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FORAMINIFERAL BIOSTRATIGRAPHY OF THE OLIGOCENE/MIOCENE LIMESTONES OF CHRISTMAS ISLAND (INDIAN OCEAN)

by

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ABSTRACT

Foraminifera indicative of the Tertiary Lower e, Upper e and Lower f 'Stages' of the East Indian Letter Classification are recognized in the post-Eocene limestones of Christmas Island. The local ranges of Spiroclypeus globulus Nuttall (here regarded as a junior synonym of S. margaritatus), Miogypsina neodispansa (Jones & Chapman), Lepidocyclina (Eulepidina) ephippioides J. & C. and L. (E.) andrewsiana J. & C. - for all of which this small island is the type area - are determined. Five faunal assemblages are recognized, and one new species, Heterostegina barrici, described.

INTRODUCTION

Christmas Island lies almost 320 km south of Java and has an area of about 140 km^2. It is basically a truncated volcanic cone, capped with about 190 m of mainly flat-lying Cenozoic limestones, rising some 2450 m from the floor of the eastern part of the Indian Ocean. The island is heavily forested, the best natural exposures of limestone being in the steep inland cliffs. The area was active tectonically throughout Tertiary times, and the sedimentary succession is much affected by faulting. The geology was originally described by Andrews (1900), the only recent accounts being a paper by Trueman (1965) and an unpublished report by Barrie (1967) for the British Phosphate Commissioners.

The Tertiary foraminifera of the island were first described by Jones & Chapman (in Andrews, 1900) on the basis of 58 poorly localized rock samples which failed to yield a recognizable faunal sequence owing to the uncertainty of their stratigraphical relationships. However, a number of new species were described, the most important being Lepidocyclina (E.) andrewsiana, L. (E.) ephippioides, L. (E.) murrayana, L. insulaenatalis, and Orbitoides (Lepidocyclina) neodispansa; some of these names subsequently came into general use throughout the region. The main part of the limestone was thought to be of early Miocene age, but of the few samples which appeared to have been taken from at or near the base of the succession in the area of Flying Fish Cove, No. 595 contained planktonic foraminifera (including Orbulina) now known not to occur below Blow's zone N.9 (approximately base of Lower f), while samples 924 and 220 yielded Miogypsina, a genus which appears first in strata of Upper e age in Indonesia. The faunas from these three samples therefore conflicted with the evidence for the age (Lower e) of the overlying beds. Nuttall (1926) revised the orbitoids with the aid of additional sections cut from Andrews' samples, and cleared up some of the confusion caused by the poor original descriptions. However, Tan (1936) noted that the published descriptions of Miogypsina neodispansa were still inadequate for the satisfactory establishment of its systematic position. Ludbrook (1965) described the fauna from 22 isolated samples collected from different parts of the island. Although Nuttall and Ludbrook both contributed to our knowledge of the faunas, neither had access to material which would have enabled them to solve the basic stratigraphical problems. In 1965 Mr. J.H. Barrie, then with the Commonwealth Bureau of Mineral Resources, carried out a geological survey of the island for the British Phosphate Commissioners;

material collected by him showed conclusively that the base of the 'Miocene' limestones was older than insueta Zone, but otherwise added little to our knowledge of the island's stratigraphy. One of us (D.J.B.) therefore visited the island in 1967 and collected more than 200 samples in stratigraphical order along the five traverses shown on Text-fig. 1. Although the results presented here are based primarily on this material, all the previous collections have been re-examined and evaluated in interpreting the biostratigraphy.

Of the three anomalous samples collected by Andrews and referred to earlier, that containing Orbulina (595) was undoubtedly obtained from one of the plankton-rich fissure infillings which occur in Flying Fish Cove. The occurrence of Miogypsina neodispansa in samples 220 and 924 is more difficult to explain. Mr P.J. Barrett and Mr D.A. Powell recently collected further material (G.840; G.852-860) from a poorly exposed yellowish limestone in contact with the basalt at the point where Andrews obtained rock no. 924. Nine of these samples yielded M. neodispansa; the fauna of the yellowish limestone cannot be traced laterally, and two samples collected immediately above (G.861-862) contain a Lower e stage fauna. Mr Barrett considers the yellowish limestone to be different from others in the area, and regards it as being formed also as a result of fracture filling, perhaps of a tension fracture which was gradually opening as the island underwent adjustment. This seems to be the only explanation for a younger limestone directly against the basalt with an older limestone at a higher level. It is unfortunate that the limestone occurs at the northern end of a fault zone where the succession is obscure. Sample 220 is probably from the same locality.

Figured specimens prefixed CPC are deposited in the Commonwealth Palaeontological Collection, Bureau of Mineral Resources, Canberra, Australia; those prefixed P are deposited in the Palaeontology Department, British Museum (Natural History), London, England. Thin sections representative of the samples referred to in this paper are deposited in both Canberra and London.

ACKNOWLEDGEMENTS

We wish to thank the British Phosphate Commissioners for permitting one of us (D.J.B.) to visit Christmas Island, for providing all necessary facilities and for permitting us to quote results from the ST.1 stratigraphic bore; Mr K. Lourey, then Island Manager; Messrs E. Brennan and P.J. Barrett, B.P.C. geologists, at that time, for assistance with the geological work; Mr D.A. Powell, whose knowledge of the island and of access to the sections sampled was invaluable; and Messrs Morgan, Ingram, and Johnson of the B.P.C. Fremantle Office, who helped in many ways with travel arrangements. Our thanks are also due to Dr N.H. Ludbrook for allowing one of us (C.G.A.) to examine her material in Adelaide, and for providing a report on material from the ST.1 stratigraphic bore. We thank Messrs Barrett and Powell for their assistance in determining the type locality of Miogypsina neodispansa, and for collecting in the Flying Fish Cove area.

Permission to publish has been received by one of us (D.J.B.) from the Director, Bureau of Mineral Resources, Geology and Geophysics.

LITHOLOGY, STRATIGRAPHY & FAUNAL SUCCESSION

The greater part of the succession is made up of foraminiferal and algal debris in a matrix of carbonate mud. Molluscs, corals, and coral debris are present in many samples, but only in 'G' Traverse is there direct evidence for a coral reef. The limestone contains few planktonic foraminifera except in fissure infillings. Assemblages of miliolids and peneroplids known to be characteristic of shallow-water sheltered environments (e.g. lagoons) occur at many levels, whereas foraminifera believed to be typical of higher energy environments are virtually restricted to Assemblage 1. The post-Eocene limestones are seen to rest on basalt or tuff wherever they are exposed although the contact is usually obscure; in some places it is certainly a fault plane but in others may be an erosion surface with a limestone breccia or conglomerate above. In the traverses detailed below, the base of the limestone rests on basalt. Some traverses have been named after localities in which they occur; others are differentiated by letters assigned by Barrie (1967). The discontinuity of sample numbers in the traverses resulted either from difficulty of access, particularly in 'D' Traverse, so that several visits were necessary at different times, or from further collecting in order to check particular parts of traverses after preliminary examination of samples on the island.

On discovering that the faunal sequence was difficult to interpret, we decided to take no risks with the identification of species thought to be of age-diagnostic value. The distribution charts (Text-figs 6-10) are, therefore, more complex than usual. Whenever we have been unable to see the diagnostic characters of a species (a common situation when random thin sections of limestone are studied), we have recorded it simply as 'X' sp. Thus, in 'D' Traverse (Text-fig. 6) we recognize Miogypsina (Miogypsinoides) bantamensis, M. (Miogypsinoides) complanata, M. (Miogypsinoides) cf. complanata, and M. (Miogypsinoides) sp. This, we believe, fairly reflects the difficulties encountered in distinguishing individual species when the critical characters vary in the degree to which they are visible.

1. 'D' Traverse (Text-fig. 2). A stream traverse on the north side of the island immediately southwest of Flying Fish Cove. Fifty samples were available from the south side of the stream and nine from the north side. A further 15 samples had been collected previously by Barrie. The sequence here has a vertical thickness of about 165 m. The lower part of the sequence is composed entirely of skeletal calcarenites and limestone breccias, the faunas of which show no signs of reworking. Above sample 1170 the limestones are calcarenitic micrites or true skeletal calcarenites. Calcareous algae are common throughout.

The lowermost 73 m of rock contains a fauna which includes Lepidocyclina (Eulepidina) spp., Miogypsina (Miogypsinoides) bantamensis, Spiroclypeus margaritatus, Sorites cf. orbiculus, Borelis spp., and rare specimens of Austrotrillina striata. From about 122 m the hillside is covered with limestone boulders and basalt rubble, no exposure of solid rock being visible. Thin sections cut from several of the boulders revealed a fauna similar to that occurring at higher levels in the succession, and it seems probable that the rocks have fallen more than 45 m to their present positions. At about 114 m the sequence is faulted, about 4.5 m of Eocene limestone being introduced at this level. These Eocene beds are terminated abruptly by basalt, which produces a steep slope about 43 m high. The nature of the contact between the limestone and basalt is unknown. Immediately above the basalt the slope has been graded for the construction of a pilot washing and screening plant, and new 'C' grade calcination plant.

The nearest continuous limestone exposure at this level is in a cliff about 10 m high beginning near Flying Fish Cove some 380 m to the north. This may be Andrews' locality 'at 500 feet running south from Flying Fish Cove'. If so, his sample 549 must have been taken somewhere in this vicinity. The fauna in this small outcrop is dominated by Heterostegina barriei sp. nov. and Spiroclypeus; many of the foraminifera appear to be rolled and abraded. Barrie's sample D.2 collected from the site of the washing and screening plant contains the same fauna, as do several samples collected between 189 and 195 m (i.e., just below the South Point Road).

2. 'G' Traverse (Text-fig. 3). This, in effect, is a continuation of 'D' Traverse to the top of the island, but offset a little to the south. Twenty-seven samples were collected by Belford and seventeen by Barrie, through a vertical distance of 100 m. The succession is relatively well-exposed between the railway line and the 'C' Grade access road, but is then rather poorly exposed up to the level of M. dehaarti. At higher levels the outcrop is fairly continuous. The lower and upper parts of the sequence are formed of skeletal calcarenites, but between 220 and 250 m corals and calcareous algae are well developed and may represent a true reef.

The microfauna of the lower part of the section is characterized mainly by the presence of Sorites, Austrotrillina striata and Spiroclypeus margaritatus. Eulepidina and Miogypsina (Miogypsinoides) are absent. At about 270 m there is a facies change and M. (Miogypsinoides) dehaarti occurs in abundance, accompanied by Carpentaria and Amphistegina. At this level the rock becomes a true foraminiferal coquina for the first time.

The combined thicknesses of 'D' and 'G' Traverses total about 270 m, of which at least 4.5 m is Eocene limestone and 44 m basalt.

3. Waterfall Traverse (Text-fig. 4). Thirty-seven samples were collected by Belford and Barrie from about 161 m of strata exposed in this traverse on the eastern side of the island. The lithology is remarkably uniform throughout the traverse, the limestone consisting essentially of calcilutitic skeletal calcarenites.

Six samples from the lowest 15 m yielded no species of age-diagnostic value. H. barriei appears in sample 1095 and continues up to the 121 metre level (sample 1284). The upper part of the traverse is characterized by the occurrence of Tayamaia marianensis, a species which has not been found in situ on the western side. Miogypsina (Miogypsinoides) is fairly common throughout the section. A single specimen of Lepidocyclina in 1095 is clearly redeposited. The Waterfall Traverse thus seems to be equivalent to 'G' Traverse plus the top of 'D' Traverse (Eocene beds excluded) on the northwest side of the island.

4. Ross Hill Traverse (Text-fig. 5). Sixty-one samples were collected by Belford and Trueman from the traverse, which covers about 200 m of limestone on the eastern side of the island. The twelve samples taken from the lowermost 91 m came from limestone blocks in basalt rubble and not necessarily in situ, although their faunas suggest that they are not far out of position. The greater part of this sequence consists of fine to coarse-grained skeletal calcarenites with varying amounts of calcilutite and secondary calcite. The small 'steps' in the profile above 130 m probably represent faults, and in this connexion it should be noted that Miogypsina (Miogypsinoides) dehaarti occurs in sample 1304 only 6 m above M. (M.) complanata in 1303 (see p.).

The lowermost 80 m is characterized by an association of Spiroclypeus and Heterostegina barriei. This is followed at 140 m (Sample 1304) by Miogypsina (Miogypsinoides) dehaarti and at 164 m by Tayamaia marianensis. At 213 m (Sample 1228) M. (Miogypsina) cf. neodispansa occurs. However, it disappears again 7.5 m higher in the sequence. Austrotrillina howchini occurs in sample 1317 (220 m) and continues almost to the top of the section, where Flosculinella bontangensis appears. A. howchini and F. bontangensis have not been seen in the same samples, and the latter has not been found associated with any other age-diagnostic species.

5. Sydney's Dale Traverse. The 21 samples from this stream traverse on the western side of the island represent about 60 m of limestone consisting of limestone breccias and calcarenitic muds. The lower half of the sequence is quite well exposed and is represented by 16 samples, at least 4 of which (between 1244 and 1246, see Text-fig. 10) contain reworked Eocene foraminifera. These, however, are never numerous. The occurrence of Miogypsina (Miogypsinoides) dehaarti and Tayamaia marianensis in the lowest sample (1244) indicates that no part of the sequence is older than Assemblage 3.

The frequency of occurrence of each species on the distribution charts (Text-figs. 6-10) has been determined as the maximum number observed in any one thin section from a sample. Because of their large size, B forms of Lepidocyclina (Eulepidina) in the 'D' Traverse are recorded only as present. Encrusting genera are similarly treated since individual specimens tend to be badly fragmented, rendering counts meaningless.

AGE OF THE FAUNAS

Five faunal assemblages have been recognized within the post-Eocene limestones, Assemblages 1 and 2 probably being in part laterally equivalent (p.).

1. Lepidocyclina (Eulepidina) ephippioides/Miogypsinoides bantamensis/Spiroclypeus margaritatus Assemblage. These species form the bulk of this Assemblage which is seen only in 'D' Traverse.
Age: Lower e.

2. Heterostegina barriei/Spiroclypeus margaritatus Assemblage. Well developed in 'D' Traverse and also seen in the Waterfall Traverse.
Age: Lower e, on the presence of M. (Miogypsinoides) complanata in a few samples.

3. M. (Miogypsinoides) dehaarti/Tayamaia marianensis Assemblage. Seen in the Waterfall and Ross Hill Traverses where it is well developed; also occurs in Sydney's Dale.
Age: Upper e.

4. Miogypsina/A. howchini Assemblage. Seen in stratigraphical sequence only in the Ross Hill Traverse, although isolated samples are known from the vicinity of Flying Fish Cove and Sydney's Dale.
Age: Upper e.

5. Austrotrillina howchini/Flosculinella bontangensis Assemblage. Believed to be restricted to a thin zone at the top of the succession and so far observed only in the upper part of the Ross Hill Traverse.
Age: Lower f.

These faunas tend to grade into one another and their constituent species are not necessarily mutually exclusive. Hence, M. (M.) bantamensis and Spiroclypeus margaritatus may be found in Assemblage 3, as may Austrotrillina howchini. Long ranging species such as Gypsina globula (Reuss), Borelis pygmaeus Hanzawa and Sorites cf. orbiculus (Forskal) occur throughout the greater part of the succession.

The faunal sequence shows certain pecularities. Occurrences of M. (Miogypsinoides) complanata in sample 64 (near Jedda Cave), samples 1302 and 1303 (Ross Hill Traverse), and D.3 in the 'D' Traverse, either within or above the range of M. (M.) bantamensis, are anomalous. In each sample, all the numerous specimens of miogypsinids appear to have long neponic spires, thus ruling out the possibility that we are dealing merely with a few reworked individuals. It might be argued that sample 64 has been raised to its present high position by faulting, but this explanation will not suffice for samples 1302 and 1303, sample D.3, and 135B (Dolly Beach), in each of which M. (M.) complanata occurs with foraminifera typical of Assemblage 2.

Although the oldest Tertiary e limestones appear to be those in the lower part of 'D' Traverse on the northwest side of the island, they have evidently reached their present position by faulting. They are nowhere seen immediately beneath the Assemblage 2 faunas in a continuous section. There is, therefore, a definite possibility that Assemblage 1 may be partly or entirely the lateral equivalent of Assemblage 2, the composition of the faunas reflecting differences in the local environment of deposition rather than any significant stratigraphical change. However, the occurrence of M. (M.) complanata with Spiroclypeus and Heterostegina barriei at Dolly Beach, Ross Hill, and in the 'D' Traverse strongly suggests that the lower part of Assemblage 2 is slightly older than the lowest beds yielding Assemblage 1 in 'D' Traverse. This interpretation would explain the occurrence of rolled and abraded specimens of Eulepidina (nearly always microspheric forms) in Assemblage 2, and the absence or rarity of encrusting genera in Assemblage 1.

Lower e is now believed (Adams, 1970) to be equivalent to the upper Oligocene (Chattian) of Europe, Upper e to the lower Miocene (Aquitanian and Burdigalian in the type areas) and Lower f to the early middle Miocene (Vindobonian).

The minimum thickness of post-Eocene limestone on the island (assuming that Assemblages 1 and 2 are laterally equivalent) is about 190 m. If they are not equivalent, the figure increases to 265 m. In this connexion, it may be noted that a borehole in the South Point area was abandoned while still in limestone at 244 m (pers. comm., D.A. Powell), whereas another hole (No. 14) on the plateau northeast of Smith Point reached basalt at 167 m. A stratigraphic bore ST.1, Jones Spring, north of the Waterfall Traverse, passed through 23 m of Tertiary 'e' limestone and 55.5 m of basalt before entering an upper Eocene (Tertiary b) limestone.

SYSTEMATIC PALAEONTOLOGY

The limestones of Christmas Island are rich in micro-fossils, which, unfortunately, have had to be examined mainly by means of random thin sections. Only a few oriented sections could be prepared owing to the difficulty of freeing individual specimens from the hard rock matrix. This rendered specific determinations difficult, especially for genera such as *Miogypsina*, *Cycloclypeus*, and *Lepidocyclina*, in all of which the nature of the embryonic apparatus is of critical importance.

It is usually impossible to determine the range of variation of species seen only in random sections, since two or more species of the same genus may be present in the rock. For this reason, no serious taxonomic revisions are attempted here. Synonymies are restricted to the original description, to previous records from Christmas Island and, where appropriate, to important recent redescriptions.

Special mention must be made of the work of Jones & Chapman (1900). These authors based their descriptions on a very small number of thin sections (one or two per sample), and misinterpreted many of the specimens. Not only did they mistake Miogypsina (Miogypsinoides) for Heterostegina and Miogypsina (Miogypsina) for Orbitoides (Lepidocyclina), but they failed to distinguish between specimens now referred to Spiroclypeus and Lepidocyclina. They also erected new species on shape and size alone, disregarding the possibility that these characters might be highly variable. Nuttall (1926), in revising the orbitoids, corrected most of their taxonomic errors.

Family MILIOLIDAE Ehrenberg, 1839

Genus AUSTROTRILLINA Parr, 1942

This genus was revised by Adams (1968) and nothing new can be added here. The commonly occurring species on Christmas Island is A. striata, but at high levels in the succession it is replaced by forms transitional to A. howchini.

Austrotrillina howchini (Schlumberger)

Pl. 3, fig. 7

1893 Trillina howchini Schlumberger, p. 119, text-fig. 1, pl. 3, fig. 6.

1968 Austrotrillina howchini (Schlumberger); Adams, p. 86, pl. 2, figs. 1-7, pl. 6, figs. 1-5, 7.

Remarks. Associated with Miogypsina in the upper part of the Ross Hill Traverse. Ludbrook's record (1965, p. 291) of A. howchini in association with F. bontangensis was an error; these species have not been observed together either in the original slides from sample P. 33, or in material subsequently obtained from this locality. There is, however, no reason why A. howchini should not be found with F. bontangensis, since their ranges are known to overlap elsewhere in the region (e.g., Australia;

Crespin, 1955). All the individuals seen so far are fairly primitive forms lacking the greatly thickened wall so characteristic of the end members of the lineage.

Austrotrillina striata Todd & Post

Pl. 3, fig. 6

1954 Austrotrillina striata Todd & Post, p. 555, pl. 198, fig. 9

1965 Austrotrillina howchini (Schlumberger); Ludbrook, p. 292, Pl. 21, figs. 4-6

1968 Austrotrillina striata Todd & Post; Adams, p. 92, pl. 4, figs. 1-13, pl. 6, fig. 9.

Remarks. A. striata occurs at intervals throughout the Tertiary e limestones. Its first occurrence is in sample 1334 ('D' Traverse); its last, in sample 1228 (Ross Hill Traverse). At higher levels it is replaced by fairly primitive forms of A. howchini.

Family SORITIDAE Ehrenberg, 1839

Genus SORITES Ehrenberg, 1839

Type species Sorites dominicensis Ehrenberg = Nautilus orbiculus Forskal

Sorites cf. orbiculus (Forskal)

Pl. 4, figs. 2, 10

1775 Nautilus orbiculus Forskal, p. 125

1965 Sorites martini (Verbeek); Ludbrook, pp. 290-292

1965 Sorites orbiculus (Forskal); Cole, p. 20, pl. 6, figs. 1-5, 7, 9; pl. 7, figs. 1-8, 10-12; pl. 8, figs. 7-9.

1969 Sorites orbiculus (Forskal); Cole, p. C5, pl. 3, figs. 7, 8, 16; pl. 4, figs. 3-7.

Remarks. This long-ranging species occurs throughout the entire Oligocene/Miocene sequence. It is never abundant, random sections usually showing one or two individuals only. Cole (1969) gave reasons for regarding this form as S. orbiculus rather than S. martini, the name applied by most previous authors to Tertiary e specimens. In the absence of good equatorial sections it is impossible to be certain that some specimens do not belong to _S. marginalis_ (Lamarck).

Genus MARGINOPORA Blainville 1830

Type species _Marginopora vertebralis_ Blainville

Marginopora vertebralis Blainville

Pl. 4, fig. 11.

1830 _Marginopora vertebralis_ Blainville, p. 377.

Remarks. Individuals referable to this species occur in a few samples from the upper part of the Ross Hill Traverse in Assemblages 3-5. Unfortunately, they are not numerous and no well oriented sections have been obtained.

Family ALVEOLINIDAE Ehrenberg, 1839

Genus BORELIS de Montfort, 1808

Type species _Nautilus melo_ var. B Fichtel & Moll, 1798

Borelis pygmaeus Hanzawa

Pl. 1, figs. 9-14.

1900 _Alveolina melo_ (Fichtel & Moll); Jones & Chapman, p. 255.

1930 _Borelis_ (_Fasciolites_) _pygmaeus_ Hanzawa, p. 94, pl. 26, figs. 14 & 15.

1965 _Borelis pygmaeus_ Hanzawa; Ludbrook, p. 292, pl. 21, figs. 7 & 8.

Remarks. This well-known species is common in Assemblages 1 to 3. Small inflated forms of _Borelis_, very like the Recent _B. pulchrus_, also occur at some horizons and seem to grade into _B. pygmaeus_. Cole (1969) referred all such specimens from Midway to _B. melo_. However, the typical _B. melo_, from the middle Miocene of the Mediterranean region and the Middle East, is a strongly inflated form (usually higher than wide) which shows no axial thickening and tends to develop supplementary chamberlets (_B. melo curdica_). _B. pulchrus_ and _B. pygmaeus_ always show a tendency towards axial thickening, are rarely, if ever, higher than wide, and do not develop supplementary chamberlets. This is not the place, nor is the present material appropriate, for a revision of the genus Borelis. We are therefore retaining Hanzawa's specific name, while drawing attention to the similarity between these specimens and the Recent B. pulchrus and B. pulchrus schlumbergeri. The difference between B. pulchrus schlumbergeri and B. melo is very well illustrated by Reiss & Gvirtzman (1966, pls. 1 & 2).

Genus FLOSCULINELLA Schubert

Type species Alveolinella bontangensis Rutten, 1913

Flosculinella bontangensis (Rutten)

Pl. 4, fig. 3.

1913 Alveolinella bontangensis Rutten, p. 221, pl. 14, figs. 1-3

1965 Flosculinella botangensis (Rutten); Ludbrook, p. 292, pl. 21, fig. 13.

Remarks. This species is known only from the uppermost beds in the Ross Hill Traverse. It has been found associated with Amphistegina, Sorites, and encrusting genera. However, Austrotrillina howchini occurs at about the same level and is known to have co-existed with F. bontangensis elsewhere in the region.

Flosculinella sp.

Remarks. A single individual was seen in Barrie's sample 69F (Batu Merah, Flying Fish Cove). It is impossible to decide whether this specimen should be referred to F. reicheli Mohler or to F. globulosa (Rutten). However, its occurrence with an Assemblage 2 fauna almost certainly means that the genus can no longer be relied on to mark the base of Upper e.

Family NUMMULITIDAE de Blainville, 1825

Subfamily CYCLOCLYPEINAE Butschli, 1880

Genus CYCLOCLYPEUS Carpenter, 1856

Type species C. mammilatus Carter 1861

Cycloclypeus cf. eidae Tan Sin Hok

1932 Cycloclypeus eidae Tan Sin Hok, p. 50, pl. 5, fig. 6, pl. 12, figs. 2-3, pl. 13, fig. 2.

?1965 Cycloclypeus cf. eidae Tan Sin Hok; Ludbrook, p.291.

Remarks. This species is rather rare. It occurs in a number of samples from 'D' Traverse (Assemblage 1); Ludbrook reported it from sample P. 52, Flying Fish Cove.

Genus HETEROSTEGINA d'Orbigny, 1826

Type species H. depressa d'Orbigny

Heterostegina barriei sp. nov.

Pl. 1, figs. 1-4

1900 Heterostegina depressa d'Orbigny; Jones & Chapman, pp. 244 & 252 Not p. 229, pl. 20, fig. 1.

This species is named after Mr J.M. Barrie, in whose samples it was first recognized.

Description of holotype. Test small, with evolute primary chambers arranged in 3 rapidly expanding whorls. Proloculus and deuteroconch minute, followed by 5 operculine chambers. Secondary septa long, and well developed from their first appearance. No ornament visible.

Dimensions. Diameter 1.0 mm (test incomplete). Diameter of proloculus 0.05 mm.

Variation. Other specimens show that the diameter of the test ranges at least up to 2.1 mm, although the flange is almost always broken. The number of operculine chambers ranges from 5 to 8, and the number of whorls from 3 to 3½. Secondary septa are always long. Although no ornament has been observed, its presence cannot be entirely ruled out since small pustules do not always show up in random sections.

Locality and horizon. Holotype from sample 1168, 'D' Traverse, at base of the limestone outcrop at this locality. This species is characteristic of Assemblage 2. Age: Lower e.

H. barriei appears to differ from all other described species of the genus in being unusually small (under 2 mm average diameter) and in having a very small embryonic apparatus followed by from 5-8 operculine chambers in the megalospheric form. It most closely resembles H. granulatestata subsp. praeformis Papp & Kupper from the middle Miocene of southern Europe, but is smaller and has long secondary septa only. H. suborbicularis d'Orbigny is the commonly reported Tertiary e species in the Indo-Pacific region, but this is involute and has very many more operculine chambers (cf. Cole, 1969, pl. 3, figs. 1-5, 18).

Heterostegina cf. borneensis van der Vlerk 1929

Pl. 1, figs. 5-7.

Remarks. Specimens probably referable to this species have been seen in a few samples (G.837, G.838 & G.862) from Flying Fish Cove. They are two or three times the size of the largest specimens of H. barriei, and the two species have not been seen in association. A positive identification is, unfortunately, impossible in the absence of sections showing the embryonic apparatus and first whorl.

Genus OPERCULINA d'Orbigny, 1825

Remarks. Specimens occur at intervals throughout the succession. They are rarely numerous and appear to be specifically indeterminable in random sections. It is possible that more than one species is represented.

Genus SPIROCLYPEUS Douville, 1905

Type species S. orbitoideus Douville, 1905

At least 11 nominal species of this genus have been described from Tertiary e strata in the Indo-West Pacific region, and although attempts have been made to distinguish between them (e.g., Krijnen 1931), authors have found the greatest difficulty in naming specimens satisfactorily. It is undoubtedly significant that no one has yet described a succession in which even a few of these species have been shown to succeed one another in time, and as Cole (1969) has pointed out, several authors have found two or three so-called species in the same beds. Cole (op. cit.) therefore assigned seven of the 'species' occurring in the Tertiary e rocks of the region to S. margaritatus (Schlumberger). Although first inspection of the present material suggested that several species were represented, closer examination indicated that transitional forms occur. This, together with the absence of any obvious pattern of stratigraphical distribution, strongly suggests that only one species is present despite the wide range of morphological variation.

Spiroclypeus occurs abundantly only in 'D' Traverse. It is common at some levels in 'G' Traverse, but well-oriented individuals have not been seen. It occurs in four samples near the base of the Ross Hill Traverse, but except in 1302, specimens are rare and specifically indeterminable. It is also present in four samples from the succession in Sydney's Dale.

Spiroclypeus margaritatus (Schlumberger)

Pl. 2, figs. 1-11.

1900 Orbitoides (Lepidocyclina) sumatrensis Brady; Jones & Chapman, p. 244, pl. 20, fig. 6.

1902 Heterostegina margaritatus Schlumberger, p. 252, pl. 7, fig. 4.

1926 Spiroclypeus globulus Nuttall, pp. 36, 37, pl. 5, figs. 5-7, test-Fig. 1.

1965 Spiroclypeus globulus Nuttall; Ludbrook, p. 291, pl. 22, fig. 3.

1969 Spiroclypeus margaritatus (Schlumberger); Cole, p. C8, pl. 2, figs. 1-20, pl. 3, figs. 9-14, 19 (synonymy).

Remarks. The highly inflated form (S. globulus of Nuttall) of this species is common to abundant throughout the upper part of 'D' Traverse (Assemblage 2). However, it is usually abraded and shows signs of having been rolled and redeposited. The flange is rarely preserved except in the thicker and stronger 'B' forms. It occurs also in Assemblage 2 at the base of the Ross Hill Traverse and in Assemblages 2 and 3 at Waterfall.

The chief variation in the present material is in the strength of the ornament and width of the walls between the lateral chambers. Some highly inflated forms, particularly those of the microspheric generation, seem to possess a single umbonal pillar; however, this effect can also be produced by sections through thickened lateral walls.

The only differences between S. leupoldi and S. margaritatus seem to be the inflation of the test and the number of lateral layers. No differences can be seen in equatorial sections obtained near the base and the top of 'D' Traverse (1332-1177).

Family MIOGYPSINIDAE Vaughan, 1928

Genus MIOGYPSINA Sacco, 1893

Subgenus MIOGYPSINOIDES Yabe & Hanzawa, 1928

Miogypsina (Miogypsinoides) complanata Schlumberger

Pl. 3, figs. 1-5.

1900 Miogypsina complanata Schlumberger, p. 330, pl. 2, figs. 13-16

1936 Miogypsinoides ubaghsi Tan Sin Hok, p. 48, pl. 1, figs. 1-7

Remarks. This primitive species is found at only four localities. It occurs in 1302 and 1303, Ross Hill Traverse (Assemblage 2); in Barrie's samples D.3 from the 'D' Traverse and 135B above Dolly Beach

(East Coast), each with an Assemblage 2 fauna; and it forms a true foraminiferal coquinite in Barrie's sample 64 near Jedda Cave in the centre of the island. Sample D.3 is accurately located in the sequence; 64 and 135B are isolated samples which cannot at present be located accurately relative to the local stratigraphical succession. Samples 1302 and 1303 are from a boulder-strewn slope and must be older than other samples collected from boulders occurring at lower levels along the same traverse. There are two possible explanations for this peculiar distribution. Either all rocks containing M. (M.) complanata are up-faulted relative to all those containing M. (M.) bantamensis or the ability to produce a long periembryonic spire had not been entirely lost by the time M. (M.) bantamensis evolved. The former explanation is considered to be the most likely since all the specimens seen in each sample appear to have the same grade of structure.

Cole (1969) argued that because M. (M.) dehaarti, M. (M.) lateralis, M. (M.) mauretanicus, M. (M.) formosensis, and M. (M.) bantamensis could be shown to occur in association in one part of the region or another, only one species should be recognized. However, he failed to notice that the gradation is in time rather than in space. Hence, M. (M.) complanata is never found with M. (M.) dehaarti, whereas either (but not both) may occur with M. (M.) bantamensis.

Variation. Nepionic spire long (16-23 chambers in the A form), test relatively small (up to 1.3 mm in maximum diameter), lateral walls nearly always thin.

Miogypsina (Miogypsinoides) bantamensis Tan Sin Hok

Pl. 3, figs. 8-11; text-fig. 11

1936 Miogypsinoides complanata (Schlumberger) forma bantamensis Tan Sin Hok, p. 48, pl. 1, fig. 13.

1940 Miogypsinoides lateralis Hanzawa, p. 783, pl. 39, figs. 10-14.

Remarks. Cole (1969) has argued that M. (M.) bantamensis is a junior synonym of M. (M.) dehaarti and that the two cannot be distinguished in the drill holes on Midway Atoll. However, if the principle of nepionic acceleration is valid, M. (M.) bantamensis must be slightly older than M. (M.) dehaarti. This is supported by the stratigraphical distribution of these two species on Christmas Island. M. (M.) bantamensis is common in Assemblage 1 ('D' Traverse) and also occurs in Assemblage 3 (Ross Hill and Sydney's Dale), although the paucity of well-oriented individuals renders identification difficult in many samples.

Present evidence suggests that the earliest representative of M. (Miogypsinoides) in the Indo-Pacific region (M. (M.) complanata) gradually underwent a shortening of the periembryonic spire leading to the condition seen in M. (M.) bantamensis. This process continued until individuals recognizable as M. (M.) dehaarti were produced. This shortening of the spire was accompanied at first by an increase in the number of equatorial chambers, thus producing a larger test, and later by increase in the thickness of the lateral walls. The shortening of the spire may have been linked with an increase in the internal diameter (volume) of the proloculus. The evolutionary sequence is tabulated below.

3. M. (M.) dehaarti	Upper e
2. M. (M.) bantamensis	Late Lower e
1. M. (M.) complanata	

As these changes in shell form were gradual and progressive, transitional forms occur between 1 and 2 and 2 and 3. However, M. (M.) complanata and M. (M.) dehaarti have never been found in natural association.

Cole's evidence from Midway is not opposed to this hypothesis. His figured specimens show an overall increase in the length of the spire with depth.

Data from Cole (1969, pl. 1)

Depth	No. of chambers in spire
595-600 ft	figs. 3 & 4 (&); figs. 1, 11 & 12 (9)
901-906 ft	figs. 9 (10); fig. 20 (9+); fig. 8 is a microspheric form.
926-927 ft	figs. 5 & 6 (10); figs. 13, 14, 16 & 17 (13); figs. 18 & 19 (12+)

Hanzawa (1957) and others have attributed importance to the attitude of the embryonic chambers relative to the apex of the shell. However, this is determined by the length of the spire. Once median chambers have begun to form, the spire cannot be continued for more than half a turn (usually 7-9 chambers) without the typical fan shape being lost.

Variation. Periembryonic spire of medium length and formed of 9 to 13 chambers. Internal diameter of the proloculus 0.133 to 0.150 mm (6 measured specimens). Test up to 2.2 mm long and 0.76 mm thick; always longer than wide.

Since this species evolved from *M.* (*M.*) *complanata* and into *M.* (*M.*) *dehaarti*, it follows that transitional forms occur and that an arbitrary specific diagnosis will not be satisfactory for the early and late representatives of the '*bantamensis*' part of the lineage.

Miogypsina (*Miogypsinoides*) *dehaarti* van der Vlerk

Pl. 3, figs. 12-14.

1900 *Heterostegina depressa* d'Orbigny; Jones & Chapman, p. 257.

1924 *Miogypsina dehaartii* van der Vlerk, p. 429, text-figs. 1-3.

1965 *Miogypsinoides dehaarti* (van der Vlerk); Ludbrook, p. 293, pl. 21, figs. 9-11 & fig. 12 (part).

Remarks. Little can be added to previous descriptions. In the present material the nepionic spire consists of from 7 to 10 chambers of which the last few are usually very small. The test is usually wider than long, and the lateral walls are well developed. The test ranges up to 1.2 mm in thickness; some specimens have a strongly pustulate appearance, others are smooth.

This species forms a foraminiferal coquina in some samples (e.g., 1058, 1059, 1061, 'G' Traverse and Andrews' No. 131, Flying Fish Cove); it is common in the Ross Hill and Waterfall sequences.

M. (M.) dehaarti occurs in Assemblages 3 and 4. It overlaps and grades into M. (M.) bantamensis in the lower part of Assemblage 3, and overlaps with M. (Miogypsina) cf. neodispansa in Assemblage 4. Ludbrook (1965) figured an association of M. (M.) dehaarti and M. (Miogypsina) neodispansa.

Miogypsina (Miogypsina) neodispansa (Jones & Chapman)

Pl. 1, figs. 16-18.

1900 Orbitoides (Lepidocyclina) neodispansa Jones & Chapman, pp. 235, 240, pl. 20, figs. 3 & 4.

1926 Miogypsina neodispansa (Jones & Chapman); Nuttall, pp. 37, 38, pl. 5, fig. 4.

1965 Miogypsina neodispansa (Jones & Chapman); Ludbrook, p. 290, pl. 2, fig. 12 (part)

Remarks. The original description of M. (M.) neodispansa is poor, and Nuttall's emendation little better, since he gave no information about the nepionic spire, the one part of the test considered to be of diagnostic importance by modern workers.

Examination of numerous random sections has revealed the following variation in test morphology:

1. Size. The maximum diameter of the test ranges from 2-4 mm, and averages about 2.5 mm. The maximum thickness (1.6 mm in the type slides) is dependent on the number (6-12) of lateral chamber layers developed.

2. Surface ornament. This varies from finely to coarsely pustulate. The maximum diameter of the pustules is about 250μ, but many individuals are ornamented with pustules not exceeding 50μ in diameter.

3. Chamber shape and arrangement. The embryonic chambers and median chambers do not always lie in the same plane, a feature which makes the preparation of oriented thin sections rather difficult.

The median layer is composed of a few rhombic and many hexagonal chambers. This layer is not always flat, and wavy tests of the *M.* (*M.*) *bifida* and *M.* (*M.*) *polymorpha* types are quite common. In the two oriented sections obtained from Barrie's sample 50 (Andrews Point) the median layers appear to be composed entirely of rhombic chambers.

4. Embryonic apparatus. The internal diameter of the protoconch in most specimens falls within the range 0.12-0.20 mm. However, one individual in a sample from South Point has an initial chamber with a diameter of 0.25 mm. The deuteroconch is usually considerably larger than the protoconch. Two protoconchal spirals are clearly visible, and the two primary auxiliary chambers are usually unequal in size. The larger chamber gives rise to a spire of three chambers while the smaller produces a shorter spire of two chambers.

M. (*M.*) *neodispansa* was one of the first miogypsinids to be described from the Indo-West Pacific region, and as such is an important species. Its association with *M.* (*Miogypsinoides*) *dehaarti* and a fairly primitive form of *Austrotrillina howchini* fixes its position as Upper *e*, while the fact that it occurs fairly high in the succession (not very far below *Flosculinella bontangensis*) probably means that it is a late Upper *e* form.

It is still impossible to state clearly how M. (M.) neodispansa differs from other described Indo-West Pacific species of the genus. Further data on the periembryonic and median chambers of this and other species are required, and these await the collection of better material. However, present evidence suggests that M. (M.) neodispansa is more highly evolved than M. (M.) thecideaeformis and M. (M.) globulina (= M. (M.) kotoi) since both protoconchal spires are well developed and the median chambers appear to be markedly hexagonal. On the other hand, it is less advanced than M. (M.) indonesiensis which has subequal primary auxiliary chambers and median chambers that are hexagonal throughout.

On the basis of individual specimens it would be possible to recognize four or five 'species' in the Christmas Island samples.

M. (M.) neodispansa occurs in great abundance in three samples from different parts of the island (Flying Fish Cove, No. 220 and 924; South Point area, K. 129). Specimens probably referable to this species occur in three samples from the upper part of the Ross Hill Traverse.

Family LEPIDOCYCLINIDAE Scheffen, 1932

Genus LEPIDOCYCLINA Gümbel, 1870

Type species Nummulites mantelli Morton, 1833

Christmas Island is the type locality for six species of Lepidocyclina, five of which were erected by Jones & Chapman (1900) on the basis of a small number of random sections through fourteen samples of limestone. Nuttall (1926), after having additional sections cut from the same material, recognized the following species: Lepidocyclina andrewsiana Jones & Chapman, L. ephippioides J. & C., L. (E) ?formosa Schlumberger (=L. murrayana J. & C.) L.chapmani Nuttall, L. inaequalis J. & C., and L. insulaenatalis J. & C.. Ludbrook (1965) reported, but did not figure or describe, all six species from two samples (P. 132 & P. 52). None of these authors had access to material collected in stratigraphical order, and all used test shape and size as the basis for distinguishing between species; internal characters, although sometimes mentioned, were not used in a systematic manner.

The present material shows that Lepidocyclina occurs mainly in the northwest part of the island. The megalospheric form of Eulepidina occurs most commonly in the lowermost 250 feet of 'D' Traverse (Assemblage 1). There is one doubtful occurrence (1095) in the Waterfall Traverse (Assemblage 2), and numerous inflated 'A' forms (E. andrewsiana type) occur in sample 1122 (Assemblage 3, Sydney's Dale Traverse). Individuals present in the higher part of 'D' Traverse (Assemblage 2) are mainly microspheric forms of the chapmani/insulaenatalis type and show obvious signs (breakage and abrasion) of redeposition. Many are coated with calcareous algae. No recognisable megalospheric forms are seen above sample 1030, other than a single specimen in sample 1045 (from a rolled boulder).

It is clear that Eulepidina is represented here by several types of test (flattened or disc-like; lenticular; saddle-shaped; and highly inflated with a flange), but so far as can be ascertained from random sections, gradation occurs between the different types. The facts that most of these can be found in two of the lowest samples (1328 and 1078) from 'D' Traverse and that no type is restricted to a definite stratigraphical interval probably mean that this diversity of form reflects variation within a single species. However, Andrews' sample 827 from 3 km south of Flying Fish Cover and four of Belford's samples from Smith Point contain a few inflated megalospheric forms which must be referred to L. (E.) andrewsiana, pending further investigation. Unfortunately, the associated foraminifera in these five samples are undiagnostic and could represent either Assemblage 1 or Assemblage 2.

The subgenus Eulepidina is in need of revision. The specific characters on which the numerous nominal species have been based need to be evaluated statistically on the basis of matrix-free material. Until this has been done it will not be possible to name specimens occurring in hard limestones satisfactorily.

LEPIDOCYCLINA (EULEPIDINA) H. Douville, 1911

Type species Orbitoides dilatata Michelotti, 1861

Lepidocyclina (Eulepidina) andrewsiana (Jones & Chapman)

Pl. 4, figs. 7-8.

1900 Orbitoides (Lepidocyclina) andrewsiana Jones & Chapman, p. 255, pl. 21, fig. 14.

Remarks. The specimens referred to this species occur in four samples from Smith Point (1257, 1258, 1262, 1263) and one (827, the type sample) from the base of a limestone cliff resting on basalt at 150 m 3 km south of Flying Fish Cove. They appear to differ from E. ephippioides in being more inflated and in tending to develop very thick lateral walls between the lateral chambers. It is, however, quite possible that transitional forms to E. ephippioides would be found if matrix-free material were available.

Lepidocyclina (Eulepidina) ephippioides Jones & Chapman

Pl. 4, figs. 4-6, 9, 12, 14.

1900 Lepidocyclina ephippioides Jones & Chapman, pp. 251-2, pl. 20, fig. 9.

1900 Lepidocyclina murrayana Jones & Chapman, pp. 252-3, pl. 21, fig. 10.

1902 Lepidocyclina (Eulepidina) formosa Schlumberger, p. 251, pl. 7, figs. 1-3.

1926 Lepidocyclina ephippioides Jones & Chapman; Nuttall, pp. 34-36, pl. 5, figs. 1, 2, 3, 8 and 10.

1926 Lepidocyclina (Eulepidina) ?formosa Schlumberger; Nuttall, pp. 22-30.

1965 Lepidocyclina (Eulepidina) ephippioides Jones & Chapman; Ludbrook, pp. 290, 291.

1965 Lepidocyclina (Eulepidina) murrayana Jones & Chapman; Ludbrook, p. 290.

Remarks. Nuttall (1926) distinguished L. ephippioides from L. andrewsiana on size (the former was, he thought, slightly larger) and on the appearance of the embryonic apparatus, which he considered to be truly eulepidine only in L. andrewsiana. However, he was comparing a well-centred section of L. andrewsiana with off-centre sections of L. ephippioides, and as shown by Text-fig. 12 the appearance of the embryonic apparatus in Eulepidina depends entirely on the plane of section. Nuttall (op. cit., p. 35) himself observed that L. ephippioides 'except for the nucleoconch strongly resembles E. formosa', a taxon now generally regarded as synonymous with E. ephippioides.

The lectotype designated by Nuttall is from Andrews' sample 549 taken 'at the base of an inland cliff at 500 feet, running south from Flying Fish Cove'. Whether from a fallen block or in situ rock was not stated. The occurrence of Eulepidina in Assemblage 1 makes it certain that L. (E.) ephippioides came from low in the post-Eocene succession. It is usually associated with Spiroclypeus margaritatus, Miogypsina (Miogypsinoides) bantamensis and Austrotrillina striata, and is therefore of Lower e age. It is worth noting that the type slides of L. murrayana contain a typical Assemblage 2 fauna.

Lepidocyclina sp.

Pl. 4, fig.13.

Large inflated 'B' forms are common throughout 'D' Traverse and are virtually the only specimens present in the upper part of the section, i.e., above sample 1045. They show considerable variation in shape and size. A particularly prominent feature is the tendency of inflated forms to develop thick walls between the lateral chambers in the umbonal region (pl. 4, fig. 13). Cuts through these walls can produce the appearance of coarse pustules in sagittal sections.

LEPIDOCYCLINA (NEPHROLEPIDINA) H. Douville, 1911

Type species Nummulites marginata Michelotti, 1841

L. (Nephrolepidina) spp.

This subgenus is surprisingly rare in the samples so far obtained from Christmas Island. It occurs sparsely in 'D' Traverse, Sydney's Dale Traverse and in a few other localities (e.g., Flying Fish Cove, Andrews' sample 646). In the absence of oriented thin sections it is impossible to assign a specific name to these individuals, some of which have hexagonal equatorial chambers. They occur in Assemblages 1-3, and it is certain that more than one species is represented.

Family HOMOTREMATIDAE Cushman, 1927

Genus CARPENTERIA Gray, 1858

Type species Carpenteria balaniformis Gray, 1858

Carpenteria spp.

Numerous fragments and some larger specimens of this genus occur throughout Assemblages 2 to 5. No attempt has been made to distinguish between different species.

Family ACERVULINIDAE Schultze, 1854

Genus GYPSINA Carter, 1877

Type species Polytrema planum Carter, 1876

Gypsina globula (Reuss)

1848 Ceriopora globulus Reuss, p. 33.

1900 Gypsina globulus Reuss; Jones & Chapman, p. 229 et seq.

Remarks. G. globula occurs throughout most of the succession and is particularly common in Assemblages 2 and 3. There is nothing to add to previous descriptions.

Family PLANORBULINIDAE Schwager

Genus TAYAMAIA Hanzawa, 1967

Type species Gypsina marianensis Hanzawa

Tayamaia marianensis (Hanzawa)

Pl. 1, fig. 8; pl. 4, fig. 1.

1957 Gypsina marianensis Hanzawa; p. 66, pl. 21, fig. 9, pl. 27, figs. 1-8.

1965 Gypsina marianensis Hanzawa; Ludbrook, p. 292, pl. 22, fig. 2.

1967 Tayamaia marianensis (Hanzawa); Hanzawa, p. 22, fig. 3.

Remarks. A long-ranging species that occurs particularly frequently in Assemblages 2-4.

OTHER ATTACHED AND ENCRUSTING GENERA

Numerous attached and encrusting forms referable to Acervulina, Borodinia, Kanakaia and Sporadotrema are present throughout the succession, being particularly common in Assemblages 2 to 5. The comparative rarity of these forms in Assemblage 1 is consistent with this having been deposited in a fore-reef environment.

SUMMARY

The larger Tertiary foraminifera occurring in the post-Eocene limestones of Christmas Island appear to be characteristic of the Tertiary Lower e, Upper e, and Lower f Letter Stages. Five locally significant faunal assemblages can be recognized; two of these are probably in part laterally equivalent, and brought into their present topographical positions by fault movements.

The close stratigraphical juxtaposition of Miogypsina (Miogypsinoides) complanata, M. (M.) bantamensis, and M. (M.) dehaarti seem to indicate that the evolution of this lineage proceeded very rapidly during the late Oligocene. The early members of the

M. (Miogypsina) kotoi - M. (M.) indonesiensis lineage have not been observed on Christmas Island. M. (M.) neodispansa is a fairly advanced form which may well prove to be of regional value in the recognition of late Upper e sediments. Flosculinella is poorly represented on the island. Apart from a single, specifically indeterminable specimen in Assemblage 2 (sample 69F, Batu Merah, Flying Fish Cove), the genus is not seen until well-developed specimens of F. bontangensis appear high in the Ross Hill Traverse. However, the occurrence of what appears to be a primitive form with a good Assemblage 2 fauna almost certainly means that this genus can no longer be relied on to define unequivocally the base of Upper e.

Although it has not been possible to determine how many species of Lepidocyclina are represented in the Christmas Island succession, it can be stated that all those described by Jones & Chapman were from limestones of late Lower e age.

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Plate 1

FIGS. 1-4. Heterostegina barriei sp. nov. All from 'D' traverse, x60. 1, paratype A, CPC. 13734, median section, sample 1173; 2, paratype B, CPC. 13735, transverse section, sample 1180; 3, holotype, CPC. 13733, slightly oblique median section, sample 1168; 4 paratype C, CPC. 13736, median section, sample 1170.

FIGS. 5-7 Heterostegina cf borneensis van der Vlerk. All transverse sections, x 10. 5, CPC.13737, oblique transverse section, sample G837, Flying Fish Cove; 6, CPC. 13738, transverse section, sample G838, Flying Fish Cove; 7, CPC.13739, transverse section, sample G837, Flying Fish Cove.

FIG. 8. Tayamania marianensis (Hanzawa), CPC.13740, x30. Sample 1216, Ross Hill traverse.

FIGS. 9-14. Borelis pygmaeus Hanzawa. Specimens from 'D' traverse showing variation in shell size and form. 9, CPC. 13741, off-centre, slightly oblique section, x40; sample 1356. 10, CPC. 13742, slightly off-centre axial section, x40; sample 1334. 11. CPC. 13743, slightly off-centre axial section, x40; sample 1334. 12, CPC.13744, axial section, x48; sample 1037. 13. CPC.13745, slightly off-centre axial section, x40; sample 1333. 14, CPC. 13746, off-centre axial section, x40; sample 1080.

FIG. 15. Borelis melo (Fichtel & Moll). Axial section P.49087, x50, from the Miocene of Turkey; introduced for comparison with B. pygmaeus.

Plate 1 contd.

Figs. 16-18 Miogypsina (Miogypsina) neodispansa (Jones & Chapman). All from Andrews' sample No. 220, south side of Flying Fish Cove. 16, P. 49088, transverse section, x30. 17, P. 49089 oblique transverse section, x24. 18, P. 49090, slightly oblique median section showing embryonic apparatus, x30.

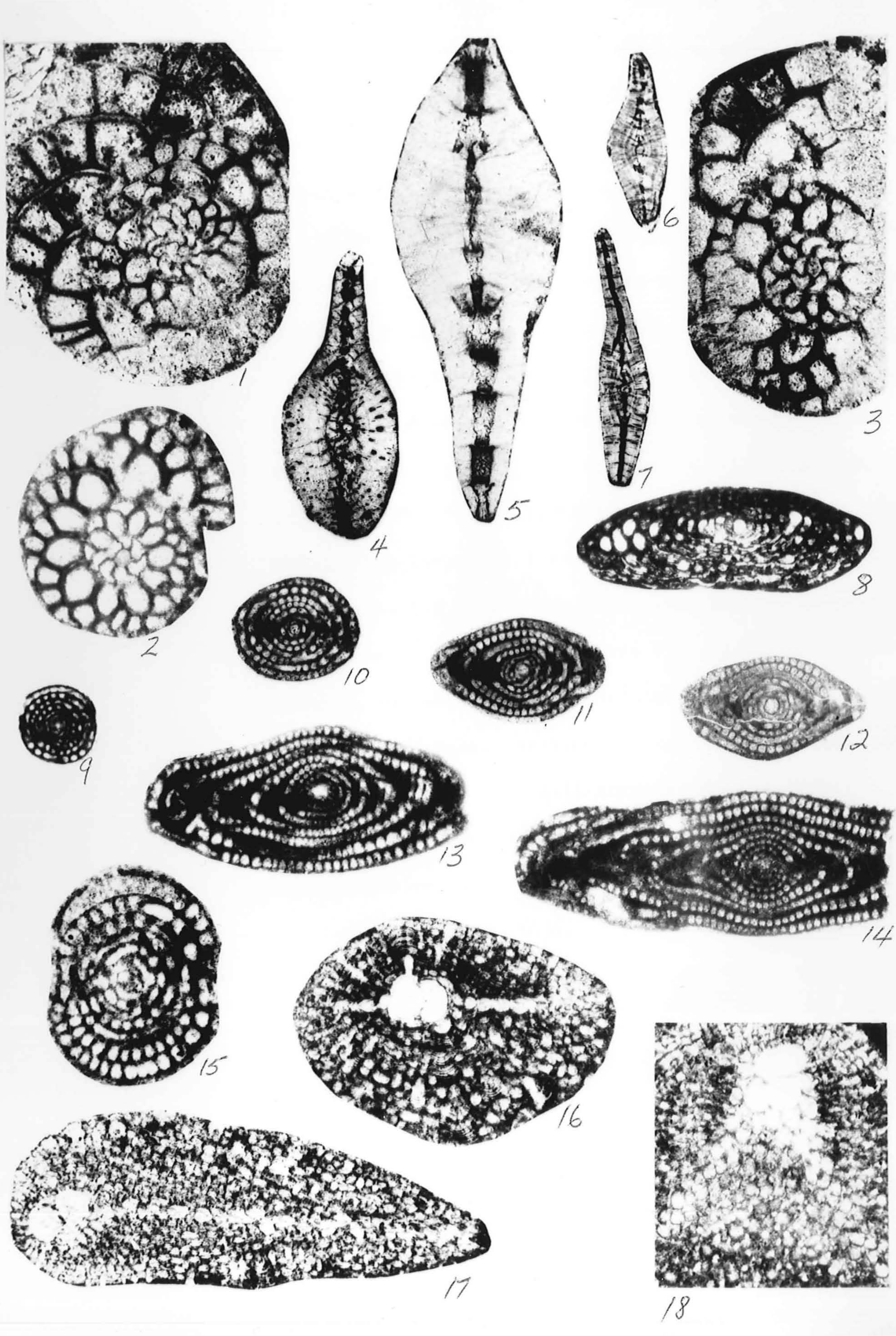
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Plate 2

FIGS. 1-11. Spiroclypeus margaritatus (Schlumberger). All except 7 from 'D' transverse.

1, CPC. 13747, off-centre transverse section through microspheric form, x10. Note thick pseudo-pillars and compare with figs 3 & 4; sample 1172. 2, CPC. 13748, typical transverse section through inflated form ("S. globulus" of Nuttall), x20. Most individuals from Christmas Island are of this type; sample 1177. 3, CPC. 13749, oblique transverse section showing pseudo-pillars, x10. Probably a micro-spheric form; sample 1171. 4, CPC. 13750 off-centre transverse section, probably through a microspheric form, x10. Note the massive umbonal pseudo-pillar and compare with Lepidocyclina sp., pl. 4, fig. 13; sample 1332. 5, CPC. 13751, slightly off-centre transverse section through megalospheric form, x20; sample 1026. 6, CPC. 13752, slightly off-centre transverse section through megalospheric form, x20. A more typical shape for the species, but not common on Christmas Island; sample 1169. 7, CPC. 13753, median section through megalospheric form, x20; sample 1302, Ross Hill traverse. 8, CPC. 13754, transverse section, x20; sample 1172. 9, CPC. 13755, median section, x20; sample 1332. 10, CPC. 13756, median section x20; sample 1036. 11, CPC. 13757, median section, x20; sample 1079.

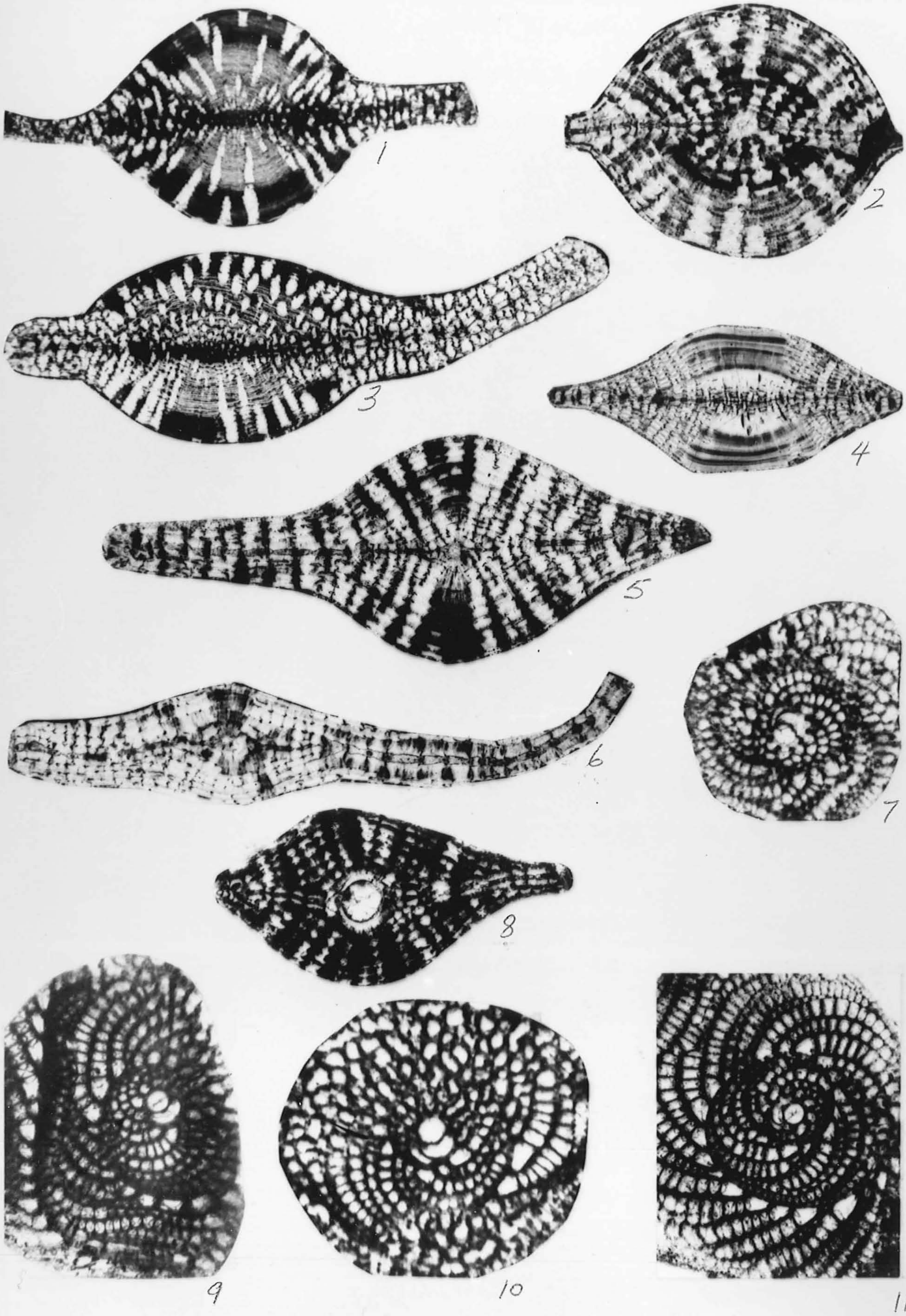
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Plate 3

FIGS. 1-5. Miogypsina (Miogypsinoides) complanata Schlumberger. 1. CPC. 13758, oblique median section through microspheric form, x30; Ross Hill traverse; sample 1302. 2. CPC. 13759, transverse section through megalospheric form, x30; Ross Hill traverse; sample 1303. 3. CPC. 13760, median section through megalospheric form, x30; Ross Hill traverse; sample 1303. 4. CPC. 13761, median section through megalospheric form, x40; "D" traverse (Barrie's sample D3). 5. CPC. 13762, off-centre transverse section x40, same locality as 4.

FIG. 6. Austrotrillina striata Todd & Post, CPC. 13763, off-centre transverse section, Ross Hill traverse; sample 1303.

FIG. 7. Austrotrillina howchini (Schlumberger), CPC. 13764, transverse section, x50. Ross Hill traverse; sample 1239.

FIGS. 8-11. Miogypsina (Miogypsinoides) bantamensis Tan Sin Hok, all x30. All from 'D' traverse. 8. CPC. 13765, megalospheric form in median section; sample 1079. 9. CPC. 13766, off-centre transverse section; sample 1334. 10. CPC. 13767, transverse section of megalospheric form; sample 1079. 11. CPC. 13768, median section of megalospheric form; sample 1079.

FIGS. 12-14. Miogypsina (Miogypsinoides) dehaarti van der Vlerk. All from 'G' traverse. 12. CPC. 13769, transverse section through megalospheric form, x50; sample 1061. 13. CPC. 13770, median section through megalospheric form, x30; sample 1059. 14. CIC. 13771, slightly oblique median section through megalospheric form, x30; sample 1061.

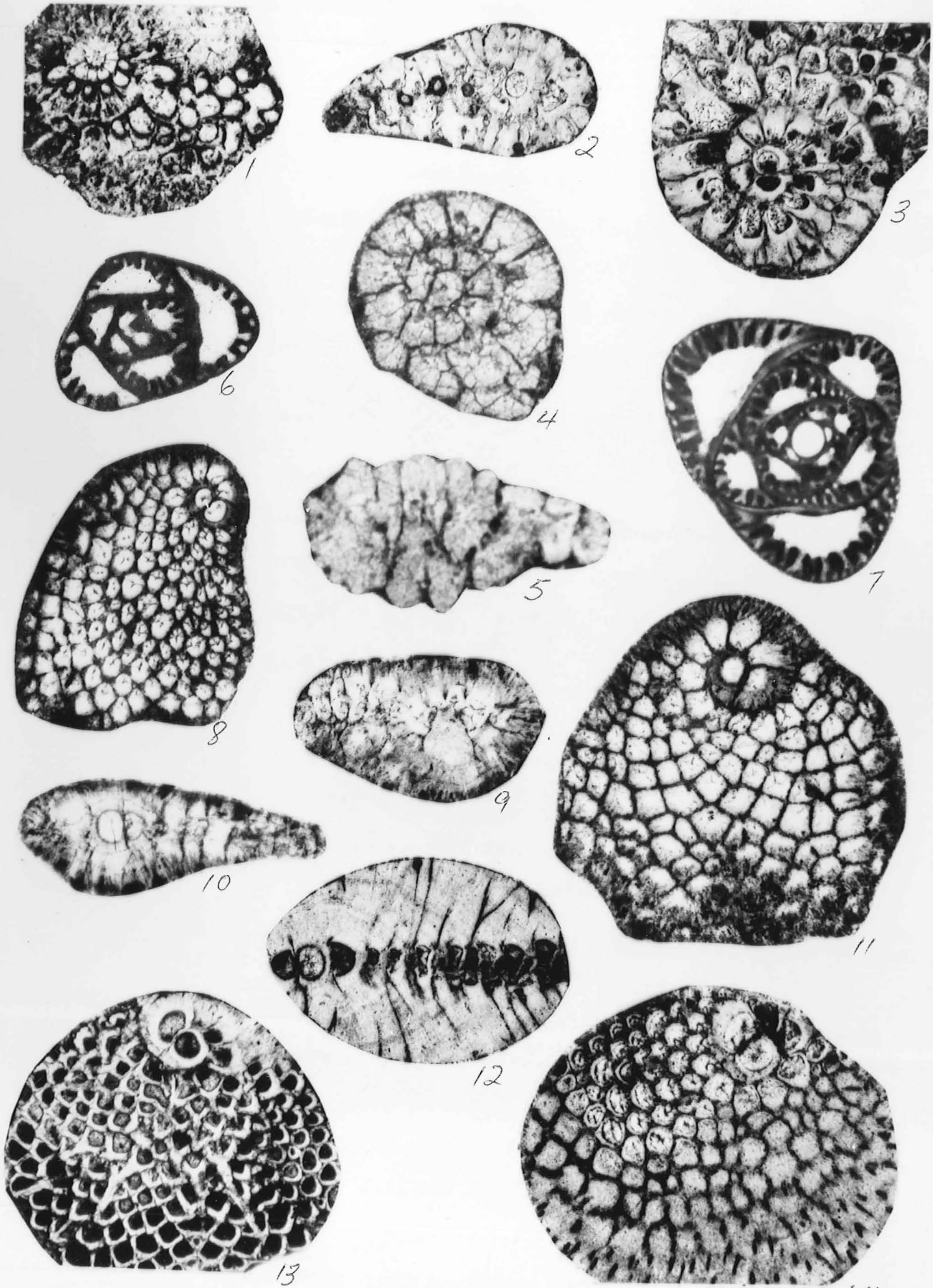
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Plate 4

FIG. 1. Tayamaia marianesis (Hanzawa), CPC. 13722, slightly off-centre transverse section, x20; sample 1065, between 'G' traverse and Waterfall.

FIGS. 2, 10. Sorites cf orbiculus (Forskal). 2. CPC. 13773, oblique median section, x40; sample 1358, 'D' traverse. 10. CPC. 13774, highly oblique median section, x30; sample 1355, 'G' traverse.

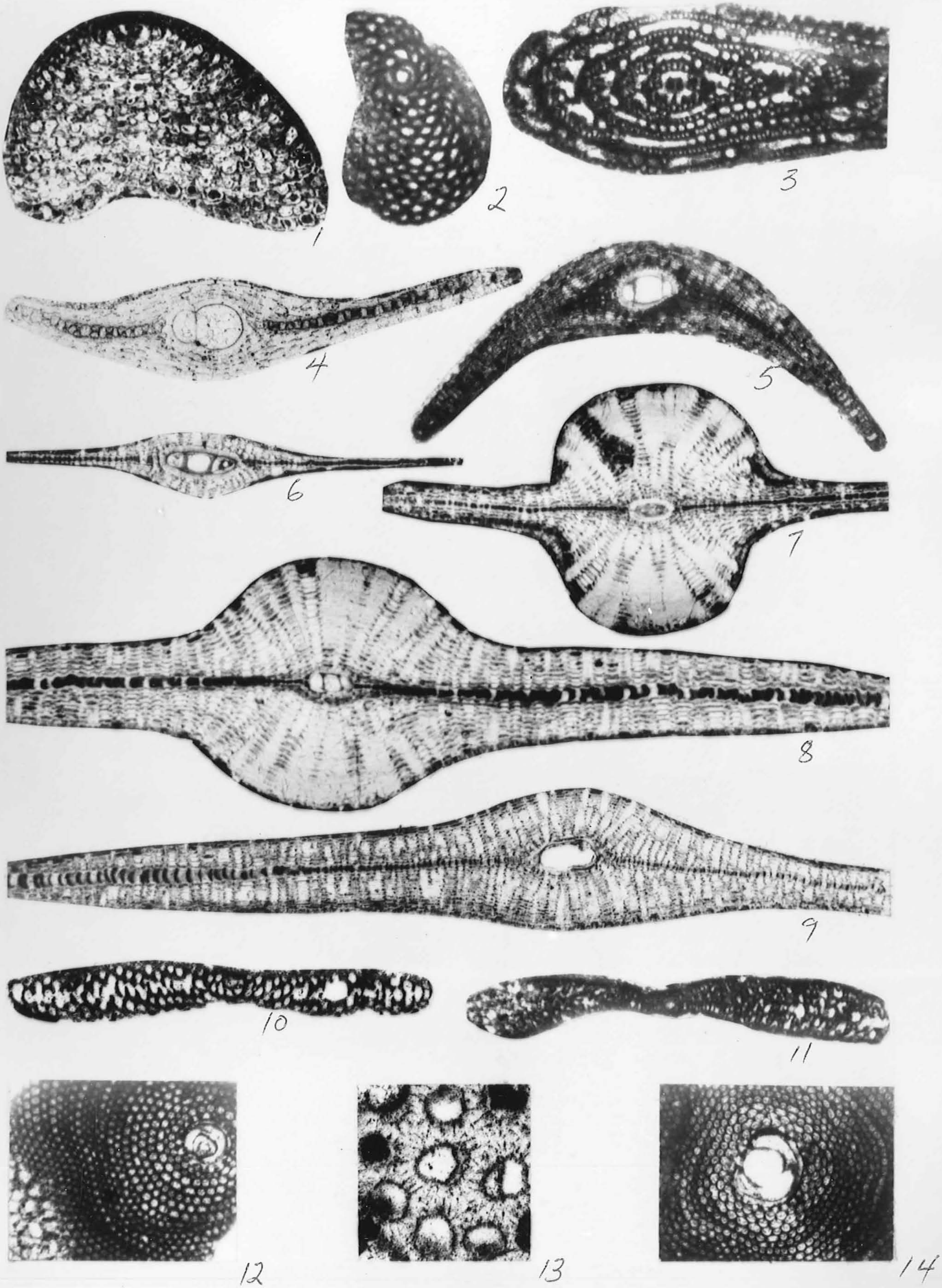
FIG. 3. Flosculinella bontangensis Rutten. CPC. 13775, off-centre axial section x30; sample 1237 (Ludbrook's P33 locality), near Ross Hill.

FIGS. 4-6, 9, 12, 14. Lepidocyclina (E.) ephippioides Jones & Chapman, all from 'D' traverse. 4-6, 9, transverse sections showing variation in shape, size, and number of lateral chambers. 4. CPC. 13766, sample 1045, x20; 5. CPC. 13777, sample 1044, x10; 6. CPC. 13778 sample 1331, x10; 9. CPC. 13779, sample 1331, x10. 12,14, median sections through megalospheric forms, both x20. 12. CPC. 13783, sample 1078; 14. CPC. 13784, sample 1328.

FIGS. 7-8. Lepidocyclina (E.) andrewsiana Jones & Chapman. CPC. 13780 and 13781. Transverse sections showing inflated umbonal region, x10. Both from sample 1261, Smith Point at 60 ft.

FIG. 11. Marginopora vertebralis Blainville. CPC. 13782, off-centre transverse section, x40; sample 1238.

FIG. 13. Lepidocyclina sp., P. 49091. Tangential section through umbonal region of inflated form (probably L. (E.) andrewsiana) showing greatly thickened walls of lateral chambers, x16. Thin sections cut along lines a-a or b-b would appear to show thickened umbonal pillars; Andrews' sample 827, 2 miles south of Flying Fish Cove.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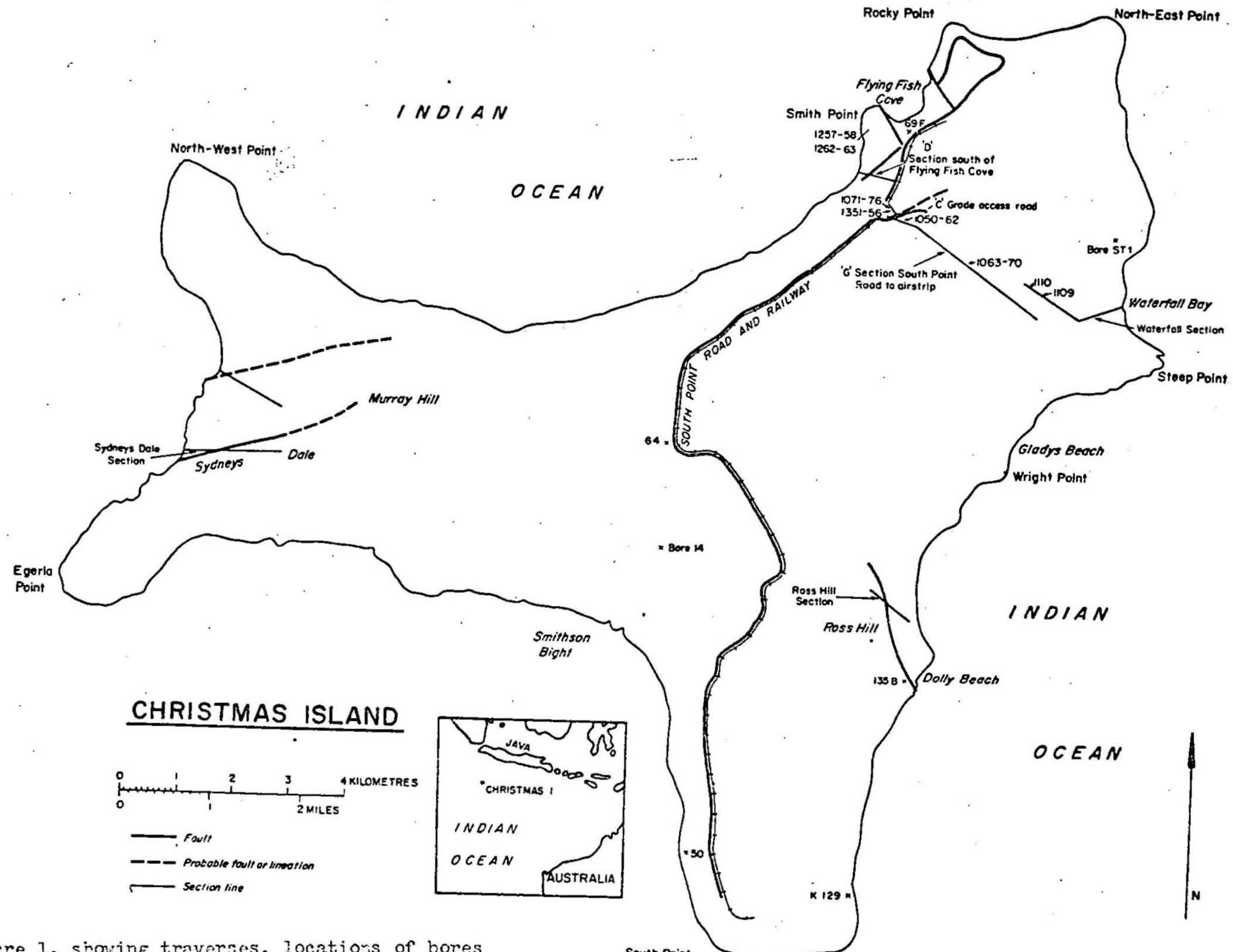
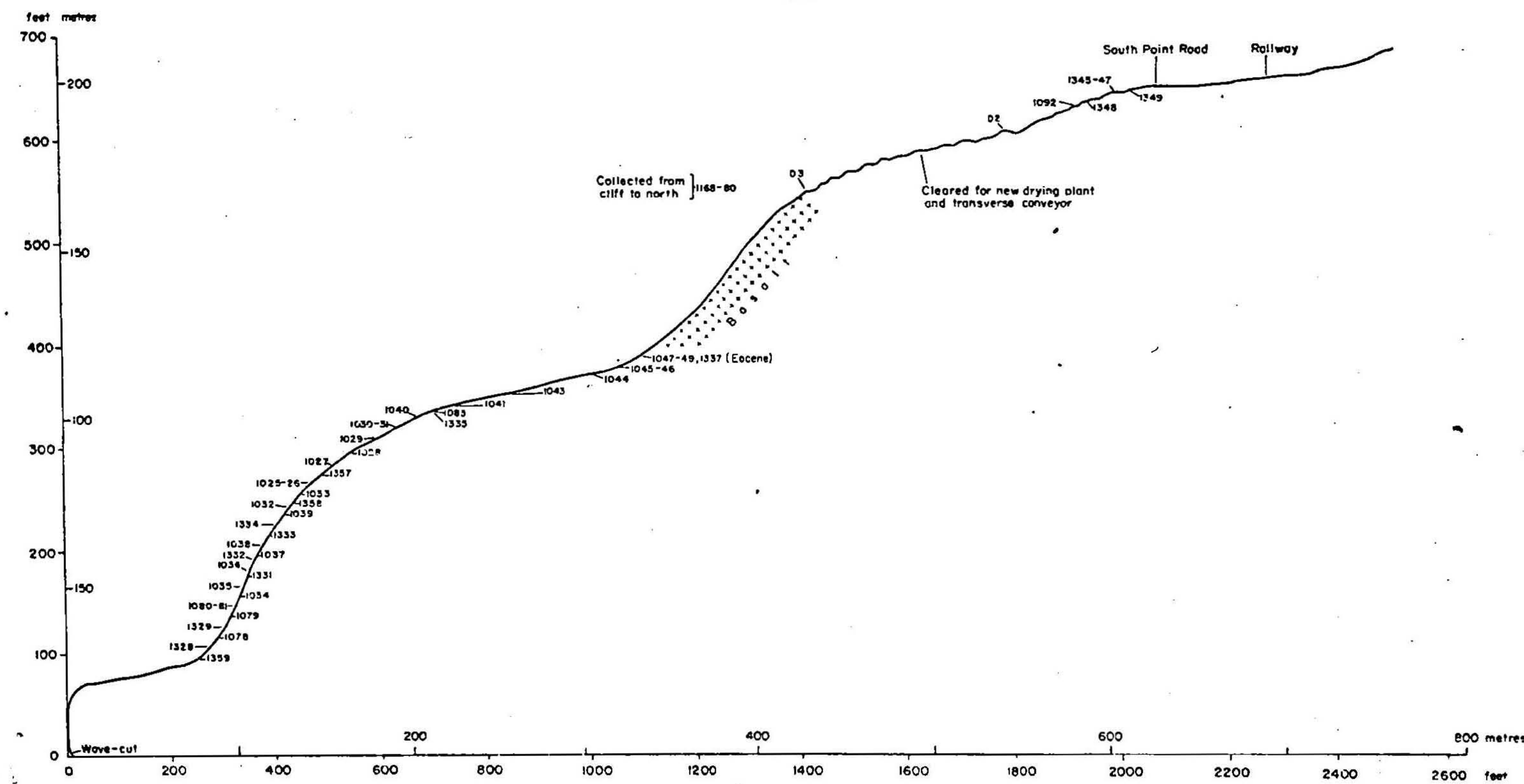
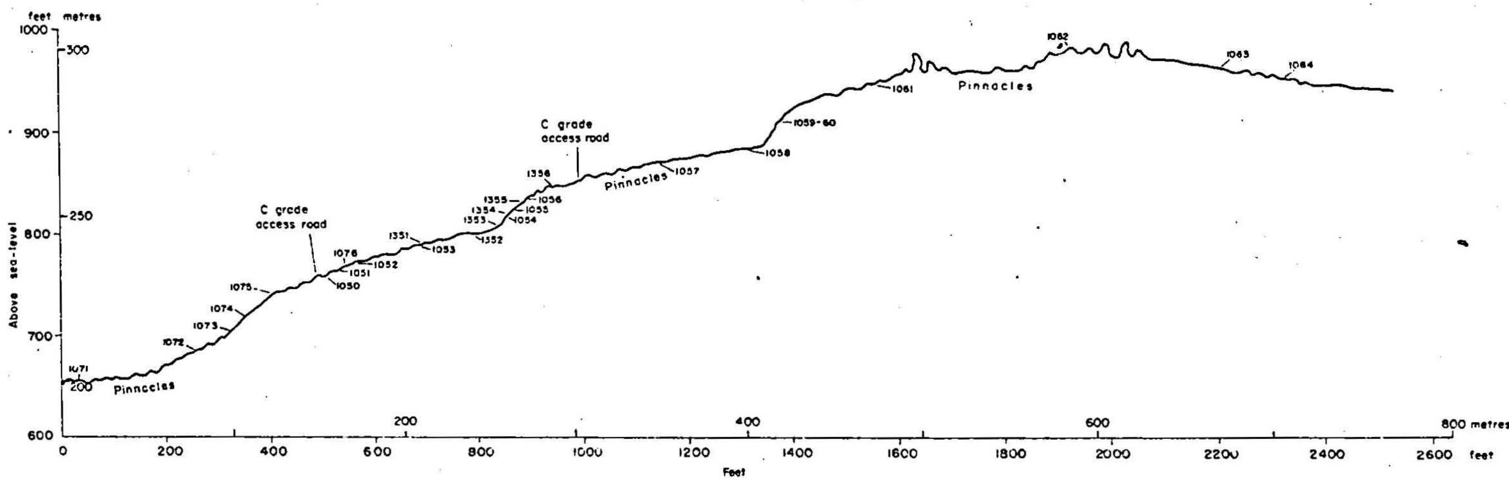


Text-figure 1, showing traverses, locations of bores and single samples discussed.



Text-figure 2, Profile, 'D' Traverse, showing sample locations

02/2



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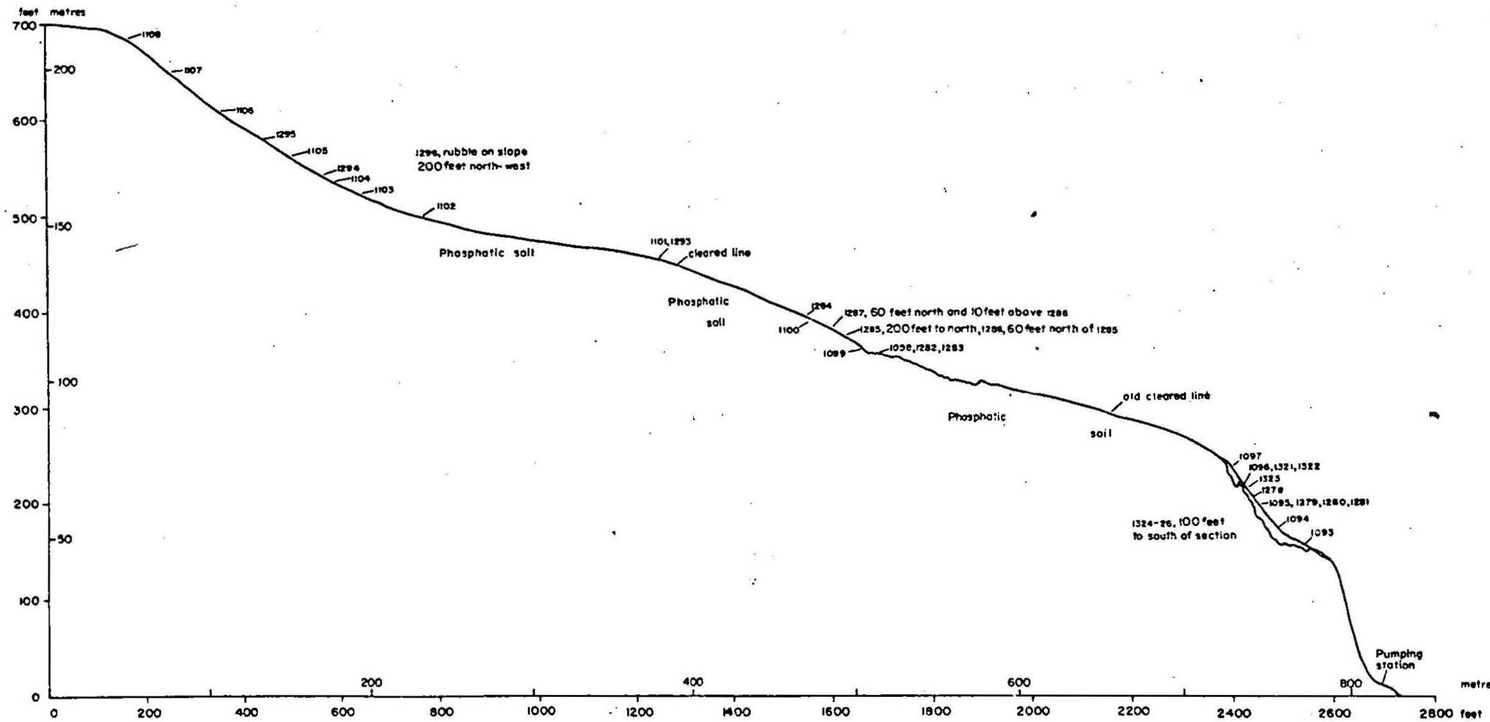
Text-figure 3. Profile, 'G' Traverse, showing sample locations



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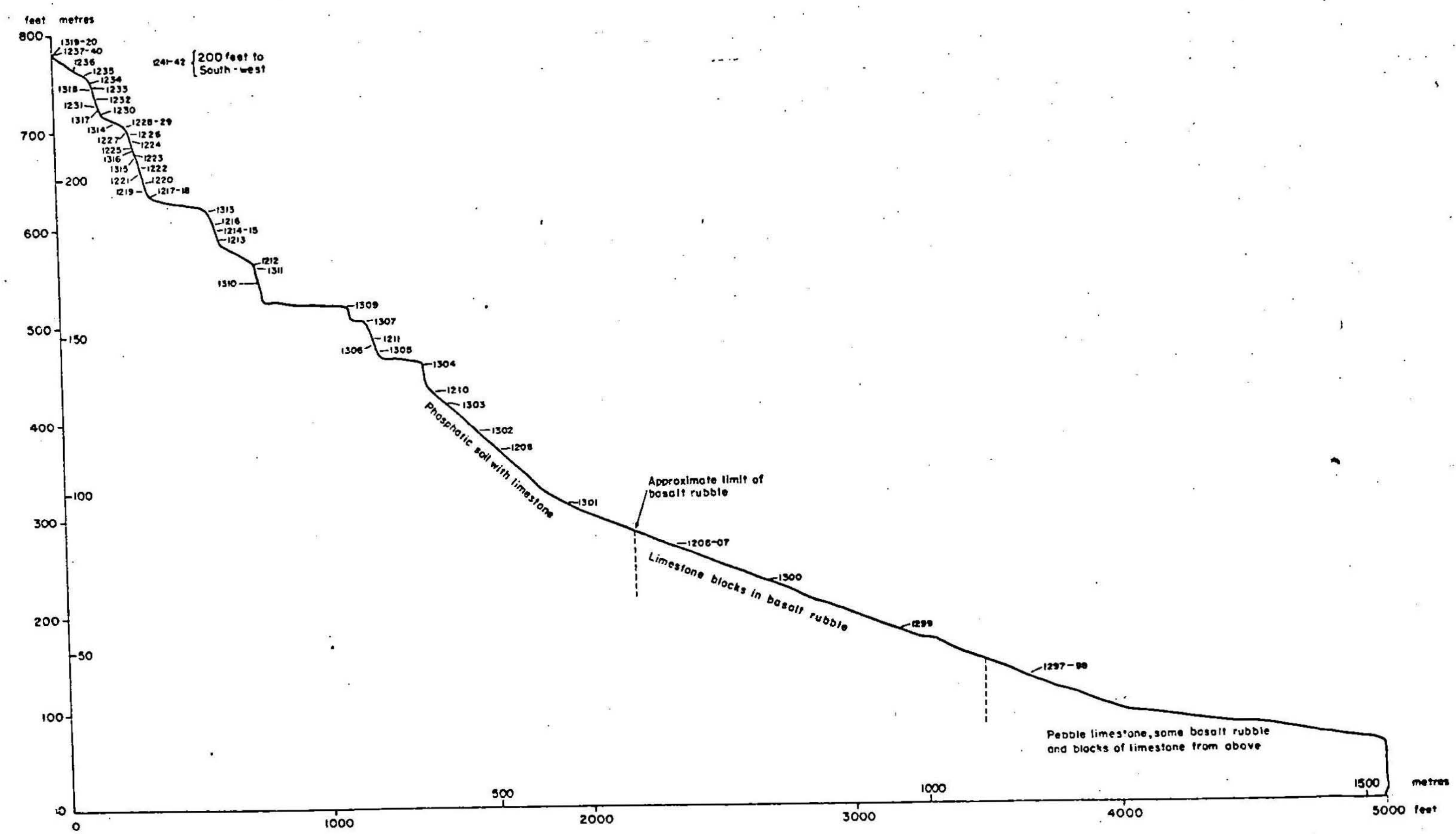
Text-figure 4. Profile, Waterfall Traverse showing sample locations



Text-figure 5, Profile, Ross Hill Traverse, showing sample locations.

02/5

LEGEND

P = Present
X = Rare (< 3 specimens)
O = Few (3-10 ")
● = Common (11-25 ")
■ = Abundant (> 25 ")

'D' SECTION / SAMPLE No	1349	1345	1346	1347	1348	1092	D2	1180	1179	1178	1177	1176	1175	1174	1173	1172	1171	1170	1169	1168	D3	1045	1046	1044	1043	1041	1083	1335	1040	1030	1031	1029	1028	1027	1357	1026	1025	1033	1358	1032	1039	1334	1333	1038	1037	1332	1036	1331	1035	1034	1081	1080	1079	1329	1078	1320	1359
ACERVULINA ; BORODINIA ; KANAKAIA	P	P		P	P		P	P	P	P	P	P		P		P		P		P	P															P		P							?					?	?		X			P	P
CARPENTERIA ; SPORADOTREMA																													P	P	P					P	P		P		P		P	P		P			P			P				P	P
AMPHISTEGINA																			X		O		●	O	O		O		●									O														●			■	■	
GYPSINA GLOBULA			X		X	X		X	X	X		X			X	X	O	X		X				X												X		X	X				X													X	
OPERCULINA																																																									O
LEPIDOCYCLINA (E.) sp.						X								X	X	?	?	X	?			X	X			X	X	O	X	X	X	X	X	X	X				X	X	X	O	X		O		X			X	X	X	X	X	■	■	■
L. sp. (B form)											P	P	P	P	P			P				P	P		P			P																P				P	P			P	P				
BORELIS PYGMAEUS							X							X															X			X	X		X		X		X	X	X	O	O	O	O	O	X	O	X		O	O	X	X	X	O	
B. sp.	X												X		O					X					X						X					X														X				X		X	
SORITES cf. ORBICULUS	X			X			O																		O	X		O	X	X	X				X	O	O	O	O		X	O		X	X		X	X	X	O	O	O	O	O	X	X	
SPIROCLYPEUS MARGARITATUS ('GLOBULUS' type)	■	■	●	●	?		■	X	●	●	■	■	■	■	■	■	■	■		■	■																							■		X											
S. MARGARITATUS																			●									■		●	●	O	O	X	X	●	●		O	O	O	O	O		O	■	■	■	●	●	●	●	O	O			
S. sp	O																												O																												
MIOGYPSINOIDES BANTAMENSIS																												X		■	●	O	O		O	●	●		O	O	X	●	●	●	O	O	●	●	O	O	O	O	■	O			
AUSTROTRILLINA STRIATA	X		X			?																	X			X		O					X		X							X															
LEPIDOCYCLINA (N) sp.																									?				X		?																										
HETEROSTEGINA BARRIEI	●	■	●	●	■	X	●	■	■	■	●	●	O	●	■	●	●	O		●	■			O	X	?	?																?	●								X			?		
H. sp.																																						X																	O		
CYCLOCLYPEUS cf. EIDAE																												X		X	X	?	?					?					X									X			?	●	O
MIOGYPSINOIDES cf. COMPLANATA																			?																X		X			X		?		?			?	?					?				
GYPSINA DISCA																																					X																				
LEPIDOCYCLINA (E) EPHIPPIOIDES																								P	P							?				X	X							O		X		O				O		X			
MILIOLIDS	■		●				O							X	●	O		X	O	●		O	O		O			●		O								●		X									O			O		O	O	O	O
MIOGYPSINOIDES sp.													X																																												
MIOGYPSINOIDES COMPLANATA																						■																																			
ASSEMBLAGE																2																												1													

M(P)372

Text-figure 6. Faunal Distribution, 'D' Traverse

LEGEND

P = Present
X = Rare (<3 specimens)
O = Few (3-10 ")
⊙ = Common (11-25 ")
⊡ = Abundant (>25 ")

'G' SECTION / SAMPLE No	1063	1064	1061	1059	1060	1058	1057	1356	1056	1355	1055	1354	1054	1353	1352	1351	1053	1052	1076	1051	1050	1075	1074	1073	1072	1071
ACERVULINA, BORODINIA, KANAKAIA	P	P								P	P	P		P		P	P		P	P						
CARPENTERIA, SPORADOTREMA	P	P	P	P	P		P		P		P			P			P							P		
AMPHISTEGINA	⊡	⊡	X	X	X	O					O		X													
BORELIS PYGMAEUS																										
B. sp								O		X													X			
SORITES cf. ORBICULUS	X	O					?	⊙		O	X			X	X	X							X		X	
SPIROCLYPEUS MARGARITATUS														⊙	O	⊙			O			O	⊙	⊙	⊙	⊡
S. sp												O														
AUSTROTRILLINA STRIATA							X	O		X								X		X					?	
HETEROSTEGINA sp.																									X	
MIOGYPSINOIDES DEHAARTI			⊡	⊡	?	⊡																				
AUSTROTRILLINA sp.		X																								
TAYAMAIA MARIANENSIS					?																					
MILIOLIDS								⊡		⊡		X	X		X	O	O			O	X	O	O	O	⊙	O
											X															

ASSEMBLAGE |← 3 →|← 2 →| (Assemblage 3: samples 1063–1058; Assemblage 2: samples 1057–1071)

M(P)373

Text-figure 7. Faunal distribution, 'G' Traverse

LEGEND

P = Present
X = Rare (<3 specimens)
O = Few (3–10 specimens)
● = Common (11–25 specimens)
■ = Abundant (>25 specimens)

WATERFALL SECTION / SAMPLE No	1108	1107	1106	1295	1296	1105	1294	1104	1103	1102	1293	1101	1284	1100	1287	1285	1286	1099	1283	1282	1098	1097	1322	1321	1096	1323	1278	1281	1279	1280	1095	1326	1325	1324	1094	1093
ACERVULINA, BORODINIA, KANAKAIA		P			P								P	P			?	P	P									P	P	P	P					
CARPENTERIA, SPORADOTREMA		P			P	P	P	P	P		P	P	P	P	P	P	P	P	P	P		P	P	P	P	P						P	P			P
AMPHISTEGINA		●			●			O	●	●	●	X				X						O	O	●	●	●						■		O		■
GYPSINA GLOBULA													X	X					X		X							X	X	X	O				?	
LEPIDOCYCLINA sp (B form)																															X					
BORELIS PYGMAEUS																												X		X						
B. sp.								X							X							X						X	X					X		
SORITES cf. ORBICULUS			X		X		X	O							X				?		X	O			X	X	X	X		X			?	O		
SPIROCLYPEUS MARGARITATUS														X	X	X	X	X	X	X	O															
S. MARGARITATUS ('GLOBULUS' type)													●				X		X		X							■	●	■	X					
MIOGYPSINOIDES cf. BANTAMENSIS																											?						X			
AUSTROTRILLINA STRIATA							X								O						X								X	X	X					
LEPIDOCYCLINA (N) sp.		?																																		
HETEROSTEGINA BARRIEI													X	X						X	?							●	■	■	●					
MIOGYPSINOIDES DEHAARTI				■																		■		■	■									O		
TAYAMAIA MARIANENSIS		●				●			X	O	O	●				?																				
MILIOLIDS			●		X		■	■	X	O		O	X				O		X	X	X	O			O	O		■	●	●	■			●	O	
MIOGYPSINOIDES cf. DEHAARTI					O		O	■	X	O													O			O										
HETEROSTEGINA sp.																			X																	
ASSEMBLAGE	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2

M(P)374

Text-figure 8. Faunal distribution, Waterfall Traverse

Text-fig. 9

ROSS HILL SECTION

LEGEND

P = Present
X = Rare (< 3 specimens)
O = Few (3-10 ")
● = Common (11-25 ")
■ = Abundant (> 25 ")

SAMPLE No	1319	1320	1237	1238	1239	1240	1241	1242	1236	1235	1234	1233	1318	1232	1231	1317	1230	1314	1228	1229	1227	1226	1224	1225	1316	1223	1315	1222	1221	1220	1219	1218	1217	1313	1216	1214	1215	1213	1212	1311	1310	1309	1307	1211	1306	1305	1304	1209	1210	1303	1302	1208	1301	1206	1207	1300	1299	1297	1298
ACERVULINA ; BORODINIA ; KANAKAIA	P	P	P	P		P	P	P	P			P	P	P	P	P		P	P	P	P	P	P	P	P	P		P	P	P	P	P	P	P		P		P					P		P									P	P				
CARPENTERIA ; SPORADOTREMA			P	P	P		P	P	P			P	P		P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P		P	P	P	P	P			P		P		P	P	P	P		P
AMPHISTEGINA	?	O	O	O	●	O		O	X	O		●	O		O	O	O		●	●	●	O	O		X	O	X	O	O		O	●	X	●	O	O				O	O		X	■	■	O	X		O	P			O		X	O	O	X	■
GYPSINA GLOBULA																																																			X			X	X				
BORELIS PYGMAEUS	X			X	O														X											X																				X					X				
B. sp.	X		X	X					X													X		X	X	X		X				X							X			X								X		X							
SORITES cf. ORBICULUS	X		X	O	O			X	?		O			O	O				O	X	O	X	X	X	O	O	O	O	O	●		X	X	X								X			X	X								X	O				
SPIROCLYPEUS sp.																																																							O				
MIOGYPSINOIDES BANTAMENSIS															?					?											?	?			?	?		?	?	?					?												P		
M. sp.																X				■	O										●	■		■	●	●		●	O	O	O					O	O										O		X
AUSTROTRILLINA STRIATA																			X					X		X							X																	O		X							
HETEROSTEGINA BARRIEI																																																			■							●	
MIOGYPSINOIDES DEHAARTI															O					P										■	P	P		P	P	P		P	P	P		X		O	■		P										?		
TAYAMAIA MARIANENSIS		X										X					X		O	■		X	●	●	●	O	X				■		O		■	●	O	●		O	O																		
MIOGYPSINA cf. NEODISPANSA															O	X			O																																								
AUSTROTRILLINA HOWCHINI					O					●							O																																										
FLOSCULINELLA BONTANGENSIS			O	X			X	X																																																			
MILIOLIDS	■	X	●	■	■		O	■	O	X	■	●		■					O		O	O	O	●	O	●	X	O		O		O	O	X	O		O	X	●		O	■		O		X	O		O	●				O	●			X	
? MARGINOPORA VERTEBRALIS				O	X					X														?		?							X																										
? ARCHAIAS sp.					X																																																						
PENEROPLIDS											O																												O																				
OPERCULINA																																X																											
"ROTALIA" sp.																																																■	■				●	O					
MIOGYPSINOIDES COMPLANATUS																																																		O	O								
SPIROCLYPEUS MARGARITATUS ('GLOBULUS' type)																																																			O			O	O			O	
ASSEMBLAGE						5								4																			3														FAULT ?						2						

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Text-figure 9. Faunal distribution, Ross Hill Traverse

SYDNEY'S DALE SECTION	LEGEND: P = Present; X = Rare (< 3 specimens); O = Few (3-10 "); ◉ = Common (11-25 "); ▣ = Abundant (> 25 ") — SAMPLE No	1136	1134	1133	1132	1130	1129	1128	1127	1246	1126	1125	1245	1124	1123	1122	1121	1120	1119	1244
ACERVULINA, BORODINIA, KANAKAIA					P	P	P		P											
CARPENTERIA, SPORADOTREMA					P	P	P	P	P						P	P	P	P	P	P
AMPHISTEGINA			◉				O								X	O				O
GYPSINA GLOBULA			X			X	X	X	X	◉	X	X	◉	▣			O	X		
OPERCULINA											?					X				X
LEPIDOCYCLINA (E) sp.																O				
BORELIS PYGMAEUS				X		X	X													
B. sp.					X		X											X	X	
SORITES cf. ORBICULUS					X	◉												X	O	X
SPIROCLYPEUS sp. indet.				X	X	X		X	X										O	
MIOGYPSINOIDES cf. BANTAMENSIS								X	X						O			X		O
AUSTROTRILLINA STRIATA						X													X	X
LEPIDOCYCLINA (N.) sp. indet.									X											
MIOGYPSINOIDES DEHAARTI															▣			O		◉
TAYAMAIA MARIANENSIS					X		X	X	X											O
MIOGYPSINA cf. NEODISPANSA					X	X		X	X											
DISCOCYCLINA spp.										X	X		X							X
HETEROSTEGINA cf. SAIPANENSIS												?	X	O						
'ROTALIA' spp.		▣			▣	X	O	◉		▣	O	◉	O	O		▣		◉		▣
MILIOLIDS					O				◉										▣	
MIOGYPSINOIDES cf DEHAARTI					O	X	X		X											
MIOGYPSINA sp.							X													
GYPSINA DISCA											X									
ASSEMBLAGE		←—————									3									—————→

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Text-figure 10. Faunal distribution, Sydney's Dale Traverse