Middle Tertiary calcareous nannofossils from the Torquay Basin, Victoria, Australia.

WILLIAM G. SIESSER

Siesser, W.G. Middle Tertiary nannofossils from the Torquay Basin, Victoria, Australia.

Fifty-four different species of calcareous nannofossils have been identified in Oligocene-lower Miocene rocks of the Torquay Basin. These species allow zonation of an offshore subsurface section (Nerita 1 oil well) and two onshore sections (near Torquay). Special attention is given to the placement of the Oligocene-Miocene boundary.

The Angahook Formation in the Nerita 1 well is in Martini's (1971) NP 22 calcareous nannofossil Zone (early Oligocene). The base of the Jan Juc Formation is also NP 22. NP 23 could not be defined with certainty, but Zones NP 24/25 (late Oligocene) to NN 2 (early Miocene) were identified in the Jan Juc. The Oligocene-Miocene boundary occurs between 122 m and 135 m below the sea floor at this site. The Puebla Formation is exposed at the sea floor at the site, and is in NN 5 which spans the early-middle Miocene boundary.

The Angahook Formation along the Torquay coast is in NP 24/25 (late Oligocene); the Jan Juc Formation at Bird Rock is also in NP 24/25 except the uppermost 2½ m, which is in NN 1. The NN 2 Zone begins at the Jan Juc-Puebla contact and continues upward to at least 3 m above the contact. After a covered interval, NN 4 is found about 10 m above the contact. The Oligocene-Miocene boundary is placed at the base of the hard band capping Bird Rock at the type locality of the Jan Juc Formation.

Nannofossil assemblages in the Torquay sections suggest deposition in cool, shallow continental-shelf waters. The assemblages in Nerita 1 also suggest cool, fairly shallow shelf waters, although deeper than at Torquay.

W.G.Siesser, Department of Geology, University of Melbourne, Vic.,Australia 3052.

The late Oligocene-early Miocene time period has long been of interest to stratigraphers and palaeontologists because of the marked change in Cenozoic macro- and microfauna (and flora) which occurs during this interval. Gradual decrease and extinction of Palaeogene organisms occur during the late Oligocene/early Miocene, with replacement by the first typically Neogene organisms during the early Miocene. Notwithstanding the considerable worldwide study of this interval, the exact placement of the Oligocene-Miocene boundary is still a warmly contested point in many regions; difficulties in recognizing this boundary in Victoria have been commented on by McGowran et al. (1971, p.279) and Abele et al. (1976, p.186).

Calcareous nannofossils have become important biostratigraphic tools in recent years, although only a few studies of Australian strata have utilized them thus far. The main purposes of this paper are; (1) to determine the distribution of calcareous nannofossils in the late Oligocene-early Miocene interval in Victoria, (2) to zone this interval biostratigraphically, using nannofossils, and (3) to attempt to recognize the Oligocene-Miocene boundary in Victoria.

Study area

I chose the Torquay Basin (Abele et al., 1976) for investigation because the Oligocene-Miocene interval is well represented and the lithostratigraphy well established in this area. The stratotype of the Janjukian Stage also occurs here, and this Stage is believed to span the Oligocene-Miocene boundary. The Janjukian Stage has been restricted by Raggatt & Crespin (1955) to correspond with the Jan Juc Formation along the Torquay coast. This formation is excellently exposed in cliff sections from near Torquay to Bell's Headland (Fig.1).

Most of the samples used from these outcrops (including the Angahook and Puebla Formations) were collected by Miss Anne Reeckman in the course of her study of the petrology and physical stratigraphy of the Jan Juc Formation (Reeckman, in prep.), supplemented by samples I collected from selected stratigraphic intervals. I obtained off-shore subsurface samples from the Nerita 1 oil-exploration well (Fig.1). These included sidewall cores from the Angahook and Jan Juc Formations, supplemented by cuttings from critical intervals and where sidewall cores were widely separated. A whole core taken at the sea floor at the Nerita site provided samples of the Puebla Formation. Figure 2 shows the position of samples and the biostratigraphy of the sections studied.

*Figs. 1 & 2

Calcareous nannofossils

Calcareous nannofossils are the remains of unicellular algae. Interest in these fossils has increased sharply in the last decade, largely owing to the recognition of their usefulness in biostratigraphic studies. Characteristics which make them of great use in stratigraphic correlation are: (1) They are very abundant in marine sediments -- a spatula-tip of sediment may easily contain thousands of specimens -- (2) as planktic organisms they have (and had) virtually world-wide distribution in oceanic waters, and (3) rapid evolutionary changes in this group allow narrow subdivision of the geologic time column.

Table 1 lists species epithets of calcareous nannofossils listed in this report. Tables 2 and 3 show the distribution, relative abundance and preservation of nannofossils in the Nerita 1 well and the Torquay sections, respectively. Nannofossil abundance and preservation are denoted qualitatively as follows : A = Abundant -- more than 10 specimens of a single species occur in a standard 1000X light microscope field of view. C = Common -- one to 10 specimens in a single field.

F = Few -- at least one specimen per three fields. R = Rare -- I had to search more than three fields to find a single specimen. VR = Very rare -- fewer than three specimens found in the entire slide. B = Barren -- no nannofossils found. G = Good -- little apparent overgrowth or dissolution effects. M = Moderate -- a moderate amount of calcite overgrowth on specimens and dissolution of the more susceptible species. P = Poor -- much overgrowth; numerous species removed.

*Table 1

In the Nerita 1 well I found very rare to few, poor to moderately preserved specimens in the Angahook Formation ("Demon's Bluff" in the well report -- Anonymous, 1969). Abundance and preservation varies considerably in the overlying Jan Juc; samples containing rare or few, poorly preserved specimens are interlayered with samples containing common, moderately to well-preserved specimens. The Puebla Formation cored at the sea floor contains common, moderately to well-preserved nannofossils.

Nannofossils in the Angahook Formation at Bell's Headland are fairly common and moderately to well preserved. Preservation is best in samples collected near the top of the Angahook. Nannofossils are few to common in most of the Jan Juc Formation at Bird Rock and preservation is mostly moderate. Preservation is best in the finer-grained sediments near the top of the unit. Nannofossils are most common and preservation is best in the Puebla Formation overlying the Jan Juc at Bird Rock.

Species listed in these Tables are typical for the age of the rock units studied, with the notable exceptions of Micrantholithus procerus Bukry & Bramlette (Fig.4B) and Vermiculithina arca Bukry & Percival (Fig.5C). The former was previously reported to occur only in middle Eocene rocks (Bybell & Gartner, 1972; Bybell, 1975), but I found it in both upper Oligocene and lower Miocene rocks in the Torquay Basin. Similary, V. arca was previously reported from the lower Oligocene (Bukry & Percival, 1971), but it also occurs in upper Oligocene and lower Miocene sediments in this area.

Systematic notes

Coccolithus eopelagicus (Bramlette & Riedel) (Fig.3A) as used here includes all the forms reported in Eocene-Miocene sediments as Coccolithus pelagicus, C. eopelagicus, C. muiri and Ericsonia ovalis. Roth et al. (1971) followed this convention, pointing out the intergradation among these forms and the difficulties in distinguishing among them. Moreover, Roth et al. (1971) note that Coccolithus pelagicus (Wallich) from Quaternary sediments has a construction very different from the Eocene/Miocene forms; the exact time of appearance of C. pelagicus s.s. is not known with certainty.

Specimens resembling Reticulofenestra scissura Hay, Mohler & Wade occur in some of the upper Oligocene samples. This species is, however, difficult to identify with certainty, as no light microscope photograph of the type specimen was presented with the original description. Moreover, the reported age range of this species corresponds to that of the closely related R. coenura (Reinhardt) (Fig.4E). R. scissura is thus not in itself very useful as a stratigraphic marker, and I have included "R. scissura" specimens with R. coenura for convenience.

Micrantholithus australiensis Rade (Fig.4A) is an important component of the samples studied. *M. pinguis* Bramlette & Sullivan also occurs, although much less frequently. The specimens I have listed under *M. pinguis* probably also include *M. bassiensis* Rade, as the specimens illustrated by Rade (1977) appear to be within acceptable limits of intraspecific variation for *M. pinguis*.

Finally, I have not used a number of discoasters originally reported from this time interval (viz. *Discoaster lidzii* Hay, *D. nephados* Hay and *D. trinidadensis* Hay), as they almost certainly result from varying degrees of overgrowth on specimens of *D. deflandrei* Bramlette & Riedel (Fig.3G) or *D. variabilis* Martini & Bramlette (Perch-Nielsen, 1971; Roth & Wise, unpublished data presented at Kiel, 1974). Perch-Nielsen (1971) also indicates the questionable status of *D. aulakos* Gartner and *D. saundersi* Hay; nevertheless I have recorded(as "cf.")specimens which resemble these last two "species".

*Tables 2 & 3

Biostratigraphy of the Nerita 1 and Torquay sections

The lithostratigraphic section studied offshore and onshore comprises, from oldest to youngest, the Angahook Formation, the Jan Juc Formation and the Puebla Formation (the last two units make up the Torquay Group).

Nerita 1

The lowermost datable sample in the Nerita 1 well is a sidewall core at 352 m from the Angahook Formation ("Demon's Bluff" Fm. -- Anonymous, 1969). This core contains *Isthmolithus recurvus*, *Transversopontis zigzag*, *Lanternithus minutus*, *Reticulofenestra umbilica*, *R.* cf. *R. hillae* and *R. bisecta*, indicating a maximum age range of NP 19 to NP 22. However, the absence of *Discoaster saipanensis*, *D. barbadiensis* and *Coccolithus formosus*, which are almost everywhere associated with this assemblage in Zones NP 19-21, strongly suggests that this core lies in

NP 22 (early Oligocene), and I accordingly assign that zone (Fig. 2). NP 22 continues upwards to 319 m (lowermost Jan Juc Formation) after which *Isthmolithus recurvus* and (slightly earlier) *Reticulofenestra umbilica* disappear, marking the top of NP 22. I could not determine NP 23 in itself, but the interval 307-310 m contains the first *Helicosphaera obliqua* and *H.* cf. *H. perch-nielsenasae*, which indicates an NP 24/NP 25 age. (If the identification of the rare *H. perch-nielsenasae* is correct, this interval may be further restricted to NP 24, as can all samples up to at least the 277-280 m interval).

The NP 24/25 assemblage extends up to at least the 216-219 m interval, where I found the last *H. recta* (which formally defines the top of NP 25). However, the Helicosphaerids are fairly rare in these rocks, owing to the cool waters prevailing at the time of deposition, and the frequency of *H. recta* is rare and sporadic in the samples up to the time of its final disappearance. A more reliable indicator of the top of NP 25 in hemipelagic sediments is the extinction of *Zygrhablithus bijugatus* (Fig.5D-E) at the top of this zone (Martini, 1971; Roth et al. 1971). This species is ubiquitous and common in these Oligocene samples. Its frequency drops sharply between 210 m and 197 m in the Nerita 1 well. I found only one specimen in cuttings from the 197-200 m interval, and none from the sidewall core at 199 m. *Reticulofenestra bisecta* (Fig.4D) also becomes extinct at about this level (Bukry, 1973a; Gartner, 1977) or just above the top of NP 25 (Martini, 1971). *R. bisecta* shows the same marked decrease in frequency between 210 m and 197 m; I found only a single specimen higher in the well (at 199 m). The NP 25 - NN 1 boundary (also the Oligocene-Miocene boundary) thus lies between 210 and 197 m in Nerita 1 (Fig.2).

The first NN 2 assemblage occurs in a sidewall core at 171 m. The assemblage includes the first appearance of *Discoaster druggii* (the defining marker) and *Helicosphaera carteri*. *Discoaster variabilis* is also present. This species is reported to make its first occurrence at this level (Bukry, 1973b, p. 659). I found rare, sporadic specimens of D. variabilis in lower samples, but the first significant numbers of D. variabilis occur at 171 m. I accordingly place the NN 1 - NN 2 boundary between 171 m and 185 m. Samples between 171 m and 154 m (where the first cuttings were taken) are barren or contain non-age-diagnostic nannofossils. The report on the Nerita 1 well (Anonymous, 1969) indicates that these NN 2 samples are still in the Jan Juc Formation.

The core taken at the sea floor at the Nerita site (identified as Puebla Formation -- Anonymous, 1969) contains an NN 5 assemblage (NN 5 spans the early-middle Miocene boundary). I assign this zone on the range overlap of Sphenolithus heteromorphus and Discoaster exilis.

*Fig. 3

Torquay

The Angahook samples collected at Bell's Headland are late Oligocene (NP 24/25) in age (Fig.2). This is also the only age I could assign at Bird rock up to the Oligocene-Miocene boundary, except for samples 22 and 23 (Fig.2). The tropical-water sphenolith species usually marking the NP 24 - NP 25 boundary do not occur in the Torquay Basin. However, samples 22 and 23 are NP 25, on the basis of the range overlap of Discoaster calculosus and Zygrhablithus bijugatus. I place the boundary between the NP 25 Zone and the NN 1 Zone between samples 23 and 24 (Fig.2) at the type locality of the Jan Juc Formation at Bird Rock, based, as in Nerita 1, on the sudden sharp decline and extinction of Z. bijugatus and the virtual extinction of Reticulofenestra bisecta at the same level (only one specimen was found in the sample immediately above).

The NN 1 Zone extends from this boundary to the top of the Jan Juc Formation. The base of the overlying Puebla Formation is in NN 2, based on the first appearance of Discoaster druggii, Helicosphaera carteri (Fig.3I) and D. variabilis.

Sample 27, taken 3 m above the Jan Juc-Puebla contact is also in NN 2, but samples taken at about 10 m and 20 m above the contact are NN 4, based on the range overlaps of *Discoaster druggii*, (Fig.3H) *Helicosphaera obliqua* (Fig.4L), *Cyclococcolithus leptoporus* s.l. (Fig.3F) and *Sphenolithus heteromorphus* (Fig.5A). The rocks in the section between the last NN 2 sample and the first NN 4 sample are poorly exposed, but NN 3 can reasonably be expected to occur there.

*Fig. 4

Oligocene-Miocene boundary

Berggren (1971) reviewed, inter alia, the Oligocene-Miocene boundary problem. He points out that placement of the boundary between these two Epochs is initially complicated by the very old question of whether to consider the Aquitanian Stage as lowest Miocene (preferred by invertebrate palaeontologists) or as uppermost Oligocene (the opinion of vertebrate palaeontologists). This question was seemingly laid to rest through decisions taken by the Committee on Mediterranean Neogene Stratigraphy (1958, 1959 and 1964 meetings). This Committee reached a consensus that the Aquitanian s.s. is lowermost Miocene. The designated stratotype is located in the Aquitaine Basin along the Saucats River at Moulin de Bernachon, France, where Mayer-Eymar (who named the Aquitainian) reported the best outcrops (Berggren, 1971; Van Couvering, 1978). The base of the Aquitainian, by international agreement, defines the Oligocene-Miocene boundary (Van Couvering, 1978). The base of the Aquitainian stratotype is now known to lie somewhere within planktic foraminiferal Zone N 4 (and not, as previously believed, at the base of N 4). However, the Aquitainian base lies at approximately the boundary between the NP 25 and NN 1 calcareous nannofossil Zones (Theyer & Hammond, 1974; Van Couvering, 1978).

The NP 25 - NN 1 boundary is thus the closest approximation that can be used for international correlation with the Oligocene-Miocene stratotype boundary. In the Nerita 1 well this boundary occurs between 197 m and 210 m below sea level (between 122 m and 135 m below the sea floor); along the Torquay coast the boundary occurs at the base of the hard band capping Bird Rock, approximately 2½ m below the Jan Juc-Puebla Formation contact.

+Fig.5

Palaeo-ecology

Members of the genera *Braarudosphaera* and *Micrantholithus* are extremely rare in open-ocean deposits, and are thus strong indicators of nearshore environments. *Helicosphaera*, *Pontosphaera*, *Lanternithus* and *Zygrhablithus* are also most common in nearshore waters. The abundance of these genera in the Torquay section, together with calcareous ascidian spicules belonging to the family Didemnidae (Fig.5F) indicate deposition in a shallow-water environment. However, the large number of nannofossils present in these rocks suggests unrestricted connection with the open sea at the time. Nerita 1 contains the same nannofossil genera, but in significantly reduced numbers, suggesting, as expected, that the depositional environment at this site was deeper than the Torquay section during the late Oligocene-early Miocene.

The dominance or presence of cool-water nannofossils, such as *Chiasmolithus* spp., *Isthmolithus recurvus*, *Cyclicargolithus floridanus* and *Lanternithus minutus* in the early Oligocene and *C. floridanus*, *Discoaster variabilis* and *Reticulofenestra pseudoumbilica* during late Oligocene/early Miocene, together with the absence of strictly warm-water indicators (e.g., *Scyphosphaera* and various warm-water species of *Sphenolithus* and *Discoaster*) suggest that cool-water conditions, not unlike those of the northern Bass Strait today (12^o-17^oC -- Rochford, 1957) prevailed in the Torquay Basin during Oligocene and early Miocene times.

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Figure Captions

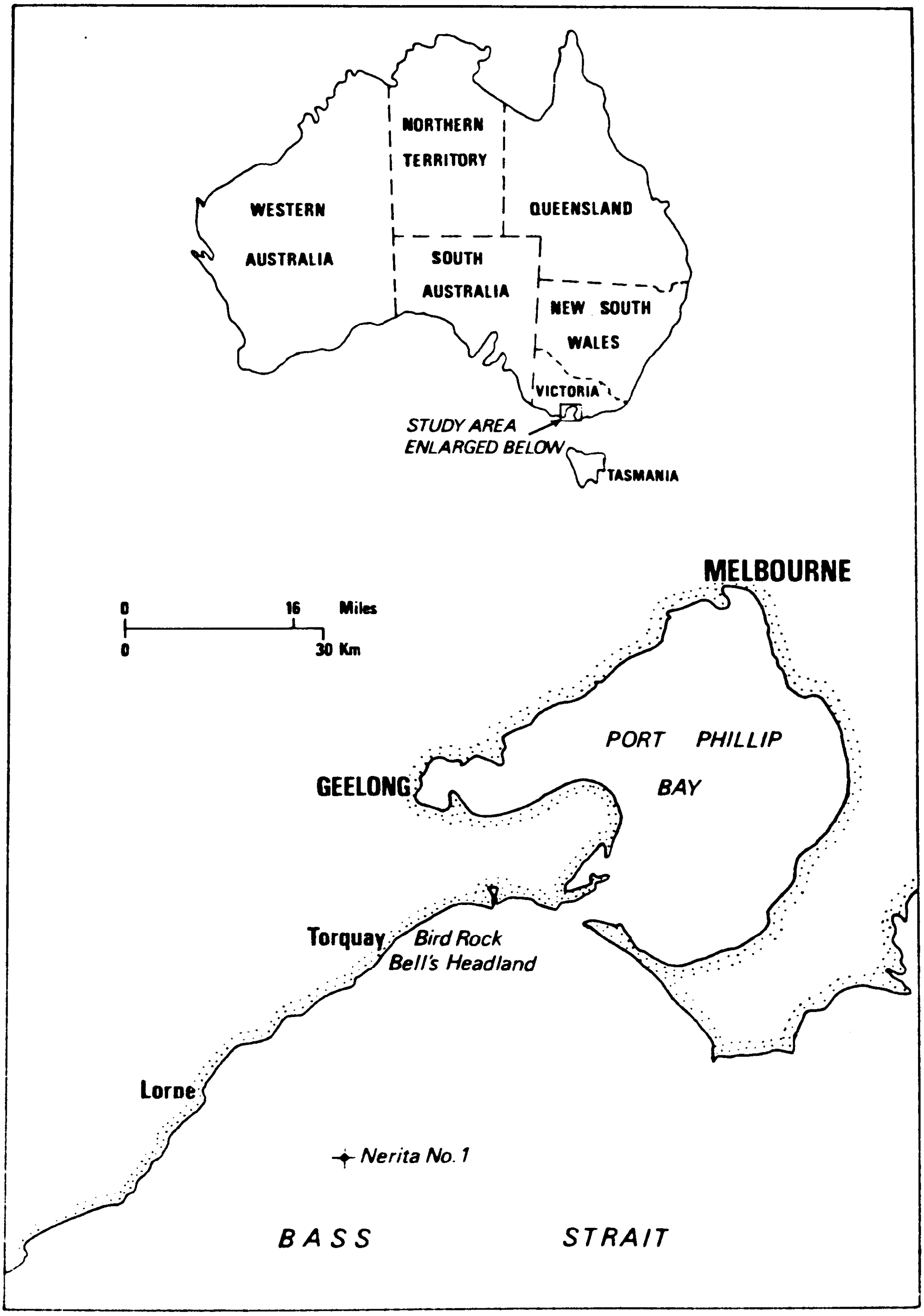
Fig. 1 Location map showing the position of the Nerita 1 oil-exploration well and the coastal sections (Bird Rock and Bell's Headland) near Torquay.

Fig. 2 Nerita 1 and Torquay (Bell's Headland and Bird Rock) stratigraphic sections. Positions of samples used in this study and their biostratigraphic assignments are shown. Depths in the Nerita 1 well are in metres below sea level. Lithostratigraphy of the Nerita 1 well is modified from Anonymous (1969); lithostratigraphy of the Torquay sections was provided by Miss Anne Reeckman.

Fig. 3 SEM photographs of calcareous nannofossils from the Torquay Basin. A. *Coccolithus eopelagicus*, distal side, scale = 3µ; B. *Coronocyclus nitescens*, scale = 2µ; C. *Discosphaera tubifera*, scale = 3µ; D. *Cyclicargolithus floridanus*, distal side = 3µ; E. *Cyclicargolithus floridanus*, proximal side (lower left), *Reticulofenestra abisecta*, distal side (upper right), scale = 7µ; F. *Cyclococcolithus leptoporus*, distal side, scale = 3µ; G. *Discoaster deflandrei*,scale = 5µ; H. *Discoaster druggii*, scale = 4µ; I. *Helicosphaera carteri*, proximal side, scale = 3µ; J. *Helicosphaera intermedia*, distal side, scale = 3µ; K. *Helicosphaera intermedia*, proximal side, scale = 4µ; L. *Helicosphaera obliqua*, proximal side, scale=4µ.

Fig. 4 SEM photographs of calcareous nannofossils from the Torquay Basin. A. *Micrantholithus australiensis*, scale = 4µ; B. *Micrantholithus procerus*, scale = 5µ; C. *Pontosphaera* sp., scale = 2µ; D. *Reticulofenestra bisecta*, distal side, scale = 3µ; E. *Reticulofenestra coenura*, distal side, scale = 2µ; F. *Reticulofenestra pseudoumbilica*, proximal side, scale = 3µ; G. *Reticulofenestra* aff. *R. pseudoumbilica*, distal side, scale = 2µ; H. *Rhabdosphaera claviger*, scale = 3µ; I. *Rhabdosphaera longistylis*, scale = 5µ; J. *Scapholithus fossilis*, scale = 2µ; K. *Triquetrorhabdulus carinatus*, scale = 3µ; L. *Trochoaster simplex*, scale = 5µ.

Fig. 5 SEM photographs of calcareous nannofossils from the Torquay Basin. A. *Sphenolithus heteromorphus*, scale = 3µ; B. *Sphenolithus moriformis*, scale = 2µ; C. *Vermiculithina arca*, scale = 25µ; D. *Zygrhablithus bijugatus*, short, squat form, scale = 4µ; E. *Zygrhablithus bijugatus*, long, narrow form, and *Reticulofenestra* sp., scale = 6µ; F. *Ascidian spicule*, scale = 12µ.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TASMANIA
MELBOURNE
0
16
Miles
0
30 Km
PORT PHILLIP
BAY
GEELONG
Torquay
Bird Rock
Bell's Headland
Lorne
Nerita No. 1
BASS STRAIT

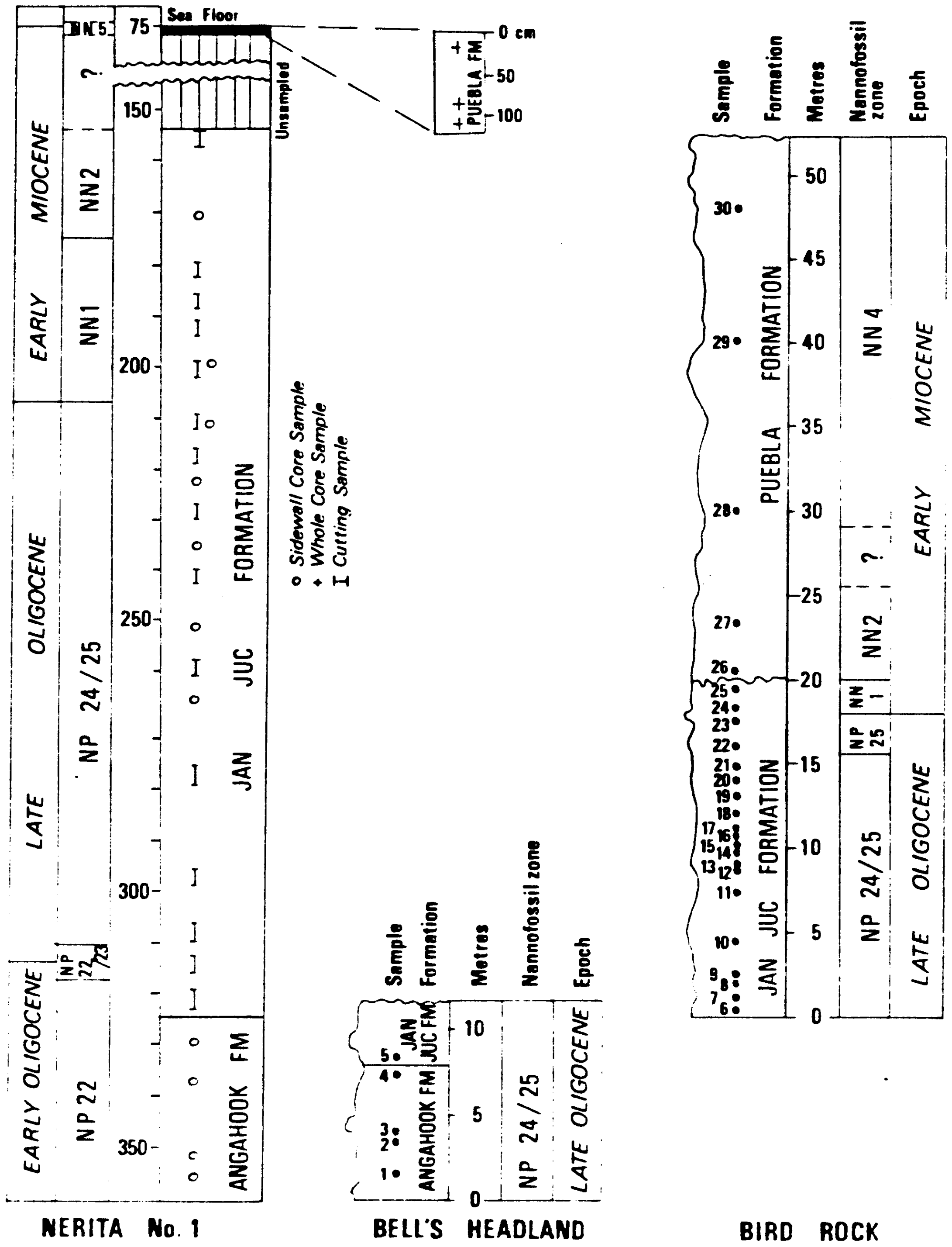
NERITA No. 1
BELL'S HEADLAND
BIRD ROCK
Sea Floor
0 cm
50
100
PUEBLA FM
Unsampled
EARLY MIOCENE
LATE OLIGOCENE
EARLY OLIGOCENE
NN5
?
NN2
NN1
NP 24/25
NP 22/23
NP 22
75
150
200
250
300
350
JAN JUC FORMATION
ANGAHOOK FM
o Sidewall Core Sample
+ Whole Core Sample
I Cutting Sample
Sample
Formation
Metres
Nannofossil zone
Epoch
JAN JUC FM
ANGAHOOK FM
NP 24/25
LATE OLIGOCENE
0
5
10
PUEBLA FORMATION
JAN JUC FORMATION
NN4
NN2
NN 1
NP 25
NP 24/25
EARLY MIOCENE
LATE OLIGOCENE
15
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FIG. 2

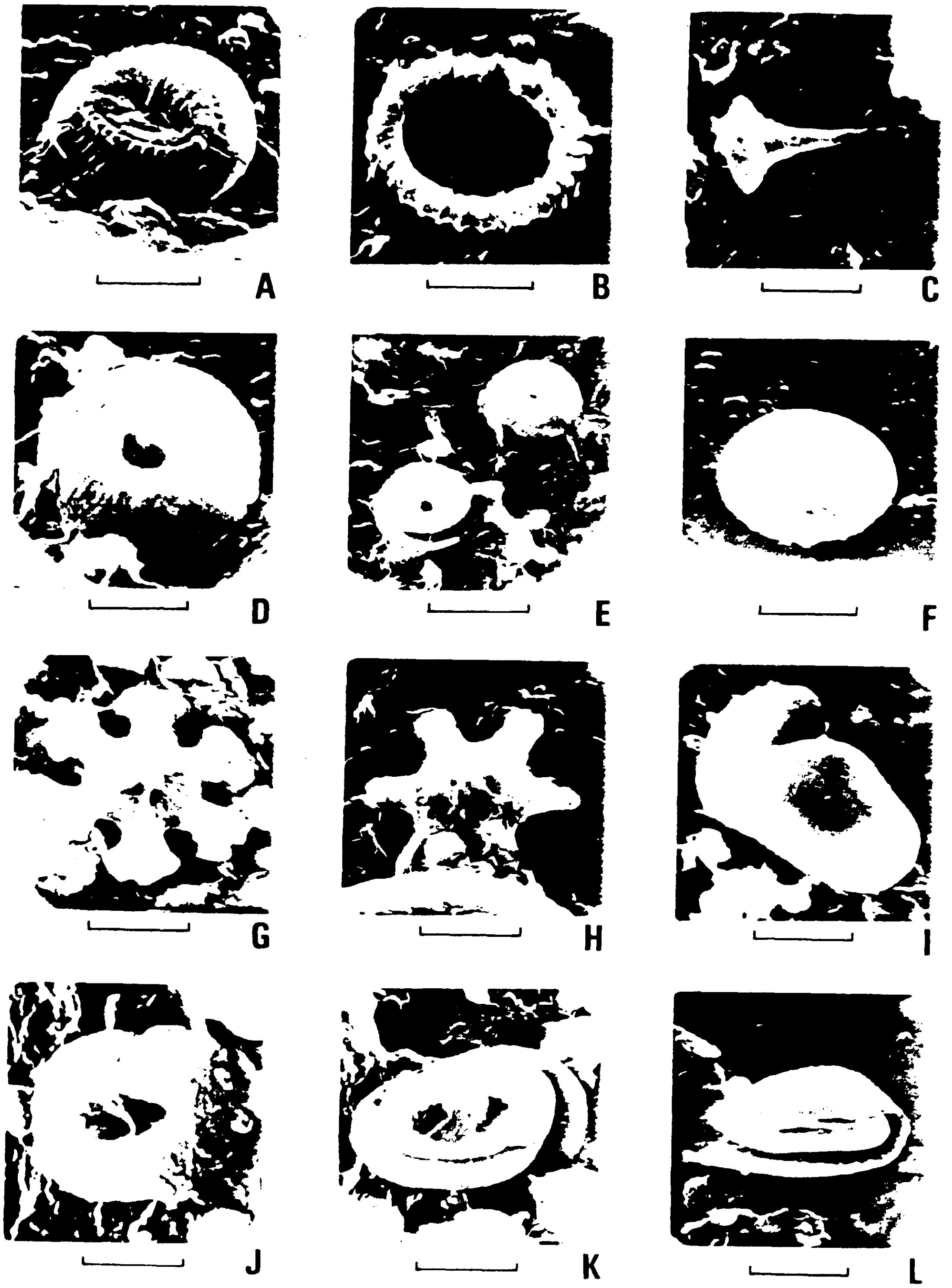

FIG. 3

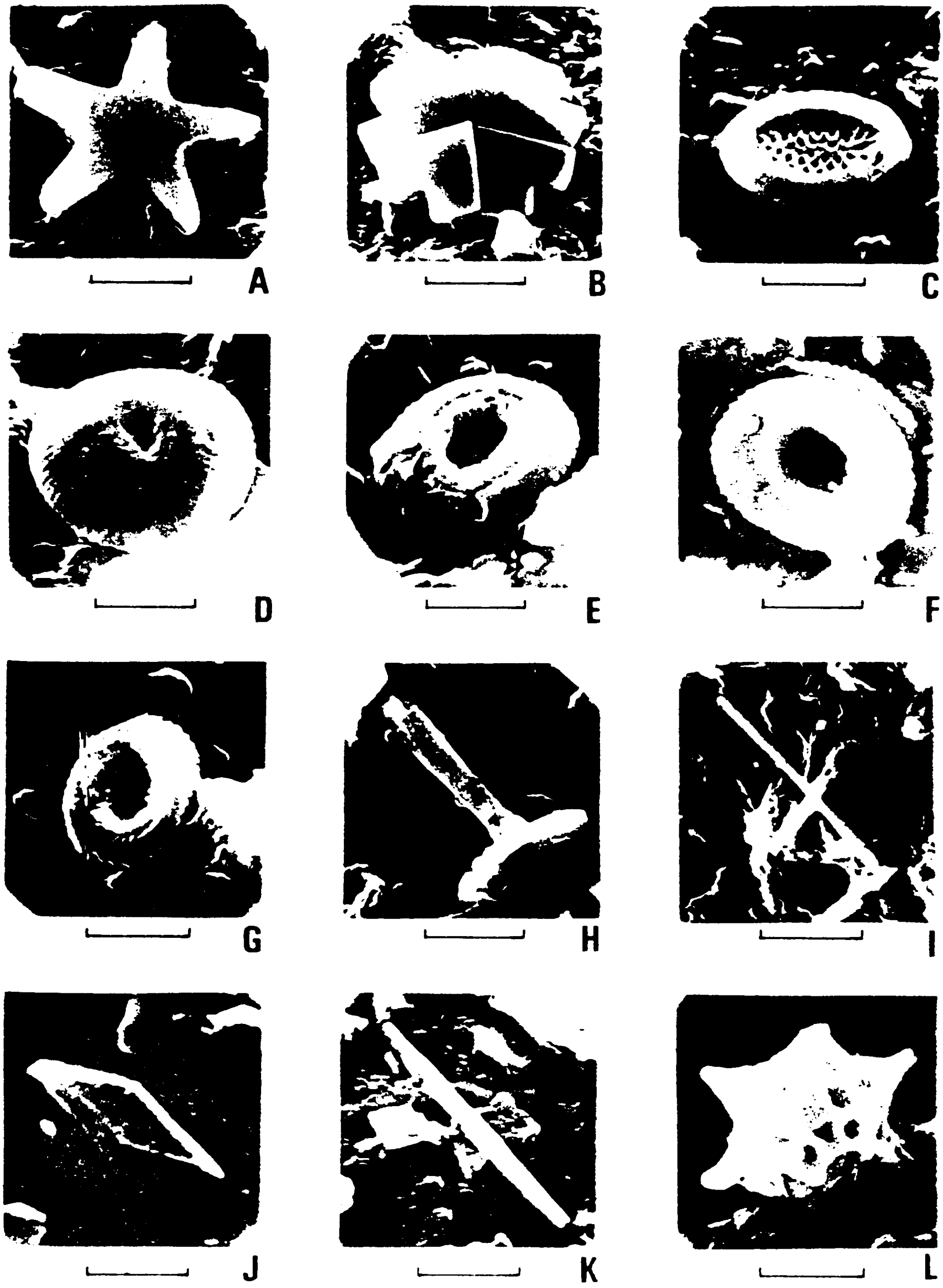

FIG. 4

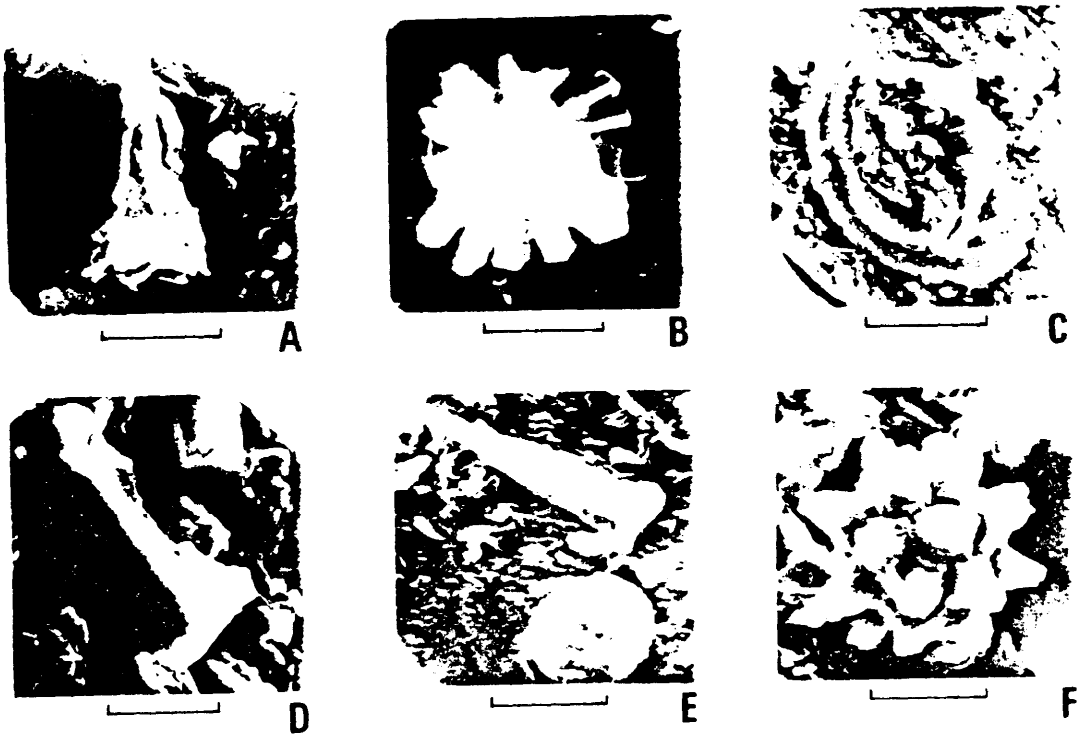

FIG.5

TABLE 1

NANNOFOSSIL SPECIES CONSIDERED IN THIS REPORT

(ALPHABETICAL ORDER OF SPECIES EPITHET)

Reticulofenestra abisecta (Müller) Roth & Thierstein, 1972.
Discoaster adamanteus Bramlette & Wilcoxon, 1967.
Micrantholithus aequalis Sullivan, 1964.
Chiasmolithus altus Bukry & Percival, 1971.
Vermiculithina arca Bukry & Percival, 1971
Discoaster aulakos Gartner, 1967.
Micrantholithus australiensis Rade, 1977.
Micrantholithus basquensis Martini, 1959.
Braarudosphaera bigelowi (Gran & Braarud) Deflandre, 1947.
Zygrhablithus bijugatus (Deflandre) Deflandre, 1959.
Reticulofenestra bisecta (Hay, Mohler & Wade) Roth, 1970.
Discoaster calculosus Bukry, 1971.
Triquetrorhabdulus carinatus Martini, 1965.
Helicosphaera carteri (Wallich) Kamptner, 1954.
Sphenolithus ciperoensis Bramlette & Wilcoxon, 1967.
Rhabdosphaera claviger (Murray & Blackman) Kamptner, 1944.
Reticulofenestra coenura (Reinhardt) Roth, 1970.
Blackites creber (Deflandre) Roth, 1970.
Discoaster deflandrei Bramlette & Riedel, 1954.
Braarudosphaera discula Bramlette & Riedel, 1954.
Discoaster distinctus Martini, 1958.
Discoaster druggii Bramlette & Wilcoxon, 1967.
Coccolithus eopelagicus (Bramlette & Riedel) Bramlette & Sullivan, 1961.
Helicosphaera euphratis (Haq) Martini, 1969.
Discoaster exilis Martini & Bramlette, 1963.
Cyclicargolithus floridanus (Roth & Hay) Bukry, 1971.
Discoaster formosus Martini & Worsley, 1971.
Scapholithus fossilis Deflandre in Deflandre & Fert, 1954.
Corannulus germanicus Stradner, 1962.
Sphenolithus heteromorphus Deflandre, 1953.
Reticulofenestra hillae Bukry & Percival, 1971.
Helicosphaera intermedia (Martini) Hay & Mohler in Hay et al., 1967.
Cyclococcolithus leptoporus (Murray & Blackman) Kamptner, 1954.
Rhabdosphaera longistylis Schiller, 1925.
Lanternithus minutus Stradner, 1962.
Sphenolithus moriformis (Bronimann & Stradner) Bramlette & Wilcoxon, 1967.
Coronocyclus nitescens (Kamptner) Bramlette & Wilcoxon, 1967.
Chiasmolithus oamaruensis (Deflandre) Hay, Mohler & Wade, 1966.
Helicosphaera obliqua (Bramlette & Wilcoxon) Haq, 1973.
Helicosphaera perch-nielsenasae (Haq) Haq, 1973.
Micrantholithus pinguis Bramlette & Sullivan, 1961.
Micrantholithus procerus Bukry & Bramlette, 1969.
Reticulofenestra pseudoumbilica (Gartner) Gartner, 1969.
Helicosphaera recta (Haq) Martini, 1969.
Rhabdolithus rectus Deflandre, 1954.
Isthmolithus recurvus Deflandre in Deflandre & Fert, 1954.
Discoaster saundersi Hay in Hay et al., 1967.
Trochoaster simplex Klumpp, 1953.
Blackites spinosus (Deflandre & Fert) Hay & Towe, 1962.
Discosphaera tubifera(Murray & Blackman) Ostenfeld, 1900.
Reticulofenestra umbilica (Levin) Martini & Ritzkowski, 1968.
Discoaster variabilis Martini & Bramlette, 1963.
Micrantholithus vesper Deflandre in Deflandre & Fert 1954.
Rhabdosphaera vitrea (Deflandre) Roth, 1970.
Transversopontis zigzag Roth & Hay et al., 1967.

TABLE 2. DISTRIBUTION, ABUNDANCE AND PRESERVATION OF NANNOFOSSILS IN NERITA No.1 OIL WELL (See Fig.2)

SAMPLE (metres below S.L.)	ABUNDANCE	PRESERVATION	Reticulofenestra abisecta	Discoaster adamanteus	Micrantholithus aequalis	Chiasmolithus altus	Discoaster cf. D. aulakos	Micrantholithus australiensis	Braarudosphaera bigelowi	Zygrhablithus bijugatus	Reticulofenestra bisecta	Triquetrorhabdulus carinatus	Helicosphaera carteri	Helicosphaera aff. H. carteri	Sphenolithus cf. S. ciperoensis	Reticulofenestra coenura	Blackites creber	Discoaster deflandrei	Braarudosphaera discula	Discoaster distinctus	Discoaster druggii	Coccolithus eopelagicus	Helicosphaera euphratis	Discoaster exilis	Cyclicargolithus floridanus	Discoaster formosus	Scapholithus fossilis	Corannulus germanicus	Sphenolithus heteromorphus	Reticulofenestra cf. R. hillae	Helicosphaera intermedia	Lanternithus minutus	Sphenolithus moriformis	Coronocyclus nitescens	Chiasmolithus cf. C. oamaruensis	Helicosphaera obliqua	Helicosphaera cf. H. perchnielsenasae	Micrantholithus pinguis	Micrantholithus procerus	Reticulofenestra pseudoumbilica	Reticulofenestra aff. R. pseudoumbilica	Helicosphaera recta	Rhabdolithus rectus	Isthmolithus recurvus	Discoaster cf. D. saundersi	Blackites spinosus	Discosphaera tubifera	Reticulofenestra umbilica	Discoaster variabilis	Rhabdosphaera vitrea	Transversopontis zigzag	Chiasmolithus sp.	Thoracosphaera sp.	Pontosphaera spp.	Ascidian spicules
23 cm	C	M			R		C	R	C				R					F				F			C				F		R		C					R	R	F			R										R	R	F
84 cm	C	M					F	R	F									C						R	C				C				C							C			R		R		R		R				R	R	R
108 cm	C	G							F				C					C		F		C			C				F				C	R							F		F						R					R	
154-157	B	-																																																					
171	F	G	F									VR	R					F		R	R	C			C						R		F	R							F								F					R	R
179-182	B	-																																																					
185-188	C	M	C	R			R	R	F					VR				R				F	R		C						F		F			R			R		R		R		R				R					F	R
191-194	F	P										R						R				R			C								F																						
199	F	M	VR						R		VR							R				F			C								F						R														R		
197-200	C	M	R	R					R	VR								R				R			C	VR					R		R																VR					R	
212	F	M	F						C	VR	R	R						R	R			C			C			R			F		R	R		R			R															R	
210-213	C	G	F					R	F	F	VR								R			R	VR		C								C	R		R			R																
216-219	C	G	F		R			R	F	F	R				VR			VR				C			C		R						C			R		R	R			R							VR					R	
224	F	M	C						R	F	VR					R		R				F			F								R									R	R										R	R	
228-231	C	G	F		R			R	C	C	R											F			C						R		C					R				R								R				F	
237	R	P																							F																														
240-243	F	P																							F								R																						
252	R	P								R															F																													R	
258-261	R	P	R								R														C								R																						
265	VR	P																							R																														
277-280	C	M	R						R	F	R				VR	R						R			C								C	R			R	R				R	R											R	
295-298	F	M	R		R	VR			R	F	R											R			C									R		R																		F	
307-310	F	G	VR			R			R	F	R					R						F			C						R		F			R	R						R											C	
313-316	C	M								F	R					F						F			C								F		R								R			R								R	
319-322	C	M						R		C	R					R						R			C							R		R	R									R							R			F	
331	VR	P																							R																														
337	F	M				R				R	R					C	R					F			R								F										R			R		R						R	R
352	F	M			R	R			R	R	R					F		R				F			C					R		R	F					R					VR	R		R		F			R	R		R	
356	R	P																																														R							

TABLE 3. DISTRIBUTION, ABUNDANCE AND PRESERVATION OF NANNOFOSSILS AT TORQUAY (See Fig.2)

SAMPLE	ABUNDANCE	PPESERVATION	*Reticulofenestra abisecta*	*Discoaster adamanteus*	*Micrantholithus aequalis*	*Vermiculithina area*	*Discoaster* cf. *D. mirackos*	*Micrantholithus australiensis*	*Micrantholithus* cf. *M. basquensis*	*Braarudosphaera bigelowi*	*Zygrhablithus bijugatus*	*Reticulofenestra bisecta*	*Discoaster calculosus*	*Triquetrorhabdulus carinatus*	*Helicosphaera carteri*	*Sphenolithus* cf. *S. ciperoensis*	*Rhabdosphaera clavigera*	*Discoaster deflandrei*	*Braarudosphaera discula*	*Discoaster distinctus*	*Discoaster druggii*	*Coccolithus eopelagicus*	*Cyclicargolithus floridanus*	*Scapholithus fossilis*	*Corannulus germanicus*	*Sphenolithus heteromorphus*	*Helicosphaera intermedia*	*Cyclococcolithus leptopora*	*Rhabdosphaera longistylis*	*Sphenolithus moriformis*	*Coronocyclus nitescens*	*Helicosphaera obliqua*	*Helicosphaera* cf. *H. perch-nielsenasae*	*Micrantholithus pinguis*	*Micrantholithus procerus*	*Reticulofenestra* aff. *R. pseudoumbilica*	*Helicosphaera recta*	*Rhabdolithus rectus*	*Discoaster* cf. *D. saundersi*	*Trochoaster simplex*	*Discosphaera* cf. *D. tubifera*	*Discoaster variabilis*	*Micrantholithus* cf. *M. vesper*	*Discoaster* sp.	*Thoracosphaera* sp.	*Pontosphaera* spp.	Ascidian spicules
30	F	M						R		R								F				F	F							C	F					F										R	F
29	C	G	R	R	F	R				F					C		R	F			R	C	F	R			R	R	C	C		R		R	R	F		F								R	F
28	C	G	R		R			R		F			R					F		R	F	F	C			R	R			C	F			R				R	R		R	F			R	R	F
27	C	G	C		F					F				R	R							F	C				R			C	R				R			R				F	R			F	F
26	C	G	F	R	R		R	F		F			R	R	R		R	R			R	F	C				F			C	R				R	F		F				F	VR			R	
25	F	M	R							R				R				VR				R	C				R			F		R			R			R								F	
24	F	M	VR							R		VR		R				VR				R	C							F		R		VR				R								R	R
23	C	M	R	R				R		R	VR	R		R				R				F	C							F		R		R	R			R									F
22	C	G	R		R	R		F		C	R		R	R				R	R	R		F	C							F				R	R			R		R				R		C	R
21	C	G	R					R		R	C	R		R				R	R			F	C		VR		R			F	R	R	R	R										R		F	R
20	F	P	R								F	R										C	C										VR					R								R	
19	C	P				R		R		F	F	VR										C	C							F	R			R	R			R								R	R
18	C	M						R		F	C												C							F	R			R												R	R
17	C	M								R	C	R										R	C							C		R						R								R	
16	R	M								R	R											R	F							R																F	
15	R	M									R	R											F							F																R	
14	F	M	VR					R		R	F	R						R		R		R	C				R			F							R	R								F	R
13	F	M	VR							F	F	R										F	C							F		R												R		R	R
12	F	M	R					R			F	R										F	C							F		R														R	R
11	C	M			R			R		R	F											F	C							F																F	
10	C	M	F		R			R		F	C	F										F	C							C		R		R										R		R	R
9	F	M	R					R		C	C	R										R	C							F				R												R	R
8	C	M	R					R			F	R				R						R	C				R			C	R	R	VR					R									R
7	C	M						R		R	F	R						R		F			C							F		R		R			R							R		F	R
6	C	M	R					R		R	F	VR										F	C				R			F							R									C	
5	F	M	R								R												C				R			F							R									F	
4	C	G	F		R					F	R	F										F	C				R			F		VR		R										R		R	R
3	C	G	F		R				VR	R	R											F	C							R													R			F	R
2	C	M	R					R			C	R										F	C							C														R		F	
1	R	M	R									R										F	C																								