the basis of study of the embryonic plus the first few generations of equatorial chambers. Adequate morphological descriptions are given in Glaessner (1945) and Renz & Küpper (1946) and further elaboration here is not necessary. In taxonomic language, the eulepidine group has long been accepted as a subgenus *Eulepidina* of *Lepidocyclina;* as also are the nephrolepidine and trybliolepidine groups, subgenera *Nephrolepidina* and *Try-*

bliolepidina. But the multilepidine group, after initial acceptance as a subgenus, *Multilepidina*, now has a lesser, shadowy status, probably as a result of Glaessner's suggestion (1945) that this type of embryonic complex was teratological (roughly speaking, a biological monstrosity).

Outer Melanesian specimens of *Eulepidina* clearly belong to the one species, *E. ephippioides* (Jones & Chapman). Thin-section study of free specimens or 'located' specimens (individual specimens located in massive or strongly coherent limestone and then extracted and critically thin-sectioned as part of a small tablet, by means of diamond discs and dental drill (Coleman, 1963)), as well as random thin-sections, show that the nucleoconch is for the most part tangentially placed within the deuteroconch but that the apparent degree of envelopment is in fact controlled by the plane of the section (see also Adams & Belford, 1974, p. 502). They confirm the absence of large first-generation auxiliary chambers. While the shape of the equatorial chambers is consistent and shows little variation, there is wide variation in pillaring, the number and size of layers of lateral chambers (and hence the degree of inflation), and of overall size and shape, from sellate (twisted) to flat, from circular to star-shaped. There is no discernible trend in this variation, either geographical or stratigraphical, although as mentioned earlier, the younger specimens (from the New Hebrides) show a qualitatively-estimated tendency to be heavily pillared and markedly sellate; but this could well be a localised and environmentally controlled, phenotypic phenomenon. *E. ephippioides*, as a species represented by the specimens studied, lends support to the acceptance of the eulepidine group as a subgenus *Eulepidina*.

Study of Outer Melanesian specimens of the nephrolepidine and trybliolepidine groups of species shows that the degree of overlap of nucleoconch by deuteroconch is again dependent on the precise position of the plane of the thin-section. What might be termed 'typical' trybliolepidine development appears to be a more common condition in younger species of late Early Miocene and younger age. None of even these younger species examined showed an exclusively trybliolepidine condition; even small samples of a half-dozen specimens may show a gradation from nephrolepidine to trybliolepidine (again, it is difficult to allow for the masking complication that the degree of overlap observed is dependent on the actual plane of thin-section). It is relevant here to record part of the results of a study (unpublished) of embryonic complexes in *Lepidocyclina* done by A. M. Phillips Jr (Louisiana State University) and myself. Air-filled specimens of Miocene age from St Stephen's Quarry, Washington County, Alabama, were ground down to the vicinity of the embryonic complex. They were then dissected with micro-scalpel, chamber by chamber, until the complex was laid open. Of more than thirty specimens, only a few showed a spherical nucleoconch; in the remainder it was shaped like a short fat sausage, sometimes irregular at that, and without any fixed orientation to the equatorial plane. Older specimens of eulepidine type from the same sequence, and similarly dissected, showed even more irregularly situated nucleoconchs.

Distinction between *'Nephrolepidina'* and *'Trybliolepidina'* based on thin-section study, including that of oriented specimens, would seem to be risky. Whether the nephrolepidine group as a whole should be recognised as a subgenus, separate from *Lepidocyclina* (*Lepidocyclina*), is another question not directly affected by my Outer Melanesian studies. But if an irregular relation between nucleoconch, deuteroconch, and the plane of the thin-section is also demonstrated for the older species then a thin-section distinction between *'Nephrolepidina'* and subgenus *L.* (*Lepidocyclina*) will be difficult to justify.

Following the exposure of the equatorial plane of the holotype of *L. radiata* (Martin) by van der Vlerk (1961), it is clear that Cole (1960a) was right in his assertion that such species as *L. suvaensis* Whipple, *L. fijiensis* Cole, *L. oneataensis* Cole, *L. luxurians* Tobler, and *L. irregularis* Hanzawa, all with multilepidine embryonic chambers, should be placed in the synonymy of *L. radiata*. Sectioning of some fifty specimens of a multilepidine species, accepted as *L. radiata*, from the early Late Miocene Tangareso Shale on Guadalcanal (Coleman & McTavish, 1964) showed considerable variation in the size, arrangement, and orientation of the component embryonic chambers. This variation embraced not only that of the species listed by Cole, but others, for example, *L. wanneri* van den Abeele. If Cole's assertion be granted, then *L. radiata* had a geographic range covering most of the Western Pacific and, further, van der Vlerk (1961) could well be correct in saying that *L. radiata* was the youngest and possibly the last of the species of *Lepidocyclina*. The spread of this species and the consistency in variation of the embryonic apparatus suggests a normal biological response not accurately covered by the term teratological. But to go further and perpetuate the notion of a subgenus *Multilepidina* seems unnecessary.

In summary, the study of Outer Melanesian lepidocyclines supports the continued use of the subgenus *Eulepidina*. Thin-section differentiation between *L.* (*'Nephrolepidina'*) and *L.* (*'Trybliolepidina'*) is difficult and, for the time being at least, is subjective; one is left with the impression that the trybliolepidine condition is rather more common in post-Early Miocene populations. *L. radiata* need not be set apart as the subgenus *Multilepidina*.

The question of what constitutes a 'species' in larger foraminifera is a long-standing one, as it is on other groups of fossils. In the attitude of many experts towards this problem there has been a strong element of stratigraphical pragmatism. Roughly speaking, if a debated species has, or is presumed to have, stratigraphical value, then let it stand. Although understandable and even excusable, this attitude is abiological and offends the maxim that species help define stratigraphy rather than the other way round. Although it meant reversing some of his previous attitudes, Cole argued strongly for a biological approach to the species-question in a series of papers beginning in 1957 (e.g. Cole, 1957, 1959, 1960a, 1960b, 1961, 1966). His arguments were solidly based on acute descriptions and his practice of using large number of specimens to make thin-sections of outstanding quality.

My own studies of *Lepidocyclina*-species fully confirm the overall soundness of Cole's arguments. For example, the species *L. sumatrensis*, widespread throughout Melanesia, shows the same variation that Cole described (1957) and confirms his contention that vertical sections cannot be used to identify positively this and many other species of *Lepidocyclina*. Although Cole greatly enlarged the concept of *L. sumatrensis* and stressed its variation, so that it is now a readily recognisable taxon, it is still by no means clear-cut. It has fringing relationships with another highly variable group, that of *L. japonica* (Yabe, 1906) (with *L. angulosa* Provale 1909 as a synonym) which also has a wide geographic range but is possibly a younger species. 'Typical' specimens of *L. japonica* are quite distinctive (see Cole, 1963; Coleman, 1963; Binnekamp, 1973) but even small samples of this species will usually include not only typical specimens but also intergrading ones, some of which could be identified in both vertical and equatorial thin-section as *L. verrucosa* Scheffen and yet others as atypical *L. sumatrensis.* A somewhat similar situation exists with *L. sumatrensis* and *L. verbeeki* Newton & Holland. And there is further complication, both nomenclatural and taxonomic. My own identification of *L. sumatrensis,* and that of other workers also, is based on a traditional concept; I cannot be sure that a batch of specimens which I identify in thin-section as *L. sumatrensis* belong to the population which yielded Brady's 'two or three specimens'. By today's standards, Brady's description was poor and no one can say what are the internal features of his species. Many other species of *Lepidocyclina* have a similar unsubstantial and ghostly status.

It seems to me that extremely wide, even startling, variation is an integral feature of *Lepidocyclina*-populations. An explanation for this wide variation is probably centred on the apparently symbiotic relationship between certain algae (including zooxanthellae) and many species of foraminifera (see Ross, 1972, and Röttger, 1972). This opinion is illustrated by work such as that of Chaproniere (1975) and Haynes (1965) who suggest that the evolution of life-styles and hence of structures, especially those of the larger foraminifera, is due to this symbiosis.

Because the symbiont algae are extremely light-sensitive, the host foraminifer must live in the euphotic zone and concentrate the algal 'gardens' in the outer, light-prone parts of the test. The amount of light-energy available varies greatly from locality to locality and from one depth to another. Given the interplay between amount of light, type of algae, and crystalline structure of the test wall of the foraminifer, and its preferred depth range, then considerable variation in peripheral structures is to be expected. That extinct forms, such as *L. sumatrensis,* also had the symbiosis with algae is a highly likely supposition. If so, *L. sumatrensis* was capable of supporting algal symbionts over a wide range of light energies; its structural plasticity was the evolutionary product of adaptation and selection for the most efficient nurture of algal symbionts. Here also may be part of the explanation for the geographic spread of this species and its tolerance of differing environments, the latter being indicated by the range of lithologies of the sediments in which it is found.

Although I have cited *Lepidocyclina*-populations, the problems of generic boundaries and of inter- and intraspecific variation also occur to varying degrees in other genera such as *Miogypsina, Miogypsinoides, Spiroclypeus, Asterocyclina* and so on. These problems have been appreciated by some workers for a long time. Indeed, much of what I have said (and a good deal besides) was reviewed in general terms in an article by Glaessner for the opening number of 'Micropaleontology' in 1955.

The study of this interesting variation in fossil large foraminifera will require the use of large numbers of specimens and the effort to see more of the embryonic complex than is exposed in simple thin-section. The latter is not an easy task. The sort of meticulous dissection mentioned earlier is just not practical and my own attempts, using radiography, to obtain three dimensional images of specimens ground down to the vicinity of the equatorial plane, were not very successful (although promising). My educated guess is that a thorough study of variation in *Lepidocyclina* will probably lead to a drastic revision of what constitutes a species in this genus and, as a corollary, in other genera as well. The results would be unpalatable, amounting to a nuisance, but not necessarily unproductive. Given precise relative and absolute dating of samples (by way of planktic foraminifera), various peaks of variation may show a stratigraphic and/or geographic bias and, with more information from current biological studies of living foraminifera, may assist in deducing environmental parameters. Such peaks in variation (which might correspond roughly with *sumatrensis*-type, *japonica*-type and so on) could be codified; they need not and should not be incorporated into formal nomenclature. Granted this, they would complement the results of bioseries studies. In this way the stratigraphic and ecological value of the lepidocyclines (and again by implication, other genera) would be enhanced rather than reduced. The crippling effect of the maelstrom of nomenclaturally valid but biologically unsound species, devoid of significant concept, would be circumvented. The problem of just what should be done with this host of unsatisfactory, nominal species remains, but it is a problem too large for me.

Tan Sin Hok pioneered the application of the bioseries concept to larger foraminifera. His work on *Cycloclypeus,* summarised in his 1939 paper, has not been improved significantly. The importance of this work, both in evolutionary studies and in biostratigraphy, was outlined by Glaessner (1945, p. 225) but until recently relatively few workers have followed it up, possibly because of the tedium and hard work involved in obtaining the necessarily large number of thin-sections and the need for careful stratigraphic controls, at least in the early stages of study of a bioseries. The work that has been done, however, has enhanced the earlier potential so that the target of a codified gapless biochronology free of the restrictions imposed by the Linnaean system still remains a valid one. Applied to planktic foraminifera, this point is argued well by Emiliani (1969).

In the larger foraminifera the biocharacter which has been used so far is the embryonic apparatus and its progressive structural change through time (one of possibly several awaiting recognition). As far as I know, no one has given a convincing biological and evolutionary explanation of such bioseries—of just why, for example, the lepidocycline nucleoconch should be increasingly enveloped by the deuteroconch in the younger populations.

Study of *Cycloclypeus* from the Solomon Islands and New Hebrides region gives partial support for Tan's conclusion that the number of nepionic chambers decreases in successively younger populations. The support is partial because free specimens were quite rare; the number of equatorial sections, covering the range *C. eidae-posteidae-indopacificus-carpenteri,* is statistically quite inadequate. For *C.* (*C.*) *indopacificus,* twenty-odd thin-sections indicate a smaller range of variation in number of nepionic chambers (3-7) than was observed by Tan (2-10). Specimens of *Lepidocyclina* are more readily available and have received more attention (for New Britain, see Binnekamp, 1973). Although the number of thin-sections is again too small for an unqualified statement, they support the later version of van der Vlerk's ideas (van der Vlerk, 1963, 1968; van der Vlerk & Postuma, 1967). With *Lepidocyclina*, however, a substantial reservation as to the validity of 'grade of enclosure' has to be made. This concerns the same problem mentioned earlier, that the 'grade of enclosure' is an accident dependent on the plane of the thin-section relative to actual position of the nucleoconch within the deuteroconch (van der Vlerk's results inspire confidence because of the large number of specimens examined). Besides this technical problem there was another. The Solomons and New Hebrides specimens could not be placed within a sufficiently refined time-scale. The species-assemblages from which they came, e.g. the *Spiroclypeus-Eulepidina* fauna, spans too many millions of years. It was not possible to sample closely over thick, uninterrupted sequences (there were none) but a diligent search for associations of this fauna with planktic forms, preferably within single samples, could well have given finer time controls: *Lepidocyclina*-N.4 could then be compared with *Lepidocyclina*-N.5. For a variety of reasons this was not done but in the future it should be. Drooger and his colleagues have achieved notable success with bioseries studies of *Miogypsina* and *Miogypsinoides* (Drooger's methods are described in his 1963 and 1974 papers). Their results have not been tested against Outer Melanesian species. Free specimens are decidedly rare and specimens extracted from massive limestones seem to have undergone a peculiar diagenesis; I have been quite unable to obtain thin-sections of the required precision.

In brief, Outer Melanesian larger foraminifera offer limited support to the bioseries studies so far investigated. I use them, even so, to advocate the notion. They also point to the necessity of searching for other biocharacters and, more urgently, for simpler and more direct methods of studying the biocharacters involved: even the enthusiastic Ph.D. candidate can hardly be blamed for recoiling when told that, as part of a project, many hundreds of critically oriented thin-sections must be cut, not one of which has much individual validity.

Finally, there is the problem of geographic distribution of larger foraminifera. For me, this is one of the large problems in palaeontology. To name but one, by no means exceptional, of a number of species, we have a protozoan, *Lepidocyclina* (*Eulepidina*) *ephippioides*, with a geographic spread in terms of today's geography of at least 7000 km, west to east, and many hundreds of kilometres south to north. Most of us would accept that this species was a benthic, shallow-water (probably less than 50 metres water depth) species, which cultivated symbiont algae and which favoured tectonically active subtropical or tropical coasts. It is a plastic species as indicated by its variation, but even the most ardent splitter would be hard put to recognise significant variational shifts over the whole or any part of its range; no convincing difference exists between representatives from Christmas Island, in the Indian Ocean, and those from the New Hebrides. Its overall age-range lies within N.1 to N.4 or Late Oligocene to earliest Miocene, spanning roughly 10 m.y. All of this implies rapid distribution and, it could be argued, pervasive gene-flow throughout the area of distribution.

The problem of distribution of this species would be less severe if it were found in areas which were once part of the one plate. It could not have been the Indo-Australian plate. Even those reconstructions (e.g. Audley-Charles, Carter & Milsom, 1972) which would place parts of Indo-China and Indonesia adjacent to Australia in the Cretaceous, have them well removed before the Oligocene. As well, if the Solomons and New Hebrides are treated as part of the Indo-Australian plate, then the distribution of *L.* (*E.*) *ephippioides* in the Late Oligocene would have to cover a much greater latitudinal swathe than it does now and with this, a much greater palaeoclimatological range. There is some evidence, however, that the Solomons and New Hebrides were oceanic islands and part of the Pacific Plate in Oligocene time (Coleman, 1975). Granted this, *L.* (*E.*) *ephippioides* becomes a southeast Asian species (i.e. inhabiting coastlines which were part of the Eurasian plate) with a spread eastwards for some thousands of kilometres to include the Marianas, Solomon, New Hebrides, and Fiji groups. Although easily overlooked, embyonic forms of *L.* (*E.*) *ephippioides* are surprisingly common in sediments containing both adults and planktic foraminifera. They are 'globigerine', so that one is reminded of Vaughan's proposal (1933) that the spread of larger foraminifera could be explained if they had an extended zoospore stage during which they behaved as plankton. Despite the dismissal of this idea by Myers (1936), it deserves to be looked at again. It is not discussed further because I do not know of any evidence, for or against, from students of living foraminifera.

Cole (1960c), following Myers (1936), has suggested that larger foraminifera achieved wide distribution as epibionts, as passengers, on drifting weed. Given today's examples, such as *Marginopora* living on the seagrass *Posidonia*, this is an attractive mechanism. Applied to *L.* (*E.*) *ephippioides*, it would be not only attractive but likely if it could be shown that the pattern of ocean currents in the Late Oligocene squared with the distribution of this species. The Oligocene was a time of major reshaping of Southern Hemisphere ocean currents (Kennett et al., 1972) and it would be both difficult and of dubious value to speculate on the Late Oligocene current patterns for the region between Southeast Asia, the Western Pacific, and a north-moving Australia. A global treatment is mandatory. Theoretical estimates (e.g. Frakes & Kemp, 1973) suggest a generally west-flowing body of water north of Australia. Detailed reconstructions will require extremely detailed synthesis using data which are not yet or are only just becoming available. A model approach in which the parameters could be varied at will could also be profitable, similar to that of Luyendyk et al. (1972). The results from their experiment suggest that a major equatorial current flowed east to west in the Tethys-Pacific region in middle Tertiary time, accepting as likely premises that there was a constriction of water flow in the Malaysian area and that the Middle Americas was an open passage. These results do not mean necessarily that *ephippioides* 'migrated' east to west; they simply reflect a model situation in which likely items such as counter-equatorial currents did not become manifest. This was a pioneer effort, and as Luyendyk and his colleagues affirm, it is capable of refinement.

Both theoretical and model approaches are promising. For the Cainozoic especially we will soon have much of the data we need for an elaborate synthesis which would include results from palaeontology, palaeoclimatology, palaeobathymetry, relative positions of the landmasses, and their topographies, all subject to desirable constraints. From such synthesis we can hope for palaeogeographies and climates for the Epochs, and even for some Ages, and thence for solutions to problems of distribution not only of the foraminifera but for the great bulk of Cainozoic animals and plants. Thanks to seafloor spreading theory, it is likely (to quote Emiliani, 1969) that palaeontology 'now appears to be at the dawn of a new era of exciting development. . . .'

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Onestia McLearn, an unusual cardiacean pelecypod from the Lower Cretaceous of Australia and Canada

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The cardiacean pelecypod genus *Onestia* McLearn is unusual in that it lacks radial ornament, has smooth inner margins, and has anterior lateral teeth that are either blade-like, or rudimentary, or absent. Four species, including two new species, are referred to the genus: *Onestia onestae* (McLearn) the type species from the middle Albian of Alberta, Canada, the Australian Aptian species *O. etheridgei* (Etheridge Jnr) and *O. crespinae* sp. nov., and the Australian late Albian form *O. orbicula* sp. nov. *Onestia* is most closely related to *Lahillia* Cossmann, and may be the ancestor of this Senonian-Miocene genus. It is therefore suggested that *Onestia* should be included in the family Lahilliidae. The known distribution of the genus, western Canada and Australia, is an enigma.

INTRODUCTION

Genera included in the Superfamily CARDIACEA Lamarck are characterised by a remarkably constant dentition with cyclodont cardinal teeth and lateral teeth that are rarely subject to reduction; a wide variety of radial ornamentation is generally displayed, and the inner margins are at least partially digitate or denticulate. The genus *Onestia* McLearn (1933) is unusual in that radial ornament is lacking, the inner margins are smooth, and the anterior laterals are reduced in some species. The distribution of the genus, western Canada and Australia, is equally peculiar.

In this paper, the classification and distribution of the genus *Onestia* are reviewed and the four known species *O. onestae* (McLearn), *O. etheridgei* (Etheridge Jnr), *O. crespinae* sp. nov. and *O. orbicula* sp. nov. are described. *Onestia onestae*, the type species, occurs in the securely dated middle Albian Clearwater Formation of Alberta, Canada. The remainder are Australian species. The Aptian forms *O. etheridgei* from the Maryborough Basin and *O. crespinae* from the Surat and Eromanga Basins, are associated with a typical Roma fauna (Day, 1969). *Onestia orbicula* occurs in the Eromanga Basin with a typical late Albian Tambo fauna (Day, 1969, table 8:4).

Fossil localities in the Queensland parts of the Eromanga and Surat Basins are shown on 1st Edition 1:250 000 Geological Series Maps:

Augathella (GAB 2049)
Mitchell (GAB 2098; (GAB 2166)
Muttaburra (GAB 1384)
Roma (SB 116; SB 117; SB 122, SB 123; RD 122)

Repositories of fossils are indicated by a prefix system:

CPC	Commonwealth Palaeontological Collections, Bureau of Mineral Resources, Canberra
GSC	Geological Survey of Canada
GSQ	Geological Survey of Queensland
QM	Queensland Museum
UQ	Department of Geology and Mineralogy, University of Queensland.

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SYSTEMATIC DESCRIPTIONS

Genus **Onestia** McLearn, 1933

Type species (by original designation): *Laevicardium onestae* McLearn, 1931, Albian, Alberta, Canada.

Original diagnosis: "This subgenus is made for quadrate fairly convex shells without radial ornament and with smooth inner margin and in the right valve with two conical and somewhat arched cardinal teeth, anterior and posterior lateral dental sockets at some considerable distance from the cardinals and small, little projecting lateral teeth. On the interior an illdefined ridge runs from in front of the posterior adductor towards but not to the beaks. The external ligament is short and set in a deep groove" (McLearn, 1933, p. 152).

Remarks: Inclusion of the three Australian species now referred to *Onestia* necessitates some amendment to the original diagnosis of McLearn. In *Onestia etheridgei* (Etheridge Jnr, 1892) and *Onestia orbicula* sp. nov., anterior lateral teeth are weakly developed or absent, while in the former and *Onestia crespinae* sp. nov., a shallow but distinct pallial sinus is developed. *Onestia etheridgei* and *O. crespinae* could be separated subgenerically from *Onestia*, if the action of Finlay & Marwick (1937) in the case of the sinupalliate form of *Lahillia* were adopted. However, the writer does not consider such action to be warranted.

Emended diagnosis: Thick shelled. Small to large in size. Orbicular to subquadrate in shape. Subequilateral. Equivalve; well inflated. Umbones broad, slightly anterior. Hinge formula $\frac{\text{(AI) (AIII) 3a 3b PI PIII;}}{\text{(AII)2 4b PII}}$ cardinal teeth cyclodont; anterior laterals subject to reduction, blade-like, rudimentary, or absent; posterior laterals laminar or somewhat tuberculiform. Ligament external, opisthodetic, seated on prominent nymphs. Inner ventral margins smooth. Pallial line simple or with a broad, shallow sinus. Ornament consisting of fine, concentric growth lines and widely spaced concentric furrows marking growth halts.

Range: Aptian-Albian.

Onestia onestae (McLearn)

Plate 1, figs. 1-3

1931 *Laevicardium onestae* McLearn, p. 7; pl. 1, fig. 1.

1933 *Integricardium (Onestia) onestae* (McLearn), p. 152; pl. 2, figs. 8-10.

1945 *Onestia onestae* (McLearn), p. 10; pl. 3, fig. 9.

1964 *Onestia onestiae* (McLearn). Jeletzky, pp. 9, 76; pl. 24, figs. 9, 11.

Holotype: GSC No. 6345, a left valve. Locality: East bank Athabasca River, 3 miles below Brûlé rapids, Alberta; Clearwater Formation, early middle Albian, *Beudanticeras affine* Zone, *Arcthoplites mcconnelli* Subzone.

Material: One left valve and two right valves available for study.

Specific diagnosis: Medium sized *Onestia* with posterior obliquely truncate and expanded more than anterior; anterior lateral teeth well developed.

Description: Medium sized (length approximately 30 mm). Equivalve; well inflated. Subquadrate to suborbicular; length greater than height. Subequilateral; anterior length approximately 42% of total length. Antero-dorsal and postero-dorsal margins straight; gently sloping and terminating in dorsal one-third of shell height. Anterior and ventral margins gently rounded. Posterior expanded more than anterior and obliquely truncate. Umbones broad, moderately elevated. Beaks slightly anterior, orthogyral. Lunule ill-defined. Escutcheon well impressed. Hinge plate narrow, bearing two cyclodont cardinal teeth in each valve. Hinge formula

$$\frac{\text{AI AIII 3a 3b PI PIII?}}{\text{AII 2 4 b PII}}$$

Left anterior cardinal (2) trigonal, prosocline; situated in front of beak, projecting only slightly above hinge plate. Left posterior cardinal (4b) orthocline; situated immediately behind beak; approximately the same size as (2). Right anterior cardinal (3a) trigonal, prosocline, situated on hinge margin and projecting well above hinge plate. Right posterior cardinal (3b) trigonal, slightly opisthocline, situated beneath beak. Anterior lateral teeth laminar, weakly elevated, situated close to cardinals; AIII formed by shell margin. Posterior lateral teeth remote from and below cardinal teeth; apparently laminar, but not well preserved. Ligament external, opisthodetic; seated on small nymphs. Anterior and posterior adductor scars small, well impressed, weakly buttressed. Anterior scar cuneiform, tapering towards umbonal cavity. Posterior scar ovate, slightly larger than anterior scar. Anterior wall of umbonal cavity with small, deeply impressed pedal muscle scar. Anterior parts of pallial line convex and concordant with shell margin. Posterior parts of pallial line somewhat obscure; apparently almost a straight line from the mid-ventral part of the posterior adductor scar to the postero-ventral extremity. Ornament of fine concentric growth lines and at least 6 prominent, fairly regularly spaced concentric depressions marking growth halts.

Dimensions: (mm)	Length	Anterior length	Height	Inflation
Holotype				
GSC No. 6345 (left valve)	30	12.5	25	11 (1 valve)
GSC No. 8003 (left valve)	27+	—	25+	11 (1 valve)
GSC No. 8004 (right valve)	31	13	26	*ca* 10 (1 valve)

Remarks: Onestia onestae (McLearn, 1931) most closely resembles *O. orbicula* sp. nov. from the late Albian Allaru Mudstone of western Queensland. However, the latter is more orbicular and lacks anterior lateral teeth.

The Australian Aptian species *O. etheridgei* (Etheridge Jnr, 1892) and *O. crespinae* are clearly distinguished by their shape and pallial features.

Occurrence: GSC localites 5896, 5897 (Jeletzky, 1964). Clearwater Formation, early middle Albian, Alberta.

Onestia etheridgei (Etheridge Jnr)

Plate 2, figs. 3-5

1872 Genus ? Etheridge Snr, p. 339; pl. 19, fig. 4.

1892 *Unicardium ?etheridgei* Etheridge Jnr, p. 569; pl. 27, fig. 1.

1968 *Onestia etheridgei* (Etheridge Jnr). Hill, Playford, & Woods, pl. KVI; figs. 1a-b.

1970 *Onestia etheridgei* (Etheridge Jnr). Fleming, p. 7; pl. 2, figs. 1-4.

Lectotype: QM F1258, specimen figured by Etheridge Snr (1872, pl. 19, fig. 4). Locality: Maryborough, Queensland; Maryborough Formation, Aptian. Etheridge Jnr (1892, p. 569) in proposing this species had more than one specimen for study, so Etheridge Snr's specimen which was designated "holotype" by Ludbrook (1966, p. 184), is actually the lectotype. Fleming (1970) overlooked Ludbrook's selection and erroneously cited GSQ F7477 as "holotype".

Material: Fifteen specimens, mostly internal moulds of closed valves; some valves are displaced by compression and bear an imprint of the external ornament on the internal mould.

Specific diagnosis: Large sized *Onestia* with broadly rounded anterior and posterior; anterior lateral teeth very weakly developed; pallial sinus wide and shallow.

Description: Large (average length 100 mm). Equivalve; well inflated. Subquadrate, length greater than height. Subequilateral; anterior length 45-47% of total length. Antero-dorsal and postero-dorsal margins almost straight; gently sloping and terminating in approximately the dorsal one-quarter of shell height. Anterior, posterior, and ventral margins gently rounded. Umbones broad, moderately elevated. Beaks subcentral, orthogyral. Hinge plate relatively wide and thickened; bearing two cyclodont cardinal teeth in each valve. Hinge formula

$$\frac{\text{(AI) (AIII) 3a 3b PI PIII.}}{\text{(AII) 2 4b PII}}$$

Left anterior cardinal (2) trigonal, orthocline; situated below and in front of beak, projecting well above hinge plate. Left posterior cardinal (4b) opisthocline; situated immediately behind beak, smaller than (2). Right anterior cardinal (3a) trigonal, prosocline; situated on hinge margin immediately in front of beak and projecting above hinge plate. Right posterior cardinal (3b) trigonal, orthocline; situated beneath beak and rising well above hinge plate. Anterior lateral teeth very weakly developed; almost in line with cardinal teeth; AI and AII poorly defined laminar ridges; AIII rudimentary, formed by shell margin. Posterior laterals remote from and slightly below the line of the cardinals; PI and PII strong and blade-like; PIII formed by shell margin. Ligament external, opisthodetic, but features not clearly observable. Adductor scars large, ovate; moderately impressed. Anterior adductor scar tapered towards umbonal cavity; weakly buttressed in some specimens. Large pedal muscle scar on anterior wall of umbonal cavity. Pallial line with broad shallow sinus. Ornament of fine, concentric growth lines and slightly more prominent and more widely spaced concentric depressions marking growth halts.

Dimensions: (mm) *Lectotype*	Length	Anterior length	Height	Inflation
QMF 1258 (internal mould of right valve)	90		76	20 (1 valve)
GSQF 1414 (internal mould of closed valves)	98	42	82	43
GSQF 7477 (compressed internal mould of closed valves)	106	50	90	40
GSQF 7326	115	53	95	25 (1 valve)

Remarks: Onestia etheridgei (Etheridge Jnr, 1892) is most closely related to *O. crespinae* sp. nov., and their pallial features are notably similar. The former differs from the latter in its subquadrate, more equilateral shape and very weakly developed anterior lateral teeth.

Occurrence: Maryborough Basin—Baddow Quarry area, Maryborough. Maryborough Formation, Aptian. Fleming (1970, p. 7) reported that the species was fairly common in the upper part of the Maryborough Formation.

Onestia crespinae sp. nov.

Plate 1, figs. 6-9; Plate 2, figs. 1-2

1901 *Cyrena*(?) n.sp. Gürich, p. 486; pl. 19, figs. 1-2.
1925 Gen. et sp. nov. Whitehouse, p. 34; pl. 1, fig. 6.
1964 *Unicardium ?etheridgei* Etheridge Jnr. Day, table 3.
1966 *Onestia etheridgei* (Etheridge Jnr). Ludbrook, p. 183; pl. 23, fig. 11.
1969 *Onestia* cf. *etheridgei* (Etheridge Jnr). Day, p. 150; table 8:5.

Holotype: UQ F64775, an internal and partial external mould of a specimen with opened valves. *Paratypes:* UQ F64776, a left valve retaining shell material; GSQ F7836, an internal mould of a left valve; GSQ F9230, an external mould of the dorsal part of a right valve. Locality: RD 122, south bank of Wallumbilla Creek, about 8 km southeast of Wallumbilla, on Portion 652, Parish of Wallumbilla; map ref. 207692 Roma 1:250 000 Sheet area. Doncaster Member, Wallumbilla Formation, Aptian.

Material: Twenty specimens mostly preserved as internal and external moulds of separated valves.

Specific diagnosis: Medium to large sized *Onestia* with broadly rounded anterior and narrower somewhat tapered posterior; pallial sinus wide and shallow.

Description: Medium to large (length 40-90 mm). Equivalve; well inflated umbonally. Subquadrate with broadly rounded anterior and narrower somewhat tapered posterior; length greater than height. Subequilateral; anterior length 45-49% of total length. Antero-dorsal margin straight and sloping; postero-dorsal margin gently arched, sloping more steeply; dorsal margins terminating in approximately the dorsal one-quarter of shell height. Anterior and ventral margins evenly rounded; posterior somewhat tapered. Umbones broad, moderately elevated. Beaks orthogyral, slightly prosogyral, or slightly opisthogyral; central to slightly anterior. Lunule ill-defined. Escutcheon deep, lanceolate. Hinge plate thickened, bearing two cyclodont cardinal teeth in each valve. Hinge formula

$$\frac{\text{AI (AIII) 3a 3b PI PIII.}}{\text{AII 2 4b PII}}$$

Left anterior cardinal (2) trigonal, prosocline, situated immediately in front of the beak. Left posterior cardinal (4b) behind the beak; smaller, opisthocline. Right anterior cardinal (3a) trigonal, projecting from the shell margin in front of the beak. Right posterior cardinal (3b) situated immediately below the beak, trigonal, distally pointed, slightly opisthocline. Anterior laterals AI and AII weakly elevated, short, laminar, situated near the anterior extremity of the hinge line just below the line of the cardinals; AIII rudimentary, formed by shell margin. Posterior laterals much stronger, remote from and below the line of the cardinals; PI and PII somewhat tuberculiform; PIII formed by the shell margin. Ligament external, opisthodetic, seated on prominent nymphs. Adductor scar large, situated at the extremities of hinge margin. Anterior adductor scar tapered towards the umbonal cavity and buttressed by a low ridge. Posterior adductor scar ovate, generally less well impressed. Anterior wall of umbonal cavity of each valve with a large deeply impressed pedal muscle scar. Pallial line continued from the anterior adductor scar to the pedal muscle as a row of close-set pits. Pallial sinus broad and shallow. Ornament consisting of fine concentric growth lines and less regularly spaced concentric undulations marking growth halts.

Dimensions: (mm)	Length	Anterior length	Height	Inflation
Holotype				
UQ F64775 (internal mould)	84	41	68	17+ (1 valve)
Paratype				
UQ F64776 (left valve)	87	42	70	20 (1 valve)
Paratype				
GSQ F7836	70	33	55	16 (1 valve)
Paratype				
GSQ F9230	55	—	—	—
GSQ F7848	62+	30	57+	15 (1 valve)

Remarks: As discussed above, *Onestia crespinae* sp. nov. is most closely related to *O. etheridgei* (Etheridge Jnr) from the Aptian Maryborough Formation of the Maryborough Basin.

The new species is fairly widely distributed and occurs in the Surat Basin in Queensland and in the Eromanga Basin in New South Wales (Gürich, 1901), in South Australia (Ludbrook, 1966) and in Queensland.

Specimens from the Surat Basin commonly have interiors encrusted by annelids, indicating that the shells were dead before fossilisation.

Occurrence: Surat Basin—?L149 GSQ; ?SB122. Minmi Member, Bungil Formation, early Aptian, Queensland. RD 122; RD 221; SB116; SB117; SB123; GAB 2098; GAB 2166. Doncaster Member, Wallumbilla Formation, Aptian, Queensland. Eromanga Basin—GAB 1384. Doncaster Member, Wallumbilla Formation, Aptian, Queensland. "Peake Station (Whitehouse, 1925); 5/571/9; 5/571/11; 5/571/17; 5/571/33; 5/571/45; 5/571/46; 5/580/2; 5/644/1; 5/644/2; 5/644/3; 5/581/1; 5/609/3 (Ludbrook, 1966). Marree Formation, Aptian, South Australia. "White Cliffs" (Gurich, 1901), New South Wales.

Onestia orbicula sp. nov.

Plate 1, figs. 4-5

1969 *Onestia* sp. Day, p. 148; table 8:4.

Holotype: CPC 9295, an internal and external mould of a right valve. Locality: GAB 2049, Tributary of Damson Creek about 4 km northwest of Oxford Downs homestead; map ref. 421844, Augathella 1:250 000 Sheet area. Allaru Mudstone, late Albian.

Material: The holotype and a few incomplete valves.

Specific diagnosis: Small, orbicular, equilateral *Onestia*, with no anterior lateral teeth and a simple pallial line.

Description: Small to medium sized (length 25 mm). Orbicular. Equivalve; well inflated. Equilateral. Dorsal margins gently arched. Anterior, posterior and ventral margins gently rounded. Umbones broad, moderately elevated. Beaks small, orthogyral, centrally situated. Lunule and escutcheon ill defined. Hinge plate narrow. Hinge of right valve with two small, cyclodont cardinal teeth (3a, 3b); 3a trigonal, projecting from the hinge margin in front of the beak; 3b trigonal, distally pointed, situated immediately below the beak. No anterior lateral teeth. Posterior lateral PI prominent, laminar, remote from the cardinals; PIII formed by the shell margin. Ligament features and nymphs not observed. Adductor scars ovate, well impressed. Wall of umbonal cavity with a large, well impressed pedal muscle scar. Pallial line simple, extended beyond the anterior adductor scar to the pedal muscle scar. Ornament consisting of fine concentric growth lines and occasional concentric depressions marking growth halts.

Dimensions: (mm)	Length	Anterior length	Height	Inflation
Holotype				
CPC9295	25	12	10	10 (1 valve)

Remarks: Onestia orbicula sp. nov. is smaller and more orbicular than the Aptian species *O. etheridgei* (Etheridge Jnr, 1892) and *O. crespinae* sp. nov., and lacks the pallial sinus of those species.

Onestia onestae (McLearn, 1931) from the middle Albian Clearwater Formation of Alberta, is simlar in size to *O. orbicula* but is more transversely ovate and has well developed anteror lateral teeth.

Occurrence: Eromanga Basin—GAB2049, Allaru Mudstone, late Albian, Queensland.

CLASSIFICATION

McLearn (1933, p. 152) proposed *Onestia* as a subgenus of *Integricardium* Rollier (1912), but subsequently McLearn (1945) assigned the taxon generic rank. The Jurassic-Cretaceous *Integricardium,* type species *Cardium dupinianum* d'Orbigny from the Upper Cretaceous of France, resembles *Onestia* in lacking radial ornament, the principal difference lying in the former's much stronger tuberculiform lateral teeth. Although Keen (1969, p. N589) retained McLearn's original subgeneric classification of *Onestia,* the differences in dentition merit the distinction of the two at the generic level.

McLearn also compared *Onestia* with the Cretaceous genus *Thetironia** Stoliczka (1870) and noted the absence of radial ornament and an internal rib in the former. The family affinities of *'Thetironia'* have been in dispute (see Woods, 1907, p. 165; Keen, 1937, p. 13; Chavan, 1969, p. N512). Keen (1937) suggested a relationship between *'Thetironia'* and *Lahillia* Cossmann (1899). The latter genus appears to be the closest relative to *Onestia.*

The generic name *Lahillia* was introduced by Cossmann (1899, p. 134) as a *nomen substitutum* for *Iheringia* Cossman (1899, p. 90) (*nomen correctum pro Theringia* Cossmann, 1899, p. 45) (*non* Keyserling, 1891, *non* Lahille, 1898), which in turn was proposed as a *nomen substitutum* for the preoccupied *Amathusia* Philippi, 1887 (*non* Fabricius, 1807). The type species selected by Finlay & Marwick (1937) is *Amathusia angulata* Philippi from the Tertiary of Chile, and the genus is also known from Antarctica, New Zealand, and southern Australia. *Lahillia* approaches *Onestia* in shape and ornament and has smooth inner margins. However, *Lahillia* has a more massive hinge plate and all species of the genus lack anterior lateral teeth. *Onestia orbicula* sp. nov. lacks such teeth, and their development in *O. etheridgei* (Etheridge Jnr) is rudimentary.

In view of the considerable stability of the hinge features within the CARDIACEA, the absence and/or tendency towards reduction of the anterior lateral teeth in *Onestia* and their absence in *Lahillia* is highly significant. The *Onestia* genus group is probably the ancestral stock from which the Senonian-Miocene *Lahillia* evolved.

Lahillia is so unlike other cardiacean genera that Finlay & Marwick (1937) erected a subfamily to accommodate it. Marwick (1944) elevated the taxon to family rank and this was accepted by Keen (1969). Most authors have referred *Onestia* to the family Cardiidae (e.g. Keen, 1937, 1969; Vokes, 1967). However, because of the close relation existing between *Onestia* and *Lahillia,* it seems preferable to place the former in the family Lahilliidae. This would necessitate broadening the concept of the group to include forms with concentric ornament, smooth inner margins, and bladelike, but not tuberculiform, anterior lateral teeth.

The Lahilliidae share some features with the Mesozoic tellinacean family Tancrediidae, notably poorly developed anterior lateral teeth, smooth inner margins, and a simple or slightly sinuate pallial line. However, these features are outweighed by the cardiacean characters such as cyclodont cardinal teeth and basically cordate shape.

DISTRIBUTION

Onestia onestae (McLearn) occurs in early middle Albian sediments of the Clearwater Formation of the Peace River Lowlands, Alberta. This area is a part of the Western Interior Basins of North America.

Australian species of the genus *Onestia* occur in Aptian and Albian sediments of three sedimentary basins. *Onestia orbicula* sp. nov. is known from only one locality in the late Albian Allaru Mudstone of the Eromanga Basin in central western Queensland. *Onestia etheridgei* (Etheridge Jnr) is confined to the upper part of the Aptian Maryborough Formation of the Maryborough Basin in southeastern Queensland. The most widely distributed species, *Onestia crespinae* sp. nov. occurs in the late Aptian Doncaster Member of the Wallumbilla Formation in the Surat and Eromanga Basins in central western Queensland, in equivalent strata in the latter basin in northeastern South Australia and northwestern New South Wales, and some poorly

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* According to Chavan (1969, p. N512) this is an objective synonym of *Thetis* J. de C. Sowerby, 1826.

preserved material suggests the presence of the species in the early Aptian Minmi Member of the Bungil Formation of the Surat Basin.

During late Aptian time the Eromanga, Surat, and Maryborough Basins were interconnected and share a common fauna, termed the Roma fauna (Day, 1969). However, the seaway between the Maryborough and Surat Basins was probably coincident with the Toowoomba Strait (for the position of this feature see Day, Cranfield & Schwarzbock, 1974) and not as far north as shown in Day (1969, p. 164, fig. 33).

Both the Roma fauna and the Tambo fauna, with which *O. orbicula* is associated, were interpreted by Day (1969) as provincial, temperate or cool-temperate equivalents of Northern Hemisphere boreal faunas. This view has found favour with other workers, and the Australian region has been included in a Southern Hemisphere analogue of the Cretaceous Boreal Province variously termed the 'Austral Biogeoprovince' (Scheibnerova, 1970, 1971), the 'Austral Realm' (Stevens, 1971, 1973) and the 'Austral Province of the South Temperate Realm' (Kauffman, 1973).

The Canadian form *Onestia onestae* is similarly a cool-temperate or temperate species and occurs within the 'North American Boreal Province of the Boreal Realm' (Jeletzky, 1970, 1971a, b). This province exhibits a degree of endemism which is reflected in the nomenclature of the partly coincident 'Western Interior Endemic Center of the North American Province of the North Temperate Realm' of Kauffman (1973).

Occurrences of the genus *Onestia* in cool-water provincial Early Cretaceous faunas in opposite hemispheres and on opposite sides of the ancestral Pacific Ocean is an enigma, notwithstanding the reduced size of that ocean in Cretaceous time (see Smith, Briden & Drewry, 1973, text-fig. 1). The puzzle is compounded by the apparent lack of direct connection between the Peace River Lowland and the Pacific Coastal area (see Jeletzky, 1971, p. 43, fig. 9). Local provincial differences are such that separate zonal schemes are required for the two areas, and both Jeletzky (1970, 1971a, b) and Kauffman (1973) have recognised the Pacific Coastal area as a separate province, 'the North Pacific Province'.

This situation is to some extent paralleled by the close affinities existing between species of the ammonite *Tropaeum* in the Aptian Roma fauna and those of the 'North American Boreal Province' in Arctic Canada (Jeletzky, 1964; Day, 1974).

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PLATE 1

Onestia onestae (McLearn)

Figs.

1 Holotype, GSC No. 6345, lateral view of partly exfoliated left valve; x1. Locality, east bank of Athabasca River, 3 miles below Brûlé Rapids, Clearwater Formation, Alberta.

2 GSC No. 8004, interior lateral view of right valve; x1. Locality, same as fig. 1.

3 GSC No. 8003, interior lateral view of left valve; x1. Locality, north bank of Athabasca River, talus just below Brûlé Rapids, probably from Clearwater Formation, Alberta.

Onestia orbicula sp. nov.

Figs.

4 Holotype, CPC 9295, interior lateral view of latex cast of right valve; x1. Locality, GAB 2049, Allaru Mudstone, Queensland.

5 Same specimen as fig. 4, antero-lateral view of latex cast of external mould; x1.

Onestia crespinae sp. nov.

Figs.

6 Holotype, UQ F64775A, interior lateral view of latex cast of internal mould of right valve; x1. Locality, RD 122, Doncaster Member, Wallumbilla Formation, Queensland.

7 Holotype, UQ F64775B, interior lateral view of latex cast of internal mould of left valve; x1. Opposing valve to specimen of fig. 6.

8 Paratype, GSQ F7836, interior lateral view of latex cast of internal mould of left valve; x1. Same locality as figs. 6 and 7.

9 GSQ F7848, interior lateral view of latex cast of internal mould of right valve; x1. Locality, RD 221, east bank of Maranoa River 1 km north of railway crossing at Mitchell, Doncaster Member, Wallumbilla Formation, Queensland .

5

6

1

4

2

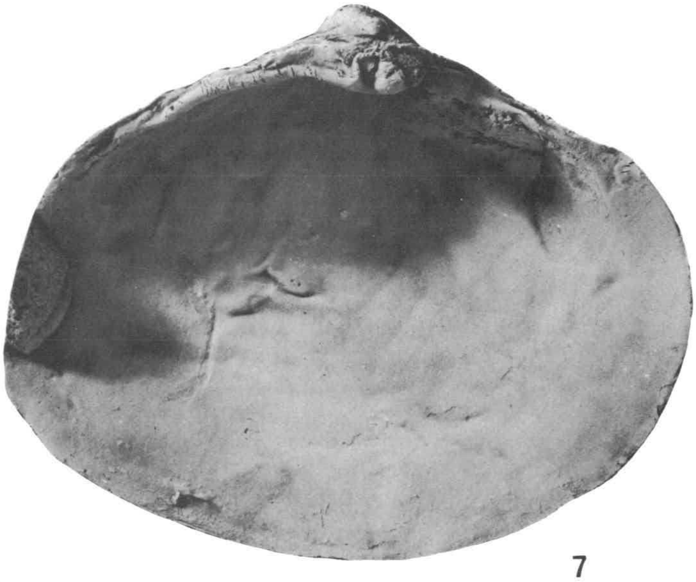

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PLATE 2

Onestia crespinae sp. nov.

Figs.

1 Paratype, GSQ F9230, dorsal view of latex cast of external mould of right valve; x1. Locality, RD 122, Doncaster Member, Wallumbilla Formation, Queensland.

2 Paratype, UQ F64776, exterior lateral view of partly exfoliated left valve; x1. Locality, same as fig. 1.

Onestia etheridgei (Etheridge Jnr)

Figs.

3 Lectotype, QM F1258, interior lateral view of latex cast of right valve; x0.5. Locality, Baddow quarry area, Maryborough Formation, Queensland.

4 Same specimen as fig. 3, lateral view of internal mould of right valve; x1.

5 GSQ F7326, lateral view of latex cast of hinge of left valve; x1. Locality, same as fig. 3.

Relationship of *Mourlonia* and *Ptychomphalina*, Upper Palaeozoic Gastropoda

by

J. M. Dickins

On the basis of morphological differences—particularly shape, external ornament, and characters associated with the selenizone—the type species of *Mourlonia* and *Ptychomphalina* are regarded as distinct species. In addition these differences are regarded as sufficient to warrant recognition of *Mourlonia* and *Ptychomphalina* as separate genera.

If this conclusion is accepted, the generic nomenclature of a number of Upper Palaeozoic species is simplified.

INTRODUCTION

The relationship between *Mourlonia* (de Koninck, 1883) and *Ptychomphalina* (Fischer, 1887) has been discussed by Dickins (1957, 1961, 1963) and Batten (1967). Knight, Batten & Yochelson (1960) in the Treatise on Invertebrate Paleontology regarded *Ptychomphalina striata* (J. Sowerby) 1817, p. 159, pl. 171, fig. 1, the type species of *Ptychomphalina,* as a synonym of *Mourlonia carinata* (J. Sowerby) 1812, p. 34, the type species of *Mourlonia,* and therefore regarded *Ptychomphalina* as a synonym of *Mourlonia.* Batten (1967) considered that the two species 'probably represented distinct natural groups at the species level'. In the present paper evidence is considered on the relationship between the two species based on examination of specimens, including the type specimens, at the British Museum (Natural History), London. The problem seems worthy of further consideration because if the two genera are synonymous, drastic changes in generic nomenclature are required for a number of Upper Palaeozoic species.

FEATURES OF *MOURLONIA CARINATA* AND *PTYCHOMPHALINA STRIATA*

In the collections at the British Museum (Natural History) individuals are readily separable into the two morphological groups representing the two species. The following characters separate the two:

1. *P. striata* has a narrow but distinct groove under the selenizone. This groove is not present in any specimens examined of *M. carinata.*
2. The whole cross-section is more evenly rounded in *M. carinata.* In *P. striata* the lower whorl surface is flatter than the upper whorl surface.
3. Transverse (collabral) ornament is strongly developed in *P. striata* whereas it is subdued in *M. carinata* which on the other hand has better developed revolving ornament.

In a letter E. L. Yochelson has also pointed out that in *M. carinata* the selenizone is flat but in *P. striata* it lies in a groove between an upper and a lower flange. All these features are shown clearly in the holotypes.

Particularly important in separating the two species are specimens of *Mourlonia carinata* from Malham, Yorkshire (PG 5034-5) and Balladoole, Isle of Man (PG 5036-7) from the collections of the British Museum (Natural History). These specimens seem to confirm the distinctive characters of *Mourlonia* and *Ptychomphalina* (Pl. 1, figs. 3-5; Pl. 2, fig. 6). In all four specimens distinctive spiral ornament is shown on the lower and upper whorl surfaces. In addition, however, spiral ornament is also present on the selenizone where up to 5 to 6 spiral lirae are visible.

The nature of the umbilicus of the two groups is not clear. None of the specimens of *P. striata* in the British Museum (Natural History) show an umbilicus. In some specimens of *M. carinata,* however, an umbilicus is present, whereas, in others, which do not seem separable on other grounds, an umbilicus is absent. In the holotype, however, an umbilicus is present (see Pl. 1, fig. 1), although Batten (1967, p. 262) says this specimen has a closed umbilicus. Knight (1941) does not figure the base of the specimen.

The evidence, therefore, indicates that the two groupings should be regarded as separate species and further, it is reasonable to contend that the differences are sufficient to warrant generic separation.

IMPLICATIONS FOR GENERIC NOMENCLATURE

To *Ptychomphalina* can be related numerous Upper Palaeozoic species, whose whorl cross-section is not evenly rounded but tends to have flat upper and lower whorl surfaces with the lower flatter than the upper. The transverse ornament is conspicuous whereas the revolving ornament is either absent or poorly developed. The nature of the ornament appears to be stable over a long period of time and, therefore, is of taxonomic significance. An umbilicus is invariably absent and a narrow sulcus may be developed below the selenizone. *Ptychomphalina maitlandi* Etheridge Jnr 1903, *P. talboti* Dickins, 1963 (see Dickins 1963, pp. 125-126, pl. 24) and other undescribed Australian Permian species are examples.

On the other hand many species of shells with distinct revolving ornament and a basal umbilicus are at present without a generic name if *Ptychomphalina* is considered a synonym of *Mourlonia* and the characters above ascribed to *Ptychomphalina* become the characters attached to *Mourlonia.* Examples of this from the Australian Permian are *Mourlonia lyndonensis* Dickins 1957 and *Mourlonia* sp. Dickins 1963 (see Dickins 1963, p. 119, pls. 23, 24).

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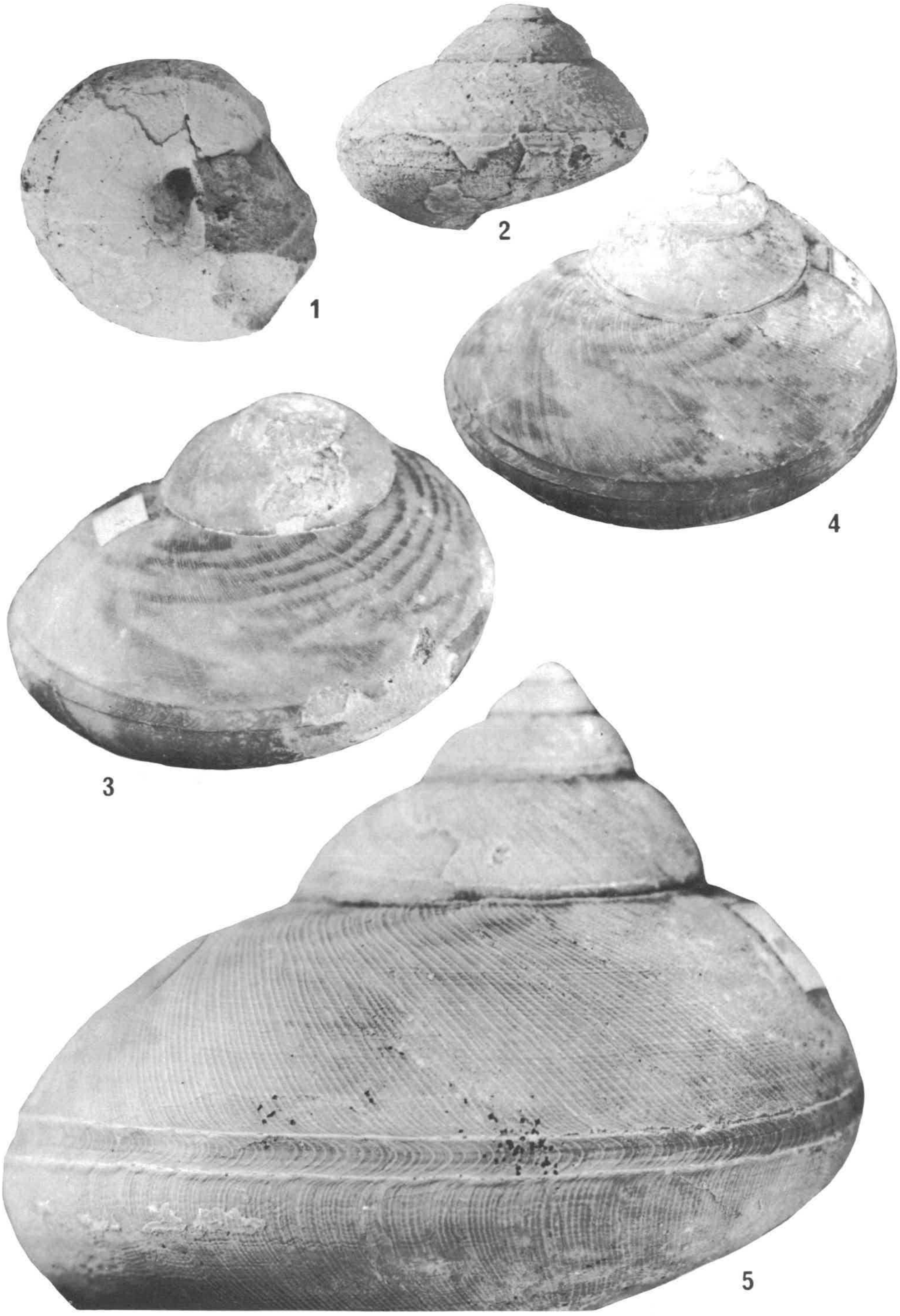


PLATE 1

Mourlonia carinata (J. Sowerby 1812)

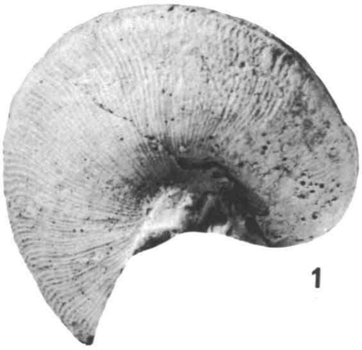
Figs.

1, 2 Plaster cast of holotype, No. P.G. 138, Lower Carboniferous, Visean, near Settle, Yorkshire. —1. Basal view showing umbilicus, x1. —2. Side view, x1.

3 No. P.G.5035, Carboniferous limestone, Malham, Yorkshire, side view, tilted to show colour banding, x2.

4, 5 No. P.G.5034, Carboniferous limestone, Malham, Yorkshire, —4. Side view, tilted to show colour banding, x2. —5. Side view to show ornament, x4.

All illustrated specimens are held in the British Museum (Natural History), London.



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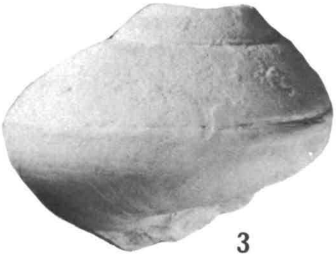

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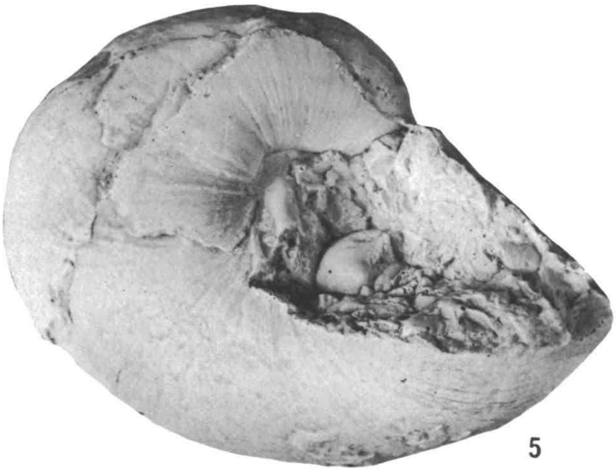

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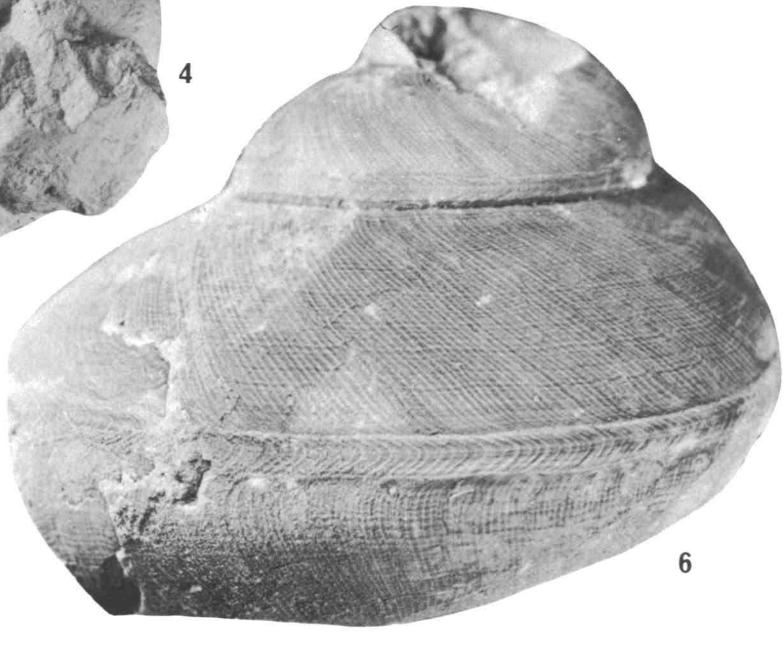

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PLATE 2

Ptychomphalina striata (J. Sowerby 1817)

Figs.

1, 2 Plaster cast of holotype, Lower Carboniferous, Derbyshire. —1. Basal view, x1. —2. Side view, x1.

Mourlonia carinata (J. Sowerby 1812)

3, 4 Plaster cast of No. P.G.139. Carboniferous limestone, ?Bollard, near Settle, Yorkshire. —3. Side view, x1. —4. Basal view to show umbilicus, x1.

5 Plaster cast of No. P.G.40, Lower Carboniferous, Bollard, Yorkshide. Basal view of a specimen of which Knight (1941, pl. 29, fig. 1b) figured a side view; x1.

6 No. P.G.5036, Poyllvaaish Limestone, from immediately below the top soil at the E end of Chapel Hill Quarry (SC 245682), Carboniferous. Balladoole, Isle of Man. Side view to show ornament, x4.

All illustrated specimens are held in the British Museum (Natural History), London.

Correlation of the Cambrian/Ordovician boundary in Australia

by

E. C. Druce

Although sections which straddle the Cambrian/Ordovician boundary have been known in Australia for many years, it is only recently that detailed biostratigraphic results have been published. Because they were the first group to be dealt with in detail, the boundary, at present, is defined in terms of conodonts and is drawn at a diagnostic faunal change.

A lower fauna, composed of virtually unornamented, thin-walled simple cones associated with W-shaped forms, is restricted to the Cambrian. This fauna is known from the *Acerocare* Zone (6a) of the Acado-Baltic region and is thus of latest Cambrian age. An upper fauna, representing a considerable diversification of ornamented forms from two simple ancestors, is characterized by the incoming of *Cordylodus proavus.* The cordylodid sequence has been divided into six successive assemblage-zones in Australia; the upper two zones are equivalent to the late Tremadocian of the Baltic area. The early Tremadocian of the Baltic area comprises the *Dictyonema* Shale from which conodont faunas are known, but not yet published. The unpublished results suggest that faunas similar to those found in the lower four conodont zones of the Australian sequence can be recognized, lending strength to the view that the incoming of *Cordylodus proavus* is, at least, a close approximation to the boundary between the *Acerocare* Zone and the Tremadocian. If we accept that the Tremadocian should belong in the Ordovician rather than the Cambrian, then *Cordylodus proavus* is a satisfactory guide to the base of the Ordovician.

Late Cambrian and early Tremadocian conodonts show no noticeable provincialism and do not appear to be facies-controlled. Complete skeletons were probably composed of very similar units, and preferential preservation of disjunct units does not appear to pose problems. The presence of six conodont zones in Australia during Tremadocian time indicates that a conodont zone spans approximately a million years, an order of precision half that seen in Devonian conodont zones, and in Jurassic ammonite zones.

Although Late Cambrian and Early Ordovician conodonts have been studied less than those of later time intervals, there is a reasonable worldwide distribution of reported occurrences.

The sequence of faunas described from Australia has also been described, independently, from North and Central America, where the Cambrian/Ordovician boundary has been similarly and coincidently drawn at the incoming of *Cordylodus proavus.* The Late Cambrian fauna recognized in Australia is also known from Iran, Kazakhstan, and China, and Tremadocian faunas similar to the Australian sequence have been reported from the southeast Siberian Platform, South Korea, and New Zealand.

Thus, although the *Cordylodus proavus* Zone is known definitely in only Australia, North and Central America, and Siberia, the worldwide occurrence of both ancestors and descendants demonstrates its potential usefulness in recognizing the Cambrian/Ordovician boundary.

In North America the detailed conodont stratigraphy parallels a detailed trilobite stratigraphy. The Cambrian/Ordovician boundary has long been recognized in terms of trilobites as the boundary between the *Saukia* Zone (Cambrian) and the *Symphysurina* Zone (Ordovician). This latter zone has now been divided, the lowest part being generally recognized as the *Missiquoia* Zone. Comparison with conodont zonation shows that *Cordylodus proavus,* in sections as far apart as Texas and Alberta, first occurs at or near the base of the *Corbinia apopsis* Subzone, the youngest of four subzones of the *Saukia* Zone. Although this subzone is extremely thin and probably represents a short time interval, the conodont boundary and the traditional trilobite boundary appear not to coincide.

However, conodont and trilobite faunas from Mexico suggest that saukiids may range into the Lower Tremadocian. Faunas from Afghanistan support this interpretation; palaeontological proof was provided by the recovery of a mixed trilobite fauna in which Acado-Baltic early Tremadocian trilobites and saukiids are present.

The continued use of the demise of the saukiids as the basis for delineating the Cambrian/Ordovician boundary could lead to pitfalls similar to the use of the "last" graptolite to define the lower boundary of the Devonian. The use of trilobites, although obviously valuable in local correlation, may be inhibited by the occurrence of biomeres, sudden non-evolutionary changes in faunas not obviously associated with lithological changes.

Other groups which may prove useful in delineating the boundary include brachiopods and molluscs. Phosphatic brachiopod faunas have not been fully described but appear to offer some promise although slow and minor morphological changes may detract from precision. The molluscs were in the process of rapid evolution and may be a useful tool, although ecological factors hinder their use.

At the present time conodonts offer the most precise method of correlating the latest Late Cambrian and Early Ordovician; zones of the order of a million years' duration can be recognized, and major evolutionary changes occurred coevally worldwide. The ease of recovery and of identification of conodonts are added benefits. The only drawback to their use is the difficulty of recovering them from indurated and silicified clastic sediments.

INTRODUCTION

The Cambrian and Ordovician Systems were established in Britain, and the placement of their common boundary is based on historical priority. As Henningsmoen (1973) pointed out, Lapworth (1879), whilst drawing the boundary at the base of the Lower Arenig, included the Upper Tremadocian within the Lower Arenig. The absence of a precise definition has meant that the Cambrian/Ordovician boundary has been placed at different horizons in various countries.

In Australia the boundary has been consistently drawn at the base of the Tremadocian. This paper discusses the recognition and distribution of sequences which overlap this boundary, and the possibilities of recognizing this horizon around the world. The complex problem of the positioning of the Cambrian/Ordovician boundary (for which see Henningsmoen, 1973) is not discussed, but this paper will provide information which may influence the final choice of a boundary and its stratotype.

Late Cambrian and Early Ordovician seas covered the eastern part of the Australian continent and extended as a wide tongue westward into the central and north-central parts of the continent (Fig. 1). Within this sea sediments were deposited in different tectonic regimes: near what is now the eastern seaboard subsidence and volcanism occurred with resultant interfingering of thick clastic and volcanic rocks. To the west, on the other hand, sedimentation took place on a stable platform represented by carbonate-clastic sequences.

Over the last century geological investigations in Australia have developed from reconnaissance to detailed mapping and have progressed from the populated southeastern part of the continent into the less hospitable arid centre. The search for strata which cross the Cambrian/Ordovician boundary has followed a similar pattern and thus the boundary was recognized initially in geosynclinal sediments and then in platform sequences.

In Tasmania, Cambrian rocks are known from the Dundas Trough in which a predominantly conglomerate, greywacke and tuff sequence is preserved; rare fossils indicate the Middle and early Upper Cambrian (Banks, 1956).

Recently Jago (1972) has reported trilobites indicative of the North American *Ptychaspis-Prosaukia* Zone (late Upper Cambrian) and suggests that there is very little time missing between the siltstone in which this fauna occurs and the overlying Junee Group, which includes the Gordon Limestone and which is, in part, Tremadocian.

In the type area of the Junee Group the stratigraphy has been refined (Corbett & Banks, 1974): a basal sandstone or conglomerate is overlain by the Florentine Valley Formation which is dominantly siltstone with some sandstone, chert, and limestone. This is, in turn, overlain by the Gordon Limestone Sub-group. The oldest faunas are found in the Florentine Valley Formation and include graptolites which suggest a Lancefieldian (La2 or La3) age (late Tremadocian or earliest Arenigian). However, Corbett & Banks (p. 214) feel that the basal Reeds Conglomerate may be latest Cambrian because of its apparent conformity with the underlying Upper Cambrian and transition into the Florentine Valley Mudstone.

In Victoria, the Heathcote sequence extends from the Lower Cambrian into the Ordovician. Unfortunately, the Goldie Shales which lie between the Middle Cambrian Knowsley East Formation and Lancefieldian (La1) rocks, are unfossiliferous. The Lancefieldian is Tremadocian, probably late Tremadocian because it contains *Dictyonema* and *Staurograptus*: Thomas & Singleton (1956) place the Cambrian/Ordovician boundary 'at the entry of greywackes which mark the first appearance of abundant detrital quartz and granite accessory minerals' which is about 30 m below the first occurrence of *Dictyonema* and *Staurograptus*.

Northward, within the geosyncline, the Cambrian may be represented by low-grade metamorphic rocks which crop out in a discontinuous linear belt through New South Wales and Southern Queensland (Brown et al., 1968) and possibly as far north as Rockhampton (Kirkegaard et al., 1970).

Shergold (1971) reviewed the previous literature on Cambro-Ordovician rocks in northwestern New South Wales, and reported that in the Gnalta-Mootwingee area late Upper Cambrian and early Ordovician faunas are present in shelf sediments and are similar to faunas from western Queensland (see below).

As geological investigations began in central Australia, it became obvious that there were large areas of virtually undeformed fossiliferous Cambrian and Ordovician rocks. In the Georgina Basin, Whitehouse, in a series of pioneer papers (1936-1945), recognized Late Cambrian (his Pituri Series and in part Georgina Series) and Early Ordovician (Ninmaroo Series). He thought the Ninmaroo Series probably overlay the Georgina Series in the region of Black Mountain (Mount Unbunmaroo), 50 km northeast of Boulia, Queensland, and that a continuous sequence from Upper Cambrian into Ordovician was present. Farther west, in the western part of the Georgina Basin and the Amadeus Basin, Cambrian rocks were recognized by Madigan (1932b), and a single locality near Huckitta in the Georgina Basin, yielded Ordovician fossils. Information from these reconnaissance surveys was greatly amplified during systematic mapping of the Georgina and Amadeus Basins by BMR.

The Georgina Basin contains several Late Cambrian-Early Ordovician sequences. In the west, in the area of the Dulcie Range, sandstone and siltstone of the Tomahawk Beds straddle the boundary. Fossils are mainly confined to the lower part and the boundary cannot yet be defined. In the eastern part of the basin, at the Mount Unbunmaroo locality mentioned by Whitehouse, the Upper Cambrian Chatsworth Limestone is overlain by the Lower Ordovician Ninmaroo Formation (Smith, 1972). The boundary between the formations is drawn at the change from limestone to dolomite; coincidentally a nautiloid fauna first appears

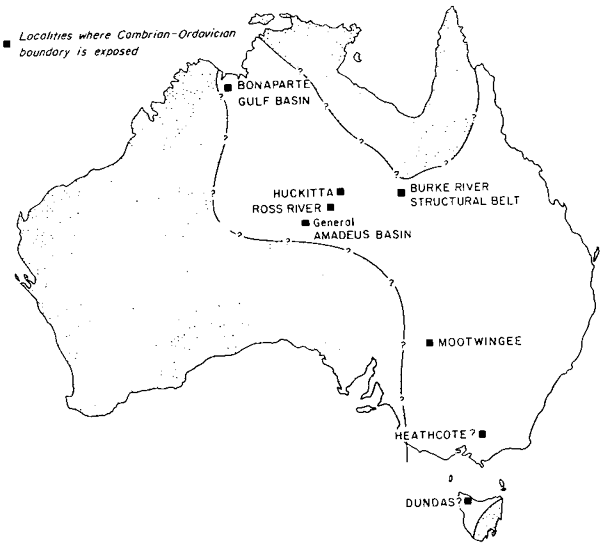

Figure 1. Approximate limits of sea at Cambrian/Ordovician boundary

at this horizon and this has been taken as the Cambrian/Ordovician boundary (Casey, 1968).

In the Amadeus Basin the Pacoota Sandstone straddles the boundary (Wells et al., 1970); fossils are few and are confined to bands, which means that the age of unfossiliferous interbeds cannot be established.

In Western Australia Cambrian rocks appear to be absent from the Canning Basin although there is a considerable thickness of Lower Ordovician rocks present. However, Upper Cambrian and Lower Ordovician sediments are exposed in the Bonaparte Gulf Basin and yield a succession of twelve faunal units (Kaulback & Veevers, 1969), ranging from earliest Middle Cambrian to late Tremadocian or perhaps early Arenigian (Öpik *in* Kaulback & Veevers, 1969, p. 75). Öpik considers the sequence to be continuous from Unit VII (middle Upper Cambrian) and that the Cambrian/Ordovician boundary occurs between units XI and XII. Unit XI is represented by only one collection containing a *Tellerina*-like pygidium and fragmentary cranidia of Saukiidae. Unit XII yields Richardsonellinae, Leiostegiidae, and protopliomerid trilobites (Öpik, ibid.). This section was re-collected by Shergold (1971) who reports Upper Cambrian Ptychaspididae (*Ptychaspis*), Saukiidae (*Prosaukia, Saukia, Saukiella,* and a form suggestive of *Tellerina*) and Tsinaniidae in profusion from the Clark Sandstone. The highest beds of the Clark Sandstone yield Datsonian Richardsonellinae and Leiostegiidae trilobites. This horizon marks the incoming of glauconite into the quartz sandstone sequence and was tentatively placed by inference in the Pander Greensand by Jones, Shergold, & Druce (1971, p. 22). The Pander Greensand *sensu stricto* ranges into the Arenigian.

However, the exposures around Mount Unbunmaroo and other exposures along the Burke River Structural Belt in the Georgina Basin offer the best opportunity for delineating the Cambrian/Ordovician boundary. Jones et al. (1971) summarize the previous investigations; thus far the conodont results are published (Druce & Jones, 1971) and the systematic description of the trilobite faunas has been completed (Shergold, 1975).

THE CONODONT BOUNDARY

The Mount Unbunmaroo section has yielded good conodont faunas which have been supplemented by material from Mounts Ninmaroo and Datson to the southeast, along the Burke River Structural Belt (Fig. 1).

The conodonts are represented by two distinct faunas. The earlier fauna comprises simple thin-walled cones with little ornament, and the enigmatic westergaardodinids; the latter fauna comprises more complex cones with more massive cusps and considerable and varied ornament (Fig. 2).

The boundary postulated by Casey (1968) between the calcarentite of the Chatsworth Limestone and the basal dolomite of the Ninmaroo Formation approximates the boundary between these faunas.

The fauna from the Chatsworth Limestone is characterized by *Proconodontus muelleri* Miller, *P. notchpeakensis* Miller, *P. tricarinatus* (Druce & Jones), *Prooneotodus gallatini* (Müller), *P. tenuis* (Müller), *Furnishina furnishi* (Müller), *Prosagittodontus dahlmani* Müller, *Problematoconites perforatus* Müller, *Westergaardodina amplicava* Müller, *W. bicuspidata* Müller and *W. mosseburgensis* Müller.

The last reasonably abundant Cambrian fauna was recovered from a horizon 97.5 m below the Chatsworth/Ninmaroo boundary on Mount Unbunmaroo and the younger, Ordovician, fauna appears 61 m above the base of the Ninmaroo Formation. Within this 159 m gap there are isolated occurrences of *Proconodontus muelleri* Miller, *P. notchpeakensis* Miller, and *Oneotodus nakamurai* Nogami.

The first occurrence of the later fauna which included *Cordylodus proavus* Müller, *C.* cf. *C. proavus* and *Fryxellodontus inornatus* Miller, marks the base of the Datsonian Stage and the upper limit of the Payntonian Stage (Jones et al., 1971). Jones et al. concluded that the Cambrian/Ordovician boundary is located, by correlation overseas, at the base of the Datsonian Stage, and that the incoming of the *Cordylodus proavus* Assemblage Zone fauna is approximately coeval with the incoming of the *Dictyonema* graptoloid faunas of the Acado-Baltic Province.

Therefore, the Cambrian/Ordovician boundary in central Australia, which is considered to be at the base of the Tremadoc, is drawn at the first appearance of *Cordylodus proavus* Müller; and the *Cordylodus proavus* Assemblage Zone becomes the earliest Ordovician biostratigraphic zone.

It is followed by five further zones (in ascending order the *Oneotodus bicuspatus-Drepanodus simplex, Cordylodus oklahomensis-C. lindströmi, Cordylodus prion-Scolopodus, Cordylodus rotundatus-C. angulatus,* and *Chosonodina herfurthi-Acodus* Assemblage Zones) recognized in the Mount Unbunmaroo area (Druce & Jones, 1971) which are in turn succeeded by the *Drepanodus? gracilis-Scolopodus sexplicatus* Assemblage Zone of Arenigian age known from the Bonaparte Gulf and Daly River Basins. This last zone is known from the Mount Unbunmaroo area but the junction with the underlying *Chosonodina herfurthi-Acodus* Assemblage Zone has not yet been determined (Jones et al., 1971, p. 14).

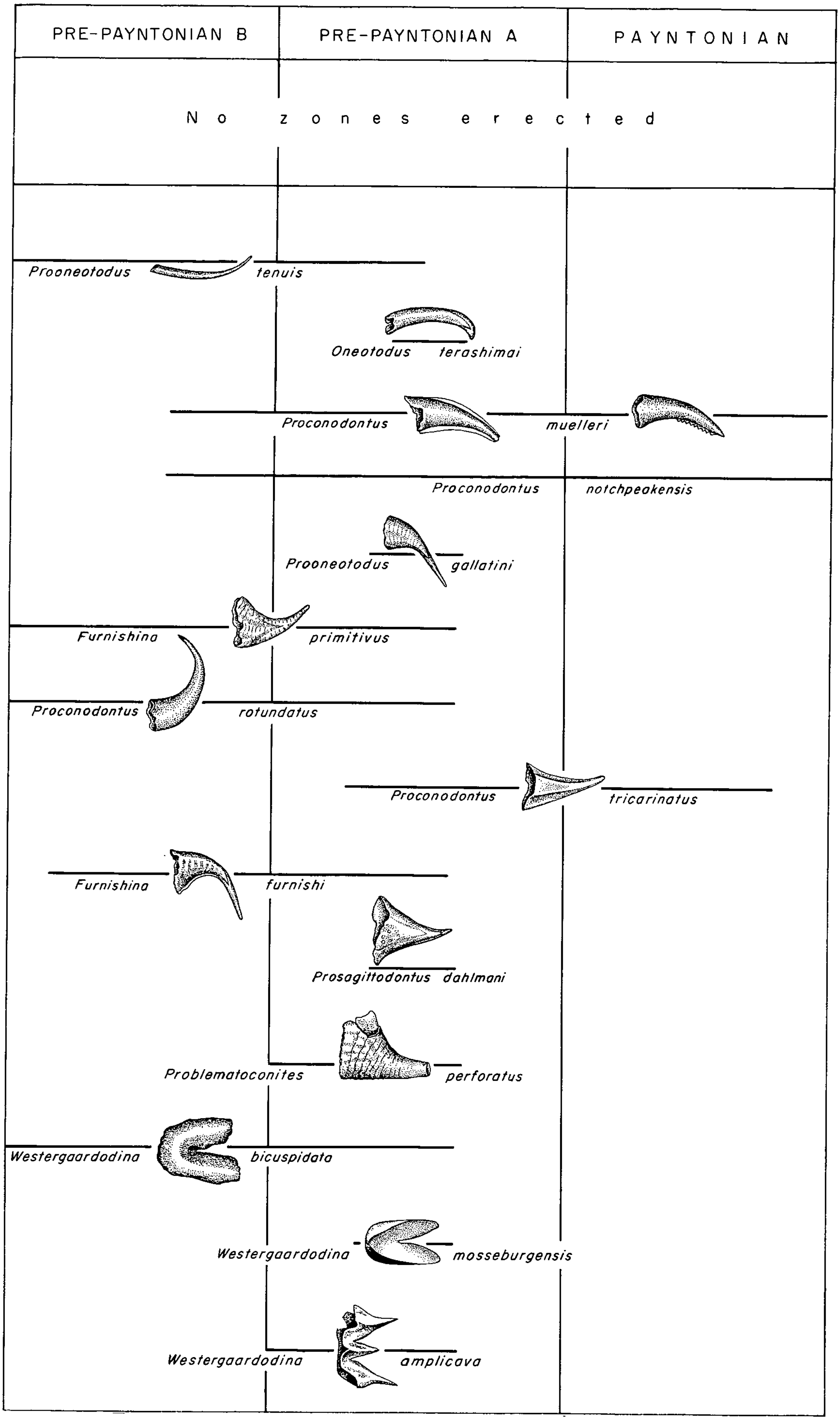

Figure 2a. Distribution of Upper Cambrian conodonts, Burke River Structural Belt M(P)332 A

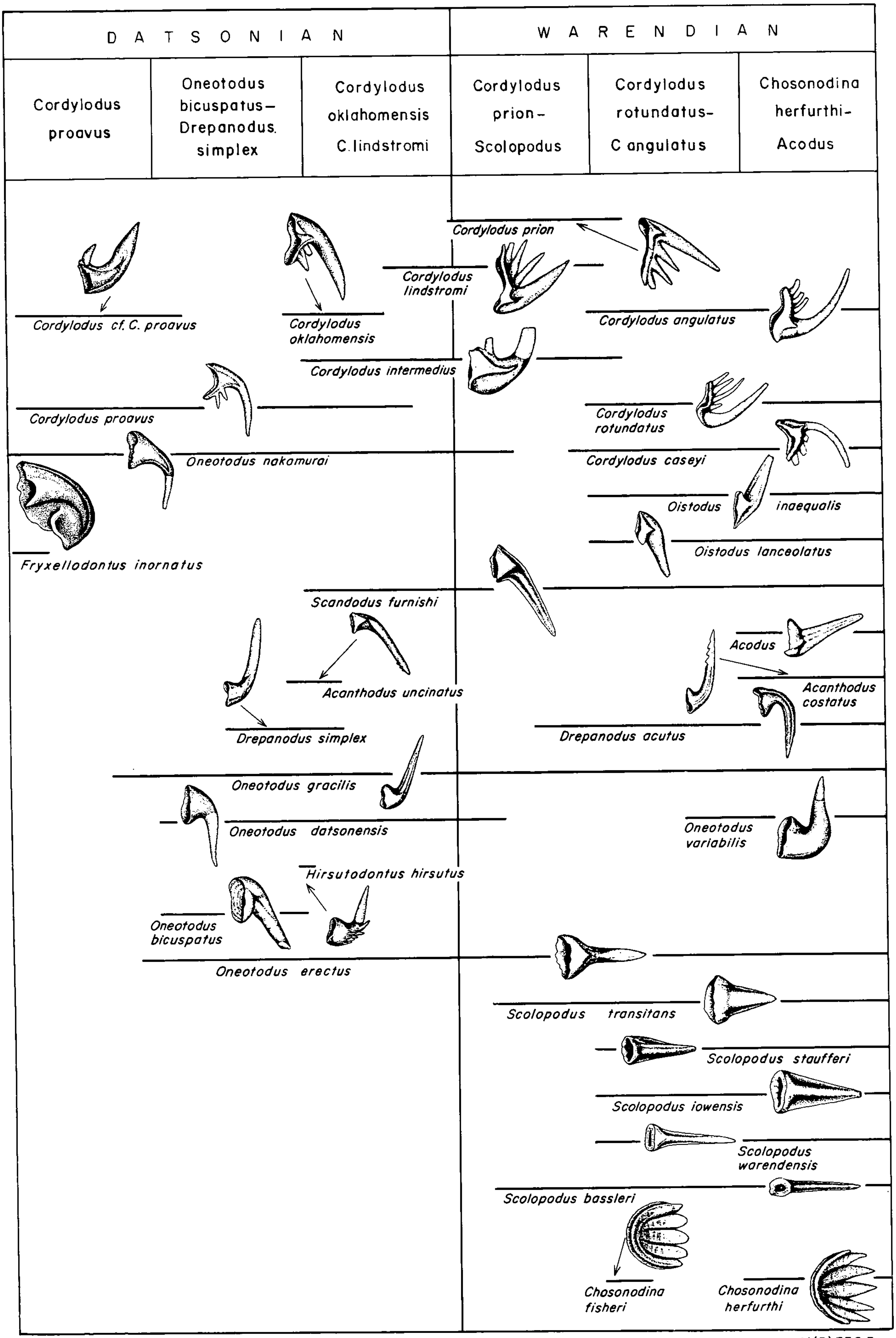

Figure 2b. Distribution of Lower Ordovician conodonts, Burke River Structural Belt

M(P) 332 B

Thus the Datsonian and Warendian which are probably equivalent to the Tremadocian, which spans about 5 million years (Harland et al., 1964), are represented by six conodont zones with an average age span of the order of a million years per zone (Druce & Jones, 1971).

PROBLEMS ASSOCIATED WITH CONODONT ZONATION

As conodont studies progressed during the 1950s and 1960s it became apparent that the group possessed two traits which commended them for use as zonal fossils. Firstly they showed rapid evolution and secondly a worldwide distribution. The Devonian conodont zonation is closely comparable to the Devonian goniatite zonation and the same age inferences are drawn from both groups in Europe, North America, and Australia. Conodont zone boundaries thus provide one of the closest approximations to worldwide time planes known, having the same order of precision as ammonites in the Jurassic. Additionally it was thought that they were not confined to sedimentary facies because the same species were found in different rock types (Müller, 1962). Conodonts appeared to be the panacea for biostratigraphic ills.

'Facies' control

Continued research showed that independence of facies was not universal; Merrill (1962) was the first to suggest 'facies' control on conodont distribution, especially in Pennsylvanian rocks of eastern and central USA. Other examples of 'facies' control were reported from the Lower Carboniferous (Druce, 1969) and the Upper Devonian (Seddon, 1970a) of Australia.

These results, plus additional information, culminated in the ecological models for conodonts propounded by Seddon & Sweet (1971) and Druce (1973). These authors conclude that conodont faunas were vertically stratified in the water body; Seddon & Sweet (p. 879) postulates at least two faunal layers and Druce (p. 211) believes there were three or perhaps four layers during the Late Palaeozoic.

The ecological interpretation is complicated by the fact that provincialism is also apparent in Arenig to early Wenlock faunas (Barnes et al., 1973) and possibly in the latest Tremadoc faunas (Jones et al., 1971; Jones, 1971). It should be pointed out that element distribution can be affected by biofacies in such a way as to geographically separate species (or genera) but that the scale is much less than that seen in distribution anomalies caused by provincialism. Thus Seddon & Sweet (1971) were able to recognize both biofacies and provincialism in the faunas discussed by them.

The effect of biofacies on conodont zonation was summed up by Druce (1970, p. 386) who concluded that 'zonations based exclusively on deep water faunas are difficult to apply to shallow water deposits'.

The original Tremadocian conodont zonation was erected using faunas recovered from calcareous rocks comprising calcareous dolomite, mottled limestone, calcilutite, minor calcarenite, breccia, pelletal limestone, oolite, limestone conglomerate, and chert (Jones et al., 1971, p. 10). The similarity of faunas of this age recovered from different rock types suggests there was little facies control in the region during the Tremadocian epoch.

The confirmation that this zonation was applicable in northern Australia was provided by Jones (1971) who described the Cambro-Ordovician conodonts from the Bonaparte Gulf Basin. In section 249 Jones identified the pre-*Cordylodus proavus* and the five post-*C. proavus* Tremadocian Zones and one (new) Arenigian zone. The sequence is arenaceous, the pre-*C. proavus* Zone occurring in the Clark Sandstone, a red medium-grained glauconitic sandstone (Kaulback & Veevers, 1969) and the Datsonian and Warendian zones in the lower part of the Pander Greensand, a glauconite-rich (up to 60%) medium-grained quartz sandstone.

Unfortunately the *Cordylodus proavus* Zone has not been recognized because conodonts were not found in the lower 27 m of the 107 m thick Pander Greensand (Jones, 1971, p. 12). However, the presence of the later Datsonian and Warendian zones with their diagnostic species suggests that this absence is not necessarily a response to a subtle change in environment but is probably due to insufficient sampling.

Provincialism

Conodont faunal provinces were first recognized in the Ordovician by Sweet et al. (1959), and their distribution and characteristics have been augmented by subsequent workers. Most workers identify two faunal provinces, the North American Midcontinent Province and the Anglo-Scandinavian Province; Bergström (1971, p. 130) tentatively suggests a third, Australian, province. Constituents of each faunal province are known to occur in the other provinces and neither of the well recognized provinces is confined to the geographic areas implied in its name (Bergström, 1973, fig. 5). Bergström (op. cit.) considers that 'the distribution of Ordovician conodont faunas may well provide one of the most striking illustrations of faunal provinces known anywhere in the geological record'.

This provincialism did not appear to have been important until the Arenigian (Barnes et al., 1973, p. 157). In the Cambrian, conodont faunal data is so sparse that provincialism would be difficult to demonstrate, even if it existed. The Tremadocian faunas are better known; no provincialism is obvious and Barnes et al. (p. 183) conclude that they are cosmopolitan. However, Jones et al. (1971, p. 25) and Jones (1971, p. 35) suggest that provincialism may have occurred in the latest Tremadocian, where cordylodids appear to be the only common elements between Australia, North American, and Scandinavian faunas.

Conodont assemblages

The previous discussion has been concerned solely with form genera and species erected for discrete elements associated, in life, with other elements within the conodontifer. Little is known of Cambrian and Ordovician apparatuses (also known as assemblages); Druce & Jones (1971), from computer studies, suggest that two Cambrian forms were possibly present, one composed completely of furnishinid cones and the other of furnishinids and westergaardodinids (1971, p. 29). Miller (pers. comm., and in press) has recently described an in-situ apparatus of Cambrian age composed solely of primitive (furnishinid) cones.

Earliest Ordovician apparatuses have been described by Miller (1969) and Druce & Jones (1971). Miller considered that several discrete elements of differing morphology, but showing a symmetry transition (sensu

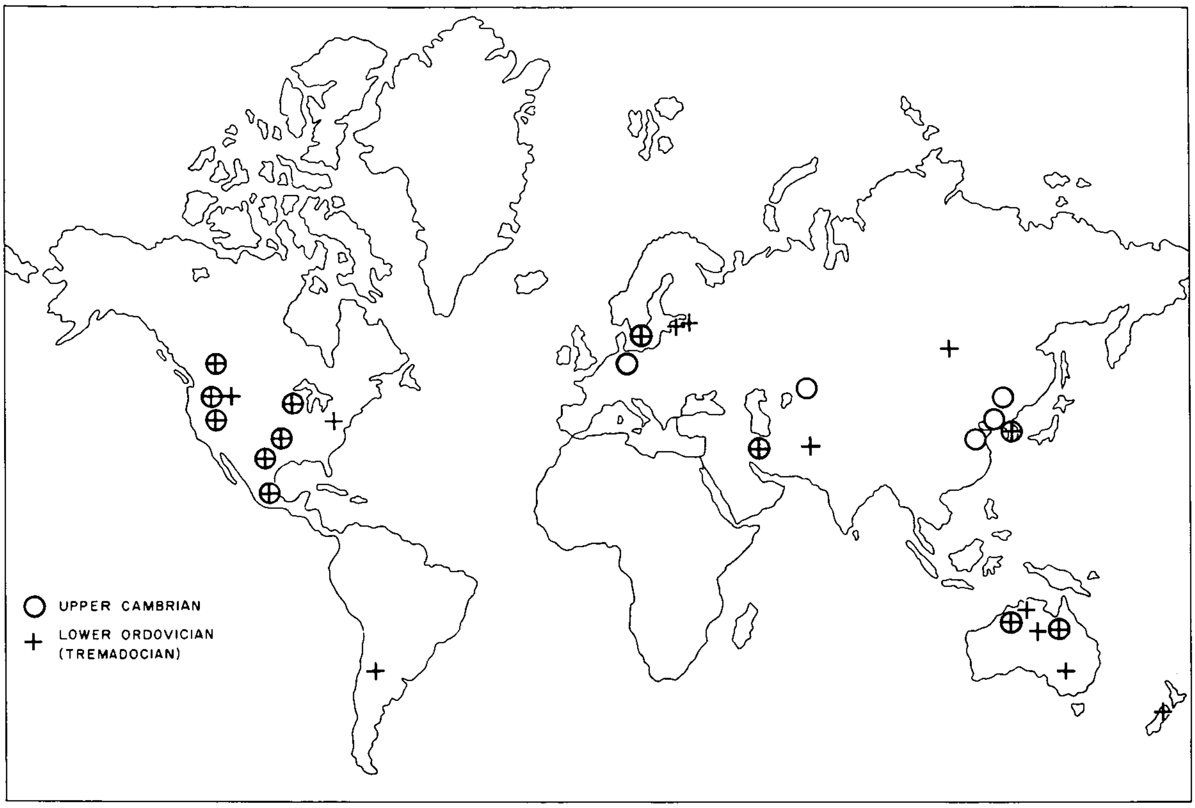

Figure 3. Distribution of Upper Cambrian and Lower Ordovician (Tremadocian) conodont faunas

Lindström), should be brought together as one species; he recognized two such groupings referable to *Fryxel lodontus*, of earliest Ordovician age. Druce & Jones (1971) considered that an apparatus composed of *Cordylodus proavus* and *C.* cf. *proavus* together with an apparatus composed solely of *Oneotodus nakamurai* appeared in the earliest Ordovician. The sole fryxellodontid element in their fauna was not considered in the analysis.

Thus correlation problems caused by partial preservation and recovery of very different elements from the same conodontifers do not occur; the individual skeletons were made up of morphologically similar elements.

INTERCONTINENTAL CORRELATION (Figs. 3 & 4)

North America

Cordylodus proavus was first recognized from the Signal Mountain Limestone of Oklahoma, USA (Müller, 1959), from an horizon originally thought to be Cambrian, but now considered Ordovician (Branson, 1957).

The section has been re-collected by Miller (pers. comm.) who records the first occurrence of *Cordylodus proavus* 130 m above the base of the Signal Mountain Limestone. Below this horizon a typical proconodontid fauna with *Furnishina* is found.

The first occurrence of *Cordylodus proavus* is also seen in sections in Utah (Miller, 1969), Wyoming (Rhodes, pers. comm.) and Texas (Miller, pers. comm.). In the House Range, Utah, *C. proavus* first appears in the Notch Peak Limestone, 54 m above the base of the 103 m thick Member 6. In the Llano uplift areas of Texas the first occurrence of *C. proavus* is within the Wilberns Formation, 69 m above the base of the San Saba Limestone Member. The faunal transition is virtually identical to that seen in Oklahoma and Utah (Miller, pers. comm.).

In Wyoming, Rhodes (pers. comm.) has recovered a similar conodont sequence from the Gros Ventre and Gallatin Formations.

Cordylodus proavus has been reported from Mexico (Pantoja-Alor & Robison, 1967) in a condensed sequence from which latest Cambrian and earliest Ordovician trilobites have also been recovered. If the Cambrian/Ordovician boundary is within the 200 m Tiñu Formation in the Nochixtlán region it is probably near the base of the 15 m of dark fossiliferous limestone and interbedded shale comprising the lower member.

Ethington & Clark (1971) recognized the distinctive *Cordylodus proavus* fauna as their Fauna A. In addition to the above occurrences they also report it from the lower part of the Manitou Formation in Glenwood Canyon, central Colorado, and possibly from the basal Goodwin Limestone near Eureka, Nevada. They consider that the fauna reported from the Deadwood Formation, South Dakota and the Emerson Formation, Montana by Goodwin (1961), probably also represents Fauna A. Miller (pers. comm.) has recovered conodonts from the Deadwood section and considers them to be slightly younger than the first occurrence of *Cordylodus proavus*, although they do belong to Fauna A.

The conodont sequence seen in Mexico, Oklahoma, Texas, and Utah is present in Alberta at Mount Wilson North, the standard Ordovician section for Canada

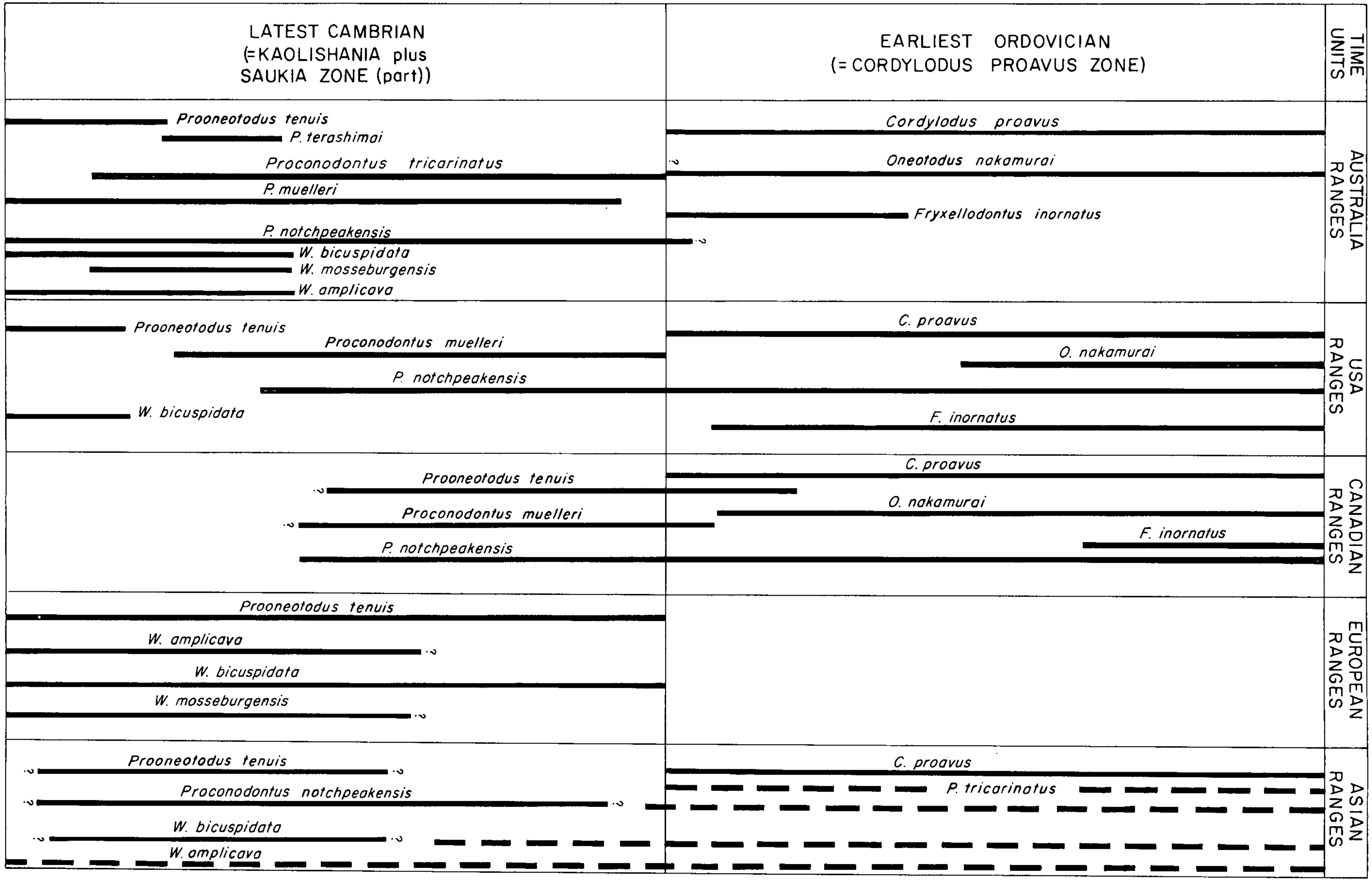

Figure 4. Composite range charge of common worldwide latest Cambrian and earliest Ordovician conodonts; broken lines are ranges from Muller (1973)

(Derby et al., 1972). *Cordylodus proavus* first appears 18 m above the base of the Survey Rock Formation. There is some overlap between the ranges of the proconodontids (of Cambrian aspects) and the Ordovician cordylodids, hirsutodontids, and fryxellodontids.

Europe

The latest Cambrian conodonts recovered are from the *Acerocare* Zone (6a) (Müller, 1959) of Sweden; a similar fauna has been recovered from erratic boulders in Germany (Müller, 1959, 1971).

The earliest Ordovician conodonts are from the Tremadocian upper *Dictyonema* Shale (Viira, 1966) and overlying *Ceratoypge* Limestone (Viira, op. cit.; Lindström, 1954). The fauna includes the late Tremadocian *Cordylodus angulatus* and *C. rotundatus;* lower beds have yielded early Tremadocian cordylodids but not, as yet, the *Cordylodus proavus* fauna (Löfgren, pers. comm.). Nevertheless, the similarity between the Australian and European faunas during both the latest Cambrian and Tremadocian is striking, suggesting that the non-recovery of *C. proavus* is probably due to a hiatus, to non-sampling of the correct horizon, or perhaps to non-recovery.

Asia

Reported conodont faunas from Asia are few and far between, but a late Tremadocian fauna similar to those found in the Early Ordovician of Australia was reported by Müller (1964) from South Korea. In 1966 Nogami described a fauna from the Yenchouan (latest Upper Cambrian) and, later, from the earliest Upper Cambrian Kushanian (Nogami, 1967).

It was not until 1972 that the *Cordylodus proavus* fauna was reported by Abaimova (1972a, b), from the Ustkutski Horizon, of the southeastern Siberian platform. This is the oldest fauna in the sections described and although the sequence of faunas across the Cambrian/Ordovician boundary is not recorded the lower boundary of the *Cordylodus proavus* fauna is probably within the basal part of the section. In Kazakhstan latest Cambrian conodonts, including proconodontids and westergaardodinids, are known (Abaimova et al., 1973).

Other reported faunas which are very similar to Australian Late Cambrian-Early Ordovician ones include those from the latest Cambrian of Iran (Müller, 1971, 1973; Kushan, 1973), and latest? Tremadocian of Malaya (Igo & Koike, 1967) and New Zealand (Cooper & Druce, 1975).

A detailed study by Müller (1973) from spot samples in the Mila Group in Iran produced some interesting results. Although the fauna is comparable with faunas of the same age from elsewhere in the world and the sequential appearance of species is similar, the ranges given are much longer and Late Cambrian forms are found in association with Late Tremadocian faunas (Fig. 4). These occurrences are enigmatic; Müller suggests that insufficient sampling in Queensland or ecological control may be the cause. However, the former suggestion can be ruled out; trough sampling was detailed and took place at three distinct and well exposed sections; ecological control may well be a factor, but to this should be added the possibility of reworking (or of stratigraphic leaks).

The Late Cambrian-Early Ordovician conodont faunas give every appearance of being cosmopolitan, enhancing the precision of correlation in this interval.

RELATIONS BETWEEN OTHER FOSSIL GROUPS AND THE CONODONT BOUNDARY (Fig. 5)

Australia

In Victoria the Cambrian/Ordovician boundary has been drawn near, but below, the first occurrence of *Dictyonema campanulatum* Harris & Keble, *D. scitulum* Harris & Keble, and *Staurograptus diffissus* Harris & Keble. This horizon is probably earliest Warendian (Jones et al., 1971) which is equivalent to late Early Tremadocian (the Anisograptid and *Dictyonema* Zone of Skevington, 1963). Unfortunately no accounts of Tremadocian sequences containing both conodonts and graptolites have been described from Australia. Additionally, no earliest Tremadocian graptoloids have been reported.

Trilobite faunas are known from the Burke River Structural Belt and the Bonaparte Gulf Basin from the same sequences as the conodonts. Some of this work is in press (Shergold, 1974) and details of the specific faunas are not available. However, the fauna changes from Tsinaniidae, Saukiidae, Ptychaspididae, Shumardiidae, Richardsonellinae, Pseudagnostidae, and Geragnostidae in the Payntonian (latest Late Cambrian) to faunas dominated by Leiostegiidae in the Datsonian (earliest Early Ordovician) in Western Queensland (Shergold, 1971). A similar sequence is apparent in the Bonaparte Gulf Basin and in northwestern New South Wales (Gnalta-Mootwingee area), although Richardsonellinae commonly occur with the Leiostegiid faunas. The change in trilobite faunas may be contemporaneous with the change in the conodont fauna.

North America

In North America detailed conodont and trilobite studies have been completed on sections which include the lower boundary of the *Cordylodus proavus* Zone. In terms of the trilobite scale the lower boundary of the *Corbinia apopsis* Subzone (Stitt, 1971), which is the youngest of four divisions of the *Saukia* Zone (Trempealeauan), approximates the incoming of the *Cordylodus proavus* Zone (Miller, pers. comm.). The *Corbinia apopsis* Subzone is a relatively thin unit wherever it has been recognized (Oklahoma, Texas, and Alberta) and is probably of short time duration; in Oklahoma (Stitt, 1971) and Texas (Miller, pers. comm.) it is conformably succeeded by the *Missisquoia* Zone.

Thus the lower boundary of the *Cordylodus proavus* Zone may be correlated with the lower boundary of the *Corbinia apopsis* Subzone rather than with the presently accepted Cambrian/Ordovician boundary horizon between the *Saukia* and *Missisquoia* Zones. It must be pointed out that the difference in time is probably small; the *Corbinia apopsis* Subzone consists of only the upper 4 m of the 192 m thick *Saukia* Zone in Oklahoma (upper 3 m of 56 m in Texas).

In Alberta, at Mount Wilson North, the same sequence of trilobite and conodont faunas is seen (Derby et al., 1972); the *Corbinia apopsis* Subzone is 3.6 m thick, and its base again coincides with the incoming of *Cordylodus proavus.* Derby et al. draw the

	Balto Scandia	Afghanistan	Kazakhstan	N.E. China	Australia	Western U.S.A.	Mexico
EARLIEST ORDOVICIAN	cordylodids MACROPYGE HARPIDES PILEKIA	cordylodids MACROPYGE HARPIDES PILEKIA SAUKIA			cordylodids LEIOSTEGIIDAE RICHARDSONELLINAE	cordylodids SYMPHYSURINA MISSISQUOIA SAUKIIDAE	cordylodids OLENIDS RICHARDSONELLINAE SAUKIIDAE
LATEST CAMBRIAN	ACEROCARE proconodontids westergaardodinids		ACEROCARE proconodontids westergaardodinids LOTAGNOSTUS	SAUKIIDAE TSINANIIDAE proconodontids westergaardodinids	SAUKIIDAE proconodontids TSINANIIDAE westergaardodinids	SAUKIIDAE proconodontids westergaardodinids	

Fig. 5. Latest Cambrian and Early Ordovician trilobites and conodonts

Cambrian/Ordovician boundary at the top of the *Corbinia apopsis* Subzone, recognizing the traditional boundary between the *Saukia* and *Missisquoia* Zones. Thus the conodont boundary, based on *Cordylodus proavus*, is at the base of the *Corbinia apopsis* Subzone whereas the boundary based on trilobites is at the top. It may be dangerous to continue drawing the Cambrian/Ordovician boundary at the extinction of the last Saukiid; there is some evidence that convincingly Tremadocian Saukiids do occur (Wolfart, 1970a, b). Accordingly we may develop a boundary situation analogous to the Silurian/Devonian boundary problems when the boundary between those systems was drawn higher and higher in the sequence in order to accommodate the extinction of the graptolites within the Silurian.

This overlap of the *Saukia* Zone with the *Cordylodus proavus* Zone may account for the joint occurrence of saukiids and *C. proavus* in Mexico (Pantoja-Alor & Robison, 1967; Robison & Pantoja-Alor, 1968). But their conclusion that the traditional Cambrian/Ordovician boundary (the *Saukia*/*Symphysurina* zonal boundary) is equivalent to the Lower/Upper Tremadocian boundary cannot be substantiated. It should be noted that in some areas the *Saukia* Zone is followed by the *Missisquoia* Zone which is probably equivalent to the lowermost part of the *Symphysurina* Zone.

The standard section for the Late Cambrian in North America has traditionally been the St Croixian Series of the Upper Mississippi Valley. The upper boundary has been placed at the contact between the Sunset Point Member of the Jordan Sandstone and the Oneota Dolomite. Recently Miller & Melby (*in* Clark, 1971) have demonstrated that the Van Oser and Sunset Point Sandstone Members are Tremadocian and contain a mixed fauna of elements found in the *Missisquoia* and *Symphysurina* Zones in Oklahoma and Texas. The Jordan Sandstone has yielded a saukiid trilobite fauna (Raasch, 1950).

Thus the incoming of *Cordylodus proavus* probably corresponds to a horizon in the lower part of the Jordan Sandstone or possibly the underlying St Lawrence Formation. The traditional boundary is, however, within the Tremadocian and therefore the Trempealeauan is equivalent, in part, to the early Tremadocian.

Europe

The *Cordylodus proavus* fauna has yet to be recognized in Europe; nevertheless it was extant during the time interval between the Upper Cambrian *Acerocare* Zone and the upper part of the *Dictyonema* Zone. Accordingly, the first occurrence of *Cordylodus proavus* and *Dictyonema* may approach contemporaneity.

Asia

The sparse and scattered information on Asian conodont faunas does not allow for a close comparison of various aspects of the fauna to be made. But Late Cambrian conodont faunas in China are associated with saukiid and tsinaniid trilobites (Jones et al, 1971) and the same is true in Iran (Kushan, 1973). Tremadocian conodont faunas are associated with leiostegiids, saukiids, and pliomerids in Afghanistan (Wolfart, 1970a).

USEFULNESS OF FOSSILS OTHER THAN CONODONTS IN DEFINING BOUNDARY

Trilobites are the best documented alternative biostratigraphic 'tool' to conodonts. Jones et al. (1971) point out that the Upper Cambrian trilobite faunas known from central Australia are widespread in eastern Asia; some elements are present in North America.

However, some trilobite faunas appear to be provincial and there is little correspondence between faunas from the Acado-Baltic and North American (apart from the east coast) and Asian and Australian regions. In Afghanistan there is mixing of the Asian and Acado-Baltic faunas (Wolfart, 1970b).

Furthermore trilobite faunas are sometimes biomeres, 'a regional biostratigraphic unit bounded by abrupt nonevolutionary changes in the dominant elements of a single phylum' (Palmer, 1965). Stitt (1971) points out that the Cambrian/Ordovician boundary has been drawn at an abrupt faunal change caused by unknown factors which left no imprint on the fairly uniform Signal Mountain Limestone.

Accepting these limitations, trilobite faunas are of considerable use in regional correlation; evidence from North America and Australia suggests that precision in correlation is virtually identical to that of conodonts.

Graptolites provide a key to the beginning of the Ordovician; unfortunately they are absent from Upper Cambrian rocks and cannot provide an evolutionary sequence across the boundary.

Other groups have received little systematic appreciation. Molluscs began an evolutionary radiation in the Late Cambrian and Early Ordovician which may have induced rapid migration, although the mode of life of some classes makes them suspect as precise time indicators.

Phosphatic brachiopods may provide a suitable zonation across the Cambrian/Ordovician boundary, but their apparent absence from geosynclinal sediments inhibits their use.

CONCLUSIONS

Conodonts provide the most precise and wide-ranging method for delineating the Cambrian/Ordovician boundary.

There is a distinct conodont faunal change at the boundary, only a very few Late Cambrian forms persisting into the Early Ordovician.

The base of the Ordovician is marked by a rapid and spectacular diversification which was accompanied by an equally rapid dispersion.

These cosmopolitan faunas are known from Europe, North America, Asia, and Australasia. They do not appear to be affected by facies because clastic and carbonate rocks yield similar faunas.

Each conodont zone spans approximately one million years, so conodonts provide precision in correlation as accurate as any group throughout the Palaeozoic.

Conodonts have an added advantage in that they are easily recoverable and are simple to identify, especially in the Cambrian and early Ordovician.

The major drawback to using conodonts is the difficulty of recovering specimens from indurated and silicified clastic sequences.

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The oldest foraminifera

by

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Foraminifera are not known to have existed before the Cambrian. Some Precambrian and Lower Cambrian tubular microfossils described as possible foraminifera are of uncertain systematic position, some others are generally considered as algae. The oldest Lower Cambrian "zone-fossil" from northern and eastern Europe, *Platysolenites antiquissimus* Eichwald, though generally considered as an annelid worm tube, has no distinctive characters of the Annelida but is difficult to distinguish from foraminifera of the genus *Baythsiphon* Sacco (Palaeozoic to Recent) to which it appears to be closely related. *Platysolenites* is the oldest known genus of foraminifera.

A statement that certain fossils are the oldest representatives of a taxon is always problematic unless its origination from another preceding taxon can be demonstrated. This is not possible in relation to the origin of the Order Foraminiferida. They must have evolved from naked Protozoa which cannot be preserved in sediments. The oldest representatives of a given group are where we find them, and it is always possible that somewhere and some time older ones will be found. The view that fossil Protozoa, including foraminifera, presumably of Precambrian age, must be the oldest fossils, because of their lowly place in the evolutionary sequence of the morphological complexity of organisms is certainly not correct. It is a survival of the ancient and naive concept of a straight 'ladder of life', a time sequence reflecting morphological progress along a straight line from lowest to highest. This does not correspond to observed facts. It is now known from abundant material that foraminifera have evolved in morphological complexity throughout Phanerozoic time, from simple beginnings, on a different plan, in different directions, but not necessarily to a different extent of biological diversification in comparison with metazoan Orders. Attempts to study the pathways and timing of the evolution of the foraminifera have shown that they had simple and undifferentiated beginnings in Early Palaeozoic time (Glaessner, 1963). Abundant available material of Late Precambrian and Palaeozoic microfossils shows that instead of dating back to the presumed origin of eucaryote protistan cells in mid- or late Proterozoic time, the evolution of the Order Foraminiferida was essentially a Phanerozoic phenomenon. All available evidence of early Palaeozoic representatives indicates that at that time it had not progressed very far. In many microfossils of that age the structure of the test is so simple that it is difficult to find convincing evidence on which they can be definitely recognized as belonging to one group of Protista and excluded from all others. This affects the present state of our knowledge of Early Cambrian foraminifera.

Four groups of microfossils must be considered in a search for the oldest foraminifera. One consists of unquestionable foraminiferal tests but with morphological characters indicating much younger age so that their dating must be questioned. This includes particularly *'Scaniella'* Pflug, 1965 from Andrarum in Schonen (Scania), Sweden. In its wall structure and chamber arrangement it is indistinguishable from the common *Heterohelix*. It has probably drifted into minute fissures in the Upper Cambrian rocks from the Cretaceous sediments which transgressed widely over Schonen; similar 'intrusions' of palynomorphs and conodonts into older rocks are well known. The second group includes problematic fossils of definitely Lower Cambrian age which show neither definite resemblance to any living forms nor distinct morphological characters supporting their assignment to the foraminifera. Their systematic position remains doubtful. This was stated clearly and correctly by Loeblich & Tappan (1964, p. 787) concerning the coiled tubular microfossils found by Reitlinger (1948) and Vologdin (1958) in the Lower Cambrian of Siberia. They were listed under the heading 'Order Reitlingerellida Vologdin, 1958'. The third group comprises common Cambrian microfossils which are generally considered as algae, particularly the well known genera *Renalcis* Vologdin, 1932 and *Chabakovia* Vologdin, 1939. At various times, attention was directed to their similarity to foraminifera; Elias (1950) first made this point which was taken up a decade later by other authors. They did not produce proof of more than general and superficial resemblances.* It is significant that A. Yu. Rozanov who has much experience with Siberian material of these genera considers that their wall structure corresponds more closely to that of known algae than of foraminifera (pers. comm., 1975). Convergence of chambered, straight, or coiled, tubular structures ranges widely from algae to Protozoa, sponges, and coelenterates. This problem can be resolved either through studies of ultrastructure or through the discovery of specific structures characterizing either one or the other kind of organism.

The same applies also to some calcareous microfossils from Late Precambrian terrigenous sediments of the western Ural and Baikal regions. Some more or less thick-walled, subspherical, calcareous shelly objects (*Archaeosphaera rossica* Koroljuk, 1965, *Palaeosphaeroidina* Koroljuk, 1965, *Lenticularia* Koroljuk, 1963) were described as possible foraminifera. These fossils, which resemble calcispheres, may be algal spores. They require further studies on better preserved material. *Valdella* Koroljuk, 1965 (type sp. *V. valda*) is based on a single sectioned specimen from the Upper Bavlinsk Formation of the Valdai Series of the western

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* After the completion of this study, a paper by R. Riding & M. Brasier ("Earliest calcareous foraminifera", Nature vol. 257, 1975, p. 208-210) appeared which deals, among others, with the genera *Renalcis* and *Chabakovia*. It does not present sufficiently convincing data to necessitate any alteration in what has been stated here about them.

Ural region. It consists of a central chamber (diameter 0.3 mm) and a surrounding possibly spiral coil; the walls are agglutinated. In connection with this group which presents problems of identification, some other tubular or irregularly chambered objects should also be mentioned. They were figured by Pflug (1965, pl. 10, figs. 1, 7, 11) from the Late Precambrian Belt Supergroup of Montana. The tubes, which are about 0.15 mm long, were considered by Pflug as agglutinated foraminifera (with a question mark), but by Tappan & Loeblich (1971, p. 269) as 'probably blue-green algae'. Until more material is found and described, the presence of foraminifera in the Precambrian remains questionable and, in view of the large amount of work done on ancient rocks, improbable. The fourth group comprises Lower Cambrian fossils which have been generally considered as worm tubes and which are indistinguishable from well known tubular agglutinating foraminifera belonging to the Family Astrorhizidae Brady, 1881, of the Superfamily Ammodiscacea Reuss, 1862. They are assigned to the genus *Platysolenites* Eichwald, 1860 which is of considerable stratigraphic importance.

In many parts of northern Europe, *Platysolenites* is the oldest solid-shelled fossil. Its geographic range includes the Leningrad region, the Moscow Syneclise, Estonia, Latvia, Poland, southern and northern Norway and northern Sweden and it was recently reported by A. W. A. Rushton at a working group meeting on the Precambrian/Cambrian boundary (in Paris, June 1974) from Wales. A number of authors including Öpik (1956) used the term 'Zone of *Platysolenites*' for the oldest biostratigraphic zone of the Lower Cambrian, but the range of this fossil appears to be of Stage magnitude, as will be seen in the concluding stratigraphic remarks.

These fossils were considered as annelid worm tubes by Eichwald (1860) and his lead was followed by most later authors, without critical re-examination of the material. They were, however, assigned to cystoids or crinoids by Schmidt (1888); he had seen specimens reacting with acids while earlier and later observers had found *Platysolenites* to be siliceous. It is possible that Schmidt's calcareous tubes which occur together with *Volborthella* are not identical to the typical material from other localities. This possibility was considered by Yanishevsky (1926). Another possibility is that they may have been secondarily calcified. Sokolov (1974, p. 16) grouped them with Hyolithelminthes.

I examined typical *Platysolenites* tubes from Yanyshevsky's collection in Leningrad (Glaessner, 1963) and found them indistinguishable from the tubes of the foraminiferal genus *Bathysiphon* Sars, 1872, which is known to range from Ordovician to Recent. A Lower Cambrian age of the oldest *Bathysiphon* was accepted accordingly by Loeblich & Tappan (1964) and others. Hamar (1967) described new finds of *Platysolenites* from northern Norway, assigning them 'with reservation' to the Family Serpulidae. It should also be noted that Danner (1955) had described Lower Cretaceous 'worm tubes' from Washington State. They are identical in appearance and size to *Bathysiphon*, and Danner mentioned that similar fossils from the Upper Jurassic/Lower Cretaceous of California, 'up to 3 inches in length, resembling pine needles' had been described as *Bathysiphon*. Avnimelech (1952) restricted this genus to species 'made up of, or characteristically containing, sponge spicules'. This restricted definition was rejected by Loeblich & Tappan (1964) who extended the genus again to include as synonyms Avnimelech's genera *Argillotuba*, *Psammosiphonella* and *Micatuba* (with, respectively, argillaceous, arenaceous, and micaceous tubes).

Malecki (1973) who described a *Bathysiphon* from the Eocene flysch of Poland considered that the genus represented annelid worm tubes. He did not refer to *Platysolenites*. He noted the mode of embedding of the tubes and their deformation (which is very similar in both genera). Discussing the systematic position of *Bathysiphon* he admits that 'there is no evidence of their belonging to the Annelida' (p. 167) but then lists indications for this systematic placing. The initial part tapers to a very thin, sharp termination instead of a proloculus. This is, however, the normal condition in many tubular foraminifera. Their size (up to 20 mm according to the description of his new species but up to 45 mm according to Malecki's plate 1; he also quotes a reference to specimens 13 cm long which have not been illustrated) is said never to have been equalled in Recent or fossil foraminifera, but that is wrong: the maxmium test size of *Bathysiphon filiformis* in the collections of the British Museum (Natural History) is 50 mm, the agglutinated test of *Loftusia* attains 80 mm, and the greatest recorded diameter of the calcareous test of *Cycloclypeus annulatus* is 150 mm (personal communication from Dr C. G. Adams, October 1975). Malecki notes that growth takes place identically, by accretion of successive rings, both in annelids and in *Bathysiphon*, but this mode of growth is not uncommon in tubular foraminifera. His final argument is that the bathysiphons are 'primarily found in clayey or marly sediments' without small or large foraminifera. This is also incorrect. They occur often in association with abundant agglutinated foraminiferal tests and occasionally with calcareous ones. As *Bathysiphon* mainly inhabits deep water, the absence of larger foraminifera from beds containing this genus is hardly surprising. Malecki states that the surfaces of the beds containing *Bathysiphon* 'are covered with many and varied hieroglyphs, most of them being traces of the annelids'. This sweeping assertion as to their origin is not accepted by other students of the flysch facies. Even if it were true, environments favourable to annelids are more often than not favourable to foraminifera also. The occurrences of the serpulid *Rotularia* in the Upper Eocene with nummulites and of *Ditrupa* in the Miocene with smaller foraminifera, and of the sabellariid *Phragmatopoma* with the rich foraminiferal fauna of the Straits of Florida, are examples of such associations. Malecki's arguments for assigning *Bathysiphon* to the Annelida cannot be accepted. They are also invalidated by recorded observations of protoplasm and pseudopodia in Recent specimens of *Bathysiphon*.

A study of abundant material of *Platysolenites antiquissimus* Eichwald, 1860 from the Lower Cambrian Blue Clay, River Tosna near Leningrad (kindly presented by Professor R. F. Hecker, Moscow) shows that there are no distinctive features which would support an assignment of these tubes to the annelid worms. The main reasons against it are the uniform size (within the range of about 1-2 mm width of compressed tubes) and the pronounced transverse layering of grains in their walls, which leads to transverse external grooving and transverse fracturing. Neither of these characters is distinctive for, or even common in, thick-walled worm tubes. These, if built from agglutinated sand grains, are arranged in inward-sloping layers (Glaessner, 1976). Worm tubes consisting of a single layer of grains (or foraminiferal tests, Barnard 1956) have them arranged in transverse rows. Needles of rutile were found regularly laid at right angles to the axis of the test of *Bathysiphon argenteus* (fide Loeblich & Tappan, 1964, p. C89).

The tubes of *Platysolenites* are several centimetres long. The thick walls (Pl. 1, figs. 1-3), which are compressed in specimens preserved in clays, consist of quartz grains (Pl. 1, fig. 6). One of the larger grains measured directly was 20.8 μm in diameter. There is some admixture of clay minerals. The infilling of the internal cavity is often pyritic. The lateral ridges frequently found on compressed tests result simply from the greater mechanical strength of the sides of the tubes under compaction. The transverse grooving and fracturing is the result of transverse layering of grains in the wall (Pl. 1, figs. 4, 5). Because of the organic cement which agglutinates the grains, arenaceous foraminiferal tests may be somewhat flexible and compressible (Hedley, 1963) or may become softened in early stages of diagenesis. *Platysolenites lontowa* Öpik, 1926 was considered a possible synonym of *P. antiquissimus* by Hamar (1967), probably because the pronounced transverse ridges in *lontowa* were believed to be preservational or morphotypic variations. The spirally coiled tubes figured by Hamar as *P. antiquus* from the Breivik Formation at one locality in Finmark (northern Norway) are not likely to represent this species. They do not occur regularly with typical straight tubes in the Baltic area and do not justify Hamar's amended diagnosis of *Platysolenites* as 'small siliceous-calcareous helical-shaped tubes' (Hamar, 1967, p. 90).

There are no diagnostic characters in composition, texture and fabric, or wall thickness of the tubes of *Platysolenites* which would allow a close comparison with any known tubicolous annelid genus, but in a number of characters this genus is closely comparable with the long-ranging foraminiferal genus *Bathysiphon* (Pl. 1, fig. 7). Characters which may serve to distinguish *Platysolenites* from *Bathysiphon* are the microscopically observable transverse layering of the grains in the wall, their uniformly small size, and the shallow-water habitat. Although these diagnostic characters are not very obvious and the stratigraphic gap between *Platysolenites* and the oldest *Bathysiphon* which are of Ordovician age is not great, it would be premature as well as inconvenient to place the genus *Bathysiphon* Sars, 1872, in the synonymy of the less well known genus *Platysolenites* Eichwald, 1860.

The stratigraphic range of *Platysolenites* appears to be confined to the lowest Cambrian, i.e. to the probable equivalents of the Tommotian Stage in Siberia (Rozanov, 1973). However, the genus has not been found in the Cambrian of the Siberian Platform. A reference to a species *P. sibericus* Volkov is apparently erroneous (pers. comm. from A. A. Missarzhevsky and A. Yu. Rozanov, 1975). The distribution of the genus in the Baltic area can be seen in a number of stratigraphic columns from surface outcrops and bores, representing a cross-section of the East European Platform (Rozanov, 1973, fig. 128). *Platysolenites* is shown occurring in the Rovno, Lontova, and the recently separated Glebov Beds which together constitute the sequence of the Blue Clay of Early Cambrian age. This sequence was designated the Baltic Stage by Sokolov (1958), together with the overlying Lukati Beds (with *Volborthella*) which were later removed from it (see Sokolov, 1974). The same sequence was correlated with the Tommotian Stage by Rozanov. A reference to the occurrence of *Platysolenites* in the Late Precambrian Gdov Beds of the Valdai 'Series' representing the upper division of the Vendian (Sokolov, 1973) is given by Martinsson (*in* Holland, 1974, p. 197). This is based on an early mis-correlation of subsurface strata in the western part of the Russian Platform (pers. comm. from A. Yu. Rozanov, 1975). It has not been confirmed by any of the large number of precise stratigraphic placings of occurrences of this genus which according to published data and on the basis of new palynological zoning of the relevant interval fall within the limits of the Lower Cambrian. As there is as yet no unanimity about the placing of its lower boundary (Cowie & Glaessner, 1975) it should be explained that according to the leading authorities on the stratigraphy of the Russian Platform the basal formation of the Blue Clay, the Rovno Beds with the oldest known *Platysolenites*, could be placed either above or below that boundary, depending on the eventual choice of a boundary stratotype.

In conclusion, it can be stated that the youngest occurrences of *Platysolenites* seem to coincide with the oldest recorded occurrences of *Volborthella* at the base of the Atdabanian or *Holmia* Stage of the Lower Cambrian. Öpik (1926, p. 41) noted that in Estonia the two genera occur together extremely rarely, though joint occurrences have been reported from Scandinavia. If the base of the Cambrian is drawn at the base of the Rovno Beds and at the equivalents of the base of the Blue Clay (Baltic Stage), then the oldest occurrences of *Platysolenites* mark the base of the Cambrian in an area extending from Scandinavia to England and over much of the East European Platform to Poland and the Ukraine. It is not only the oldest but also the structurally simplest of the known foraminifera.

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ADDENDUM

The discussion about the systematic position of similar tubular fossils of different ages has continued after this paper went to press. Hatai & Noda (1975) described from the Miocene of Japan a new genus *Yokoia* (type species *Terebellina kattoi* Hatai & Saito, 1962) as an "armored worm". These fossils resemble *Platysolenites* and *Bathysiphon* in general appearance and size. Their resemblance to typical *Bathysiphon* is strengthened by the abundance in its tubes of sponge spicules which Hatai and Noda considered as either secreted, or eaten and retained as waste matter, or "less probably" as agglutinated. A similar spicule-containing fossil from the Pliocene of Japan was described as a sponge *Sagarites chitanii* Makiyama, 1931. Its generic name (non *Sagarites* Ashmead) was amended to *Makiyama* by Laubenfels (1955, p. E 39) who placed it in the "Demospongia, fam. uncertain". For stated reasons Hatai & Noda (1975, p. 213) do not identify *Yokoia* with *Baythsiphon* and they proceed to question "whether *Bathysiphon* is a true Foraminifera", without presenting convincing new evidence. The generic distinction between *Yokoia* and *Baythsiphon* appears to be questionable. *Platysolenites* should be retained as a genus of the Foraminiferida.

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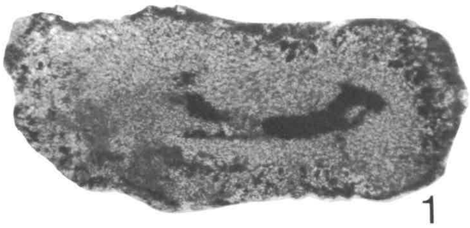

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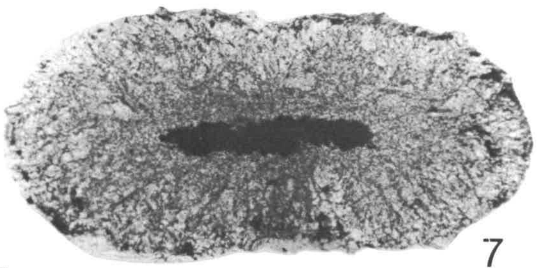

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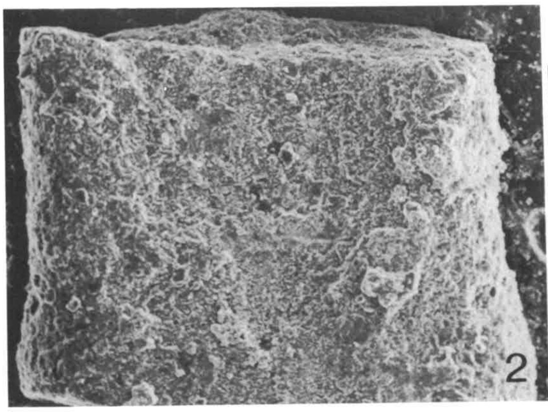

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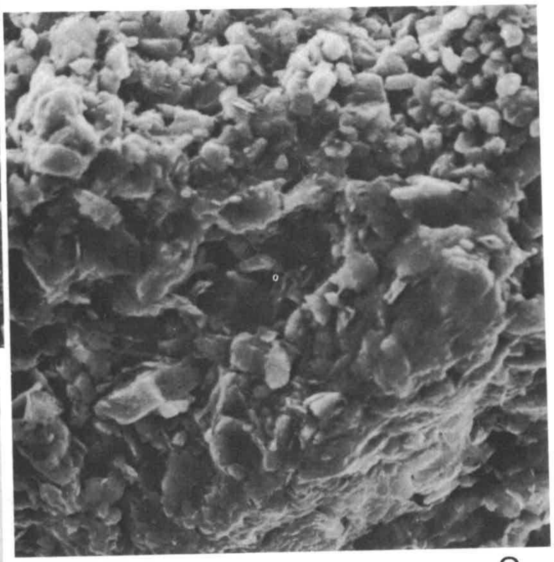

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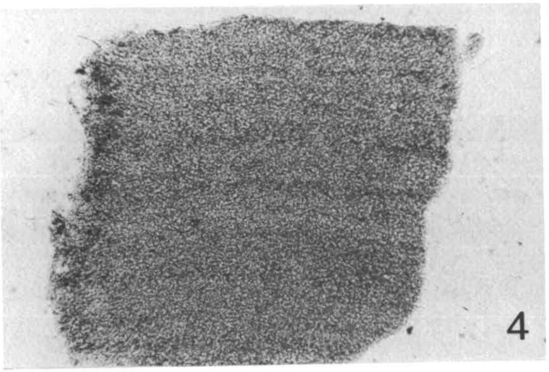

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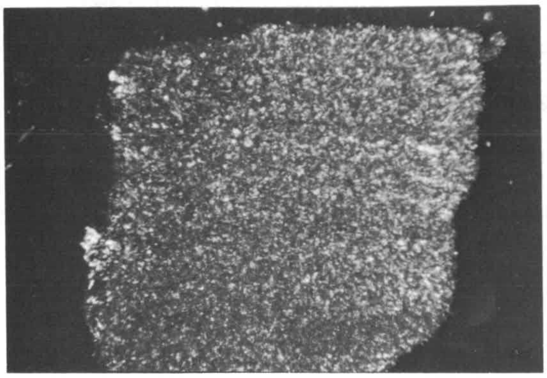

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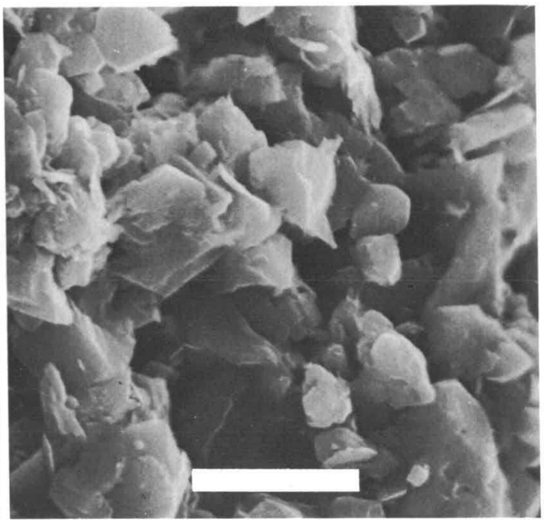

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PLATE 1

Platysolenites antiquissimus Eichwald

Lower Cambrian, Blue Clay, R. Tosna near Leningrad

Figs.

1 Transverse section, x80.

2 S.E.M. photograph of tube fragment, x80.

3 S.E.M. photograph showing transversely broken portion of tube (upper part) and surface of tube tilted 40° downward (lower part, darker, coarser grains); x1200.

4 Section parallel to surface of tube showing transverse layering; x80

5 Same as Fig. 4, crossed polars

6 S.E.M. photograph of broken tube surface, showing quartz crystals; x4400. The length of the scale bar represents 5 μm.

Bathysiphon sp., Middle Eocene

Mount Salt Bore, near Mount Gambier, South Australia, 935 m

7 Transverse section, x70.

Scanning Electron Microscope photographs (Fig. 2, 3, 6) taken on an ETEC Autoscan in the University of Adelaide Central Electron Optical Laboratory by Dr K. Bartusek. Optical photomicrographs (Figs. 1, 4, 5) taken in the Palaeontological Laboratory, University of Adelaide, Department of Geology, by Mrs S. McGowran.

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Late Cretaceous agglutinated foraminifera from sediments interbedded with the Tangihua Volcanics, Northland, New Zealand

by

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Siliceous agglutinated foraminifera from red, green, and purple mudstones interbedded with the Whangakea volcanics of the Tangihua Volcanic Group in northern Northland indicate Late Cretaceous age and deposition in a fairly deep basin roughly at or below the foraminiferal carbonate compensation depth which was probably shallower than at present.

INTRODUCTION

One of the most prominent topographic features of Northland is a group of high-standing blocks of basic volcanic rocks, consisting of basic lava, often with pillow form, breccia, tuff, and dolerite. They were mapped as fault-bounded by Kear & Hay (1961) and their relation to adjoining marine sediments, which are mostly of Late Cretaceous age, has been a subject of long-standing debate.

Quennell & Hay (1964) have interpreted them as old seamounts which erupted during a single geosynclinal volcanic episode that occupied a short time range, forming guyots at a depth of 600-900 m on the floor of the North Auckland Cretaceous Geosyncline in which sedimentation was already well advanced. They suggested that complete or partial burial followed as a result of later sedimentation from a rising eastern source.

The northernmost group of volcanics, in the vicinity of North Cape, was named the Whangakea Series by Bell & Clarke (1910) who also described associated greenish and purplish indurated stratified rocks. At Pandora (N.Z.M.S.1, grid ref. N1/265480) McKay (1894) discovered pink fossiliferous, highly calcareous, fine-grained radiolarian-rich rock containing abundant prisms of a molluscan shell, apparently interbedded with pillow lava. A bivalve collected by R. F. Hay was identified as *Meleagrinella* (Hay, 1960, p. 55; Bowen, 1966) indicative of Jurassic or Early Cretaceous age, but the specimens are now considered to be probably a pectenid or pterioid bivalve of unknown age significance (Dr I. G. Speden, pers. comm.).

The main group of older basic volcanics in Northland have been generally referred to the Tangihua Volcanics (Ferrar, 1934, p. 52), taking their name from the Tangihua Range, 25 km SW of Whangarei. Most subsequent authors (Quennell & Hay, 1964; Brothers, 1974) consider the northern (Whangakea) and southern older volcanics to be coeval, and combine them within the Tangihua Volcanic Group.

Associated with the Tangihua Volcanic Group are fine-grained green and red shales and, less commonly, grey concretionary sandstone. They are generally impersistent along the strike and are commonly crushed and dislocated, their induration ranging from soft to brittle and hard.

The relation of these associated sedimentary rocks to the volcanics has been a source of uncertainty and argument over many years because, in many places, late Cretaceous and younger sediments in wide areas of Northland are known to have been emplaced over younger beds in regional gravity slides which could have forced them against the volcanic massifs in attitudes that simulate both sedimentary and faulted contacts.

From such apparently interbedded strata, fossils of several different ages have been reported. Hay (1960) recorded *Inoceramus* sp. from pink limestone apparently interbedded with Tangihua Volcanics at Houtu Hills. Specimens of *Buchia* cf. *subpallasi*, later collected from the same locality (Brothers, 1974, p. 3) indicate a Late Jurassic age (Puaroan Stage, Tithonian; I. G. Speden, pers. comm.). Hughes (1966) collected an Otaian (early Miocene) foraminiferal fauna including *Ehrenbergina* aff. *marwicki*, *Globoquadrina dehiscens*, and *Globigerina woodi* in a sample (N23/f570) said to be clearly interbedded with Tangihua Volcanics in the Maungaru Range, adjacent to the Tangihua Range. Kear & Hay (1961) noted the presence of minor volcanics uncertainly mapped as Tangihua Group in marine Paleocene to Eocene rocks and suggested that the Whangakea and Tangihua rocks might collectively represent intermittent volcanicity from Jurassic to Eocene time.

Bowen (1966) argued on the basis of two species of foraminifera (*Glomospira corona* and *Pelosina* sp. (= *Hormosina globulifera*)) from strata interbedded with the volcanics in the area between Cape Maria van Diemen and Spirits Bay, that a Late Cretaceous age was most likely for the Whangakea Volcanics.

Brothers (1974), in summing up the evidence for the age of the Tangihua Volcanic Group, has rejected the early Miocene age in favour of the Jurassic age indicated by the Houtu Hills *Buchia*. He also remarks that the adjacent Cretaceous to Oligocene sediments are notable for their paucity of volcanic debris.

More recently, one of us (R.F.H.) has been carrying out a revision of the mapping of the Whangakea Volcanics and associated sediments, and many samples have been collected and processed for microfossils. These have produced small assemblages of non-calcareous foraminifera from the following seven localities (Fig. 1, Table 1, Plate 1):

N1/532, 533, outcrops in the sand dunes on the slopes of Herangi Hill, red shale interbedded with Whangakea Volcanics, N.Z.M.S.1, grid refs. 153455 and 152450 (1961 map ed.).

N1/f535-540, Twilight Beach. Here the volcanic sequence passes up into well-bedded shales and red and green

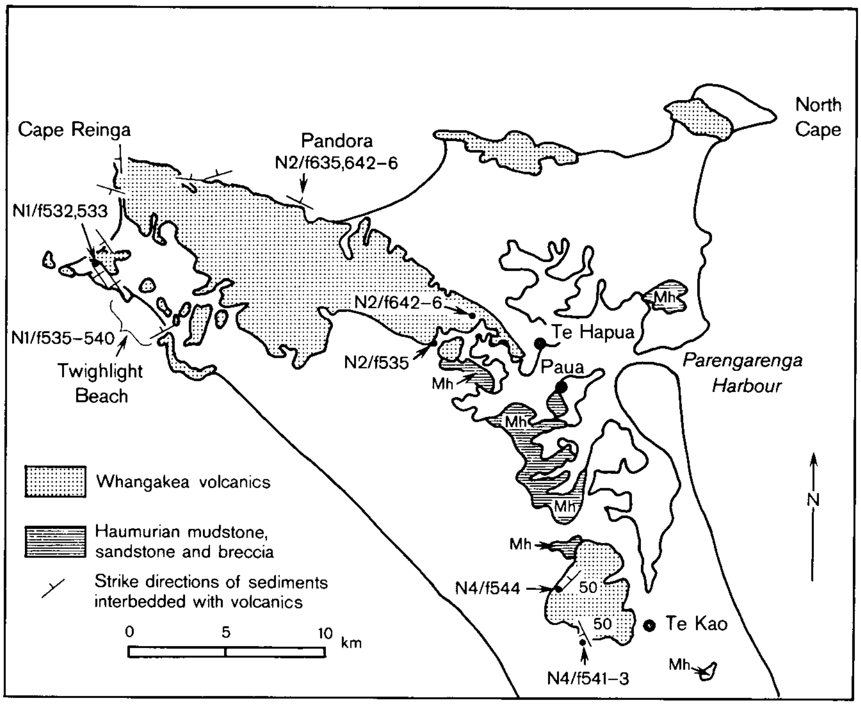

Figure 1. Map of northernmost New Zealand showing localities of samples

TABLE 1: DISTRIBUTION OF FORAMINIFERA IN SAMPLES FROM SEDIMENTARY ROCKS INTERBEDDED WITH THE TANGIHUA VOLCANICS, NORTHLAND, N.Z.

	Herangi		Twilight Beach		Te Hapua							Ngatiwhetu			Herekino-Whangape Coast
	N1/ f532	N1/ f533	N1/ f535	N1/ f536	N2/ f635	N2/ f642	N2/ f643	N2/ f644	N2/ f645	N2/ f646	N4/ f541	N4/ f542	N4/ f543	N4/ f544	N13/ f522
Hyperammina sp.		x		x			x			x			x	x	
Hormosina ovula (Grzybowski)		x		x	x	x	x	x	x		x			x	
Glomospira charoides (Jones & Parker)		x		x	x	x	x	x	x		x		x	x	x
Trochamminoides irregularis White	x	x		x								x	x		
Rzehakina epigona (Rzehak)		x				x									
Kalamopsis grzybowskii (Dylazanka)			x	x								x			
Ammodiscus cretaceus (Reuss)			x	x									x		
Cyclammina sp. cf. *elegans* Cushman & Jarvis			x												
Bathysiphon robusta (Grzybowski)					x	x				x					
Thalmannammina subturbinata (Grzybowski)						x									x
Pseudonodosinella nodulosa (Brady)															x

highly calcareous sandstones with incomplete valves of *Inoceramus*. Abundant white calcite occurs as interstitial masses among the pillows, as at Pandora, and as extensive infillings of vesicles in the pillows. Dr C. P. Wood (N.Z. Geological Survey), who carried out a petrological examination of these sandstones, describes them as poorly sorted silty medium sandstones and a lithic feldsarenite. They include volcanics, mainly felsic, some of which could be keratophyric.

N2/f635, red shale forming a lens or mass in the volcanics in a cutting on the Waitiki Landing, Te Hapua Road, N.Z.M.S.1, grid ref. N2/338405 (1954 map ed.).

N2/642-646, red shales crop out in the face of the Te Hapua Quarry but their relation to the volcanics is not entirely clear and they may be a lens or mass in the volcanics, N.Z.M.S.1, grid ref. N2/357421 (1954 map ed.).

N4/541-3 blue-grey, red, and cholocate shales with residual cherty bands, dipping beneath volcanics on the Te Kao-Bluff Road, N.Z.M.S.1, grid fer. N4/427238 (1967 map ed.).

N4/f544 in a cutting on Te Ahu Road, N.Z.M.S.1, grid ref. N4/426346 (1967 map ed.), chocolate and very light grey shales crop out in the water-table and dip beneath red and grey volcanic clays.

N13/f522, purple mudstone interbedded with volcanics and cropping out in the shore platform on the coast between Herekino South Head and Whangape North Head, N.Z.M.S.1, grid ref. N13/918935 (1944 map ed.).

The sedimentary rocks intimately associated with the Whangakea Volcanics are mostly very fine-grained and suggestive of a quiet, low-energy environment of deposition such as might be found in a basin or in deep water. Even the pink rocks at Pandora, containing abundant prismatic molluscan shells, are not a typical limestone as they consist of a high proportion of Radiolaria which apparently accumulated in an unusual local environment associated with the volcanicity. Numerous thin sections of this limestone have failed to reveal any definite foraminifera other than a small arenaceous form, probably a *Gaudryina* or *Bigenerina*.

The Late Cretaceous strata in the general vicinity of the Whangakea Volcanics are mostly Haumurian flysch deposits with red and green mudstones alternating with coarse sandstone and slump breccia containing broken thick shells of *Inoceramus*. Only at the localities listed above have reasonably clear sedimentary relationships of Cretaceous rocks with the volcanics been seen.

AGE

The foraminiferal assemblages (Table 1, Plate 1) are sparse and contain very few species, all of which are agglutinated types or 'siliceous'. They are of Late Cretaceous age but lack species which could be used to determine the age closely.

The assemblages differ markedly from the few known Clarence Series microfaunas in Northland and closely resemble microfaunas of known Haumurian age in the area, in which all the same species occur. However, the Haumurian assemblages of agglutinated species have, in addition, *Bolivinopsis spectabilis*, common *Rzehakina epigona lata*, large *Cyclammina elegans*, *Conotrochammina whangaia*, and occasionally *Dorothia elongata*.

An age range of Late Raukumara Series to Early Haumurian (Wellman, 1959), (Santonian to Maastrichtian) seems fairly well established as *Kalamopsis grzybowskii* is not known to be present in the Lower Raukumara Series. Judged by the scarcity of more characteristically Haumurian species, the evidence, on balance, favours Teratan or Piripauan age (Senonian or Campanian) although, admittedly, the scarcity of more characteristically Haumurian species may be due to an unfavourable environment.

Whatever their exact age, these microfaunas convincingly show that sediments interbedded with the Whangakea volcanics of the Tangihua Group in the far north are Late Cretaceous and narrow down the age considerably from some previous estimates (Brothers, 1974).

PALAEOENVIRONMENT

Very similar assemblages of agglutinated foraminifera have been described from present-day abyssal habitats, differing markedly from shallow-water assemblages which typically contain *Ammobaculites*, *Haplophragmoides*, *Trochammina*, and *Textularia*.

The present-day abyssal foraminiferal fauna lies below the foraminiferal carbonate compensation depth and contains no calcareous foraminifera. It is characterised by an abundance of tubular forms like *Hyperammina* and *Bathysiphon*, coiled tubular siliceous forms like *Ammodiscus* and *Glomospira*, asymmetrically coiled agglutinated species resembling *Thalmannammina* of the Late Cretaceous and Eocene, and also forms with constricted chambers such as *Hormosina* and *Pseudonodosinella* (Saidova, 1961, 1965, 1970) and *Pelosina* (Hofker, 1972).

Pseudonodosinella nodulosa (Brady) found in purple mudstone interbedded with Tangihua Volcanics in Sample N13/f522, collected on the coast between Herekino South Head and Whangape South Head, was found as a typical member of the modern abyssal fauna by the Challenger Expedition (Brady, 1879, 1884), and Saidova (1970, p. 149) records its depth range in the Kurile-Kamchatka trench in the North Pacific as 4895-7710 m. Numerous fish teeth also present in the sample could be interpreted either as evidence of prolonged deposition in quiet water or of the toxic effects of volcanism on the fish populations.

Assemblages similar to the modern abyssal ones have been recorded in the Initial Reports of the Deep Sea Drilling Project from Late Cretaceous sediments in a deep part of the eastern Atlantic where, according to Hayes et al. (1972), at Site 141, 350 km north of the Cape Verde Islands, drilling in water depths of 4148 metres, a deepening sequence was found, described as follows: 'In cores 6 and 7 we can follow an excellent series of progressive stages of calcite solution until the samples become practically non-calcareous in the lower part of Core 7. Cores 8 and 9 contain only a few agglutinated benthonic foraminifera [*Cyclammina* cf. *deformis*, *Bathysiphon* sp., *Pelosina* sp., *Lituotuba lituiformis*, *Haplophragmoides eggeri*, *Glomospira charoides*, *Gaudryina* cf. *bentonensis*, *Trochamminoides coronatus*, *Ammodiscus incertus*, *Ammoglobigerina* sp. etc.] indicating deposition below the calcite compensation depth.

Similar agglutinated Middle Cainozoic assemblages containing *Rhabdammina* sp., *Miliammina* sp., *Ammodiscus* sp., *Glomospira* sp., *Saccammina* sp., *Ammosphaeroidina* sp., and *Haplophragmoides* and lacking in-situ calcareous microfossils, are reported by Burns et al. (1973) from DSDP Site 204, 116 km east of the axis of the Tonga Trench, drilled in a water depth of 5364 m.

Webb (1975) has described Paleocene agglutinated foraminifera from DSDP Site 283 in the South Tasman Basin between 4948 and 5309 m below sea level. They include some of the same species present in the Late Cretaceous of Northland. Webb concluded that sedimentation at this site proceeded in an abyssal depth well below the calcite compensation depth.

Assemblages almost identical to those in the New Zealand Late Cretaceous have been described by Grzybowski (Webb, 1970) and by Geroch (1959) from the Late Cretaceous to Paleocene flysch deposits of the Carpathians and from flysch deposits of similar ages from the Vienna Woods by Grün (1969).

Pokorný (1960), in a discussion of the Carpathian flysch of Middle Moravia, commented on the striking similarity of the siliceous foraminifera to the modern abyssal fauna, but he did not postulate deposition at a similar order of depth because of the strong likelihood of differences in ocean chemistry in the Late Cretaceous.

Have the microfaunas in beds associated with the Tangihua volcanics suffered from leaching of calcite which removed the calcareous foraminifera? This seems unlikely when they are compared with the agglutinated species associated with other known Late Cretaceous calcareous assemblages in Northland, which usually include species of *Marssonella*, *Dorothia*, *Gaudryina*, and *Bolivinopsis* in addition to most of the species mentioned above. Could the impoverished nature of the assemblages be due to the unfavourable effects of major submarine volcanism? Since very similar assemblages are common in other Late Cretaceous sediments in Northland not associated with the volcanics, the volcanism does not seem to be the main restricting factor.

The interpretation of these agglutinated assemblages characteristic of much of the New Zealand Late Cretaceous has been a long-standing problem (Webb, 1966). It seems to be related in some way to the very low calcite content typical of rocks of this age throughout New Zealand where Late Cretaceous limestones are almost unknown and highly siliceous facies are predominant.

On one hand the erosion of the land to a surface of very low relief with formation of coal measures in the South Island, which is the only part of New Zealand where much is known about terrestrial conditions at that time, is suggestive of intense weathering and leaching. The weathered products of such a landscape may well have formed very fine-grained siliceous sediments producing almost lime-free conditions inimical to calcareous foraminifera.

On the other hand, the resemblance of the assemblage described above to modern abyssal assemblages must contain a strong clue as to the environment of deposition. Present-day abyssal foraminifera in the Antarctic live in depths between 3500 and 5000 m, with temperatures from 0.13 to 0°C and salinity about 34.7% (Saidova, 1961) and at even greater depths in the Pacific (Saidova, 1965). The present-day abyssal fauna has colonised deep troughs with restricted circulation and low oxygen content, below the calcium compensation depth (CCD), and has evolved from the very similar genera and species common in the Late Cretaceous. Does this necessarily mean that the Late Cretaceous assemblage lived in equally great water depths? The presence of thin beds of green and red limestone at Twilight Beach, and the calcareous red marl with abundant prismatic bivalve shells apparently interbedded with the volcanics at Pandora, indicate that deposition and survival of calcite was still possible. Specimens of rather thin-shelled *Inoceramus* occur in greenish limestone interbedded with fairly coarse sandstone at Twilight Beach. *Inoceramus* in the Late Cretaceous in the vicinity of Paua occurs in beds of coarse grit or breccia which appear to be slump deposits from a shallow-water source. Their stout shells, up to nearly 10 mm thick, have survived dissolution, possibly because they were buried in sediment below the sediment/water interface.

Evidence for fluctuations of the CCD and a particularly marked upward migration to quite shallow depths in the latest Maastrichtian has been discussed extensively by Tappan (1968), Worsley (1971, 1974), and Ramsay (1974). Tappan postulated reduced phytoplankton activity as the main factor leading to an increase in CO_2 pressure and an increase in the solution of calcium carbonate in the oceans. Worsley suggested that fixation of carbonates by nannoplankton in chalk deposits depleted the CO_2 in the atmosphere and led to climatic cooling and increased solubility of calcium carbonate in higher latitudes.

The effects of a rise in the CCD would have been felt most strongly in cool seas in high latitudes. There is now considerable evidence that New Zealand lay close to the Antarctic Continent in Late Cretaceous time prior to the initiation of the circum-Antarctic current system. Low temperatures and unfavourable conditions for the precipitation of calcium carbonate are likely to have existed at much shallower depths than in modern abyssal zones.

Edwards (1973, pp. 713, 718) noted the absence of calcareous microfossils in the Late Cretaceous claystones containing only agglutinated foraminifera of Haumurian age at DSDP site 207 on the Southern Lord Howe Rise, drilled by the Glomar Challenger in a water depth of 1393 metres. He suggested that there was a roughly latitudinal variability in the CCD in latest Cretaceous time. Worsley also defined tropical and polar provinces in the late Maastrichtian, based on the distribution of calcareous nannofossils, and included New Zealand in the southern polar province.

Kennett et al. (1973) found only siliceous foraminifera of the genus *Bolivinopsis* in Late Cretaceous rocks at DSDP site 275 on the Campbell Plateau in a water depth of 2827 metres. They considered this to be evidence of a much shallower CCD in Late Cretaceous time than at present.

It does not seem possible to make a confident assessment of the depth of deposition of the Late Cretaceous sedimentary rocks interbedded with the Tangihua Volcanic Group in northernmost Northland on the basis of foraminiferal palaeoecology alone. They appear to have been deposited below the foraminiferal CCD that operated at that latitude in Late Senonian or Early Maastrichtian time. Judging from the estimates of Late Cretaceous levels of the CCD made by Ramsay (1974) the depth of deposition could have been of the order of several kilometres but, taking into account the low latitude, it may have been considerably less. The presence of breccias with *Inoceramus* within greenish fine-grained sediments in the Late Cretaceous flysch at several localities is strongly suggestive of slumping into a basin or trough, which is unlikely to have existed at shallow depths. However, the possibility of later emplacement as olisthostromes, of those Late Cretaceous rocks not actually interbedded with the volcanics, introduces an element of doubt as to their relevance to this question.

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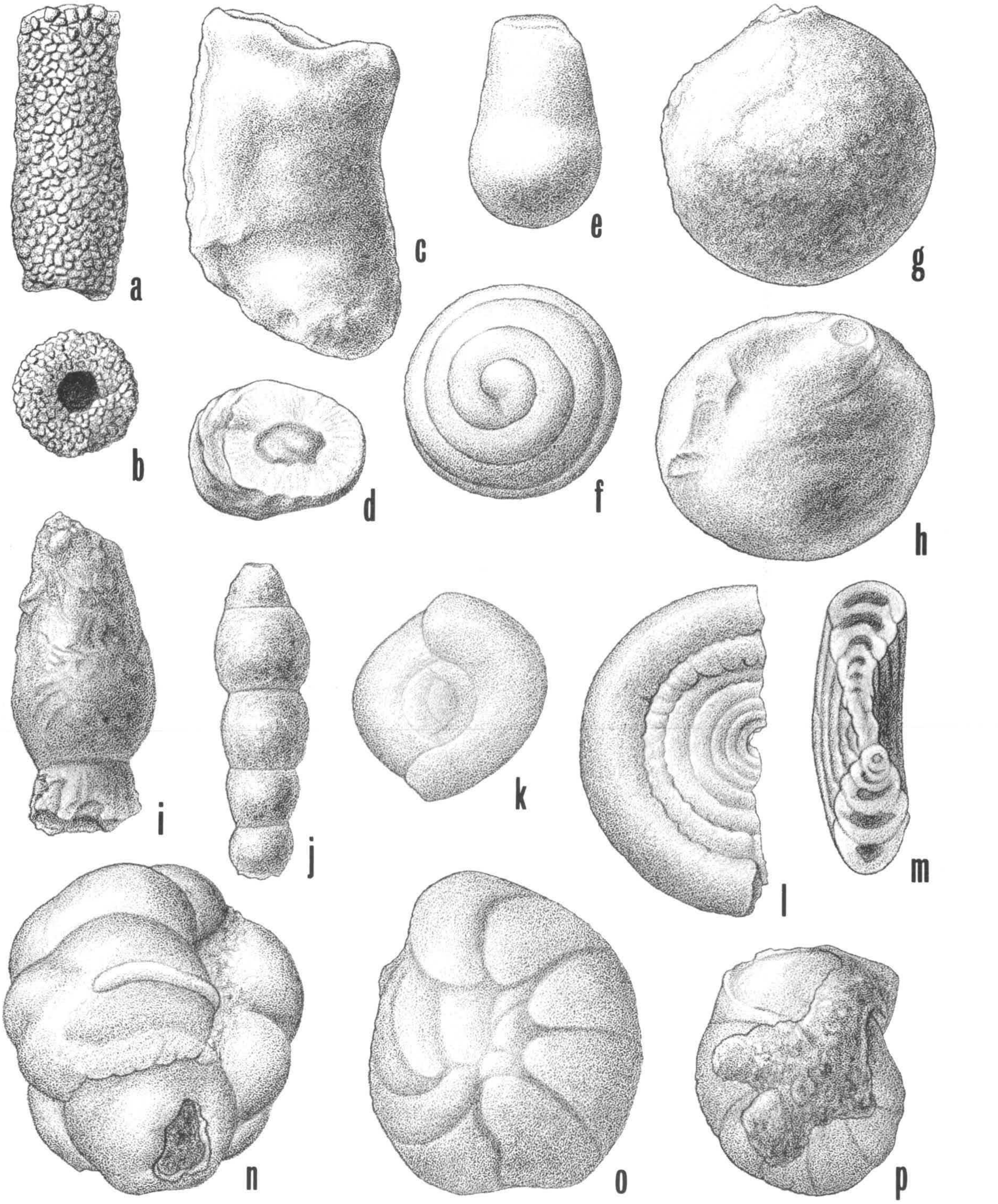

PLATE 1

Late Cretaceous foraminifera from sediments associated with the Tangihua Volcanics. (The figured specimens are deposited in N.Z. Geological Survey collections registered under FP 2562).

Figs.

a, b *Hyperammina* sp. (N4/f543); x75

c, d *Bathysiphon robusta* (Grzybowski), (N2/f642); x60

e *Kalamopsis grzybowskii* (Dylazanka), (N4/f543); x75

f *Glomospira charoides* (Jones & Parker), (N4/f543); x75

g, h *Hormosina ovula* (Grzybowski) (N2/f635); x60

i, j *Pseudonodosinella nodulosa* (Brady), (N13/f522); x75

k *Rzehakina epigona* (Grzybowski) (N2/f642); x75

l, m *Ammodiscus cretaceus* (Reuss), (N14/f543); x75

n *Trochamminoides irregularis* White (N4/f543); x75

o *Thalmannammina subturbinata* (Grzybowski), N2/f642); x75

p *Cyclammina* sp. cf. *elegans* Cushman & Jarvis (N1/f535); x75

Microfossils of fungal origin from Tertiary sediments on the Ninetyeast Ridge, Indian Ocean

by

Elizabeth M. Kemp

Microfossils of fungal origin form part of a suite of palynomorphs recovered from shallow-water sediments of Early Tertiary age at Deep Sea Drilling Project Site 254, on the Ninetyeast Ridge, Indian Ocean. The fungal remains include both fruiting bodies and spores. Fructifications are those of the epiphyllous family Microthyriaceae, and mature forms of these are referred to the organ-genera *Callimothallus* Dilcher and *Notothyrites* Cookson. Dispersed spores have not been identified with extant families, and most are given broad taxonomic treatment. One new species, *Diporicellaespories endogranulosus,* is erected, and the form-genus *Granatisporites* Elsik & Jansonius is placed in synonymy with *Brachysporisporites* Lange & Smith.

The fossil record of the fungi is at present attracting renewed attention, a large part of which is being directed towards the documentation of dispersed spores and fruiting bodies, in the hope of determining the stratigraphic importance of these and their value in understanding the evolutionary history of the group. The palaeobotanical and stratigraphical usefulness of many dispersed fungal remains has yet, however, to be firmly established; the spread of morphological spore types across taxonomic boundaries makes determination of their natural affinities difficult, and the range in time of many forms has yet to be worked out. Nonetheless, proper assessment of the ultimate value, both geological and biological, of these fossils can only be made after extensive documentation of their morphology and occurrence.

Much of the interest in the past ten years has been in the fungal component of Tertiary sediments, particularly those from North America, where studies have been directed either towards biological aspects of fungi associated with host organisms (Dilcher, 1965), or towards description of dispersed organs, usually spores, for primarily stratigraphic purposes (Clarke, 1965; Elsik, 1968; Sheffy & Dilcher, 1971; Elsik & Jansonius, 1974). A similar intensification of interest in Tertiary fungal microfossils has occurred in India (see papers by Venkatachala & Kar, 1969; Jain & Gupta, 1969; Kar, Singh & Sah, 1972). In the southern hemisphere, although Tertiary spore and pollen studies have burgeoned in recent years, studies of fungal remains have been few. The pioneering study of Cookson (1947) on fungal fruiting bodies from Tertiary depo-

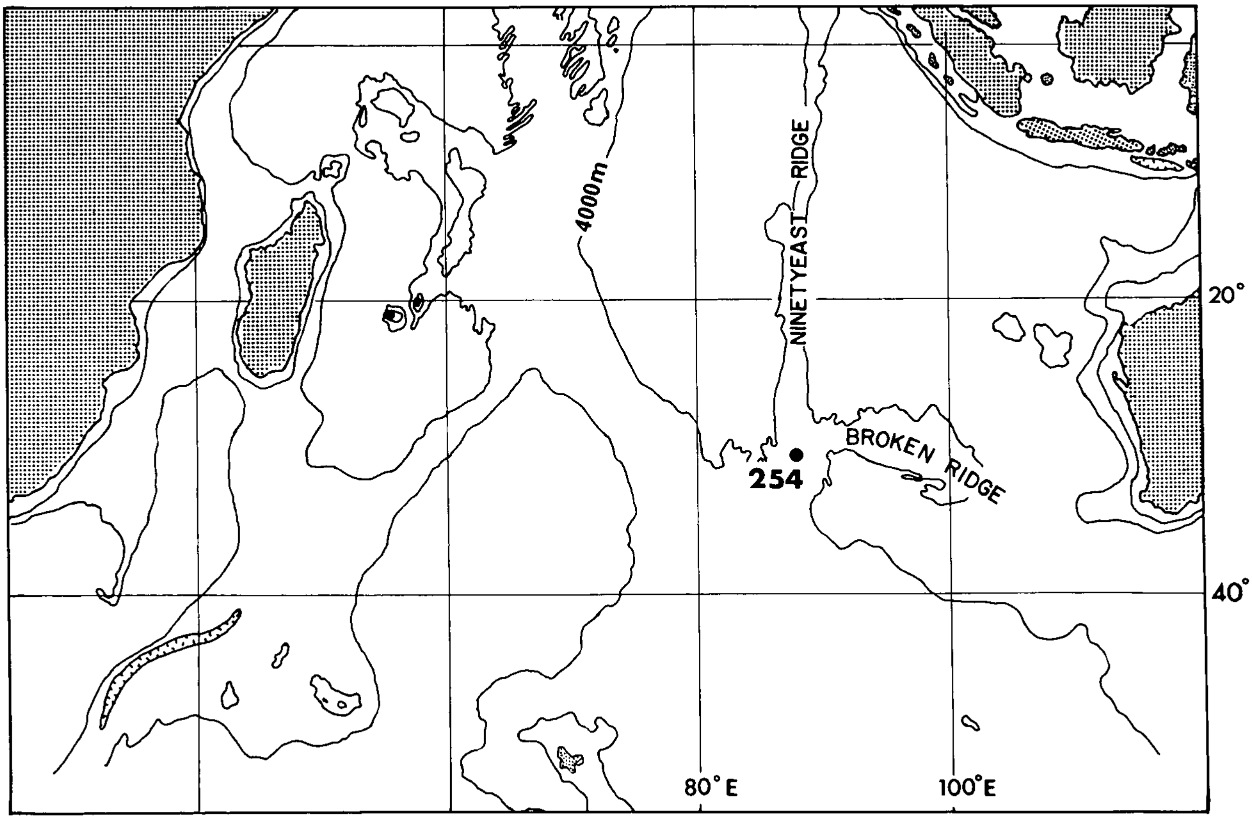

Figure 1. Locality map showing Site 254 at the southern end of the Ninetyeast Ridge, Indian Ocean.

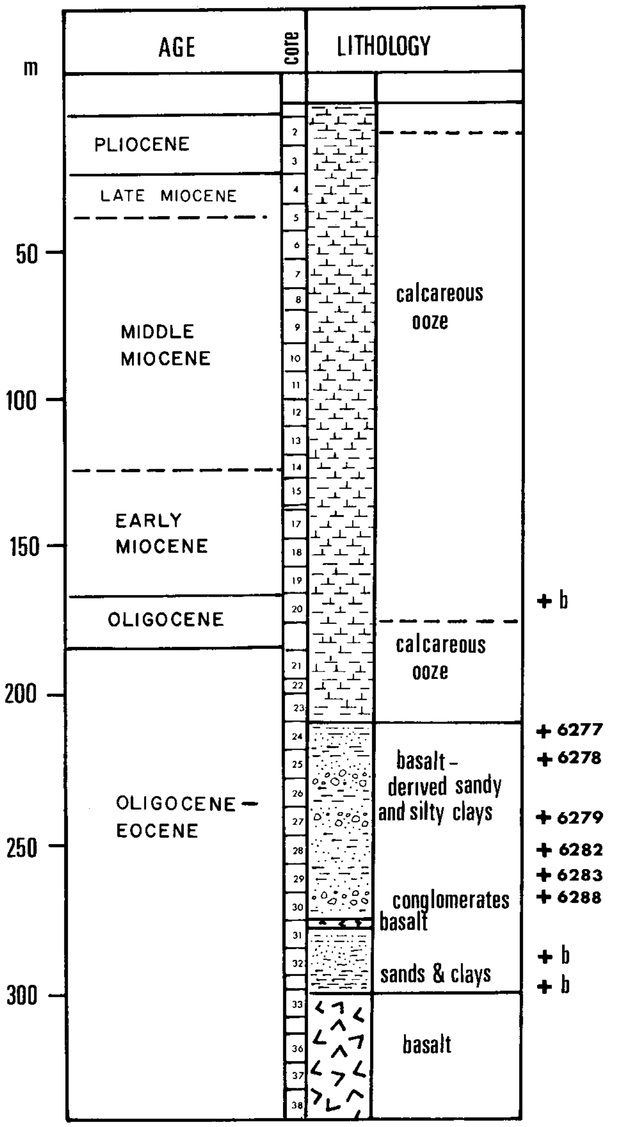

Figure 2. Stratigraphic sequence at Site 254 (modified from Davies, Luyendyk, et al., 1974). Palynological sample horizons are indicated by slide numbers on the right; barren samples are indicated by b. Ages in the left hand column are faunally determined.

sits in Australia, New Zealand, and Kerguelen was followed only by brief reference to fungal microfossils in papers on Late Tertiary palynology of Africa (Thiergart et al., 1962; Sah, 1967), until the recent intensive studies of Lange (1969, 1970), Lange & Smith (1971), and Selkirk (1972) on Australian fossil fungi.

The fungal remains described in this study formed part of a diverse assemblage of palynomorphs recovered from core material from Deep Sea Drilling Site 254 (Fig. 1), drilled on the southern end of the Ninetyeast Ridge, Indian Ocean (lat. 30°58.15′S, long. 53.72′E). The presence of fungal microfossils at this site was briefly reported and some were figured in a preliminary account of the palynology (Kemp, 1974).

GEOLOGICAL SETTING

The Ninetyeast Ridge is a seafloor elevation that extends for 5000 kilometres along the 90°E meridian, and may owe its origin to volcanic activity near the junction of a former spreading centre and a transform fault, the latter being parallel to and almost coincident with the present trace of the ridge (Sclater & Fisher, 1974). The ridge appears to be tectonically associated with the Indian plate to the west, and to have undergone northward movement along with that plate. The ridge crest deepens progressively from south to north, and basement ages in drilled sites increase in the same direction. Basalts drilled at the sites show evidence of subaerial weathering, and are overlain by lignites, shallow-water volcaniclastic sediments, and reefal deposits which pass upwards into calcareous pelagic oozes. The picture represented by the lithologic sequence at the drilled sites is one of a chain of volcanic islands which were emergent along the line of the ridge crest in the Early Tertiary, and which have progressively subsided to the north.

The sequence at Site 254 is illustrated in Figure 2. Basalt at the base of the section is weathered, and is overlain by shallow-water volcaniclastics, mainly sand and silty clay, with rare pebble conglomerates and some lignitic material. This is in turn overlain by deeper-water calcareous oozes. It is from the basal sedimentary unit that the remains of terrestrial plants have been recovered. Well-preserved pollen and spores, tracheids, cuticles, and fungal debris in cores from the unit probably reflect a vegetation which flourished on islands on the ridge, and which has been preserved in part in lagoonal or shallow shelf environments on or adjacent to the ancient islands.

The age of the unit from which the plant microfossils have come remains problematic, but seems likely, on faunal grounds, to be Oligocene or late Eocene. Foraminifera in the lower part of the overlying calcareous ooze units are mid to late Oligocene (Davies, Luyendyk et al., 1974). Within the basal unit itself, age determinations based on different fossil groups are ambiguous. Foraminifera are restricted, shallow-water types which are not biostratigraphically useful; ostracods suggest an Eocene or Oligocene age, and molluscs could be used only to indicate the pre-Miocene, although the absence of Eocene forms is notable. Spores and pollens in the unit could not clarify this ambiguity; forms there which also occur in dated Australian sequences are long-ranging types. The presence of some broad pollen groups, such as Compositae, seems, however, to be more in accord with an age as young as Oligocene than with an Eocene one.

MATERIAL AND METHODS

Fungal debris, consisting chiefly of spores and vegetative hyphae, but including some fructifications, was present in all palyniferous samples from Site 254, although in varying amounts. In most cases fungal remains made up some 2 to 5 percent of the organic remains in the sample, but in one, that from core 30 at 268.1 metres sub-bottom, they were the dominant fossil forms. Spores and pollen were generally thin-walled and poorly preserved in this sample, so that the concentration of microfossils of fungal origin may be ascribed to their selective preservation.

Standard palynological extraction techniques using hydrofluoric acid, hydrochloric acid, Schultze solution, and dilute alkali were used to isolate the microfossils. Residues are mounted in Clearcol. Figured specimens are stored in the Commonwealth Palaeontological Collection, housed at the Bureau of Mineral Resources, Canberra, and are identified with CPC numbers.

Microscope co-ordinates quoted in plate explanations are those of the Leitz Ortholux No. 724105 in the BMR.

The classification of dispersed spores used here is a strictly morphological one, using characteristics of shape, cell and aperture number, following the systems used by Clarke (1965), Elsik (1968), Sheffy & Dilcher (1971) and other workers, and as such, has no phylogenetic implications. Formalized form-species names have been applied only when sufficient characters are available to enable the limits of variation within a population to be documented. In other cases an 'open' taxonomic treatment has been utilized, using established form-genera to categorize relatively broad morphologic groups. This approach is a compromise between that of Sheffy & Dilcher (1971), who used a large number of form-species to accommodate the observable variation in fungal spore dispersions, and that of Lange & Smith (1971, p. 678), who used an illustrative, largely non-taxonomic method, believing that 'the form-species may be stretched beyond its limits to accommodate such diversity'.

SYSTEMATIC SECTION

A. FRUCTIFICATIONS

Fossil fructifications, or spore-bearing structures, can be referred to living taxonomic groups with greater accuracy than can dispersed spores, and hence are likely to be of more value in unravelling fungal evolution and palaeoecology. In this study, all of the fruiting bodies recovered can be referred to the subfamily Microthyriae of the family Microthyriaceae.

Fungal fructifications closely similar to those produced by members of the extant Microthyriaceae have been recorded in the palynological literature from Tertiary sediments at widely scattered geographic localities. Members of the family are epiphyllous in habit, and produce spores in flattened ascocarps borne either on or below the leaf surface. Within the subfamily Microthyriae the fruiting bodies are disc-like, formed from the fusion of radially aligned hyphae. Isolated fossil fructifications of this general form have been assigned to a number of organ-genera; these have been listed by Dilcher to 1965 and new genera have since been described by Venkatachala & Kar (1969) and Jain & Gupta (1970). Organ-genera have been characterized by such features as general body shape, the size and distribution of hyphal cells within it, the presence or absence of a neck-like opening or ostiole, and the presence or absence of pores within individual hyphal cells.

In the Ninetyeast Ridge sediments, microthyriaceous fructifications were common in most residues from Site 254, but notably so in Core 30. Among the mature fructifications, two distinct types were distinguishable and have been referred to the organ-genera *Callimothallus* Dilcher and *Notothyrites* Cookson. The immature forms, on the other hand, are morphologically alike; these early developmental stages have been referred to as 'stigmocysts' by Edwards (1922) and as 'germlings' by Dilcher (1965). No spores were found in association with any of the fruiting bodies although they were abundant in the preparations.

MICROTHYRIACEOUS GERMLINGS (Plate 1, figs. 1-5)

Remarks: All stages in the development of germlings were recorded, from tiny, near-circular discs, through forms beginning to show marginal invagination (Pl. 1, fig. 1), and development of a central hyaline spot (Pl. 1, fig. 2), to near-mature forms showing the initial stages of radial and tangential wall development.

MATURE FORMS

Genus **Callimothallus** Dilcher, 1965

Type species: Callimothallus pertusus Dilcher, 1965

Forms assigned to this genus are non-ostiolate, but possess numerous pores.

Callimothallus cf. **C. assamicus** Kar, Singh & Sah, 1972

Plate 1, fig. 7

cf. *Callimothallus assamicus* Kar et al., 1972, pl. 2, figs. 19, 20.

Dimensions: Stromata 43-80 μm diameter.

Description: Stromata roughly circular, radiate, without a central dehiscence area. Central cell trapezoidal, with thickened walls. The surrounding, radially aligned hyphal cells occur in 4 or 5 series; each of the cells in the inner 2 to 3 rows bears a single pore. The pores are situated at the inner ends of the cells, and are nearly equal to the cell width in diameter. The equatorial margin of the stromata is irregular and thickened.

Remarks: The basic morphology of these specimens resembles that of *C. assamicus,* from the Tertiary of Assam, except that the hyphal cells are smaller and more densely packed in the Ninetyeast Ridge form.

Genus **Notothyrites** Cookson, 1947 ex Kemp

Type species: (Here designated) *N. setiferous* Cookson, 1947, p. 209, pl. 11, figs. 1-6.

Notothyrites sp.

Plate 1, fig. 6

Dimensions: Not measurable because of fragmentary nature of specimens. Greatest measured fragment 76 μm.

Remarks: These fructifications were much less common than those compared to *Callimothallus,* and were invariably incomplete, with only the central, ostiolate part of the ascomata remaining. The radially aligned hyphal cells are elongate in the outer part of the disc; towards the central dehiscence area they are squarish and much thickened. Cells are non-porate. No setae were observed in the vicinity of the ostiole.

Comparison: In the shape of the ostiole, and in the distribution of cell types within the stromata, these fragments are morphologically close to *N. setiferous* Cookson. At present, it is uncertain whether the lack of setae precludes their assignment to this species, since Cookson (1947) included non-setiferous specimens within *N. setiferous,* remarking both on the extreme variability in observed numbers of setae and on the possibility that their lack may be due to loss during fossilization and preparation.

B. DISPERSED FUNGAL SPORES

Genus **Diporicellaesporites** Elsik, 1968

Type species: Diporicellaesporites stacyi Elsik, 1968

Diporicellaesporites endogranulosus Kemp, sp. nov.

Plate 1, figs. 12-15

Holotype: Plate 1, figure 12. Sample 6288/4; 107.5, 33.8 (CPC 15738). Overall spore length 54 μm, major cell length 42 μm, breadth 28μm, pores 3 μm in diameter. Type locality: Site 254, Ninetyeast Ridge. Lat.

30°58.15′S; Long. 87°53.72′E. Core 30, Section 1 at 159-161 cm, 268.1 m sub-bottom.

Diagnosis: Five-celled, broadly fusiform fungal spore consisting of large fusiform central cell with two smaller, cylindrical cells at each end. Terminal cells each have a single pore. Inner wall of major cell granulate.

Dimensions: Overall spore length 47 (55) 63 μm; maximum width 22 (25) 30 μm; major cell length 42-51 μm (20 specimens measured).

Description: Overall spore outline broadly fusiform; the main body is occupied by the fusiform central cell, equal in length to 70-80 percent of the overall spore length. The wall of the central cell is approximately 1.0 μm thick; its inner surface is ornamented with grana 0.5-0.8 μm in diameter and height. The grana are 2-3 μm apart, separated by smooth wall areas. Cells of the pair at each end of the central cell are size-graded, the terminal cell being smallest. Terminal cells are thin-walled, hyaline, and each bears a pore 2-3 μm in diameter in the end wall. The cell walls are brittle, and almost all specimens show irregular fracturing, especially of the central cell wall.

Remarks: Punctodiporites harrisii, which was described as a pollen grain from the Eocene-Oligocene of India (Varma & Rawat, 1963), seems more likely to be fungal in origin, and bears some resemblance to *D. endogranulosus.* The Indian form, however, is described as punctate; there is no indication of internal granulation. Additionally, the illustrations of *Foveodiporites anklesvarensis* Varma & Rawat (1963, figs. 11, 12) suggest similarity to the Ninetyeast Ridge species, but the wall structure is foveolate, rather than internally granulate. *Diporites granulatus* Rouse, 1962 (Pl. 5, figs. 5, 6) is also basically similar, but the structure of the pore-bearing cells is obscure, and the granulation was not described as internal.

Distribution: Site 254, Core 30 only. Similar forms have been observed by the author in middle Eocene deposits near Nerriga, New South Wales.

Affinity: Unknown.

Diporicellaesporites spp.
Plate 2, figs. 1-3

Remarks: Four-celled fungal spores referable to *Diporicellaesporites* are relatively common at Site 254. Two basic shape classes are present. The most common is that illustrated in Plate 2, figures 1, 2, which is a narrowly fusiform spore in which the ratio of cell length to cell width ranges from 4:1 to 7:1. The terminal cells taper to a blunt point, and each bears a single, narrow, terminal pore. Overall spore length is in the range 55-73 μm.

The rarer form (Pl. 2, fig. 3) is broadly fusiform, with a length to width ratio between 2:1 and 3:1, and with flattened terminal cells bearing pores. Spore lengths range from 43-55 μm. Affinities are unknown.

Genus **Brachysporisporites** Lange & Smith, 1971

1971 *Brachysporisporites* Lange & Smith, 1971, p. 677.
1974 *Granatisporites* Elsik & Jansonius, 1974, p. 953.

Type species: Brachysporisporites pyriformis Lange & Smith, 1971.

Remarks: Brachysporisporites was erected to accommodate phragmospores of several cells which are size-graded from a large and domed apical cell down to a small attachment cell. The cells are separated by thick, dark septa. The genus *Granatisporites* Elsik & Jansonius was created for spores of three or more cells which become widest toward the aporal, non-attachment end. The only distinction between the two generic concepts, based on their descriptions, is the mention of the thick, dark nature of the septa in *Brachysporisporites.* Although this feature is not specified in the description of *Granatisporites,* it is evident from illustrations of the type species, *G. cotalis* Elsik & Jansonius, and from other species assigned to the genus, that thick and dark septa are also characteristic of that taxon. Further, there appears to be little difference, except one of size, between the type species of *Brachysporisporites, B. pyriformis* Lange & Smith, and *G. cotalis.* The two form-genera are therefore regarded as synonymous.*

Brachysporisporites pyriformis Lange & Smith, 1971
Plate 1, figs. 8, 9

1971 *Brachysporisporites pyriformis* Lange & Smith, p. 677, pl. 3, figs. 160, 167; pl. 6, fig. C.
?1974 *Granatisporites cotalis* Elsik & Jansonius, p. 954, fig. 13.

Dimensions: Spore length 31 (36) 41 μm; maximum width 15 (18) 20 μm. (10 specimens measured).

Remarks: G. cotalis is placed in synonymy tentatively, as the size difference between this and *B. pyriformis* may be enough to warrant specific separation. The Ninetyeast Ridge forms conform closely to *B. pyriformis,* described originally from the middle Eocene Maslin Bay Beds in South Australia. In all specimens observed, the pore in the attachment cell is distinct, and is emphasized by a slight necking-in of the spore wall at the opening. The major septum, separating the apical cell from its neighbour, is 3-4 μm thick. The form is of unknown affinity, and occurs as a rare element in Cores 29 and 30.

Genus **Fusiformisporites** Rouse emend. Elsik, 1968

Type species: F. crabbii Rouse, 1962.

Fusiformisporites sp.
Plate 2, figs. 13, 14

Dimensions: Spore length 55-61 μm, maximum width 21-26 μm (6 specimens).

Remarks: Fusiform, inaperturate, dicellate fungal spores with fine longitudinal ribbing, which were observed in the Ninetyeast Ridge residues, probably represent a single form-species. All are acutely pointed at their apices, and show a restriction of the ribbed surface to the central two-thirds of each cell. Spores may or may not be necked at the single relatively thick (2-4 μm) septum.

Comparison: The species is probably a new form, distinguished from previously described types by the fineness and distribution of its ribbing, and its acutely pointed apices. However, insufficient specimens were recovered for formal description and typification. Elsik (personal communication, 1975) reports Neogene specimens from the United States Gulf Coast which have a slightly coarser ribbing.

Distribution: Site 254, Core 30; rare.

Genus **Dyadosporonites** Elsik, 1968

Type species: D. schwabii Elsik, 1968.

Dyadosporonites cf. **D. schwabii** Elsik, 1968
Plate 2, fig. 7

cf. *Dyadosporonites schwabii* Elsik, p. 279, pl. 2, fig. 30.

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* This synonymy was also noted by Jansonius (Geoscience & Man, 15, 129) while this paper was in press.

Dimensions: Spore length 27-31 μm; maximum width 14-16 μm. Pores 2-3 μm in diameter.

Remarks: This form differs from *D. schwabii*, originally described from the Paleocene of Texas (Elsik, 1968), only in possessing a slight thickening of the wall adjacent to the terminal pores.

Distribution: Site 254, Core 30; rare.

Genus **Involutisporonites** Clarke, 1965 emend. Elsik, 1968

Type species: I. foraminus Clarke, 1965.

Involutisporonites sp.

Plate 2, fig. 9

Dimensions: Overall diameter of cell cluster 24-33 μm; individual cells 9-11 μm in diameter.

Remarks: Coiled aggregates of from four to ten cells occur rarely in samples from Site 254. The aggregates appear to be formed as a two-cell deep planispiral whorl. Wall pigmentation obscures details of the septa, so that the presence or absence of an opening within the septa is not determinable. Only in occasional specimens is the pore in the terminal cell of the whorl distinct.

Distribution: Site 254, Core 30; rare. Similar forms were described from the Late Cretaceous of Colorado by Clarke (1965).

Genus **Staphlosporonites** Sheffy & Dilcher, 1971

Type species: S. conoideus Sheffy & Dilcher, 1971.

Staphlosporonites sp.

Plate 2, fig. 4

Remarks: This form genus is used as a broad category to accommodate psilate spores comprising four or more cells in clusters, rather than aligned along a single axis. The most common form in the residues from Site 254 is that figured in Plate 2, figure 4, which is an ovoid body of 12 or more cells arranged in a series of irregular rows. No pores are visible.

Linear phragmospores

Plate 2, figs. 5, 6, 10

Remarks: A wide range of multicellular spore forms occurring at Site 254 is herein grouped within this broad morphological category. An open taxonomy is adhered to here because of problems in resolving morphology, especially that related to pore development. Apertures are usually very difficult to discern; small pores are hard to see in thick-walled, heavily pigmented spores, and, in some cases, breakage of the cell wall may suggest pores when in fact none are present. Grouped under this broad heading are multicelled types with a small number of large cells (Pl. 2, fig. 5, ?*Pluricellaesporites*), or a large number of small cells (Pl. 2, figs. 6, 10). The latter group, if truly diporate, should be referred to *Diporicellaesporites*.

Unicellate fungal spores

Plate 1, figs. 10, 11. Plate 2, figs. 8, 11

Remarks: Unicellular, usually psilate spores are the most abundant element among the fungal remains observed at Site 254. The extremely simple and generalized morphology of these spores, together with the high degree of inter-gradation observable between different shape and size classes makes detailed taxonomic treatment of doubtful value, so they are treated here as a single broad category. On a stricter basis, inaperturate, usually oval types are referable to the form genus *Inapertisporites* van der Hammen, a genus which includes the form with a reticulate wall (Pl. 2, fig. 11, cf. *I. reticulatus* Sheffy & Dilcher). Teardrop-shaped forms, probably with pores (Pl. 1, fig. 11; Pl. 2, fig. 8) have been referred to the form genus *Lacrimasporonites* by Clarke and other authors, while monoporate forms (Pl. 1, fig. 10) are frequently accommodated within *Monoporisporites* van der Hammen.

Hyphae

Plate 2, fig. 15

Dispersed fragments of hyphae are common in residues from Site 254, and are septate and frequently branching. No structure diagnostic of particular fungal classes were noted; the clamp connections of Basidiomycetes were not identified, although 'pseudoclamps' (Dennis, 1969) were relatively common (Pl. 2, fig. 15). Hyphae were not observed in association with fragments of leaf cuticle, although these latter are abundant.

COMPARISONS

Comparison of this with other Tertiary fungal assemblages is difficult because of the lack of publications dealing with total or near-total assemblages. An exception is the middle Eocene assemblage from Maslin Bay, which Lange & Smith (1971) figured in detail. The Ninetyeast Ridge assemblage has some elements in common with the South Australian one, notably its diversity of single-celled amerospores (although this may be common to most assemblages), the presence of *Brachysporisporites* and of microthyrialean elements (Lange, 1970). The Indian Ocean suite, however, lacks the abundance and diversity of linear phragmospores evident at Maslin Bay.

In North America, the Paleocene to middle Eocene assemblages from Gulf Coast sediments (Elsik, 1968; Sheffy & Dilcher, 1971) also contain an abundance and diversity of single-celled types, but in addition are characterized by a wide variety of multicelled forms (*Multicellaesporites*) with thick dividing septa. These were not recorded from the Ninetyeast Ridge. The diversity of microthyrialean forms in the U.S. Gulf Coast is likewise not matched. The distinctive genera recorded from the northwest coast of North America (Elsik & Jansonius, 1974) have not been identified to date either in Australia or on the Ninetyeast Ridge. Assemblages from India have only been described in part to date, but already it is evident that the diversity of microthyrialean remains is much greater on the subcontinent than on the oceanic islands.

PALAEOECOLOGY

The diversity of fungal remains at former island sites on the Ninetyeast Ridge, and the presence of Microthyriaceae within the fossil suites, suggest that the islands experienced a very humid climate during their emergence. The fungal microfossils, however, give little indication of the temperatures that prevailed. Although Microthyriaceae is a family which at present has a predominantly tropical distribution (Alexopoulus, 1956; Dilcher, 1965), there are records of fossil fructifications in what must have been relatively cool high-latitude localities (Godwin & Andrew, 1951), so that warm temperatures cannot be automatically assumed from the presence of these fossils.

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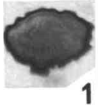
PLATE 1

(magnifications x1000 unless stated otherwise)

Figs.	
1–5	Microthyriaceous germlings. Slide 6288/3 —1. Early growth stage, with invagination of margin just beginning; CPC 15673. —2, 3, 4. More advanced stages, central hyaline spot visible in 2 and 4. CPC Nos 15674, 15675. —5. Scanning electron micrograph, x2500.
6	*Notothyrites* sp. Slide 6288/2, 112.4, 32.3. CPC 15676. Near-complete specimen showing ostiole formed of thick-walled, square cells.
7	*Callimothallus* cf. *C. assamicus* Kar, Singh & Sah. Slide 6288/4, 101.8, 37.0. CPC 15677. Pores in hyphal cells distinct on right hand side of larger specimen. Additional small ascostromata attached on right.
8, 9	*Brachysporisporites pyriformis* Lange & Smith. —8. Slide 6288/3, 112.0, 42.0, CPC 15678. —9. Slide 6288/3, 112.0, 42.0, CPC 15678. —9. Slide 6288/3, 110.0, 41.9. CPC 15735.
10	*Monoporisporites abruptus* Sheffy & Dilcher. Slide 6283/3, 99.1, 32.1 CPC 15736.
11	*Lacrimasporonites* sp. Slide 6288/2, 96.1, 36.2. CPC 15737.
12–15	*Diporicellaesporites endogranulosus* Kemp sp. nov. —12. Holotype Slide 6288/4, 107.5, 33.8. CPC 15738. Median focus showing all cells in optical section; terminal pores distinct. —13. Slide 6288/2, 97.0, 35.7. CPC 15739. —14. Slide 6288/2, 96.9, 35.7. CPC 15740, Nomarski interference contrast, showing dense internal granulations of wall. —15. Slide 6288/1, 92.6, 31.4. CPC 15741, specimen with abruptly narrowing terminal cells.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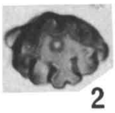
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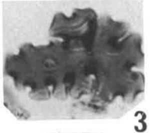
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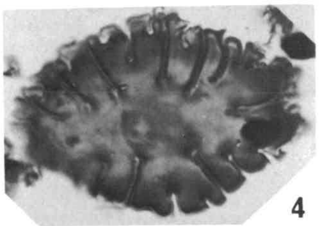
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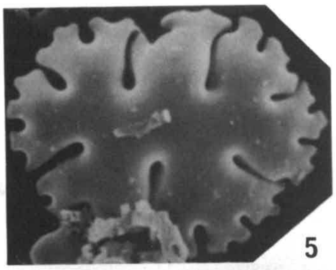
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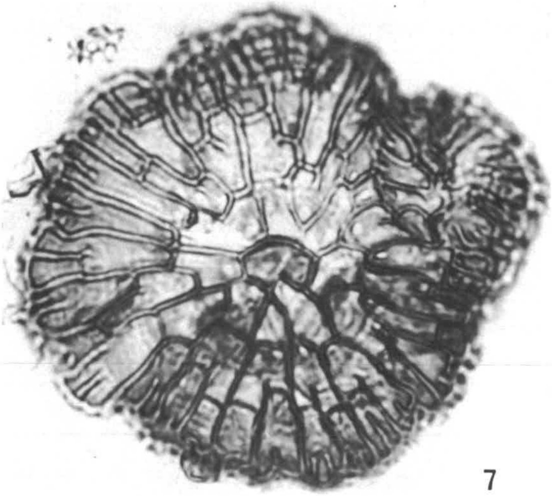
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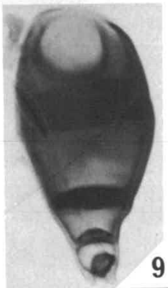
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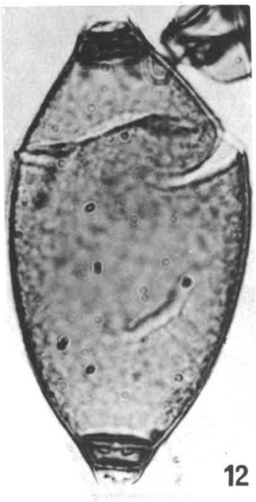
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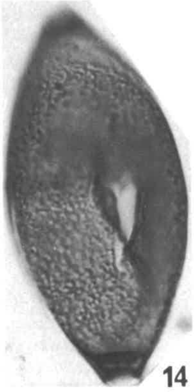
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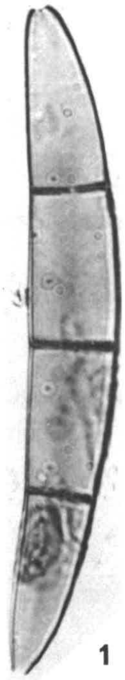
PLATE 2

(magnifications x1000)

Figs.	
1–3	*Diporicellaesporites* spp.—1, 2. Slender, elongate forms, terminal pores distinct. Slide 6288/4, 107.5, 33.8. CPC 15742, Slide 6288/1, 106.0, 43.7, CPC 15743. —3. Broad, thick-walled form. Slice 6288/2, 100.9, 31.9. CPC 15744.
4	*Staphlosporonites* sp. Form with cells in irregular series. Slide 6288/2, 99.8, 34.8. CPC 15745.
5, 6, 10	Linear phragmospores. —5. ?*Pluricellaesporites* sp. Slide 6283/1, 11.9, 46.8. CPC 15746. —6, 10. ?*Diporicellaesporites* sp. Slides 6288/1, 110.6, 42.9. CPC 157 15747, 6288/2, 107.0, 27.0. CPC 15748.
7	*Dyadosporonites* cf. *D. schwabii* Elsik. Slide 6288/1, 93.1, 31.4. CPC 15749.
8	*Lacrimasporonites* sp. Slide 6288/2, 94.2, 41.0. CPC 15750.
9	*Involutisporonites* sp. Slide 6288/2, 108.2, 34.5. CPC 15751.
11	*Inapertisporites* cf. *I. reticulatus* Sheffy & Dilcher. Slide 6288/1, 94.5, 44.8. CPC 15752.
12	?*Dicellaesporites* sp. Form with incipient development of additional cross-walls. Slide 6288/1, 92.6, 31.4. CPC 15753.
13, 14	*Fusiformisporites* sp. —13. Ribbed form with distinct restriction of ribbing to centre part of cell. Slide 6288/3, 106.3, 36.0. CPC 15754. —14. Slide 6283/1, 107.1, 44.0. CPC 15755.
15	Branching, septate hyphae. Slide 6288/1, 108.2, 45.0. CPC 15756.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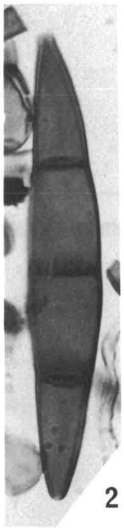
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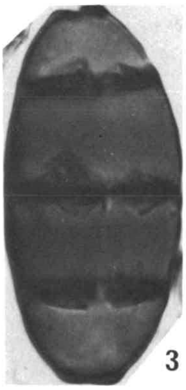
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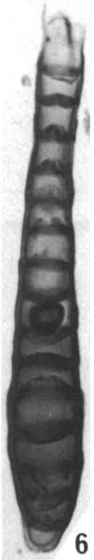
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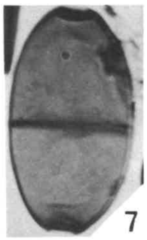
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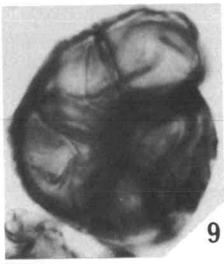
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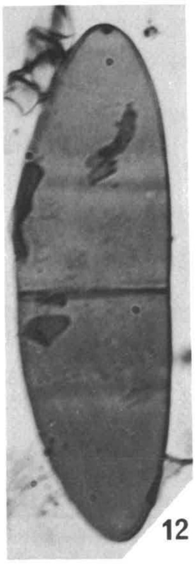
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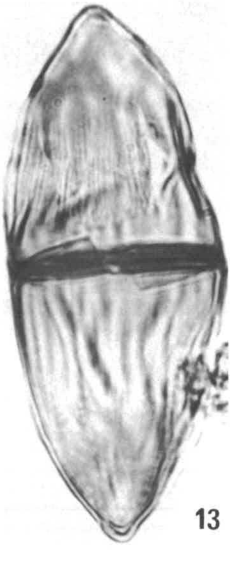
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Early Tertiary foraminiferal biostratigraphy in southern Australia: a progress report

by
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The Paleocene-Eocene planktonic foraminiferal assemblages of the southern Australian margin occur in two distinct stratigraphic sequences. In the Paleocene and Lower Eocene, marine ingressions in a marginal marine, essentially detrital sequence are correlated tentatively with the standard P-zones of lower latitudes via the rather more complete successions in the Carnarvon Basin and the Indian Ocean. A composite, essentially calcareous Middle to Upper Eocene sequence records a succession of biostratigraphic events which are also matched against the P-zones. An oceanic calcareous section on the Naturaliste Plateau largely fills the previous gap in the composite picture across the Lower/Middle Eocene boundary.

Eocene assemblages reflect fluctuations in watermasses. Even so, a succession of biostratigraphic events common to southern Australia and New Zealand demonstrates that those fluctuations were rapid and regional in their extent. The proliferation of southern extratropical zones and zonal nomenclature is regarded without enthusiasm by one of the culprits; we can progress without those zones by relating regional events to the P-zones even though this matching is by no means perfect. A collage of physical and biological events in and marginal to the ocean is correlated with a recent isotope temperature curve.

INTRODUCTION

Previous discussions of Paleocene (McGowran, 1970) and Eocene (McGowran, 1973a) foraminiferal biostratigraphy can be summarized and extended usefully, because there has been progress in the southern extratropical region (Jenkins, 1975) and in relating events to the 'tropical standard' succession (McGowran, in press).

Southern Australasian micropalaeontology, as we now know it, goes back to the pioneering studies by Irene Crespin, H. J. Finlay, M. F. Glaessner, and W. J. Parr (see Crespin, 1955). In this and subsequent work (Hornibrook, 1958; Carter, 1958; Jenkins, 1960; Wade, 1964) it was becoming clearer that the local assemblages were provincial but with 'windows' provided by excursions from the tropics (thus, the *Hantkenina* Zone of Glaessner, 1951). The importance of biogeography to biostratigraphic analysis was spelled out in practice by Wade (1964) and the reverse, giving an idea of climatic variation in the Tertiary, was summarized by McGowran & Wade (1967). Scheibnerova (1971) was a decade or more too late in urging Tertiary biostratigraphy in terms of provinces.

The conceptual framework for planktonic foraminiferal biostratigraphy includes the following: (1) Species are restricted in space, their distribution being controlled by watermass configuration and change. Some are 'tropical' or 'extratropical' (and the versatile or opportunistic species tend to survive longest); others are oceanic, occurring sporadically over the continental shelves, or vice versa. (2) Deep-water assemblages reflect populations in the water column only in part: selective dissolution introduces a taxonomic bias. (3) Climatic changes (a simplistic phrase) mean rapid, far-reaching and reversible changes in the distribution of species. (4) The time/space distributions in the southern Australian Palaeogene are peculiarly susceptible to what now might be called the stratotectonic situation: a new trailing continental margin was influenced by consequent major changes in oceanic circulation. In this situation, conventional ideas on presence-or-absence, stratigraphic range, extinction, and so on have proved to be rather dangerous. This paper is a progress report but will, hopefully, clarify some of these points whilst incorporating them in a biostratigraphy which relates southern Australia to New Zealand and to the lower latitudes.

STRATIGRAPHIC BACKGROUND

CHRONOSTRATIGRAPHIC FRAMEWORK

All charts presented here are related to the scale of Berggren (1972), in keeping with common practice in the Deep Sea Drilling Project and in such quantifications as sediment accumulation rates, seafloor spreading rates, and oxygen isotope ratios. Berggren's scale relates planktonic foraminiferal biostratigraphy to epochs and to a geochronological scale; radiolarian and calcareous nannofossil systems are related to this framework, as is a recent revision of the geomagnetic reversal scale (Sclater and others, 1974). The desirability of this procedure is founded not so much in accuracy—there are numerous assumptions and plenty of hopeful interpolation especially in the Palaeogene which, in contrast to the Neogene, has remained relatively stable through several editions of Berggren's synthesis—as in consistency and communication. Thus, geohistorical and biohistorical studies can be updated as the scale is updated, and so remain useful for longer.

The awareness that a standard historical scale is desirable does not remove the need for local and multiple biostratigraphies and local chronostratigraphies: the Earth's surface is too subtle and variable for that. But I confess to decreasing enthusiasm for chronostratigraphic causes once promoted (McGowran, 1968, 1970; McGowran, Lindsay & Harris, 1971). Disagreement about the Paleocene/Eocene boundary (McGowran, 1970) or the Lower/Middle Eocene

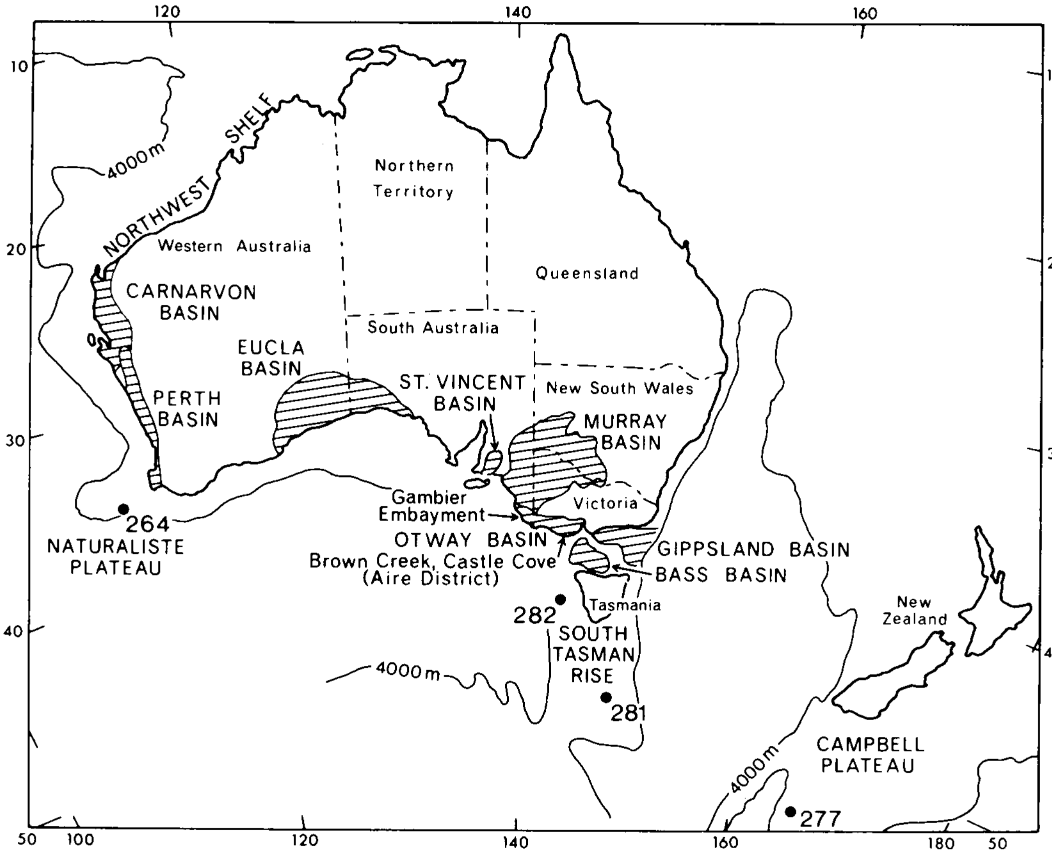

Figure 1. Localities referred to in southern Australasia. For Deep Sea Drilling Project (DSDP) Site 264, see Hayes, Frakes & others (1975); for Sites 277, 281, 282, see Kennett, Houtz & others (1975).

boundary (Hornibrook & Edwards, 1971) is not discussed here. Similarly, biostratigraphic zones are not stressed in this report: as the significance of foraminiferal assemblages and stratigraphic events becomes clearer, so does it seem that formal zonal definitions not only must proliferate and cause confusion, but actually hamper stratigraphic thinking (Jenkins's (1971) observation that Wade's (1964) zones are 'rather ill-defined' is, perhaps, accurate, but is rejected as a criticism).

LITHOSTRATIGRAPHIC FRAMEWORK

The correlation of rock units (Fig. 2), taken from many sources including present conclusions, can be summarized rather broadly as two stratigraphic sequences:

1. *Paleocene to Lower Eocene.* The sequence is detrital on the southern margin, with planktonic and calcareous-benthonic foraminiferal assemblages occurring as sporadic ingressions in a marginal, marine (agglutinated foraminifera, organic-walled phytoplankton) to nonmarine regime. The facies of the King's Park Formation suggests rather comparable conditions at the same time. In contrast, the sequence consists of carbonates in the Carnarvon Basin.

2. *Middle to Upper Eocene.* For the first time since the Palaeozoic, a shelf carbonate facies regime is established in southern Australia, and foraminiferal ranges and zones become a little more meaningful than before. Facies are diachronous (see especially Taylor, 1971; McGowran, 1973a) and the sequence is 'less marine' to the east of the Otway Basin.

PALEOCENE ASSEMBLAGES AND CORRELATIONS

In comparison with the Eocene, the recognition of a consistent succession of biostratigraphic events in the Paleocene at lower latitudes is rather more straightforward; almost all the 'standard' events have been seen in the Indian Ocean (McGowran, 1974, and in press; see Fig. 3). Figure 4 summarizes the available data on the western and southern margins of the Australian continent. The composite succession for the Carnarvon Basin and the Northwest Shelf is taken from McGowran (1968, 1969), Wright (1973, plus unpublished range chart) and added personal observations incorporated in charts prepared for a project on correlation (Bolli, 1969) but never published.

The main assemblage in the King's Park Shale, Perth Basin (McGowran, 1964, 1968, 1969; Quilty, 1974a) is correlated quite firmly on the presence of *Planorotalites chapmani* and *Acarinina mckannai.* The higher assemblages, correlated with Zone P.6b or possibly Zone P.7 but older than the *Morozovella caucasica* assemblage on the Naturaliste Plateau (Table 1), was discovered by Quilty (1974a). Nannofossil evidence seems to throw some doubt on whether it is in place or reworked to the level shown as 'unnamed formation' in Figure 2 (Shafik, this volume).

There is nothing to be added to the previous discussions of the marine ingressions in the Otway Basin (McGowran, 1965, 1970). But it is worth repeating two points: (1) *Planorotalites chapmani haunsbergensis,* the only significant planktonic in the Pebble Point For-

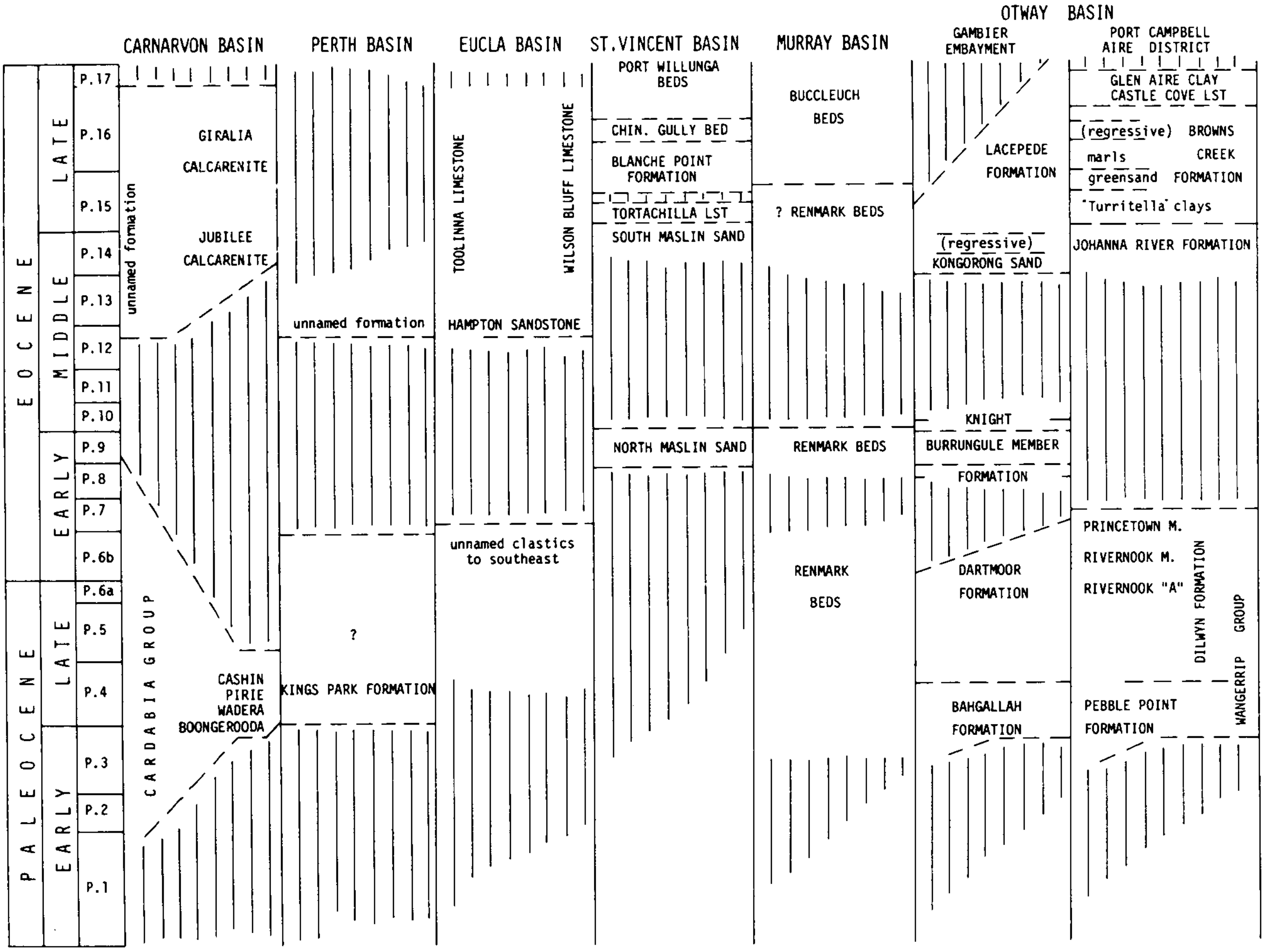

Figure 2. Correlation of rock units. Abbreviations: Lst, Limestone; M, Member; Chin. Gully Bed, Chinamans Gully Bed. In this and all subsequent text figures the vertical dimension is drawn to scale after the estimated duration of the planktonic foraminiferal Zones P.1 to P.17 (Berggren, 1972).

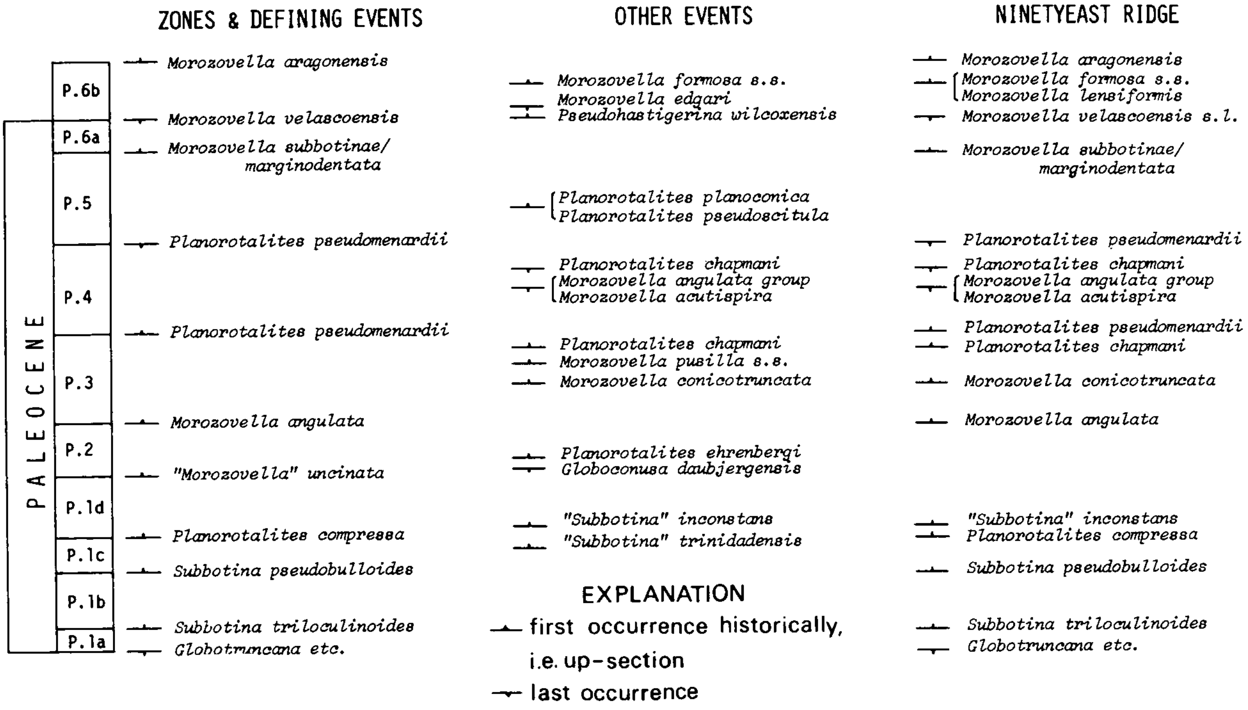

Figure 3. Biostratigraphic framework for the Paleocene, after McGowran (in press).

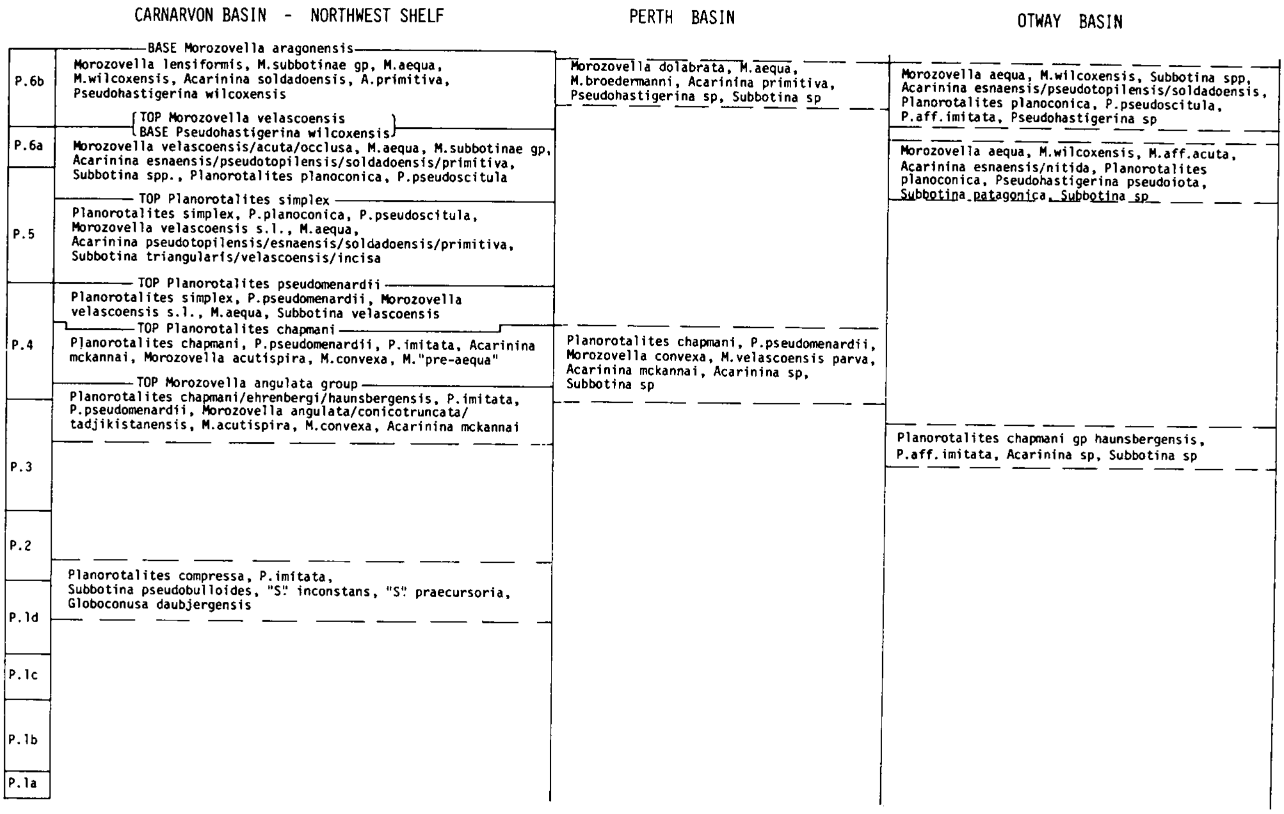

Figure 4. Paleocene and earliest Eocene planktonic foraminiferal assemblages and events, western and southern continental margins.

mation, was (and is) the evidence for a correlation with Zone P.3, via the Carnarvon Basin assemblage, but this is weakened by the probability that the provincial, extratropical *Planorotalites australiformis* is a direct descendant. A firm, precise age on the Pebble Point Formation is needed, because it is critical to palynobiostratigraphy (Harris, 1971; McGowran, 1974) and to such stratotectonic notions as the 'breakup unconformity' in southern Australia (Falvey, 1974). (2) The assemblage with *Pseudohastigerina pseudoiota* ('Rivernook A'; Fig. 2) seems to be slightly older than the *Pseudohastigerina* datum, although the evidence boils down to a few specimens of the *Morozovella velascoensis* group, here labelled *M.* aff. *acuta.* The assemblage in the Rivernook Member includes *Morozovella aequa,* and is no younger than Zone P.6.

Correlation with New Zealand is not yet clear. The data available (Jenkins, 1966, 1971, 1974; Hornibrook, 1969; Hornibrook & Edwards, 1971) indicate that the range of *Planorotalites pseudomenardii* (total range = Zone P.4) encompasses short-lived immigrations by *Morozovella aequa* and *M. velascoensis* and the first occurrences of *Planorotalites australiformis* and *Acarinina primitiva* (see especially Hornibrook & Edwards, 1971, table 1). *Planorotalites chapmani,* in strong contrast to present observations (Figs. 3, 4) has a short range immediately preceding *Pseudohastigerina wilcoxensis.*

EOCENE ASSEMBLAGES AND CORRELATIONS

The succession of biostratigraphic events in southern Australia (Fig. 5) is pieced together from several more-or-less isolated assemblages; it cannot be stressed too strongly that the succession is composite. Figure 5 includes a column for the Ninetyeast Ridge (McGowran, 1974 and in press) which is critical in relating southern extratropical to tropical successions.

LOWER EOCENE, NATURALISTE PLATEAU

The assemblage (Table 1) is correlated with assemblages including *Morozovella caucasica* on the Ninetyeast Ridge. *Morozovella caucasica* includes *M. crater* (Finlay) (Krasheninnikov & Hoskins, 1974; personal observations). In New Zealand, the *M. 'crater'* Zone includes *M. rex* (Martin) and *M. dolabrata* Jenkins (? = *M. lensiformis* (Subbotina)) (Fig. 6) which seem to represent hangovers from Zone P.7. This is interesting, because *M. crater* seems to flourish beyond the lower limits of temperature tolerated by most morozovellids, being analogous in this respect to *Globotruncanella mayaroensis* versus late Cretaceous keeled globotruncanids, and to *Globorotalia truncatulinoides* among Late Cainozoic keeled globorotaliids.

MIDDLE EOCENE, NATURALISTE PLATEAU

The assemblages listed in Table 1 are distinguished from coeval assemblages at lower latitudes by the dominance of acarininids (especially *Acarinina primitiva)* and the poor record of morozovellids. The interval between top *Morozovella caucasica* and base *Globigerinatheka index* and characterized by prominent *Guembelitria* is judged to correlate with Zones P.10-P.11 (Fig. 5) and thus with good evidence for a cool climatic interval on the Ninetyeast Ridge and the cherts of 'Horizon A' in the Indian Ocean (McGowran, in press). On comparison with the Ninetyeast Ridge, where both events occur, top *Planorotalites australiformis* and base *Globigerinatheka index* are placed in

TABLE 1: Summary of planktonic foraminiferal succession, Site 264, Naturaliste Plateau. Paleocene: from P. N. Webb, in Site Report (Hayes, Frakes, & others, 1975, Chapter 2). Eocene: personal observations.

NATURALISTE PLATEAU: DSDP SITE 264

			Neogene assemblages
LOWER — MIDDLE EOCENE	Nanno ooze	31m	UNCONFORMITY
			Acarinina primitiva, A. collactea, A.aff. spinuloinflata, Morozovella densa (some"pre-*topilensis*"), keeled morozovellid juveniles, *Subbotina linaperta/ angiporoides, S. yeguaensis* group, *S. frontosa*?, bullate globigerinids including *turgida*, turborotaliids (*wilsoni/pseudomayeri*), *Globigerinatheka index, Planorotalites pseudoscitula* (very sporadic), *Pseudohastigerina wilcoxensis* (*micra*-like at top). *Globorotalia cerroazulensis pomeroli* at top (very rare). Preservation deteriorating upwards; radiolaria common to abundant at top.
		80m	Base *Globigerinatheka index*
	Nanno chalk with chert throughout		Assemblages as above.
		96m	Top common to abundant *Guembelitria*
			Assemblages mostly as above; *Guembelitria stavensis, Morozovella crassata, Globigerinatheka senni.*
		132m	Top *Planorotalites australiformis*
			Acarinina primitiva, A. broedermanni, A. pentacamerata, A. spinuloinflata/ pseudotopilensis, Morozovella densa (some "pre-*topilensis*"), *M. crassata, Subbotina aff. linaperta, S. frontosa*, bullate globigerinids, turborotaliids (*wilsoni/pseudomayeri*), *Globigerinatheka senni, Planorotalites australiformis, P. pseudoscitula* (sporadic), *Pseudohastigerina wilcoxensis, Guembelitria stavensis.* Interval includes horizon with glauconite and reworked *Heterohelix* (Cretaceous) and *Morozovella aragonensis* (Lower Eocene).
		145m	Base *Guembelitria*
UPPER-LOWER EOCENE		155m	Top *Morozovella caucasica*
			Morozovella caucasica, M. aragonensis, M. crassata, M. densa, Acarinina primitiva, A. broedermanni, A. angulosa, Planorotalites australiformis, P. pseudoscitula, Pseudohastigerina wilcoxensis, Subbotina aff. linaperta, S. frontosa, S. patagonica, Globigerinatheka senni.
		163m	UNCONFORMITY
			Paleocene assemblage (Zones P.3-P.4): *Planorotalites pseudomenardii, P. chapmani, Subbotina triloculinoides, S. pseudobulloides, Morozovella uncinata, M. angulata, M. pusilla, Acarinina mckannai.*
		169m	UNCONFORMITY
			Upper Cretaceous planktonic assemblage.
		171m	
			Bottom-hole in volcaniclastic conglomerate.
		215m	

Zone P.11. The Neogene/Palaeogene unconformity extends down to Zone P.12. Thus the thick section of chalk and ooze at Site 264 spans almost all the stratigraphic gap between the *Morozovella aequa* ingression in the Otway Basin and the Eocene of the Eucla Basin.

The age of the Burrungule Member of the Knight Formation in the Otway Basin (Ludbrook & Lindsay, 1969; McGowran & others, 1970, 1971) remains unclear. Identification of a *Guembelitria* assemblage at Site 264 in Zone P.10-P.11 equivalents may strengthen the significance of *G.* aff. *columbiana* in the Burrungule Member, but I am now more impressed by the fact that *Pseudohastigerina wilcoxensis* there is strongly asymmetrical (*pseudoiota*-like) because such forms do not extend above the Lower Eocene in New Zealand (Jenkins, 1971).

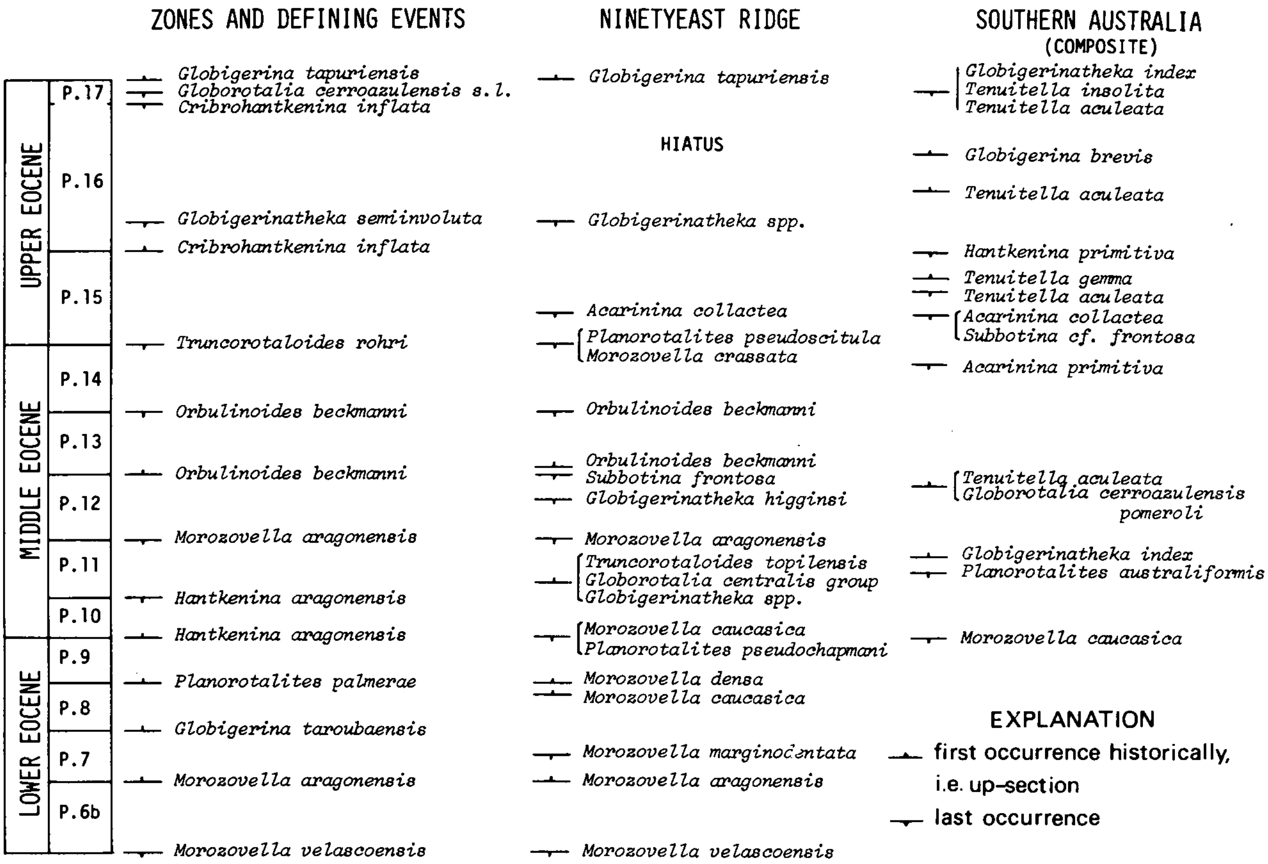

Figure 5. Biostratigraphic framework for the Eocene, after McGowran (in press). The estimated position of the southern Australian events is the main control on the spacing of events in Figures 6 and 7.

MIDDLE EOCENE, EUCLA BASIN

McGowran & Lindsay (1969) illustrated the assemblage from the base of the marine section (Hampton Sandstone and basal, partly glauconitic levels of the Wilson Bluff Limestone); this assemblage is widespread in the Eucla Basin, occurring as well in the coarser, better sorted Toolinna Limestone (McGowran & Lindsay, 1969; Lindsay & Harris, 1975; the partly Middle Eocene age of the Toolinna Limestone was not noted by Lowry (1972) or by Quilty (1974b)) and in marginal facies (Lindsay & Harris, 1975).

The assemblage includes *Acarinina collactea,* with morphotypes recalling *A. pseudodubia* or *A. rugoso-aculeata, A. primitiva, Morozovella densa,* very rare morozovellids of the *spinulosa/crassata* group, *Truncorotaloides* 'pre-*topilensis*', *Planorotalites pseudoscitula, Pseudohastigerina wilcoxensis-micra,* turborotaliids (*pseudomayeri/nana*), *Globorotalia cerroazulensis pomeroli, Tenuitella aculeata, Subbotina linaperta* s.l., *Subbotina frontosa, Globigerinatheka index, G. higginsi, Chiloguembelina* aff. *cubensis, C. martini,* and rare *Hantkenina australis.*

With reference to the succession in the Indian Ocean (McGowran, 1974; in press) I would correlate this assemblage with upper Zone P.12 or possibly Zone P.13 (see also Shafik, this volume). *Tenuitella aculeata* was found (rarely) below *Orbulinoides beckmanni* on the Ninetyeast Ridge but was not found on the Naturaliste Plateau.

Although the assemblage obviously lacks such tropical elements as *Orbulinoides,* the rare specimens of *Morozovella, Globorotalia* and *Hantkenina* hint at a 'warm incursion' at the foot of this Middle Eocene transgression. This is consistent with regional evidence, in that this transgression starts virtually isochronously (upper Zone P.12 to Zone P.13) from southern Australia to Pakistan, and concurrently there was an expansion of the tropical zone, both on the evidence of planktonics and on an excursion southwards by *Discocyclina* (McGowran, in press). Probably more of the Wilson Bluff Limestone is of Middle Eocene age than is shown by Quilty (1974a); in South Australia the bulk may be Middle Eocene (Lindsay & Harris, 1975). However, the assemblages are poorly preserved above the base of the formation.

MIDDLE EOCENE, OTWAY BASIN

An assemblage with *Acarinina primitiva* has been recognized in several subsurface sections in the Gambier Embayment (Ludbrook & Lindsay, 1969; Ludbrook, 1971; McGowran, 1971, 1973a). The assemblage includes *Acarinina primitiva, Acarinina collactea* ('group B' of McGowran (1973a), meaning a rather wide range of morphologies recalling also *A. pseudotopilensis, A. spinuloinflata*), *Subbotina linaperta/angiporoides, Subbotina* cf. *frontosa* (see Ludbrook & Lindsay, 1969, pl. 2, figs. 14, 15), *Globigerina* spp., turborotaliids including *'Globorotaloides' turgida, Pseudohastigerina* aff. *micra, Globigerinatheka index,* and very rare *Hantkenina* aff. *australis.*

Ludbrook & Lindsay (1969) and Ludbrook (1971) recognized Jenkins's (1966, 1971) *Acarinina primitiva* and *Globigerinatheka index* Zones in continuous succession above the *Planorotalites australiformis* Zone in the Gambier Embayment, and this was perpetuated by McGowran & others (1970, 1971). However, the *Acari-*

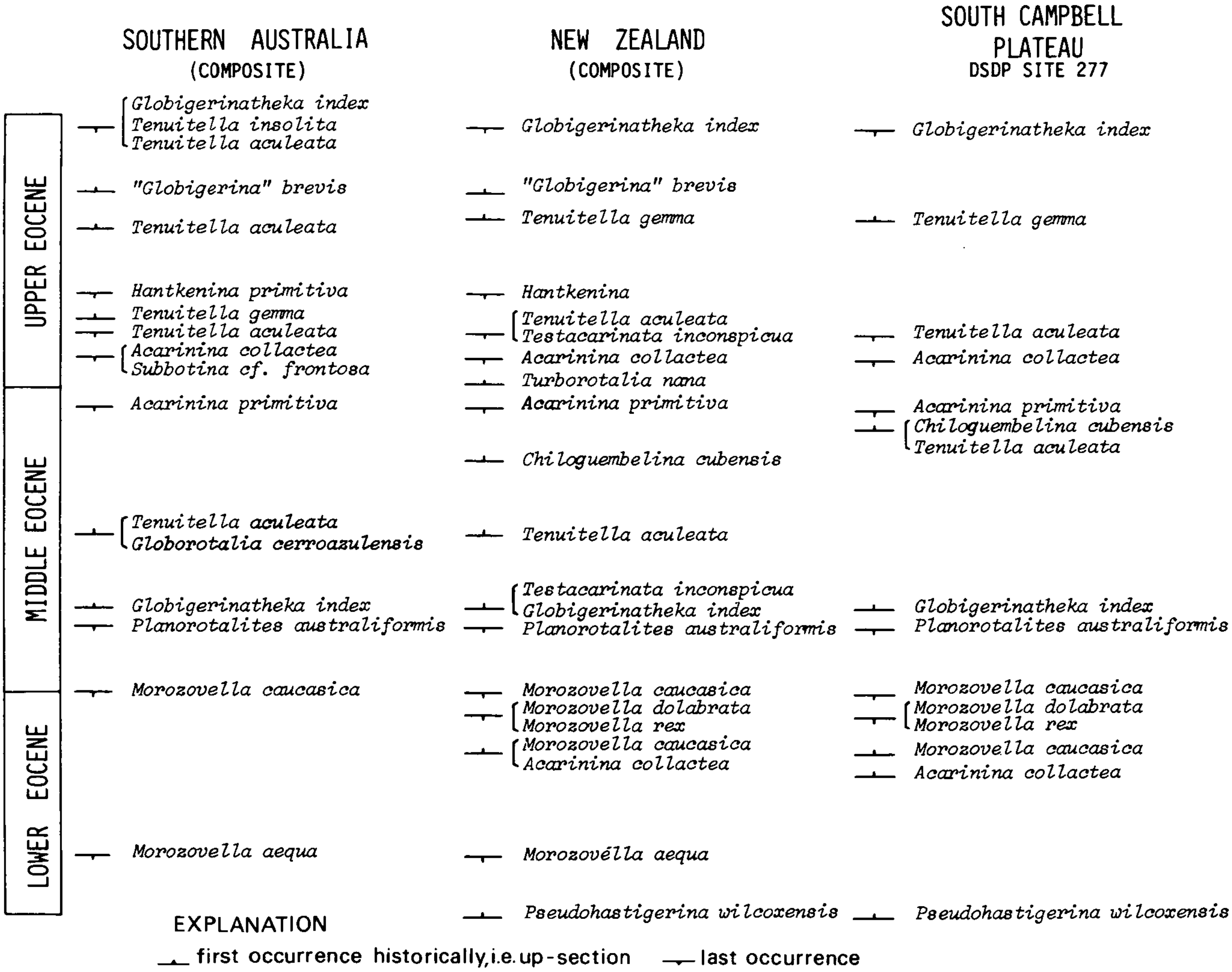

Figure 6. Comparison of planktonic foraminiferal successions in the Eocene of southern Australasia. Southern Australia: from Figure 5. New Zealand: compiled from Jenkins (1966, 1971, 1974), Hornibrook (1969), Hornibrook & Edwards (1971). South Campbell Plateau: from Jenkins (1975).

nina primitiva Zone was abandoned, being based on very slender exidence, and the Kongorong Sand with the assemblage listed above was recognized as representing a stratigraphically isolated marine ingression, being separated by an interval barren of planktonics from the main (Late Eocene) transgression in at least three sections (McGowran, 1973a).

The correlation of the assemblage remains a problem. *Acarinina primitiva* ranges as high as probable Zone P.14 in the Carnarvon Basin. On the absence of *Subbotina frontosa* (identified incorrectly by McGowran, 1973a) and *Planorotalites pseudoscitula* the assemblage is now considered tentatively to be slightly younger than the assemblage in the Eucla Basin, and the Kongorong Sand accordingly is placed against Zone P.14 (Fig. 2).

LATE EOCENE, OTWAY BASIN

The section at Browns Creek at the eastern end of the Otway Basin in Victoria has been a standard for the Upper Eocene for the thirty years since Parr discovered *Hantkenina* there (Parr, 1947). But even now, the foraminiferal succession is given only in a summary form (Table 2). In the Gambier Embayment in South Australia, the record is based on subsurface sampling (Ludbrook & Lindsay, 1969; Ludbrook, 1971; McGowran, 1973a) but includes—unlike all Victorian sections— the important top to the range of *Acarinina collactea.*

Acarinina collactea extends slightly above the topmost *Morozovella* and *Planorotalites pseudoscitula* in several sections in the Indian Ocean (reviewed by McGowran, in press). The latter horizon is taken as the Middle/Upper Eocene boundary, and so that boundary is drawn in southern Australia and New Zealand between top *Acarinina primitiva* and top *Acarinina collactea* (Figs. 5, 6).

In the Gambier Embayment *A. collactea* is associated with *Subbotina* cf. *frontosa, S. linaperta, Globigerina officinalis/angustiumbilicata/praebulloides, Globigerinita* spp., *Tenuitella insolita, Pseudohastigerina* aff. *micra, Chiloguembelina cubensis,* etc. *Tenuitella aculeata* is sporadic but becomes abundant above top *Acarinina collactea.* The latter event is very close to the base of the planktonic/marine section at Browns Creek, because *Subbotina* cf. *frontosa* occurs there and *A. collactea* does not, whereas the order is reversed farther west (McGowran, 1973a); the events are lumped together in Figures 5 and 6.

There are three particularly noteworthy points about the foraminiferal succession in Table 2: (1) The absence of any event that allows direct correlation with standard zones (cf. Fig. 5); the faunas were extratropical. (2) Several species distributions are disjunct, and relative

TABLE 2: Summary of planktonic foraminiferal succession in the Upper Eocene, western Victoria.

		AIRE DISTRICT: BROWNS CREEK AND CASTLE COVE
	Calder River Limestone	Late Oligocene assemblage with *Globorotalia kugleri* group
		UNCONFORMITY
	Glen Aire Clay	*Tenuitella aculeata* abundant to absent; *T.gemma* being replaced by *T.munda; Subbotina linaperta* by *S. angiporoides*. Small globigerinids (*praebulloides* group), large globigerinids (*tripartita* group, *brevis*, etc), turborotaliids (mostly *testarugosa*, occasional *nana*).
		Top *Globigerinatheka index;* Top *Tenuitella insolita*
	Castle Cove Limestone	*Tenuitella aculeata* abundant to rare, *Pseudohastigerina micra* rare. *Globigerinatheka index, Subbotina linaperta, Chiloguembelina cubensis.* Large globigerinids as above, small globigerinids as above.
Browns Creek Formation		As above, plus rare "*Globigerina*" cf. *pseudoampliapertura.* Facies with no planktonics; Eocene benthonics.
		BASE CASTLE COVE SECTION
		TOP BROWNS CREEK SECTION
	bryozoal marls "*Turritella*" clays quartz sand-silt 10 m	Spectacular variation in abundance of *Globigerinatheka index, Tenuitella insolita* and *Tenuitella aculeata;* also of turborotaliids (*testarugosa*, occasional *nana*). Sporadic occurrences *Turborotalia increbescens*, "*Globigerina*" cf. *pseudoampliapertura, Pseudohastigerina micra, Chiloguembelina cubensis, Subbotina linaperta, Tenuitella gemma*, small (*praebulloides* group) and large globigerinids (*tripartita* group, *brevis*). One horizon with aragonitic benthonics and abundant small gastropods but no planktonics (except rare steinkerns).
		Base *Tenuitella aculeata*
	bryozoal marls 18 m	*Globigerinatheka index, Subbotina linaperta, Chiloguembelina cubensis, Tenuitella insolita, Tenuitella gemma* (some match *munda*), *Turborotalia testarugosa.* *Pseudohastigerina micra* fluctuates strongly near top. "*Globigerina*" *tripartita* group increases up-section. Assemblages monotonous.
		Top *Hantkenina;* Base "*Globigerina*" *tripartita* group
	shelly "greensand" 2 m "*Turritella*" clays	***Pseudohastigerina micra*** mostly common, some seemingly transitional to *Hantkenina primitiva*, which is sporadic (common to absent). *Subbotina linaperta, Globigerinatheka index, Chiloguembelina cubensis, Turborotalia testarugosa* (occasional *nana*), *Globigerina praebulloides* group, *Tenuitella insolita. Globorotalia cerroazulensis* group extremely rare.
		Base *Tenuitella gemma;* Base *Hantkenina;* Base common/consistent *Pseudohastigerina*
		Top *Tenuitella aculeata*
	"*Turritella*" clays, silts sandy at base 9 m	*Globigerinatheka index, Chiloguembelina cubensis, Turborotalia testarugosa, Turborotalia nana* group, *Tenuitella insolita, Globigerina praebulloides* group. *Subbotina linaperta* less common and consistent than above; *Subbotina* cf. *frontosa* present. *Pseudohastigerina micra* almost absent.
		Base planktonic assemblages
	carbonaceous quartz sand-silt Johanna River Formation	No foraminifera; or agglutinated assemblage (*Bathysiphon, Ammodiscus, Haplophragmoides/Cyclammina*).

numbers of various species fluctuate enormously. (3) Planktonics disappear altogether at one horizon some 10 m below the top of the Browns Creek section and also near the base of the section at Castle Cove; in both cases, Eocene benthonics are present (it may be that the two horizons are the same). *Tenuitella aculeata* and *Pseudohastigerina micra* are the best examples of disjunct ranges; indeed, both species also vary from abundant to absent in the older planktonic assemblages already discussed. Most of this fluctuation occurs in approximately the 10 m at the top of the Browns Creek section, and the temporary, total disappearance of *Globigerinatheka index* below the horizon with no planktonics was taken previously, on inadequate sampling, as top *G. index* (McGowran, 1973a).

Since the Upper Eocene assemblages are clearly extratropical, the correlation of events with the P-zones (Fig. 5) must be tentative. However, to place the *Hantkenina* ingression in the vicinity of the Zone P.15/P.16 boundary (McGowran & others, 1971) and top *Globigerinatheka index* in the vicinity of Zone P.17 (McGowran, 1973a), is not too inconsistent with the evidence from calcareous nannofossils (S. G. Shafik, pers. comm.).

UPPER EOCENE CORRELATIONS, SOUTHERN AUSTRALIA

As noted above, a regressive interval has been detected in several sections in the Gambier Embayment. It ends at the base of the Upper Eocene transgression which must be close to the Middle/Upper Eocene boundary, and must be almost synchronous across to Browns Creek in the east. In the St Vincent Basin, the *Hantkenina* interval is near the base of the Blanche Point Formation, but just below that interval the assemblage lacks both *Hantkenina* and *Tenuitella aculeata*.

The higher regressive phase in the St Vincent Basin, the Chinamans Gully Bed, lies between the *Hantkenina* ingression and the highest records of *Tenuitella aculeata* and *Globigerinatheka index* (Lindsay, 1967, 1969). Within the limits of resolution available, that is where the regressive interval occurs at Browns Creek, and it seems likely that the two horizons are synchronous responses to some eustatic event.

In the Eucla Basin the facies of the Toolinna Limestone extends into the Upper Eocene in South Australia on the evidence of an association of *Globigerinatheka index*, *Subbotina linaperta*, and *Tenuitella gemma* (Lindsay & Harris, 1975). The Wilson Bluff Limestone facies also extends into the Upper Eocene: Quilty (1974b) records an association of *Globigerina gortanii praeturritilina*, *"G"*, cf. *pseudoampliapertura* and *Turborotalia increbescens*. On the south coast of Western Australia, southwest from the Eucla Basin, several studies listed by Quilty (1974b) point to a Late Eocene age. The planktonic assemblage described by Quilty (1969) contains *Globigerinatheka index*, large and small globigerinids, *Subbotina linaperta*, *Pseudohastigerina micra* and others, but not *Hantkenina* or *Tenuitella aculeata*. On negative evidence it may fit within the gap in the recorded range of *T. aculeata*.

Sediments with Upper Eocene planktonic foraminifera were encountered at DSDP Sites 281 and 282, but nothing useful is added thereby to southern Australian biostratigraphy. Jenkins (1975) records, at Site 281, *Subbotina angiporoides/linaperta*, *Globigerinatheka index*, *Turborotalia nana*, *Tenuitella* cf. *insolita*, *Chiloguembelina cubensis;* and at Site 282, *Subbotina angiporoides/linaperta*, *Globigerinatheka index*, *Turborotalia nana*, *Tenuitella gemma*, *Chiloguembelina cubensis*.

TRANS-TASMAN CORRELATIONS, EOCENE

The composite succession of events pieced together from geographically scattered assemblages in southern Australia (Fig. 5 and discussion above) is repeated in Figure 6 for the purpose of comparison with New Zealand. McGowran (1973a) showed that several important events in the Middle and Upper Eocene could be recognized on both sides of the Tasman Sea and concluded that their succession in the same order meant that they were probably synchronous (geologically speaking). Jenkins (1974), on the other hand, tends to emphasize diachronism (see especially his Table 4).

The three successions compared in Figure 6 are 'objective' in the sense that each is independent of the others. The parallelism in consistent order of the following, in particular, would seem to be powerful evidence for synchronism: top *Morozovella caucasica*, top *Planorotalites australiformis*, base *Globigerinatheka index*, base *Tenuitella aculeata*, top *Acarinina primitiva*, top *Acarinina collactea*, top *Tenuitella aculeaa* (N.B. lower top in southern Australia), *Hantkenina* interval (shown only as top), base *'Globigerina' brevis*, top *Globerigerinatheka index*. The only significant differences—among biostratigraphically important taxa—are (1) the upper main segment in the disjunct range of *Tenuitella aculeata* is not known yet in the New Zealand region; (2) *Tenuitella gemma* occurs together with *Hantkenina* in southern Australia (Table 2) but not in New Zealand; (3) *Testacarinata inconspicua* is known only from one or two samples in southern Australia. These differences can be explained in the same way as the fluctuations among species in the Upper Eocene (Table 2), that is, as responses to rapidly shifting watermasses. The evidence indicates pulses which will be virtually synchronous across a region, with abundance fluctuations and disjunct distributions giving either synchronous or allochronous biostratigraphic events rather than the diachronous and untrustworthy patterns suggested by Jenkins for, among others, top *Acarinina primitiva*. And instead of the broadly diachronous Eocene transgression in southern Australia (McGowran, 1973a, b) an allochronous pattern probably is more accurate: a Middle Eocene transgression/ingression in Zones P.13-14, and a more extensive transgression low in Zone P.15.

ZONES AND DATUMS

Figure 7 demonstrates how cluttered southern extratropical biostratigraphic nomenclature in the Eocene has become. There has been some transposing of zonal names; thus *Globigerapsis index*, the nominate species for an Upper Eocene Zone (Carter, 1958; Wade, 1964), was then used in the Middle Eocene (Ludbrook & Lindsay, 1969) as an approximate equivalent of Jenkins's (1966) zone of that name. McGowran (1973a) suggested that the earlier usage was more appropriate. Meanwhile, Jenkins (1974) has erected a set of Subzones in New Zealand, although those proposed for the Upper Eocene are, strictly, alternative units rather than subdivisions of the zones erected previously.

I would suggest now, especially after contemplating Figure 7, that zonal nomenclature really is of rather little and decreasing practical significance. What count are events in the fossil record, be they demonstrably widespread initial appearances or disappearances, or temporary immigrations and ephemeral occupations, or the fossil evidence of stratigraphically isolated marine ingressions (i.e. ephemeral transgressions). It would seem better to concentrate on the further recognition and clarification of the various types of events, on their stratigraphic and historical meaning, and on the attempt to relate them to the standard P-Zones.

A NOTE ON CLIMATIC CHANGE

The overall impression of Late Eocene fossil assemblages is that they indicate warm conditions (McGowran & Wade, 1967). Cockbain (1967) has found *Asterocyclina* in southwestern Western Australia, thus reinforcing this impression which is based on the presence of *Hantkenina*, among the planktonics, but

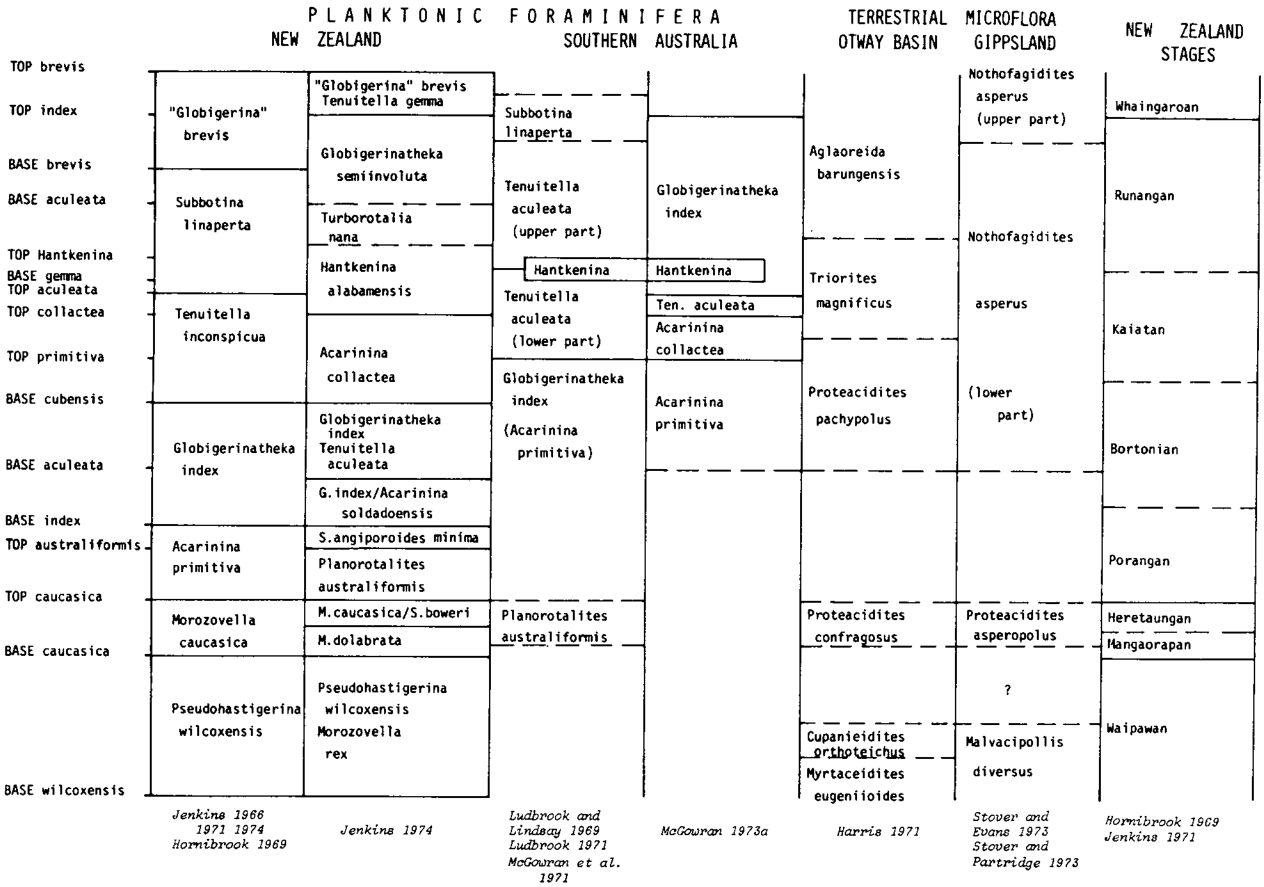

Figure 7. Comparison and correlation of various biostratigraphic systems in southern Australasia, plus New Zealand chronostratigraphy, against defining (foraminiferal) events (at left).

especially on the occurrence of the benthonic genera *Halkyardia* and *Linderina* in the Buccleuch Beds in the Murray Basin (Ludbrook, 1961) and in the Tortachilla Limestone and Port Willunga Beds in the St Vincent Basin (Lindsay, 1967, 1969). At the same time, evidence has accumulated for recognizing major stratigraphic events related in some way to Australia/Antarctica separation (McGowran, 1973b; Falvey, 1974) and for a strongly discontinuous pattern in the planktonic foraminiferal record, as summarized briefly above.

Figure 8 attempts to put an assortment of physical and biological evidence into chronological perspective. The general impression is that there is a strong correlation between changes in the isotope temperature curves and events perceived in the oceanic and continental stratigraphic record:

(1) Paleocene-Early Eocene. The ingressional foraminiferal assemblages in southern Australia tell us very little as yet; more meaningful is the absence of larger foraminifera from the neritic shelf carbonates of the Carnarvon Basin (at a time when they were well established in New Guinea) in contrast to the Middle-Upper Eocene. This contrast has been related to the onset in the interim of seafloor spreading and the first deflection of Antarctic water to the south of Australia (McGowran, in press). The major terrestrial floral change (Harris, 1971) occurs between the *Cupanieidites orthoteichus* and *Proteacidites confragosus* Zones (Fig. 7). This is close to the time, firstly, when sediment accumulation resumed above synchronous hiatuses across the Paleocene/Eocene boundary on the Naturaliste Ridge, Chagos-Laccadive Ridge and Mascarene Plateau in the Indian Ocean, and secondly, when there was a very widespread regression around the northern and eastern margins of the Indian Ocean (McGowran, in press).

(2) Early-Middle Eocene. The sharp decline in isotope temperatures from the Early to the Middle Eocene is reversed at the time of the extratropical flourishing (atypical of morozovellids, as noted above) of *Morozovella caucasica,* and the excursion by *Asterocyclina* to New Zealand. McGowran (in press) has summarized and discussed the correlation (Zones P.10-P.11) of evidence for cooling in the Indian Ocean, including penetration northwards by the extratropical *Acarinina primitiva* and *Planorotalites australiformis,* with the top, throughout the Indian Ocean, of the 'cherty' (opaline silica) carbonates; and this was the time too of the *Guembelitria*-dominated assemblages on the Naturaliste Plateau (Table 1).

(3) Middle-Upper Eocene. The major transgression on the continental margins, seen in southern Australia in the Hampton Sandstone and Toolinna and Wilson Bluff Limestones, seems to be synchronous around the northern-eastern margin of the Indian Ocean and is related in time (upper Zone P.12-P.13) to the excursion southwards by *Discocyclina,* among larger benthonics, and by *Orbulinoides* and *Globorotalia cerroazulensis cocoaensis* among planktonics (McGowran, in press). The temporary warming indicated by the isotope temperature curve is also reflected in the records, in the Bortonian Stage in New Zealand, of *Discocyclina* and of the planktonics *Globorotalia centralis* (?= *cerro-*

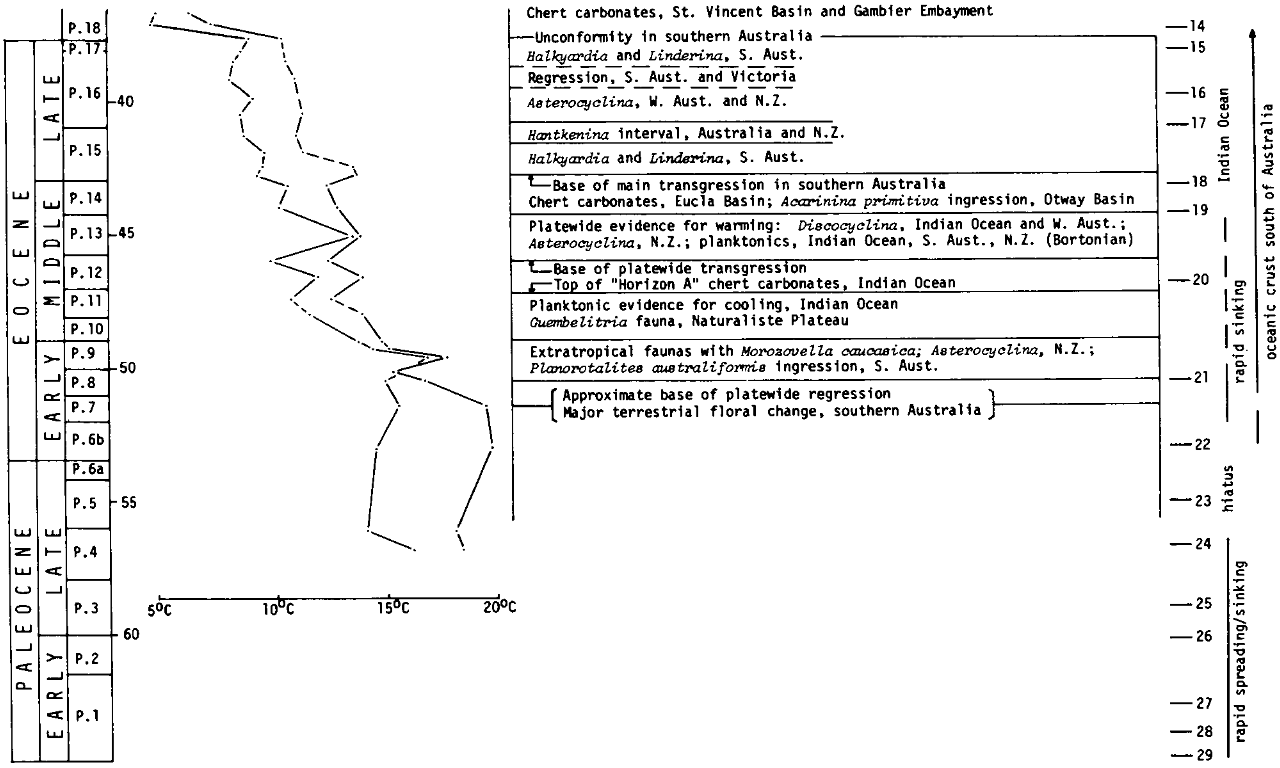

Figure 8. **Comparison of historical data in the southern extratropical region during the early Tertiary. Ages, zones, and millions of years B.P., from Berggren (1972). The palaeotemperature curves are taken from oxygen isotope palaeotemperature curves produced by Shackleton & Kennett (1975, fig. 2, 3, 7) from samples from DSDP Site 277, South Campbell Plateau; the only change has been to redraw the curves against a time scale on the basis of data provided by Jenkins (1975) on planktonic foraminifera (see Fig. 6) with some reference to calcareous nannofossils (A. R. Edwards, in Kennett, Houtz & others, 1975); left curve, deep water record (ca. 1000 metres) based on benthonic foraminifera; right curve, surface water record, based on planktonic foraminifera. Events from present paper and McGowran (in press). Geomagnetic time scale: Anomalies 29 to 14, as rescaled by Sclater & others (1974). Tectonic generalizations for the Indian Ocean: from stratigraphic record on several oceanic structures (McGowran, in press) which seems consistent with seafloor magnetic and other evidence (Sclater & Fisher, 1974; Sclater, von der Borch and others, 1974). Ocean crust south of Australia, after Weissel & Hayes (1972).**

azulensis pomeroli), *Planorotalites pseudoscitula, Hantkenina australis, Truncorotaloides topilensis* and various acarininids. These happenings are concentrated in the interval of upper Zone P.12-Zone P.13, by when oceanic conditions were well established south of Australia; the subsequent accumulations of chert in neritic carbonates in the late Middle Eocene and Early Oligocene are distinctly younger than those in the oceanic sediments in the Indian Ocean.

The isotope temperature curves for the Late Eocene are not under good biostratigraphic control; nor, indeed, are any events in the southern extratropical region at that time. However, the sharp drop in temperature into the Oligocene is preceded and foreshadowed clearly by pulses recorded in the short-lived, if widespread, records in southern Australia and New Zealand of larger foraminifera and planktonic species (*Hantkenina*, the *Globorotalia cerroazulensis* group), in the fluctuations in planktonic assemblages discussed already, and in the probably synchronous regression.

Acknowledgements

The samples on which Table 2 is based were collected during several visits to Browns Creek, but the most comprehensive series was supplied by Mr David Taylor. The samples from DSDP Site 264 (Table 1) were supplied by Dr Larry Frakes. I am grateful to both colleagues.

ADDENDUM

Since this manuscript was completed in November 1975, there have been several developments from which the following are selected.

Hardenbol & Berggren (1976) have made a significant change to the time-scale used here (Berggren, 1972). The traditionally Late Eocene Bortonian Stage contains planktonic microfossils of Middle Eocene type, and the authors propose—correctly, in my opinion—to move the Bartonian into the Middle Eocene rather than take the much more disruptive step of moving Zones P.13 and P.14 into the Late Eocene. The dates given are: Eocene/Oligocene boundary, 37 Ma; Late/Middle Eocene boundary, 40 Ma; older boundaries, unchanged. Thus, the zones in the figures (herein) are compressed in the Late Eocene and expanded in the Middle Eocene. This change intuitively is acceptable, because the sparseness of biostratigraphic events in the standard Late Eocene schemes has never been adequately explained, whereas the compressing of foraminiferal-biostratigraphic and palaeoclimatic events in southern Australia heightens the sense of rapid fluctuation before the great change between the Eocene and the Oligocene.

Kennett & Shackleton (1976) have examined the implications of the sharp drop in oxygen isotope palaeotemperature at the Eocene/Oligocene boundary at

DSDP Site 277 (Shackleton & Kennett, 1975; figure 8, herein). They suggest that it occurred within the earliest Oligocene, being distinctly above the last occurrence of *Globigerinatheka index* (taken as the boundary, as in New Zealand) and *Discoaster saipanensis*. However, this argument goes beyond the current limits of biostratigraphic and chronostratigraphic refinement, although the possibility of using the event in isotope stratigraphy obviously is very important, as is the event itself in Tertiary geohistory and biohistory.

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Conodont faunas from the Mount Frome Limestone (Emsian/Eifelian), New South Wales

by
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The conodont succession in the Mount Frome Limestone is described and illustrated. The faunas indicate an age range of late Emsian to mid-Eifelian for the limestone. Important in correlation are elements of *Eognathodus bipennatus* subsp. A, *Pandorinellina expansa* Uyeno & Mason, *Polygnathus perbonus perbonus* (Philip) and *Polygnathus perbonus* new subsp. D, Perry et al.

INTRODUCTION

The Mount Frome Limestone was recognized to be Devonian in age as long ago as 1878, by Clarke, who reported the occurrence of *Calceola.* Subsequent workers (Carne & Jones, 1919; Game, 1935; David, 1950) considered it to be Silurian. The next to once again consider a Devonian age was Pedder (1964), who referred to 'possible Emsian or Eifelian beds near Mudgee', without indicating any basis for this opinion. Wright (1965) suggested a Mid-Devonian age on the basis of the presence of the corals *Pachyphyllum, Endophyllum* and *Stringophyllum.* In subsequent papers, Wright described a new coral, *Melrosia rosae,* from the limestone (1966) and briefly discussed the relations (1968), concluding that it was of a 'Middle Devonian age, perhaps more of Givetian aspect than Eifelian'. This age was based on fairly provisional identifications of corals and a single species of brachiopod. At the same time, Philip & Pedder (1968) reached an essentially similar conclusion concerning the age of the limestone, quoting a much greater number of corals and the conodont *Spathognathodus bipennatus* Bischoff & Ziegler. They considered the corals fairly inconclusive, but pointed out that the conodont implied an early Givetian age.

Later, Wright (1969) presented much more comprehensive faunal lists for the limestone than were previously available, indicating a succession of six coral faunas, all of which he considered of Givetian age. During a review of Mid-Devonian stratigraphy, the present author (Pickett, 1972) compared these assemblages with the biostratigraphic succession of Philip & Pedder (1967), suggesting that the greatest similarities lay with their fauna G, of early Eifelian age, the fauna of the Loomberah and Sulcor Limestones. Yields from conodont samples taken in connection with the review were disappointingly low, but suggested that the limestone was at least in part Emsian. Consequently, in the correlation table accompanying the review, the limestone was shown as spanning the Emsian/Eifelian boundary. This placement is supported by the present evidence, taken from a second set of conodont samples collected subsequent to publication of the review.

Recently, Philip (1974) recorded from Mount Frome a number of conodont species whose occurrence had not been noted previously. These include *'Polygnathus' costatus patulus* Klapper, late forms of *Polygnathus perbonus* (Philip), *'Spathognathodus' exiguus* Philip subsp. nov. (? = *Pandorinellina expansa* Uyeno & Mason), and *'Spathognathodus' bipennatus* Bischoff & Ziegler subsp. nov. No polygnathan elements were recovered from samples from the upper part of the limestone during the present study; however, the presence of *'P.' costatus patulus* would not conflict with the present observations.

STRATIGRAPHY

The Mount Frome Limestone crops out on the western and southern flanks of Mount Frome, east of Mudgee. The base of the formation is nowhere exposed, as the lowest beds are covered with alluvium. On the southern side the limestone is truncated by a concealed fault coincident with the course of the Cudgegong River. Conformably overlying the limestone is the sandy Boogledie Formation, from which Wright reports a variety of marine fossils, though it is unclear from which area of outcrop they were obtained. This may be important, as the age of the limestone at Mount Knowles, at present included within the Boogledie Formation, is Emsian (Pickett, 1972) and not Givetian as previously thought. A probable slight angular unconformity separates the Boogledie Formation and the overlying Buckeroo Conglomerate, the basal formation of the Late Devonian Lambie Group in this area.

AGE OF THE CONODONT FAUNAS

The distribution of discrete and multi-element species through the limestone is shown in Table 1; Figure 1 gives the levels from which the samples were taken. The limestone of samples C071 and C072, which yielded no identifiable conodonts, showed isolated patches of clear calcite in the dark grey limestone. These patches were very similar to the birdseye structure generally considered characteristic of subaerial episodes in limestone deposition. Their shape was less lensoidal than that of typical birdseye sructures, and they were transparent rather than white. Their presence, coupled with the absence of conodonts from these samples, does suggest that there may have been a period of supratidal deposition during latest Emsian time.

In general, the succession of conodont faunas is very similar to that described by Uyeno (McGregor & Uyeno, 1972) from Bathurst Island in Arctic Canada. Of particular importance is the presence of the distinctive *Pandorinellina expansa* Uyeno & Mason. This species occurs near the top of the Stuart Bay Formation, a level which Uyeno considers topmost Emsian in age. Its probable range is given by Uyeno & Mason (1975, fig. 2) as late Emsian to mid-Eifelian. In Uyeno's (McGregor & Uyeno, 1972) samples, how-

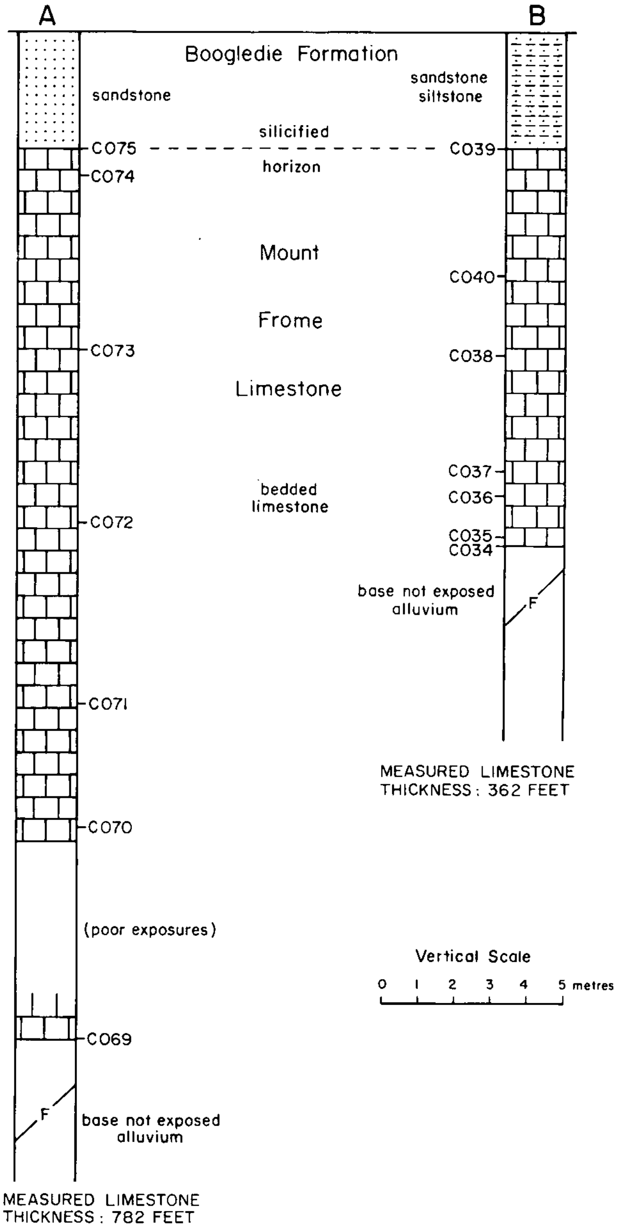

Figure 1. Stratigraphic sections, Mount Frome Limestone, showing positions of samples. Section A was measured on the western flank of Mount Frome, Section B on the southern side, west of Melrose homestead.

ever, the first specimens of *'Spathognathodus'* cf. *bipennatus* do not appear until well into the Blue Fiord Formation, near the top of the Eifelian, whereas these elements occur together at Mount Frome in sample C074, which marks the first appearance for each of them, although their appearances are separated by 760 m of strata at Bathurst Island.

The specimens of this latter spathognathodontan element described here are not considered closely similar to the single specimen from the late Eifelian kalkige Zwischenschichten (Bischoff & Ziegler, 1957) described as *'Spathognathodus' cf. bipennatus;* instead, they are compared with Uyeno's material from the Blue Fiord Formation and the Belgian material of Bultynck (1970) from the Assize de Couvin. The oldest specimens in the Belgian section occur in the sub-division Co2bV, which Bultynck correlates with the base of the Günteröder Kalk, i.e. mid-Eifelian or early mid-Eifelian (Carls et al., 1972, fig. 7). The report of *Sp. bipennatus* by Scheibe (1966) is probably a little older (early Eifelian), placing a lower limit on the age of the faunas of samples C074 and C075.

On the other hand, the O_1 and P elements here referred to *Pandorinellina expansa* and illustrated by Uyeno (McGregor & Uyeno, 1972) were considered by Uyeno to be topmost Emsian in age, since the O_1 element occurred together with *'Polygnathus' foveolatus.* This latter association is not represented in the present faunas, so it seems probable that *Pandorinellina expansa* ranges into the Eifelian, and that the Emsian/Eifelian boundary lies between samples C073 and C074.

The faunas from the lower part of the Mount Frome Limestone (C069, C070) are typical of the late Emsian, with their abundance of *'Polygnathus' foveolatus, 'Spathognathodus' exiguus* and *'Ozarkodina' denckmanni.* This fauna, reported by Uyeno (McGregor & Uyeno, 1972) from 60 m and more below the top of the Stuart Bay Formation, was described by Klapper (1969) from 60-120 m above the base of the Blue Fiord Formation on Devon Island, so these formations must be strongly diachronous.

This fauna is still present in sample C073, which is taken as Emsian, the faunal break occurring between samples C073 and C074.

In terms of the informal conodont units put forward by Perry et al. (1974, p. 1062), the present faunas represent the units of *Polygnathus perbonus perbonus, P. perbonus* new subsp. D, and *P. costatus costatus,* the second of these being represented only by sample C073.

SYSTEMATIC PALAEONTOLOGY

Family **POLYGNATHIDAE**

Eognathodus bipennatus subsp. A.

Plate 2, figs. 4-17

1966 *Spathognathodus* cf. *bipennatus* Bischoff & Ziegler; Bultynck, B202, pl. 2, figs. 4-8.

1968 *Spathognathodus* cf. *bipennatus* Bischoff & Ziegler; Godefroid, pls. 3, 7.

1970 *Spathognathodus* cf. *bipennatus* Bischoff & Ziegler; Bultynck, p. 134, pl. 18, fig. 9; pl. 19, figs. 1-5.

1972 *Spathognathodus* cf. *bipennatus* Bischoff & Ziegler *sensu* Bultynck (1970); McGregor & Uyeno, p. 16, pl. 5, figs. 24-27.

1974 *Eognathodus bipennatus* (Bischoff & Ziegler); Perry et al., p. 1084, pl. 6, figs. 14, 15.

Description: The most characteristic element of this species is the P element, which is spathognathodontan with 3 to 5 slightly higher denticles anteriorly, these being replaced in the central part of the blade by two parallel, non-denticulate ridges. These are replaced in turn by transverse ridges formed of fused denticles (about 6 pairs), gradually tapering to the end. In lateral view the unit is highest anteriorly, where the denticles show distinctly; it is then smooth and horizontal in the mid-section, turning downwards markedly in the posterior quarter. The aboral margin is straight, sometimes a little curved aborally at the posterior. The whole unit is slightly curved. The basal cavity expands to form prominent, rounded, slightly asymmetrical

	C069	C070	C071	C072	C073	C074	C075	C034	C035	C036	C037	C038	C040	C039
Ozarkodina sp.														
P element	426	15			2									
O$_1$ element	(51)	(6)			(1)							(1)		
N element	-	-			(2)									
A$_1$ element	(27)	(8)			(5)									
A$_2$ element	-	-			2									
A$_3$ element	2	1			-				2					
Pandorinellina expansa Uyeno & Mason														
P element						87								
O$_1$ element						4								
N element						1								
A$_1$ element						(19)								
A$_2$ element						-								
A$_3$ element						-								
Eognathodus bipennatus (Bischoff & Ziegler) subsp. A														
P element						43	12							
O$_1$ element						3	-							
N element						1	1							
A$_1$ element						(19)	4							
A$_2$ element						-	-							
A$_3$ element						-	-							
Polygnathus perbonus (Philip), late form														
P element	35	2			1									
O$_1$ element	(51)	(6)			(1)							(1)		
N element	17	-			(2)									
A$_1$ element	(27)	(8)			(5)									
A$_2$ element	1	-			-					1				
A$_3$ element	-	-			-									
Polygnathus perbonus subsp. D Perry et al.														
P element					31									
O$_1$ element					(1)									
N element					(2)									
A$_1$ element					(5)									
A$_2$ element					-									
A$_3$ element					-									
"Lonchodina" sp.	18	4			1				1					
"Belodella" devonica Stauffer	75	10			6		3		1					
"Ozarkodina" media Walliser	2													
"Drepanodus" sp.					3							1		
"Panderodus" spp.	912	46			7		38					16	1	
"Spathognathodus" sp.										1		1		

Figure 2. Distribution of conodonts in samples from Mount Frome Limestone. The figures in brackets are those which appear twice, because they cannot be unequivocally assigned to one multi-element species.

lobes, the external one slightly larger, which lie near the mid-point of the unit.

The O$_1$ element is a stout form of *'Ozarkodina denckmanni'*, which is too poorly preserved in the present fauna for detailed description. The N element is represented by a single poorly preserved specimen. Similarly, a single hindeodellan unit is differentiable as the probable A$_1$ element of this species; it is chiefly characterized by a very short anterior bar. A$_2$ and A$_3$ elements have not been identified, so the species is referred with reservation to *Eognathodus*.

Remarks: 'Spathognathodus' bipennatus was originally described from the mid-Givetian *Sparganophyllum*-Kalk (Ostrheinisches Schiefergebirge); a single specimen referred to *'Sp.'* cf. *bipennatus* was described from the late Eifelian kalkige Zwischenschichten (Bischoff & Ziegler, 1957). I am not satisfied that the forms here described and those included in the synonymy are conspecific with *'Sp.'* cf. *bipennatus* of Bischoff & Ziegler (1957, p. 116, pl. 6, figs. 7a, b).

The Australian specimens so far referred to *bipennatus* (Philip, 1967; Pedder et al., 1970a) are more closely similar to this specimen than to those here described, or to the holotype of *'Sp.' bipennatus* figured by Bischoff & Ziegler (1957, pl. 21, figs. 31a-c), as more of them show the median groove and smooth ridges so characteristic of the Australian, Belgian, and Canadian specimens. The figured holotoype appears to have smooth ridges near the middle, and two distinct rows of denticles posteriorly. This feature marks it off from all other material so far described. The specimen figured by Ziegler (1965, pl. 1, figs. 11a-c) shows two fully denticulate ridges separated by a pronounced median groove. This species is probably the 'new and slender subspecies of *"Spathognathodus" bipennatus*' mentioned by Philip (1974, p. 305).

The presence of smooth ridges on the oral surface is a characteristic already well established in the P element of *Eognathodus sulcatus* Philip figured by Klapper (1969, pl. 3), so that it seems entirely reasonable to refer the present forms to this genus as suggested by Perry et al. (1974).

Ozarkodina sp.

Plate 1, figs. 8-16, 26-27

1966 *Spathognathodus exiguus* Philip, p. 449, pl. 3, figs. 26-37; text-fig. 7 (P element).

1969 *Spathognathodus exiguus* Philip; Klapper, p. 16, pl. 5, figs. 1-7.

1970b *Spathognathodus steinhornensis exiguus* Philip; Pedder et al., p. 217, pl. 38, fig. 13.

1971 *Spathognathodus exiguus* Philip; Fahraeus, p. 678, pl. 77, figs. 25-30, 32.

1972 *Spathognathodus exiguus* Philip; McGregor & Uyeno, p. 13, pl. 5, figs. 17, 18.

1974 *Pandorinellina exigua exigua* (Philip); Perry et al., p. 1086, pl. 6, figs. 12, 13.

Remarks: The presence of this species in the Mount Frome faunas can only be detected by its P element. Not all the other elements can be positively identified, despite the fact that sample C069 yielded over 400 specimens of the P element.

There is a certain amount of variation in the basal cavity within the populations. Some specimens (e.g. that illustrated in Pl. 1, fig. 9) display a condition approximating to that of the P unit of *P. expansa* from younger samples, while others are more constricted posteriorly (Pl. 1, fig. 11). The population from sample C070 is quite variable. All specimens are similar in their general morphology: the hindmost of the anterior set of denticles is the highest; the whole set is slightly displaced to the right, regardless of the left or righhanded nature of the specimen; the lateral profile is similar. In the form of the basal cavity, however, the specimens differ among themselves, and differ from those of sample C069. The cavity may be sharply demarcated behind and before (Pl. 1, fig. 15), or its internal side may begin somewhat in front of the other, inflected aborally at the same time. The basal cavity of the specimens from C070 thus seems closer to that of *'Sp.' exiguus philipi* (Klapper, 1969, p. 17) than does that of the nominate subspecies, but this would imply a reversal of the trend described by Klapper for these species. Figures of the basal cavity of *philipi* and the Prongs Creek Formation specimens of Perry et al. (1974, pl. 6, figs. 12, 13) are not available, so that for the present no taxonomic separation of these elements can be considered. Some specimens from sample C070 are much larger than those from the older sample, reaching a length of 1.6 mm, whereas those from C069 virtually never exceed 0.9 mm. The larger specimens from the younger horizon show a tendency for the denticles to develop as a double row, although the row is quite single in smaller specimens, and the proportions and other characteristics are the same.

The spathognathodontan elements from C073 are very fragmentary; there is, however, a notch behind the anterior denticles, and the basal cavity is similar to that shown in Plate 1, fig. 15.

The replacement of the trichonodellan A_3 element of *Ozarkodina* by the diplododellan A_3 element of *Pandorinellina* is considered to have occurred with *P. optima* (Moskalenko) (Klapper & Philip, 1972); thus Perry et al. (1974) referred the P element *'Spathognathodus' exiguus exiguus* to *Pandorinellina.* No diplododellan elements have been recovered from any of the samples examined in this study; in assemblages with *Pandorinellina* and *Polygnathus* the trichonodellan elements would remain unassigned, and it is chiefly for this reason that the apparatus is referred to *Ozarkodina.* In distinguishing between the two genera it is significant that the beautifully preserved 'holotype' of *Ozarkodina steinhornensis* (Ziegler) figured by Mashkova (1972) includes no A_3 element at all, bringing it closer to the Carboniferous genera *Scottognathus* and *Lewistownella.*

Pandorinellina expansa Uyeno & Mason

Plate 1, figs. 1-7

1972 *Ozarkodina* n. sp. A, McGregor & Uyeno, p. 13, pl. 5, figs. 4, 5 (O_1 element).

1972 *Spathognathodus* n. sp. A, McGregor & Uyeno, p. 13, pl. 5, figs. 19-21, 30-32 (P element).

1974 *Pandorinellina exigua* n. subsp. A, Perry et al., p. 1087, pl. 6, figs. 1-8.

1975 *Pandorinellina expansa* Uyeno & Mason, p. 718, pl. 1, figs. 6, 9, 11-19.

Description: The P element is spathognathodontan, straight, with the 4-5 anterior denticles markedly higher than the rest, the hindmost of these being the highest. There may be some fusion of these denticles and they are always laterally compressed. The remainder of the blade consists of 7-10 denticles forming a slightly arched row, whose highest point is near the middle of the whole unit or slightly posterior of it. In lateral view the aboral margin of the blade rises anteriorly below the high anterior denticles; behind the lowest point, which is immediately below the highest denticle, the margin is inflected upwards and then continues nearly horizontally to the rear of the unit. This inflection demarcates the most characteristic feature of the unit, which is its very expanded basal cavity. This expansion begins at the lowest part of the unit, reaches its maximum below the highest part of the lower row of denticles, and tapers away gradually towards the rear. There is no pronounced asymmetry, though the basal cavity is usually a little more expanded externally.

The O_1 element is equally distinctive, ozarkodinan with a very long apical denticle, which is curved backwards to continue the line of the apices of the anterior denticles, of which there may be 8, the last two fused with the apical denticle. The area behind the cusp is deeply embayed and quite smooth, with only 1 or 2 very small denticles at the end of the unit. The tip of the cusp projects beyond the end of the base of the unit. The basal cavity is a narrow groove anteriorly, widening under the cusp and tapering gradually to the posterior end.

A high slender cusp characterizes the N element. The A_1 elements are poorly preserved and not distinctive, but the A_2 element can be recognized by a straight but downturned anterior section bearing about 8 denticles, smaller than those on the posterior section. No A_3 elements were recovered.

Remarks: The occurrence of this species in areas as widely separated as Bathurst Island (Arctic Canada) (McGregor & Uyeno, 1972) and eastern Australia is striking. It has been found in Alaska and Nevada (Uyeno & Mason, 1975; Perry et al., 1974).

Polygnathus perbonus perbonus (Philip, 1966), late form

Plate 1, fig. 17-22

1956 *Polygnathus linguiformis* Hinde; Ziegler, p. 103, pl. 7, figs. 11, 12, 19, 20.

?1962 *Polygnathus linguiformis* Hinde; Walliser, p. 284, fig. 1, No. 38.

1967 *Polygnathus linguiformis linguiformis* Hinde; Philip & Jackson, p. 1264, figs. 2b, 2c.
?1968 *Polygnathus linguiformis* Hinde; Schulze, p. 214, pl. 19, fig. 11 (probably in part only).
1969 *Polygnathus foveolatus* Philip & Jackson; Klapper, p. 13, pl. 6, figs. 19-30.
non 1969 *Hibbardella perbona* (Philip); Flood, p. 7, pl. 21, figs. 1, 2 (A_3 element associated with *"Polygnathus" dehiscens* Philip & Jackson).
1970b *Polygnathus linguiformis linguiformis* Hinde; Pedder et al., p. 216, pl. 40, figs. 9, 10.
1970 *Polygnathus linguiformis foveolatus* Philip & Jackson; Pedder et al., p. 216, pl. 40, fig. 7.
1972 *Polygnathus foveolatus* Philip & Jackson; McGregor & Uyeno, p. 13, pl. 5, figs. 13, 14.
1974 *Polygnathus perbonus perbonus* (Philip) (late form); Perry et al., p. 1089 (*partim*), pl. 8, figs. 1-8.

Remarks: The Mount Frome specimens of the P element are characterized by a marked angulation of the outer posterior portion of the platform, which, however, does not result in the truncated appearance of the next subspecies. The internal and external parts of the platform are of approximately the same height, further marking it off from subspecies D, in which the outer part of the platform is very high in front of the angulation.

The A_3 element, which gives the species its name, was not recovered from any of the present samples.

Polygnathus perbonus new subsp. D, Perry et al. 1974

Plate 1, figs. 23-25; plate 2, fig. 18

1967 *Polygnathus linguiformis linguiformis* Hinde; Philip & Jackson, p. 1264, figs. 2a, 3c(?).
1970b *Polygnathus linguiformis linguiformis* Hinde; Pedder et al., p. 216, pl. 40, figs. 6, 8.
1974 *Polygnathus perbonus* new subsp. D, Perry et al., p. 1089, pl. 8, figs. 9-13, 15, 16.

Remarks: Only the P element of this subspecies has been positively identified. It is distinguished by the extreme inflection of the posterior part of the unit, the angulation at the outer margin coming close to 90°, producing a truncated appearance. In front of the angulation the outer part of the platform is markedly higher than the opposite side. This results in a close similarity in oral aspect to *'P.' linguiformis* forma γ of Bultynck (1970), or the forms from the Moore Creek Limestone referred to *'P.' linguiformis* by Philip (1967), but the nature of the basal cavity and the position of the pit are critical in assigning the unit. The inequilateral development of the margins of the pit is not as great in the present specimens as it is in some of the material figured by Perry et al., in which the protuberance on the outer side may extend as far as the outer margin (1974, pl. 8, fig. 12).

Acknowledgements

The author is particularly indebted to T. T. Uyeno for discussion of the material, and for making available information published subsequent to preparation of this article (Uyeno & Mason, 1975). Permission to publish was granted by the Under Secretary, New South Wales Department of Mines.

Specimen numbers prefixed by the letters MMMC refer to the microfossil collection of the Geological Survey of New South Wales, and are housed in the Geological and Mining Museum, Sydney.

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NOTE

Since this article went to press an important work (Telford, 1975) on conodonts of similar age from eastern Australia has appeared. Importantly, the specimens from sample C070 discussed under *Ozarkodina* sp., and bearing a double row of denticles (Pl. 1, fig. 16 herein), are referable to Telford's species *'Spathognathodus' palethorpei.* The elements designated by Telford as *Spathognathodus* new sp. A are herein referred to *Pandorinellina expansa* Uyeno & Mason. These two forms are index species for Telford's *Spathognathodus* new sp. fauna and his *foveolatus-palethorpei* fauna. Their occurrence at Mount Frome is inverted with respect to that described from North Queensland. Further, *Polygnathus foveolatus serotinus* Telford (= *Polygnathus perbonus* new subsp. D, Perry et al., herein), a characteristic species of the *foveolatus-palethorpei* fauna, occurs between the two, but still below *Pandorinellina expansa.* The concept of *P. foveolatus* presented by Telford is the same as that of the late form of *P. perbonus* described by Perry et al. (1974). The evidence of Perry et al. places the *foveolatus-palethorpei* fauna at the very top of the Emsian.

The ages suggested by Telford are older than a comparison with the American successions described by McGregor & Uyeno (1972) and Perry et al. (1974) indicates. In assigning ages to his faunas, Telford seems to have been influenced by the similarity of his subspecies *serotinus* to the species *foveolatus* Philip & Jackson. It is significant that, in all the sections examined by Telford, there is a gap in the conodont succession above the *exiguus* fauna, covering the interval in which *Polygnathus* first appears. This gap is greater than recognized by Telford.

A more recent article by Snigireva (1975) introduces the name *totensis* for specimens plainly conspecific with *serotinus* Telford. Snigireva's specimens come from the 'middle Devonian', eastern slope of the northern and polar Urals. The holotype is from the zone of *Conchidiella pseudobaschkirica.* Regrettably, precise indications of which species were obtained from the individual samples are lacking, but as far as can be determined from the 'assemblages' indicated by Snigireva, the zones of *Favosites regularissimus* and *Conchidiella pseudobaschkirica* would both have to be considered Emsian rather than Eifelian, on conodont evidence.

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PLATE 1

All figures x40

Pandorinellina expansa Uyeno & Mason

Figs.	
1, 2	P element, lateral and oral views, MMMC 00870, C074
3	P element, aboral view, MMMC 00896, C074
4	O_1 element, lateral view, MMMC 00871, C074
5	N element, MMMC 00872, C074
6	A_1 element, MMMC 00873, C074
7	A_2 element, MMMC 00874, C074

Ozarkodina sp.

8, 9, 10	P element, lateral, aboral and oral views, MMMC 0085, C069
11	P element, aboral view, MMMC 00886, C069
12	O_1 element, MMMC 00888, C069
13	N element, MMMC 00889, C069
14	A_3 element, MMMC 00891, C069
15	P element, aboral view, MMMC 00884, C070
16	P element, oral view showing broadening of denticles, MMMC00883, C070
26, 27	Lateral and aboral views of P element doubtfully referred to this species, MMMC 00899, C070

Polygnathus perbonus perbonus (Philip), late form

17, 18	P element, oblique and aboral views, MMMC 00859, C069
19	O_1 element, MMMC 00860, C069
20	N element, MMMC 00863, C069
21	A_1 element, MMMC 00862, C069
22	A_2 element, MMMC 00861, C069

Polygnathus perbonus subsp. D, Perry et al.

23, 24	P element, oblique and oral views, MMMC 00866, C073
25	P element, aboral view, MMMC 00867, C073

"Belodella" devonica Stauffer

28, 29, 30	Various morphological types, MMMC 00895, 00896, 00894 respectively, all from C069

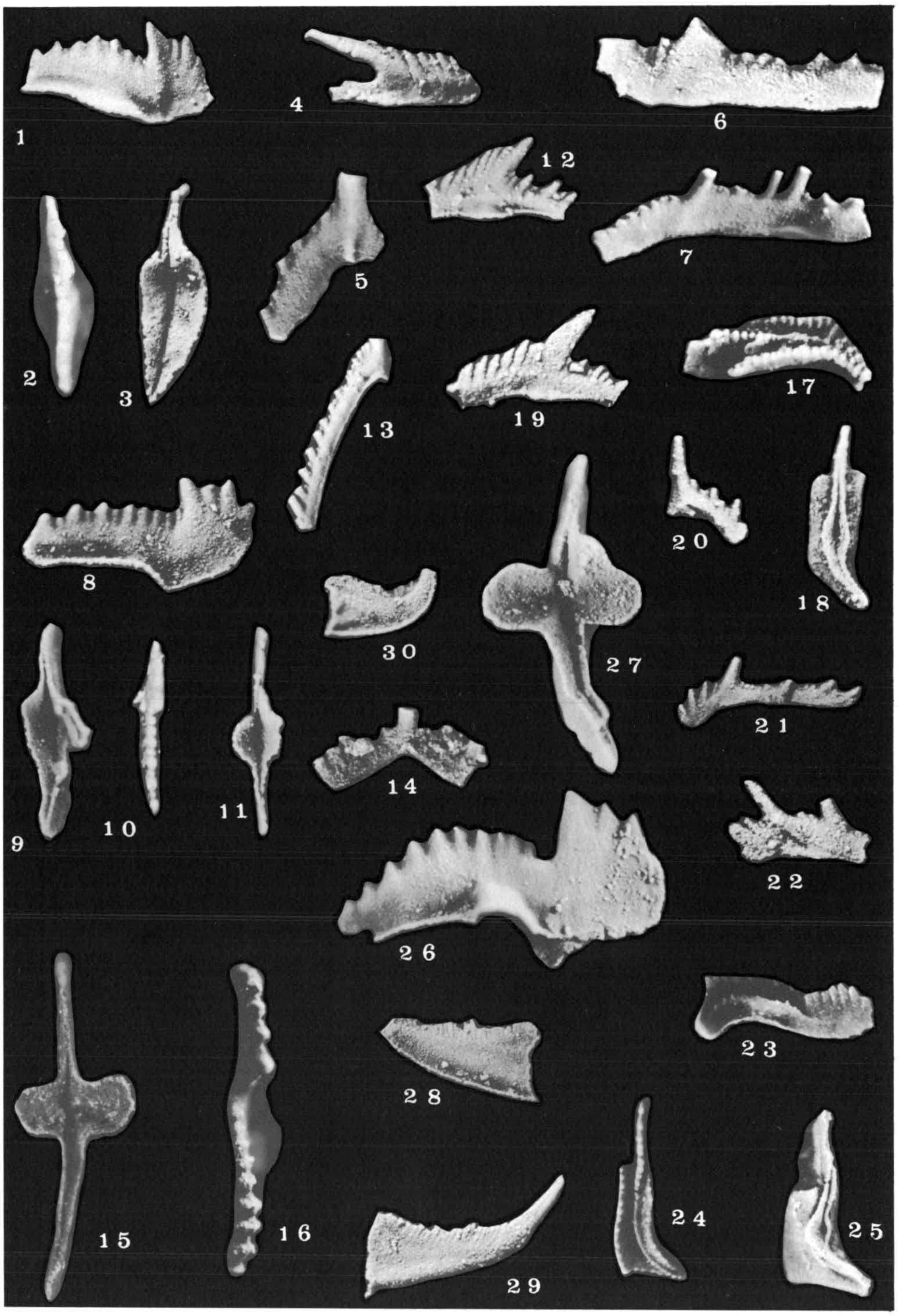
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PLATE 2

All figures x40

"Lonchodina" sp.

Figs.

1 Lateral view, MMMC 00868, C069

"Ozarkodina" media Walliser

2 Lateral view, MMMC 00896, C069

"Drepanodus" sp.

3 Lateral view, MMMC 00897, C073

Eognathodus bipennatus (Bischoff & Ziegler)

4, 5 P element, lateral and oral views, MMMC 00875, C074

6, 7 P element, lateral and oral views, MMMC 00881, C075

8, 9, 10 P element, lateral, aboral and oral views, MMMC 00882, C075

11, 12, 13 P element, internal lateral, external lateral, and oral views, MMMC 00876, C074

14 P element, oral view, MMMC 00877, C074

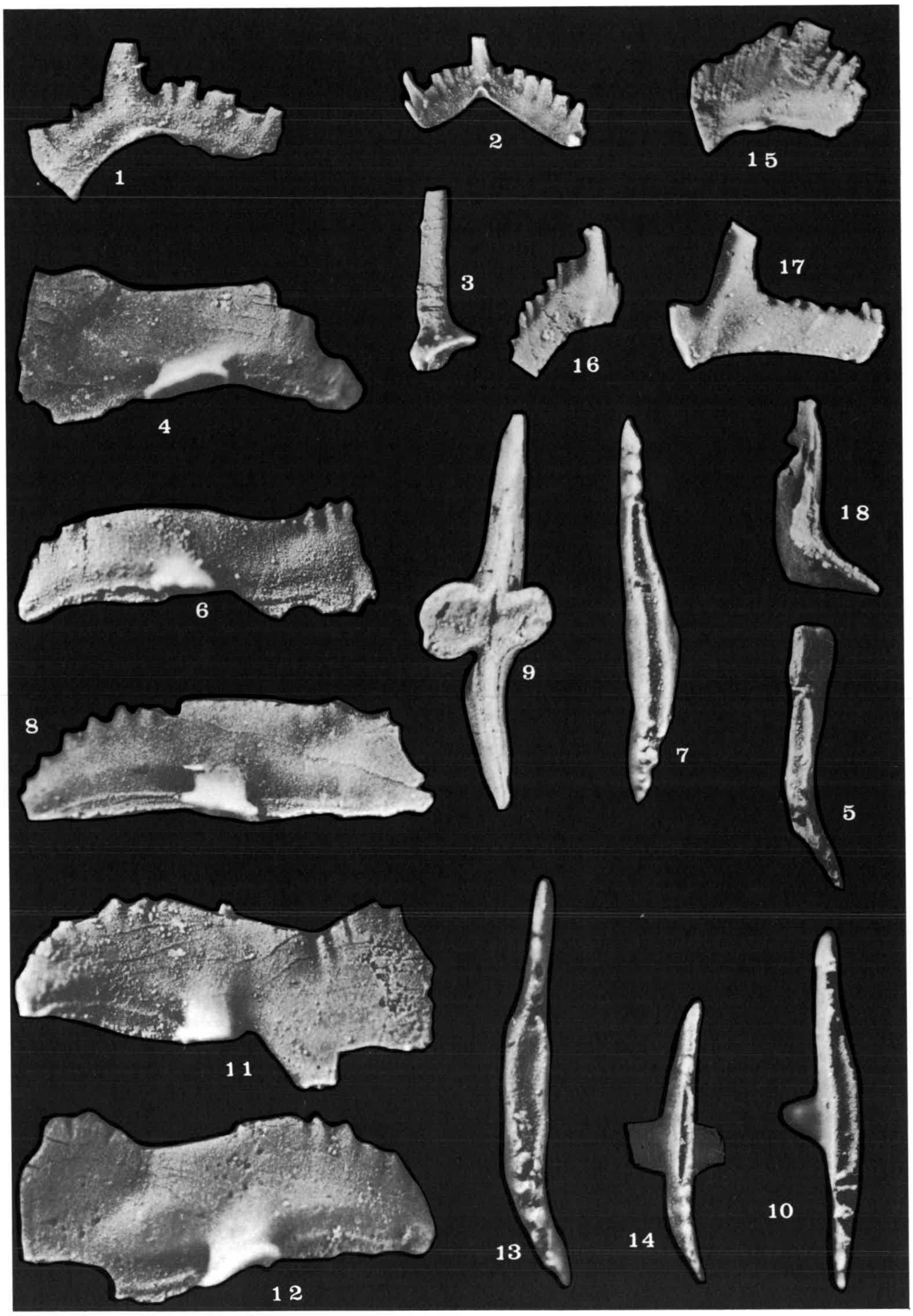
15 O_1 element, MMMC 00878, C074

16 N element, MMMC 00880, C074

17 A_1 element, MMMC 00880, C074

Polygnathus perbonus subsp. D, Perry et al.

18 P element, aboral view, MMMC 00900, C073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The Late Cretaceous-Tertiary section in Challenger No. 1 (Perth Basin)—details and implications

by

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Incorporated are the palaeontological and stratigraphical results of examination of three wells offshore from Perth: Challenger No. 1, Bouvard No. 1 (both WAPET 1975 oil explorations wells), and the Rottnest Island Bore (1913 water exploration well). Challenger No. 1 and the Rottnest Island Bore both contain significant Upper Cretaceous and/or Cainozoic sections which lead to the recognition of previously unknown episodes in the history of the area.

Challenger No. 1 contains Upper Miocene and Upper Eocene sections (both previously unrecorded from the Perth area) and a continuous Upper Paleocene (P.4) to Lower Eocene (P.6b) section of a carbonate facies not recorded from the Perth Basin previously. Upper Santonian sediments in this bore are the first offshore record of equivalents of the Gingin Chalk.

Re-examination of the Rottnest Island Bore shows that what has usually been referred to the Kings Park Formation should not be referred to that unit as it formed during a distinct brief episode of Middle Eocene sedimentation. The "Rottnest Sandstone" is probably Late Miocene or younger and is a yellow to red calcarenite which is herein defined as the Rottnest Formation.

Range charts of foraminifera and some calcareous nannoplankton are included and systematic comments are made on several foraminifera. Several important index species of planktic foraminifera are recorded for the first time from the Perth area.

INTRODUCTION

In late 1974, and early 1975, West Australian Petroleum Pty Ltd (WAPET) drilled two wells in the offshore Perth Basin, both of which have helped greatly in elucidating the distribution of Upper Cretaceous and Cainozoic sediments in the offshore Perth area. The first of the two wells—Bouvard No. 1—was drilled at latitude 32°31.5′S, longitude 115°15.2′E (Fig. 1). It penetrated no Cainozoic section apart from some thin unidentified surface sediment, and helps greatly in controlling the eastern margin of the Upper Cretaceous-Cainozoic sediment wedge. The other well—Challenger No. 1—was drilled at latitude 32°25.3′S, longitude 115°00.8′E. It bottomed at 2250 m in the Late Jurassic (Filatoff, Quilty, & Williams, 1975). Water depth is 197 m and the rotary table (R.T.) was 15 m above sea level. Most of the comments in this paper are based on examination of material from Challenger No. 1.

The Tertiary section in the well is totally different from that encountered anywhere in the Perth Basin to date and it was considered that it would be a of great interest to those concerned with the Tertiary, even though sample control in the well is not as good as would be desirable. Upper Miocene, Upper Eocene, and Upper Santonian beds and a carbonate facies equivalent to the Upper Paleocene to Lower Eocene Kings Park Formation are previously unknown in the Perth area.

Samples

The material studied consists of ditch cuttings samples taken at 15 m intervals. These consist of rock fragments broken from the rock by the drill bit and collected by sieving from the drilling mud. Ditch cuttings samples often contain downhole contamination, but in Challenger No. 1 there seems to be little mixing of faunas. Processing is by a simple H_2O_2 disintegration technique.

The uppermost sample in the well is from the interval 455-470 m which is 440 m below sea level and 268 m below the seabed.

Logs

In the interval studied (455-770 m), Induction Electric (IES) and Borehole Compensated Sonic Gamma Ray (BSGR) logs were run. The section is dominantly carbonate so the BSGR was chosen to form the basis for the summary diagram (Fig. 2a) as the sonic velocity curve is very sensitive to variations in cementation in carbonates.

Time scale

Quilty (1974b) showed that Blow's (1969, and see also Berggren, 1972) warm-water foraminiferal zonation of the Cainozoic is applicable to Perth Basin sediments where known. In the new section studied, parts of the Cainozoic not previously documented from the Perth Basin are shown to be present. Faunas present indicate that Blow's zonation is applicable, and it is followed throughout.

Acknowledgements

I am grateful to the management of WAPET for permission to publish this work. At WAPET, Miss K. Longman has been responsible for typing and Mr Wayne Copley for the SEM photography and nannoplankton identifications. M. H. Johnstone and D. C. Lowry criticised the manuscript and made many valuable suggestions for improvement.

I thank Drs V. Scheibnerová and D. Belford for the invitation to participate in this tribute to Dr Crespin, whose studies on Western Australian material laid the foundation on which all later workers have relied.

Material from the Rottnest Island Bore was obtained through the efforts of the staff of the Geological Survey of Western Australia, particularly Mr J. H. Lord,

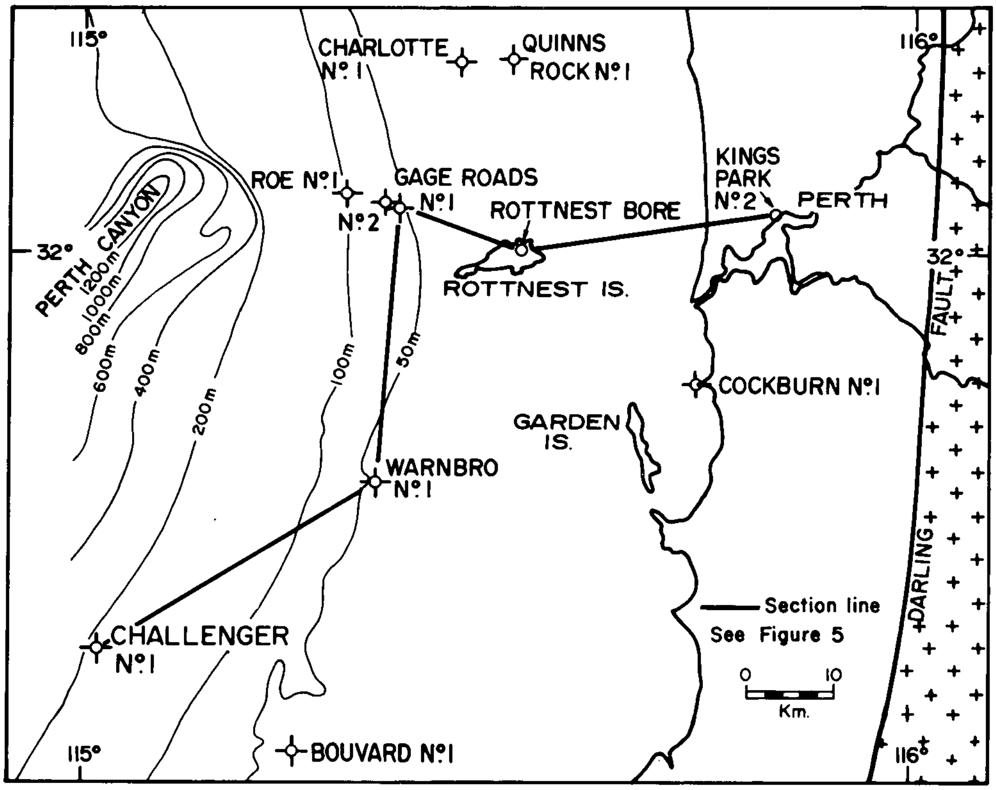

Figure 1. Locality map

Director and Dr A. E. Cockbain and Mr J. Backhouse. Discussion with Drs B. McGowran and A. Partridge prompted re-examination of the Rottnest Island Bore material.

SUBDIVISION OF THE SECTION IN CHALLENGER No. 1

The lithology and age given below are also summarised in Figure 2. This information is based mainly on wellsite examination of cuttings samples by WAPET geologists, Mr T. Barr and Dr D. S. Broad, supplemented by my own office examination of representative samples from the same section.

INTERVAL 465-530 m—LATE MIOCENE, UNNAMED FORMATION

This interval seems to be one of continuous Late Miocene sedimentation but can be divided into two subunits on a lithological basis.

Lithology

1. 465-498 m: White, uniform-grained chalk with minor pale brown chert and traces of glauconite. Muscovite is present as fine-grained flakes in the upper part of the interval. Foraminifera are abundant and quite well preserved. It is not known whether the chert is in the form of isolated nodules or as more or less continuous beds, but the high-velocity peaks on the Sonic Velocity Log would suggest that the chert is in large masses above 472 m.
2. 498-530 m: White friable calcarenite composed dominantly of foraminifera. Pale pink chert is abundant, making up 60-90% of the cuttings seen, although this figure probably errs on the high side as finer calcareous material may be lost during sample recovery. Above 518 m, chert is probably present as small discontinuous masses as there are no high-velocity peaks on the Sonic Velocity Log. In the interval 518-530 m, there are several peaks suggesting that chert in that section is in the form of larger masses.

Fauna and age

Three samples have been examined from this interval. All give an age of Late Miocene (N.18, *Globorotalia tumida tumida-Sphaeroidinellopsis subdehiscens paenedehiscens* Partial range zone of Blow, 1969). Important index species occurring in the interval include *Globigerina nepenthes* Todd (apparently the first record from Western Australia), *G. rubescens decoraperta* Takayanagi & Saito, *Globorotalia tumida* subsp., *G. crassula conomiozea* Kennett, *G. merotumida* Blow & Banner, and *G. internec merotumida-plesiotumida.*

Discussion

The fauna is very diverse and includes abundant keeled *Globorotalia* indicating warm water conditions. Considerations of lithology and site of deposition are all consistent with deposition on the outer continental shelf off a coast of little apparent drainage or denudation. Although the samples examined only record an age of Late Miocene, it seems probable that sedimentation continued until the present day, perhaps affected by sea level fluctuations in the Quaternary. Between the sea-floor and 465 m there is an unsampled interval of 253 m.

INTERVAL 530-597 m—LATE EOCENE, UNNAMED FORMATION

As in the interval above, the section of this age can be divided into two subunits.

Lithology

1. 530-567 m: White chalk with abundant chert and traces of glauconite. Chert comprises 80-90% of the cuttings. The Sonic Velocity Log shows a series of

high-velocity peaks which indicate that the chert must be in large masses. Towards the base of the interval, the character of the carbonate content changes to include a higher proportion of coarser, friable, bryozoal-echinoderm calcarenite.

2. 567-597 m: White friable chalk and bryozoal-echinoderm calcarenite with 20-30% chert in the cuttings. There are no high-velocity peaks on the Sonic Velocity Logs. Towards the base of the section, some foraminiferal tests are glauconite-filled. The chert in this latter interval is significantly darker grey than in the Late Miocene and Late Eocene samples above.

Fauna and age

Two samples were examined from this interval. Both contain well preserved, very diverse Late Eocene faunas referable to Blow's P.16 (*Cribrohantkenina inflata* Total-Range zone). Important zonal species are *Hantkenina primitiva* Cushman & Jarvis, *H. alabamensis* Cushman, *Globigerinatheka index index* (Finlay), *G. subconglobata luterbacheri* Bolli, *Globorotalia cerroazulensis* subspp., and many other species.

Discussion

The fauna helps fill a large distributional gap in the southern Australian area. It also gives credence to the suggestion by Glover (1975) that Eocene sediments exist offshore north of Perth to act as a source of chert for aboriginal artifacts.

As with most of the younger Cainozoic of Western Australia this sediment accumulated in warm-water conditions off a coast of negligible drainage.

INTERVAL 597-740 m—LATE PALEOCENE-EARLY EOCENE EQUIVALENTS OF KINGS PARK FORMATION

This interval can be divided into three subunits on both lithological and time bases, but there is no evidence to suggest coincidence of the boundaries.

Lithology

1. 597-678 m: As with all units above, there are two major components: chert and biogenic carbonate. In this section, chert is abundant above 615 m but there is a marked decrease in content at that depth, and towards the base chert seems to be almost absent.

   The carbonate content takes two forms: white chalk with a trace of glauconite, and a coarser compact white calcarenite. The compact calcarenite is mainly below 615 m and there is an almost constant occurrence of high-velocity peaks on the Sonic Velocity Log even though there is a marked change in lithology at 615 m. Between approximately 620 and 655 m the chalk is slightly greyer, suggesting the presence of some clay and thus some minor drainage. Below approximately 655 m, the glauconite content increases enough to give the rock a pale green colour in places.

   Glauconite also occurs sporadically as fine sand-size grains or as coarse sand-size pellets. The carbonate content below 655 m is sporadically present as compact limestone and some quartz sand is present in the interval 660-670 m.

2. 678-694 m: Lithology is very variable in this interval but consists basically of medium to coarse quartz sandstone with varying amounts of bryozoal calcarenite, in places recrystallised to compact limestone. Glauconite is usually present in trace quantities only but makes up to about 1% and is sometimes present as coarse pellets. There are also very rare ferruginous pellets of coarse sand size, similar to some known in the Upper Eocene Giralia Calcarenite of the Carnarvon Basin (Condon et al., 1956).

3. 694-740 m: Lithology is very variable in this section also. Chalk is dominant over quartz sand but the chalk grades into marl. Chert is sporadic throughout the section but is never dominant and usually only comprises a minor part of the samples. The chert is not in pure masses as in the younger sections but often seems to be only partly silicified carbonate. Glauconite is ubiquitous, often in the form of very coarse pellets.

   This last interval seems to be the product of a very variable influx of sand and clay into an otherwise carbonate facies sediment.

Fauna and age

For the first time in the Perth Basin, a continuous P.4 to P.6 section is seen to be present in one stratigraphic section and the three zones (P.4, *Globorotalia pseudomenardii* Total-Range Zone; P.5, *G. velascoensis* Partial Range Zone; and P.6, *G. subbotinae* Zones) can be recognised.

605-620 m: P.6—The *G. subbotinae* zone can be divided into two subzones (Berggren, 1972) of which the upper (P.6b) is taken as Early Eocene and the lower (P.6a) as Late Paleocene. Only P.6b is identified in Challenger No. 1 and only in the one sample representing the interval 605-620 m.

The fauna is not as diverse as in other sections but includes *Pseudohastigerina wilcoxensis* (Cushman & Ponton), *P. sharkriverensis* Berggren & Olsson, *Globorotalia wilcoxensis* Cushman & Ponton, *G. irrorata* Loeblich & Tappan, and *Subbotina linaperta* (Finlay).

635-680 m: P.5—Within this interval two samples were studied and there are no species in common between the two faunas although a P.5 age is given to both. The upper sample (635-650 m) contains *Subbotina linaperta*, *Globigerina inaequispira* Subbotina, *G.* cf. *mckannai*, *G. spiralis* Bolli, *Pseudogloboquadrina primitiva* (Finlay) and lacks *Globorotalia chapmani* and *G. pseudomenardii*. The lower sample (665-680 m) includes *Subbotina triloculinoides* (Plummer), *Globigerina velascoensis* Cushman, and various *Globorotalia*. Again *G. chapmani* and *G. pseudomenardii* are absent.

695-740 m: P.4—Two samples (695-710 m; 725-740 m) have been studied. Both contain *Globorotalia pseudomenardii* Bolli but only the lower contains *G. chapmani* Parr. Both faunas are dominated by *Subbotina triloculinoides* and both contain *Chiloguembelina* spp.

INTERVAL 740-773 m—LATE SANTONIAN, GINGIN CHALK EQUIVALENT

Lithology

Greyish green, richly glauconitic calcareous sandstone. *Inoceramus* prisms are rare and consist of very fine needles.

Fauna and age

Only one sample (755-770 m) was examined. It contains a small, excellently preserved fauna including *Heterohelix striata* (Ehrenberg), *H. reussi* (Cushman), *Globigerinelloides alvarezi* (Eternod Olvera), *G. bentonensis* (Morrow), *Globotruncana arca* (Cushman), *G. cretacea* (d'Orbigny), and *G. tricarinata* (Quereau). A Late Santonian age, equivalent to the lower part of the Gingin Chalk is indicated.

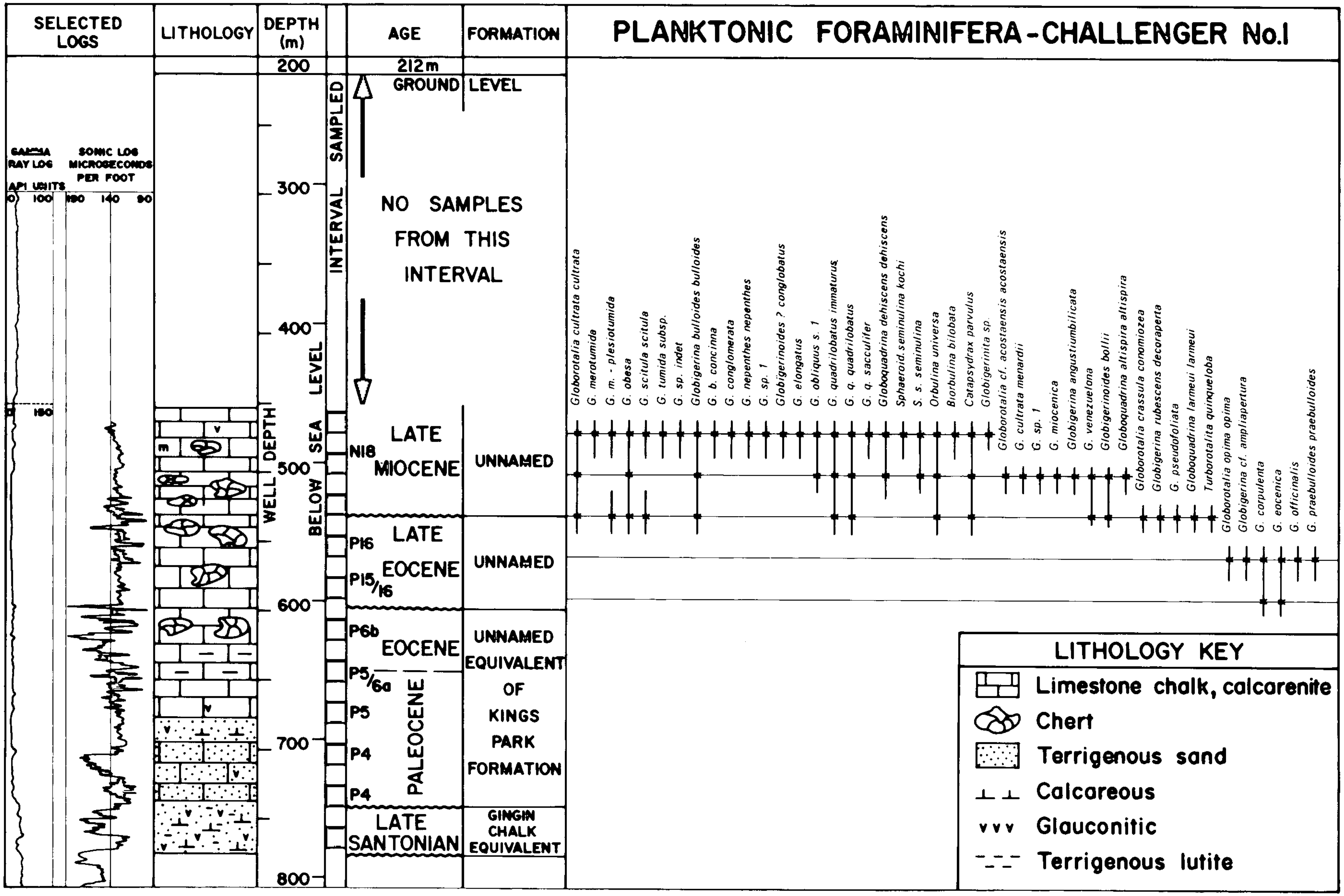

Figure 2a. Challenger No. 1—summary of stratigraphic data and distribution of planktic foraminifera

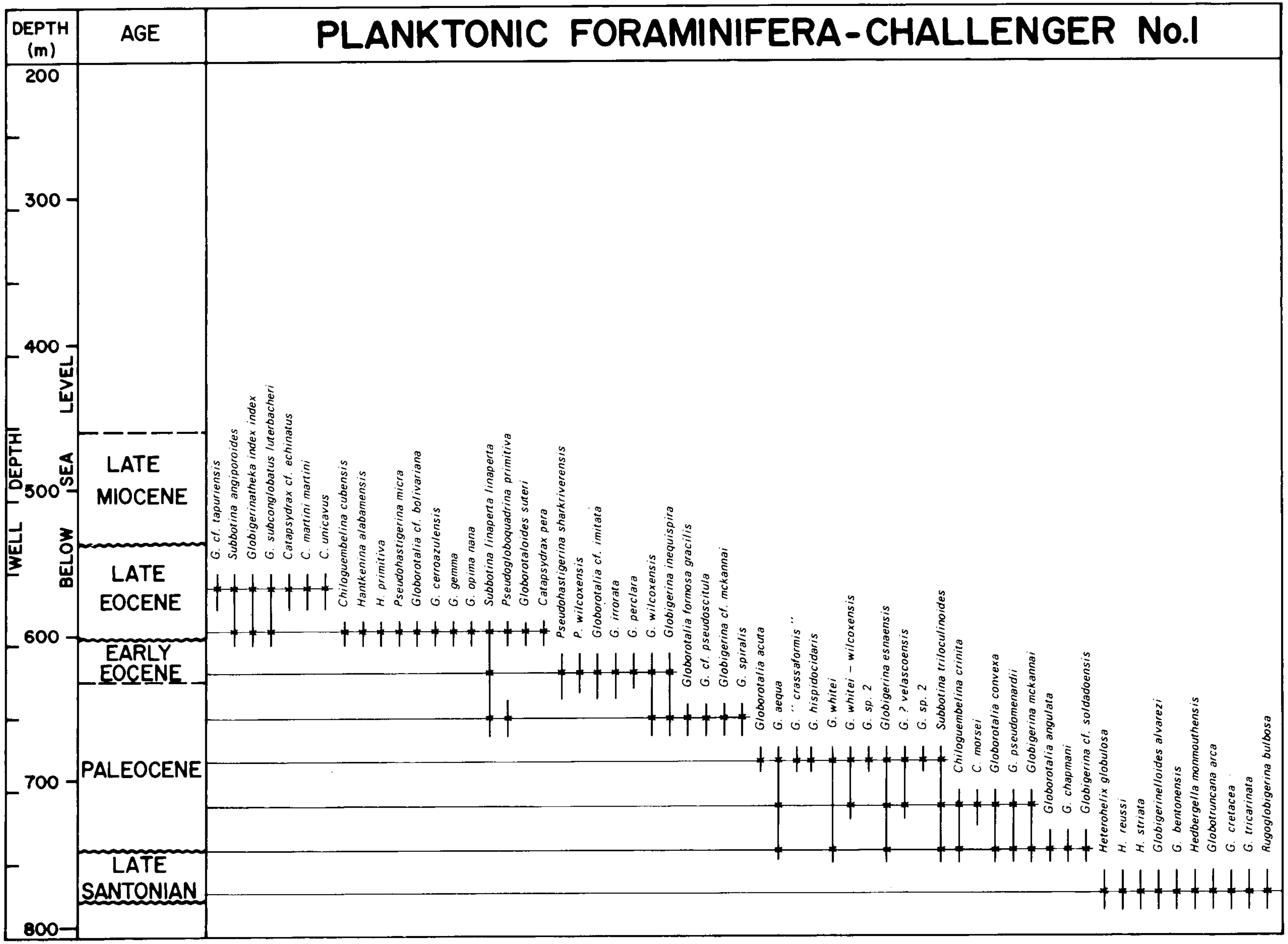

Figure 2b. Challenger No. 1—distribution of planktic foraminifera (continued from Fig. 2a)

RESULTS OF THE RE-EXAMINATION OF THE ROTTNEST ISLAND BORE

This well was discussed briefly by Quilty (1974b) who recognised two major Tertiary units. They were: 71-284 m, 'Rottnest Sandstone'; 284-666 m, Kings Park Formation.

Faunas from both formations are very meagre and statements based on them were somewhat tentative. Owing partly to the significance of the new section in Challenger No. 1, and also to some controversy over age data presented by Quilty (1974b), more material has been examined from the Rottnest Island Bore and several statements made previously have been revised.

ROTTNEST FORMATION (new formation)

Preamble: Quilty (1974b) referred to the informal use of the term 'Rottnest Sandstone'. This enigmatic unit has been examined further and the new information gained indicates that the formation should be formally defined.

The presence of Upper Miocene (and presumably younger) sediments in Challenger No. 1, and the parallelism of sedimentary cycles now recognised in the Perth and Carnarvon Basins, would suggest that the 'Rottnest Sandstone' is either Middle Miocene (N.9-N.12) or Late Miocene to Recent (N.18-N.23) in age.

In order to resolve the problem, large samples of the formation were processed from ditch cuttings samples in Gage Roads No. 1 (WAPET). A few very poorly preserved, *tentatively* identified planktic foraminifera were recovered. Species identified are *Orbulina suturalis* Brönnimann, *O. universa* d'Orbigny, *Globigerinoides conglobatus* (Brady), *G. obliquus obliquus* Bolli and *Globigerina bulloides* d'Orbigny. These are consistent with an age of Late Miocene to Recent (N.17-N.23) and indicate that the Rottnest Formation is a shallower-water, higher-energy equivalent of the Upper Miocene chalks and cherts recovered from Challenger No. 1. Accompanying and dominating the planktic foraminiferal fauna is a fauna of larger benthic species including *Amphistegina lessonii* d'Orbigny, *Operculina ammonoides* (Gronovius) (*sensu* Barker, 1961) and *Cycloclypeus carpenteri* Brady. Rocks of this age are known in the Carnarvon Basin (Quilty, 1974a) but the shallow-water facies has not previously been recognised in the Late Miocene from Western Australia.

Type section: Rottnest Island Bore in the interval 71-284 m. Coordinates: latitude 31°59.9′S, longitude 115°32.1′E.

Reference section: As sample control in the type section is so poor (McWhae, 1967), it is necessary to designate a well sampled reference section. The section chosen is in Gage Roads No. 1 (WAPET) in the interval 100-389 m. Coordinates: latitude 31°57.4′S, longitude 115°22.7′E.

Derivation of name: The name Rottnest Sandstone was first used informally by McWhae (1967) for sediments described in drillers' records as 'red and brown sands' in the interval 71-284 m in the Rottnest Island Bore. No samples were taken and no records are now available from the bore.

Thickness: In the type section 213 m, in the main reference section approximately 289 m. In Gage Roads No. 2, less than 260 m.

Sample control: The Rottnest Formation is very poorly represented in sample collections. The following are the samples so far retained:

Rottnest Island Bore—none
Gage Roads No. 1. Core 1—301-304 m; cuttings 107-137 m
Gage Roads No. 2. Rock sample recovered from blade of 20-inch bit at 30 m.

Lithology: It is clear from a core taken in Gage Roads No. 1 (301-304 m) and from ditch cuttings from the same well that the section is the same as in the Rottnest Bore and consists not of 'sandstone', but of yellow and red calcarenite, limestone, and dolomite. In the light of the obvious misnomer 'sandstone', the term 'formation' is preferred.

Although the entire interval has not been sampled in any single section, the samples so far seen consist of partly recrystallised, highly porous and permeable yellow to red, well-sorted, medium to coarse-grained bryozoal-echinoderm calcarenite with a rich foraminiferal fauna, particularly of large species. The meagre evidence available to date suggests that the colour changes down section from yellow at the top and pink to red at the base. No subdivision of the unit is obvious so far.

Fauna and age: The fauna, the dominant component of the formation, consists of bryozoa, echinoderms, rare solitary corals, molluscs, and common larger foraminifera. Planktic foraminifera are very rare. All are poorly preserved owing to partial recrystallisation and, in places, dolomitisation. The fauna is listed earlier in the preamble. The age seems to be in the Late Miocene to Recent.

Relations of boundaries: The lower boundary is, where known, unconformable with the Middle Miocene Stark Bay Formation or the Eocene. Details of the upper boundary are unknown but the formation is either continuous with Recent sediment, crops out on the seafloor, or is overlain by the Quaternary Coastal Limestone.

Distribution: The Rottnest Formation is now known in Gage Roads No. 1, Gage Roads No. 2, and the Rottnest Bore. Its presence is also suspected in Roe No. 1 (unknown limits in the interval 30-399 m) and Charlotte No. 1 (unknown limits in the interval 93-209 m).

Repository of comparative material: Representative portions of the samples listed above are housed in the collections of the Geological Survey of Western Australia and of the Bureau of Mineral Resources, Canberra.

'KINGS PARK FORMATION'

Quilty (1974b) listed several species of planktic foraminifera from the Rottnest Island Bore, indicative of an Early Eocene (P.6) age. Many are not age diagnostic, and the total recovered and identified is very small.

Dr A. Partridge (oral comm.) stated that dinoflagellates from the bore indicated a Middle to Late Eocene age rather than Early Eocene, which is more in keeping with the results of Eisenack (1961), Churchill (1973), and Stover (1975). To try to clear up the confusion, large samples were examined for foraminifera. Foraminifera are rare and only about 1% of the fauna consists of planktic species. The total fauna of planktics is still meagre, but several positively identifiable index forms have now been recovered from a sample in the interval 486-616 m. The main forms are *Pseudohastigerina micra* (Cole), *P. sharkriverensis* Berggren & Olsson, *Truncorotaloides densus* (Cushman), *Globorotalia cerroazulensis* (Cole) subsp., and *G.* cf. *spinuloinflata* (Bandy). While still a small species list, these forms indicate that the sediments accumulated during the Middle Eocene (P.11-P.13 of Berggren, 1972).

In an attempt to refine this age further, W. K. Copley (WAPET) examined calcareous nannoplankton from the same samples and identified the key forms shown in Table 1.

These indicate a Middle Eocene age (NP16/17 of Martini, 1971) and thus support and refine the new foraminiferal dates. It also supports and refines the age determination of Dr A. Partridge using dinoflagellates.

Several other important results follow from examination of the Rottnest Island Bore biota.

1. The Eocene sediments in the Rottnest Island Bore formed during an episode of sedimentation considerably younger than that which deposited the Late Paleocene-Early Eocene Kings Park Formation. Thus the name Kings Park Formation is not appropriate; the sediments must now be referred to an unnamed series of beds, and this is how they are recorded on the accompanying diagrams. Whether they formed during the early part of the transgression that led to the deposition of the Late Eocene sediments in Challenger No. 1 is not yet clear.
2. The consistent presence of very low percentages of planktic foraminifera in a marine fauna suggests very shallow-water sedimentation, probably much less than 30 m.
3. The domination of such a shallow-water planktic fauna by *Pseudohastigerina* spp. indicates that *Pseudohastigerina* lived close to the seawater surface and dominated the shallow-water planktic foraminiferal fauna.
4. The 382 m of pale brown calcareous shale and siltstone in this Middle Eocene section contain abundant terrigenous material indicating significant drainage at that time and that the Middle Eocene was the most recent interval during which significant drainage can be documented in the Perth Basin.

LATE PALEOCENE-EOCENE PALAEOGEOGRAPHY

Sediments representing zone P.4 to P.6 are well known and widespread in the Perth area, onshore and offshore. The type section of the Kings Park Formation is in Kings Park No. 2 in the interval 37-238 m where the age is P.4. The same lithology is present in several other metropolitan bores (Pudovskis, 1962) and the age there also is P.4.

A sandstone unit (the Mullaloo Sandstone Member) was defined by Quilty (1974b) for sand facies now known in the northern part of the area covered by the Kings Park Formation mainly offshore. Sediments of this age are absent from such wells as Gage Roads Nos. 1, 2, the Rottnest Island Bore, Roe No. 1, and Bouvard No. 1. Challenger No. 1 intersected the only documented complete P.4 to P.6 sequence although this age seems to be present onshore (Quilty, 1974b, footnote, p. 31). This distribution is summarised in Figure 3.

The facies recorded in Challenger No. 1 is different from that known elsewhere, and contains diverse, abundant planktic foraminifera, a fauna far richer than any previously known from rocks of this age in the Perth area. The lithology also is different and contains a substantial carbonate content, often with chert and quartz sand. The lithology cannot be referred to any previously named formation and is left unnamed here.

TABLE 1: CALCAREOUS NANNOPLANKTON, ROTTNEST ISLAND BORE (after W. K. Copley)

SPECIES	DEPTH (m)		
	392-427	486-616	617-666
Discoaster barbadiensis Tan	x		
Discolithus pulcher Deflandre	x		x
D. punctosus (Bramlette & Sullivan)	x		x
Lanternithus minutus Stradner	x	x	x
Micrantholithus ornatus Sullivan	x		
M. parisiensis major Bouche	x	x	x
Polycladolithus operosus Deflandre	x		x
Zygodiscus simplex B & S	x		
Zygrablithus bijugatus (Deflandre)	x	x	x
Chiasmolithus bidens (B & S)		x	x
Cyclococcolithus formosus Kamptner		x	
Discolithina pulchra (Deflandre)		x	
Markalius astroporus (Stradner)		x	
Micrantholithus attennuatus B & S		x	
Zygolithus aureus Stradner		x	
Braarudosphaera discula Bramlette & Riedel			x
Clathrolithus ellipticus Deflandre			x
Discolithus distinctus B & S			x
D. solidus Deflandre			x
Reticulofenestra umbilica (Levin)			x
Zygolithus dubius Deflandre			x
AGE	NP17	NP16/17	

The sedimentation history seems to be of deposition in a submarine valley trending ENE with sedimentation more strongly marine to the WSW (Fig. 4). Deposition in the Perth area always seems to have been in shallow-marine conditions with only a few planktic foraminifera reaching the site of deposition. Sediment was very dominantly terrigenous shale and minor sandstone. At the same time, sediments in the vicinity of Challenger No. 1 were being deposited in deeper water with considerable influx of biogenic carbonate. As time progressed, the sediment closer to shore and to the north of the Rottnest Island-Perth area became sandier and perhaps less marine, while at the site of Challenger No. 1, less terrigenous material was deposited, allowing an increase in biogenic carbonate content.

The valley in which the Kings Park Formation and its equivalents accumulated may have been the landward end of the Perth Canyon (von der Borch, 1968).

The sediments formed in the Late Paleocene-Early Eocene were eroded somewhat during the Early-Middle Eocene interval P.7 to P.11, re-excavating an embayment, again situated at the eastern extremity of the Perth Canyon.

Renewed Middle Eocene sedimentation produced the sediments encountered so far only in the Rottnest Island Bore. The lithology and *benthic* foraminiferal content are very similar to those of the Kings Park Formation. The planktic percentage is very low, comparable with that in the Kings Park Formation, but the list of planktic foraminifera is significantly different. Conditions of sedimentation seem very similar to those in existence during deposition of the Kings Park Formation; that is, steadily rising sea level in a marine embayment.

POST-OLIGOCENE CARBONATE DEPOSITION

Two post-Oligocene phases of carbonate sedimentation—both offshore—are known in the Perth area. The earlier one was described by Quilty (1974b) and no new information on it will be presented here.

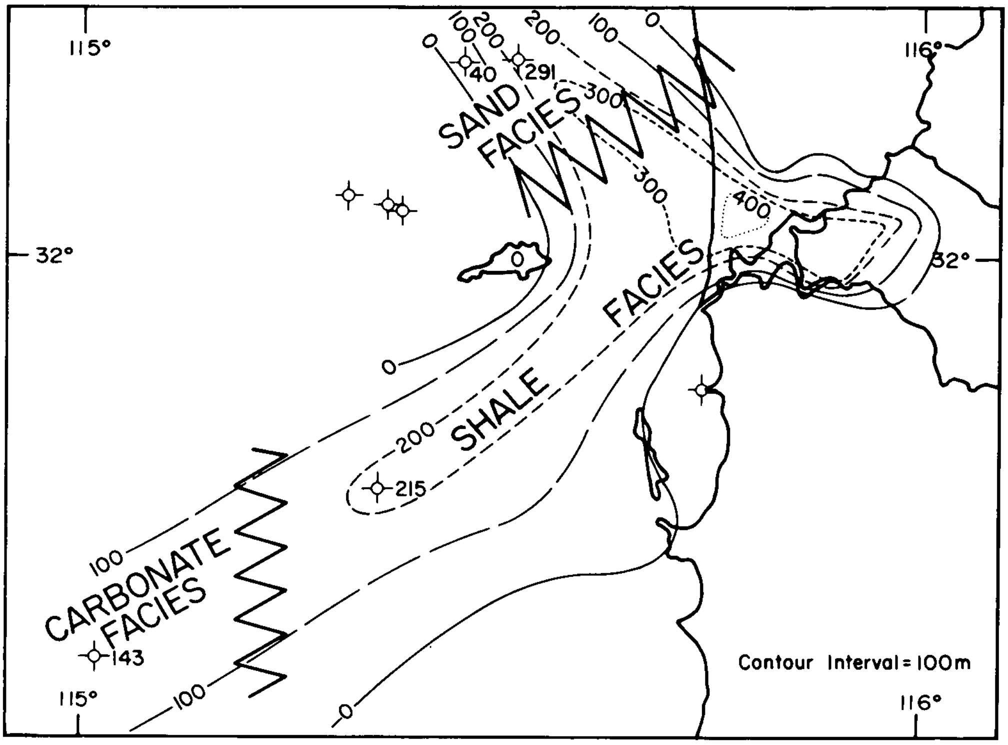

Figure 3. Isopach and facies diagram—Kings Park Formation

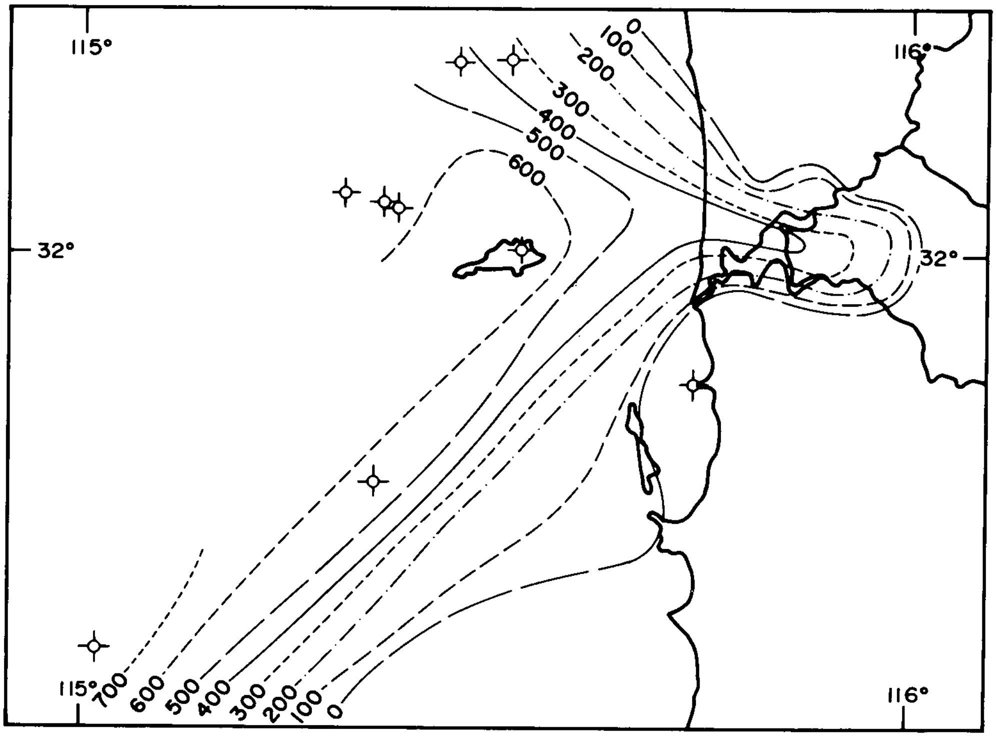

Figure 4. Depth to base Tertiary

The later one commenced in the Late Miocene (N.18) and is well represented in Challenger No. 1. Its products probably also include the Rottnest Formation defined herein (see earlier).

The locus of sedimentation for the two phases of sedimentation was the same as for the Palaeogene phases. Each occurred in a broad, shallow-marine embayment floored by carbonate sediments without any significant terrigenous content.

In a general way, this contrast between Palaeogene sediments with significant detrital content and Neogene without, occurs in both the Carnarvon Basin-Northwest Shelf area and in the Perth Basin and reflects the inhibition to transport of fine sediment brought about by the Oligocene period of lateritisation mentioned by Johnstone et al. (1973). Late Eocene terrigenous sediment is not yet known in the Perth Basin but is known in the Carnarvon Basin. Whether or not this suggests an earlier onset of lateritisation in the Perth than the Carnarvon Basin is conjectural at present.

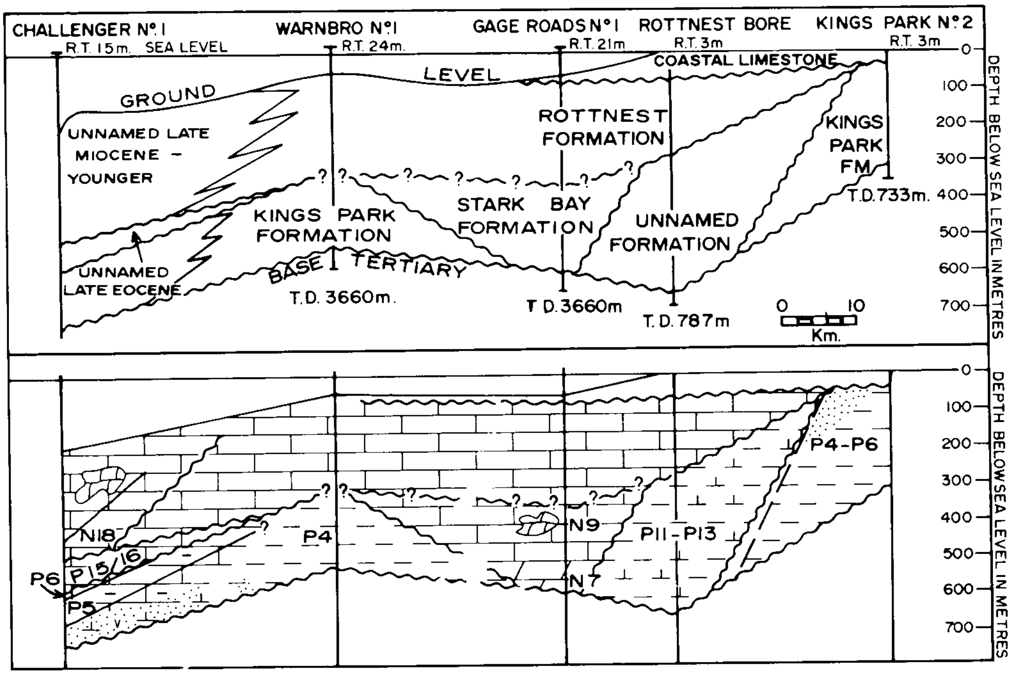

Figure 5. Correlation section, Challenger No. 1—Kings Park No. 2

RELATION TO PREVIOUSLY DOCUMENTED SECTIONS IN THE PERTH AREA

Quilty (1974b) presented several correlation sections of the Cainozoic in the Perth area. To a large extent these are still valid and Figure 5 is an attempt to integrate new data. The section line is shown in Figure 1.

Figure 5 is a stratigraphic summary of the Late Cretaceous-Cainozoic section in the Perth area.

COMPARISON WITH NEARBY DEEP SEA DRILLING PROJECT SECTIONS

Three DSDP sections can be said to be nearby. They are at Sites 257 and 258 of Leg 26 (Davies et al., 1974) and 259 of Leg 27 (Veevers et al., 1974). DSDP sections are considerably thinner than time equivalent sections on the continental shelf. Cores taken at Site 257 recovered Quaternary and Cretaceous. Whether there is any other Cainozoic between Quaternary and Cretaceous section is unknown.

At Site 258, there is an apparently continuous Upper Miocene to Recent sequence about 105 m thick—equivalent to the Upper Miocene and younger in Challenger No. 1—overlying a Cretaceous section consisting of apparently continuous Albian to Santonian. The upper part of this section may be equivalent in part to the Upper Santonian in Challenger No. 1, the section immediately underlying the Cainozoic in that well. There is no equivalent in the Site 258 section of the Paleocene-Lower Eocene or Upper Eocene sequences in Challenger No. 1, nor of the Lower-Middle Miocene present in other Perth Basin wells such as Gage Roads No. 1 and Roe No. 1.

Site 259 is the closest DSDP hole to Challenger No. 1, but it encountered only Quaternary and Paleocene-Lower Eocene sections overlying Lower Cretaceous.

Thus DSDP drilling has discovered only the Paleocene-Lower Eocene and Upper Miocene to Recent sediment cycles recognised elsewhere in the offshore Perth Basin.

SYSTEMATIC PALAEONTOLOGY

The species discussed below are only those for which some comment is prompted by their occurrence in Challenger No. 1 and, to a very much smaller extent, in the Rottnest Island Bore.

Following the systematic section, there is a list of all species occurring in Challenger No. 1.

Family **HETEROHELICIDAE** Cushman, 1927

Genus **Heterohelix** Ehrenberg, 1843

Type species: Spiroplecta americana Ehrenberg, 1844.

Heterohelix cf. **globulosa** (Ehrenberg), 1840

Plate 1, fig. 1

Remarks: The single specimen recovered occurs together with quite abundant *H. globulosa*. The specimen is significantly larger, has a much lower angle of divergence of the sides of the test, and has more appressed, less globular chambers with less depressed sutures which are perpendicular to the axis of the test. The weakly striate surface is unlike that of *H. striata* as the striae consist of discontinuous, slightly elongate ridges which are arranged in a weakly spiral pattern.

Occurrence: 755-770 m.

Heterohelix striata (Ehrenberg), 1840

Plate 1, figs. 2, 3

1840 *Textularia striata* Ehrenberg, *Abh. preuss. Akad. Wiss.* (1839), p. 135, pl. 4, figs. 1a, 1al, 2a, 3a, 9a.

1959 *Heterohelix striata* (Ehrenberg); Eternod Olvera, *Bol. Assoc. Mexicana Geol. Petrol.,* 11, p. 71, pl. 2, figs. 4, 8.

1960 *Pseudogümbelina striata* (Ehrenberg); Belford, *Bur. Miner. Resour. Aust. Bull.* 57, p. 60, pl. 15, figs. 12, 13.

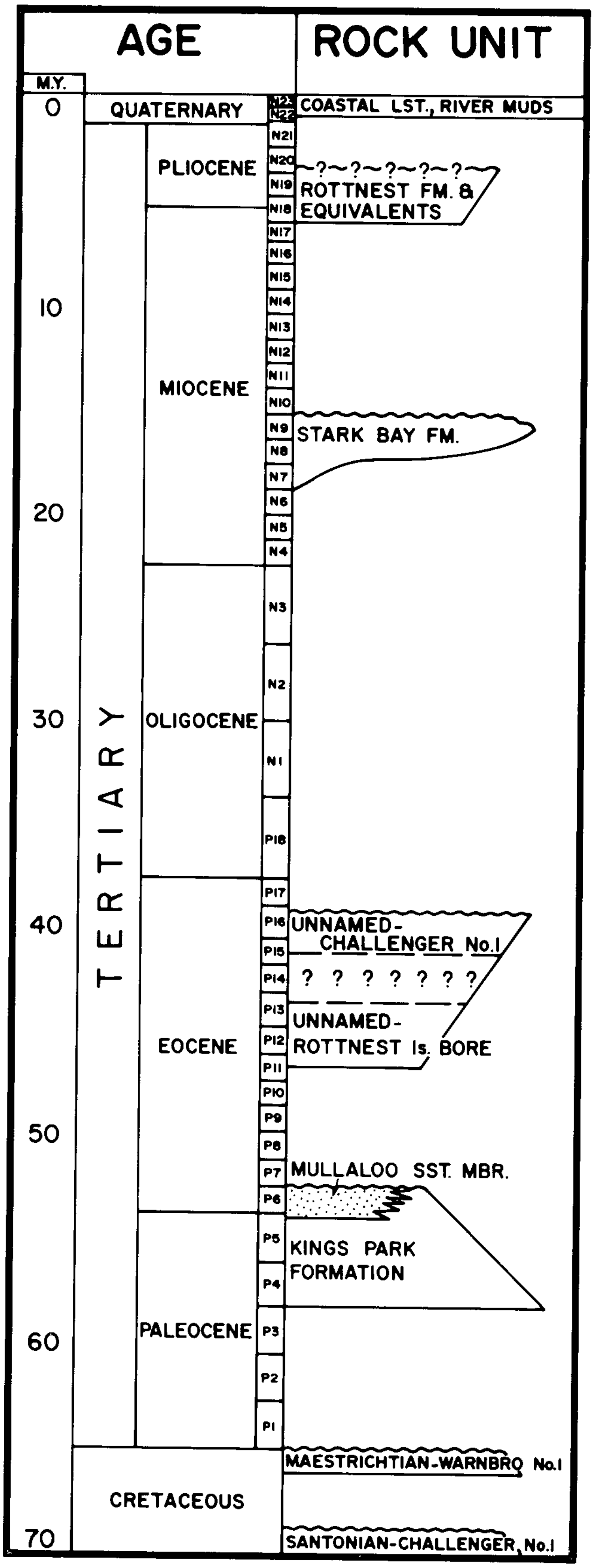

Figure 6. Stratigraphic column for the Late Cretaceous-Cainozoic of the Perth area

Remarks: Two forms are included in this category. One, the dominant form (α) seems to be *H. striata* in the strict sense, finely striate from the initial chamber to the ultimate chamber and without obvious pores in the wall. The second form (β) has a more rapidly expanding test and an initial coil in the single specimen recovered. The main features of the species are that it is more coarsely striate than *H. striata* and that there are many obvious pores evenly distributed over the entire surface. This form may be intermediate between *H. striata* and *H. punctulata* (Cushman).

Occurrence: 755-770 m.

Family **PLANOMALINIDAE** Bolli, Loeblich & Tappan, 1957

Genus **Globigerinelloides** Cushman & Ten Dam, 1948

Type species: Globigerinelloides algeriana Cushman & Ten Dam, 1948.

Globigerinelloides bentonensis (Morrow), 1934

Plate 1, fig. 6

1934 *Anomalina bentonensis* Morrow, *J. Paleont.*, 8, p. 201, pl. 30, fig. 4.

1961 *Globigerinelloides bentonensis* (Morrow); Loeblich & Tappan, *Micropaleontology*, 7, p. 267, pl. 2, figs. 8-10.

1967 *Globigerinelloides bentonensis* (Morrow); Bandy, *Micropaleontology*, 13, p. 12, text fig. 5, no. 7.

1970 *Globigerinelloides bentonensis* (Morrow); Eicher & Worstell, *Micropaleontology*, 16, p. 297, pl. 8, figs. 17, 19; pl. 9, fig. 3.

Remarks: The specimen figured has quite coarse spinose projections in the early part of the final whorl, becoming smoother walled towards the end. It is thus more like the specimen figured by Bandy (op. cit.) than others listed above. Its occurrence in Late Santonian sediments is unexpected.

Occurrence: 755-770 m.

Family **ROTALIPORIDAE** Sigal, 1948

Genus **Hedbergella** Brönnimann & Brown, 1958

Type species: Anomalina lorneiana d'Orbigny var. *trocoidea* Gandolfi, 1942.

Hedbergella monmouthensis (Olsson), 1960

Plate 1, figs. 7, 8

1960 *Globorotalia monmouthensis* Olsson, *J. Paleont.*, 34, p. 74, pl. 9, figs. 22-24.

1964 *Hedbergella monmouthensis* (Olsson); Olsson, *Micropaleontology*, 10, p. 161, pl. 1, fig. 3.

Remarks: The well preserved specimen recovered and figured here has a distinctly hispid wall which may reflect the 'short spines' of the original description. Bandy (1964) recorded a hispid wall for the species but Sliter (1968) described it as having a rugose wall.

Occurrence: 755-770 m.

Family **HANTKENINIDAE** Cushman, 1927

Genus **Hantkenina** Cushman, 1924

Type species: Hantkenina alabamensis var. *primitiva* Cushman & Jarvis, 1929.

Hantkenina primitiva Cushman & Jarvis, 1929

Plate 3, fig. 20

1929 *Hantkenina alabamensis* var. *primitiva* Cushman & Jarvis, *Contr. Cushman Lab.*, 5, p. 16, pl. 3, figs. 2, 3.

1962 *Hantkenina primitiva* Cushman & Jarvis; Blow & Banner *in* EAMES et al., FUNDAMENTALS OF MID-TERTIARY STRATIGRAPHICAL CORRELATION, p. 127, pl. 16, figs. A, B.

Remarks: Only a single spine-bearing chamber is preserved on one of the specimens recovered but this is enough to permit identification of this important species.

Occurrence: 575-590 m.

Genus **Pseudohastigerina** Banner & Blow, 1959

Type species: Nonion micrus Cole, 1927.

Discussion: Berggren, Olsson & Reyment (1967) discussed the evolution of *Pseudohastigerina* from *Globorotalia chapmani* Parr. One 'ancestral' feature retained after this evolution is the imperforate keel of *G. chapmani* which is preserved in most Eocene *Pseudohastigerina* as an imperforate venter. This is certainly true of *P. wilcoxensis* and *P. sharkriverensis* but by the time *P. micra* evolved, it is less markedly so, and many specimens of *P. micra* seem to have a perforate venter. *P. barbadoensis* has a venter less perforate than the test sides but the less perforate ventral band is not as clearly distinct as it is in the early members of the lineage.

Pseudohastigerina micra (Cole), 1927

Plate 3, figs. 21, 22

1927 *Nonion micrus* Cole, *Bull. Amer. Paleont.*, 14(51), p. 22, pl. 5, fig. 12.
1959 *Pseudohastigerina micra* (Cole); Blow & Banner, *Palaeontology*, 2, p. 19, pl. 3, figs. 6a, b, text figs. 4g-i.
1969 *Globanomalina micra* (Cole), Quilty, *J. Roy. Soc. W. Aust.*, 52, p. 43, fig. 6, nos. 1, 2.
1974 *Pseudohastigerina* sp., Quilty, *J. Roy. Soc. W. Aust.*, 57, figs. 21, 22.

Remarks: Further examination of material from the Rottnest Island Bore shows that the specimen figured by Quilty (1974b) is *P. micra* and the sediments from which it was recorded are considerably younger than indicated in that paper.

Two forms of this genus occur in the Rottnest Island Bore in the interval 486-616 m. They are *P. micra* and *P. sharkriverensis*. *P. micra* is typical, with compressed chambers, recurved sutures, and occasionally with bipartite apertures.

The species found in Challenger No. 1 does not have the slightly angular ventral margin, a result of the normal slightly compressed test. The chambers are more globular and thus reminiscent of *P. barbadoensis* or *P. naguewichiensis*. However, the sutures are distinctly recurved distally and the test surface is smooth.

Occurrence: Rottnest Island Bore, 486-616 m; Challenger No. 1, 575-590 m.

Pseudohastigerina sharkriverensis Berggren & Olsson, 1967

Plate 3, figs. 23, 24

1967 *Pseudohastigerina sharkriverensis* Berggren & Olsson, *Micropaleontology*, 13, p. 280, pl, 1, figs. 7-11.

Remarks: A single specimen from the Early Eocene in Challenger No. 1 is accompanied by several specimens of *P. wilcoxensis* (Cushman & Ponton). *P. sharkriverensis* is very distinct by virtue of its being more robust, larger, and having more globular appressed chambers and straight radial sutures. Preservation in the apertural area is not good but enough can be seen to show that the aperture is bipartite.

New processing of material from the Rottnest Island Bore has yielded several specimens of a form very closely allied to, and here identified as, *P. sharkriverensis*. It has globular chambers, straight radial sutures, enlarged last few chambers and the ultimate chamber often somewhat reduced in size. Some specimens show a very minor degree of compression with the resultant faint angularity of the venter. Some early sutures may show some recurvature. This form may be part of the lineage from *P. wilcoxensis*-*P. sharkriverensis* or may be related to Gohrbandt's species mentioned by Berggren et al. (1967).

Occurrence: Challenger No. 1, 605-620 m; Rottnest Island Bore, 486-616 m.

Family **GLOBOROTALIIDAE** Cushman, 1927

Genus **Globorotalia** Cushman, 1927

Type species: Pulvinulina menardii (d'Orbigny) var. *tumida* Brady, 1877.

Globorotalia cf. **acostaensis acostaensis** Blow, 1959

Plate 5, fig. 2

Remarks: The species is similar to *G. acostaensis acostaensis* in all major details except number of chambers per whorl. Instead of the usual 5-6 chambers in the final whorl, the form figured here has only 4.

Occurrence: 485-500 m.

Globorotalia cf. **bolivariana** (Petters), 1954

Plate 2, figs. 1, 2

Remarks: The tentative identification is given because the specimens recovered have a slight peripheral shoulder which is not described from *G. bolivariana* and also because it is slightly younger stratigraphically than expected for *G. bolivariana sensu stricto.*

Occurrence: 575-590 m.

Globorotalia cerroazulensis (Cole), 1927

Plate 3, figs. 25, 26

Remarks: This name is employed for specimens identical with that figured by Toumarkine & Bolli (1970, pl. 1, figs. 25-27) as 'transition entre *G. cerroazulensis cerroazulensis* (Cole) et *G. cerroazulensis cocoaensis* Cushman'.

Occurrence: 575-590 m.

Globorotalia "crassaformis" *sensu* Subbotina, 1953

Plate 2, figs. 6, 7

1953 *Acarinina crassaformis* (Galloway & Wissler); Subbotina, *Trudy VNIGRI*, 76, pl. 21, figs. 1a-7c.

Remarks: A great variety of forms is included in *G. aequa* (Cushman & Renz) and the specimens discussed here could be incorporated. However, there is a group of species with only slightly angled margins, less lobate periphery and which are thicker dorso-ventrally than *G. aequa* which Subbotina referred to *G. crassaformis.* That is the sense in which the name is used here. Of course they cannot be referred to *G. crassaformis sensu stricto* as that is a Neogene form.

Occurrence: 665-680 m.

Globorotalia cf. **imitata** Subbotina, 1953

Plate 2, figs. 14, 15

Remarks: This species has a very markedly flat dorsal surface which is in agreement with the original description (Subbotina, 1953) but there is a slightly acute, non-keeled periphery. The form could be a relative of *G. compressa* or *G. chapmani* or even of *G. pseudomenardii* by loss of the keel and flattening of the dorsal surface.

Occurrence: 605-620 m.

Globorotalia *internec* **merotumida-plesiotumida**

Plate 5, figs. 11, 12

Remarks: The species included here is very common in the Late Miocene of Challenger No. 1, where it is a dominant part of the planktic foraminiferal fauna. Many specimens can be placed in either *G. merotumida* Blow & Banner or *G. tumida plesiotumida* Blow & Banner, but many cannot be placed uniquely in either, having some important characters in common with both of the species listed. This is perhaps to be expected when the forms named are part of an evolving plexus.

Occurrence: 455-470; 485-500 m.

Globorotalia cf. **pseudoscitula** Glaessner, 1937
Plate 2, figs. 20, 21

1957 *Globorotalia pseudoscitula* Glaessner; Loeblich & Tappan, *Bull. U.S. nat. Mus.*, 215, p. 193, pl. 48, figs. 3a-c.

Remarks: This name is applied only in the sense that it is used by Loeblich & Tappan in plate 48 of the 1957 paper. In that sense, it is a very compact species with a high domed ventral surface and rugose ventral extremities of the chambers. It also has an almost flat dorsal surface. It thus differs quite markedly from the original description.

Occurrence: 635-650 m.

Globorotalia tumida (Brady) subsp.
Plate 5, figs. 17, 18

Remarks: The few specimens seen seem to be juveniles, probably of *G. t. tumida*, but the material is insufficient for positive identification.

Occurrence: 455-470; 515-530 m.

Globorotalia *internec* **whitei-wilcoxensis**

Remarks: Quite common in the samples listed below are forms which at population level cannot be assigned to either *G. whitei* Weiss or *G. wilcoxensis* Cushman & Ponton, although individual specimens can be tentatively identified as one or the other.

Occurrence: 665-680; 695-710 m.

Globorotalia, sp. 1
Plate 5, figs. 19, 20

Remarks: The species has an almost flat dorsal surface, slightly angled margin, a low domed ventral surface, 4½ chambers in the final whorl, and recurved intercameral sutures. The most similar species seems to be *G. subscitula* Conato, but that species has a slightly greater rate of increase of chamber size and is a little more compressed.

Occurrence: 485-500 m.

Globorotalia sp. 2
Plate 3, figs. 3, 4

1957 *Globorotalia* sp.; Loeblich & Tappan, *Bull. U.S. nat. Mus.*, 215, p. 197, pl. 45, figs. 8a-c.

Remarks: A single specimen of the same form recorded by Loeblich & Tappan (1957) was recovered. It is from rocks of P.5 age a little younger than the Matthews Landing Member of the Porters Creek Clay from which they recovered their specimen.

Occurrence: 665-680 m.

Family **GLOBIGERINIDAE** Carpenter, Parker & Jones, 1862

Genus **Globigerina** d'Orbigny, 1826

Type species: Globigerina bulloides d'Orbigny, 1826.

Globigerina cf. **ampliapertura** Bolli, 1957
Plate 4, fig. 5

? *Globigerina ampliapertura* Bolli; Lindsay, *Bull. geol. Surv. S. Aust.*, 42, p. 35, pl. 1, figs. 2, 7.

Remarks: The material encountered in Challenger No. 1 is more compact than true *G. ampliapertura* and has less lobulate equatorial profile. Another very similar species is *G. frontosa* Subbotina.

G. ampliapertura occurs in the Plantagenet Group (Quilty, 1969) in sediments of P.15/16 age. This occurrence is in conflict with the range of P.17 to N.2 suggested by Blow (1969) for the species.

Occurrence: 545-560 m.

Globigerina cf. **soldadoensis** Brönnimann, 1952
Plate 3, figs. 11, 12

1957 *Globigerina* cf. *soldadoensis* Brönnimann; Loeblich & Tappan, *Bull. U.S. nat. Mus.*, 215, p. 182, pl. 53, figs. 4a-c.

Remarks: The comparative identification is used in the same sense as by Loeblich & Tappan (op. cit.).

Occurrence: 725-740 m.

Globigerina cf. **tapuriensis** Blow & Banner, 1962
Plate 4, fig. 11

1962 *Globigerina tripartita tapuriensis* Blow & Banner, *in* EAMES et al., FUNDAMENTALS OF MID-TERTIARY STRATIGRAPHICAL CORRELATION, p. 97, pl. 10, figs. H-K.

1969 *Globigerina tripartita* form *tapuriensis* Blow & Banner; Quilty, *J. Roy. Soc. W. Aust.*, 57, p. 47, fig. 7, nos. 37-39.

Remarks: Blow (1969) regards the total range of *G. tapuriensis* as being P.18-P.19. The specimen found here in rocks of P.16 age is indistinguishable from the forms figured by Blow (1969) with SEM photographs. The specimen figured by Quilty (1969) is more similar to that figured using drawings and seems to have a less markedly hispid surface.

Occurrence: 545-560 m.

Globigerina sp. 1
Plate 6, figs. 8, 9

Remarks: This species seems to be related to *G. rubescens decoraperta* but has only 3½ chambers in the final whorl, giving it a trilobed outline.

Occurrence: 455-470 m.

Globigerina sp. 2
Plate 3, figs. 15, 16

Remarks: Included here is a very high spired form with a bulla which has a single umbilical aperture. The most similar species seems to be *'Globigerinoides' higginsi* Bolli, but that species has a spinose surface, which is hardly the case with the specimen figured here. There are no sutural supplementary apertures on the Western Australian species, which occurs in older rocks than would be expected for *'G.' higginsi*. Another similar species is *Globigerina chascanona* Loeblich & Tappan (Loeblich & Tappan, 1957, esp. pl. 49, figs. 5a-c) but that species can be distinguished by virtue of its spinose wall.

Occurrence: 665-680 m.

Genus **Globigerinatheka** Brönnimann, 1952

Type species: Globigerinatheka barri Brönnimann, 1952.

Globigerinatheka index index (Finlay)
Plate 4, fig. 15

1939 *Globigerinoides index* Finlay, *Trans. Roy. Soc. N.Z.*, 69, p. 125, pl. 14, figs. 85-88.

1969 *Globigerapsis index* (Finlay); Quilty, *J. Roy. Soc. W. Aust.*, 57, p. 47, fig. 7, nos. 42-48.

1972 *Globigerinatheka index index* (Finlay); Bolli, *J. foramin. Res.*, 2, p. 124, pl. 1, figs. 1-4, 6, 7.

Remarks: This species is one of the most common species found in the Late Eocene in the well. The intercameral sutures are much less deeply incised than in the material studied by Quilty (1969).

Occurrence: 545-560, 575-590 m.

Globigerinatheka subconglobata luterbacheri Bolli, 1972

Plate 4, fig. 16

1972 *Globigerinatheka subconglobata luterbacheri* Bolli, *J. foramin. Res.*, 2, p. 132, pl. 1, figs. 17, 22-25; pl. 7, figs. 1-17.

Remarks: Typical specimens are very well preserved but not abundant. The species does not occur in the Plantagenet Group material studied by Quilty (1969).

Occurrence: 545-560; 575-590 m.

Genus **Catapsydrax** Bolli, Loeblich & Tappan, 1957

Type species: Globigerina dissimilis Cushman & Burmudez, 1937.

Catapsydrax cf. **echinatus** (Bolli), 1957

Plate 4, figs. 19, 20

Remarks: The specimen recovered is a nonbullate, thin-walled form. It occurs in sediments of P.16 age, significantly younger than the expected range.

Occurrence: 545-560 m.

PLANKTIC FORAMINIFERA FROM CHALLENGER No. 1

The following list is in lieu of a large detailed systematic section. Species marked (*) are discussed further in the systematic section. Most species are not discussed in detail, but are figured. References given here are not necessarily listed in the reference list at the end of the paper.

Specimens figured are housed in the collection of the Geology Department, University of Western Australia and the number following the abbreviation UWAGD is the number on that collection.

The classification used follows that of Loeblich & Tappan (1964) at Family level.

Family **HETEROHELICIDAE**

Genus **Heterohelix** Ehrenberg, 1843

Heterohelix reussi (Cushman) = *Gümbelina reussi* Cushman, 1938, *Contr. Cushman Lab.*, 14, 11, pl. 2, figs. 6-9.

H. cf. *globulosa* (Ehrenberg)

H. striata (Ehrenberg)

Genus **Chiloguembelina** Loeblich & Tappan, 1956

Chiloguembelina crinita (Glaessner) = *Guembelina crinita* Glaessner, 1937, *Prob. Paleont. Moscow Univ.*, 2-3, p. 383, pl. 4, fig. 34.

C. cubensis (Palmer) = *Gümbelina cubensis* Palmer, 1934, *Mem. Soc. Cubana Hist. nat.*, 8, p. 74, text figs. 1-6.

C. morsei (Kline) = *Guembelina morsei* Kline, 1943, *Bull. Mississippi geol. Survey*, 53, p. 44, pl. 7, fig. 12.

Family **PLANOMALINIDAE**

Genus **Globigerinelloides** Cushman & Ten Dam, 1948

Globigerinelloides alvarezi (Eternod Olvera) = *Planomalina alvarezi* Eternod Olvera, 1959 *Bol. Asoc. Mexicana Geol. petrol.*, 11, p. 91, pl. 4, figs. 5-7.

G. bentonensis (Morrow)

Family **ROTALIPORIDAE**

Genus **Hedbergella** Brönnimann & Brown, 1958

Hedbergella monmouthensis (Olsson)

Family **GLOBOTRUNCANIDAE**

Genus **Globotruncana** Cushman, 1927

Globotruncana arca (Cushman) = *Pulvinulina arca* Cushman, 1926, *Contr. Cushman Lab.*, 2, p. 23, pl. 3, fig. 1.

G. cretacea (d'Orbigny) = *Globigerina cretacea* (d'Orbigny), 1840, *Mem. Soc. geol. Fr.*, 4, p. 34, pl. 3, figs. 12-14.

G. tricarinata (Quereau) = *Pulvinulina tricarinata* Quereau, 1893, *Beitr. geol. Karte Schweiz.*, 33, p. 89, pl. 5, fig. 3a.

Genus **Rugoglobigerina** Brönnimann, 1952

Rugoglobigerina bulbosa Belford, 1960, *Bur. Miner. Resour. Aust. Bull.* 57, p. 94, pl. 26, figs. 1-10.

Family **HANTKENINIDAE**

Genus **Hantkenina** Cushman, 1924

Hantkenina alabamensis Cushman, 1925, *Proc. U.S. nat. Mus.*, 66 (2567), p. 3, pl. 1, figs. 1-6; pl. 2, fig. 5.

H. primitiva Cushman & Jarvis

Genus **Pseudohastigerina** Banner & Blow, 1959

Pseudohastigerina micra (Cole)

P. sharkriverensis Berggren & Olsson

P. wilcoxensis = *Nonion wilcoxensis* Cushman & Ponton, 1932, *Contr. Cushman Lab.*, 8, p. 64, pl. 8, figs. 11a, b.

Family **GLOBOROTALIIDAE**

Genus **Globorotalia** Cushman, 1927

Globorotalia cf. *acostaensis acostaensis* Blow.

G. acuta Toulmin = *G. wilcoxensis* Cushman & Ponton var. *acuta* Toulmin, 1948. *J. Paleont.*, 15, p. 608, pl. 82, figs. 6-8.

G. aequa Cushman & Renz = *G. crassata* (Cushman) var. *aequa* Cushman & Renz, 1942, *Contr. Cushman Lab.*, 18, p. 12, pl. 3, figs. 3a-c.

G. angulata (White) = *Globigerina angulata* White, 1928, *J. Paleont.*, 2, p. 191, pl. 27, figs. 13a-c.

G. cf. *bolivariana* (Petters)

G. cerroazulensis (Cole)

G. chapmani Parr, 1938, *J. Roy. Soc. W. Aust.*, 24, p. 87, pl. 3, figs. 8, 9.

G. convexa Subbotina, 1953, *Trudy VNIGRI*, 76, p. 209, pl. 17, figs. 2, 3.

G. 'crassaformis' (Galloway & Wissler) *sensu* Subbotina.

G. crassula conomiozea Kennett = *G. conomiozea* Kennett, 1966, *Micropaleontology*, 12, p. 235, pl. 1, figs. 8-18; pl. 12, figs. 6-13.

G. cultrata cultrata (d'Orbigny) = *Rotalina cultrata* d'Orbigny, 1839, 'Histoire physique, politique et naturelle de l'Ile de Cuba', p. 76 (fig. 8, pl. 5, figs. 7-9).

G. c. menardii (d'Orbigny) = *Rotalia menardii* d'Orbigny, 1826, *Ann. Sci. nat. Paris*, 7, p. 273, modeles No. 10.

G. formosa gracilis Bolli, 1957, *Bull. U.S. nat. Mus.*, 215, p. 75, pl. 18, figs. 4-6.

G. gemma Jenkins, 1966, *N.Z. J. Geol. Geophys.*, 8, p. 1115, fig. 11, Nos. 97-103.

G. hispidocidaris Loeblich & Tappan, 1957, *Bull. U.S. nat. Mus.*, 215, p. 190, pl. 58, figs. 1a-c.

**G.* cf. *imitata* Subbotina.

G. irrorata Loeblich & Tappan, 1957, *Bull. U.S. nat. Mus.*, 215, p. 191, pl. 46, figs. 2a-c, 5a-c.

G. merotumida Blow & Banner, 1965, *Nature*, 207 (5005), p. 1352.

**G. internec merotumida-plesiotumida.*

G. miocenica Palmer = *G. menardii* (d'Orbigny) var. *miocenica* Palmer, 1945, *Bull. Amer. Paleont.*, 29 (115), p. 70, pl. 1, figs. 10a-c.

G. obesa Bolli, 1957, *Bull. U.S. nat. Mus.*, 215, p. 119, pl. 29, figs. 2a-3.

G. opima nana Bolli, 1957, *Bull. U.S. nat. Mus.*, 215, p. 118, pl. 28, figs. 3a-c.

G. o. opima Bolli, 1957, *Bull. U.S. nat. Mus.*, 215, p. 117, pl. 28, figs. 1a-2.

G. perclara Loeblich & Tappan, 1957, *Bull. U.S. nat. Mus.*, 215, p. 191, pl. 40, figs. 7a-c, etc.

G. pseudomenardii Bolli, 1957, *Bull. U.S. nat. Mus.*, 215, p. 77, pl. 20, figs. 14-17.

**G.* cf. *pseudoscitula* Glaessner

G. scitula scitula (Brady) = *Pulvinulina scitula* Brady, 1884, *Proc. Roy. Soc. Edinburgh*, 11, p. 716 (figs. Brady, 1884, *Scient. Results Challenger Expedn, Zool.*, 9, pl. 103, figs. 7a-c).

**G. tumida* (Brady) subsp.

G. whitei Weiss, 1955, *J. Paleont.*, 29, p. 18, pl. 6, figs. 1-3.

**G. internec whitei-wilcoxensis*

G. wilcoxensis Cushman & Ponton, 1932, *Contr. Cushman Lab.*, 8, p. 71, pl. 9, figs. 10a-c.

**G.* sp. 1

**G.* sp. 2

G. sp. indet.

Family **GLOBIGERINIDAE**

Genus **Globigerina** d'Orbigny, 1826

**Globigerina* cf. *ampliapertura* Bolli

G. angustiumbilicata Bolli = *G. ciperoensis angustiumbilicata* Bolli, 1957, *Bull. U.S. nat. Mus.*, 215, p. 105, pl. 22, figs. 12a-13c.

G. bulloides bulloides d'Orbigny, 1826, *Ann. Sci. nat. Paris*, 7, p. 277, Modeles No. 76.

G. bulloides concinna Reuss = *Globigerina concinna* Reuss, 1850, *Denkschr. Akad. Wiss. Wien.*, 1, p. 375, pl. 47, fig. 8.

G. conglomerata Schwager, 1866, *Geol. Theil Novara Expedn*, 2, p. 255, pl. 7, fig. 113.

G. corpulenta Subbotina, 1953, *Trudy VNIGRI*, 76, p. 76, pl. 9, figs. 5-7; pl. 10, figs. 1-4.

G. eocaenica Terquem, 1882, *Mem. geol. Soc. Fr.*, 2, p. 86, pl. 9, fig. 4.

G. esnaensis Le Roy, 1953, *Mem. geol. Soc. Amer.*, 54, p. 31, pl. 6, figs. 8-10.

G. inaequispira Subbotina, 1953, *Trudy VNIGRI*, 76, p. 69, pl. 6, figs. 1-4.

G. mckannai White, 1928, *J. Paleont.*, 2, p. 194, pl. 27, figs. 16a-c.

G. cf. *mckannai* White

G. nepenthes nepenthes Todd, 1957, *U.S. geol. Surv. Prof. Paper* 280-H, p. 301, pl. 78, fig. 7.

G. officinalis Subbotina, 1953, *Trudy VNIGRI*, 76, p. 78, pl. 11, figs. 1a-c.

G. praebulloides praebulloides Blow, 1959, *Bull. Amer. Paleont.*, 39 (178), p. 180, pl. 8, figs. 47a-c.

G. pseudofoliata Parker, 1967, *Bull. Amer. Paleont.*, 52 (235), p. 170, pl. 27, figs. 1a-c.

G. rubescens decoraperta Takayanagi & Saito = *G. druryi decoraperta* Takayanagi & Saito, 1962, *Sci. Rept Tohoku Univ.* Ser. 2, *Spec. vol.* 5, p. 85, pl. 28, figs. 10a-c.

**G.* cf. *soldadoensis* Brönnimann

G. spiralis Bolli, 1957, *Bull. U.S. nat. Mus.*, 215, p. 70, pl. 16, figs. 16-18.

**G.* cf. *tapuriensis* Blow & Banner

G. velascoensis Cushman, 1925, *Contr. Cushman Lab.*, 1, p. 19, pl. 3, fig. 6.

G. venezuelana Hedberg, 1937, *J. Paleont.*, 11, p. 681, pl. 92, figs. 7a, b.

**G.* sp. 1

**G.* sp. 2

G. sp. indet.

Genus **Subbotina** Brotzen & Pozaryska, 1961

Subbotina angiporoides angiporoides (Hornibrook) = *Globigerina angipora* Finlay, 1939, *Trans. Roy. Soc. New Zealand*, 69, p. 125.

S. linaperta linaperta (Finlay) = *Globigerina linaperta* Finlay, 1939. *Trans. Roy. Soc. New Zealand*, 69, p. 125, pl. 23, figs. 54-57.

S. triloculinoides (Plummer), 1926 = *Globigerina triloculinoides* Plummer, 1926, *Bull. Univ. Texas*, 2644, p. 134, pl. 8, figs. 10a-c.

Genus **Globigerinoides** Cushman, 1927

Globigerinoides bollii Blow, 1959, *Bull. Amer. Paleont.*, 39 (178), p. 189, pl. 10, figs. 65a-c.

G. ?conglobatus (Brady)

G. elongatus (d'Orbigny) = *Globigerina elongata* d'Orbigny, 1826, *Ann. Sci. nat. Paris*, 7, p. 277 (figs. Parker, Jones & Brady, 1873, *Ann. Mag. nat. Hist.*, ser. 4, 8, pl. 11, fig. 129).

G. obliquus (s.l.) Bolli, 1957, *Bull. U.S. nat. Mus.*, 215, p. 113, pl. 25, figs. 9a-10c.

G. ?obliquus Bolli

G. quadrilobatus immaturus Le Roy, 1939, *Natuurk. Tijdschr. Nederl.-Indië.*, 99, p. 263, pl. 3, figs. 19-21.

G. q. quadrilobatus (d'Orbigny) = *Globigerina quadrilobata* d'Orbigny, 1846, 'Foraminiferes fossiles du Bassin Tertiare de Vienne (Autriche)', p. 164, pl. 9, figs. 7-10.

G. q. sacculifer (Brady) = *Globigerina sacculifera* Brady, 1877, *Geol. Mag.* dec. 2, 4 (12), p. 535 (figs. Brady, 1884, *Scient. Results Challenger Expedn, Zool.*, 9, pl. 80, figs. 15, 16).

Genus **Globoquadrina** Finlay, 1947

Globoquadrina altispira altispira Cushman & Jarvis) = *Globigerina altispira* Cushman & Jarvis, 1936, *Contr. Cushman Lab.*, 12 (1), p. 5, pl. 1, figs. 13a-c.

G. dehiscens dehiscens (Chapman, Parr & Collins) = *Globorotalia dehiscens* Chapman, Parr & Collins, 1934, *Linn. Soc. London, J. Zool.*, 38 (262), pl. 11, figs. 36a-c.

G. larmeui larmeui Akers, 1955, *J. Paleont.*, 29, p. 661, pl. 65, figs. 4a-c.

Genus **Pseudogloboquadrina** Jenkins, 1965

Pseudogloboquadrina primitiva (Finlay) = *Globigerina primitiva* Finlay, 1947, *N.Z. J. Sci. Technol.*, 28 (5), p. 291, pl. 8, figs. 129-134.

Genus **Globorotaloides** Bolli, 1957

Globorotaloides suteri Bolli, 1957, *Bull. U.S. nat. Mus.*, 215, p. 166, pl. 37, figs. 10-12.

Genus **Sphaeroidinellopsis** Banner & Blow, 1959

Sphaeroidinellopsis seminulina kochi (Caudri) = *Globigerina kochi* Caudri, 1934, *Eclog. geol. Helv.*, 18 (2), p. 355, figs. 8a, b.

S. seminulina seminulina (Schwager) = *Globigerina seminulina* Schwager, 1866, *Novara Expedn, Geol. Theil* 2, p. 256, pl. 7, fig. 112.

Genus **Orbulina** d'Orbigny, 1938

Orbulina universa universa d'Orbigny, 1839, 'Voyage dans l'Amerique meridionale', 5 (5), p. 2 (fig. 3, pl. 1).

Genus **Biorbulina** Blow, 1956

Biorbulina bilobata (d'Orbigny) = *Globigerina bilobata* d'Orbigny, 1846, 'Foraminiferes fossiles du Bassin Tertiare de Vienne (Autriche)', p. 164, pl. 9, figs. 11-14.

Genus **Globigerinatheka** Brönnimann, 1952

**Globigerinatheka index index* (Finlay)

**G. subconglobatus luterbacheri* Bolli

Genus **Turborotalita** Blow & Banner, 1962

Turborotalita quinqueloba (Natland) = *Globigerina quinqueloba* Natland, 1938, *Bull. Scripps Institn Oceanogr. Tech. Ser.*, 4 (5), p. 149, pl. 6, figs. 7a-c.

Genus **Catapsydrax** Bolli, Loeblich & Tappan, 1957

**Catapsydrax* cf. *echinatus* Bolli

C. martini martini (Blow & Banner) = *Globigerinita martini martini* Blow & Banner, 1962, 'Fundamentals of Mid-Tertiary stratigraphical correlation', p. 110, pl. 14, fig. O.

C. parvulus Bolli, Loeblich & Tappan, 1957, *Bull. U.S. nat. Mus.*, 215, p. 36, pl. 7, figs. 10a-c.

C. pera (Todd) = *Globigerina pera* Todd, 1957, *U.S. geol. Surv. Prof. Paper* 280-H, p. 301, pl. 70, figs. 10, 11.

C. unicavus primitivus (Blow & Banner) = *Globigerinita unicava primitiva* Blow & Banner, 1962, 'Fundamentals of Mid-Tertiary stratigraphical correlation', p. 114, pl. 14, figs. J-L.

Genus **Globigerinita** Brönnimann, 1951

Globigerinita sp.

CONCLUSIONS

The following are the main contributions to knowledge of the Cainozoic to come from examination of the section in Challenger No. 1.

1. The Late Paleocene-Early Eocene section in Challenger No. 1 is in a totally different facies from that previously recorded and has a much more diverse, richer planktic foraminiferal fauna than previously recorded in sediments of this age in the Perth Basin.
2. The Late Eocene section is previously unrecorded from the Perth Basin, although the presence of artifacts of chert of this age (Glover, 1975) has been strong evidence for its presence offshore north of Perth. The faunas and lithology are consistent with warm-water deposition off a coast of negligible drainage.

   The documentation of the existence of this cycle of deposition in the Perth Basin virtually completes its record in all areas of sedimentation around the western and southern margins of Australia.
3. The Late Miocene section is probably the base of a section representing continuous Late Miocene to Recent sedimentation as recently documented for the Northwest Shelf (Quilty, 1974a). Again sedimentation occurred in warm water off a coast of negligible drainage.
4. Several important zonal index foraminifera such as *Hantkenina* and *Globigerina nepenthes* are recorded for the first time from the Perth Basin, and in some instances from Western Australia.
5. Warm-water faunas are now known from all recorded Tertiary sections in the Perth Basin, and the warm-water zonal schemes of Blow (1969) and Berggren (1972) are applicable throughout the Tertiary, on the western margin of Australia. This is in marked contrast to much of southeastern Australia.
6. All sedimentary cycles known in the Carnarvon Basin, with the exception of the Late Oligocene-Early Miocene, are now known also in the Perth Basin.
7. The maximum depth at which Early Miocene, Middle Eocene, and Late Paleocene are known directly to overlie Cretaceous is in the range of 600-750 m below sea level. There has therefore been no major Neogene down-arching of the continental shelf edge as there has been in the Carnarvon Basin-Northwest Shelf (Quilty, 1974a).

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PLATE 1

CRETACEOUS

Figs.

1 *Heterohelix* cf. *globulosa* (Ehrenberg); UWAGD 77687, x55, 755-770 m.

2 *H. striata* (Ehrenberg), *sensu stricto* form α; UWAGD 77689, x80, 755-770 m.

3 *H. striata* (Ehrenberg), form β; UWAGD 77690, x100. Note initial plainspiral coil; 755-770 m.

4 *H. reussi* (Cushman); UWAGD 77688, x120, 755-770 m.

5 *Globigerinelloides alvarezi* Eternod Olvera; UWAGD 77694, x85, 755-770 m.

6 *G. bentonensis* (Morrow); UWAGD 77695, x80, 755-770 m.

7, 8 *Hedbergella monmouthensis* (Olsson); UWAGD 77696, x100, 755-770 m.

9, 10 *Globotruncana arca* (Cushman); UWAGD 77697, x75, 755-770 m.

11, 12 *G. cretacea* (d'Orbigny); UWAGD 77698, x75, 755-770 m.

13, 14 *G. tricarinata* (Quereau); UWAGD 77699, x60, 755-770 m.

15 *Rugoglobigerina bulbosa* Belford; UWAGD 77700, x75, 755-770 m.

LATE PALEOCENE-EARLY EOCENE

16 *Chiloguembelina morsei* (Kline); UWAGD 77693, x100, 695-710 m.

17 *C. crinita* Glaessner; UWAGD 77691, x120, 695-710 m.

18, 19 *Globorotalia acuta* Toulmin; UWAGD 77707, x60, 665-680 m.

20 *G. aequa* Cushman & Renz; UWAGD 77708, x60, 695-710 m.

21, 22 *G. angulata* (White); UWAGD 77709, x75, 725-740 m.

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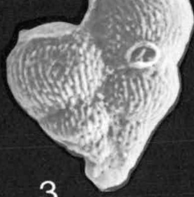

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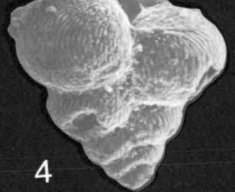

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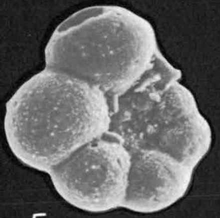

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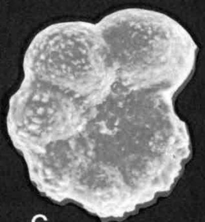

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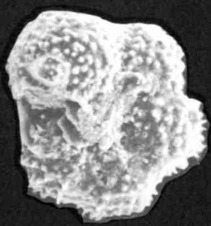

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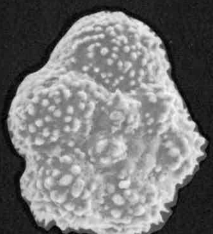

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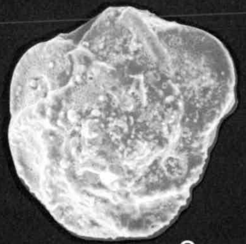

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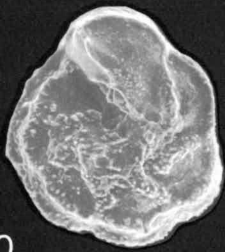

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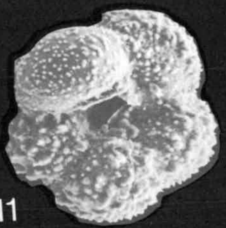

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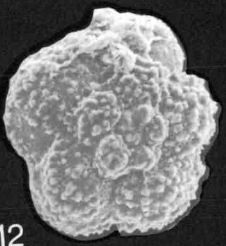

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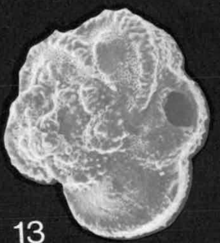

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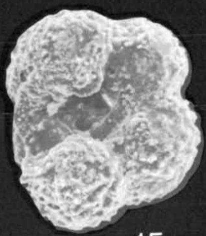

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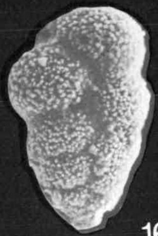

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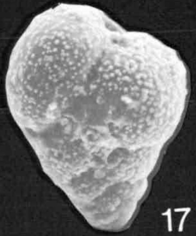

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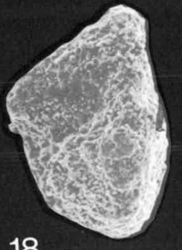

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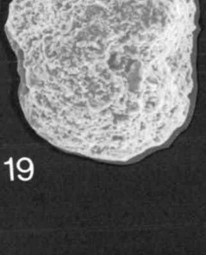

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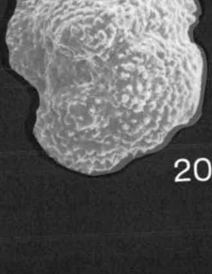

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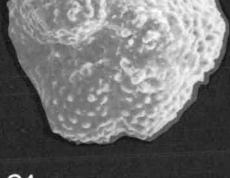

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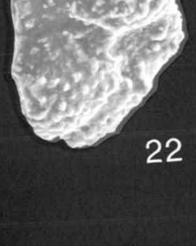

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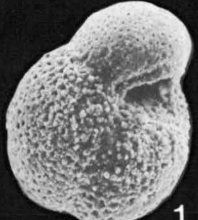
PLATE 2

LATE PALEOCENE-EARLY EOCENE

Figs.	
1, 2	*Globorotalia* cf. *bolivariana* (Petters); UWAGD 77710, x90, 575-590 m.
3, 4	*G. chapmani* Parr; UWAGD 77712, x75, 725-740 m.
5	*G. convexa* Subbotina; UWAGD 77713, x120, 695-710 m.
6, 7	*G. "crassaformis" sensu* Subbotina; UWAGD 77714, x95, 665-680 m.
8, 9	*G. esnaensis* (Le Roy); UWAGD 77718, x70, 665-680 m.
10, 11	*G. formosa gracilis* Bolli; UWAGD 77719, x90, 635-650 m.
12, 13	*G. hispidocidaris* Loeblich & Tappan; UWAGD 77721, x110, 665-680 m.
14, 15	*G.* cf. *imitata* Subbotina; UWAGD 77722, x135, 605-620 m.
16	*G. irrorata* Loeblich & Tappan; UWAGD 77723, x160, 605-620 m.
17, 18	*G. perclara* Loeblich & Tappan; UWAGD 77730, x120, 605-620 m.
19	*G. pseudomenardii* Bolli; UWAGD 77731, x120, 695-710 m.
20, 21	*G.* cf. *pseudoscitula* Glaessner; UWAGD 77732, x100, 635-650 m.
22	*G. whitei* Weiss; UWAGD 77734, x100, 725-740 m.
23, 24	*G. wilcoxensis* Cushman & Ponton; UWAGD 77736, x120, 605-620 m.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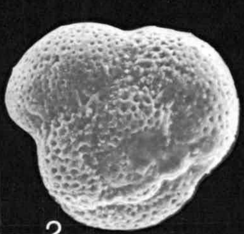
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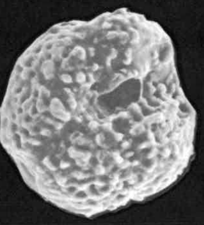
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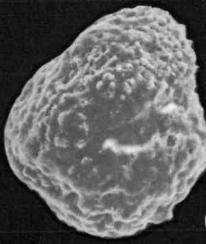
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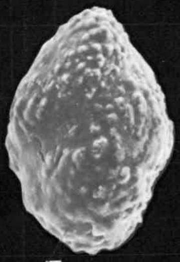
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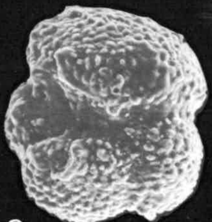
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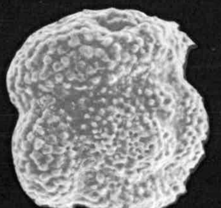
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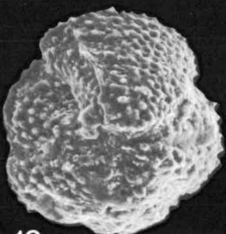
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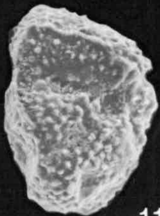
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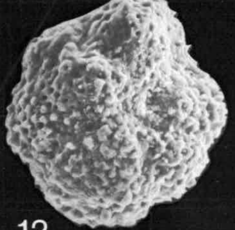
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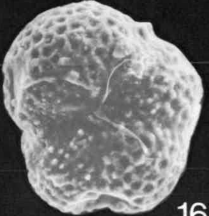
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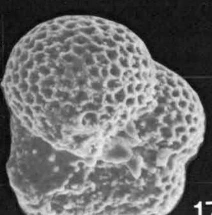
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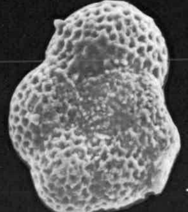
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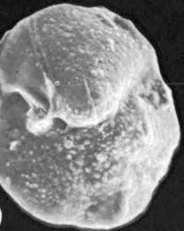
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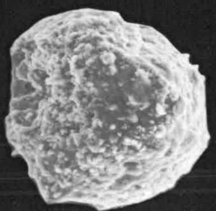
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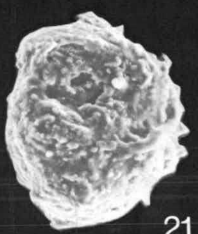
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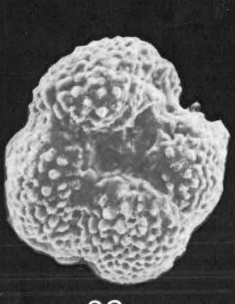
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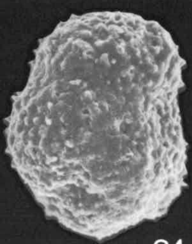
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PLATE 3

Late Paleocene-Early Eocene

Figs.

1, 2 *Globorotalia internec whitei-wilcoxensis;* UWAGD 77735, x120, 665-680 m.

3, 4 *G.* sp. 2; UWAGD 77738, x100, 665-680 m.

5, 6 *Pseudohastigerina wilcoxensis* (Cushman & Ponton); UWAGD 77705, x85, 605-620 m.

7 *Globigerina inaequispira* Subbotina; UWAGD 77746, x55, 605-620 m.

8 *G. mckannai* White; UWAGD 77747, x75, 695-710 m.

9, 10 *G.* cf. *mckannai* White; UWAGD 77748, x75, 635-650 m.

11, 12 *G.* cf. *soldadoensis* Brönnimann; UWAGD 77754, x110, 725-740 m.

13 *G. spiralis* Bolli; UWAGD 77755, x120, 635-650 m.

14 *G. velascoensis* Cushman; UWAGD 77757, x70, 665-680 m.

15, 16 *G.* sp. 2; UWAGD 77760, x125, 665-680 m.

17 *Subbotina triloculinoides* (Plummer); UWAGD 77763, x80, 665-680 m.

Late Eocene

18 *Chiloguembelina cubensis* (Palmer); UWAGD 77692, x120, 575-590 m.

19 *Hantkenina alabamensis* Cushman; UWAGD 77701, x60, 575-590 m.

20 *H. primitiva* Cushman & Jarvis; UWAGD 77702, x70, 575-590 m.

21, 22 *Pseudohastigerina micra* (Cole); UWAGD 77703, x120, 575-590 m.

23, 24 *P. sharkriverensis* Berggren & Olsson; UWAGD 77704, x110, 605-620 m.

25, 26 *Globorotalia cerroazulensis* (Cole); UWAGD 77711, x100, 575-590 m.


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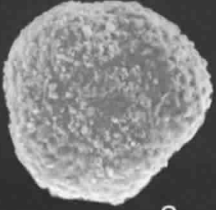
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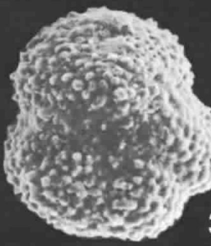
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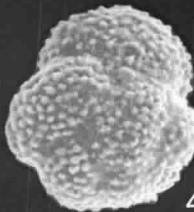
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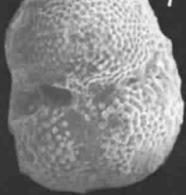
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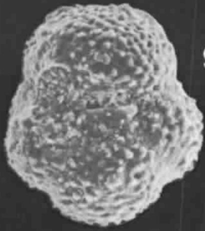
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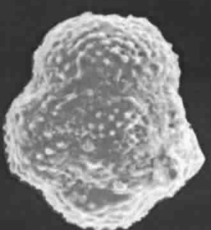
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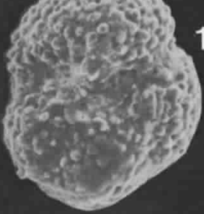
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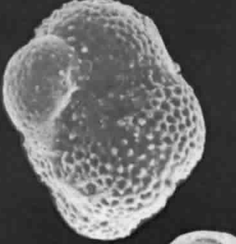
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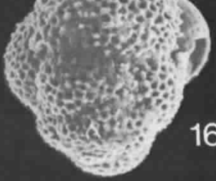
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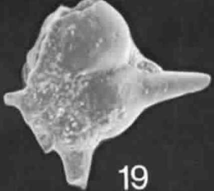
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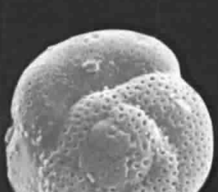
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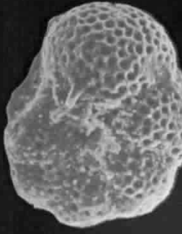
PLATE 4

LATE EOCENE

Figs.	
1	*Globorotalia gemma* Jenkins; UWAGD 77720, x120, 575-590 m.
2	*G. opima nana* Bolli; UWAGD 77729, x110, 575-590 m.
3, 4	*G. o. opima* Bolli; UWAGD 77728, x110, 545-560 m.
5	*Globigerina* cf. *ampliapertura* Bolli; UWAGD 77739, x90, 545-560 m.
6, 7	*G. corpulenta* Subbotina; UWAGD 77744, x50, 545-560 m.
8	*G. eocaenica* Terquem; UWAGD 77745, x55, 545-560 m.
9	*G. officinalis* Subbotina; UWAGD 77750, x150, 545-560 m.
10	*G. praebulloides* Blow; UWAGD 77751, x110, 545-560 m.
11	*G.* cf. *tapuriensis* Blow & Banner; UWAGD 77756, x75, 545-560 m.
12, 13	*Subbotina angiporoides angiporoides* (Hornibrook); UWAGD 77761, x90, 545-560 m.
14	*S. linaperta* (Finlay); UWAGD 77762, x90, 575-590 m.
15	*Globigerinatheka index index* (Finlay); UWAGD 77774, x60, 545-560 m.
16	*G. subconglobatus luterbacheri* Bolli; UWAGD 77775, x45, 545-560 m.
17, 18	*Globorotaloides suteri* Bolli; UWAGD 77771, x120, 575-590 m.
19, 20	*Catapsydrax* cf. *echinatus* Bolli; UWAGD 77777, x125, 545-560 m.
21, 22	*C. martini martini* Blow & Banner; UWAGD 77778, x100, 545-560 m.
23	*C. pera* (Todd); UWAGD 77780, x85, 575-590 m.



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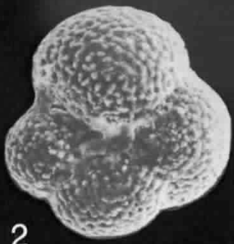

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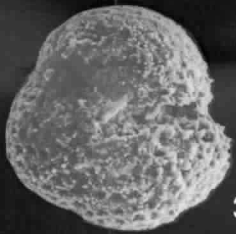

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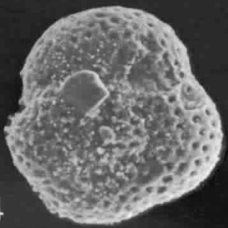

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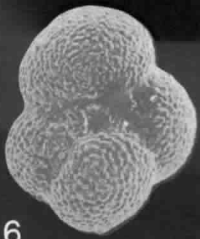

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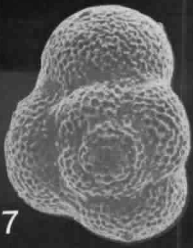

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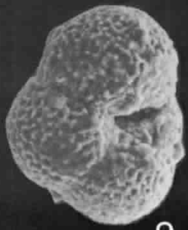

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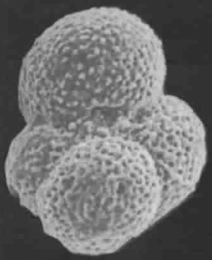

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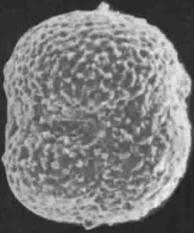

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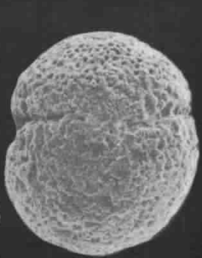

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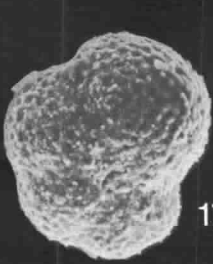

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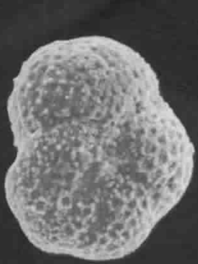

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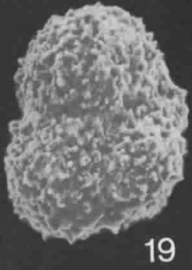

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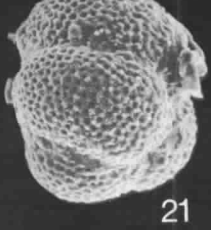

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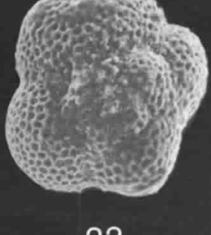

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PLATE 5

LATE EOCENE

Figs.

1 *Catapsydrax unicavus primitivus* (Blow & Banner); UWAGD 77781, x110, 545-560 m.

LATE MIOCENE

2 *Globorotalia* cf. *acostaensis acostaensis* Blow; UWAGD 77706, x85, 485-500 m.

3, 4 *G. crassula conomiozea* Kennett; UWAGD 77715, x40, 515-530 m.

5, 6 *G. cultrata cultrata* (d'Orbigny); UWAGD 77716, x45, 515-530 m.

7, 8 *G. c. menardii* (d'Orbigny); UWAGD 77717, x60, 485-500 m.

9, 10 *G. merotumida* Blow; UWAGD 77724, x85, 455-470 m.

11, 12 *G. internec merotumida-plesiotumida;* UWAGD 77725, x45, 455-470 m.

13–15 *G. miocenica* Palmer; UWAGD 77726, x40, 485-500 m.

16 *G. obesa* Bolli; UWAGD 77727, x85, 485-500 m.

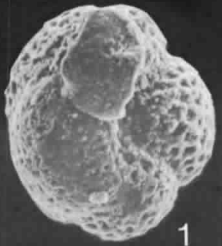
17, 18 *G. tumida* (Brady) subsp.; UWAGD 77733, x60, 455-470 m.

19, 20 *G.* sp. 1; UWAGD 77737, x120, 485-500 m.

21, 22 *Globigerina angustiumbilicata* Bolli; UWAGD 77740, x100, 485-500 m.

23 *G. bulloides bulloides* d'Orbigny; UWAGD 77741, x65, 455-470 m.

24 *G. b. concinna* Reuss; UWAGD 77742, x55, 455-470 m.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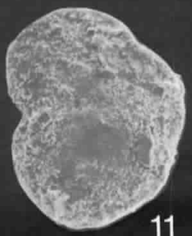
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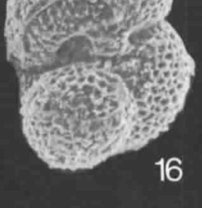
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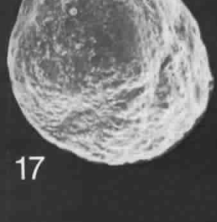
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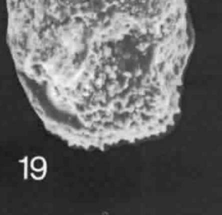
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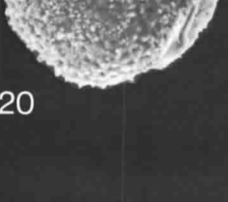
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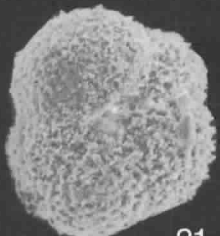
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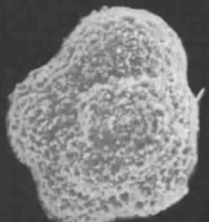
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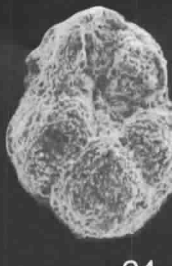
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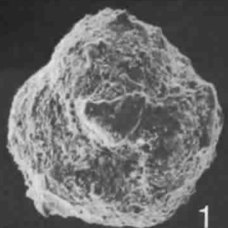
PLATE 6

LATE MIOCENE

Figs.	
1	*Globigerina conglomerata* Schwager; UWAGD 77743, x50, 455-470 m.
2	*G. nepenthes nepenthes* Todd; UWAGD 77749, x50, 455-470 m.
3, 4	*G. pseudofoliata* Parker; UWAGD 77752, x55, 515-530 m.
5	*G. rubescens decoraperta* Takayanagi & Saito; UWAGD 77753, x95, 515-530 m.
6, 7	*G. venezuelana* Hedberg; UWAGD 77758, x40, 485-500 m.
8, 9	*G.* sp. 1; UWAGD 77759, x90, 455-470 m.
10, 11	*Globigerinoides bollii* Blow; UWAGD 77764, x130, 515-530 m.
12	*G. obliquus* Bolli; UWAGD 77765, x60, 485-500 m.
13, 14	*G. quadrilobatus immaturus* Le Roy; UWAGD 77766, x45, 455-470 m.
15	*G. q. sacculifer* (Brady); UWAGD 77767, x55, 455-470 m.
16	*Globoquadrina altispira altispira* (Cushman & Jarvis); UWAGD 77768, x70, 485-500 m.
17, 18	*G. dehiscens dehiscens* (Chapman, Parr & Collins); UWAGD 77769, x60, 455-470 m.
19	*G. larmeui larmeui* Akers; UWAGD 77770, x60, 515-530 m.
20	*Sphaeroidinellopsis seminulina seminulina* (Schwager), UWAGD 77772, x65, 455-470 m.
21	*Orbulina universa universa* d'Orbigny; UWAGD 77773, x30, 455-470 m.
22	*Turborotalita quinqueloba* (Natland); UWAGD 77776, x85, 515-530 m.
23	*Catapsydrax parvulus* Bolli, Loeblich & Tappan; UWAGD 77779, x90, 455-470 m.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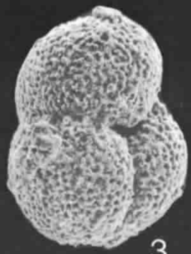
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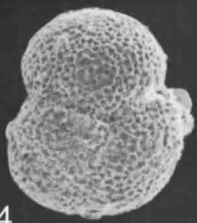
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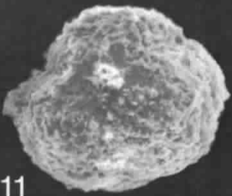
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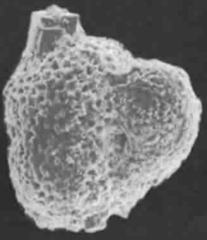
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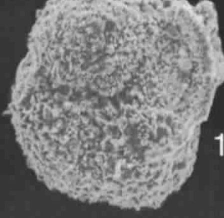
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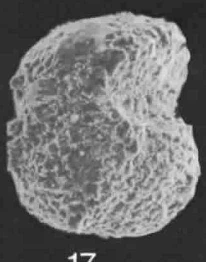
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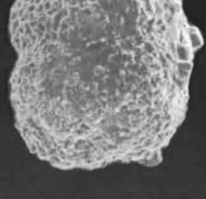
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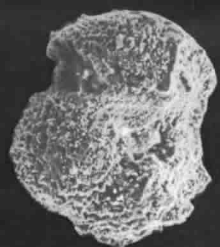
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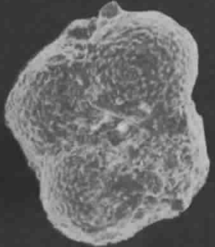
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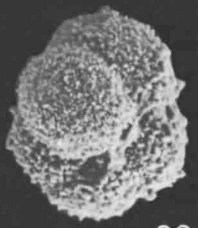
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Some Cretaceous foraminifera from Leg 26 of the DSDP in the Indian Ocean

by

Viera Scheibnerová

The most important species in Cretaceous sediments recovered by the DSDP in the Indian Ocean are described and illustrated. The great majority of these species have been previously described from coeval sediments on adjacent land, most prominently in the Great Australian Basin. Therefore, they are typically Austral in their composition, bioprovincial value, and ecology (mostly in the shallow to extremely shallow depth range). A few species resemble those which have previously been recovered only from Boreal sediments in the Northern Hemisphere, in Mangyshlak and the Asiatic parts of the USSR, and California. One new species—*Charltonina australis* n.sp.—is described.

Introduction

As part of her synthesis of Cretaceous benthonic foraminifera the author had the opportunity to study Cretaceous foraminifera of Leg 26, Sites 256, 257, and 258 through the courtesy of Dr René Herb (Geologisches Institut, University of Bern, Switzerland). Special emphasis is put on the foraminiferal assemblages of Site 258 as they contained the greatest variety of excellently preserved species.

Sixty-four species of planktonic and benthonic foraminifera were determined and some of them are described in this paper, most from Site 258. Stratigraphically, they mostly represent Albian, with some species from the Late Cretaceous (Cenomanian, Turonian, Santonian, and Campanian). Scanning electron photographs were taken in the Electron Microscope Unit of the Sydney University. All prints were prepared by Mr D. Barnes of the Geological Survey of New South Wales in Sydney. All specimens are housed in the Micropalaeontological Collection of the Geological Survey of New South Wales.

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Dentalina santoodnae Ludbrook

Plate 1, fig. 13

1966 *Dentalina santoodnae* Ludbrook, p. 113, pl. 8, fig. 6.

1976 *Dentalina santoodnae* Ludbrook, Scheibnerová, p. 66, pl. 22, figs. 6-7, text-figs. 55, 56.

Description and remarks: The test is free, large, broadly elongate, making a robust impression, straight or gently curved. The globular proloculus is followed by 5 to 9 (rarely 9 to 11 as mentioned by Ludbrook, 1966) chambers increasing gradually in size as added. The chambers are appressed, low and broad, increasing gradually in height, so that the last (largest) chamber is as high as broad. The sutures are distinct, flush with the surface or later constricted, slightly oblique in the early portion, becoming horizontal in the later portion. The wall is calcareous, finely perforate, the surface is smooth and often shiny. The radiate aperture is terminal, excentric and slightly produced. The occurrence of *D. sandtoodnae* at such a high stratigraphical level is quite interesting, because in the Great Australian Basin it tends to occur lower in the section.

Dimensions: length 0.35-1.40 mm; width 0.20-0.30 mm.

Marginulinopsis santoodnae Ludbrook

Plate 2, fig. 3

1966 *Marginulinopsis santoodnae* Ludbrook, p. 122, plate 9, figs. 14, 15.

Description and remarks: The test is free, small, broad, ovate in section. The early portion, composed of four to six coiled chambers, is planispirally coiled and the chambers increase gradually in size and are followed by 2 or 3 chambers in a straight line, which are more than twice as broad as high. The chambers are compressed and slightly carinate on the dorsal side, inflated on the ventral side, with the final chamber inflated ventrally; the sutures are distinct, depressed, gently curved, radial in the coiled portion and oblique in the uncoiled portion; the aperture is radiate, at the peripheral angle. The wall is calcareous, hyaline, finely perforate, smooth.

Dimensions: length 0.28-0.40 mm, width 0.15-0.20 mm, thickness 0.10-0.15 mm.

Praebulimina nannina (Tappan)

Plate 2, figs. 8, 9

1940 *Bulimina nannina* Tappan, p. 116, pl. 19, fig. 4.

1962 *Praebulimina nannina* (Tappan), Tappan, p. 187, pl. 49, figs. 6-9.

1966 *Praebulimina* sp. cf. *P. nannina* (Tappan), Ludbrook, pp. 133-134, pl. 10, fig. 25.

1974 *Praebulimina* sp. Scheibnerová, p. 712, pl. 10, fig. 12; pl. 15, fig. 3.

1976 *Praebulimina nannina* (Tappan), Scheibnerová, pp. 81-82, pl. 41, fig. 1, text-fig. 98.

Description and remarks: The test is free, tiny, triserial, flaring. The early chambers are small, increasing rapidly in size so that the last 2 chambers are about half the length of the test. The chambers are inflated. The sutures are distinct, constricted. The wall is calcareous, finely perforate, hyaline; the surface is smooth. The aperture is loop-shaped, extending up the face of the final chamber.

Dimensions: length 0.15-0.20 mm, width 0.10-0.15 mm.

Buliminella fabilis Cushman & Parker

Plate 2, fig. 10

1936 *Buliminella fabilis* Cushman & Parker, p. 7, pl. 2, fig. 5.

1970 *Buliminella fabilis* Cushman & Parker, Eicher & Worstell, p. 290, pl. 3, figs. 13, 14.

Description and remarks: The test is free, forming a high and close spire formed by numerous, high and narrow chambers. The last whorl is composed of 3½ inflated elongate chambers. The aperture forms a high narrow loop with an internal tooth plate connecting the aperture with that of the previous chamber.

Dimensions: length 0.15-0.26 mm, width 0.10-0.15 mm.

Tappanina laciniosa Eicher & Worstell

Plate 2, figs. 11-13

1970 *Tappanina laciniosa* Eicher & Worstell, p. 291, pl. 4, figs. 6, 7, 11, 12.

Description and remarks: The test is free, small, flaring, consisting of biserially arranged 5-7 pairs of chambers, often slightly twisting about the longitudinal axis, the periphery is serrated. The early chambers are smooth and subglobular, later ones increase more rapidly in their width than in height and become typically cuneiform. Later chambers of most specimens develop an irregular skirt-like flange which extends continuously or brokenly from one side to the other and around the periphery. The development of these flanges varies, and they may be missing completely; very few specimens develop peripherally overhanging chambers. The sutures are distinct, becoming slightly depressed, and curving toward the periphery. The wall is calcareous, finely perforate. The aperture forms an arch on one side of a deep indentation in the apertural face, bordered by a lip. The tooth-plate was not observed.

The specimens found in the DSDP samples from the Indian Ocean are practically identical with the American specimens kindly provided by Dr D. L. Eicher. The only difference is that in the American material there are many more specimens with well developed flanges, compared with the material from the Indian Ocean. Stratigraphically, the species in both regions appears as a good Cenomanian indicator.

Dimensions: length 0.22-0.30 mm, width 0.15-0.20 mm.

?**Discorbis** sp.

Plate 2, fig. 14; plate 3, figs. 1-3

1972 *Discorbis* sp. Scheibnerová, p. 213, pl. 1, figs. 1a-c; pl. 2, figs. 1a, b.

1974 *Discorbis* sp. Scheibnerová, Lambert & Scheibnerová, p. 22, pl. 1, figs. 6, 7.

1976 ?*Discorbis* sp., Scheibnerová, p. 83, pl. 42, figs. 1-4; pl. 43, figs. 1, 2, text-figs. 99a-c, 100a-c.

Description and remarks: The test is free, trochospiral, calcareous, plano-convex or concavo-convex, flat or concave on the umbilical side. The primary aperture is an interiomarginal extra-umbilical arch; very characteristic are the secondary sutural openings on opposite sides of each chamber flap. These remain open as successive chambers are formed. In some very well preserved specimens they are clearly visible extending from the basal portion of each chamber towards the umbilical region; these openings extend along the proximal side of each radial umbilical flap and connect through cavity beneath the flaps to the interior of the chamber.

Practically identical specimens occurred in coeval samples from South Africa and were described by Lambert & Scheibnerová (1974). Malumian (*in* Flores, Malumian, Masiuk & Riggi, 1973) reported the same form in the Albian and Cenomanian in South America. A detailed description of these interesting forms is in preparation and the results will be published by Scheibnerová, Malumian & Lambert (in prep.).

Dimensions: maximum diameter 0.25-0.55 mm, minimum diameter 0.25-0.40 mm, thickness 0.15-0.25 mm.

Valvulineria loetterlei (Tappan)

Plate 3, figs. 5, 6

1940 *Gyroidina loetterlei* Tappan, p. 120, pl. 19, fig. 10.

1943 *Gyroidina loetterlei* Tappan, Tappan, p. 512, pl. 82, fig. 9.

1962 *Valvulineria loetterlei* (Tappan), Tappan, p. 194, pl. 54, figs. 1-4.

1966 *Valvulineria crespinae* Ludbrook, p. 134, pl. 12, figs. 1, 2.

1970 *Valvulineria loetterlei* (Tappan), Eicher & Worstell, p. 29, pl. 4, figs. 13a, b, 14a, b.

1976 *Valvulineria loetterlei* (Tappan), Scheibnerová, pp. 82-83, pl. 41, figs. 4-6.

Description and remarks: The test is free, small, trochospiral, with the periphery rounded. The last whorl is composed of 7 chambers. The chambers increase gradually in size and are moderately inflated. The sutures are at first indistinct, only those between the chambers of the last whorl being deep and distinct. The aperture forms a low peripheral arch extending onto the umbilical side, in our specimens not reaching into the umbilicus. The intercameral foramen reaches only about half way to the umbilicus. The wall is finely perforate; the surface is smooth.

Specimens of *V. loetterlei* are relatively frequent in all the DSDP samples in the Indian Ocean. Their stratigraphic value is relatively small; they occur throughout the Albian and Cenomanian.

Dimensions: diameter 0.20-0.25 mm; thickness 0.18-0.20 mm.

Pseudopatellinella howchini Ludbrook

Plate 3, figs. 7, 8

1966 *Pseudopatellinella howchini* Ludbrook, pp. 134-135. pl. 10, figs. 16-19.

Description and remarks: The test is free, small, oval in outline, trochospirally coiled with all whorls visible on the spiral side and only two chambers visible on the umbilical side. The spiral side is mostly much more convex than the umbilical side. The small proloculus is followed by a series of undivided crescentic chambers, two per whorl. The sutures are distinct, slightly depressed or flush with the surface. The wall is calcareous, coarsely perforate, hyaline, smooth, often translucent or transparent. The aperture is a high broad interiomarginal crescentic arch.

Dimensions: maximum diameter 0.15-0.30 mm, minimum diameter 0.13-0.25 mm, height 0.13-0.25 mm.

?**Serovaina** sp. cf. **orbicella** (Bandy)

Plate 4, figs. 3, 4

1951 *Gyroidina globosa* (Hagenow) var. *orbicella* Bandy, p. 505, pl. 74, fig. 2.

1976 *Serovaina* cf. *orbicella* (Bandy), Scheibnerová, p. 90, pl. 59, fig. 4.

Description and remarks: The test is free, trochospiral with the spiral side partly evolute and the umbilical side completely involute. The last whorl is composed of 6 to 8 inflated chambers increasing rapidly in size. The sutures are distinct, radial and depressed. The periphery is broadly rounded. The wall is calcareous, finely perforate, radial in structure, monolamellar and smooth. The aperture forms a low interiomarginal slit at the base of a high apertural face and extends from near the periphery to the umbilicus, often with a small lip.

Specimens from the Great Australian Basin, referred to as *S.* cf. *orbicella* were studied in some detail by the author. They were compared with the specimens determined as *S. orbicella* by Dr J. H. Wall (personal communication) and found to be indistinguishable. It is a very interesting form, but its morphological simplicity makes its exact determination quite difficult.

TABLE 1: THE MOST IMPORTANT BENTHIC AND PLANKTIC FORAMINIFERA OF DSDP LEG 26

* sensu Scheibnerová, 1976 † sensu Scheibnerová, 1973	256-9-1	256-9-1 (120-122)	256-8-6 (115-119)	256-8-1 (above basalt)	256-7cc	257-8cc	258-5-2 (115-119)	258A-8-6	258A-8-6 (141-144)	258-9cc	258-10cc	258-11cc	258-12cc	258-12-1 (100-103)	258-13cc (bottom)	258-13cc (middle)	258-14-1 (75-79)	258-14-1 (125-127)	258-14cc	258-15-1 (128-132)	258-15cc	258-16-1 (bulk)	258-16cc	258-17-1 (95-99)	258-17cc	258-18cc	258-18-1 (115-119)	258-20cc
Alabamina sp.	..	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Alabamina australis	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Allomorphina whangaia	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Ammobaculites fisheri	..	..	..	x	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	x	..	..	..	..
Ammodiscus sp.	..	..	..	x	x	x	..	..	..	..	..	..	..	..	..	..	..	..	x	..	x	..	x	x	x	x	..	..
A. cretaceus	x	x	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..
Anomalina sp.	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Aragonia sp.	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Bolivina sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..
Buliminella fabilis	..	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..	..	x	..	..	..	..	..	..	..	..	..
Charltonina australis	x	..	..	..	..	x	..	..	..	..	..	..	..	..	x	..	x	x	x	x	x	..	..	..	..	..	..	..
Cibicides excavata	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Citharina sp.	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..	x	..	..	..
Coryphostoma sp.	..	x	x	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Dentalina santoodnae	x	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..
?*Discorbis* sp.	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	x	..	..	..	..	..	..	..	..
Dorothia sp.	..	..	..	x	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Eggerella sp.	x	..	..	..	x	x	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..
Eponides sp.*	x	x	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	x	..	..	..
Eponides sp. *"rosa"*†	..	..	..	..	..	..	..	x	..	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Eponides concinna	..	..	..	..	..	..	..	x	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Frondicularia sp. 1 (ribbed)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..
Frondicularia sp. 2 (smooth)	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..
Gaudryina bevissensis	x	..	..	x	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x
Gavelinella oodnadattaensis	..	..	..	x	..	x	..	..	..	..	..	..	..	..	..	x	x	x	x	x	..	x	..	..	..	..	..	..
G. ex gr. *intermedia*	x	x	..	x	..	..	..	..	..	..	..	..	..	..	x	x	x	x	x	x	x	x	..	..	..	x	..	x
G. compressa	..	..	..	..	..	..	x	x	x	x	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"Globigerinelliodes" gyroidinaeformis	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	..
Globotruncanid	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	x	..	x	..	..	..	..	..	x
Globorotalites cf. *umbilicatus*	..	..	..	..	..	..	x	x	x	x	x	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Glomospira gordialis	x	x	..	x	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Gubkinella sp.	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Gyroidina sp.	..	..	..	..	..	..	x	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Gyroidinoides sp.	..	..	..	..	..	x	x	..	..	..	x	..	x	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..
G. primitiva	x	x	..	x	..	..	..	..	..	..	..	..	..	..	x	x	x	..	x	x	x	..	..	..	x	..	..	x
G. cf. *primitiva*	x	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Haplophragmoides sp. 1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	x	..	..	x	x
Haplophragmoides sp. 2	x	..	..	x	x	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Hyperammina sp.	x	x	..	x	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..
Labrospira pacifica	x	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Lenticulina sp.	x	x	..	x	..	..	x	..	..	..	x	..	x	x	..	..	..	..	x	..	..	x	x	..	..	x	..	..
Lenticulina cf. *taylorensis*	..	..	..	..	..	..	..	..	x	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Lingulogavelinella frankei	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..	x	x	x	..	..	..	..	x	x	..	x
L. orbiculata	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	x	..	..	x	x	x	..	..	x
Marginulinopsis santoodnae	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x
Marssonella oxycona	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..
Matanzia sp.	..	x	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Nodosaria cf. *septemcostata*	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..
N. gidya	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..	x	x	..	..
Osangularia utaturensis	..	x	x	x	..	x	..	..	..	..	..	..	..	..	..	x	..	..	..	..	x	..	..	..	..	x	..	x
Pleurostomella sp.	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..	x	..	..	..
P. obtusa	x	..	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	x	..	x	x	x	..	..	..	..	..
Praebulimina sp.	..	..	..	x	..	x	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
P. reussi	..	..	..	..	..	..	..	x	x	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..
P. nannina	x	x	..	x	..	x	..	..	..	..	..	..	..	..	x	x	..	..	..	..	..	..	..	..	..	..	..	..
Psammosphaera parva	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Pseudobolivina variana	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..
Pseudolamarckina sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	x	..	..	x	..	..	..	..	..	..	..	..	..
Pseudopatellinella howchini	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	x	x	..	x	..	..	..	..	..	..	..	..	..
Pullenia sp.	x	x	..	x	..	..	x	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..
Pullenia cretacea	..	..	..	..	..	..	..	x	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Quinqueloculina sp.	..	..	..	x	..	..	x	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..
Recurvoides sp.	x	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Rotaliatina asiatica	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..	x	x	x	..	x	..	..	..	x	..	..
Saracenaria erlita	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..
?*Serovaina* sp. cf. *orbicella*	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..
Tappanina laciniosa	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	x	x	..	..	..	..	..	..	..	..	..
Textularia sp.	..	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..	x	..	x	..	..	..	..
Textularia cf. *trilobita*	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..
Tribrachia australiana	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..
Tritaxia sp.	x	..	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Valvulineria gracillima	x	x	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Valvulineria loetterlei	..	..	..	..	..	x	..	..	..	..	..	..	..	..	..	..	x	x	..	..	..	..	..	..	..	..	..	x
Valvulineria sp.	x	..	..	x	..	x	..	..	..	..	..	..	..	..	..	..	..	..	..	x	x	..	..	..	..	..	x	x
Verneuilina sp.	x	..	..	x	..	x	..	..	..	..	..	..	..	..	..	..	..	x	..	..	..	..	..	..	x	x	..	..

Osangularia utaturensis (Sastry & Sastri)
Plate 4, figs. 5-7

1966 *Eponides utaturensis* Sastry & Sastri, p. 292, pl. 19, figs. 6a-c.
1970 *Osangularia californica* Dailey, pp. 108-109, pl. 13, figs. 3, 4.
1974 *Osangularia utaturensis* (Sastry & Sastri), Scheibnerová, p. 714, pl. 4, figs. 27, 28; pl. 5, figs. 1-9; pl. 11, figs. 4a-c, 5a-c.

Description and remarks: The test is free, circular or nearly circular in outline, equally biconvex or with spiral side more convex than the umbilical. The chambers are almost flat, generally 10-12 in the final whorl and increasing gradually in size as added. All chambers are visible on the spiral side, only those of the final whorl are visible on the umbilical side. The sutures are distinct, oblique, straight or slightly curved initially and becoming strongly curved later, on both the spiral and umbilical sides. All sutures except for those between the last 2-3 chambers, are limbate and raised, sometimes meeting at the periphery to form quite acute and elevated keels. The wall is calcareous, finely perforate, smooth, with layers of imperforate secondary calcite along the sutures and central part of the test on both sides. The aperture is V-shaped and forms a slit at the base of the final chamber, then bends obliquely up the apertural face. Sometimes 2 isolated slits (an interiomarginal and areal) occur.

Specimens of *O. utaturensis* from the Leg 27 of the DSDP were compared with those determined as *O. californica* by Dailey (1970) and found to be conspecific. Forms referred to *O. calcifornica* are widely distributed in the Austral and Boreal Biogeoprovinces.

Dimensions: diameter 0.14-0.40 mm, thickness 0.09-0.20 mm.

Rotaliatina asiatica N. Bykova
Plate 4, figs. 8-12; plate 5, fig. 1

1947 *Rotaliatina asiatica* N. Bykova, p. 234, table 1, figs. 9a-c (fide Vasilenko, 1961, p. 49).
1961 *Rotaliatina asiatica* N. Bykova, Vasilenko, pp. 49-50, pl. 9, figs. 1-4, 11.

Description and remarks: The test is free, small, trochospiral, with the spiral side more convex than the umbilical one, often with the central part highly conical. The outline is rounded, lobulate. The last whorl consists of 5-6 chambers which are wider than long. The septal sutures are deep, curved on both sides. On the umbilical side only the chambers of the last whorl are visible and are of almost the same size. The umbilicus is narrow and quite deep. The periphery is wide and rounded. The aperture is short, interiomarginal, forming a clear arch-like opening along the suture of the last chamber from near umbilicus to about ¾ of its length, bordered by a narrow lip. The wall is thin, calcareous, covered by sparse, quite large pores.

Dimensions: maximum diameter 0.15-0.30 mm, minimum diameter 0.14-0.28 mm, height 0.07-0.15 mm.

Charltonina australis sp. nov.
Plate 5, figs. 2-5

Material examined: about 200 specimens from the Late Albian-Cenomanian of holes 256, 257, and 258 of Leg 26.

Holotype: specimen no. MMMC 00904; Housed in the Micropalaeontological collection of the Geological Survey, New South Wales in the Geological and Mining Museum. Figured Plate 5, figs. 2, 3 herein.

Paratypes: specimen nos. 00906, 00907 (all from 26-258-14cc).

Type level: Cenomanian of DSDP Site 258.

Type locality DSDP Site 258, core 14 cc, Naturaliste Plateau, eastern Indian Ocean.

Diagnosis: Trochospiral, biconvex, test small to medium size with 5-9 chambers in the last whorl and lobulate periphery.

Description and remarks: The test is free, trochospiral, lenticular, with carinate periphery. All chambers are visible on the spiral side, only those of the final whorl are visible on the umbilical side. The final sutures are strongly oblique, the umbilical ones are curved to strongly curved. The umbilicus is closed. The aperture forms an elongate slit extending from the umbilicus to the periphery and bending up the apertural face, being parallel to the peripheral keel. The wall is calcareous, smooth, covered by sparse, quite large pores.

Dimensions: diameter 0.20-0.35 mm; thickness 0.10-0.20 mm. Holotype: diameter 0.30 mm, thickness 0.15 mm.

Gavelinella oodnadattensis Ludbrook
Plate 3, figs. 6, 9

1966 *Gavelinella oodnadattensis* Ludbrook, p. 144, pl. 12, figs. 17, 18.
1976 *Gavelinella oodnadattensis* Ludbrook, Scheibnerová, p. 93, pl. 66, fig. 4, text figs. 108-109.

Description and remarks: The test is free, very tiny, low trochospiral, very slightly convex on the spiral side, concave on the umbilical side and rather compressed in profile. The periphery is bluntly carinate and slightly lobulate. The last whorl is composed of 7 to 8 chambers with very slightly inflated umbilical sides, increasing gradually in size as added. The sutures are distinct, depressed, gently curved. The aperture forms a low interiomarginal slit with triangular imperforate flaps and extends from the peripheral margin to the umbilicus beneath the umbilical chamber flap. The occurrence of this tiny *Gavelinella* in the samples recovered by the DSDP in the Indian Ocean is of a great interest, especially because here it is associated also with deposits of definitely Cenomanian age. The same age can be attributed to the uppermost part of the marine Cretaceous section of the Great Australian Basin.

Dimensions: diameter 0.15-0.25 mm; thickness 0.08-0.10 mm.

Gavelinella ex gr. **intermedia** (Berthelin)
Plate 5, figs. 7, 8, 10, 11

1880 *Anomalina intermedia* Berthelin, pp. 67-68, pl. 4, figs. 14a-c.
1965 *Gavelinella* (*Berthelina*) *intermedia* (Berthelin), Malapris, pp. 138-139, pl. 1, figs. 2-4, 6 (non figs. 1, 5, 7); plate 2, figs 2-4, (non figs. 2, 5, 7).
1966 *Gavelinella intermedia* (Berthelin, 1880), Michael, pp. 432, 434, pl. 50, figs. 4-13 (cum syn.).
1972 *Gavelinella* (*Berthelina*) *intermedia* (Berthelin) Gawor-Biedowa, pp. 120-121, pl. 15, figs. 7-9 (a-c), fig. 12.
1974 *Gavelinella* ex gr. *intermedia* (Berthelin), Scheibnerová, p. 714, pl. 5, figs. 18-24; pl. 6, figs. 1-4.

Description and remarks: The test is free, calcareous, planispiral, nearly bilaterally symmetrical, rounded in outline. The dorsal side is more convex than the ventral, semi-involute with the chambers of 1½ whorls partly visible. The last whorl is composed of 9-12 chambers (mostly 9-10). The umbilical depression on one side is sometimes filled with imperforate secondary calcite in the form of a knob. The aperture is slit-like, interiomarginal-equatorial, covered by a more-or-less wide imperforate lip entering into the ventral side and reaching under the imperforate flaps of the last chambers. The sutures are slightly curved and distinct only between the 3-5 last chambers of the last whorl. The periphery is narrowly rounded. Although there is quite an extensive variability in size, convexity of the test and the chambers, and the extent of deposition of the imperforate secondary calcite, the species is rather characteristic.

Dimensions: diameter 0.20-0.45 mm; thickness 0.15-0.30 mm.

Lingulogavelinella frankei (Bykova)

Plate 6, figs. 3-11

1970 *Lingulogavelinella frankei* (Bykova), Scheibnerová, pp. 111-113, pl. 1, figs. 1-11; text-figs. 2, 3 (cum syn.).

Description and remarks: The test is free, small, low trochospiral, slightly asymmetrical, generally with 6 to 7, rarely 5 chambers in the last whorl. The ventral side is completely involute. The last 2-3 chambers are inflated and the sutures are radial and depressed. The aperture is peripherodorsal and interiomarginal. The peripheral part of it is bordered by a rim and its dorsal part by tongue-like extensions of the chamber wall running along the sutures between the chambers, covering sometimes ¾ of the length of the sutures. The periphery is lobulate. When observed by the stereoscopic microscope, the surface appears smooth, with no characteristic ornamentation such as ribs or pustules. However, the scanning electron microscope reveals quite a high degree of granulation of the wall. As shown by thin sections of several specimens, the wall is bilamellar. The monolamellar appearance is probably caused by recrystallisation.

Dimensions: maximum diameter 0.29-0.33 mm; minimum diameter 0.24-0.30 mm; thickness 0.15-0.20 mm.

Lingulogavelinella orbiculata (Kuznetsova)

Plate 6, fig. 12; plate 7, figs. 1-2

1972 *Lingulogavelinella orbiculata* (Kuznetsova 1953), Gawor-Biedowa, pp. 111-112, pl. 15, figs. 3a-c (cum syn.).
1976 *Lingulogavelinella orbiculata* (Kuznetsova), Scheibnerová, pp. 100-101, pl. 72, fig. 4; pl. 73, figs. 4, 5, text. figs. 119, 120.

Description and remarks: The test is free, small, globular, strongly involute. The last whorl is composed of 4 to 5, rarely 5½ to 6 dorsally and ventrally inflated chambers. The last chamber is especially strongly inflated on its ventral side and much larger than the previous ones. The aperture is periphero-dorsal, with its dorsal part covered by the perforate chamber wall extensions. The sutures on the dorsal side are radial, flush with the surface, those of the ventral side are radial and strongly depressed. The peripheral margin is rounded, wide to extremely wide. The wall is calcareous, thin, perforate.

Dimensions: diameter 0.18-0.30 mm; thickness 0.10-0.20 mm.

Gubkinella californica Church

Plate 8, figs. 1-3

1968 *Gubkinella californica* Church, p. 573, pl. 7, fig 8.
1973 *Gubkinella californica* Church, Dailey, p. 81, pl. 17, fig. 3.

Description and remarks: The test is free, tiny, high trochospiral, stout with 4 inflated chambers in each whorl. The aperture is a low interiomarginal arch bordered by a thickened rim. The surface is smooth.

Gubkinella californica Church figured here was found in Leg 27-263 samples. Although this paper deals only with Leg 26, this species is described and illustrated because Leg 27 foraminifera will not be dealt with again in the foreseeable future. In Leg 26 samples, only ?*Gubkinella* sp. was identified (Plate 8, fig. 4).

Dimensions: height 0.10-0.15 mm; width 0.07-0.10 mm.

Schackoina cenomana (Schacko)

Plate 8, fig. 5

1896 *Siderolina cenomana* Schacko, pp. 161-168, pl. 4 (fide Loeblich & Tappan, 1964).
1953 *Schackoina cenomana* (Schacko), Subbotina, p. 128, pl. 1, figs. 1-3 (cum syn.).
1966 *Schackoina cenomana* (Schacko, 1897), Salaj & Samuel, pp. 165-166, pl. 7, figs. 8a-c.
1969 *Schackoina cenomana* (Schacko, 1896), Scheibnerová, p. 57, pl. 7, figs. 5-7a, b.
1974 *Schackoina cenomana* (Schacko), Herb, p. 751, pl. 1, fig. 6.

Description and remarks: The test is free, tiny, at first low trochospiral, later becoming almost planispiral. The chambers are radially elongate with one or more hollow tubulospines extending outward from the middle of each chamber on the periphery. The sutures are straight, radial, depressed. The number of chambers in the last whorl is 3 to 5, mostly 4. The wall is calcareous, finely perforate, the surface is smooth or finely hispid.

Dimensions: diameter 0.20-0.35 mm; thickness 0.10-0.15 mm.

Gavelinella compressa Sliter

Plate 10, figs. 1-6

1968 *Gavelinella compressa* Sliter, p. 122, pl. 24, fig. 2.

Description and remarks: The test is free, quite large, compressed, low trochospiral. The spiral side is partly evolute and all chambers are visible through low central boss, the umbilical side is partly evolute, with small spiralling umbilical boss. The periphery is first rounded and later subacute. The number of chambers in the last whorl is 11 to 13, slightly inflated. The sutures are distinct, limbate, strongly curved on both sides, initially elevated and later depressed on the spiral side, flush on the umbilical side. The wall is calcareous, finely perforate, granular in structure. The surface is smooth. The aperture is a low interiomarginal arch extending from periphery to umbilicus, covered by a narrow lip forming a triangular flap extending over the umbilicus from each chamber.

Dimensions: diameter 0.50-1.00 mm; thickness 0.12-0.25 mm.

The species was originally described from the Late Cretaceous of Southern California and northeastern Baja California, Mexico. Subsequently it has been identified in Late Cretaceous deposits in Western Australia by Dr M. Owen of the Bureau of Mineral Resources, Canberra (personal communication).

The only species that occur in the DSDP samples from the Indian Ocean but have not yet been found in coeval sediments on adjacent land are the forms described here as *Rotaliatina asiatica* N. Bykova and *Charltonina australis* sp. nov. The rest of the species have all been found and described in various parts of the Austral biogeoprovince. The Austral nature of the Cretaceous foraminiferal assemblages is beyond any doubt. Their nature has been described in several publications by the author and the reader is referred to these (V. Scheibnerová, 1971, 1972, 1974, 1976).

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PLATE 1

Fig.

1 *Psammosphaera* sp., specimen no. MMMC 00905, sample 26-258-14 cc; x100.

2 *Ammodiscus* sp., specimen no. MMMC 00982, sample 26-258-18 cc; x170.

3 *Ammodiscus* sp., specimen no. MMMC 00913, sample 26-258-14 cc; x100.

4 *Glomospira gordialis* Parker & Jones, specimen no. MMMC 00947, sample 26-257-8 cc; x250.

5 *Haplophragmoides* sp. 1, specimen no. MMMC 00980, sample 26-258-20 cc; x150.

6 *Haplophragmoides* sp. 1, specimen no. MMMC 00981, sample 26-258-20 cc; x120.

7 *Textularia* sp., specimen no. MMMC 00903, sample 26-258-14 cc; x100.

8 *Verneuilina* sp., specimen no. MMMC 00949, sample 26-257-8 cc; x70.

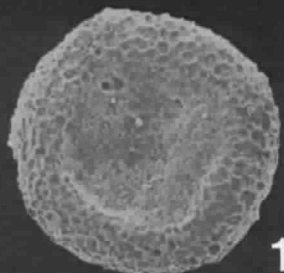
9 *Eggerella* sp., specimen no. MMMC 00948, sample 26-257-8 cc; x 120.

10 ?*Miliolinella* sp., specimen no. MMMC 00975, sample 26-258-14 cc; x100.

11 ?*Miliolinella* sp., oblique apertural view of the same specimen as above; x120.

12 *Nodosaria* cf. *septemcostata*, specimen no. MMMC 00931, sample 26-258-14 cc; x90.

14 *Dentalina santoodnae* Ludbrook, specimen no. MMMC 00914, sample 26-258-14 cc; x60.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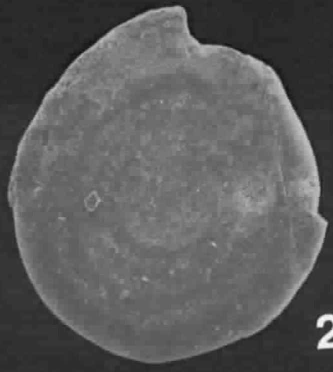
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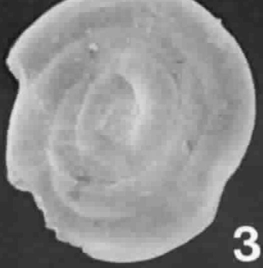
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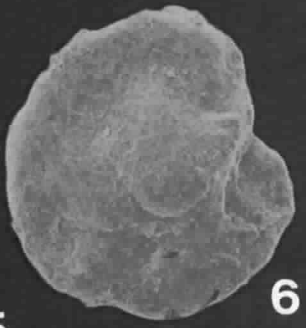
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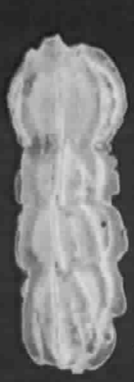
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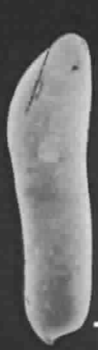
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PLATE 2

Fig.

1 *Lenticulina* sp., specimen no. MMMC 00911, sample 26-258-14 cc; x350.

2 *Lenticulina* sp., specimen no. MMMC 00916, sample 26-258-14 cc; x200.

3 *Marginulinopsis santoodnae* Ludbrook, specimen no. MMMC 01024, sample 26-258-20 cc; x200.

4 *Lenticulina* sp., specimen no. MMMC 00911, sample 26-258-14 cc, x140.

5 *Astacolus* sp., specimen no. MMMC 00917, sample 26-258-14 cc; x120.

6 *Tribrachia australiana,* specimen no. MMMC 00900, sample 26-258-14 cc; x100.

7 Polymorphinid, specimen no. MMMC 00912, sample 26-258-14 cc; x100.

8 *Praebulimina nannina* (Tappan), specimen no. MMMC 00958, sample 26-257-8 cc; x350.

9 *Praebulimina nannina* (Tappan), specimen no. MMMC 00983, sample 26-258-13 cc; x500.

10 *Buliminella fabilis* Cushman & Parker, specimen no. MMMC 00902, sample 26-258-14 cc; x300.

11 *Tappanina laciniosa* Eicher & Worstell, specimen no. MMMC 00909, sample 26-258-14 cc; x200.

12 *Tappanina laciniosa* Eicher & Worstell, specimen no. MMMC 00984, topotype, x150.

13 *Tappanina laciniosa* Eicher & Worstell, specimen no. MMMC 00986, topotype, x175.

14 ?*Discorbis* sp., spiral side, specimen no. MMMC 00961, sample 26-258-14 cc; x200.


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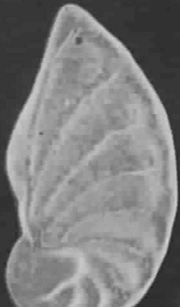
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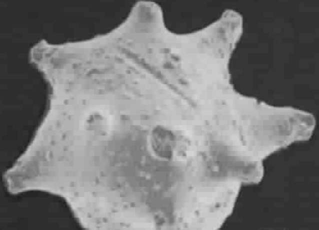
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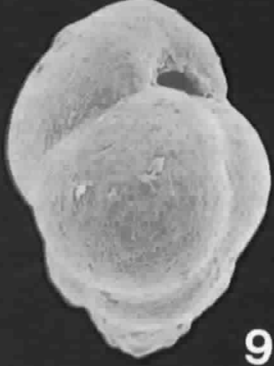
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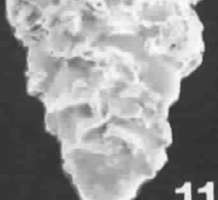
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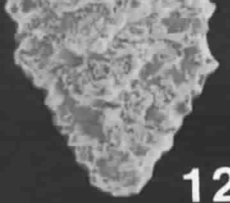
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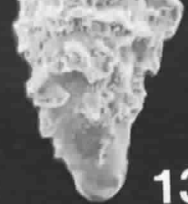
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PLATE 3

Fig.

1 ?*Discorbis* sp., oblique apertural view, specimen no. MMMC 01015, sample 26-258-14 cc; x250.

2 ?*Discorbis* sp., umbilical view, specimen no. MMMC 00994, sample 26-258-14 cc; x300.

3 ?*Discorbis* sp., umbilical view, specimen lost, sample 26-258-15-1 (128-132); x150.

4 *Valvulineria* sp., specimen no. MMMC 01029, sample 26-258-20 cc; x175.

5 *Valvulineria loetterlei* Tappan, specimen no. MMMC 01023, sample 26-258-20 cc; x350.

6 *Valvulineria loetterlei* Tappan, specimen no. MMMC 00957, sample 26-257-8 cc; x350.

7 *Pseudopatellinella howchini* Ludbrook, specimen no. MMMC 00919, sample 26-258-14 cc; x120.

8 *Pseudopatellinella howchini* Ludbrook, specimen no. MMMC 00918, sample 26-258-14 cc; x250.

9 ?*Gyroidina* sp. (sensu Scheibnerová 1976), specimen no. MMMC 00939, sample 26-258-17 cc; x400.

10 ?*Gyroidina* sp. (as above), specimen lost, sample 26-258-1 (17-19); x100.

11 *Pleurostomella* sp., specimen no. MMMC 00915, sample 26-258-14 cc; x120.

12 *Coryphostoma* sp., specimen no. MMMC 00951, sample 26-257-8 cc; x100.

13 *Coryphostoma* sp., specimen no. MMMC 00950, sample 26-257-8 cc; x190.

14 *Bolivina* sp., specimen no. MMMC 00901; sample 26-258-14 cc; x150.


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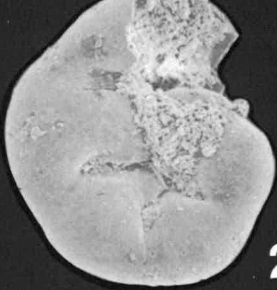
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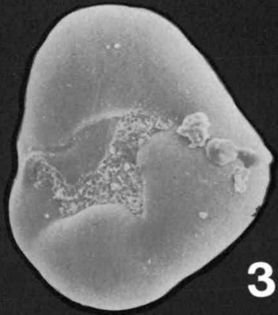
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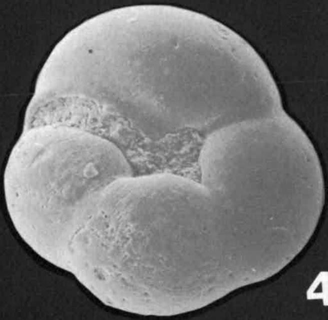
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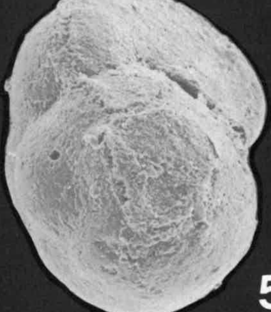
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PLATE 4

Fig.

1 *Pullenia* sp., specimen no. MMMC 00930, sample 26-258-14 cc; x170.

2 *Gyroidinoides* sp., specimen no. MMMC 00982, sample 26-257-8 cc; x170.

3 ?*Serovaina* sp., specimen no. MMMC 00960, sample 26-257-8 cc; x400.

4 ?*Serovaina* sp., specimen no. MMMC 00963, sample 26-257-8 cc; x250.

5 *Osangularia utaturensis* (Sastry & Sastri), specimen no. MMMC 00952, sample 26-257-8 cc; x120.

6 *Osangularia utaturensis* (Sastry & Sastri), specimen no. MMMC 00954, sample 26-257-8 cc; x200.

7 *Osangularia utaturensis* (Sastry & Sastri), specimen no. MMMC 00953, sample 26-257-8 cc; x100.

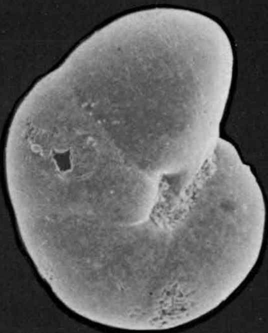
8 *Rotaliatina asiatica* N. Bykova, specimen no. MMMC 00945, sample 26-258-15-1 (128-132); x350.

9 *Rotaliatina asiatica* N. Bykova, specimen no. MMMC 00944, sample 26-258-15-1 (128-132); x270.

10 *Rotaliatina asiatica* N. Bykova, specimen no. MMMC 00929, sample 26-258-14 cc; x300.

11 *Rotaliatina asiatica* N. Bykova, specimen no. MMMC 00924, sample 26-258-14 cc; x200.

12 *Rotaliatina asiatica* N. Bykova, specimen no. MMMC 00992; sample 26-258-15-1 (128-132); x400.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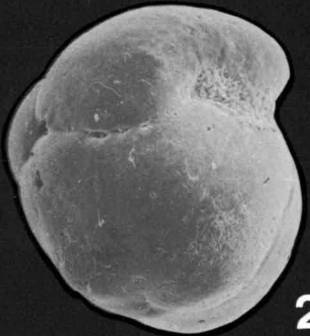
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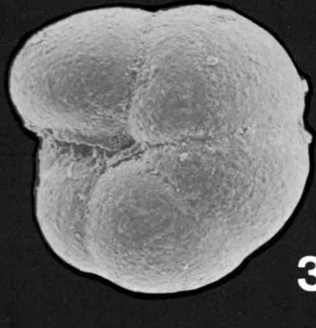
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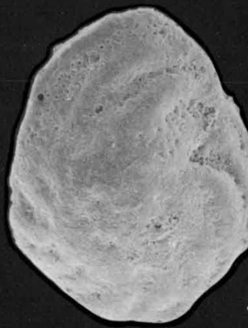
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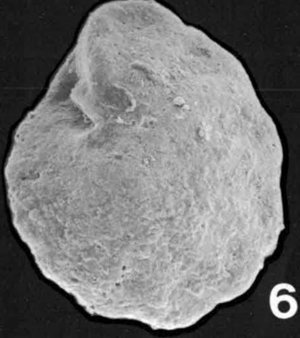
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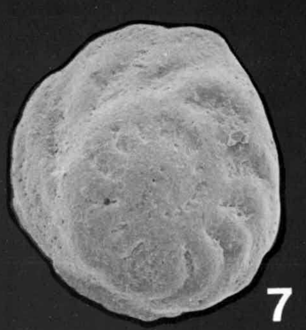
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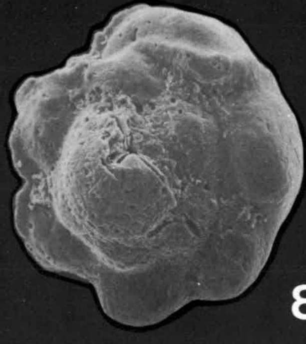
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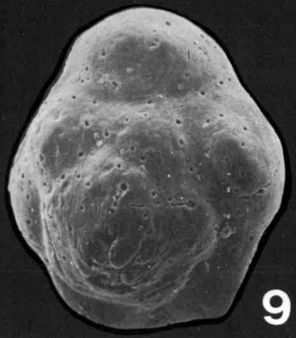
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PLATE 5

Fig.

1 *Rotaliatina asiatica,* specimen no. MMMC 00991, sample 26-25-15-1 (128-132); x350.

2 *Charltonina australis* sp. nov., **holotype,** specimen no. MMMC 00904, sample 26-258-14 cc; x500.

3 *Charltonina australis* sp. nov., **holotype;** x150.

4 *Charltonina australis* sp. nov., paratype, specimen no. MMMC 00906, sample 26-258-14 cc; x200.

5 *Charltonina australis* sp. nov., paratype, specimen no. MMMC 00907, sample 26-258-14 cc; x270.

6 *Gavelinella oodnadattensis* Ludbrook, specimen no. MMMC 00926, sample 26-258-14 cc; x150.

7 *Gavelinella oodnadattensis* Ludbrook, the same specimen as above; x150.

8 *Gavelinella* sp. (?*Orithostella*), specimen no. MMMC 01030, sample 26-258-20 cc; x180.

9 *Gavelinella* ex gr. *intermedia* Berthelin, specimen no. MMMC 00927, sample 26-258-14 cc; x115.

10 *Gavelinella* ex gr. *intermedia* Berthelin, specimen no. MMMC 00899, sample 26-258-14 cc; x115.

11 *Gavelinella* ex gr. *intermedia* Berthelin, the same specimen as above, sample 26-258-14 cc; x350.

12 *Gavelinella* ex gr. *intermedia* Berthelin, specimen no. MMMC 00920, sample 26-258-14 cc; x115.


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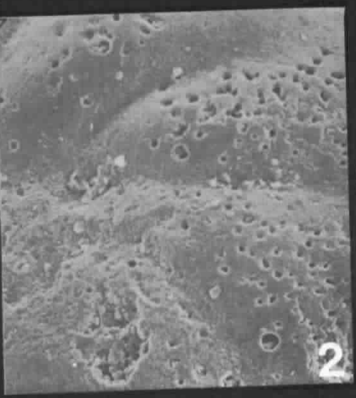
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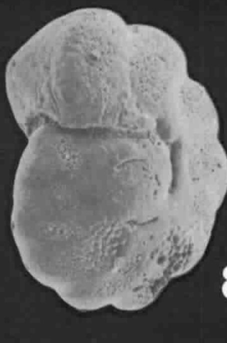
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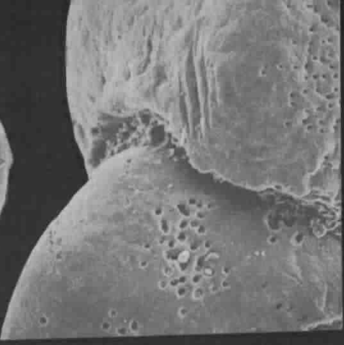
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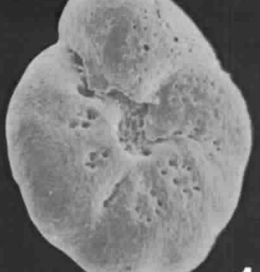
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PLATE 6

Fig.

1 *Gavelinella* sp., specimen no. MMMC 00955, sample 26-257-8 cc; x150.

2 *Gavelinella* sp., specimen no. MMMC 00987, sample 26-258-1 (128-132), x150.

3 *Lingulogavelinella frankei* (Bykova), specimen no. MMMC 01031, sample 26-258-20 cc; x350.

4 *L. frankei* (Bykova), specimen no. MMMC 01027, sample 26-258-20 cc; x250.

5 *L. frankei* (Bykova), specimen no. MMMC 01029, sample 26-258-20 cc; x175.

6 *L. frankei* (Bykova), specimen no. MMMC 01028, sample 26-258-20 cc; x225.

7 *L. frankei* (Bykova), specimen no. MMMC 00936, sample 26-258-17 cc; x350.

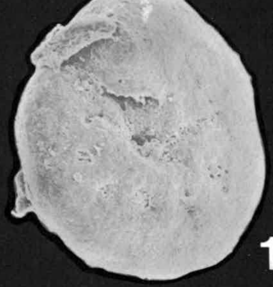
8 *L. frankei* (Bykova), specimen no. MMMC 00943, sample 26-258-15-1 (128-132); x350.

9 *L. frankei* (Bykova), specimen no. MMMC 00935, sample 26-258-15-1 (128-132); x150.

10 *L. frankei* (Bykova), specimen no. MMMC 00942, sample 26-258-15-1 (128-132); x240.

11 *L. frankei* (Bykova), specimen no. MMMC 00646, sample D. M. Bellfield DDH No. 1, 214'0"; x150.

12 *L. orbiculata* (Kuznetsova), specimen no. MMMC 00990, sample 26-258-15-1 (128-132); x350.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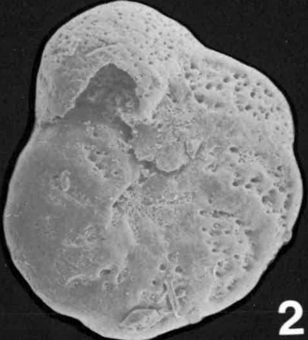
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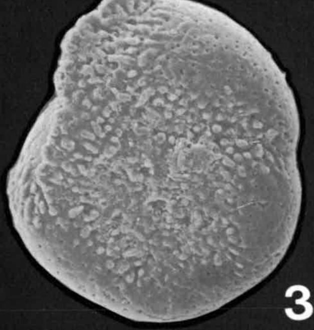
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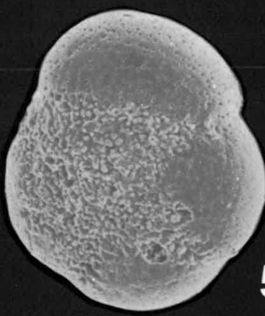
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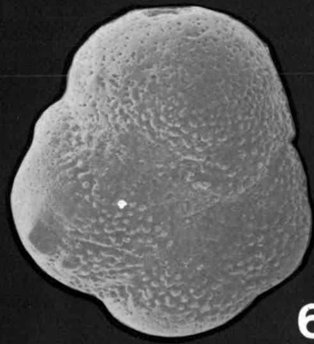
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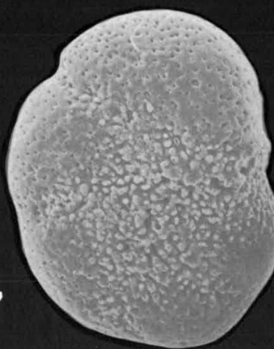
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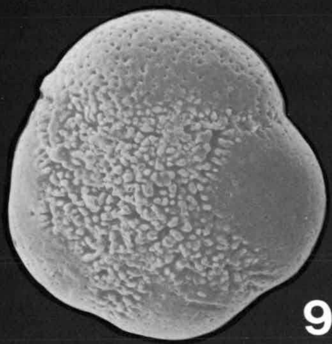
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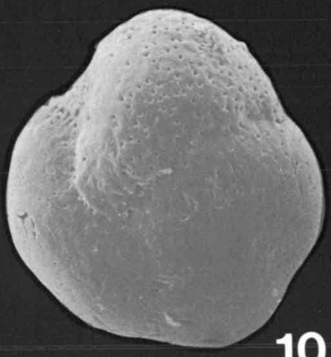
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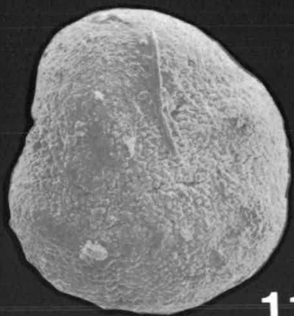
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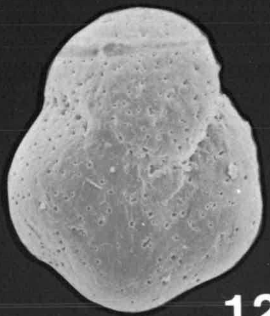
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PLATE 7

1 *L. orbiculata* (Kuznetsova), specimen no. MMMC 00938, sample 26-258-17 cc; x350.

2 *L. orbiculata* (Kuznetsova), detail of the above specimen, x1000.

3 ?*Lingulogavelinella* sp., specimen no. MMMC 00956, sample 26-257-8 cc; x300.

4–5 *Pseudolamarckina* sp., specimen no. MMMC 00976, sample 26-258-14 cc; x350.

6, 9 *Pseudolamarckina* sp. (juv.), specimen no. MMMC 00977, sample 26-258-14 cc; x300.

7 ?*Pseudolamarckina* sp., specimen no. MMMC 00959, sample 26-257-8 cc; x300.

8 ?*Globotruncana* sp., specimen no. MMMC 00946, sample 26-258-15-1 (128-132); x120.

10 ?*Globotruncana* sp., specimen no. MMMC 00922, sample 26-258-15-1 (128-132); x250.

11 ?*Globotruncana* sp., specimen no. MMMC 00933, sample 26-258-15-1 (128-132); x250.

12 ?*Globotruncana* sp., specimen no. MMMC 00923, sample 26-258-15-1 (128-132); x240.


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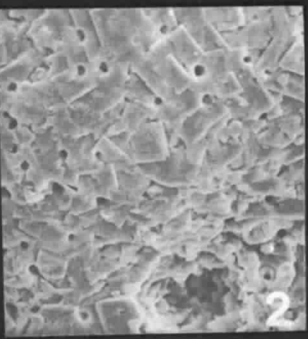
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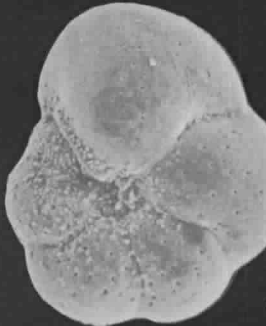
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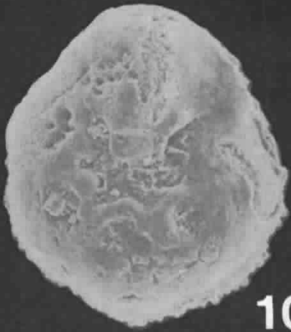
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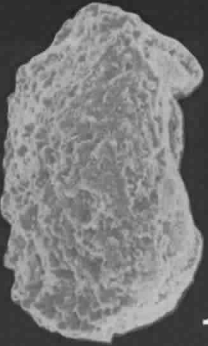
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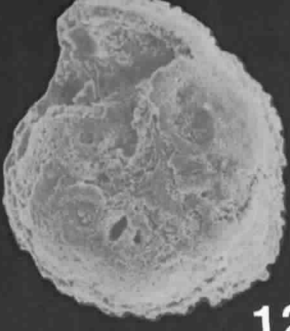
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PLATE 8

Fig.

1 *Gubkinella californica* Dailey, specimen no. MMMC 00969, sample 27-263-8 cc; x400.

2 *Gubkinella californica* Dailey, specimen no. MMMC 00968, sample 27-263-6 cc; x400.

3 *Gubkinella californica* Dailey, specimen no. MMMC 00966, sample 27-263-8 cc; x300.

4 ?*Gubkinella* sp., specimen no. MMMC 00962, sample 26-257-8 cc; x500.

5 *Schackoina cenomana* (Schacko), specimen no. MMMC 00934, sample 26-258-14 cc; x250.

6 *Labrospira pacifica* Krasheninnikov, specimen no. MMMC 00971, sample 26-256-7 cc; x200.

7 *Haplophragmoides* sp. 2, specimen no. MMMC 00972, sample 26-256-7 cc; x140.

8 *Recurvoides* sp., specimen no. MMMC 00974, sample 26-256-7 cc; x120.

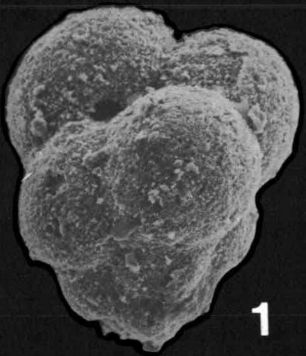
9 *Recurvoides* sp., specimen no. MMMC 00973, sample 26-257-7 cc; x150.

10 *Dorothia* sp., specimen no. MMMC 01034, sample 26-258-5-2 (115-119); x125.

11 *Quinqueloculina* sp., specimen no. MMMC 01035, sample 26-258-5-2 (115-119); x130.

12 *Frondicularia* sp. 2, specimen no. MMMC 01036, sample 26-258-14 cc; x200.

13 *Lenticulina* sp., specimen no. MMMC 01037, sample 26-258-5-2 (115-119); x150.



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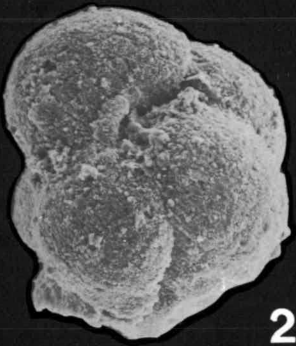

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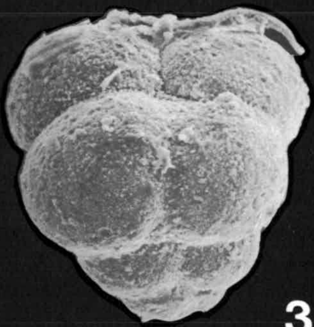

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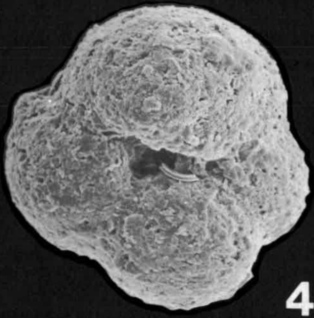

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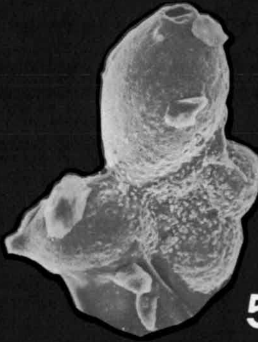

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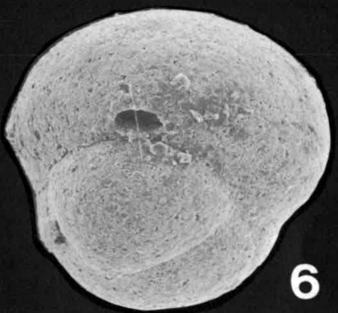

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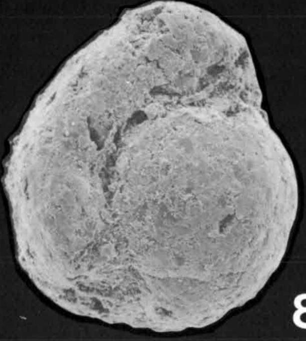

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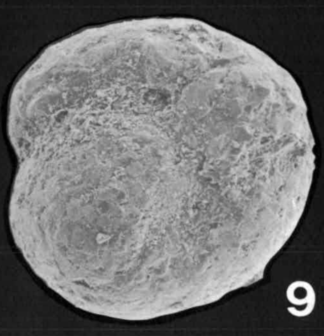

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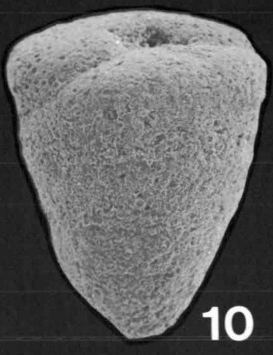

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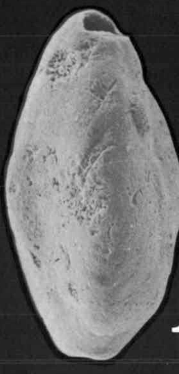

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PLATE 9

Fig.

1 *Lenticulina* sp., specimen no. MMMC 01038, sample 26-258-5-2 (115-119); x250.

2 *Pseudonodosaria* sp., specimen no. MMMC 01039, sample 26-258-5-2 (115-119); x250.

3 *Buliminella* sp., specimen no. MMMC 00983, sample 26-258-13 cc; x230.

4 *Bulminella* sp., specimen no. MMMC 01023, sample 26-258A-8-6; x330.

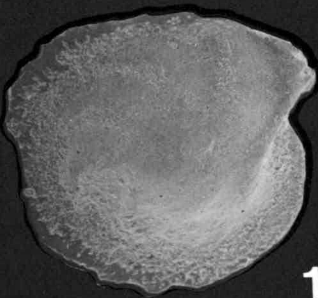
5 *Praebulimina* sp., specimen no. MMMC 01040, sample 26-258-5-2 (115-119); x260.

6 *Pleurostomella* sp., specimen no. MMMC 01041, sample 26-258-5-2 (115-119); x110.

7 *Pullenia cretacea* Cushman, specimen no. MMMC 01042, sample 26-258-5-2 (115-119); x110.

8 *Eponides "rosa"* (sensu Scheibnerová, 1973), specimen no. MMMC 01022, sample 26-258A-8-6; x300.

9 *Gyroidina* sp., specimen no. MMMC 01043, sample 26-258-5-2 (115-119); x250.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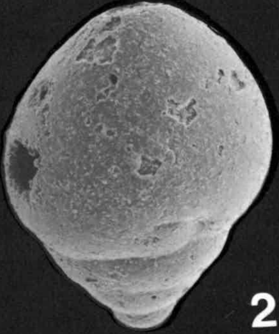
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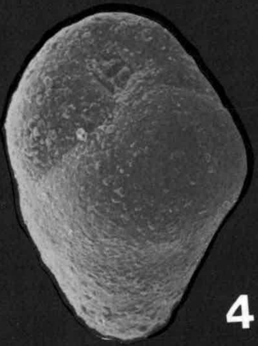
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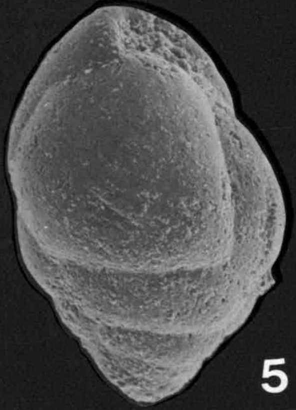
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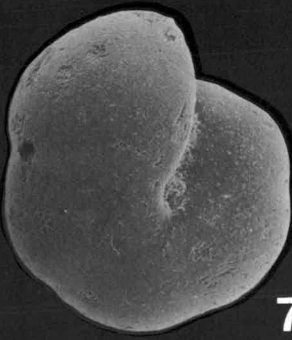
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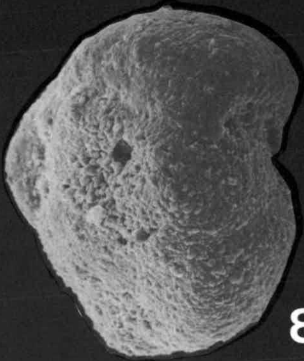
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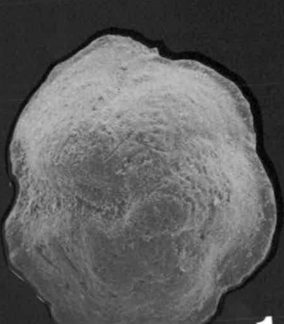
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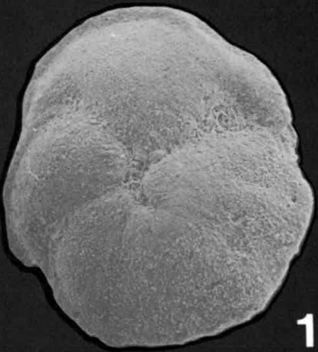
PLATE 10

1 *Gavelinella compressa* Sliter, specimen no. MMMC 01047, sample 26-258-5-2 (115-119); x120.
2 *Gavelinella compressa* Sliter, specimen no. MMMC 01048, sample 26-258-5-2 (115-119); x120.
3 *Gavelinella compressa* Sliter, specimen no. MMMC 01049, sample 26-258-5-2 (115-119); x120.
4 *Gavelinella compressa* Sliter, specimen no. MMMC 01050, sample 26-258-5-2 (115-119); x120.
5 *Gavelinella compressa* Sliter, specimen no. MMMC 01051, sample 26-258-5-2 (115-119); x100.
6 *Gavelinella compressa* Sliter, specimen no. MMMC 01052, sample 26-258-5-2 (115-119); x150.
7 *Gavelinella* sp. 1, specimen no. MMMC 01053, sample 26-258-5-2 (115-119); x200.
8 *Gavelinella* sp. 2, specimen no. MMMC 01018, sample 26-258-13 cc; x240.
9 *Gavelinella* sp. 3, specimen no. MMMC 01020, sample 26-258-13 cc; x250.
10 *Gavelinella* sp. 3, specimen no. MMMC 01020, sample 26-258-13 cc; x280.
11 *Gavelinella* sp. 3, specimen no. MMMC 01019, sample 26-258-13 cc; x200.
12 *Gavelinella* sp. 2, specimen no. MMMC 01017, sample 26-258-12 cc; x200.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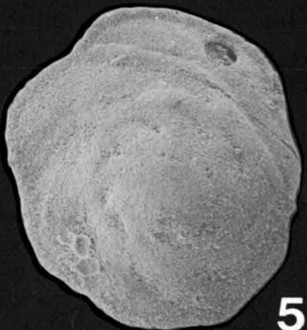
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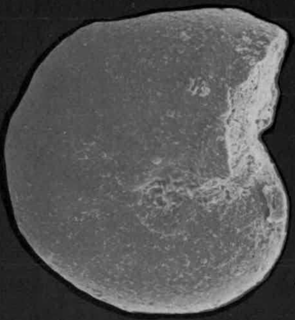
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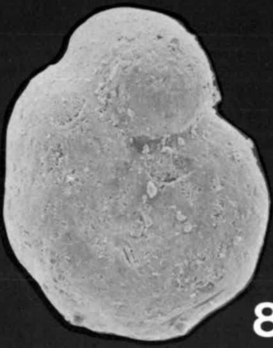
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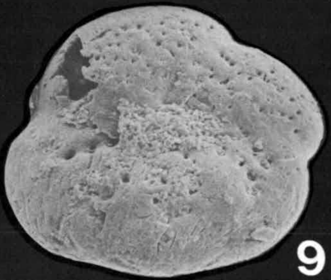
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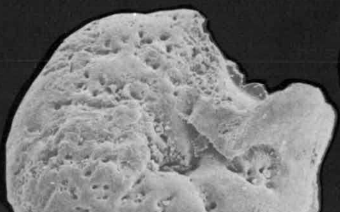
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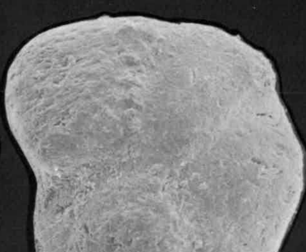
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Paleocene and Eocene nannofossils from the Kings Park Formation, Perth Basin, Western Australia

by

Samir Shafik

The nannofossil assemblages of the Kings Park Formation, in its type area, are recorded and identified as belonging to the *Heliolithus riedeli* Zone and the lower part of the *Discoaster multiradiatus* Zone. This indicates a correlation with the upper part of the planktic foraminiferal Zone P.4 (*Planorotalites pseudomenardii* Zone), confirming the late Paleocene age based previously on foraminiferal studies. Based on nannofossil evidence, the Perth area is envisaged as a shallow near-shore basin open to the ocean during the late Paleocene. Surface waters of the basin were probably cold. A river system brought in upper Cretaceous nannofossil elements, possibly from the Gingin Chalk, and supplied the basin with nutrients.

A younger horizon (uppermost Paleocene-lower Eocene) is recognized overlying a barren segment in the Claremont Asylum No. 2 Bore, Perth.

The Kings Park Formation in the Rottnest Island Bore was dated on planktic foraminiferids as Zone P.6 (*Morozovella rex* Zone), i.e. early Eocene, but a recent study suggested a middle Eocene age. The present study indicates a correlation with the planktic foraminiferal Zone P.12 (mid-middle Eocene) based on the co-occurrence of the nannofossils *Reticulofenestra umbilica*, *R. scrippsae*, *Chiasmolithus grandis*, *C. solitus*, and *Pemma papillatum*, and the presence of *Cyclicargolithus reticulatus* and *Helicopontosphaera reticulata*. It also suggests a new cycle of deposition under relatively warm-water conditions.

Displaced Upper Cretaceous nannofossils occur in both the upper Paleocene-lower Eocene and middle Eocene horizons. Among other evidence, their content and distribution suggest that tectonically and/or eustatically induced events occurred in the interim.

INTRODUCTION

The Kings Park Formation (Fairbridge *in* Coleman, 1957; emended Quilty, 1974a, b) represents the oldest Tertiary sediments in the Perth Basin. It is known only in subsurface sections and has been identified in artesian bores and excavations in the Perth metropolitan area. In its type section the formation is 265 m thick, but a thickness of 500 m has been observed. It rests disconformably on several Cretaceous formations and is overlain by Neogene and/or Quaternary sediments.

The formation consists of grey calcareous, mostly glauconitic shale and siltstone, but in places sandy and calcareous facies occur (Quilty, 1974a, b). Bryozoa, foraminiferids, molluscs, ostracods, and sponge spicules have been reported from the formation (McWhae et al., 1958); planktic foraminiferids are not common.

On foraminiferal evidence, Parr (1938) and subsequent authors considered the Kings Park Formation as late Eocene in age, but McGowran (1964) referred it to the upper Paleocene. McGowran (1968) correlated the planktic foraminiferids of the formation with his *Acarinina mckannai* zonule, which is a close correlative with the *Planorotalites pseudomenardii* Zone (Zone P.4 of Berggren, 1972) of the tropics. Cockbain (1973) recorded a foraminiferal assemblage possibly early Eocene to late Paleocene in age from the formation in the Claremont Asylum No. 2 Bore. Recently, Quilty (1974a, b) indicated that the formation is younger than the late Paleocene offshore, but recorded the basal Eocene Zone P.6 from both onshore and offshore material. More recently, Quilty (this volume) changed his dating of the Kings Park Formation in the Rottnest Island Bore to the middle Eocene.

Cookson & Eisenack (1961) studied the microplankton and microflora of the formation in the Rottnest Island Bore and suggested a correlation with the lower Tertiary 'Microflora C' of Cookson (1954).

The biostratigraphy of the Kings Park Formation lacks nannofossil contributions, notwithstanding an incomplete nannofossil list given by Copley (in Quilty, this volume, table 1). It is the main aim of the present study to record the nannofossil assemblages of the Kings Park Formation with a view to evaluating the biostratigraphy and geohistory of the formation.

Quilty (1974a, b) regarded the formation as having been deposited in a large restricted embayment or estuary fed by a river system.

Material

Fifteen samples from the Kings Park Formation in the Perth Basin have been examined by light microscopy. Procedure and conditions of preparation for all samples were kept as uniform and constant as possible. The samples are given numbers with the prefix MFN, in accordance with the Nannofossil Register of the Bureau of Mineral Resources. Sample MFN1 is from the type section, Kings Park No. 2 Bore taken at the 222 m level; in this bore the formation overlies the Cretaceous South Perth Formation and was defined between the 36.6 m and 301.7 m levels. Sample MFN2 is from a caisson excavation for the Narrows Interchange Project, less than one kilometre from the type section. This sample was taken from 2-3 m below the top of the formation (this level is approximately 27.5 m below sea level). Samples MFN3, MFN4, and MFN5 are from the Rottnest Island Bore, at 392-427 m, 451-470 m, and 617-666 m. Samples MFN6, MFN7 and MFN8 are from the Leederville Recreation Ground Bore, at 205 m, 263 m, and 277 m. In this bore the formation overlies the Cretaceous Leederville Formation and was identified between the 62 m and 289 m levels. Sample MFN9 is from the Claremont Asylum No. 1 Bore between the 216 m and 578 m levels.

TABLE 1: NANNOFOSSILS FROM THE KINGS PARK FORMATION, PERTH BASIN, W.A.

	Type section		Leederville Recreation Ground Bore			Claremont Asylum Bores				
						No. 1	No. 2			
+ present — absent ? doubtful occurrence	MFN1	MFN2	205 m MFN6	263 m MFN7	277 m MFN8	216-578 m MFN9	332 m MFN12	391 m MFN13	453 m MFN14	512 m MFN15
A. AUTOCHTHONOUS										
HOLOCOCCOLITHS AND PENTALITHS										
Braarudosphaera bigelowi (Gran & Braarud)	+	+	+	—	+	+	+	—	+	+
Braarudosphaera discula Bramlette & Riedel	+	—	—	—	—	+	+	—	+	+
Lanternithus duocavus Locker	—	—	—	—	—	—	—	+	+	—
Micrantholithus inaequalis Martini	—	+	+	+	+	+	+	—	+	—
Microlithus pinguis Bramlette & Sullivan	—	+	+	+	+	+	+	—	+	+
Semihololithus biskayae Perch-Nielsen	+	—	—	—	—	—	+	—	?	—
Semihololithus kerabyi Perch-Nielsen	+	+	+	+	+	—	—	—	—	—
OTHERS										
Chiasmolithus bidens (Bramlette & Sullivan)	+	+	+	—	+	+	+	+	+	+
Chiasmolithus californicus (Sullivan)	+	—	+	—	—	—	—	—	—	—
Chiasmolithus consuetus (Bramlette & Sullivan)	+	+	—	+	+	—	—	—	—	—
Coccolithus eopelagicus (Bramlette & Riedel)	cf.	—	cf.	—	cf.	—	—	—	—	—
Cruciplacolithus tenuis (Stradner)	+	+	—	+	+	+	+	+	+	+
Cyclococcolithina robusta (Bramlette & Sullivan)	+	+	+	+	+	+	+	+	+	+
Discoaster helianthus Bramlette & Sullivan	—	—	—	+	—	—	—	—	—	—
Discoaster multiradiatus Bramlette & Riedel	+	+	—	—	—	—	—	—	—	—
Ellipsolithus distichus (Bramlette & Sullivan)	+	+	—	+	+	—	—	+	—	—
Ellipsolithus lajollaensis Bukry & Percival	—	—	—	—	—	+	—	—	—	—
Ericsonia cava (Hay & Mohler)	+	+	+	+	+	+	+	+	+	+
Fasciculithus bobii Perch-Nielsen	+	—	—	—	—	—	—	—	—	—
Fasciculithus involutus Bramlette & Sullivan	+	+	+	—	—	—	+	+	+	—
Fasciculithus richardii Perch-Nielsen	—	—	+	—	—	—	+	+	+	—
Heliolithus kleinpellii Sullivan	+	—	+	+	—	+	+	—	+	—
Heliolithus riedeli Bramlette & Sullivan	+	+	+	—	+	+	—	+	+	+
Heliorthus chiastus (Bramlette & Sullivan)	—	—	—	—	—	—	+	—	—	—
Heliorthus concinnus (Martini)	+	+	—	—	—	—	—	—	—	—
Heliorthus distentus (Bramlette & Sullivan)	—	—	—	—	—	—	+	+	+	—
Heliorthus junctus (Bramlette & Sullivan)	—	—	+	+	—	—	—	—	—	—
Markalius astroporus (Stradner)	+	—	—	—	—	—	+	—	+	—
Scapholithus apertus Hay & Mohler	+	+	—	—	+	—	—	—	—	—
Sphenolithus primus Perch-Nielsen	+	—	—	+	+	+	+	—	+	+
Thoracosphaera operculata Bramlette & Martini	—	—	—	+	—	—	—	—	+	—
Toweius craticulatus Hay & Mohler	+	+	+	+	+	+	+	—	+	+
Toweius eminens (Bramlette & Sullivan)	+	+	+	+	+	—	—	—	—	—
Toweius tovae Perch-Nielsen	—	—	+	—	+	—	—	—	—	—
Zygodiscus herlyni Sullivan	+	—	+	—	+	—	—	—	—	—
Zygodiscus sigmoides Bramlette & Sullivan	+	—	+	+	+	—	—	—	—	—
B. ALLOCHTHONOUS										
INDICATIVE OF NEARSHORE DEPOSITION										
Tetralithus obscurus Deflandre	+	—	+	—	—	—	—	—	—	—
OTHERS										
Cretarhabdus crenulatus Bramlette & Martini	—	—	—	—	—	—	+	—	—	—
Cribrosphaera ehrenbergi (Arkhangelsky)	—	—	—	—	—	—	+	—	—	—
Eifellithus eximius (Stover)	—	+	+	—	—	—	+	+	+	—
Eiffellithus turriseiffeli (Deflandre)	—	+	—	—	—	+	—	—	—	—
Micula decussata Vekshina	+	—	—	—	—	+	—	—	—	—
Prediscosphaera cretacea (Arkhangelsky)	+	+	—	—	—	—	—	—	—	—
Watznaueria barnesae (Black)	+	+	+	+	—	+	+	+	+	—

Samples MFN10, MFN11, MFN12, MFN13, MFN14, and MFN 15 are from the Claremont Asylum No. 2 Bore, at 68 m, 88 m, 332 m, 391 m, 453 m, and 512 m.

NANNOFOSSILS

Two distinctly different groups of nannofossil assemblages have been recovered from the formation; one is found in material from the Perth metropolitan area and the other in the Rottnest Island Bore samples. To avoid confusion the two groups are treated separately.

GROUP I—PERTH METROPOLITAN AREA

Table 1 shows the distribution of the nannofossils in Group I samples; elements recorded include autochthonous and reworked taxa. In addition, objects mimicking *Tribrachiatus orthostylus* have been noticed in samples MFN1 and MFN2. Sample MFN10 is not included in Table 1 but its fossil content is given below.

Nannofossils recovered from samples MFN1 and MFN2 are fairly well preserved and similar in content. Only one species of *Discoaster* is found, but other nannofossil forms are reasonably highly diversified. Samples MFN6, MFN7, and MFN8 yielded moderately diversified but rather poorly preserved assemblages. Notable in these assemblages is the extreme scarcity of discoasters. The assemblage recovered from sample MFN9 is dominated by pentaliths, but otherwise is similar to those extracted from samples MFN6-MFN8.

Sample MFN10 contains sparse nannofossils, dominated by *Ericsonia cava, Toweius craticulatus* and *Transversopontis* sp. aff. *T. pulchra.* Other species found include *Campylosphaera eodela* Bukry & Percival, *Chiasmolithus bidens, C. consuetus, C.* sp. aff. *C. eograndis* Perch-Nielsen, *Cruciplacolithus* sp., *Cyclo-*

TABLE 2: NANNOFOSSIL DISTRIBUTION IN THE TERTIARY SECTION OF THE ROTTNEST ISLAND BORE, W.A.

+ present
— absent
? doubtful occurrence

	392-427 m MFN3	451-470 m MFN4	617-666 m MFN5
A. AUTHOCHTHONOUS			
HOLOCOCCOLITHS AND PENTALITHS			
Braarudosphaera bigelowi (Gran & Braarud)	+	+	+
Braarudosphaera orthia Bybell & Gartner	—	+	+
Dayklethra puctulata Gartner	+	+	+
Holodiscolithus macroporus (Deflandre)	—	—	+
Lanternithus minutus Stradner	+	+	+
Micrantholithus altus Bybell & Gartner	—	—	+
Micrantholithus flos Deflandre	+	—	+
Micrantholithus procerus Bukry & Bramlette	+	+	+
Pemma angulatum Martini	—	+	+
Pemma basquense (Martini)	+	+	+
Pemma papillatum Martini	+	+	+
Pemma rotundum Klumpp	+	+	+
Polyclathrolithus opersus Deflandre	—	—	+
Trochoaster simplex Klumpp	+	—	+
Zygolithus dubius Deflandre	—	—	+
Zygosphaera aurea (Stradner)	—	—	+
Zygrhablithus bijugatus (Deflandre)	+	+	+
Zygrhablithus crassus (Locker)	+	—	—
OTHERS			
Blackites tenuis (Bramlette & Sullivan)	+	—	+
Chiasmolithus grandis (Bramlette & Riedel)	+	+	+
Chiasmolithus solitus (Bramlette & Sullivan)	—	—	+
Coccolithus cribellum (Bramlette & Sullivan)	+	+	—
Coccolithus eopelagicus (Bramlette & Riedel)	+	+	+
Cyclicargolithus floridanus (Roth & Hay)	cf.	cf.	cf.
Cyclicargolithus luminis (Sullivan)	—	+	+
Cyclicargolithus reticulatus (Gartner & Smith)	+	+	?
Cyclococcolithina formosa (Kamptner)	+	+	+
Cyclococcolithina protoannula Gartner	+	—	—
Discoaster barbadiensis Tan Sin Hok	+	+	—
Discoaster distinctus Martini	+	+	+
Discoaster mirus Deflandre	+	—	+
Discoaster nodifer (Bramlette & Riedel)	+	+	+
Discoaster saipanensis Bramlette & Riedel	—	cf.	cf.
Discoaster tani Bramlette & Riedel	—	—	+
Helicopontosphaera compacta (Bramlette & Wilcoxon)	—	+	—
Helicopontosphaera lophata (Bramlette & Sullivan)	+	+	+
Helicopontosphaera papillata Bukry & Bramlette	—	—	+
Helicopontosphaera reticulata (Bramlette & Wilcoxon)	+	—	—
Markalius inversus (Deflandre)	—	—	+
Pontosphaera multipora (Kamptner)	+	+	+
Pontosphaera plana (Bramlette & Sullivan)	+	—	+
Reticulofenestra dictyoda (Deflandre & Fert)	+	+	+
Reticulofenestra hampdenensis Edwards	+	+	—
Reticulofenestra scrippsae Bukry & Percival	+	+	+
Reticulofenestra umbilica (Levin)	+	+	+
Rhabdolithus gladius (Locker)	—	—	+
Rhabdosphaera sp.	—	+	+
Sphenolithus furcatolithoides Locker	+	+	+
Sphenolithus moriformis (Bronnimann & Stradner)	+	+	+
Sphenolithus radians Deflandre	—	—	+
Sphenolithus spiniger Bukry	+	—	+
Transversopontis ocellatus (Bramlette & Sullivan)	+	+	+
Transversopontis panarium (Deflandre)	—	+	+
Transversopontis pulcheroides (Sullivan)	—	—	+
Transversopontis pulchra (Deflandre)	+	+	+
Transversopontis pulchriporus (Reinhardt)	+	—	+
B. ALLOCHTHONOUS			
INDICATIVE OF NEARSHORE DEPOSITION			
Kamptnerius magnificus Deflandre	+	+	—
Kamptnerius punctatus Stradner	+	—	—
Lucianorhabdus cayeuxi Deflandre	+	—	—
Tetralithus obscurus Deflandre	+	+	—
Tetralithus ovalis Stradner	+	+	—
OTHERS			
Arkhangelskiella cymbiformis Vekshina	+	+	+
Ahmuellerella octaradiata (Gorka)	+	+	—
Biscutum blacki Gartner	+	—	—
Broinsonia parca (Stradner)	+	+	—
Cretarhabdus crenulatus Bramlette & Martini	+	—	—
Cribrosphaera ehrenbergi (Arkhangelsky)	+	+	—
Cylindralithus gallicus (Stradner)	+	—	—
Eiffellithus eximius (Stover)	+	+	—
Eiffellithus turriseiffeli (Deflandre)	+	—	—
Gartnerago concavum (Gartner)	+	+	—
Gartnerago obliquum (Stradner)	+	—	—
Lithraphidites carniolensis Deflandre	+	—	—
Micula decussata Vekshina	+	+	+
Prediscosphaera cretacea (Arkhangelsky)	+	+	—
Prediscosphaera spinosa (Bramlette & Martini)	+	+	—
Vekshinella imbricata Gartner	+	+	—
Watznaueria barnesae (Black)	+	+	+
Zygodiscus diplogrammus (Deflandre)	+	—	—

coccolithina sp. cf. *C. formosa* (Kamptner), *C. protoannula* Gartner, *Discoaster* sp. cf. *D. diastypus* Bramlette & Sullivan, *D. multiradiatus*, *Discoasteroides megastypus* Bramlette & Sullivan, *Ellipsolithus distichus*, *Fasciculithus involutus*, *Heliolithus riedeli*, *Heliorthus distentus*, *H.* sp., *Markalius* sp. aff. *M. astroporus* Stradner, *Zygodiscus adamas* Bramlette & Sullivan, *Z.* sp. cf. *Z. sigmoides* Bramlette & Sullivan. Their preservation is moderate, the discoasters being heavily calcified. Reworked Cretaceous forms in sample MFN10 are represented by a few specimens of *Watznaueria barnesae.* Also present are ascidian spicules referred to as the form genus *Micrascidites* (Deflandre & Deflandre-Rigaud, 1956). Sample MFN11 is barren. Samples MFN12 through to MFN15 contain limited and rather poorly preserved assemblages with pentaliths constituting an essential part.

GROUP II—ROTTNEST ISLAND BORE

The Rottnest Island Bore samples (MFN3, MFN4, and MFN5) are found to contain fairly well preserved and highly diversified nannofossil assemblages. In addition to the nannofossils, ascidian spicules (*Micrascidites*) have been noticed in all samples. The distribution of the autochthonous and displaced nannofossils recovered from this bore is documented in Table 2.

Among the autochthonous elements, *Braarudosphaera bigelowi*, *Coccolithus eopelagicus*, *Cyclicargolithus* sp. cf. *C. floridanus*, *Cyclococcolithina formosa*, *Dakylethra punctulata*, *Lanternithus minutus*, *Micrantholithus procerus*, *Pemma basquense*, *P. papillatum*, *P. rotundum*, *Reticulofenestra dictyoda*, *R. umbilica* and *Zygrhablithus bijugatus* are abundant and persist throughout the samples. *Chiasmolithus grandis*, *Discoaster distinctus*, *D. nodifer*, *Helicopontosphaera lophata*, *Pontosphaera multipora*, *Reticulofenestra scrippsae*, *Sphenolithus moriformis* and *Transversopontis ocellatus* are minor constituents but common to all samples. Other autochthonous elements in Table 2 occur in a moderate to fair abundance; nevertheless, *Chiasmolithus solitus* is common to abundant in sample MFN5, *Pemma papillatum* and *Cyclicargolithus reticulatus* are important members among the assemblage of sample MFN4 and *Discoaster barbadiensis* is common in sample MFN3. *Helicopontosphaera compacta* and *H. reticulata* are fairly common in samples MFN4 and MFN3 respectively.

Reworked nannofossils are more abundant and diversified in samples MFN3 and MFN4 than in sample MFN5.

BIOSTRATIGRAPHY AND PALAEOECOLOGY

Foraminiferal studies (McGowran, 1964, 1968) suggested that the formation beneath Perth is late Paleocene in age (Zone P.4), but occurrences of the basal Eocene Zone P.6 in the formation have recently been reported (Quilty, 1974a, b). Nannofossil biostratigraphic resolution for the Zone P.4-P.6 interval is high (Table 3), and an attempt at refining the dating of the formation by means of nannofossils is rewarding. Nannofossil zones adopted in Table 3 are those most suited for mid-latitude sediments. In this zonation, the *Heliolithus riedeli* Zone may equate with the low-latitude *Discoaster nobilis* Zone of Bukry (1973a).

Shafik (in prep.) showed that, for middle Eocene nannofossil biostratigraphy, zonal assignment can be ambiguous; instead he advocated the use of biostratigraphic horizons (datum planes). The same concept is followed here for the Eocene but not for the Paleocene. On a global scale, Paleocene nannofossil biostratigraphy can be described as simple and well established; correlations based on Paleocene zones are seldom confusing.

Because of their minute size and usually great abundance, nannofossils are easily displaced (Bramlette & Sullivan, 1961). Although this is biostratigraphically disadvantageous, reworking may throw some light on past physiographic features.

GROUP I—PERTH METROPOLITAN AREA

AUTOCHTHONOUS TAXA

Age and correlation

Apart from a few long-ranging species, the authochthonous elements in Table 1 are known to be restricted to the upper Paleocene. Identification of *Tribrachiatus orthostylus* is highly doubtful and is therefore not considered in this discussion.

The Kings Park Formation in the Leederville Recreation Ground Bore (MFN6, MFN7, and MFN8), Claremont Asylum No. 1 Bore (MFN9), and Claremont Asylum No. 2 Bore (MFN12, MFN13, MFN14, and MFN15) contains the index species *Heliolithus riedeli* but lacks *Discoaster multiradiatus* and is therefore assigned to the *H. riedeli* Zone.

Assemblages recovered from the type section (MFN1) and the nearby excavation (MFN2) are readily assignable to the lower part of *D. multiradiatus* Zone on the evidence of the nominate species without the association of species indicative of younger biostratigraphic units. Bukry (1973a) incorporated some of the results of Bramlette & Sullivan (1961) and Gartner (1971), and for shallow-marine sediments used the incoming of *Rhamboaster* spp. and *Campylosphaera eodela* to distinguish a younger part in the *D. multiradiatus* Zone. Neither of these species has been encountered in samples MFN1 and MFN2 and the nannofossil suites identified hardly suggest that their absence is a result of preservational differentiation or palaeoecological exclusion. The lowest occurrence of *Rhamboaster calcitrapa* is in the lowest part of the foraminiferal Zone P.5 (Gartner, 1971). Accordingly the main part of the Kings Park Formation under Perth is considered to be confined to the upper part of Zone P.4 (see Table 3); foraminiferal results (McGowran, 1964) partly support this conclusion.

The co-occurrence of *Discoaster multiradiatus* and *Campylosphaera eodela* in sample MFN10 from the Claremont Asylum No. 2 Bore, may indicate a correlation with the top part of the *D. multiradiatus* Zone (approximate correlative with the planktic foraminiferal Zone P.5 of Berggren, 1972) thus signifying a latest Paleocene age. Most of the autochthonous nannofossil elements recorded from this sample are basically upper Paleocene, even though they may be rarely encountered in lower Eocene sediments (*fide* Bramlette & Sullivan, 1961 and Gartner, 1971). On the other hand, the

TABLE 3: NANNOFOSSIL BIOSTRATIGRAPHY OF THE UPPER PALEOCENE-BASAL EOCENE.

AGE	P-ZONES	NANNOFOSSIL ZONES / SUBZONES		CRITERIA DEFINING ZONAL BOUNDARIES (BASE OF RANGES)
EARLY EOCENE	P. 6	*Tribrachiatus orthostylus*		*Discoaster lodoensis*
		Discoaster diastypus		*Discoaster diastypus*
LATE PALEOCENE	P. 5	*Discoaster multiradiatus*	*Campylosphaera eodela*	
	P. 4		*Chiasmolithus bidens*	*Discoaster multiradiatus*
		Heliolithus riedeli		*Heliolithus reideli*
		Discoaster mohleri		*Discoaster mohleri*
		Heliolithus kleinpellii		
	P. 3			*Heliolithus kleinpellii*

presence of *Discoaster* sp. cf. *D. diastypus* in the same sample may suggest an early Eocene age, possibly the *D. diastypus* Zone (partial correlative with the foraminiferal Zone P.6 of Berggren, 1972).

Bramlette & Sullivan (1961) stated that *Discolithus* aff. *pulcher* (= atypical *Transversopontis pulchra* in this work) appears earlier than typical specimens of this species and ranges from the upper Paleocene to middle Eocene; it grades into the typical form. In sample MFN10, a very few specimens (identified still as atypical *T. pulchra*) approach the characteristics of the species by developing more-or-less distinct slits in their rims. These forms may indicate a close proximity to the base range of typical *T. pulchra*. To the writer's knowledge, typical *T. pulchra* has not been recorded from Paleocene sediments. Its lowest known occurrence is recorded in lower Eocene sediments from central California, New Zealand, and West Pakistan. Bramlette & Sullivan (1961) recorded the earliest occurrence of *T. pulchra* in the Lodo Formation within the lower part of their *Discoaster tribrachiatus* Zone which approximately correlates with the *D. diastypus* Zone in Table 3. Edwards (1971) indicated that the lowest occurrence of *T. pulchra* in New Zealand is within his *Discoaster lodoensis* Zone, i.e. above the base of the range of *D. lodoensis* (see Table 3). The oldest record of *T. pulchra* in West Pakistan is in lower Eocene sediments containing both *D. lodoensis* and *Tribrachiatus orthostylus* (Haq, 1971).

In conclusion, nannofossil evidence is equally strong in suggesting a latest Paleocene or an early Eocene age from sample MFN10. This seems to confirm results based on planktic foraminiferids. Cockbain (1973) recorded the planktic foraminiferids *Globigerina linaperta* species group, *Globorotalia aequa*, *G. rex*, and *G. esnaensis* from sample MFN10 and regarded the age as earliest Eocene, but did not rule out a possibility of a latest Paleocene age. Quilty (1974a) reported on the same sample and—on negative evidence—concluded that it is early Eocene in age (Zone P.6).

A barren segment represented by sample MFN11 underlying this upper Paleocene-lower Eocene horizon (MFN10) is identified in the Claremont Asylum No. 2 Bore.

Palaeoecology

Nannofossils are marine forms and in marginal seas good access to the open ocean is a basic requirement. The abundance of nannofossils recovered here (Table 1) suggests that open-marine conditions prevailed during the late Paleocene in the Perth metropolitan area. The presence of holococcoliths and pentaliths in the assemblages (Table 1) is taken to indicate that the formation was deposited in a shallow-water nearshore basin rich in nutrients.

The lithology of the formation does not disprove a shallow depositional environment. The rate of deposition of the formation in the Perth metropolitan area was possibly high, as can be deduced from its uniform fauna (McGowran, 1964; Quilty, 1974a, b) and flora (this study). Land close to the basin must have had a high enough relief to account for the terrigenous aspect and possible high rate of deposition of the formation. The river system suggested by Quilty (1974a, b) seems plausible as a means for contributing to the deposition of the formation and for enriching the basin with nutrients.

Biological production in the basin must have been remarkably high for the nannoplankton skeletal elements to keep pace with the influx of terrigenous material and remain abundant. This balance was disturbed at the time of deposition of the barren horizon (MFN11) in the Claremont Aslyum No. 2 Bore, and a shift towards more marginal conditions with markedly reduced marine influence is suggested. Subsequent to this interruption in the fossil record, nannoplankton regained access to the Claremont Asylum site and their remains reappeared higher in the section (sample MFN10).

Specimens belonging to the genera *Chiasmolithus* and *Cruciplacolithus* collectively exceed those of the genus *Discoaster* in samples MFN8, MFN2, and MFN1. This suggests that surface-waters were probably cold (Bukry, 1973b). Such cooling is consistent with the absence of many representatives of the genus *Discoaster*, known to occur in coeval low-latitude sediments, from the upper Paleocene assemblages recorded in Table 1.

Evidence suggesting a slight warming during the latest Paleocene-early Eocene at the Claremont Asylum site, is tenuous. Nannofossils in sample MFN10 are sparse, but specimens of *Discoaster* spp. appreciably exceed those of *Chiasmolithus* spp.

ALLOCHTHONOUS TAXA

Possible age and origin

The known ranges of the rare displaced nannofossils recorded in Table 1 suggest a late Cretaceous (possibly Santonian) age for the source sediments. The presence of *Tetralithus obscurus* indicates that the source sediments were hemipelagic, i.e. deposited on a continental shelf or in a nearshore basin. Upper Cretaceous sediments containing nannofossils are known in the Perth Basin; the Gingin Chalk, which crops out not far from Perth, is rich in nannofossils, was deposited in a nearshore basin, and is Santonian in age. It is possible that parts of the river system suggested by Quilty (1974a, b) drained land masses of the Gingin Chalk into the basin.

GROUP II—ROTTNEST ISLAND BORE

AUTOCHTHONOUS TAXA

Age and correlation

The co-occurrence of *Chiasmolithus grandis* and *Reticulofenestra umbilica* together with the presence of some other forms in the Kings Park Formation in the Rottnest Island Bore indicates a middle Eocene age for the formation. This conclusion is based on data presented by many authors working on material from various parts of the world (e.g. Gartner, 1974).

Shafik (in press) indicated that the *Reticulofenestra scissura* nannofossil datum (base of the range) is within the planktic foraminiferal Zone P.13 of Blow (1969). *R. scissura* has not been encountered in the Rottnest Island Bore samples, but its immediate ancestor, *R. scrippsae*, is found down to sample MFN5. The first appearance of *R. scrippsae* relative to the P-Zones is poorly documented in the literature; however, it may indicate a mid-middle Eocene age (Bukry, 1973a).

Gartner (1971) recognized the earliest occurrence of *Pemma papillatum* as a useful biostratigraphic datum for hemipelagic sediments. He correlated this datum with the planktic foraminiferal P.11/P.12 boundary. *P. papillatum* occurs in sample MFN5, and a correlation with the basal part of Zone P.12 of Blow (1969) seems feasible.

The first appearances of *Cyclicargolithus reticulatus* and *Helicopontosphaera reticulata* are within the lower part of Zone P.12 (Shafik, 1973). *C. reticulatus* is found in samples MFN3 and MFN4, thus suggesting a correlation with Zone P.12. This correlation is also substantiated by the presence of *H. reticulata* in sample MFN3.

Though the material studied from the Rottnest Island Bore represents a short interval of time (correlation with Zone P.12 involves a span of time less than 2 m.y.), it certainly can be divided into two distinct biostratigraphic units. The assemblage recovered from sample MFN5 differs substantially from those of samples MFN4 and MFN3; many species including several holococcoliths and some cosmopolitan species such as *Rhabdolithus gladius* and *Sphenolithus radians* are restricted to MFN5. This invites considering sample MFN5 as a separate unit, distinct from another unit comprising MFN4 and MFN3. The distinction between these two units is also manifested by their content of reworked taxa; reworked Cretaceous elements occur in much greater abundance and diversity in the upper unit.

It appears that the study of the Rottnest Island Bore material confirms indirectly a sequence of nannofossil biostratigraphic events recognized, in part, in other nannofossil studies (e.g. Gartner, 1971; Roth et al., 1971; Shafik, 1973) for the mid-middle Eocene. This sequence is: (a) last apearance of *Chiasmolithus solitus* (the youngest), (b) first appearance of *Helicopontosphaera reticulata,* (c) first appearance of *Cyclicargolithus reticulatus,* and (d) first appearances of *Pemma papillatum and Reticulofenestra scrippsae* (the oldest); the last two species were not discernible in the present study, but they may occur at a lower level than the material examined. It is worthwhile to stress that that sequence is only fairly reliable and that its greater part may be just a cluster of closely occurring events; the last appearance of *C. solitus* is based on negative evidence and therefore has uncertain reliability.

Quilty (1974a) studied the planktic foraminiferids of the Kings Park Formation in the Rottnest Island Bore. He recorded 'an unidentified *Pseudohastigerina* (*wilcoxensis* or *pseudoiota*), *Globorotalia aequa* Cushman & Renz, and *Globigerina* of the *linaperta* group' in sample 451-470 m (=MFN4 in this study) and '*Pseudogloboquadrina primitiva* Finlay, *Globigerina* of the *linaperta* group, *Globorotalia aequa* and *G. broedermanni* Cushman & Bermudez' from samples 617-666 m (=MFN5) and concluded that the age was early Eocene (Zone P.6). In sharp contrast, nannofossil evidence indicates a mid-middle Eocene age (Zone P.12), and no positive indication for reworking from upper Paleocene-lower Eocene sources has been observed. *Globorotalia aequa, G. broedermanni, Pseudohastigerina pseudoiota* and *P. wilcoxensis* are known to be restricted to upper Paleocene and/or lower Eocene sediments (Jenkins, 1971). The occurrence of these faunas in the Rottnest Island Bore is therefore problematic and their re-examination is recommended. The stratigraphic ranges of *Globigerina linaperta* and *Pseudogloboquadrina primitiva* extend into the middle Eocene (Ludbrook & Lindsay, 1969) and their presence in the Rottnest Island Bore is therefore understandable.

Quilty (this volume) augmented the planktic foraminiferal list of the Rottnest Island Bore. He identified several faunas indicative of a middle Eocene age (Zones P.11-P.13) but did not explain the occurrence of older taxa mentioned above. The middle Eocene age was supported by the occurrence of some nannofossil forms (Copley *in* Quilty, this volume, table 1).

Cookson & Eisenack (1961) recorded *Proteacidites pachypolus,* the index fossil of 'Microflora C', from 451-487 m in the Rottnest Island Bore. This indicated a younger age than the Victorian Pebble Point Formation which, according to McGowran (1965), is the oldest marine Paleocene recognized in Victoria. The index species of 'Microflora C' was recorded from beds belonging to different parts of the Eocene (Cookson & Eisenack, 1961), and a precise dating for the Rottnest Island Bore material was not possible. Harris (1965) mentioned that *P. pachypolus* ranges from upper Paleocene to upper Eocene, but it is shown restricted to the Eocene in Stover & Partridge (1973). Previously, Cookson (1954) assigned 'Microflora C' to the Eocene.

Evidence for equating 'Microflora C' with the middle to upper Eocene *Triorites magnificus* zonule (*fide* Harris, 1971) could not be found in Cookson & Eisenack (1961).

Palaeoecology

Holococcoliths and pentaliths recovered from the Rottnest Island Bore samples are more abundant and diversified than those in material examined from the Kings Park Formation in the Perth metropolitan area. Although this may still indicate shallow and nearshore deposition, it certainly reflects some environmental differences. (The presence of ascidian spicules (*Micrascidites*) may also indicate a shallow-marine environment.)

The higher diversity of the autochthonous species in Table 2 suggests warmer conditions than those prevailing during the late Paleocene-early Eocene in the Perth metropolitan area. *Discoaster* spp. are more abundant than *Chiasmolithus* spp. in the Rottnest Island Bore material, especially in MFN3 and MFN4, also indicating warmer conditions. The same can be argued from the common occurrences of *Helicopontosphaera compacta* and *H. reticulata* in samples MFN4 and MFN3 respectively. This reflects the global warming during the middle Eocene which has been recognized by many authors (e.g. Bukry, 1971).

ALLOCHTHONOUS TAXA

Possible age and origin

The composition and abundance of the displaced forms recorded from the Rottnest Island Bore material are strikingly different from those recovered from the Kings Park Formation in the Perth metropolitan area. The co-occurrence of *Broinsonia parca* and *Eiffellithus eximius* signifies a Campanian age, but the presence of other forms such as *Arkhangelskiella cymbiformis* (fairly large forms), *Kamptnerius magnificus, Lucianorhabdus cayeuxi,* and *Prediscosphaera spinosa* may indicate an age ranging to early Maastrichtian.

The hemipelagic characteristics of the source sediments for the allochthonous forms recorded in the Rottnest Island Bore material are demonstrated by the occurrences of *Kamptnerius magnificus, K. punctatus, Lucianorhabdus cayeuxi, Tetralithus obscurus,* and *T. ovalis.*

Edgell (1964) recorded Campanian microfossils from grey marls in a water-bore approximately 115 km NNE of Perth. These marls were not totally penetrated and are overlain by Quaternary sands. Edgell (1964) named the marl sequence the Lancelin Beds, and indicated that its deposition was in the inner neritic zone. According to the same author the Lancelin Beds are the youngest marine Cretaceous sediments known in the Perth Basin.

The age difference between the displaced nannofossils found in the Rottnest Island Bore material and in the Kings Park Formation from beneath Perth may be explained as due to a change in the relief of the hinterland. Such a change could be caused either by local tectonism or by a general lowering of the sea level, or both. Hemipelagic Campanian-lower Maastrichtian sediments, probably the Lancelin Beds, were elevated and the younger reworked elements were brought in during the middle Eocene deposition.

DISCUSSION

A few points with some bearing on the lithostratigraphic status of the Kings Park Formation are discussed briefly below.

1. The total absence of nannofossils in sample MFN11 from the Claremont Asylum No. 2 Bore is significant in that it indicates a change in the palaeoecological conditions prevailing during the late Paleocene. Resumption of marine conditions early in the Eocene or during the latest Paleocene is evident by the up-sequence reappearance of nannofossils (sample MFN10).
2. Marine sediments filling the biostratigraphic gap between the upper Paleocene-lower Eocene (Zones P.5-P.6) in the Claremont Asylum No. 2 Bore and the middle Eocene (Zone P.12) in the Rottnest Island Bore are not known in the Perth Basin, but are widespread in the Carnarvon Basin. A major regression most probably caused by tectonism may therefore be postulated for the Perth Basin during that time. Inherent instability may be traced back in time to the deposition of the barren horizon in the Claremont Asylum No. 2 Bore.
3. The Rottnest Island Bore material being middle Eocene in age, and containing reworked upper Cretaceous nannofossils, may be correlated with a similar horizon within the Eocene sequence of the Carnarvon Basin (personal observation). That the Carnarvon Basin horizon coincides with a regional break in sedimentation (personal observation), and thus suggests that a similar event occurred in the Perth Basin, may not be accidental.

It is therefore reasonable to conclude that some significant geohistorical events, probably regional, occurred between the deposition of the type Kings Park Formation and the deposition of the middle Eocene horizon in the Rottnest Island Bore. This indicates that the Kings Park Formation as presently indentified was deposited during two separate sedimentary cycles. It is recommended here that the middle Eocene phase based on the Rottnest Island Bore be given a separate lithostratigraphic status.

SUMMARY

Geohistory

A marine transgression over the Perth metropolitan area occurred late in the Paleocene, submerging a land surface composed of several Cretaceous formations. During this transgression, the greater part of the Kings Park Formation was laid down. Rivers drained upper Cretaceous hinterland (probably the Gingin Chalk), and brought 'Santonian' nannofossils into the basin of deposition. Surface waters of the basin were probably cold.

A change in the palaeoecological conditions occurred whereby sedimentation became devoid of nannofossils but marine conditions recurred during the latest Paleocene-early Eocene. During this marine episode, temperatures were probably slightly higher than earlier. This was followed by a postulated long interval of regression, seemingly due to local tectonism.

By the middle Eocene, a new marine transgression, probably on a regional scale, occurred and is recorded in the Rottnest Island Bore. Upper Cretaceous nannofossils were transported from a different area on the hinterland (probably the Lancelin Beds) and were deposited at the site of the Rottnest Island Bore. During this time, temperatures were higher than during the late Paleocene-early Eocene.

Biostratigraphy

Because species of *Discoaster* encountered from the upper Paleocene in this study are limited in number of species, a zone among the upper Paleocene zones is based on an alternative to a *Discoaster* event. The upper Paleocene recognized here, belongs to the *Heliolithus riedeli* Zone and the lower part of the *Discoaster multiradiatus* Zone, which collectively correlate with the upper part of the planktic foraminiferal Zone P.4 of Berggren (1972).

In addition, a younger horizon (uppermost Paleocene-lowest Eocene) is recognized based on the cooccurrence of *D. multiradiatus, Campylosphaera eodela, Discoaster* sp. cf. *D. diastypus* and *Transversopontis* sp. aff. *T. pulchra.* This horizon may be tentatively correlated with the planktic foraminiferal Zones P.5-P.6 of Berggren (1972). A barren segment underlying this horizon in the Claremont Asylum No. 2 Bore (Perth area) is recorded.

Examination of the mid-middle Eocene discovered in the Perth Basin helped in revealing a set of nannofossil sequential events known, in part, in several nannofossil studies (e.g. Gartner, 1971). This sequence is: (a) last appearance of *Chiasmolithus solitus* (the youngest), (b) first appearance of *Helicopontosphaera reticulata,* (c) first appearance of *Cyclicargolithus reticulatus,* and (d) first appearances of *Pemma papillatum* and *Reticulofenestra scrippsae* (the oldest). This sequence is correlated with the planktic foraminiferal Zone P.12 of Blow (1969).

Lithostratigraphy

Nannofossil evidence indicates that the Kings Park Formation, as presently identified, was deposited during two separate sedimentary cycles. The middle Eocene phase in the Rottnest Island Bore should, therefore, be given a separate lithostratigraphic status.

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