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## THE BIOSTRATIGRAPHY OF THE TASMANIAN MARINE TERTIARY

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(with fifteen figures)

### ABSTRACT

Tertiary marine rocks occur in small scattered outcrops around Tasmania's north and west coasts, on some islands in Bass Strait, and below sea level in Mussel Roe Bay. All occurrences except those in Mussel Roe Bay and on Preservation Island have been recorded previously. From 64 samples, about 300 categories (form, subspecies, species, genus etc.) of foraminifera have been identified. Planktonic species are generally poorly preserved, but good faunas have been identified from Fossil Bluff, Brittons Swamp and Marrawah, the latter in company with *Lepidocyclina howchini* Chapman and Crespin and *Amphistegina lessonii* d'Orbigny.

All rocks are of Early and Middle Miocene age (Longfordian and Batesfordian, Carter's Faunal Units 6, 8 and 9) with the possible exception of one sample from Mussel Roe Bay which may be Late Oligocene (Janjukian, Faunal Unit 5).

All sediments are of shallow water origin, deposited in depths of less than 20, usually less than 10, fathoms. Water temperatures were those of the Warm Temperate to Subtropical Zones in Faunal Unit 6 time, Subtropical during Faunal Unit 8 time and Tropical during Faunal Unit 9 time. Waters may have been slightly warmer in the north-east than in the north-west during Faunal Unit 6 time.

Sediments at about 100 feet below sea level in Mussel Roe Bay, and at less than 150 feet above sea level at Wynyard, King Island, Cape Grim, Mt Cameron West, Marrawah, Daisy Creek and Granville Harbour formed during a marine transgression throughout Faunal Units 5 and 6. There seems to be a Faunal Unit 7 hiatus which may represent regression.

Higher level sediments (above sea level on Cape Barren and Preservation Islands) and at 170-310 feet above sea level at Brittons Swamp, Redpa, and Marrawah formed during another, more extensive transgression in the time of Faunal Units 8 and 9.

Comments are made on the age of some basalts in the north-west of the State; on the relation of these outcropping sediments to those of the Bass Basin; on the common occurrence of large and planktonic foraminifera in a single sample from Marrawah; and a palaeogeographic map is presented.

### INTRODUCTION

#### A Brief History of the Investigation of Tasmanian Tertiary Rocks

Nye (1941) and Banks (1957) have each given a brief resumé of the history of the understanding of the Tasmanian marine Tertiary and the only history necessary here relates to foraminifera.

The first study of Tasmanian Tertiary foraminifera seems to be that by Goddard and Jensen (1907) in which there is a somewhat detailed faunal list from Fossil Bluff. Unfortunately the nomenclature used is now almost completely outdated except for the new species they described. They listed as new *Fronidularia trimorpha*, *Nodosaria roemeri* Neugeboren var. *semicostata* (renamed *Dentalina godjeni* by Quilty, 1969) and *Reophax lodderae* which Quilty (1969) showed to be an echinoid spine. They also estimated the depth of formation as 50-150 fathoms with a distinctly tropical water temperature.

Chapman (1912) is the first to have examined rocks from King Island for foraminifera. He listed four species from Seal River. He later (1922) described *Sherbornina atkinsoni* from the Freestone Cove Sandstone, Fossil Bluff, as a new genus and species. Parr and Collins (1937) published on Australian polymorphinids and listed nine species from Fossil Bluff, including *Pseudopolymorphina tasmanica* and *Sigmomorphina wynyardensis* which were described as new.

Crespin (1944 *a* and *b*) has published analyses of two foraminiferal faunas, the former from Cape Barren Island, the latter from King Island. These are mainly faunal lists from which she derived a Miocene age for the Bass Strait Islands' Tertiary. Banks (1957), Gill and Banks (1956) and Nye (1941) all contain faunal lists of foraminifera from one locality or another.

Details of other groups of fossils are to be found in Chapman (*in* Nye, 1941), Dennant and Kitson (1903), Tenison-Woods (1875), Johnston (1877, 1880*a*, 1880*b*, 1885*a*, 1885*b*, 1888), Pritchard (1896), Tate and Dennant (1896), Ludbrook (1967), Darragh (1965*a*, 1965*b*), Gill and Darragh (1963), etc.

Text figure 1 gives a general idea of the distribution of Tertiary marine rocks and is also a key to other text figures.

Throughout this work, ages are given in terms of the Faunal Unit scheme proposed by Carter (1958) and are tabulated below (Table 1).

EPOCH	AUSTRALIAN STAGE	CARTER (1958) FAUNAL UNIT.	JENKINS (1960) ZONE	CARTER (1964) ZONE	TAYLOR (1966) ZONULE	BASS No. 1		BASS No. 2		BASS No. 3		GIPPSLAND SHELF No. 1																					
						-	+	-	+	-	+	-	+																				
MIDDLE Eocene	Balcornian	10	8	<i>Globigerinoides transitarius</i>	E	2300'	230'	2200'	305'	2430'	180'	2700'	380'																				
			7											2530'	2505'	2610'	2900'	3080'															
	Longfordian	9	6	<i>Austrotrillina howchini</i>	F	3090'	410'	2505'	530'	2900'	456'	3356'	?																				
														8	5	<i>Globigerinoides ruber</i>	G	3500'	390'	3035'	3700'	600'	3080'										
														7										4	<i>Globigerinoides trilobus</i>	H	3890'	4850'	960'	3055'	445'	4300'	216'
														6																			
Janjukian	5	2	<i>Victoriella conoidea</i>	I	3890'	4850'	960'	3055'	445'	4300'	216'	3540'																					

- Interval  
+ Thickness

TABLE 1.—Australian zonal schemes and Bass Strait oil well correlations in the time represented by Tasmanian Tertiary marine sediments.

### Acknowledgements

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Others to whom I am indebted for help in this work include Messrs T. Darragh and E. D. Gill, National Museum of Victoria, Messrs M. J. Clarke, A. B. Gulline and D. Jennings, Tasmanian Mines Department, Dr N. H. Ludbrook, South Australian Geological Survey, Dr O. P. Singleton, Geology Department, University of Melbourne, Mr F. L. Sutherland, Tasmanian Museum and Mr D. J. Taylor, University of Sydney, formerly of the Mines Department of Victoria.

The use of drafting and typing facilities of West Australian Petroleum Pty Ltd, is very greatly acknowledged.

### Specimens

Specimens mentioned in this paper are housed in the collections of the Geology Department, University of Tasmania, and the number following the initials U.T.G.D. indicates the number in that collection.

### Methods of Palaeoecological Analysis

#### Depth

There are several ways of estimating depth of formation of a unit and its temperature from its contained fauna. Phleger (1960) has listed and discussed most methods. One of the most interesting recent ones for depth estimations is by comparison with a curve produced by Walton (1964, p. 218). In this, he plots Faunal Variability (number of species making up 95% of the sample) against Faunal Dominance (the percentage of the fauna made up by the dominant species). Walton made the curve from samples from the Gulf of Mexico and then did a comparison with a fossil environment in the same area. He also made a series of generalisations (p. 217) regarding the percentage of samples studied which had

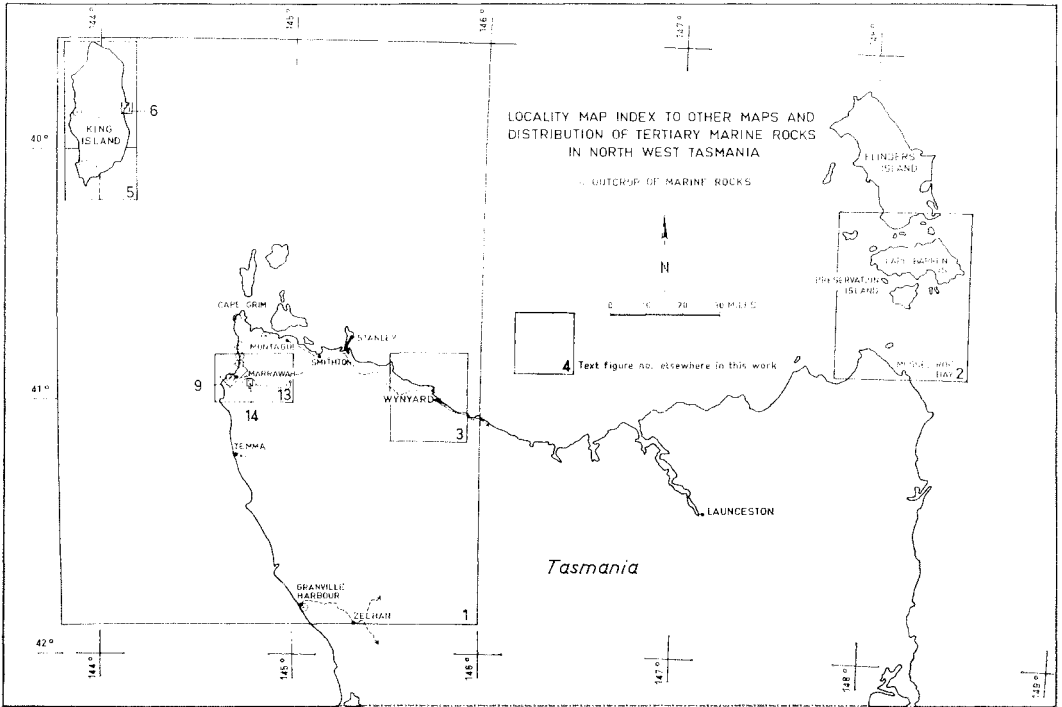


FIG. 1.—Distribution of Tertiary marine rocks in north-west Tasmania.

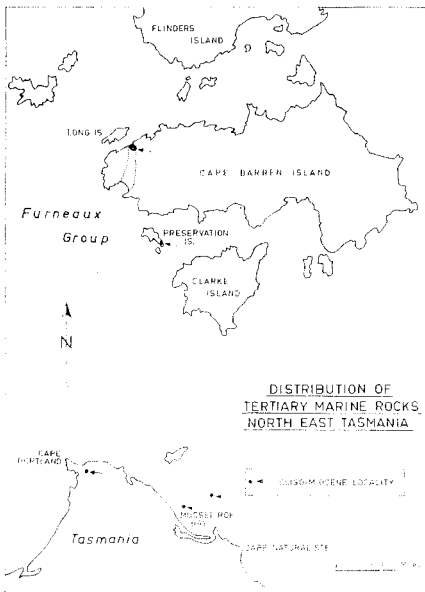


FIG. 2.—Distribution of Tertiary marine rocks, north-east Tasmania.

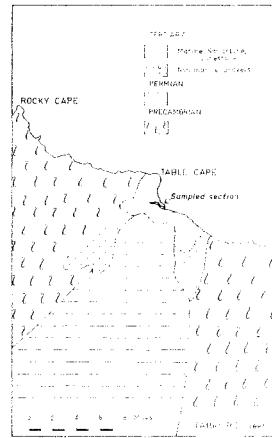


FIG. 3.—Pre-basalt palaeogeography—Wynyard area.

a certain Faunal Dominance and Faunal Variability, and the maximum depth range in which these generalisations hold true. Walton's object was to produce from studies of Recent situations, a palaeoecological tool independent of particular modern species or genera, the ecology of which is known. Walton's curve does not apply everywhere. I have compared other recent studies with Walton's and in some cases his curve holds good, in others it does not. Wilcoxon (1964) studied a series of samples along the U.S. Atlantic coast just north of Walton's area. There are several marked differences between the two areas. Wilcoxon's area has much stronger current action, being influenced by the Gulf Stream which is probably responsible for much sorting and winnowing of the sediment and its contained foraminifera. The overall gradients and total depth range are very different. The steeper floor gradient probably assists downslope movement of the faunas. Wilcoxon's faunas do not fit Walton's curve at all well, except in the 0-10 fathom range. Many of the 10-20 fathom faunas either fall outside the 10-20 fathom field which can be drawn from Walton's scatter of points, or they fall in the 0-10 fathom field. Deep samples (> 2000') often fall in the 0-10 fathom field. This latter 'anomaly' is not a criticism of Walton's work because his work did not extend to these depths. Walton did note that the number of benthonic species falls off near the edge of the continental shelf and this probably is true on the continental slope as well.

Bandy (1961) gives distribution data for the Gulf of California foraminifera. Again his figures do not plot well on Walton's curve. Depth range and depth gradients in this area are probably much greater than Walton's.

McKenzie (1962) studied foraminiferal distribution in Oyster Harbour, near Albany on the south coast of Western Australia. Here is a shallow, protected marine environment with little current effect. All his samples were collected in less than 45 feet depth and fit Walton's curve well. The list of comparisons could be extended *ad infinitum*.

The following suggestions are made concerning the use of Walton's curve. If the sample being studied does not fall on or close to Walton's curve, no comparison can be made. If the sample does plot well, other samples in the section should be compared. If all plot close to the curve, a comparison may well be valid. Walton's curve seems to be a good indicator of whether or not a fauna is biocoenotic. If a series of samples in a section does fit well, the samples are probably from a quiet water environment and represent biocoenoses.

It seems that the curve can be used in the Fossil Bluff section where the evidence from it agrees well with that of other foraminiferal indicators and lithology (see later).

It is applied to the Cape Grim section but only tentatively, as the site of deposition of the Cape Grim sediments is a narrow channel which could well be influenced by strong currents.

The sediments in the Marawah area were probably deposited in quiet embayments which extended many miles inland. When their faunas

are examined, they plot remarkably well on Walton's curve and it probably can be applied to this section.

## BIOSTRATIGRAPHY, PALAEOECOLOGY AND PALAEOGEOGRAPHY

### A. The Tertiary Marine Sediments off North-Eastern Tasmania and the Furneaux Group

#### 1. CAPE BARREN ISLAND

Blake (1935) described Tertiary marine rocks from the Cape Barren Island township area (also called The Reservation or Franklin Village) (see text figure 2). He stated 'the rocks of this series consist of level bedded, loose to partly consolidated sands with interstratified impure limestone. The limestones vary in colour from light brown to grey and blue-grey. The lime content of these rocks also varies and different types may be classified as calcareous sandstones, arenaceous limestones and limestones'. He then presented a log of approximately 13 feet in a section above high water at Sandford Bay. The sediments apparently occur mainly between sea level and 50 feet above sea level but Blake records limestones as high as 260 feet above sea level.

Dr D. J. Belford of the Bureau of Mineral Resources, Canberra, has kindly sent me some specimens from Crespin's sample washings of the Cape Barren Island material.

Mr M. J. Clarke, Tasmanian Geological Survey, has supplied a specimen of the limestone from the Survey collections. Species present are more numerous than indicated by Crespin (1944a) and include *Planorbulinella plana*, *P. inaequilateralis*, *Gypsina howchini*, *Operculina victoriensis*, *Amphistegina lessonii* and *Carpenteria rotaliformis*, all consistent with an age equivalent to Faunal Unit 8 of Carter (1958). They are thus Longfordian.

The variety of the fauna, its domination by *Calcarina verriculata* and the presence of *Operculina*, *Amphistegina* and a few miliolids suggests warm, shallow water deposition, certainly in less than 10 fathoms.

#### 2. PRESERVATION ISLAND

Preservation Island (see text figure 2) is a dominantly granitic island about 2 miles long and about 1½ miles from Cape Barren Island at its closest point. Mr R. G. Hooper has collected specimens from the shoreline at the eastern end of the island. There seem to be several types of calcareous sediment of which one is fossiliferous. It contains abundant, large (2-inch) echinoid spines and yields an extensive foraminiferal fauna. Unfortunately, not all species are well preserved and the identification of *Notorotalia howchini* is tentative only. *Astrononion centroplax*, abundant *Amphistegina lessonii*, *Planorbulinella inaequilateralis*, *Globigerina woodi* form *connecta*, *Operculina victoriensis*, *Calcarina verriculata* and *Carpenteria rotaliformis* suggest a Longfordian age, Carter's Faunal Unit 8. The similarities between this fauna and that from Cape Barren Island would suggest that they are contemporaneous.

The conditions of deposition of this deposit are not easily deduced but the water was probably subtropical to tropical and shallow (less than 10 fathoms). The very low planktonic foraminiferal population and high percentage (35%) of *A. lessoni* would suggest very shallow water, much less than 10 fathoms.

### 3. MUSSEL ROE BAY

In early 1967, the 'Wando River' working for Ocean Mining A.G., brought to the surface grey, coarse bryozoal calcarenite from two bores in Mussel Roe Bay (see text figure 2). Three samples have been examined from these bores, two of which are from borehole number NEO4. NEO4 was drilled in 75 feet of water, penetrated about 11 feet of sub-recent sand and had passed through 49 feet of calcarenite when drilling was stopped. One of the samples (U.T.G.D. 84483) is from the lower part of the calcarenite in this bore and is discussed immediately below. The other sample in this bore is from near the top of the calcarenite section.

Diagnostic foraminifera are rare in 84483 and large samples were processed to find the few diagnostic species recovered. Planktonic species make up much less than 1% of the fauna and do not help a great deal in defining the age of the deposit. Its very well preserved benthonic content includes *Sherbornina atkinsoni* Chapman, *Astronionion centroplax* Carter, *Angulodiscorbis* n.sp., *Crespinella* n.sp., *Calcarina mackayi* (Karrer) and abundant *Carpenteria rotaliformis* Chapman and Crespin. The age thus appears to be either Janjukian (Faunal Unit 5) or Longfordian (Faunal Unit 6). It is difficult to say which of these alternatives is the correct one.

Apparently out of place here, but quite common nonetheless, is the early form of *Eponides repandus* (Fichtel and Moll) known as *E. lornensis* Finlay. According to Hornibrook (1961, p. 110) this form is known only from Eocene and Early Oligocene. The specimens from Mussel Roe Bay are quite common, well preserved and typical of the form as described by Finlay. This form is not known from the Fossil Bluff section. This may suggest that this deposit is a little older than the Fossil Bluff section but the evidence is inconclusive. Thus there appears to be an Oligocene element in this sample. Because of this element, this sample is here taken as being Faunal Unit 5 in age.

In the other sample (U.T.G.D. 84481) from this bore, the fauna is essentially the same and belongs either to Faunal Unit 5 or 6. However some of the 'older' elements such as *Eponides lornensis* are absent and some newer elements (e.g. *Globigerina woodi* form *connecta* and *G. w.* form *woodi*) are present, suggesting that the age of this sample may be Faunal Unit 6.

A single sample (U.T.G.D. 84482) was examined from borehole number NEO9. NEO9 was drilled in 108 feet of water and immediately entered calcarenite for approximately 30 feet when drilling was stopped. The sample examined is from the middle of the section. There are some noteworthy differences in the faunal content of this sample from those in the samples from the other bore. *Operculina victoriensis* is a conspicuous species

here, as is an increase in planktonic content to about 5%. In other respects the fauna is similar to the samples from NEO4. The age of this sample is Faunal Unit 6. This age is based on *Globigerina woodi* form *woodi*, *Globigerinoides ruber*, *Astronionion centroplax* and *Operculina victoriensis*.

All the Mussel Roe Bay samples seem, by comparison with the curve produced by Walton (1964, p. 218, fig. 26), to have been deposited in a little more than 10 fathoms.

The main importance in this age determination lies in the fact that much of the sea floor in the vicinity of the Furneaux Group is made up of calcarenite apparently identical with the one studied here.

### 4. CAPE PORTLAND

The only marine Tertiary known from north-eastern mainland Tasmania was recovered from Cape Portland. The single specimen recovered contained a poor fauna which was reported by Quilty (*in* Jennings and Sutherland, 1969, Appendix 2).

The biota consists of very abundant ostracods, rare foraminifera, and a single charophyte. This all suggests lagoonal or shallow marine marsh sedimentation in only a few feet of water. Salinity would be approximately marine.

The age of the sample is hard to assess but *Calcarina mackayi* would suggest Carter's Faunal Units 5 or 6 which is in keeping with other ages noted along Tasmania's northern and north-western coasts. Sediments of this age are known in Mussel Roe Bay.

## B. The Tertiary Marine Sediments of North-western and Western Tasmania, and King Island

The localities mentioned in this section are shown generally in text figure 1 and in more detail in later figures.

### 1. TERTIARY MARINE SEDIMENTS IN THE WYNYARD AREA

Probably the most extensive continuous Tertiary marine deposit known in Tasmania occurs in the Wynyard area and is represented in this work by a series of 16 samples collected in a section 89 feet thick at Fossil Bluff.

Fossil Bluff is towards the western extremity of the deposit and forms the type section for the Table Cape Group. The Table Cape Group extends eastwards intermittently to Doctors Rocks, 6 miles south-east of Fossil Bluff. The maximum length (NW-SE) of the deposit is about 7½ miles. In the type section, the Table Cape Group is almost horizontal and rests on the Permian Wynyard Tillite with a very low angle unconformity. At Doctors Rocks, a few feet of sediment are found between two basalt flows at about 70 feet above sea level. In its whole development the Group is overlain by basalt and this is the reason for the formation of cliff outcrops of Tertiary. Inland from the coast, marine sediments appear to grade into river sands and gravels. These sands and gravels form two separate areas—one due south of Somerset with a north-south trend and the other south-west of Wynyard with

a north-east south-west trend. The sands and gravels were probably formed by the predecessors of the present day Flowerdale and Cam Rivers.

The area of deposition of the sediments in the Wynyard area was probably a fairly large protected bay into which flowed two rivers.

#### Stratigraphy

The distribution of rocks before the extrusion of Tertiary basalt is shown in text figure 3 which is after field mapping by Dr R. D. Gee. That figure also shows the position of the type section. The relation of the marine sediment to the volcanic centre at Table Cape cannot yet be described and so the latter is omitted from the map.

At Fossil Bluff, the Table Cape Group is divided into two formations. The lowermost 2-4 feet is the Freestone Cove Sandstone. This formation is a bimodal ferruginous coarse sandstone which is rather uniform in character wherever it is found. It seems to be the deposit formed by the transgressing sea and contains large blocks of Wynyard Tillite as well as many other rock fragments which have been derived from the Wynyard Tillite. The coarse quartz grains are well rounded and most fossils are robust types, the shells of which have been broken. Chiton plates in the lower six inches probably indicate that some of the formation formed intertidally. The formation also contains about 300 species of macrofossils, of which bivalves and gastropods are dominant. Some of the more obvious species are the bivalves *Eucrassatella oblonga* (Tenison-Woods), *Cucullaea corioensis* McCoy, *Glycimeris cainozoicus* (Tenison-Woods), *G. maccoyi* Johnston, *Corbula ephamilla* Tate, *Venericardia gracilicostata* (Tenison-Woods); the gastropods *Volutospina (Austrovoluta) anticingulata* McCoy, *Turbo tenisoni* Finlay, *Trochita subtabulata* Tate, *Turritella* spp., naticid spp., *Typhis maccoyi* Tenison-Woods, '*Voluta*' spp., *Cypraea platypyga* McCoy, *C. platyrhyncha* McCoy; the solitary corals *Placotrochus deltoideus* Duncan, *P. elongatus* Duncan; the colonial coral '*Thamnastraea*' *sera* Duncan as well as brachiopods (*Tegulorhynchia squamosa* (Hutton)), algae, fossil wood, shark teeth, etc.

The Freestone Cove Sandstone is conformably overlain by the Fossil Bluff Sandstone which is 80 feet thick in the type locality. It varies greatly in lithology, and text figure 4 shows an approximate lithologic section which also gives an idea of the outcrop pattern of the various strata. The lowermost 20 feet of the formation are composed of very friable yellowish glauconitic sandstone with very abundant *Turritella* spp. About 7 or 8 feet above the contact with the Freestone Cove Sandstone, there is a thin, highly ferruginous bed which is much richer in *Turritella* specimens than the rest of the section. The *Turritella* specimens are usually broken in this thin bed and it may mark a local period of nondeposition or even erosion and 'winnowing' of the sediment.

Above this glauconitic sandstone, the section consists of variously coloured fine siltstones, calcareous sandstones and calcarenites up to 10 feet thick, alternating irregularly with beds of soft shale or mudstone which are usually greyish in colour and 6 inches to 3 feet thick. The variety

of macrofossils is much more restricted in the Fossil Bluff Sandstone than in the Freestone Cove Sandstone. The most fossiliferous part is the glauconitic sandstone and this contains mainly small gastropods (dominantly *Turritella* spp.—so much so that Johnston (1877) called this the *Turritella* Group) but large gastropods (e.g. *Voluta stephensi* Tenison-Woods) do occur, as do the bivalves *Diplodonta subquadrata* Tate, *Eucrassatella oblonga* (Tenison-Woods), *Myadora tenuilirata* Tate, *Eotrigonia semiundulata* (McCoy), *Panopea agnewi* (Tenison-Woods), *Glycimeris cainozoicus* (Tenison-Woods) and the gastropods *Natica vixumbilicata* Tenison-Woods, *N. polita* Tenison-Woods, *Marginella* spp., *Typhis maccoyi* Tenison-Woods and other species. The squalodont whale *Prosqualodon davidi* Flynn, and the marsupial *Wynyardia bassiana* Spencer were described from the Fossil Bluff area and examination of the matrix shows that they came from glauconitic sandstone.

The history of the study of the Fossil Bluff Tertiary has been ably presented by Banks (1957, p. 74) who also helped stabilise the nomenclature of the sediments which had, up to that time, been known by a variety of informal names.

The Freestone Cove Sandstone in the Fossil Bluff section at Wynyard is the lowest, conglomeratic part of that section and represents intertidal to shallow marine sediments formed by the marine transgression at that time. It contains *Astrononion centroplax* Carter, *Sherbornina atkinsoni* Chapman, *Calcarina verriculata* (Karrer), *Lamarckina glencoensis* Chapman and Crespin, and very few planktonic species. An age corresponding to either Carter's Faunal Unit 5 or 6 is possible. The sediments immediately overlying (i.e. the Fossil Bluff Sandstone) contain *Globigerina ciproensis* Bolli and *Globoquadrina dehiscens* (Finlay) and are thus Faunal Unit 6 in age (Quilty, 1966).

Mr T. Darragh (National Museum, Victoria) and Dr O. P. Singleton (Geology Department, University of Melbourne) both assure me (verbal comm. February 1967) that the mollusc fauna of the Freestone Cove Sandstone affords good correlation with the upper part of the Jan Juc formation at Torquay, Victoria. This similarity of the molluscan faunas of the Freestone Cove and Fossil Bluff Formations suggests that there is no significant age difference. Ludbrook (1967) reiterates Pritchard's (1896) statement that the Fossil Bluff Sandstone molluscs afford correlation with the Longfordian Puebla Formation at Torquay. The boundary between Faunal Unit 5 and 6 could conveniently be drawn between the Freestone Cove and Fossil Bluff Sandstones. Also, perhaps too conveniently, the Oligocene Miocene boundary could be drawn here, following the Australian practice of placing that boundary between Faunal Units 5 and 6.

Because the foraminifera are compatible with an age of Faunal Unit 6, and because the overlying sediments are Faunal Unit 6 in age, the Freestone Cove Sandstone is here taken as Faunal Unit 6 in age.

There appears to be some uncertainty and debate about the boundary and distinction between Faunal Units 5 and 6.

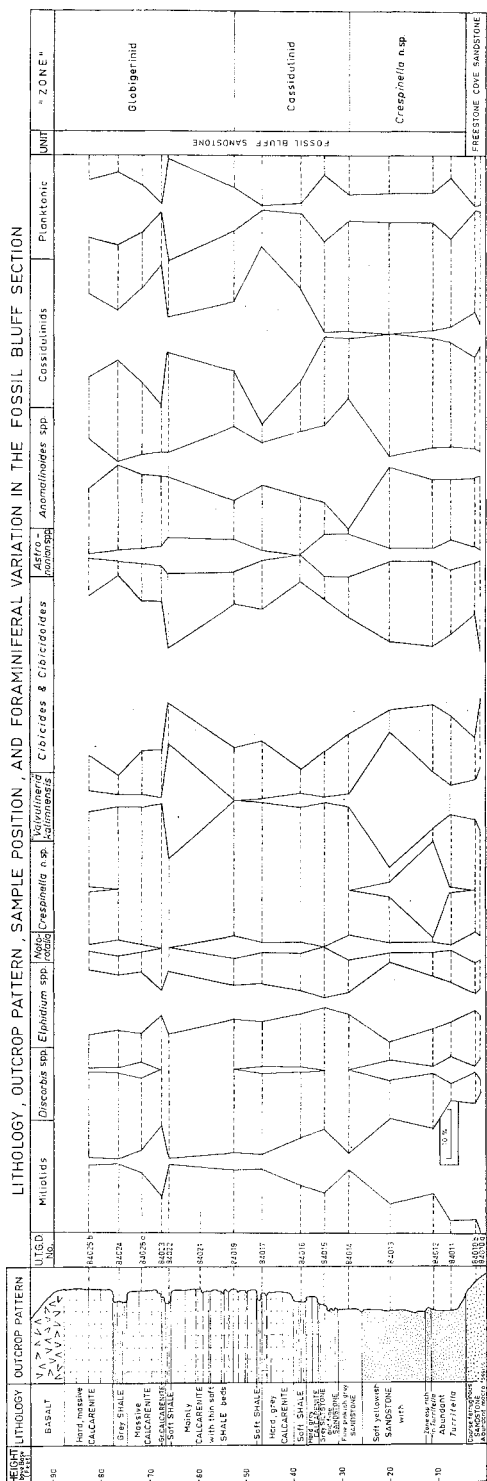


FIG. 4.—Lithology, outcrop pattern, sample position and foraminiferal variation in the Fossil Bluff section.

*Palaeoecology of the Fossil Bluff Area*

In an effort to deduce some of the aspects of the palaeoecology (and its changes) in the Fossil Bluff section, I have drawn up the main part of text figure 4 which is a plot of percentage of a foraminiferal group (species, genus, family or superfamily) against height above the base of the section. Smaller groups making up 5-15% of the samples have been ignored. Only those making up significant percentages have been used. In the same way, sample 84021 which contained only 42 specimens has been neglected, as the percentages mean very little. The other percentages are based on samples of about 300 to 1500 specimens (with the exception of 84016 which has only 100, and 84017 which has 200).

Several aspects of the distributions are noteworthy but not all can be explained or utilised.

- (i) *Miliolids*.—The miliolids show a general tapering off in abundance from the base of the section to the top. A local exception occurs at sample number 84023. The curve is generally antithetic to that of the planktonic species as would be expected.
- (ii) *Discosia*.—Species of this genus are most abundant lower in the section. It has in general, the same characters as the miliolid curve.
- (iii) *Elphidium*.—This genus has a dominant peak low in the section (20 feet) and after a 'low' at about 30 feet, increases towards the top of the section in a manner which appears antithetic to the miliolid curve. The only part of its curve which is not antithetic to that of the miliolids, is in the region around 20-30 feet.
- (iv) *Notorotalia*.—This is always a minor part of the population. Its distribution does not show a great deal, but in general parallels that of *Astrononion* and *Anomalinoidea*.
- (v) *Crespinella n.sp.*—This species reaches a high percentage in the glauconitic sandstone portion of the Fossil Bluff Sandstone but disappears between 20-28 feet and only occurs as a small percentage of sample 84025b.
- (vi) '*Valvulineria*' *kalimmensis*.—This species has peaks at 20 feet and 66 feet and has a general antithetic relationship with the cassidulinids and an approximately parallel one with *Elphidium*.
- (vii) *Cibicides*.—The curve for species of this group shows three peaks and a marked antithetic relationship with *Elphidium*, '*Valvulineria*' *kalimmensis*, *Astrononion* sp., a roughly antithetic one with miliolids, and has no parallel relationship with any group. It is the most dominant group.
- (viii) *Astrononion*.—*Astrononion* seems to have three main peaks—at 7-8 feet, 28-34 feet and 52-66 feet and these roughly parallel *Notorotalia* and *Anomalinoidea*.
- (ix) *Anomalinoidea*.—The *Anomalinoidea* curve has three main peaks which correspond

generally with those of *Astrononion* and *Notorotalia*.

- (x) Cassidulinids.—The cassidulinids are minor elements of the fauna until about 35 feet above the base of the section when they become important. One of the most marked features of all the distributions shown is the strongly antithetic character of the cassidulinid and planktonic foraminiferal curves.
- (xi) Planktonics.—The ratio of planktonic/benthonic foraminifera gives a rough guide to the amount of 'open-seaness' or 'oceanicity' of the environment. It would appear from the curves that the section has a more 'open-sea' aspect higher in the section.

From a study of the curves, several regions of the section can be delineated. These are listed below and their probable ecologic conditions noted. Of all the works published on recent foraminiferal ecology, Phleger (1960) and Walton (1964) seem to be the most useful for comparison purposes with the Fossil Bluff section. Nowhere in the section do arenaceous forms have any significant abundance. This is in keeping with the distribution of the rocks which suggests that the deposit formed in an open, fully marine bay, probably seaward from the mouth of a river or series of rivers.

*The Freestone Cove Sandstone.* This formation contains a fauna which changes from the lowest 6 inches-1 foot to the top. Overall the fauna has a very low proportion of planktonics, *Crespinella* n.sp., and relatively low numbers of cassidulinids, *Anomalinoidea*, *Elphidium*, *Astrononion* and the highest proportion of arenaceous species (1-1.5%—the only part of the section to contain an appreciable arenaceous fauna), miliolids and a fairly high amount of *Discorbis*, *Notorotalia* and '*Valvulineria*' *kalimnensis*.

The lowest portion is in part intertidal and thus forms part of the shoreline for this marine transgression. The changes upward are consistent with a shift to more marine conditions with a possible water depth in its upper parts of 2-10 fathoms, probably nearer the shallower end of this range.

*The glauconitic sandstone portion of the Fossil Bluff Sandstone.*—This part of the section could be named the 'zone' of *Crespinella* n.sp., as this genus reaches its maximum abundance in this region (4-26 feet from the base of the section) and it is not known outside it except for a few specimens at the top of the section (sample 84025b).

This region is very uniform in character without visible bedding. The section has high abundances of *Crespinella* n.sp., '*Valvulineria*' *kalimnensis*, *Elphidium* spp., miliolids, *Discorbis* spp. and low abundances of arenaceous forms, cassidulinids, *Anomalinoidea*, and relatively low *Astrononion* sp.

The depth of formation can be approximated by several means. Using Walton's Faunal Variability (Imbrie's (1956) Faunal diversity), the number (*v*) of species is 24 and the Faunal Dominance value is 28.5% (for '*Valvulineria*' *kalimnensis*). These figures are based on sample

number 84013, from 20 feet above the section base. These figures plot out very well in comparison with Walton's figure 26 (p. 218) and suggest a depth of about 10 fathoms. The percentage of cassidulinids suggests a depth of 10 fathoms and the percentage of *Elphidium* suggests a depth of 5-10 fathoms. Thus the depth of formation was probably in the range 5-10 fathoms.

*From 26-53 feet.*—This region could be termed the cassidulinid 'zone' because in this region, cassidulinids reach their maximum, this being the result of a rapid expansion at the beginning of this interval and a rather sharp diminution at the end of it. This interval also marks a very low planktonic abundance. For a sample in this range, the depth of formation is about 10 fathoms. This is based on the following evidence. The samples used have a Faunal Diversity of 15-24 species which suggests a depth of less than 20 fathoms with two of the samples in the range suggesting less than 10 fathoms. The percentages of *Bolivina*, etc., are all shallow water values. The abundance of cassidulinids is compatible with a depth of 25-200 fathoms. *Elphidium* is consistent with a depth of 5-20 fathoms, usually near the shallow end of the range. The apparent diversity of depth possibilities is probably a result of the fact that some parts of the section in this region are poorly fossiliferous and the analyses are based only on 100 and 200 specimens respectively. The others are based on 300-1500.

*From 53 feet to the top of the section.*—This part of the section has the highest percentage of planktonic specimens (15-20%), correspondingly low cassidulinid proportion, high cibicidid and *Elphidium* and very low miliolid and arenaceous content. The faunal analyses in general suggest a depth of deposition of about 100 feet or a little more.

Whenever the planktonics increase the cassidulinids decrease and vice versa, with one very minor exception. It is also noticeable that above 50 feet, the total of planktonics and cassidulinids forms an approximately constant proportion (23-30%) of the fauna.

Overall the Fossil Bluff section seems to have formed in the depth range 0-10 fathoms, the lower few feet being formed in very shallow water (in part intertidal) the next several feet (to 26 feet from the base) in 5-10 fathoms and the rest in about 100 feet or a little more.

As the sea rose, the shoreline would have progressed further inland giving the vertical section at this locality a progressively more open sea aspect. This is in accord with the observed faunal evidence. The lowest samples have a more inshore aspect than the higher ones. The general character of the fauna containing '*Valvulineria*' *kalimnensis* and *Crespinella* n.sp., would be consistent with their being environmentally analogous with *Rotalia beccarii* of modern times and would thus be found in a lower salinity, close inshore environment.



It seems consistent with the evidence available, that the entire Fossil Bluff section was being deposited during a transgressive period, with relative sea level rising throughout the time of deposition.

2. KING ISLAND

Tertiary rocks have been known from King Island since 1888 but they have never been studied extensively. Crespin (1944*b*) studied the foraminifera briefly and regarded the rocks as Middle Miocene. Several Tertiary localities are known on the island but some which have been regarded as Tertiary by Hughes (1957) are more likely to be Quaternary and thus a detailed listing of localities seems desirable (see text figure 5).

Spencer (1888) recorded limestone from the lighthouse from Cape Wickham in the north-west part of the island. Any limestones seen by the author from this locality are probably the cores of sub-Recent sand dunes. The foraminifera are often abraded, and usually Recent forms. The author was unable to locate any limestone just south of Lavinia Point on the east coast, and none of the local residents could remember any. However, thick accumulations of dune sand could easily cover any small deposit. Thus no limestones are recorded here from northern King Island.

Both Tertiary and Quaternary marine calcarenites are to be found in the vicinity of the aerodrome near Currie. The rocks collected on the

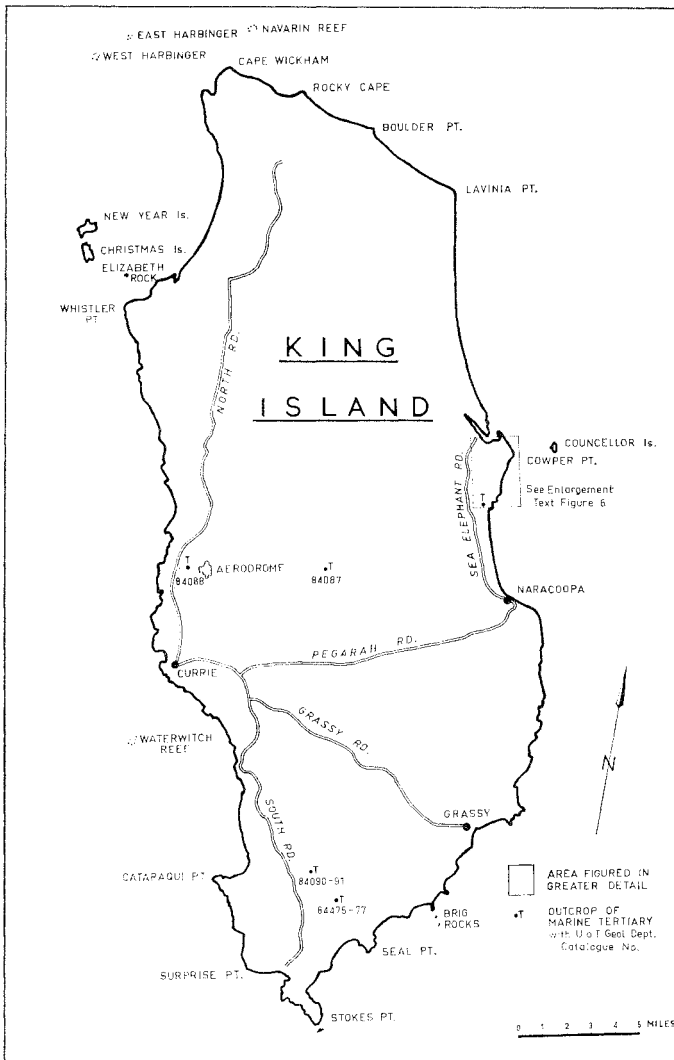


FIG. 5.—Distribution of Tertiary marine—King Island.

Great North Road 0.2 miles south of Munroes Road near the aerodrome are sub-Recent to Pleistocene. The fauna is very similar to that now known in Bass Strait. Material collected from a damsite, half a mile east of the Great North Road locality, is a white bryozoal calcarenite and has an entirely different mode of preservation, and although only a few poorly preserved species were recovered, it is likely that this material is older, as the preservation and rock types are both like those recorded elsewhere on the island for Tertiary sediments. Crespin (1944b) examined material from an abandoned quarry on 'Avondale' in the centre of the island. This quarry is now filled in and the calcarenite

The most extensive area of Tertiary rock recorded on the island is that at the mouth of Blowhole Creek (see text figure 6) on the central east coast. Immediately south of the mouth of the river there is a vertical section of massive bryozoal calcarenite but including a basal conglomerate overlying Precambrian rocks. Three samples (U.T.G.D. 84081-84083) have been examined from here.

North of the Blowhole, Tertiary sediments occur at beach level, extend out to sea, and occur for a distance of 1½ miles along the shore. Their seaward extension is clear from air photographs. Two samples (U.T.G.D. 84085, 84084) have been examined from north of Blowhole Creek (see text figure 6). Further sediments (U.T.G.D. 84086) have been examined from an outcrop at the roadside between a quarter and a half mile west of the Blowhole. All these specimens gave faunas of several hundred specimens (except 84081) although large samples had to be used. Preservation is not bad, and the specimens were clean and identifiable. No very diagnostic species were found here although *Elphidium crespinae*, *Astrononion centroplax*, *Heronallenia parri* are consistent with a lower Longfordian age. The samples are all of shallow water faunas with a very dominant species ('*Cibicides*' *perforatus*) making up 43-87% of a sample and only a few species making up the rest of the sample. This suggests deposition in the 0-10 fathom zone, somewhere towards the shallower end of the range.

Limestones have been examined from two localities in the southern half of the island. One specimen (U.T.G.D. 84090) was recovered from 12 feet in a well on the property of Mr H. Drake, and the specimen is studied through his courtesy. It is a cream rock with large specimens of *Lichenopora grandis*. Unfortunately, only a few very poorly preserved, non-diagnostic foraminifera were recovered.

The other locality is represented by three samples. The rock comes from a 25 feet thick section of pink bryozoal calcarenite on the Seal River, about a half mile north-west of its entry into swamplands east of Big Lake.

The samples were collected by Mr C. Byrne and represent the bottom (U.T.G.D. 84475), middle (U.T.G.D. 84476) and upper (U.T.G.D. 84477), parts of the section. This is probably that rock examined by Spencer (1888) and Chapman (1912). *Sherbornina atkinsoni* and *Notorotalia howchini* (from U.T.G.D. 84477) and *Astrononion centroplax*, *Heronallenia parri* and *Elphidium crespinae* (from U.T.G.D. 84084) suggest an age equivalent to Faunal Unit 6. Each of these two faunas is consistent with an age of Faunal Unit 6, so it is probable that all the Tertiary marine rocks recorded from King Island are of this age. As with the Blowhole Creek section all the material from the Seal River section appears to have been deposited in less than 10 fathoms, a conclusion based on the same evidence.

### 3. CAPE GRIM

The Tertiary sediments at Cape Grim are about 140 feet thick and fill a north-south trending channel about half a mile long and 300 feet wide, cut into the underlying Tertiary basalt. Suther-

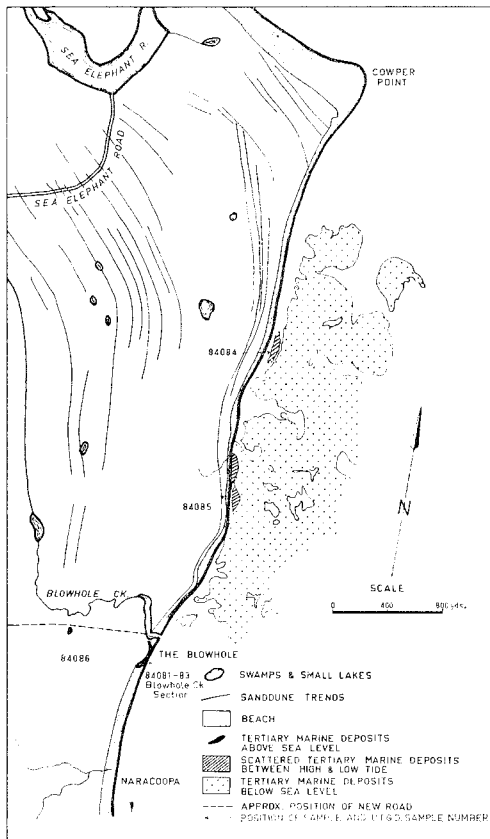


FIG. 6.—Distribution of Tertiary marine—The Blowhole area, King Island.

recorded from it is now rare. Mr H. Bartlett supplied me with the specimen I examined. The poor preservation of the specimens is typical of that of most King Island samples. The specimen used is a grey calcarenite which has undergone some recrystallisation. The foraminifera found are less diagnostic than those recorded by Crespin, who saw three specimens. The specimen supplied is like the specimen from which Crespin recorded only one species and in which I found six.

land and Corbett (1967) gave details of this channel. The sediments dip at up to 17° towards the centre of the channel. The southern end is about 100 feet above sea level and the northern end is at sea level, opening onto a bench which

may be a wave cut platform but is probably also the top of a basalt flow. The section sampled is at the northern end. Lithology, outcrop pattern and foraminiferal variation are shown in text figure 7.

The section can be divided into three parts:—

- (a) The bottom 20 feet of the section overlies massive basalt and is itself made of coarse, black basalt sand grains and is unfossiliferous.
- (b) The next 100 feet is often quite richly fossiliferous and is a pink to yellow sandstone, the fragments being volcanic, in part possibly tuffaceous. There is approximately no quartz in this part of the section and the rock is very friable and most fossils are ironstained. At about 70 feet there is a thin 6-inch band of red, non-fossiliferous rock which may be a tuff band. Macrofossils present in this 100 feet include *Volutospina (Austrovoluta) anticingulata* McCoy, *Turbo tenisoni* Finlay, rare, large *Turritella* spp., *Voluta* spp., an haliotid, *Glycimeris calmozoicus* (Tenison-Woods), *G. maccoyi* Johnston, *Diplodonta subquadrata* Tate, *Tegulorhynchia squamosa* (Hutton), and several echinoids, including *Monostychia australis* Laube and *Scutellinoides patellus* (Tate). Near the top of this part of the section is a bed about 2 feet thick containing abundant *Aturia stansburienensis* Glaessner.
- (c) The top 20 feet of the section is a light coloured bryozoal calcarenite without volcanic debris and with appreciable percentage of quartz. This rock is much more indurated than that lower in the section.

Several aspects of the foraminiferal fauna are noteworthy. The general fauna is that of normal salinity areas and planktonic foraminifera would be expected in the samples, especially as the depth of formation could be as great as 20 fathoms (see below). However, in about 10,000 specimens examined, only a single planktonic specimen was recovered, so no correlation can be made using planktonic species.

Many of the samples are dominated by a new genus and species of *Chapmaninae* which is probably an environmental analogue of *Sherbornina crassata* Wade. This species will be reported in another paper.

In the samples, there are very few species which are diagnostic in Carter's (1958) Faunal Unit scheme. However, *Astrononion centroplax* Carter and *Lamarckina glencoensis* Chapman and Crespin suggest an age of Faunal Unit 5 or 6, and *Astrononion tasmaniensis* Carter, *Notorotalia howchini* (Chapman, Parr and Collins), *Alabama tenuimarginata* (Chapman, Parr and Collins), *Heronallenia lingulata* (Burrows and Holland), *H. parri* Carter and *Cassidulinoides* spp. all suggest an age younger than Faunal Unit 5. The age is here taken as Faunal Unit 6 for the entire section. An earlier (Quilty, 1966) belief in still younger age (Faunal Unit 7 or 8) was based on (a) the

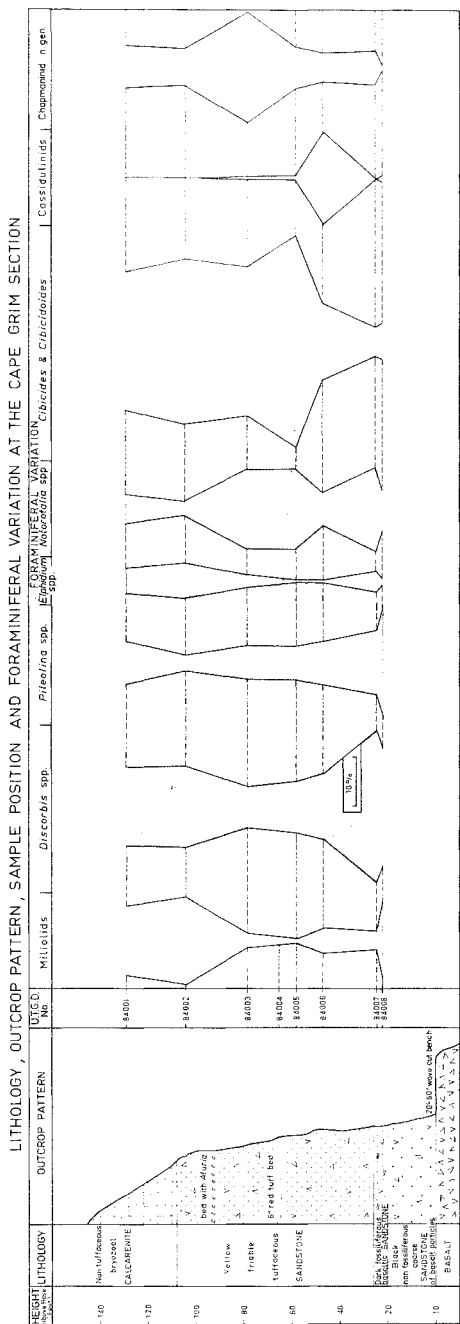


Fig. 7.—Lithology, outcrop pattern, sample position and foraminiferal variation at the Cape Grim section.

mistaken belief that the new genus reported earlier was *Planorbulinella inaequilateralis*, and (b) the mistaken belief that that species does not occur in rocks older than Faunal Unit 7. Carter's scheme depends on *P. inaequilateralis* belonging to Faunal Units 7-9, whereas at Fossil Bluff it occurs as early as at least Faunal Unit 6.

#### Palaeoecology

An attempt is made here to deduce the conditions of deposition of the sediments in this section. Any conclusions reached must be regarded as very tentative, because the very position of the sediments—in a channel—would suggest that they may have come under the influence of local currents which may have winnowed out many of the lighter species, and thus left a biased sample for study.

When the percentage of the dominant species in a sample is plotted against the number of species making up 95% of the sample, a comparison can be made with Walton's (1964, fig. 26) graph of the same plot. No positive conclusions can be reached, but a few indications of depth of formation can be seen.

The lowermost sample (84008) had 95% made up of about 25 species, the dominant one constituting 26.5% of the sample. A depth of deposition of about 10 fathoms is suggested. The composition of the next sample (84007) suggests a similar depth although this is based on only 200 specimens. Sample 84006 is possibly a deeper water sample (45 species, 12%). Sample 84005 is probably the shallowest sample in the Cape Grim section, being formed in less than 10 fathoms (14 species, 43.5%). The results for 84003 are based on only 200 specimens and do not fit the curve well (11 species, 23%) so this sample is neglected here. Sample 84002 (22 species, 32.5%) and 84001 (25 species, 26.5%) are probably formed near the boundary of the 0-10 and 10-20 fathom ranges.

This analysis, if valid, suggests that the Cape Grim sediments formed in water depths varying from less than 10 fathoms to as much as 20 fathoms and this would be expected in a fairly active area such as on the side of a volcano. This result is in contrast with molluscan faunas which have a shallower water aspect probably indicating sedimentation everywhere in less than 10 fathoms.

#### 4. MT CAMERON WEST

At Mt Cameron West, at least 32 feet of horizontal marine sediments underly about 500 feet of Tertiary basalt, apparently consisting of a single basalt extrusion (or intrusion) (see text figure 9). The lower limit of visible sediment is low tide mark. The sediments are variable in colour, usually pink to red but with some yellows and whites. They consist of fine sandstone, usually with a high detrital, non-volcanic fraction.

Text figure 8 shows the stratigraphic column for the section and notes sample positions. Sample 84116 has not been included on the range chart because any fossils present have been rendered unrecognisable by baking associated with the basalt. Sample 84121 represents a small, elongate lenticular body of yellowish sandstone within pink sandstone.

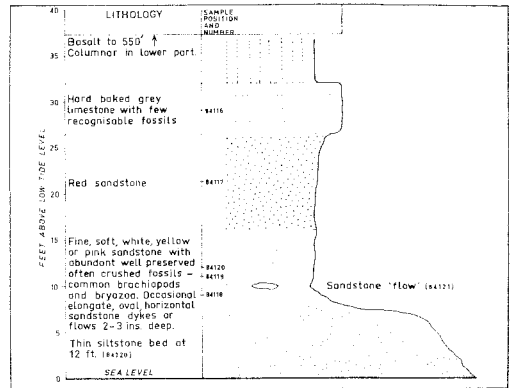


FIG. 8.—Outcrop pattern, lithology and sample localities at Mt Cameron West.

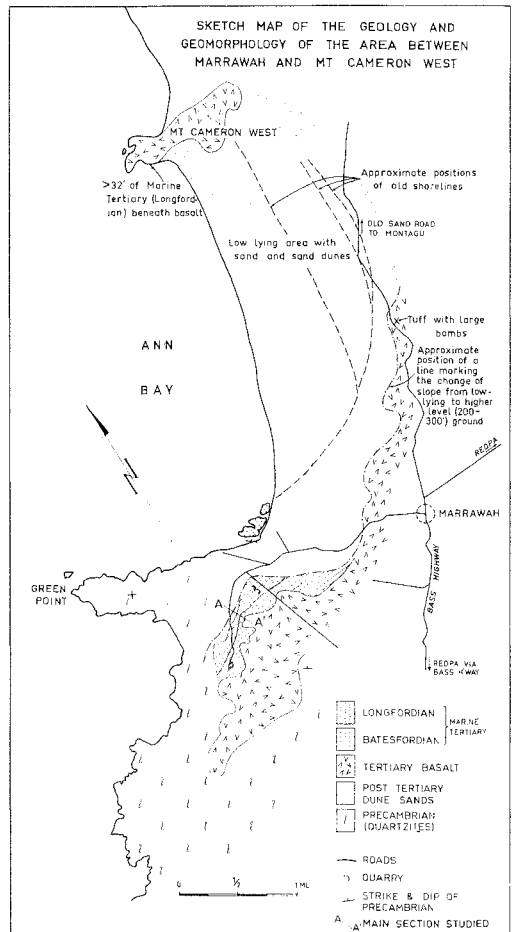


FIG. 9.—Sketch map of the geology and geomorphology of the area between Marrawah and Mt Cameron West.

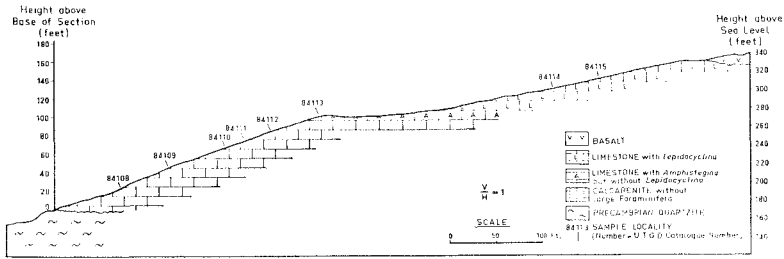


FIG. 10.—Section profile, sample localities and lithology at the Marrawah main section.

Quilty (1966) reported *Sherbornina cuneimarginata* from this section, but the specimen examined has, with further examination, proved to be *S. atkinsoni*, so the age of the material in this section is probably everywhere Faunal Unit 6, as *Globotrachina dehiscens dehiscens* also occurs here. The samples here have Faunal Diversities (Variabilities) of 12-20 and Faunal Dominance of 40-55%, all of which are consistent with a depth of formation at the deeper end of the 0-10 fathom range.

##### 5. MARRAWAH DISTRICT

Outcrops of Tertiary marine sediments are widely scattered throughout the Marrawah district (see text figure 9):—

(a) At slightly above sea level, and extending seawards in Ann Bay is a yellow bryozoal calcarenite with *Lichenopora grandis*, echinoids, brachiopods and a rich and varied fauna of foraminifera including *Sherbornina atkinsoni*, *Notorotalia howchini*, *Astronion centroplox* and various planktonic species of Longfordian age. The outcrop is Faunal Unit 6 in age.

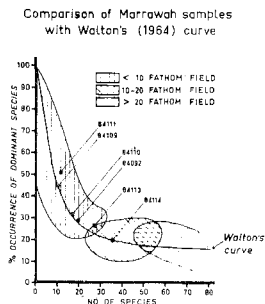


FIG. 11.—Comparison of Marrawah samples with Walton's (1964) curve.

(b) Between Ann Bay and the nearest other Tertiary outcrop, there is a gap where only Precambrian occurs. The closest Tertiary marine is taken as the main section in this area and has a total thickness of about 150 feet. Its position is shown in text figure 9 as the line A-A'. Text figure 10 shows the lithology, profile and sampling positions on this section. Samples 84108, 84112 and 84115 are very indurated limestones and have

not been included in the section on palaeoecology but specimens have been polished and traversed to get some broad idea of species abundance.

The base of the section overlies Precambrian quartzite and is situated at about 170 feet above sea level. The entire section is in indurated limestone alternating with friable calcarenite. Where possible, the calcarenite has been sampled but soil and lush growth prevent a complete sampling programme being undertaken.

The lower 95 feet (170-265 feet above sea level) of the section contain no large foraminifera, and five samples have been studied from here. *Globigerinoides siccanus* is present in this section above 235 feet. However, its absence lower down may be due to poor preservation.

The upper 55 feet of the section contain large foraminifera. The lower 10 feet (265-275 feet) contain abundant *Amphistegina lessonii* d'Orbigny and the rest has both *A. lessonii* and *Lepidocyclus howchini* Chapman and Crespin. For the purpose of this work, Faunal Unit 9 is taken as beginning where *Lepidocyclus* does, so the lower 105 feet (170-275 feet) belong to Faunal Unit 8 and possibly in the lower part, Faunal Unit 7. In the present samples there is no way of distinguishing Faunal Unit 7 from Faunal Unit 8, as none of the diagnostic Faunal Unit 7 species have been found.

The samples from this section fit very well indeed onto Walton's curve (see text figure 11). The envisaged environment of deposition is a deeply indented bay extending at least as far inland as Redpa and possibly as far as Brittons Swamp and through to Montague. From Walton's curve it seems that the lower part of the section is represented by shallow water samples (less than 10 fathoms) and the upper part by deeper water samples (15-25 fathoms), the latter representing deposition at the highest peak of sea level. Lithology sample levels, and foraminiferal variation are shown in text figure 12.

(c) As well as the Ann Bay and main sections at Marrawah, several small scattered outcrops have been sampled. The westernmost of these is in a small quarry just east of the road 2 miles west-south-west of Marrawah. The sediment in this quarry is a very clean, white calcarenite with no appreciable detrital element and containing *Lepidocyclus howchini* in all samples studied.

Two other small quarries are situated in an open sloping paddock 14 miles west of Marrawah. They are only about 50-100 yards apart. The sediment is a dirty brown calcarenite, the colour being due mainly to colouration from the overlying soil. The material from these quarries contains occasional fragments of basalt and this led Sutherland and Corbett (1967) to suggest that the limestones at Marrawah are younger than the basalt. This will be referred to again later where I hope to show that most of the basalts in the area are younger than the limestones.

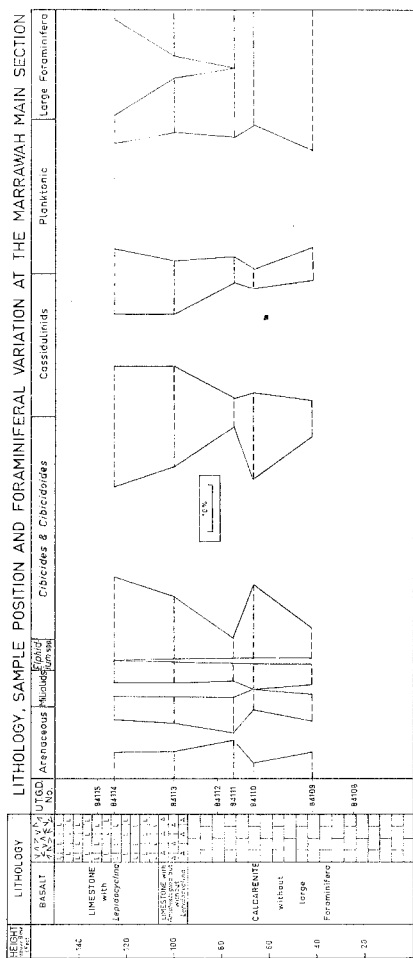


FIG. 12.—Lithology, sample position and foraminiferal variation at the Marrawah main section.

The sediments from these quarries contain no diagnostic fossils and do not contain *Lepidocyclina*. They are here regarded as Longfordian (Faunal Unit 7 or 8), more likely Faunal Unit 8. From these age determinations, the distribution of Longfordian and Batesfordian rocks is shown in text figure 9.

#### 6. REDPA

The distribution of sediments south of Redpa is shown in text figures 13 and 14. The outcrops

are scattered and thin, the main one examined being an isolated hill indicated by an arrow in text figure 14. The sediments here are only about 20-25 feet thick and four samples were examined. They overly Precambrian dolomites and are overlain by basalt.

Banks (*in* Hughes, 1957) recorded *Lepidocyclina* from the section examined. He (*pers. comm.*) states that it comes from a 6-inch thick band in the section. I have not found this species but have seen Redpa material collected by him. It contains *L. howchini* and is the same friable pink calcarenite which constitutes the rest of the section. Because of the reported *Lepidocyclina*, the Redpa Tertiary is here taken as Batesfordian, Faunal Unit 9 in age.

The sediments are composed of bryozoal calcarenites with the bryozoal colonies in imbricate patterns showing that this section has clearly been affected by current action and because of this no attempt has been made to apply Walton's curve.

#### 7. BRITTONS SWAMP

At Brittons Swamp 14 miles east of Marrawah (see text figure 13), there is an abandoned quarry in tachylitic basalt. This basalt contains abundant rock fragments including pieces of a pink, yellow or grey indurated Tertiary marine limestone. Usually this limestone is very indurated and cannot be disaggregated but a single small specimen contained a friable sample and this has yielded a rich, well preserved fauna dominated by *Amphistegina lessonii*, and also containing *Crespinella umbonifera*, *Notorotalia howchini*, *Astronionion centroplax*, *Operculina victoriensis* and *Globigerinoides siccanus*. This fauna suggests an age of Faunal Unit 8.

The origin of the limestone fragments is unknown but they are probably quite local. The main implication from this occurrence is that Tertiary marine rocks are much more widespread in north-western Tasmania than the present distribution would suggest. The restricted known distribution is probably due to two factors:—

- (a) the geology of this corner of Tasmania is poorly known, and
- (b) much Tertiary marine which does exist is probably covered by later basalt.

#### 8. DAISY CREEK—TEMMA AREA

Pebbles of limestone were first recorded from the ocean beach near the mouth of Daisy Creek by Ward (1911) who stated (p. 39):—

'Numerous pebbles of limestone were observed in association with still more abundant pebbles of vesicular or pumiceous olivine basalt along the ocean beach between Ordnance Point and the mouth of Daisy Creek, but neither rock was found *in situ*.'

He also recorded limestone 2 miles east of Temma but a search for this has been fruitless and the original locality is probably now covered by soil. However, pebbles from the beach near Daisy Creek have been examined. They consist of indurated bryozoal calcarenites. The few foraminifera recovered are dominated by '*Cibicides*' *perforatus* but *Sherbornina atkinsoni* is also

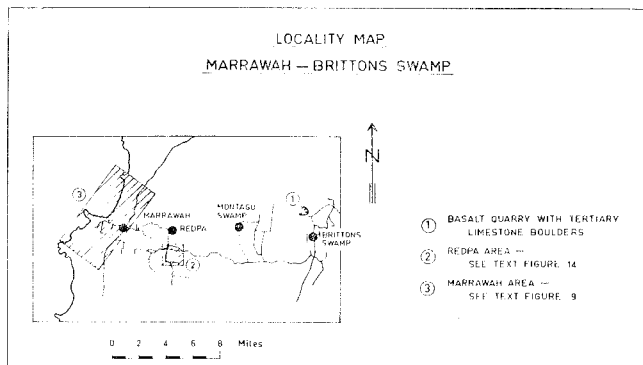


FIG. 13.—Locality map—Marrawah—Brittons Swamp.

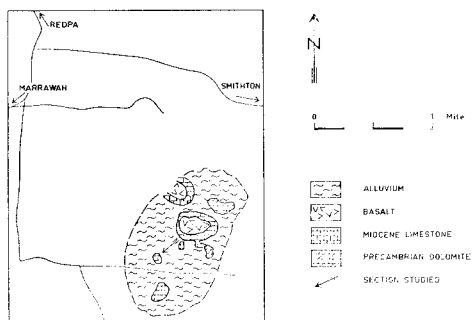


FIG. 14.— Enlargement of Area 2 in Text Figure 13.

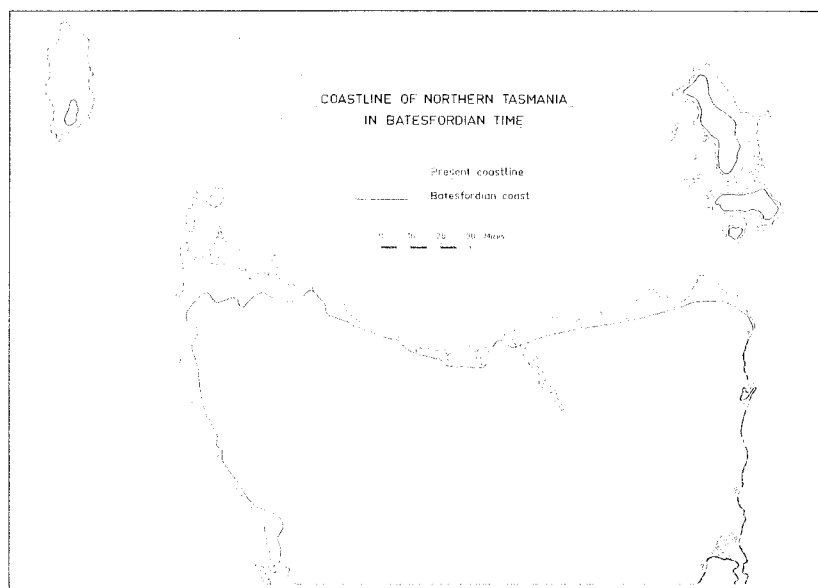


FIG. 15.—Coastline of northern Tasmania in Batesfordian time.

present. The origin of the pebbles is unknown but may well be from rocks just offshore. The rocks are very similar to those occurring at sea level at Ann Bay, Marrawah. With '*Cibicides*' *perforatus* making up 78% of the fauna and only four species making up 95%, the fauna is clearly quite a shallow, fully marine one, probably living in a depth of 2-10 fathoms and nearer the shallow end of the range.

#### 9. GRANVILLE HARBOUR

Blissett (1962, p. 75) reported a white silicified bryozoal limestone, 2½ miles east of Granville Harbour. It is almost a coquina composed of small (34 mm) gastropod shells. Gulline (pers. comm.) says that its elevation is just about 350 feet above sea level. It is a very small outcrop, only about 6-inches thick and a few square feet in area. Mr. F. L. Sutherland of the Tasmanian Museum has supplied me with a large specimen of this rock which has produced quite a good fauna. '*Cibicides*' *perforatus* is dominant. *Carpenteria rotaliformis* is also present as very poor internal moulds. *Sherbornina atkinsoni* is represented by a single immature specimen. Other species include *Globocassidulina subglobosa* and *Notorotalia howchini*.

No very diagnostic foraminifera were separated but *Sherbornina atkinsoni*, *Notorotalia howchini*, *Carpenteria rotaliformis* and *Heronallenia parri* are consistent with an age somewhere in the range of Faunal Units 5-6.

#### Temperature

It is reasonable to suggest that the current pattern during the Miocene was not markedly different from what it is now. Reed (1965) also came to this conclusion from his study of Victorian foraminifera.

Faunal Unit 6 is well represented in Tasmania, containing most of the formations studied in this work. No north-western Tasmanian samples contained anything suggesting even subtropical temperatures, unless the single keeled *Globorotalia* from Fossil Bluff implies a temperature occasionally above 17°C (Bandy, 1964). The absence of *Operculina* in north-western and western Tasmania during Faunal Unit 6 seems to be a real one. Many different lithologies and environments have been sampled and if it were present, it should have been found. It is present in north-eastern Tasmania during Faunal Unit 6 time. Its absence in the north-west could be due to a temperature barrier, the north-east being warmer than the north-west. For this reconstruction, it is probably necessary to envisage a barely subtropical Eastern Australian Current and a slightly cooler, non-subtropical West Wind Drift, the former supporting *Operculina*, while the latter was too cool.

In Tasmania, there are no indisputable occurrences of Faunal Unit 7 rocks. However, in other parts of south-eastern Australia, *Amphistegina lessoni* and *Operculina victoriensis* do suggest warm, probably subtropical waters during at least some of Faunal Unit 7 time.

It is clear that in upper Longfordian time (Faunal Unit 8) the seas were at least subtropical. There are ample occurrences of *Amphistegina lessoni* and *Operculina victoriensis* from Tasmania, Victoria, and South Australia to support this contention. There is no record of *Lepidocyclina* from this time and we may assume that the water temperatures were not quite high enough.

Also it is clear that in Batesfordian time, the seas around south-east Australia were tropical. *Lepidocyclina howchini*, *Amphistegina lessoni* and *Operculina victoriensis* all attest to that. Dorman (1966) gave a series of  $O^{16}/O^{18}$  ratio which are consistent with water temperatures of 22-26°C (with two anomalous measurements, one each of 16° and 17° which are from the Batesford Limestone).

After Faunal Unit 7 time, the temperature difference between the eastern and western current systems does not appear to have been enough to sustain any noticeable faunal difference. These temperatures appear to have been in the subtropical range by late Faunal Unit 7 and during Faunal Unit 8. By Faunal Unit 9, the temperatures were tropical.

It is difficult to put figures to the temperature regimes at this time but in terms of present day temperatures, the following figures are probably not too inaccurate:—

Faunal Unit 6—

(a) north-western Tasmania—warm temperate 15°-18°C

(b) north-eastern Tasmania—subtropical 16°-20°

Faunal Unit 8—subtropical 20°-25°

Faunal Unit 9—tropical 22°-27°

These estimates agree well with results of  $O^{16}/O^{18}$  measurements recorded by Dorman (1966) using his *Ostrea* series. If one accepts the evidence of his *Chlamys-Pecten* series, his values for Faunal Unit 6 are a little higher than estimated here.

#### Relation of Tasmanian Tertiary marine sediments to the Bass Strait sediments

Most of the studies of mainland Australia, Bass Strait and the Gippsland Shelf have been done on more continuous and thicker successions than the coastal Tasmanian sections. The maximum thickness in Tasmania is about 270 feet, made up of 120 feet at Cape Grim plus 150 feet at Marrawah.

The Tasmanian sediments form a series of thin patches around the north and west coasts. It would be gratifying to show that they bore some strong genetic relation to those formed in other Australian Tertiary areas of sedimentation, especially Bass Strait. Unfortunately, all the drilling in the Bass and Gippsland Basins done so far only suggests that the Bass Strait sediments of this age are not very closely related to the Tasmanian material. The Bass Basin sediments are a much deeper water facies with a very different fauna and lithology, although time correlations can be made.

The Tasmanian sediments are marginal to the Bass Basin and are the result of deposition during fluctuations in sea level or epeirogenic processes, whereas the Bass Basin formed as a result of larger scale tectonic activity.



### History of sedimentation

During the upper part of Faunal Unit 5 and through Faunal Unit 6, sedimentation occurred on coastal fringes of Tasmania at heights of up to 120 feet above present sea level. There are no definite Faunal Unit 7 rocks and there was probably no sedimentation during this time. It may well have been a time of regression.

A much more extensive transgression occurred during Faunal Units 8 and 9, extending several miles inland in north-western Tasmania and ceasing before Faunal Unit 10. This reached areas now about 400 feet above present sea level. This picture of transgression-regression-transgression agrees very well with the scheme proposed by Bock and Glennie (1965) for this part of geological time except that their postulated regression extends into Faunal Unit 8.

### Correlation

Ludbrook (1967) has published an account of the correlation of Australasian Tertiary rocks. It is of little use to redraw this chart in effect, to give a correlation chart for the Tasmanian Tertiary marine. Instead, only a simple table (Table 1) of ages has been drawn up and compared with Carter's (1958) Faunal Unit scheme, Carter's (1964) Zonal scheme, Taylor's (1966) Zonule scheme and Jenkin's (1960) Lakes Entrance Zonation scheme. To this has been added the data from the three Bass Basin wells and the Gippsland Shelf No. 1 well. The equivalence of Jenkin's Zones and Carter's Faunal Units is approximate only and follows Taylor (1966) although it is a little different in detail from Wade's (1964) suggestion. Thicknesses for the wells are taken directly from the relevant works of Taylor.

### The age of the Tertiary volcanic rocks of north-west Tasmania

Apart from radiometric or palaeomagnetic dating, the only way to date volcanic rocks is eventually by comparison with marine sediments. This places at least some restriction on the age. The marine Tertiary rocks in Tasmania are often associated with basalts and the basalts can be separated into pre- and post-marine sedimentation.

At Doctor's Rocks near Wynyard, Miocene sediments lie between two basalt flows. The marine bed is only a few inches or feet thick at about 70 feet above sea level. The basalts can here be divided into pre-Miocene and post-sedimentation. It is well nigh impossible to say just how much younger than the sediments the younger basalt is. Because 90 feet of sediment is overlain by basalt at Fossil Bluff, I would suggest that some time elapsed between deposition of the sediment and the later extrusion at Doctors Rocks. Any estimate of how much later is more or less a guess, but in line with more westerly occurrences, I would think that it is Upper Miocene (possibly Middle) or Pliocene.

At Cape Grim, marine sediments are clearly younger than the main mass of basalt. Sutherland and Corbett (1967) have examined this area in some detail and note that basalts are both pre- and post-sediment.

At Mt Cameron West, the only basalts known are post-sediment. Whereas most other north-western Tasmanian basalts are clearly volcanic, the origin of the Mt Cameron West mass is more obscure, but Edwards (1941) suggested that it may be a laccolith while Gill and Banks (1956) considered it to be a flow or series of flows and Sutherland and Corbett thought it may be a single flow.

The Brittons Swamp volcanics are clearly younger than the Upper Longfordian sediments in the area as they contain baked fragments of the limestone. The source of the sediments is unknown but is probably very local.

Sutherland and Corbett state that basalts in the Redpa-Marawah area overlie Precambrian and are overlain disconformably by the Longfordian and Batesfordian sediments. They regard the basalts at Marawah and Redpa as belonging to the same mass. Their evidence for the age of the basalt consists of pebbles of basalt which are found in the calcarenite from the quarries 1½ miles west of Marawah. They state that the textures in these pebbles are the same as those from the basalts in the area.

No definite contact between the basalt and the calcarenite has been observed either by me or by Corbett or Sutherland. In the Redpa area, many contacts between Precambrian dolomite and Tertiary limestone can be found in the area shown in text figure 14. Almost all the hills in the Welcome Swamp area are capped by basalt and flanked all round with limestone. A similar pattern occurs around Marawah in the vicinity of the main section of the limestone.

In both localities I have come to within 2-3 feet of the basalt-limestone contact, always with the basalt apparently lying above the limestone. The limestones have no characters which suggest deposition within a few feet of land. On the other hand, in both localities, all samples are almost devoid of detrital material, and if any is present, it is more in keeping with a Precambrian origin than with a basaltic origin. The sediments contain abundant planktonic foraminifera and this is suggestive of open marine sedimentation at some distance from land. If the terrain was volcanic, one is more likely to expect the type of sediment found at Cape Grim which was formed close to shore in a volcanic terrain and has no planktonic species and much detritus. Thus the limestones in the Marawah-Redpa area contain evidence that they were formed before the main mass of basalt in the area. This basalt was probably extruded at about the same time as that which contains Miocene limestone blocks at Brittons Swamp and also the mass at Mt Cameron West. Sutherland and Corbett record a basalt dyke 2 miles north of Ann Bay which shows that there was volcanism in the immediate neighbourhood after sedimentation.

There are older basalts in the region. At Cape Grim there are abundant pre-Miocene volcanics and there are probably others. The basalt pebbles recorded by Sutherland and Corbett may well have come from one of these.

The history envisaged in the north-west corner of Tasmania is then as follows:—

- (1) Extrusion of basalts at Cape Grim, Fossil Bluff and probably elsewhere.
- (2) Marine transgression (Faunal Unit 6).
- (3) Regression (Faunal Unit 7).
- (4) Marine transgression (Faunal Units 8 and 9).
- (5) Period of erosion to remove most of marine sediments.
- (6) Extrusion of more basalt.

The age of the younger basalts is probably Upper Miocene or Pliocene.

#### Palaeogeography

There has been much post-Oligocene movement in Tasmania and this accounts for the lack of marine sediment in areas apart from the north-west, west and north-east. Because of this movement, it is very difficult to judge where the coastline was at any particular time. During the transgression in the time of Faunal Unit 9, sea level was relatively about 400 feet above its present level in north-western Tasmania. However there is no evidence to say what its position was anywhere else.

In the south-east, faulting in the Richmond area and in the Derwent Graben has depressed non-marine sediments well below present sea level, at least 800 feet for river sediments recently found in a Tasmanian Mines Department bore at Richmond. The sediments must have formed above sea level because the site is such that if an 800 feet trough existed, it would have been filled by the sea. Unfortunately the age of the sediments is, as yet, unknown.

At St Helens, non-marine sediments extend to at least 200 feet below sea level (Jack, 1963) and in the Tamar Graben, at least 900 feet below sea level, but the movement could be older (Spry and Banks, 1962, p. 243).

Faunal Unit 8 sediments on Cape Barren and Preservation Islands are at about sea level whereas very similar sediments at Marrawah are about 300 feet above sea level. Faunal Unit 6 sediments are 100 feet below sea level in Mussel Roe Bay and up to 90 feet above sea level at Fossil Bluff, and 120 feet above sea level at Cape Grim.

All this suggests that since the Oligocene or Miocene, Tasmania has undergone epeirogenic movement with the net result that the north-east and south-east have been tilted downwards relative to the west and north-west. Thus in reconstructing the Batesfordian coastline, no position can be attributed properly to anywhere but the north-west. Its position elsewhere is only conjecture.

#### An occurrence of *Lepidocyclina howchini* and planktonic foraminifera from a single sample at Marrawah

It is only rarely that large foraminifera (*Lepidocyclina*, *Discocyclina*, etc.) are found in the same sample as planktonic forms. Because different zonations have developed based on the standards of either large foraminifera or planktonic species, and as there are so few means of comparison between

the zonations based on the two sets of standards, it is important that in any case in which members of the two standards occur together should be noted. This is particularly so in warm water areas such as the Indo-Pacific region where so much Tertiary tectonic activity has occurred.

Because south-eastern Australia has strong Indo-Pacific influences only during the Batesfordian, it seems hardly likely that any occurrences of this kind here are going to be greatly beneficial to Indo-Pacific studies. However, Batesfordian limestones from north-western Tasmania do contain *Lepidocyclina* and planktonic species in the same samples and are noted in some detail here.

Many of the Marrawah samples contain both *Lepidocyclina howchini* and planktonic forms. However, in only one (U.T.G.D. 84104) is preservation of each type good enough to allow study of the planktonic forms in any detail. The planktonic species identified are: *Globigerina bradyi* Wiesner, *G. bulloides* d'Orbigny, *G. woodi* Jenkins, *G. connecta* Jenkins, *G.w.* form *woodi* Jenkins, *Globerinoides sicanus* de Stefani, *G. glomerosus* form *transitorius* Blow, *G. quadrilobatus* form *immaturus* Le Roy, *G.q.* form *sacculifer* (Brady), *G.q.* form *trilobus* (Reuss), *G. ruber* (d'Orbigny), *Globoquadrina dehiscentis* form *dehiscentis* (Chapman, Parr and Collins), *Globorotalia menardii* form *praemenardii* Cushman and Stainforth and *Turborotalia siakensis* (Le Roy).

It is not possible to fit this fauna uniquely to the scheme proposed by Jenkins (1960) because the Marrawah material contains *Turborotalia siakensis* which occurs only in Jenkins Zone 4 and possibly 5. If Wade is correct (and it seems she is) in equating at least the upper part of Zone 6 with the lower part of Faunal Unit 9, the sample belongs to upper Zone 6 and lower Faunal Unit 9.

Again, no unique correlation can be made with Bolli's (1957) zonation scheme for Trinidad. With the exception of *Globorotalia menardii* form *praemenardii*, the fauna fits uniquely the *Globigerinatella insueta* Zone, which according to Wade (1964) embraces all of Faunal Units 7-10. *G.m.* form *praemenardii* should occur only in rocks a little younger than those found here.

No effective correlation can be made with Reed's (1965) column for the Heywood bore, Victoria.

Sample 84104 appears to fit between datum planes 18 and 19 of Jenkins (1966) and allows correlation with the New Zealand Altonian and eventually with the upper part of the Helvetian of Europe (Jenkins) or upper Burdigalian (Wade). Bandy (1964) would even go so far as to call it Aquitanian.

Drooger (1956) suggested that the Helvetian be fixed as that time between the entrance of *Globigerinatella insueta* fauna and the appearance of *Orbulina universa*. *Globerinoides sicanus* occurs in the Helvetian and lower Tortonian. The Australian Faunal Unit 9 should then be regarded as Helvetian and thus Middle Miocene. Therefore, *Lepidocyclina howchini* is an Helvetian species.

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## ADDENDUM

Since this paper went to press, the author has had an opportunity to compare the faunas of several samples with the comprehensive zonation described by Blow (*Proc 1st Internat'l Conf. Planktonic Microfossils, Geneva*, vol. 1, pp. 199-422, pl. 1-54).

Significant results are as follows:—

1. Fossil Bluff section.—Sample 84011 contains *Globigerina angulisuturalis* Bolli and *Globoquadrina dehiscens dehiscens* (Chapman, Parr and Collins). The sample is thus Early Miocene (N4) and supports the conclusions reached in the main body of this paper.
2. Mussel Roe Bay sections.—Planktonic faunas in Mussel Roe Bay are not diagnostic in Blow's scheme. However, sample 84481 contains *Globigerinoides quadrilobatus immaturus* Leroy and is thus post Oligocene, supporting the conclusion reached earlier.
3. Mt Cameron West section.—The samples contain common *Globoquadrina dehiscens dehiscens* and *Globigerina ouachitaensis ciperensis* Bolli attesting again to an N4 age.
4. Marrawah section.—Several samples (84110, 84113, 84101, 84104, 84105) contain *Globigerinoides sicanus* de Stefani and two (84101, 84104) also contain *Praeorbulina transitoria* (Blow). An age of N8-N9 is indicated for these samples.
5. Brittons Swamp.—The single sample from Brittons Swamp is N8 to N9 for the same reasons as the Marrawah section.

## CONCLUSIONS

Faunal Unit 6 appears to correlate, in whole or part, with Blow's N4, and most Tasmanian Miocene probably belongs to this zone. Faunal Unit 9 is in part at least, N8 to N9.