

ABSTRACT

The fossils, burrows and sedimentary characters of the Tertiary strata exposed in the lower Moorabool valley near Geelong, in Victoria, Australia, have been examined with the object of distinguishing the environments of deposition.

The rocks are flat-lying and are exposed in the valley between Maude in the north, and Geelong, 20 miles to the south east. They unconformably overlie Ordovician slates and are themselves covered by the thin but widespread Pleistocene basalt of the Werribee Plains.

The lowermost rocks, comprising the Lower Maude Formation were laid down during the Janjukian and Longfordian stages in continental, beach and nearshore environments. The latter contain Eotrigonia and Fibularia, both indicative of depositional depths of 20 to 30 metres. Farther to the south, a fringing calcareous-algae reef developed on the flank of an emergent granite island. The talus-slope sediments of this reef form the Batesford Limestone. During the following stage, the Batesfordian, a period of temperature-high allowed abundant Lepidocyclina to live on the reef-front.

At this time in the north, a basalt extrusion about 70' thick caused the shoreline to regress several miles. As the transgressive sea that covered it cut farther and farther northwards it deposited a thin formation, the Upper Maude Limestone, which represents intertidal and shallow subtidal environments. At the base, a basalt conglomerate rich in calcareous algae and gastropods, especially Subninella, represents subtidal rock pools, while the more silty overlying bioturbated beds represent intertidal flats.

Overlying all of these formations is the thick Balcombian - Bairnsdalian Pyansford Clay. This comprises a regressive, upward-shallowing sequence characterised by a rich fauna indicating maximum

depths of deposition in water 80 metres deep.

An unconformity separates these sediments from the Pliocene Moorabool Viaduct Sands, a thin sequence representing inshore shallow bay environments.

CHAPTER 1

INTRODUCTION

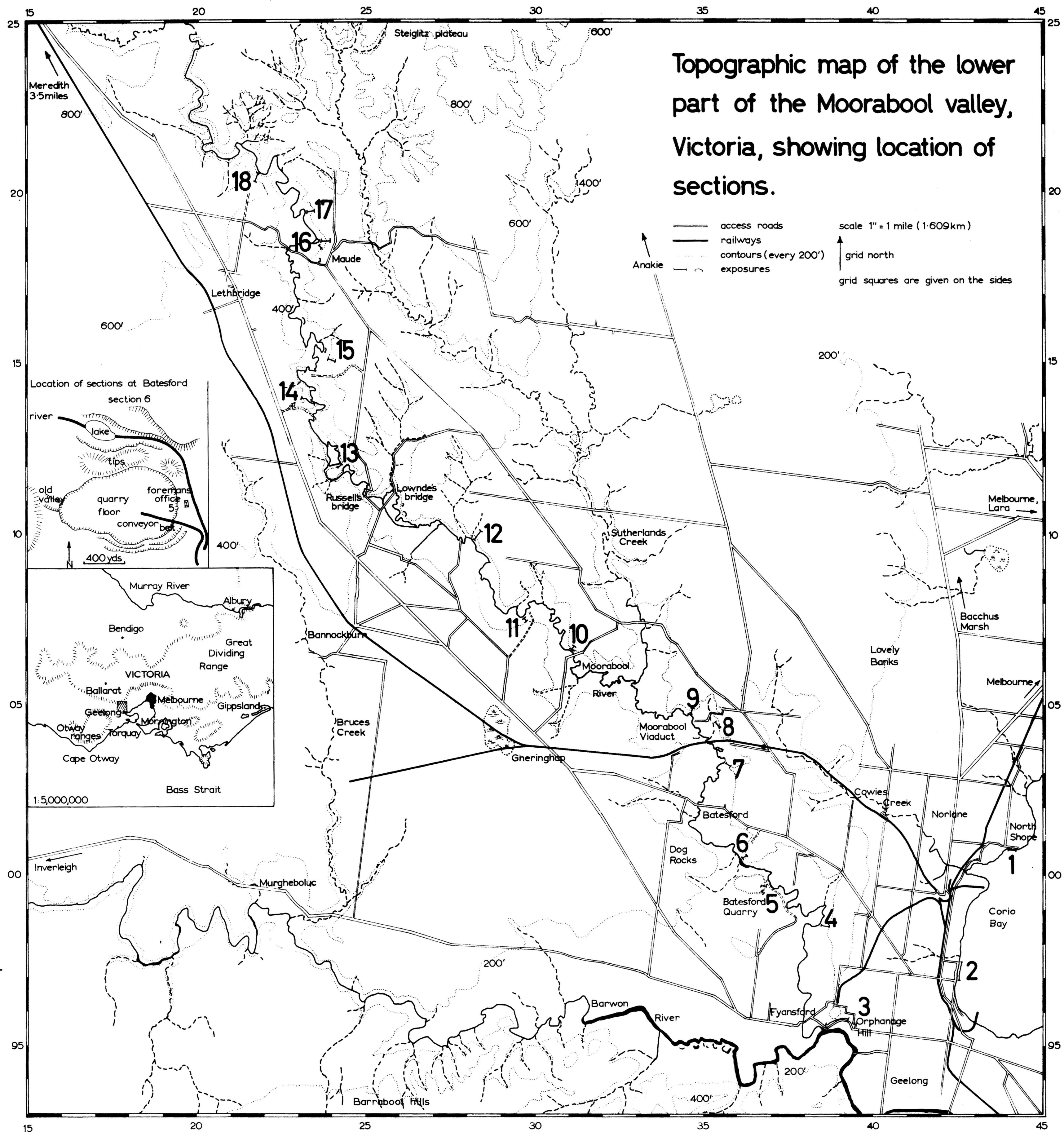
Geographic setting Figure (1) 1, (1) 2.

The rocks considered in this project are exposed in the hill sides of the lower part of the Moorabool valley near Geelong, in Victoria, Australia. They comprise sands, clays and limestones belonging to the Upper Oligocene, the Miocene and the Lower and Middle Pliocene. The Moorabool river is one of a number of north - south flowing streams that arise in the higher land to the north and flow southwards across the flat plateau of the Werribee plain. The latter is covered with a thin, but very widespread Upper Pliocene basalt flow - the Newer or Plains Basalt. It is only where the rivers cut through this basalt that the Tertiary rocks are exposed.

In the northern part of the area near Mercedith, Ordovician slates and siltstones are exposed in the higher land of the Steiglitz plateau. The Newer Basalt of the Werribee plains is banked up against it near Maude, at more or less the same position as the farthest northern limits of Tertiary marine sediments.

Near Geelong, in the southern part of the area the east-west trending Barrabool Hills composed of Mesozoic rocks terminate the exposure. The Moorabool river joins the east-west flowing Barwon river and flows southeastwards into Port Phillip Bay. Tertiary rocks occur south of the Barrabool Hills in the neighbourhood of Torquay and Anglesea near the Otway ranges, but are nearly all older than those exposed in the lower Moorabool.

The rocks are nearly all flat-lying, though occasional dips of one or two degrees may be seen in good exposures. Most of the southward



drop in the topography of the Tertiary outcrop is accounted for by the southeastward downthrow of the Rowsley fault and the Lovelybanks Monocline (210' and 109' respectively).

Previous research in the area and object of the study.

The area has been studied from various viewpoints by a large number of authors for at least a century. For a complete survey of literature and research before 1941 see Singleton 1941. The first one inch geological map of the area was produced by Wilkinson and Murray of the Victorian Geological Survey in 1865. Most of the earlier workers concentrated upon the collection and description of the abundant fossils, and many new species were described from localities in the lower Moorabool by McCoy (1874 etc.), Tate (1886 - 1893) and Tenison Woods (1879) amongst others.

Hall and Pritchard (1892, 1895, 1897) produced a series of papers describing sections and localities in the Moorabool Valley and established a general succession between Geelong and Maude. They did not attempt however, to relate these sections to each other in any detail, concentrating mainly on palaeontological correlation. Other papers describing various aspects of the geology of the lower Moorabool include those of Coulson (1932, 1938, 1960), Denmant and Mulder (1896), Keble (1932) and Mulder (1897, 1902).

Singleton (1941) in his synthesis of the Tertiary geology of Australia, set down for the first time in a systematic form the relationships and stratigraphic correlation of the various Tertiary rocks of the area.

Bowler (1963) published the major work - an account of the stratigraphy and sedimentation of the Tertiary rocks between Geelong and Maude. He considered the relationships between the various rock types and recognised five formations:-

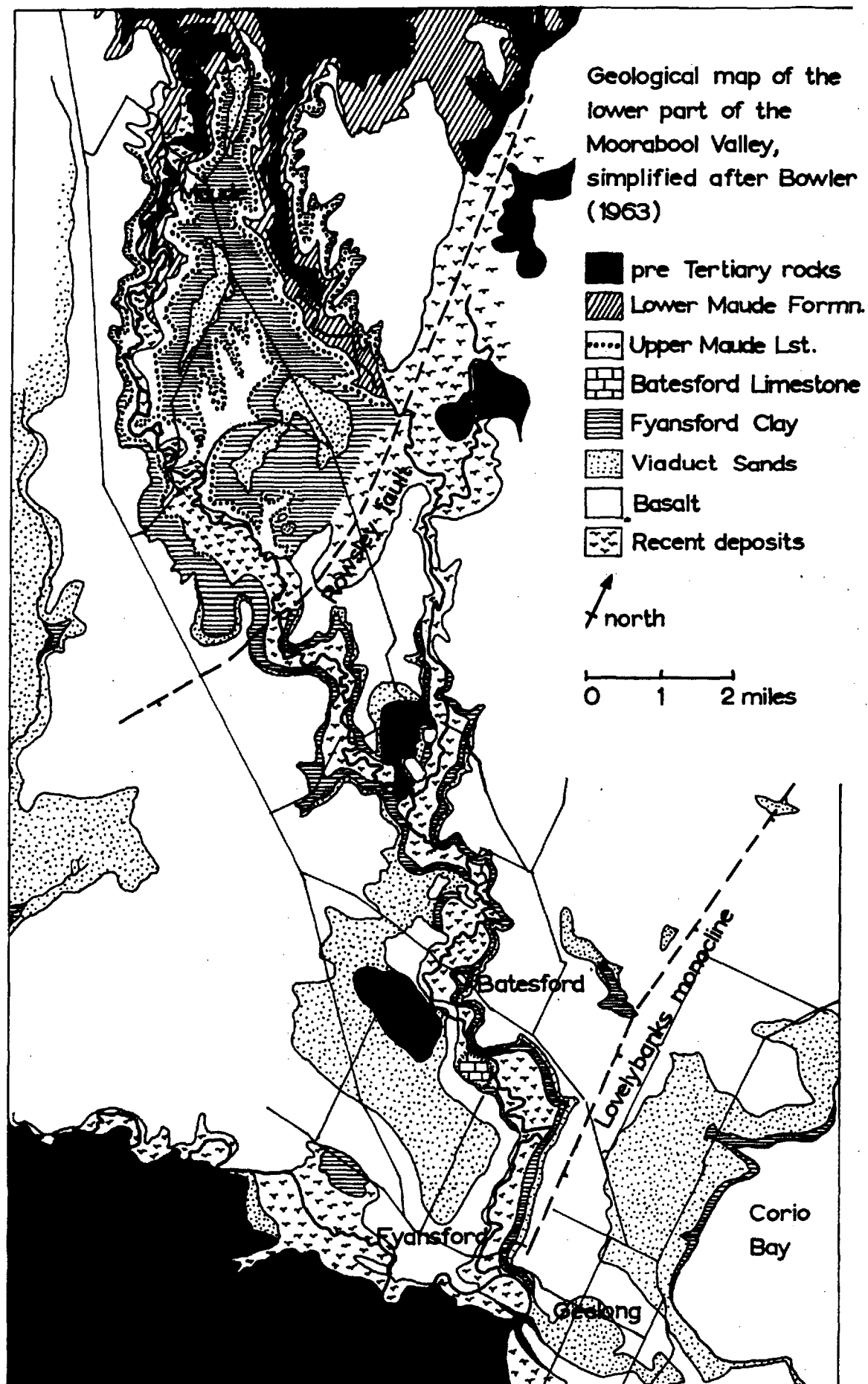


Figure 1.2

The Moorabool Viaduct Sands (Lower and Middle Pliocene)

The Fyansford Clay (Middle and Upper Miocene)

The Batesford Limestone (Lower Miocene)

The Upper Maude Limestone (Lower Miocene).

These are separated by a basalt flow - the Maude Basalt, from

The Lower Maude Formation (Upper Oligocene).

He did not however, consider the palaeontological composition of the rocks except in passing, and it is this that forms the basis of the present work.

The addition of detailed palaeontological data to Bowler's data would it was hoped, help to produce a comprehensive environmental picture of the area, and also aid in the detailed correlation of the sections. The sections of Bowler were examined and collections made from the units. As with the Libyan project the fossils were considered from a palaeoecological viewpoint and grouped into various biofacies representing various environments.

The burrows were described, but not divided into ichnofacies since they were largely exclusive of one another and were limited to particular formations.

A detailed examination of the lithology and palaeontology of the formations, and a discussion of their environments and relationships to one another, concludes the study.

Acknowledgements

The author wishes to express his appreciation to everyone who helped him both in Australia and at home.

The generosity of the Plessey Company Limited enabled me to travel to Australia twice and spend ten weeks in the Geelong area. Thanks are also due to the Communications Systems division of the Company who kindly loaned me transportation while I was there.

Professor Hills of Melbourne University kindly arranged for the initiation of the project and Dr. O.P. Singleton acted as my unofficial "supervisor" in Australia. He introduced me to the area and showed me every kindness throughout my stay in Melbourne. Tom Darragh, of the National Museum of Victoria in Melbourne also helped me enormously in all sorts of ways, but especially in allowing me to examine the collections of Tertiary fossils in the Museum's vaults and in giving me permission to publish information I obtained there.

I have benefited enormously from discussions with Dr. Singleton Mr. Darragh and David Taylor (also of the Geology Department in Melbourne University) and from the encouragement given by all three.

CHAPTER 2

THE FOSSILS

The sections are composed of relatively few units, most being soft sands, silts or clays, and it was possible to collect bulk samples of most of the units for examination. The proportion of macrofossils to sediments was generally found to be so large, however, that to obtain a representative collection for each unit, it would have been necessary to examine an enormous amount of sediment. Collections of fossils weathered out on the surface of the units were thus taken in measured areas and form the basis of the study. The coarse fractions of the bulk samples were examined for microfossils and smaller and more delicate macrofossils.

The macrofossils, especially mollusca, were preferred for use in reconstructing the environments as there is a much stricter control on the ecology of their living relatives than there is with the microfossils.

Most of the units are richly fossiliferous and contain very large numbers of well-preserved aragonitic- and calcitic-shelled specimens. In most cases the specimens in one unit are preserved in the same fashion, and for this reason the modes of occurrence and preservation have been considered in the section dealing with sediments. Very large species lists are typical of most units, though approximately half of the species are represented by one or two specimens only.

The excellent preservation of the fossils made it possible to compare them with the abundant and comprehensively described Recent biota of the Australian Seas. It was possible to find very closely related species in the Recent, and the bulk of the ecological information

is based upon them. Many closely related species within one genus have rather variable habits, so caution has been exercised.

The fossils are classified systematically, and the nomenclature has been revised as much as possible. Notes on the form and preservation have only been added to particularly common species. Ecological information has been inserted in appropriate positions. For instance, if it refers to a family, it follows the familial heading. The information following the species either refers to the most closely related living species, or to the actual species if it is still existant (such species have been indicated by an asterisk).

The distributions of the nearest living relatives occurring in the Australian seas have been expressed in terms of the component biotal regions (see Iredale and McMichael 1962).

Solanderian:- Northern and northwestern Australian coasts, including Queensland.

Peronian:- Southeastern coasts, including southern Queensland, New South Wales, eastern Victoria and Tasmania.

Flindersian:- Southern Australian coasts, including western Victoria, South Australia and southwestern Australia.

The occurrence of the species, which has been tabulated, has been limited to a note of the number of times they occur and their abundance. The latter falls into three classes:-

- (i) Rare : one or two specimens in a sample.
- (ii) Common : represented by several specimens in a sample.
- (iii) Abundant : particularly common or dominant in a sample.

The reference of a species to one of these classes takes into account the size of the sample, and inevitably has a different meaning for macro- and microfossils. The former were collected largely from surfaces measuring on average 0.5 metres², whereas the latter were examined in coarse fractions sieved from sediments on average measuring

30 cm³.

The biofacies and formations of which the fossils are most typical have been added.

PLANTS

Calcareous algae

Occurrence: Fragments of both pinnate and lichenous or encrusting skeletons occur (figure 2.1.a).

Ecology: At the present day pinnate or thinly-branching Lithothamnium are typical of sheltered waters, for instance the leeward sides of reefs, though they may occur in more exposed areas. At Funafuti (Finckh 1904) a dense growth of shrub-like clusters covers the shallow sheltered reef platform from low tide down to about 6 metres. Lichenous forms occur at the windward side of the reef from low water to a depth of 8 metres or more. In the Seychelles (Lewis and Taylor 1966) algal debris is an important constituent of the talus slopes of the forereef.

Wood and leaves

Occurrence: A few splinters of wood occur, but most common are poorly preserved ferruginous moulds of Eucalyptus sp. leaves. They crowd the bedding of a silty sandy limestone at the base of the Moorabool Viaduct sands.

Ecology: Eucalyptus occurs at the present day throughout Australia but is commonest near the coasts of the southern and eastern states.

FORAMINIFERA

Ecology: The distributions of the species have been based largely upon the work of Bandy (1964) and Walton (1964). Bandy correlated the structure of foraminifera with the environments and recognised a series of benthic marine communities:-

- (i) Bays and estuaries.
- (ii) Inner shelf (0 to 50 metres).
- (iii) Central and outer shelf (50 to 150 metres).
- (iv) Upper bathyal zone (150 to 610 metres).
- (v) Middle bathyal zone (610 to 2438 metres).
- (vi) Lower bathyal zone (2438 to 4000 metres).
- (vii) Abyssal zone (below 4000 metres).

He indicated that this scheme was dependant upon the temperature gradient and bottom character.

Walton defined depth zones in terms of the characteristic genera. In the Gulf of Mexico he recognised five generic zones in the marginal marine area where waters are shallower than ten fathoms (20 metres) and nine generic zones in the open marine area (10 - 1100 fa.). He proposed five major depth zones which had different assemblages in different geographical regions.

Intertidal to 2 fathoms :- Ammobaculites, Elphidium.

2 to 10 fa:- Streblus/Buliminella/Bolivina lowmani.

10 to 30 fa:- Nonionella/Rosalina-Hanzawaia.

30 to 100 fa:- Epistominella/Cassidulina

100 to 300 fa:- Bolivina/Bulimina.

The dominance of these genera in the zones they represent increases shorewards, concomittant with a decrease in the number of genera.

Miliolidae Ehrenberg

Triloculina spp.

Occurrence: This genus is very common in the Fyansford Clay and is always well preserved. Limonitised specimens occur in the Moorabool Viaduct Sands.

Ecology: Species of Triloculina are typical of the inner shelf and shallow bays, and are euryhaline (Bandy 1964).

Pyrgo sarsi (Schlumberger)

Ecology: Pyrgo is stenohaline and bathyal (Bandy 1964), but may occur on the shelf in tropical and subtropical seas, or be rafted in on the vegetation to which it is anchored.

Nodosariidae Ehrenberg

Nodosaria sp.Lingulina sp.

Bolivinitidae Cushman

Bolivina alata (Seguenza)

Ecology: Bolivina has been reported from all parts of the shelf and continental slope. Most species are rather "deep" water (Saidover 1960, Bandy 1964) but many occur in lagoons and shallow shelf waters (Phleger 1960, Walton 1964). The small smooth shape of B. alata suggests that it was an inner shelf species.

Islandiellidae Loeblich and Tappan

Ecology: The Islandiellidae are a rather deep water group, occurring on ~~the~~ shelf and continental slope below 60 metres.

Cassidulinoides spp

Discorbidae Ehrenberg

Discorbinella sppBaggina phillipinensis (Cushman)

Ecology: Baggina occurs in the bathyal zone of Bandy (i.e. deeper than 150 metres).

Siphoninidae Cushman

Siphonina australis Cushman

Ecology: Siphonina lives in waters deeper than 50 to 70 metres on the outer continental shelf (Phleger 1960).

Spirillinidae Reuss

Spirillina denticulata Brady

Rotaliidae Ehrenberg

Rotalia verriculata Howchin and ParrRotalia beccarii Linnaeus

Ecology: Rotalia (Streblus) beccarii was recorded by Phleger (1960) in lagoons. Bandy and Walton located it in bays and on the inner shelf down to about 20 metres.

Sherbornina cuneimarginata Wade

Elphidiidae Galloway

Elphidium chapmani Cushman

Ecology: Elphidium is a very shallow water genus, belonging to the lagoon, beach and inner shelf assemblages of Phleger (1964) and defining the intertidal down to 2 fathoms (4 metres) depth assemblage of Walton (1964).

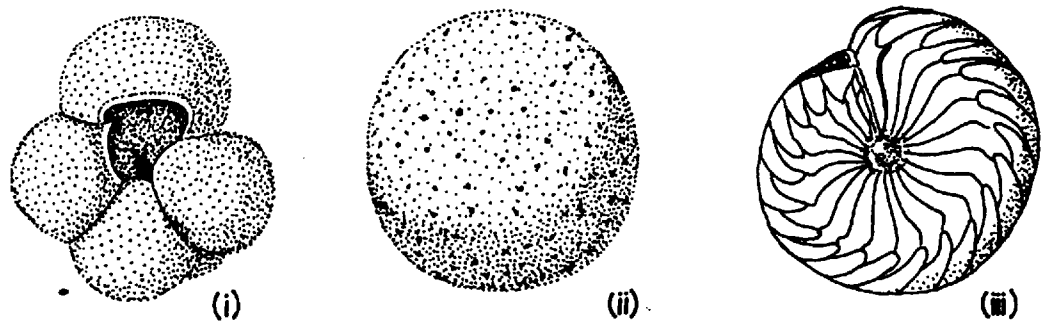
Nummulitidae de Blainville

Operculina victoriensis (Chapman and Parr)

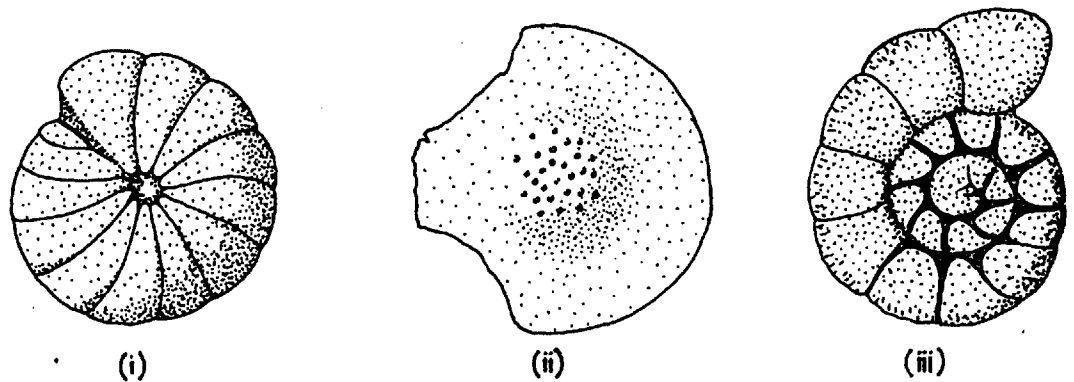
Ecology: Operculina is a tropical genus.



a (i) Pinnate calcareous algae fragments (x3) Section 13 unit 4
 (ii) Lichenous calcareous algae fragments (x1) Batesford Quarry



b (i) Globigerina bulloides d'Orbigny. (x60) After Carter 1964
 (ii) Orbulina universa d'Orbigny. (x60) After Carter
 (iii) Amphistegina lessonii d'Orbigny (x 20) After Carter.



c (i) Cibicides victoriensis Chapman, Parr and Collins. (x15)
 (ii) Lepidocyclina howchini Chapman. (x4) Batesford Quarry
 (iii) Anomalina macraglabra Finlay. (x60) After Carter.

Figure 2.1

Cyclocypeus victoriensis Crespin

Ecology: Cyclocypeus is most abundant in waters of 20 to 80 metres in the tropics and subtropics.

Globigerinidae Carpenter, Parker and Jones.

Ecology: All species of the Globigerinidae are planktonic, and their relative abundance has been taken by many authors to indicate increasing distance from the shore, lack of restriction (i.e. open coast conditions) and slow deposition.

* Globigerina bulloides D'Orbigny (figure 2.1.b(i))

G. apertura Cushman

Occurrence: These species are very abundant, occurring in 62 units.

Orbulina suturalis Bronnimann

* O. universa D'Orbigny (figure 2.1.b(ii))

Occurrence: Abundant throughout the Fyansford Clay, these species are valuable indicators of age in the Balcombian and Bairnsdalian.

Globigerinoides sp.

Eponididae Hofker

Eponides sp.

Ecology: Eponides occurs today in the deep waters of the outer shelf.

Amphisteginidae Cushman

Amphistegina lessonii D'orbigny (figure 2.1b(iii))

Occurrence: This is a common species, present in most of the formations. In one bed in the Fyansford Clay, abundant worn and limonitised specimens indicate that they may become concentrated as a lag deposit after erosion has taken place.

Ecology: Amphistegina is limited at the present day to shelf waters between 20 and 100 metres deep, especially 20 to 40 metres (Walton 1964). It is abundant in the sediments of the Seychelles bank between the islands and the shelf rim (generally shallower than 20 metres) described by Lewis and Taylor (1966).

Cibicididae Cushman

Cibicides victoriensis (figure 2.1.c(i)) Chapman, Parr and Collins

C. thiara (Stache)

Occurrences: These species are extremely abundant, occurring in 74 units. They are particularly characteristic of the Fyansford Clay and the Batesford Limestone.

Ecology: Today thick-shelled Cibicides species like these fossils are typical of the central and outer shelf (Bandy, 1964 and Phleger, 1960).

Planorbulinidae Schwager

Planorbulinella inaequilateralis (Heron-Allen and Earland)

Acervulinidae Schultze

Gypsina howchini Chapman

Lepidocyclinidae Scheffen

Lepidocyclina howchini Chapman and Crespen (figure 2.1.c(ii))

Occurrence: This is the characteristic species of the Batesfordian, and is abundant in the upper part of the Batesford Limestone.

Ecology: Lepidocyclina species became extremely abundant throughout the shallow water sediments of the tropical and subtropical parts of the world during the Miocene.

Nonionidae Schuätze

Astronion sp

Ecology: Members of the Nonionidae occur today on the outer part of the shelf in depths of 100 to 150 metres (Phleger 1960).

Anomalinidae Cushman

Anomalina macraglabra Finlay (figure 2.1.c(iii))A. nonionoides Parr

Occurrence: Anomalina species are abundant in the Fyansford Clay, and occur in 48 units all together.

Ecology: Both are living species, recorded from shallow bays in New Zealand (A. macraglabra) and shore sands in the Flindersian province of Australia (A. nonionoides).

SPONGESPlectroninia halli Hinde (spicules and cups)Bactronella parvula Hinde (spicules only)Tretocalia pezica Hinde (cups only)

Occurrence: Spicules are present in a large number of biofacies and are usually a very common constituent of coarse fractions, whereas cups are restricted to the lower part of the Upper Maude Limestone.

Ecology: Species of Plectroninia require water warmer than 15°C, between depths of 30 and 100 metres. The substrate must be fairly firm and the water not turbid.

ANTHOZOA

Isidae Lamouroux

Isis spp

Occurrence: Short disarticulated nodes as described by Duncan (1875) occur in the Lower Maude Limestone. Duncan indicated that some forms had affinities to living Isids in New Zealand and Oceania.

Duncan (1870) analysed the recent and fossil coral faunas of Australia. He noted that none of the fossils was represented by species living in the area, and that only three of the genera persisted into the Recent. All of the species are ahermatypic, belonging to the deep sea faunas of the present day, but were evidently isolated from the European area, the only common genera being Balanophyllia and Deltocyathus. None of the genera listed by Tenison Woods (1873) as littoral were found during this study.

Caryophyllidae Gray

Trematotrochus fenestratus Tenison Woods.

Ecology: Living species are typical of depths of 30 to 45 metres in the Flindersian province.

Sphenotrochus australis Duncan

Ecology: Sphenotrochus occurs today in depths of 20 to 300 metres in the Atlantic, where the temperature varies between 9° and 26°C.

Flabellidae Bourne

Flabellum sp.

Ecology: Flabellum is a tolerant genus, but prefers water deeper than 40 metres in the tropical and subtropical areas of the world (2° - 27°), especially near reefs (e.g. Fiji).

Placotrochmus deltoideus Duncan (figure 2.2.a(i))

Ecology: Placotrochmus probably has an ecology similar to that of Flabellum.

Conosmilia anomala Duncan

C. striata Duncan

C. lituolus Duncan

Ecology: Today species of Conosmilia are most common in depths of 135 - 435 metres where the temperature is between 13° and 22°C (i.e. tropical)

Dendrophyllidae Gray

Balanophyllia sp.

Ecology: Species of Balanophyllia occur at the present day in the Mediterranean and Atlantic ocean between 130 and 520 metres, though they have been recorded rarely from waters shallower than 10 metres. They can tolerate temperatures between 7° and 28°C.

CRUSTACEA

Ostracoda

Occurrence: Ostracods are usually a rare, but persistent constituent of the Fyansford Clay fauna. Nine species belonging to the Cypridae and Cytheridae, eight of which are still living, were recorded by Chapman (1909) from the Batesford Limestone. All of the living species occur in the Indian ocean and China seas, while three are represented in the Bass Strait and two in Port Jackson. All species are shallow water.

Cirripedia

Balanus sp.

Ecology: Today Balanus species are best developed in wave-exposed localities, though they can exist subtidally in areas of high current activity.

Decapoda

Ommatocarcinus corioensis Creswell

Occurrence: This species, present abundantly in the Phosphatic pebbles at the base of the Moorabool Viaduct sands, is also present at various horizons in the Fyansford Clay.

Ecology: Keble (1932) noted its similarity to O. macgillivrayi found on a modern mud flat at Port Curtis (Queensland), and on a muddy bottom in 20 metres at the northern end of North Island, N. Zealand.

SCAPHOPODA

Dentalium mantelli Zittel (figure 2.2.a(ii))

D. (laevidentalium) subfissura (Tate and Harris) (figure 2.2.a(iii))

D. (Episiphon) aratum Tate and Harris

Cadulus acuminatus Tate

Occurrence: Scaphopods are very common in the Fyansford clay, and their mode of occurrence, lying at a high angle to the bedding with their narrower end upwards, suggests that many of them are in life position.

Dentalium is a carnivorous and suspension-feeding infaunal genus.

BIVALVIA

The Tertiary bivalves and gastropods of Australia have been described by a number of authors, of whom Tate, Tenison Woods, McCoy, Pritchard and Chapman are the most important. There has been considerable

revision of the nomenclature since the first descriptions of Tate, Tenison Woods and McCoy, and synonymies have been brought up to date as far as possible.

The ecological information has been gleaned from a number of sources, the most important being Allan (1950), Cotton (1959) (1961) and Macpherson and Gabriel (1962). Most of the bivalve species are stenohaline burrowing suspension-feeders, and unless otherwise indicated they are assumed to be so.

Nuculidae

Nucula sp

Emmucula tenisoni Singleton

Ecology: Nuculids are very widespread today throughout the world at all depths and on all substrates. They are deposit feeders.

Nuculanidae

Nuculana chapmani Finlay (Leda apiculata Tate) (figure 2.2.b(i))

Ecology: This species closely resembles members of the genus Poroleda, which lives in all parts of the world between about 100 and 350 metres. Nuculanids are deposit feeders.

Leda crebrecostrata

L. woodsi Tate

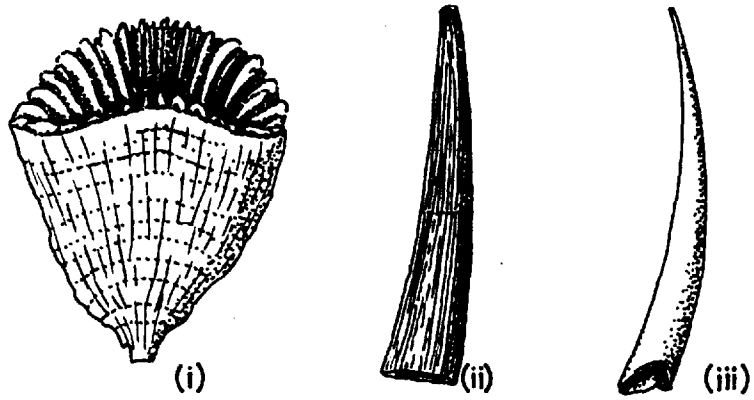
Ecology: These resemble species of Scaeoleda, present in the Peronian province between 30 and 50 metres.

Sarepta oboella (Tate)

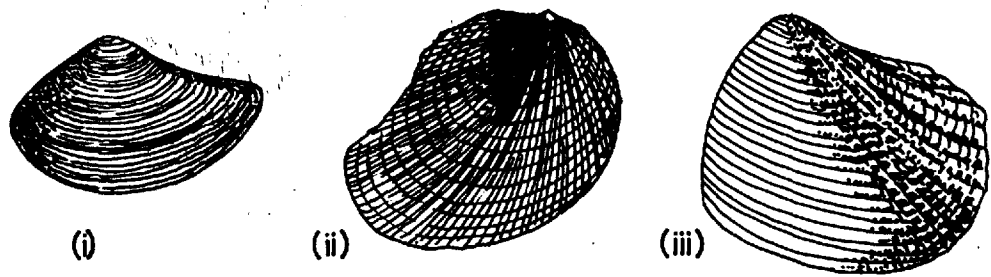
Ecology: A similar species, S. tellinaeformis Hedley occurs between 75 and 250 metres in the Flindersian and Peronian areas.

Glycimeridae

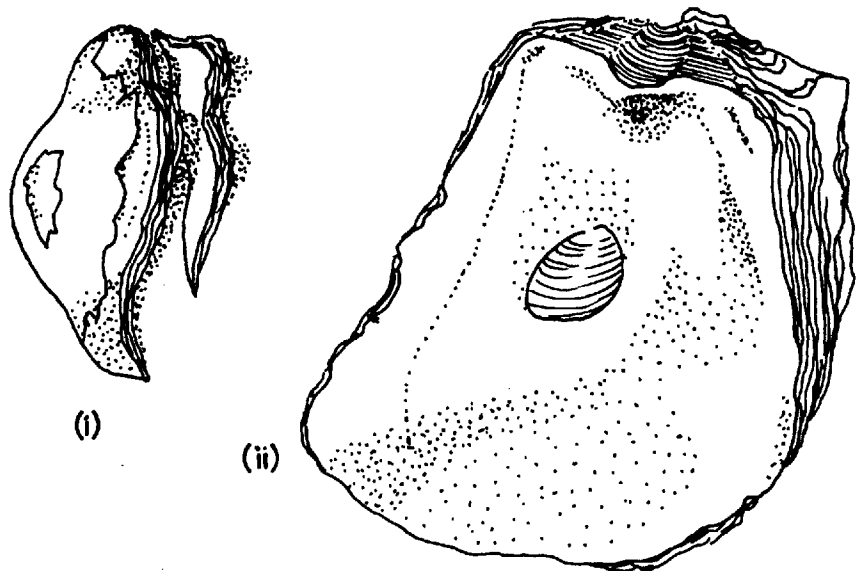
Ecology: Glycimerids are shallow burrowers at variable depths at the present day.



- a** (i) Placotrochus deltoideus Duncan. (x2) Section 3
 (ii) Dentalium mantelli Zittel (x2) Section 3
 (iii) Dentalium subfissura (Tate and Harris). (x2) Section 3



- b** (i) Nuculana chapmani Finlay. (x5) Section 3
 (ii) Limopsis maccoyi Chapman (x3) Section 3
 (iii) Eotrigonia intersitans (Tate) (x1) After Pritchard 1894



- c** (i) Ostrea ingens Zittel in life position. Horizontal face of sandy limestone. (x0.3) Section 1
 (ii) Ostrea ingens. (x0.5) Section 1

Figure 2.2

Glycimeris cainozoicus (Tenison Woods)G. convexus (Tate)

Ecology: G. convexus is close to Pectunculus flabellatus Tenison Woods, living between 15 and 260 metres in the Flindersian province.

G. granti SingletonG. gunyoungensis Chapman and Singleton.

Limopsidae

Limopsis maccoyi Chapman (figure 2.2.b(ii))

Ecology: Limopsids occur in warm seas at variable depths, the form of this species suggesting depths of 20 to 60 metres.

Arcidae

Arca capulopsis PritchardBarbatia celleporacea Tate

Ecology: This species is close to B. squamosa which occurs today in all depths down to 270 metres in the Flindersian province.

Cucullaea corioensis Singleton

Ecology: The thick-shelled form of this species suggests that it lived in shallow warm waters. Arcids are shallow burrowers.

Macrodon cainozoicus Tate

Vulsellidae

Vulsella laevigata Tate

Ecology: Vulsellids are attached epibionts, living at all depths.

Pteriidae

Pteria crassocardia

Ostreidae

Ostrea spp

Occurrence: Fragmentary and unidentified Ostrea are common in many of the units in the Fyansford Clay, Upper Maude Limestone and Batesford Limestone.

Ecology: Oysters are attached suspension feeding epifauna, and require a firm substrate. Species of the genus Ostrea generally live in fully saline waters.

*Ostrea angasi Sowerby

Ecology: O. angasi, a Peronian and Flindersian species is found on modern beaches and on gravelly ground from 0 to 180 metres.

Ostrea hippopus Tate*O. hyotis Linnaeus

Ecology: O. hyotis is a living species of shallow waters in the Solanderian province. It occurs in the shallow water biofacies of the Fyansford Clay.

O. ingens Zittel (figure 2.2c)O. manubriata Tate

Ecology: O. manubriata resembles some of the species of the euryhaline genus Crassostrea.

O. sturtiana Tate

Ecology: This species is a close relative of O. angasi (see above).

Crassostrea amasaGryphaea tarda

Trigoniidae

Trigonia sp.

Ecology: Species of Trigonia usually occur today in depths of 45 - 90 metres, though they may be washed into shallower waters.

Eotrigonia intersitans (Tate) (figure 2.2.b(iii))

E. semiundulata (McCoy)

Neotrigonia acuticostata (McCoy)

Ecology: This is closely related to species of Neotrigonia living in the Flindersian and Peronian provinces. They occur on bottoms of mud and fine sand in depths of 20 to 375 metres.

Pectinidae

Ecology: Pectinids are attached epibionts, though they may also be free swimming.

Pecten sp.

Pecten aldingensis Tate

Pecten eyrei Tate

Pecten murrayanus Tate (figure 2.3.a(i))

Pecten peroni Tate

Pecten polymorphoides Zittel

Ecology: A close living relative is Mesopeplum triggi found in 75 to 250 metres in the Flindersian province.

Chlamys flindersi (Tate)

Ecology: This species resembles Mi machlamys asperrimus (see below).

Equichlamys consobrinus (Tate)

Ecology: E. bifrons, a closely related living species, is found from 0 to 65 metres in the Flindersian and Peronian provinces.

Mi machlamys asperrimus (Lamarck)

Ecology: This species occurs throughout the Flindersian and Peronian provinces between 0 and 90 metres. It is most abundant in very shallow water.

Lentipecten victoriae Cressin

Serripecten yahlensis (Tenison Woods)Hinnites corioensis McCoy

Occurrence: This species is restricted to biofacies 14 at section 1, though it has been also recorded from section 4 (Hall and Pritchard).

Amusiidae

Propeamusium zitteli (Tate)

Ecology: P. thetidis, the closest living relative is found at all depths in both the Peronian and Flindersian provinces.

Spondylidae

Ecology: Spondylids are attached epibionts.

Spondylus gaderopoides McCoySpondylus pseudoradula McCoy

Ecology: This species resembles S. multimaureicata from the Solanderian province.

Spondylus spondyloides Tate

Ecology: S. tenellus Reeve, is closely related, and occurs in Flindersian waters.

Dimyidae

Dimya dissimilis Tate

Occurrence: This species is very common in the Fyansford Clay.

Ecology: The living species Dimyarina corrugata lives cemented to shells in waters between 120 and 145 metres deep in the Peronian province.

Limidae

Limea transenna Tate

Ecology: Recent species are attached epibionts found in waters deeper than four metres.

Anomiidae

Monia ione Gray

Ecology: This is found in both the Flindersian and Peronian provinces in waters down to 45 metres (though dead shells may occur down to 180 metres). Anomiids are cemented to shells and stones.

Placunanomia sella Tate

Mytilidae

Ecology: Mytilids are attached epibionts.

Septifer fenestratus Tate

Ecology: Recent septifers occur in Solanderian waters.

Mytilus planulatus Lamarck

Ecology: This is a Flindersian species found from high tide down to a few metres.

Mulder (1902) records M. magellanicus from the Moorabool Viaduct Sands at the viaduct, but I can find no reference to this species in the literature.

Myochamidae

Myochama sp.

Ecology: The species of this genus are attached epibionts.

Myadora tenuilirata Tate

Ecology: The living species M. pandoraeformis is found between 20 and 380 metres in the Solanderian and Peronian provinces.

Crassatellidae

Crassatella corrugata TateCrassatella dennanti TateSalaputium communis Harris

Ecology: This is close to S. probleemum, a Flindersian species found in open ocean water between 25 and 380 metres.

Carditidae

Cardita delicatula Tate

Cardita polynema Tate

Cardita tasmanica Tate

Venericardia gracilicostata (Tate) (figure 2.3.a(ii))

Ecology: The small, inflated scaly form of these species suggest that they are fairly deep water.

Venericardia latissima (Tate)

Chamidae

Chama lamellifera Tenison Woods

Ecology: Chama is an attached genus, Recent species being found throughout the Flindersian and Peronian provinces below the intertidal zone.

Lucinidae

Lucina sp

Ecology: Lucinids are common in sheltered shallow bays in the Flindersian and Peronian provinces.

Ungulinidae

Diplodonta sp.

Ecology: Diplodonts occur at all depths on all substrates in the Flindersian and Peronian provinces.

Cardiidae

Cardium sp

Cardium pseudomagnum McCoy

Ecology: Cardium (Fulvia) racketti, a Solanderian species is found down to 30 metres.

Veneridae

Dosinia sp.Dosinia johnstoni Tate

Ecology: This is close to a number of Flindersian and Peronian species found in water shallower than 20 metres.

Meretrix sp.Notocallista sp.Notocallista eburnea (Tate) (figure 2. 3a(iii))

Ecology: This is close to N. kingi and N. multistriata found at all depths throughout eastern Australia.

Chione sp.Chione allporti (Tension Woods)Chione cainozoica Tension WoodsProxichione homophora (Tate)Proxichione subtilicostata Darragh

Tellinidae

Tellina stirlingi Tate

Ecology: Tellines today are burrowing deposit feeders.

Donacidae

Donax depressa Tate

Ecology: This is similar to Plebidonax deltoides which is found today at low tide in the Flindersian region.

Alloididae

Corbula sp.Corbula ephamilla TateCorbula pixidata TateCorbula stolata (Iredale)

Ecology: This species is found living in mud at low tide in the Peronian region .

Pholadidae

Pholas australasiae Sowerby

Ecology: This commonly occurs boring into soft mud in sheltered bays from 0 - 4 metres depth. It occurs throughout southern and eastern Australia.

Pholas obturamentum Hedley

Ecology: This has much the same ecology and distribution as P. australasiae.

Teredidae

Teredo sp.

Ecology: Teredids bore into wood.

GASTROPODA

Ecology: Unless otherwise stated these are assumed to be epifaunal herbivores.

Pleurotomariidae

Pleurotomaria sp.

Fissurellidae

Notomella delicatissima (Chapman and Gabriel)Notomella dennanti (Chapman and Gabriel)

Ecology: These species resemble living Flindersian forms found on muddy bottoms from 0 to 240 metres.

Cosmetalepas laqueatus (Chapman and Gabriel)

Ecology: This is very similar to C. concatenatus, a Peronian species.

Trochidae

Astele millegranosa Pritchard

Ecology: The close living relative, A. subcarinatum Swainson, lives in inshore waters from about 20 to 180 metres on mud and shell sand in the Flindersian region.

Bankivia howitti Pritchard

Ecology: Bankivia is an inshore genus, species of which are found in shallow waters throughout the Flindersian and Peronian provinces.

Cantharidus serratulus Pritchard

Occurrence: C. serratulus is a common and well preserved member of the Fyansford Clay and Upper Maude Limestone biotas.

Ecology: Cantharidus species occur today in shallow waters and in rock pools in the Flindersian province.

Trochita turbinata Tenison-Woods

Ecology: Recent smooth Trochids like this species tend to be deep water, and a few may be carnivorous.

Liotidae

Collinista otwayensis (Pritchard)

Liota lamellosa Tenison Woods

Ecology: This is close to Mundita, a Recent Flindersian genus occurring from 10 to 45 metres under stones on sandy sea floors.

Delphinula imparigranosa Pritchard

Turbinidae

Astralium sp.

Astralium (Imperator) hudsonianum Chapman

Ecology: The closest living relative, Micrastraea rutidolma Tate is an intertidal Flindersian species.

Subrinella (Turbo) grangensis (Chapman) (figure 2.3.b(i))

Occurrence: S. grangensis is a common species indicative of the Subrinella biofacies at the base of the Upper Maude Limestone.

Ecology: It is close to Recent species of Turbo living on weeds from low tide to about 20 metres in inshore or open coast conditions of the Flindersian province.

Calyptraeidae

Calyptraea undulata Tate

Ecology: C. undulata is close to Sigapatella calyptraeformis Lamarck, found cemented to stones and shells in the shallow open waters and beaches of the Flindersian and Peronian provinces.

Cerithiidae

Ecology: Cerithiids are tropical shallow water species, abundant off the mouths of rivers.

Cerithium aphelès Tenison-Woods

Cerithium cibarioides Tenison Woods

Ecology: C. cibarioides is similar to species found in the tropics from 0 - 20 metres.

Cerithium flemingtonensis McCoy

Occurrence: This species is characteristic of the basal part of the Upper Maude limestone.

*Zeacumantis diemenensis

Ecology: This species is usually found on weed-covered sand banks in the intertidal zone. It has a Flindersian and Peronian distribution.

Triphoridae

Triphoris planata Tenison-Woods

Triphoris wilkinsoni Tenison-Woods

Ecology: Triphorids are shallow-water algal browsers.

Both species are close to the genus Notosinister, which is common in the Flindersian province between 55 and 90 metres.

Turritellidae

Ecology: Turritellids are shallow burrowing herbivores.

Turritella sp.*Gazameda iredalci Finlay (Turritella clathrata)

Ecology: This species occurs rarely today on Peronian coasts.

Colpospira tristira (Tate)Colpospira platyspira (Tenison-Woods)

Ecology: C. tristira resembles C. runcinata Watson, a species found in 60 metres of water in both the Flindersian and Peronian provinces.

Gazameda acricula (Tate)

Ecology: Living species of Gazameda are found between 200 and 180 metres in Flindersian waters.

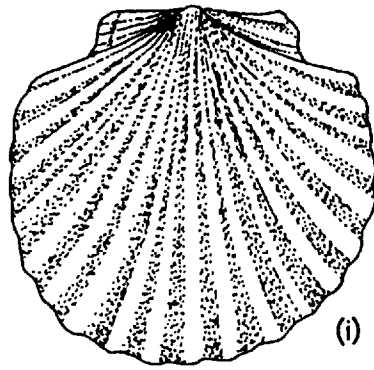
Maoricolpus murrayana (Tate) (figure 2.3.b(ii)).

Occurrence: This species is particularly abundant in the Fyansford Clay, occurring especially in the Maoricolpus and Adeona - gastropod biofacies.

Architectonidae

Solarium sp.Solarium warmonensis Tenison WoodsArchitectonica acutum (Tenison Woods) (A. balcombiensis)

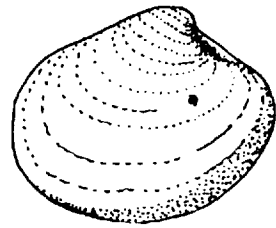
Ecology: Recent Architectonica species are Solanderian and Peronian, the smaller forms, comparable to the fossil species being typical of relatively deep water.



(i)



(ii)



(iii)

a

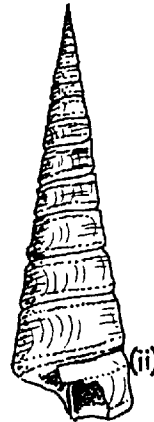
(i) Pecten murrayanus Tate (x1) Batesford Quarry

(ii) Venericardia gracilicostata (Tate). (x3) Section 3

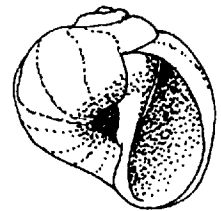
(iii) Notocallista eburnea (Tate) (x4) Section 3



(i)



(ii)



(iii)

b

(i) Subninella grangensis (Chapman). Internal mould in aphanitic limestone. (x1) Section 15. unit 12

(ii) Maoricolpus murrayana (Tate) (x1) Section 3 unit 2

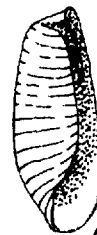
(iii) Natica subinfundibulum Tate (x3) Section 3



(i)



(ii)



(iii)



(iv)

c

(i) Nassa tatei Tenison Woods (x4) Section 3

(ii) Marginella micula Tate (x3) Section 3

(iii) Bullinella exigua (Tenison Woods) (x3) Section 3

(iv) Vaginella eligmostoma Tate (x8) After Tate 1886

Figure 2.3

Vermetidae

Ecology: Vermetids are herbivorous epibionts, attached to shells, corals and sponges.

*Vermetus arenarius Quoy and Gaimard

Ecology: This is a tropical species found today on reefs in the Solanderian province.

*Siliquaria australis

Occurrence: In the Fyansford Clay this is occasionally found forming thin colonies on bedding planes.

Ecology: This species occurs on the deep waters of the Flindersian and Peronian shelf. It is gregarious.

Thylocodes actinotus Tate

Thylocodes adolaidensis Tate

Thylocodes asper Tate

Ecology: Thylocodes is similar to Magilina, of which the smaller examples (similar to the fossils here) are deeper water.

Pyxipoma sp.

Xenophoridae

*Xenophora tatei Hedley

Ecology: X. tatei is a rather deep water tropical species found in over 100 metres in the Solanderian and Peronian provinces.

Scalidae

Scalaria (Cirsotrema) mariae Tate

Ecology: Scalaria is a carnivorous genus, the species of which are both epibionts and inbionts. S. mariae is related to Solanderian species.

Melanellidae

Eulima danae Tenison Woods

Ecology: Eulima proxima, a living Peronian species is found feeding on holothurians and sea-urchins in bays.

Leiostraca acutispira Tenison Woods

Ecology: Recent Leiostraca species are also carnivorous.

Cymatiidae

Austrotriton cyphus (Tate)

Ecology: This resembles open sea Peronian species.

Austrotriton woodsi (Tenison Woods)

Sassia protensus (Tate)

Sassia tortirostris (Tate)

Ranella pratti (Tenison Woods)

Ecology: This is closely related to Argobuccinum bassi, a species found in open and inshore waters in the Flindersian province.

Cassidae

Semicassis sp.

Ecology: Living Semicassis are carnivorous on bivalves on sand banks in the Flindersian province.

Eratoidae

Erato pyrulata Tate

Ecology: Lachryma denticulata, a closely related living species, is found in waters down to 75 metres in the Peronian province. Eratoids are carnivorous.

Triviidae

Trivia avellanoides McCoy

Ecology: Trivids are carnivorous on bryozoans in fairly deep water all around Australia. The coarse sculpture in this case

suggests relatively deep water.

Cypraeidae

Ecology: Cowries are carnivorous epibionts, found especially in the tropics.

Cypraea sp.

Cypraea contusa McCoy

Cypraea gigas McCoy

Cypraea leptorhyncha McCoy

Cypraea ovulatella Tate

Umbillia eximia maccoyi Tate

Ecology: The living example of this genus, U. hesitata is found in deep waters (150 - 200 metres) in the Peronian province.

Naticidae

Ecology: Naticids are carnivorous burrowers and epibionts.

Natica sp.

Natica perspectiva Tate

Natica subinfundibulum Tate (figure 2. 3b(iii))

Ecology: The closely related living species, N. umbillicata is found in shallow waters and down to 100 metres in the Peronian province.

Natica subnoe Tate

*Polinices sordidus Swainson

Ecology: This species is very common at and near low tide in muddy sand. It is found in the Flindersian and Peronian provinces.

Muricidae

Ecology: Muricids are carnivorous epifauna. Typically they occur on reefs in the tropics.

Ocenebra asperulus (Tate)

Chicoreus lophoessus (Tate)

Ecology: The smaller and thinner shelled species (like these) tend to occur in deeper and cooler waters than is typical for the family.

Discathais textiliosa (Lamarck)

Ecology: D. textiliosa is found near middle tide level in shallow rock pools and on firm ground. Its distribution is Peronian.

Typhis acanthopterus Tate

Ecology: This is closely related to Cyphonocheilus arenatus, a Peronian species living in 60 metres of water.

Nassariidae

Ecology: Nassariids are epibiontic and burrowing carnivores.

Nassa tatei Tenison Woods (figure 2. 3. c(i))

Occurrence: N. tatei is the most common carnivore in the Ryansford Clay biota,

Ecology: It resembles Reticunassa compacta a shallow water Peronian species.

Nassa sp.

Fasciolaridae

Ecology: Fasciolarids are also burrowing and epibiontic carnivores.

Fascolaria sp.

Ecology: Large and fine-sculptured species like this one are deeper water forms.

Clavella bulboides (Tate)

Dennantia ino (Tenison Woods)

Fusus simulans Tate

Columbarium acanthostephes (Tate)

Ecology: This is close to the living Tolema australis a Peronian species found in 30 - 40 metres.

Columbarium foliaceus (Tate)Columbarium spinatulum CossmannPeristernia sp.

Ecology: Recent Peristernia, tend to occur in the Solanderian province, though smaller and high spired forms like the fossil species may occur farther south.

Peristernia purpuroides TatePeristernia subundulosa TateSiphonalia sp.

Volutidae

Ecology: Volutes are carnivorous and burrow along the surface and in the sediment.

Voluta antiscalaris McCoy

Ecology: The Recent relative of this species is Peronian and deep water.

Voluta strophodon McCoy

Ecology: This resembles Recent Solanderian species.

Olividae

Ecology: Olives are burrowing carnivores.

Oliva adelaidensis TateOliva nymphalis Tate

Ecology: These species resemble Belloliva, a Peronian species found on sand between 10 and 20 metres.

Ancillaria orycta Tate

Ecology: Ancillaria species are typical of the tropics, but smaller forms (like the fossil) occur in deep waters in the Peronian province.

Marginellidae

Ecology: The fossil Marginellidae of Australia were described by Tate (1877), who noted that the fauna closely resembled that now found in the east Indian and China seas. The fossil fauna is related to the West Indian and European fauna.

Marginella micula Tate (figure 2.3.c(ii)).

Marginella muscaroides Tate

Ecology: Smaller smooth species like these are typical of deeper and cooler waters than is typical for the genus as a whole.

Cancellariidae

Ecology: Australian cancellarias are mostly found in the Flindersian province.

Cancellaria varicifera Tenison Woods

Mitridae

Ecology: Mitre-shells are epifaunal and burrowing carnivores typical of reefs in the Solanderian province. Smooth forms like most of the fossils tend to be burrowers.

Mitra alokisa Tenison Woods

Mitra dictua Tenison Woods

Uromitra biornata (Tate)

Microvoluta pentaploca Finlay (Mitra ligata)

Ecology: This species is similar to Microvoluta australis found in 40 metres in the Flindersian and Peronian provinces.

Waimatea complanata (Tate)

Gonidae

Ecology: Cone-shells are burrowing and epibiontic carnivores especially abundant in the Solanderian province.

Conus cuspidatus Tate

Ecology: High spired cones, like this species, tend to occur on soft substrates in deeper water than is typical for the genus.

Turridae

Ecology: Turrids are also burrowing carnivores, smooth forms generally occurring on open coasts.

Drillia integra Tenison Woods.

Drillia trevorii Tenison Woods

Drillia crenularoides Pritchard

Ecology: Recent Drillias are found in water deeper than 10 metres on the open coasts of the Peronian province.

Mangelia bidens Tenison Woods

Ecology: This resembles species living in the Flindersian and Peronian provinces at depths of 20 metres.

Apiotoma bassi Pritchard

Pleurotoma clarae Tenison Woods

Pleurotoma granti Pritchard

Pleurotoma murrayana Pritchard

Pleurotoma murndaliana Tenison Woods

Pleurotoma selwyni Pritchard

Bathytoma rhomboidalis (Tenison Woods)

*Teleochilus royanus Iredale (*Daphnella gracillima*)

Ecology: This species occurs in the Peronian province at depths of 20 to 150 metres.

Retusidae

Ecology: Retusids are burrowing and epifaunal carnivores.

Bullinella exigua (Tenison Woods) (figure 2.3.c(iii))

Ecology: This is close to Cylichna arachis found in shallow waters in the Flindersian province.

Umbraculidae

Umbraculum australiensis Cossmann

Ecology: Recent Umbraculum species are carnivorous, closely related species being found in 15 to 30 metres throughout Australian waters.

Pteropoda

Ecology: Pteropods are planktonic and carnivorous.

Styliola annulata Tate

Limacina tertiaria (Tate)

Vaginella elignostoma Tate (figure 2. 3.c(iv))

Occurrence: V. elignostoma is often an extremely abundant member of the Fyansford Clay biota, especially of the deeper water bio-facies.

BRACHIOPODA

Ecology: Tate (1880) who described the Tertiary brachiopod fauna of Australia, noted that it was of modern aspect, many of the species being closely related to Recent Australian forms. He mentioned that two of the species were related to living Mediterranean forms, and that there was a general resemblance between the fossil fauna and that of the European Miocene.

Rhynchonellacea

Tegulorhynchia squamosa (Hutton)

Ecology: This species is closely related to the living deep water species Rhynchonella nigricans of New Zealand.

Terebratellacea

Austrothyris grandis (Tenison Woods)

Magadina compta (Sowerby) (Magasella)

This species is closely related to M. cumingii Davidson found in Peronian waters from 25 to 375 metres.

Magadina tenisoni (Tenison Woods)

Magellania sp. (Waldheimia)

Magellania coriocoensis (McCoy) (figure 2.4.a(i))

Occurrence: A large number of well preserved specimens of M. coriocoensis occur in the Adeona and Hinnites biofacies.

Magellania flavescens (Lamarck)

Ecology: M. flavescens is a Peronian and Flindersian species found between 10 and 180 metres depth. M. furcata and M. garibaldiana are closely related species.

Magellania furcata (Tate)

Magellania garibaldiana (Davidson)

Stethothyris insolita (Tate)

Terebratulacea

Terebratula aldingae Tate

Ecology: Gryphus vitrea, a closely related living species is found in depths of 75 to 2,750 metres in the Mediterranean and east Atlantic.

Terebratula tateana (Tenison Woods)

Terebratula vitreoides Tenison Woods

Ecology: This also resembles Gryphus vitrea.

Terebratula scoulari Tate

Ecology: Living relatives occur in the Flindersian and

and Peronian provinces between 6 and 375 metres.

Terebratulina triangularis Tate

Murravia catenuliformis (Tate) (Terebratulina davidsoni)

Ecology: The living species M. exarata Verco found in 75 to 280 metres in the Flindersian province; is a close relative.

BRYOZOA

Ecology: The Australian Tertiary bryozoa were monographed by MacGillivray (1895), and additions and modifications were made by Maplestone in a series of papers written between 1898 and 1913. The first person to examine the fauna from an environmental point of view was Stach (1936) who attempted a correlation of the form of the zoarium with habitat. He divided the Cheilostomes into a number of zoarial types, and in a paper published a year later (1937) placed them into two groups. Lagaij and Gauthier (1965) modified Stach's groups to describe assemblages from the Recent marine sediments of the Rhône Delta. The following divisions are a combination of the divisions of Stach and Lagaij and Gauthier.

A) Stable forms: These types have one particular form and cannot accomodate to different environmental conditions. They are therefore valuable indicators of environment. They are essentially typical of depths of 30 to 60 metres.

(i) Catenicelliform: These are attached by radicles to red algae or other bryozoa in wave zones between 4 and 40 metres (especially 20 - 40 metres) (figure 2. 5.a(i)).

(ii) Cellariform: These grow around the stems of algae at a variety of depths shallower than 40 metres. They can exist in areas of rapid deposition (Lagaij and Gauthier 1965) (figure 2. 5.a(ii)).

(iii) Lunulitiform: These forms occur on sandy bottoms with strong currents away from algae and rocks. They are usually found in water deeper than 30 metres. (figure 2. 5.a(iii)).

(iv) Petraliform: These are unilaminate and are attached by radicles to algae, sand or rock in intertidal and subtidal zones (figure 2. 5.a(iv)).

(v) Reteporiform: These are bilaminate and fenestrate and are restricted to wave zones, especially subtidally where no deposition is taking place. They are common at depths of 30 metres (figure 2. 5.a(v)).

(vi) Adeoniform: Bilaminate and fenestrate zooaria of this group are flattened and are restricted to depths of 40 to 50 metres (figure 2. 5.b(i)).

(vii) Celleporiform: Massive encrusting celleporiform types are usually restricted to an algal substrate in areas of slow or non-deposition. They may be intertidal or subtidal (figure 2. 5.b(ii)).

B) Unstable forms: Unstable forms can modify their form to suit the environment. Thus a form that is vinculariform in deep water may become membraniporiform in shallower water.

(i) Vinculariform: These types branch and are not articulated. They occur in deep or sheltered water where there is little wave action and few currents (figure 2. 5.b(iii)).

(ii) Eschariform: These types are erect and bilaminate. They occur in deep but current affected water. A few eschariform species are stable (figure 2. 5.b(iv)).

(iii) Membraniporiform: Membraniporiform zooaria encrust algae or rocks in the intertidal or subtidal zones down to a depth of 20 or 30 metres. They are unimportant in deep water (figure 2. 5.b(v)).

Lagaaij and Gauthier (1965) noted that bryozoa were largely absent from areas of rapid deposition, and that other than a few membraniporiform species, they were stenohaline.

Stach (1936), (1937) analysed the bryozoan fauna of the Batesford Limestone and concluded that the assemblage - predominantly vinculariform with minor cellariform and eschariform elements - indicated placid water conditions in depths of 37 metres (20 fathoms). He attributed this to protection from a northward-moving current by the Jurassic buttress of the Barrabool Hills. Coulson (1960) concluded from a study of the fault system bounding the latter that most of the movement was post-Janjukian and pre-Balcombian. This accords well with protection during the period of deposition of the Batesford limestone, but can only refer to bottom currents, since the distribution of the relatively deep water Fyansford Clay suggests that the Barrabool Hills were not fully emergent until the end of the Bairnsdalian.

Stach (1937) also discussed the depth of the Balcombian - Bairnsdalian clays of the Port Phillip area. He noted that Chapman and Singleton (1925) had suggested a depth of about 100 fathoms (185 metres), but concluded that the abundance of algal dwelling cellariform and catenicecelliform types indicated depths of 20 to 25 fathoms (37 to 46 metres). The author is in substantial agreement with this figure (for some of the biofacies at least).

Cyclostomata

Ecology: Though not considered in Stach's scheme, most probably fall into the vinculariform group. All species are attached by pedicles to the substrate.

Crisiidae

Crisia sp.Crisia macrostoma MacGillivrayCrisia scalaris MacGillivray*Crisia setosa MacGillivray (Peronian-Flindersian)

Diastoporidae

Diastopora discoidea MacGillivray

Entalophoridae

Entalophora australis BuskEntalophora longipora MacGillivray (figure 2.4.a(ii)).

Occurrence: This species is very common in the Fyansford Clay and Upper Maude Limestone.

Entalophora punctata MacGillivrayEntalophora verticellata Goldfuss

Occurrence: E. verticellata is abundant in the Batesford Limestone.

Frondiporidae

*Frondipora palmata Busk

Ecology: Australian seas generally.

Oncouseciidae

Filisparsa orakeiensis Stoliczka

Tubuliporidae

Idmonea spp.

Occurrence: These are very common in the Batesford and Upper Maude Limestones and the Fyansford Clay.

*Idmonea atlantica Forbes

Ecology: Cosmopolitan.

*Idmonea contorta Busk

Ecology: New Zealand.

Idmonea geminata MacGillivray

Idmonea hochstetteriana Stoliczka

Idmonea incurva MacGillivray

*Idmonea radians (Lamarck)

Ecology: Flindersian-Peronian.

Idmonea venusta MacGillivray

Horneridae

*Hornera foliacea (Busk)

Ecology: Flindersian - Peronian.

*Hornera frondiculata Lamouroux

Occurrence: This species is very common in the Batesford and Upper Maude Limestones.

Ecology: Mediterranean

Hornera quadrata MacGillivray

Hornera tenuis MacGillivray

Cytididae

*Supercytis digitata D'orbigny (New Zealand)

Ecology: New Zealand

Heteroporidae

Heteropora nodulosa MacGillivray

Heteropora pisiformis MacGillivray

Lichenoporidae

Ecology: Species of Lichenopora are cemented to the substrate and are membraniporiform.

Lichenopora sp.

Lichenopora australis MacGillivray

Lichenopora reticulata MacGillivray

CHEILOSTOMATA

Arachnopusidae

Arachnopusia liversidgei (Tenison Woods) (figure 2. 4.a(iii))

Eschariform.

Occurrence: This species is very common in the Batesford and Upper Maude Limestones.

Calloporidae

Ramphonotus lusorius (Waters) Vinculariform

Occurrence: This species is common in the Batesford, Lower and Upper Maude Limestone.

Hinksiidae

Cranosina coronata Cantu and Bassler

Eschariform.

Ecology: Southwest Pacific.

Membraniporidae

Membranipora spp

Occurrence: Very common in the Fyansford Clay and Batesford Limestone.

Membranipora cyclostoma MacGillivray Eschariform.

Membranipora elliptica MacGillivray Vinculariform.

Membranipora fossa MacGillivray Eschariform.

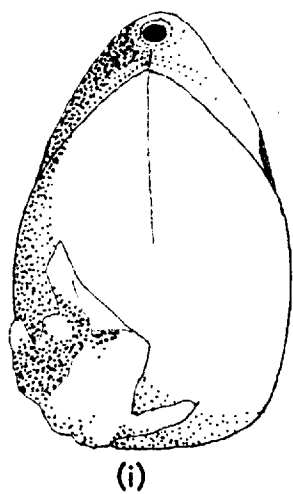
Membranipora incurvata Maplestone Membraniporiform.

Membranipora perfragilis Hincks Membraniporiform

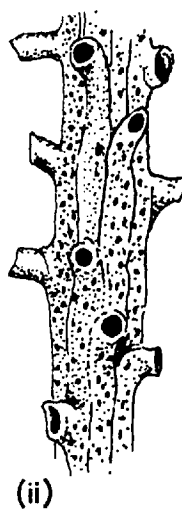
Ecology: Australian seas generally.

Membranipora striata MacGillivray Membraniporiform

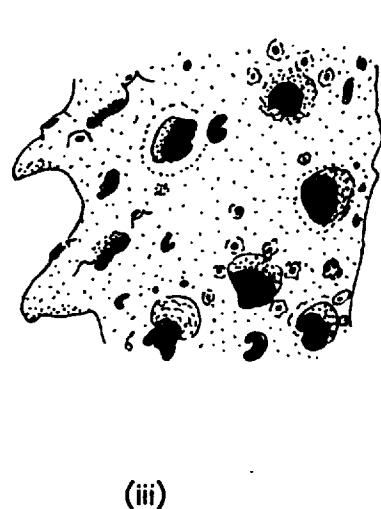
Synaptacella sp. Vinculariform



(i)



(ii)



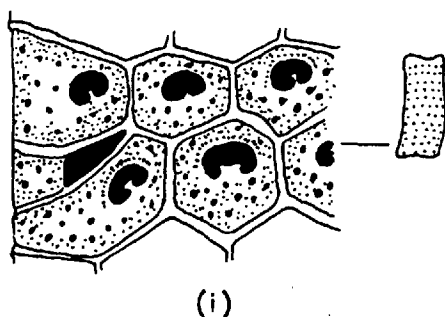
(iii)

a

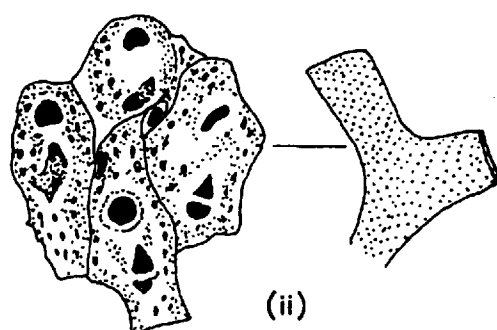
(i) Magellania corioensis (McCoy) (x1) Section 1 unit 2

(ii) Entalophora longipora MacGillivray (x30) After Macgillivray 1895

(iii) Arachnopusia liversidgei (Tenison Woods) ditto



(i)

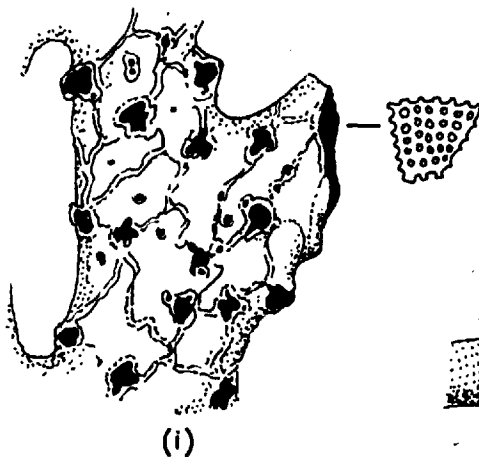


(ii)

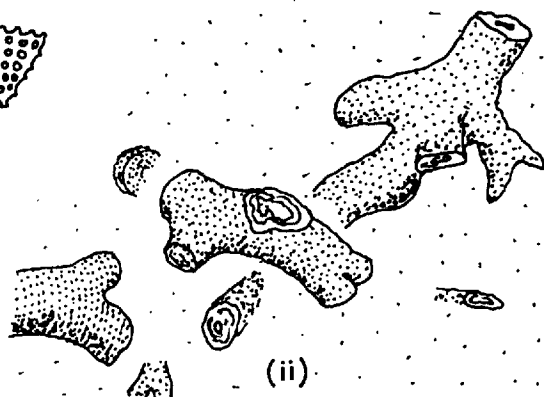
b

(i) Melicerita angustiloba (Busk). (x30, inset actual size) After Macgillivray 1895

(ii) Adeona grisea Lamouroux. (x 30, inset actual size) Ditto.



(i)



(ii)

c

(i) Retepora porcellana MacGillivray. (x30, inset actual size) Sect 2

(ii) Ramifying Schizmopora coronopus Wood. (x0.5) Horizontal face of sandy limestone. Section 4 unit 5

Figure 2.4

Aspidostomatidae

Macropora sp Eschariform

Lunulitidae

Lunulites angulipora Tenison-Woods Lunulitiform.

Lunulites canaliculata MacGillivray Lunulitiform.

Lunulites parvicella (Tenison-Woods) Lunulitiform.

Lunulites rutella MacGillivray Lunulitiform.

Microporidae

†Caleschara denticulata MacGillivray Eschariform and Membraniporiform.

Ecology: Australian seas generally.

Selenaria concinna

Cellariidae

Cellaria crassimarginata Maplestone Cellariform.

Occurrence: This species is common in the Batesford Lime - stone.

Cellaria cucullata MacGillivray Cellariform.

†Cellaria rigida var perampla (Waters) Cellariform.

Ecology: Australian seas.

Melicerita angustiloba (Busk) (figure 2. 4.b(i)) Cellariform.

Occurrence: This species is abundant in Batesford and Upper Maude Limestones.

Scrupocellariidae

Caberea sp Catenicelliform

Cribrilinidae

Corbulipora elevata (MacGillivray) Lunulitiform.

Corbulipora ornata MacGillivray Lunulitiform.

Lepralia abdita MacGillivray Membraniporiform.

Occurrence: This species is common in Batesford and Upper Maude Limestones.

Lepralia corrugata Waters Eschariform and Membraniporiform.

Lepralia filiformis Waters Vinculariform.

Lepralia perforata MacGillivray Membraniporiform

*Lepralia rotunda Waters Membraniporiform

Ecology: Australian seas generally.

Adeonidae

Occurrence: These are by far the most common macrofossils encountered. They usually occur as fragments of the compressed bilaminate zoarium, but complete skeletons lying flat on bedding planes are found here and there. They are typical of the Fyansford Clay. Anchoring tubes were described by Hall (1897), who noted their similarity to the fossil Isids.

*Adeona grisea Lamouroux (figure 2. 4.b(ii)) Adeoniform.

Occurrence: A. grisea is abundant in the Fyansford Clay.

Ecology: Australian seas, 40 metres depth.

*Adeonellopsis mucronata (MacGillivray) (Australia) Adeoniform.

Ecology: Australian seas generally.

Adeonellopsis obliqua (MacGillivray) Adeoniform.

Trigonopora moniliferum (Milne Edwards) Adeoniform.

Catenicellidae

Catenicella sp. Catenicelliform

Ditaxipora internodia (Waters) Catenicelliform.

Celleporidae

*Schizmopora coronopus Wood (figure 2. 4.c(ii)).

Schizmopora biradiata Waters Celleporiform.

Schizmopora modesta MacGillivray Celleporiform.

Sphaeropora fossa Haswell Celleporiform.

Cheiloporinidae

Cucullipora tetrasticha MacGillivray Vinculariform.

Tetraplaria australis Tenison Woods Vinculariform.

Conescharellidae

Bipora sp.

*Conescharellina cancellata (Busk) Lunulitiform.

Hippoporinidae

*Chiastocella daedala (MacGillivray)

Ecology: Australian seas.

Lekythoporidae

*Lekythopora hystrix MacGillivray Membraniporiform

Ecology: Australian seas.

Lekythopora mooraboolensis Maplestone Membraniporiform.

Microporellidae

Microporella sp.

*Microporella ciliata Linnaeus Membraniporiform

Ecology: Cosmopolitan.

Mucronellidae

Smittina oculata MacGillivray Membraniporiform.

Smittina ordinata MacGillivray Eschariform.

Smittina tatei (Tenison-Woods) Vinculariform.

Porinidae

*Porina gracilis (Lamarck)

Occurrence: This is a very common species in the limestones and clays.

Ecology: It is found in Australian and South Pacific waters from 0 - 50 metres.

Prostomariidae

Prostomaria gibbericollis MacGillivray. Catenicelliform.

Reteporidae

Retepora sp. Reteporiform.

Occurrence: This is very common in the Fyansford Clay and Batesford and Upper Maude Limestones.

Retepora permunita MacGillivray. Reteporiform.

Retepora porcellana MacGillivray. Reteporiform (figure 2.4.c(i)).

Retepora rimata Waters. Reteporiform.

Retepora schnapperensis MacGillivray. Reteporiform.

*Schizoretepora tessellata (Hincks) Reteporiform.

Ecology: This is a Flindersian-Peronian species.

*Sertella beaniana King Reteporiform

Ecology: This is found in European waters.

Sertella mucronata (Waters) Reteporiform.

Bulbipora sp. Reteporiform.

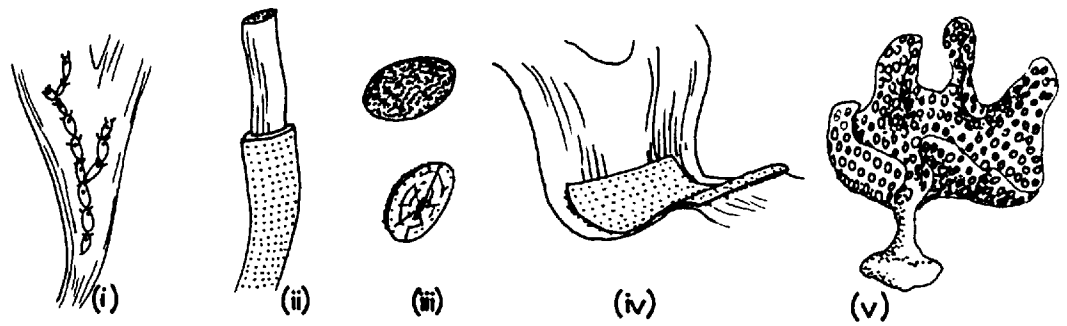
Schizoporellidae

Schizoporella convexa MacGillivray. Membraniporiform.

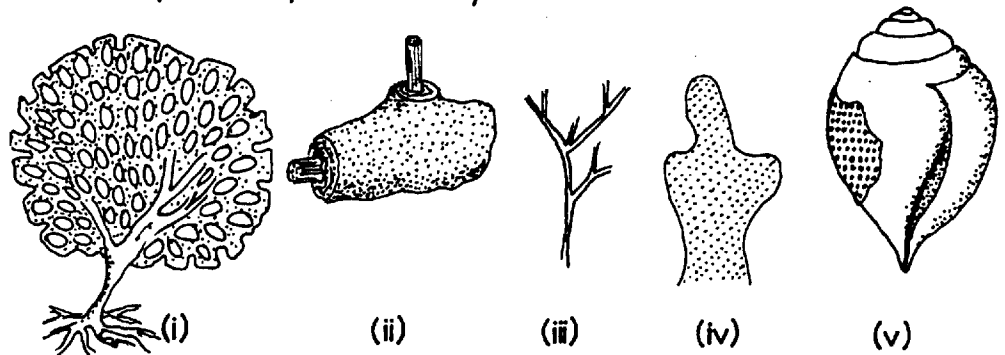
Schizoporella fenestrata Waters (S. profunda) Eschariform.

*Schizoporella lata MacGillivray. Membraniporiform.

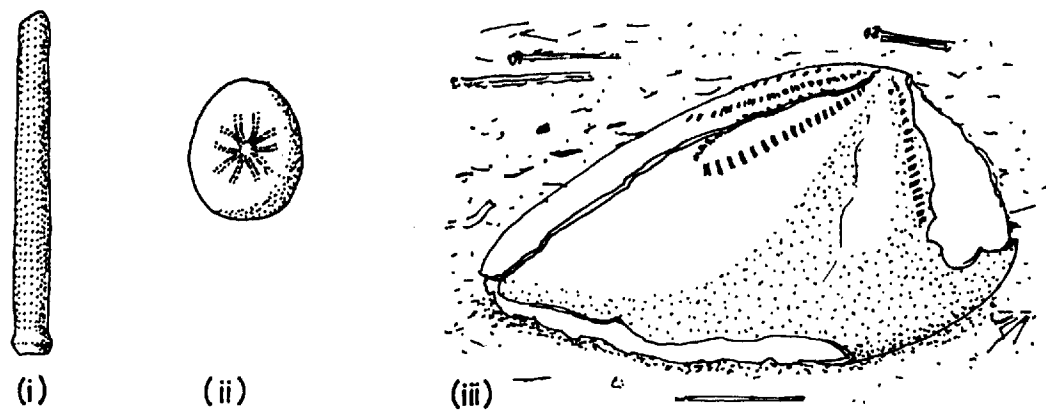
Ecology: This species is Peronian.



- a** Bryozoan forms
- (i) Catenicelliform; single row of zooecia attached to algae
 - (ii) Cellariform; zooarium around blade of algae
 - (iii) Lunulitiform; disc-shaped, free
 - (iv) Petraliform; unilaminar, attached to algae
 - (v) Reteoporiform; bilaminar, erect



- b**
- (i) Adeoniform; erect, bilaminar
 - (ii) Celleporiform; massive, encrusting algae
 - (iii) Vinculariform; branching, rigid
 - (iv) Eschariform; erect, bilaminar
 - (v) Membraniporiform; encrusting, unilaminar



- c**
- (i) Cidarid radiole (x1) Batesford Quarry
 - (ii) Fibularia gregata Tate (x4) Section 16 unit 4
 - (iii) Pericosmus sp. in life position. (x0.5) Section 5 unit 2

Figure 2.5

Schizoporella macgillivrayi Canu and Bassler (S. rhymatopora)

Vinculariform.

Schizoporella quadrata MacGillivray

Schizoporella subsinuata Hincks. Membraniporiform.

Ecology: This species is found in Australian waters generally.

Schizoporella submersa Waters. Eschariform.

Asteroidea

Asteroid plates

Ecology: Living asteroids are scavenging and carnivorous epibionts, occurring in shallow marine waters.

ECHINOIDEA

Ecology: Duncan (1877) who described the Echinodermata of the Australian Tertiary noted that the fauna seemed to be composed of three elements:-

- (i) Recent Australian genera.
- (ii) Recent extra-Australian genera, i.e. tropical.
- (iii) Genera present in the Cretaceous and Tertiary of Europe.

Clark (1946) indicated that over half of the species still living in the Australian area were found in waters shallower than 20 metres.

Cidaridae (figure 2. 5.c(i))

Ecology: Regular echinoids are epibiontic, living on algal-rich bottoms.

Stereocidaris sp.

Occurrence: Spinose radioles occur in many units of the Fyansford Clay.

Ecology: Stereocidaris is a tropical and subtropical genus.

Phyllacanthus duncani Chapman and Cudmore

Ecology: Phyllacanthus is found living in the intertidal zones of the Australian and South Pacific coasts.

Delocidaris prunispinosa (Chapman and Cudmore)

Echinidae

Psammechinus woodsi Laube.

Ecology: Species of this genus are found in the Atlantic and Mediterranean today.

Arachnoididae

Ecology: Sand dollars are shallow burrowers, usually in shallow water sandy bottoms.

Monostychia australis Laube

Scutellinoides patella (Tate)

Fibulariidae

Fibularia gregata Tate (figure 2. 5.c(ii))

Ecology: Recent Fibularia occurs in the Flindersian region in depths of about 30 to 50 metres (Cotton and Godfrey 1942)

Pericossidae

Pericossus sp. (figure 2. 5.c(iii)).

Pericossus gigas McCoy.

Ecology: Pericossus is a tropical genus, and burrows in shelly sands of coral reef areas.

Spatangidae

Ecology: Spatangoids are generally rather deep burrowers in shallow or deep water sediments.

Maretia anomala Duncan.

Ecology: This is an Indo-Pacific genus today.

Loveniidae

Lovenia forbesi Woods and Duncan

Ecology: Lovenia is a cosmopolitan neritic genus.

Sharks Teeth

Occurrence: Shark's teeth, often limonitised are found in the lower part of the Upper Maude Limestone.

Bones

Occurrence: Bone fragments occur in the Upper Maude Limestone.

Otoliths

Occurrence: These are found in many units in the Fyansford clay.

The Affinities of the Fossils and Palaeotemperatures

The present-day distributions of the living species found fossil in the Tertiary, and also of the closest living relatives of extinct species have been plotted for each of the formations.

At the present day, an average surface temperature of 14.4°C is recorded on the Victorian coast. This corresponds to the boundary between the Flindersian and Peronian provinces. Dorman (1966) published a comprehensive survey of Tertiary palaeotemperatures from Australia, and his results have been compared with the present ones:

In the Lower Maude Limestone (Janjukian - Longfordian), no living species were recorded and the distributions of the close living relatives were not particularly helpful, as there were only six.

Flindersian	3
Peronian	2
Solanderian	1

Dorman (1966) gave little data for the Longfordian, his graph showing a broad spread from 16° to 20° . Probably the average temperature was slightly warmer than today's, near 16°C .

In the Upper Maude Limestone (Batesfordian - Balcombian), three living species were recorded. Of these two are extra-Australian and one is Peronian. These affinities of these and the close living relatives are:

Flindersian	9
Extra Australian (mainly Tropical Pacific)	7
Peronian	6
Solanderian	1

This significant extra-Australian element is also present in the Batesford Limestone (Longfordian - Batesfordian). Two living species are present and both are extra-Australian. Many of the close living relatives are also:

Extra-Australian	7	(Tropical Pacific)
Flindersian	2	
Solanderian	1	

The Batesfordian, during which parts of both of the latter formations were deposited, corresponds to a period of temperature-high recorded by Dorman (1966). His figures have a wide spread from 16°C to 26°C , with most between 20° and 26°C . It seems likely that the temperature was in the latter range, accounting for the presence of extra-Australian Tropical species.

In the Fyansford Clay (Balcombian - Bairnsdalian) there are 27 living species, and 83 species with close living relatives. The affinities of each are similar:

	living species	close living relatives
Peronian	10	36
Flindersian	10	29
Solanderian	4	11
Extra-Australian	3	7

The temperature indicated is that of Peronian waters - and corresponds well with the 15° to 16°C recorded by Dorman (1966).

Similar affinities are exhibited by the species in the Pliocene Moorabool Viaduct Sands, but there are slightly more Flindersian species.

	living species	close living relatives
Peronian	9	3
Flindersian	8	3
Solanderian	11	11

Probably the temperature was the same as today's i.e. 14.4°C .

	No/units	Biofacies	Rare	Common	Abundant	Most common Biofacies.
Calcareous Algae	42	8	3	4	35	1.3.6.7.8.
Wood and Leaves	2	2	1	1		5.18.
Triloculina spp.	38	12	23	15		10.11.16.
Pyrgo sarsi	8	6	7	1		11.15.
Nodosaria sp.	1	1	1			10.
Lingulina spp.	11	7	10	1		11.13.
Bolivina alata	9	4	9	0	0	4.15.
Cassidulinoides	2	2	2			8.15.
Baggina phillipinensis	6	2	4	2		1.
Discorbinella sp.	8	2	3	5		1.
Siphonina australis	2	1	2			11.
Spirillina denticulata	4	3	4			9.
Rotalia verriculata	9	3	8	1		16.
Rotalia beccarii	2	1	2			17.
Sherbornina cuneimarginata	1	1	1			16.
Elphidium chapmani	5	2	3	2		15.
Operculina victoriensis	9	3	7	2		6.7.
Cycloclypeus victoriensis	2	1	2			7.
Globigerina spp.	62	14	17	28	17	8.9.11.13.
Orbulina suturalis	9	3	1	5	3	15.16.
Orbulina universa	31	7	10	12	9	9.13.
Globigerinoides conglobata	2	2	1	1		1.
Eponides sp.	1	1	1			10.
Amphistegina lessonii	26	12	13	13		6.7.4.

	No/units	Biofacies	Rare	Common	Abundant	Most common Biofacies.
<i>Cibicides</i> spp.	74	15	24	34	16	8.9.6.
<i>Planorbulinella</i> <i>inaequilateralis</i>	1	1	1			4.
<i>Gypsina howchini</i>	11	5	11			6.4.
<i>Lepidocyclina howchini</i>	13	2	1	1	11	6.15.
<i>Astronion</i> sp.	7.	4	1	6		8.16.
<i>Anomalina</i> spp.	48	11	14	27	7	8.9.13.
Sponge spicules	40	13	8	20	12	10.6.7.
Sponge cups	9	4	5	4		4.
<i>Isis</i> sp.	8	4	5	3		1.
<i>Trematotrechus</i> <i>fenestratus</i>	1	1	1			11.
<i>Sphenotrochus</i> <i>australis</i>	5	2	5	0	0	16.
<i>Flabellum</i> sp.	1	1	1			9.
<i>Placotrochus</i> <i>deltoides</i>	9	4	3	6		16.
<i>Conosmilia anomala</i>	8	5	8			8.
<i>Conosmilia striata</i>	3	2	3			9.
<i>Conosmilia lituolus</i>	1	1	1			8.
<i>Balanophyllia</i> sp.	4	3	4			15
Worm tubes	8	4	8			10.
Ostracoda	14	10	11	3		8.11.
<i>Balanus</i> sp.	3	3	1	2		11.18.
<i>Ommatocarcinus</i> <i>corioensis</i>	8	6	8			11.17.
<i>Dentalium mantelli</i>	15	5	1	9	5	8.12.
<i>Dentalium subfissura</i>	11	4	4	7		8.10.12.
<i>Dentalium aratum</i>	9	3	6	3		8.9.
<i>Cadulus acuminatus</i>	1	1	1			10.

	No./units	biofacies	No. of times			Most common Biofacies
			Rare	Common	Abundant	
<i>Nucula</i> sp.	2	2	2			8.9.
<i>Nucula tenisoni</i>	4	3	4			9.
<i>Nuculana chapmani</i>	16	6	8	8		8.9.10.
<i>Leda prebracostata</i>	1	1	1			8.
<i>Leda woodsi</i>	1	1	1			10
<i>Sarepta obotella</i>	3	3	3			8.9.10.
<i>Glycimeris cainozoicus</i>	1	1		1		2.
<i>Glycimeris convexus</i>	3	1	3			8.
<i>Glycimeris granti</i>	2	1	2			10.
<i>Glycimeris gunyoungensis</i>	8	5	5	3		9.11.
<i>Limopsis maccoyi</i>	18	6	8	10		9.10.15.
<i>Arca capulopsis</i>	1	1	1			14.
<i>Barbatia celleporacea</i>	8	4	8			8.9.
<i>Cucullaea corioensis</i>	2	2	1	1		14.
<i>Macrodon cainozoicus</i>	5	3	5			8.
<i>Vulsella laevigata</i>	1	1	1			9.
<i>Pteria crassicardia</i>	1	1	1			14.
<i>Ostrea</i> spp	36	11	21	15		4.5.15.7.
<i>Ostrea angasi</i>	11	3	3	4	4	14.17.18.
<i>Ostrea hippopus</i>	1	1	1			8.
<i>Ostrea hyotis</i>	11	6	5	6		11.12.14.
<i>Ostrea ingens</i>	1	1		1		14.
<i>Ostrea manubriata</i>	1	1		1		18.
<i>Ostrea sturtiana</i>	3	1	2	1		9.
<i>Crassostrea amasa</i>	2	2	1	1		17.
<i>Gryphaea tarda</i>	1	1	1			14.
<i>Trigonia</i> sp.	1	1	1			18.

	No/units	biofacies	No. of times			Most common Biofacies
			Rare	Common	Abundant	
<i>Eotrigonia intersitans</i>	2	1	1	1		2.
<i>Eotrigonia semiundulata</i>	1	1	1			11.
<i>Neotrigonia acuticostata</i>	1	1	1			10.
<i>Pecten</i> sp.	6	3	3	3		12.
<i>Pecten aldingensis</i>	2	1	2			10.
<i>Pecten eyrei</i>	6	2	4	2		11.
<i>Pecten murrayanus</i>	14	4	12	2		7.15.
<i>Pecten peroni</i>	1	1	1			11.
<i>Pecten polymorphoides</i>	8	2	6	2		4.
<i>Chlamys flindersi</i>	1	1	1			9.
<i>Equichlamys consobrinus</i>	1	1	1			14.
<i>Mimachlamys asperimus</i>	6	2	3	3		17.
<i>Lentipecten victoriae</i>	1	1	1			4.
<i>Serripecten yahlensis</i>	3	2		3		12.14.
<i>Himmites corioensis</i>	1	1		1		14.
<i>Propeamussium zittoli</i>	11	5	11			8.10.
<i>Spondylus gaderopoides</i>	4	1	3	1		12.
<i>Spondylus pseudoradula</i>	10	5	9	1		9.10.
<i>Spondylus spondyloides</i>	1	1	1			17.
<i>Dimya dissimilis</i>	20	9	16	4		9.11.14.
<i>Limea transenna</i>	1	1	1			10.
<i>Monia ione</i>	3	3	3			12.14.17.
<i>Placunanomia sella</i>	3	1	2	1		14.
<i>Septifer fenestratus</i>	2	2	2			8.12.
<i>Mytilus planulatus</i>	1	1	1			18.

	No/units	biofacies	Rare	No. of times		Most common
				Common	Abundant	Biofacies
<i>Myochama</i> sp.	1	1	1			18.
<i>Myadora tenuilirata</i>	2	1	2			8.
<i>Crassatella corrugata</i>	1	1	1			2.
<i>Crassatella demnanti</i>	.1	1	1			10.
<i>Salaputium communis</i>	1	1	1			10.
<i>Cardita delicatula</i>	5	2	5			10.
<i>Cardita polynema</i>	2	1	2			9.
<i>Cardita tasmanica</i>	1	1	1			10.
<i>Venericardia gracilicostata</i>	10	3	8	2		15.16.
<i>Venericardia latissima</i>	5	1	3	2		8.
<i>Chama lamellifera</i>	5	3	3	2		8.9.
<i>Lucina</i> sp.	2	2	2			3.18.
<i>Diplodonta</i> sp.	1	1	1			18.
<i>Cardium</i> sp.	3	3	2	1		2.
<i>Cardium pseudomagnum</i>	2	1	2			8.
<i>Dosinia</i> sp.	2	2	2			3.18.
<i>Dosinia johnstoni</i>	2	1	1		1	2.
<i>Meretrix</i> sp.	1	1	1			18.
<i>Notocallista</i> sp.	1	1	1			18.
<i>Notocallista eburnea</i>	16	5	7	9		8.9.10.12.
<i>Chione</i> sp.	4.	3	3	1		5.
<i>Chione allporti</i>	1	1	1			8.
<i>Chione cainozoica</i>	1	1	1			9.
<i>Proxichione homophora</i>	6	4	6			10.11.
<i>Proxichione subtilicostata</i>	17	7	7	10		8.10.
<i>Tellina stirlingi</i>	5	4	5			12.

	No/units	biofacies	No. of times			Most common Biofacies
			Rare	Common	Abundant	
<i>Donax depressa</i>	1	1	1			8.
<i>Corbula</i> sp.	3	3	3			1.10.15.
<i>Corbula ephamilla</i>	9	4	9			8.12.
<i>Corbula pixidata</i>	3	2	3			10.
<i>Corbula stolata</i>	2	2	1	1	1	18.19.
<i>Pholas australasiae</i>	3	2	2	1		18.
<i>Pholas obturamentum</i>	1	1	1			18.
<i>Teredo</i> sp.	1	1	1			18.
<i>Pleurotomaria</i> sp.	1	1	1			3.
<i>Notomella delicatula</i>	2	2	2			8.9.
<i>N. dennanti</i>	3	2	3			10.15.
<i>Cosmetalepas laqueatus</i>	1	1	1			2.
<i>Astele millegrosa</i>	4	1	2	2		3.
<i>Bankivia howitti</i>	1	1	1			10.
<i>Cantharidus serratulus</i>	12	7	8	4		3.15.
<i>Trochita turbinata</i>	2	1	1	1		3.
<i>Collinista otwayensis</i>	1	1	1			9.
<i>Liota lamellosa</i>	1	1	1			2.
<i>Astralium</i> sp.	2	2	2			16.18.
<i>Astralium hudsonianum</i>	2	1	1	1		3.
<i>Delphinula imparigranosa</i>	1	1	1			3.
<i>Subninella grangensis</i>	5	1	1	4		3.
<i>Calyptraea undulata</i>	1	1	1			3.
<i>Cerithium apheles</i>	9	4	8	1		9.15.
<i>Cerithium cibarioides</i>	7	4	6	1		8.15.

	No/units	biofacies	No. of times			Most common Biofacies
			Rare	Common	Abundant	
<i>Cerithium flemingtonensis</i>	5	2	1	4		3.
<i>Zeacumantis diemenensis</i>	3	2		1	3	17.18.
<i>Triphoris planata</i>	1	1	1			8.
<i>Triphoris wilkinsoni</i>	5	2	5			10.11.
<i>Turritella</i> sp.	3	2	2	1		3.
<i>Colpospira tristira</i>	12	3	12	1		8.9.
<i>Colpospira platyspira</i>	3	2	3			9.10.
<i>Gazameda acricula</i>	6	4	5	1		8.15.
<i>Gazameda iredalei</i>	1	1	1			18.
<i>Maoricolpus murrayana</i>	9	4	3	2	4	8.10.
<i>Solarium</i> sp.	1	1	1			10.
<i>Architectonica acutum</i>	2	2	2			15.16.
<i>Solarium wannonensis</i>	1	1	1			8.
<i>Vermetus arenarius</i>	1	1	1			8.
<i>Siliquaria australis</i>	8	6	6	2		9.12.
<i>Thylocodes actinotus</i>	1	1	1			9.
<i>Thylocodes adelaidensis</i>	1	1	1			8.
<i>Thylocodes asper</i>	1	1	1			9.
<i>Pyxipoma</i> sp.	3	1	3			10.
<i>Xenophora tatei</i>	3	2	3			8.9.
<i>Scalaria mariae</i>	1	1	1			12.
<i>Eulima danae</i>	1	1	1			15.
<i>Leiostraca acutispira</i>	2	2	2			9.10.
<i>Austrotriton cyphus</i>	1	1	1			8.

	No/units	biofacies	No. of times			Most common Biofacies
			Rare	Common	Abundant	
<i>Austrotriton woodsi</i>	4	2	4			8.9.
<i>Sassia protensus</i>	2	1	2			9.
<i>Sassia tortirostris</i>	3	2	3			8.10.
<i>Ranella pratti</i>	3	2	2	1		9.
<i>Semicassis sp.</i>	1	1	1			8.
<i>Erato pyrulata</i>	1	1	1			10.
<i>Trivia avellanoidea</i>	3	2	3			8.9.
<i>Cypraea sp.</i>	8	5	8			10.
<i>Cypraea contusa</i>	1	1	1			9.
<i>Cypraea gigas</i>	6	2	5	1		15.
<i>Cypraea leptorhyncha</i>	4	1	2	2		13.
<i>Cypraea ovulatella</i>	2	1	2			9.
<i>Umbillia eximia</i> <i>maccoyi</i>	1	1	1			8.
<i>Natica sp.</i>	5	3		5		3.15.
<i>Natica perspectiva</i>	4	2	4			8.
<i>Natica</i> <i>subinfundibulum</i>	5	3	3	2		8.10.
<i>Natica subnoe</i>	2	1	2			8.
<i>Polinices sordidus</i>	1	1		1		18.
<i>Ocenebra asperulus</i>	2	2	2			11.12.
<i>Chicoreus</i> <i>lophoessus</i>	1	1	1			8.
<i>Discathais textiliosa</i>	1	1	1			18.
<i>Typhis acanthopterus</i>	1	1	1			8.
<i>Nassa tatoi</i>	9	4	5	4		8.9.
<i>Nassa sp.</i>	1	1	1			18.
<i>Fasciolaria sp.</i>	1	1	1			10.
<i>Clavella bulboides</i>	1	1	1			8.
<i>Denmantia ino</i>	1	1	1			9.

	No/units	biofacies	No. of times			Most common Biofacies
			Rare	Common	Abundant	
<i>Fusus simulans</i>	3	2	2	1		8.9.
<i>Columbarium acanthostephes</i>	2	2	2			10.11.
<i>Columbarium foliaceus</i>	1	1	1			8.
<i>Columbarium spinatulum</i>	1	1	1			8.
<i>Peristernia</i> sp.	1	1	1			15.
<i>Peristernia subundulosa</i>	3	1	3			8.
<i>Peristernia purpureoides</i>	2	1	1	1		3.
<i>Siphonalia</i> sp.	1	1	1			8.
<i>Valuta antiscalaris</i>	4	3	4			10.
<i>Valuta strophodon</i>	1	1	1			8.
<i>Oliva adelaidensis</i>	1	1	1			9.
<i>Oliva nymphaelis</i>	2	2	2			8.15.
<i>Ancillaria orycta</i>	1	1	1			8.
<i>Marginella micula</i>	12	3	7	5		8.9.
<i>Marginella muscaroides</i>	2	1	2			8.
<i>Cancellaria varicifera</i>	2	2	2			8.9.
<i>Mitra alokisa</i>	3	3	2	1		15.
<i>Mitra dictua</i>	2	2	1	1		15.
<i>Uromitra biornata</i>	4	2	4			8.10.
<i>Microvoluta pentaploca</i>	4	2	3	1		9.
<i>Waimatea complanata</i>	1	1	1			10.
<i>Conus cuspidatus</i>	5	4	5			9.
<i>Drillia integra</i>	4	2	4			8.9.
<i>Drillia trevorii</i>	3	2	3			9.

	No/units	biofacies	No. of times			Most common Biofacies
			Rare	Common	Abundant	
<i>Drillia crenularoides</i>	1	1	1			8.
<i>Magelia bidens</i>	1	1	1			8.
<i>Apiotoma bassi</i>	3	1	3			8.
<i>Pleurotoma clarae</i>	1	1	1			9.
<i>Pleurotoma granti</i>	1	1	1			9.
<i>Pleurotoma murrayana</i>	1	1	1			9.
<i>Pleurotoma murndaliana</i>	6	3	6			8.9.
<i>Pleurotoma solwyni</i>	4	2	4			8.
<i>Bathytoma rhomboidalis</i>	3	3	3			8.9.
<i>Teleochilus royanus</i>	1	1	1			8.
<i>Bulinella exigua</i>	9	3	6	3		8.
<i>Umbraculum australiensis</i>	1	1	1			15.
Gastropod protoconchs	5	4		5		9.
<i>Styliola annulata</i>	4	2	1	3		8.
<i>Limacina tertiaria</i>	7	4	2	5		8.10.
<i>Vaginella elignostoma</i>	11	5		1	10	8.9.
<i>Tegulorhynchia squamosa</i>	1	1	1			3.
<i>Austrothyris grandis</i>	3	2		3		11.14.
<i>Magadina compta</i>	2	2	2			9.14.
<i>Magadina tenisoni</i>	1	1	1			6.
<i>Magellania</i> sp.	2	1		2		9.
<i>Magellania coriocoensis</i>	20	4	6	14		11.12.
<i>Magellania flavescens</i>	2	2	2			5.11.
<i>Magellania furcata</i>	3	1	2	1		10.
<i>Magellania garibaldiana</i>	7	4	4	3		7.4.

	No/units	biofacies	No. of times			Most common Biofacies
			Rare	Common	Abundant	
<i>Stethothyris insolita</i>	4	1	3	1		12.
<i>Terebratula aldingae</i>	3	2		3		4.
<i>Terebratula tateana</i>	1	1	1			4.
<i>Terebratula vitreoides</i>	4	2		4		10.
<i>Terebratulina scoulari</i>	13	4	9	4		9.10.
<i>Terebratulina triangularis</i>	8	4	7	1		11.4.
<i>Mumrayia catenuliformis</i>	1	1	1			7.
<i>Crisia</i> sp.	2	2	1	1		6.
<i>Crisia macrostoma</i>	2	1	1	1		4.
<i>Crisia scalaris</i>	2	2	2			1.11.
<i>Crisia setosa</i>	1	1	1			11.
<i>Diastopora discoidea</i>	1	1		1		15.
<i>Entalophora australis</i>	1	1	1			9.
<i>Entalophora longipora</i>	16	6	2	9	5	7.4.
<i>Entalophora punctata</i>	1	1		1		4.
<i>Entalophora verticellata</i>	3	2	1		2	6.
<i>Frondipora palmata</i>	7	4	3	4		7.
<i>Filisparsa orakeinensis</i>	3	3	2	1		7.
<i>Idmonea</i> spp	30	10	5	19	6	7.
<i>Idmonea atlantica</i>	4	2	3	1		11.
<i>Idmonea contorta</i>	1	1	1			10.
<i>Idmonea geminata</i>	1	1	1			10.
<i>Idmonea hochstetteriana</i>	5	3	3	2		11.
<i>Idmonea incurva</i>	1	1	1			11.

	No/units	biofacies	No. of times			Most common Biofacies
			Rare	Common	Abundant	
<i>Idmonea radians</i>	1	1	1			10.
<i>Idmonea venusta</i>	1	1	1			10.
<i>Hornera foliacea</i>	1	1	1			10.
<i>Hornera frondiculata</i>	13	4	2	2	9	7.4.
<i>Hornera quadrata</i>	1	1	1			8.
<i>Hornera tenuis</i>	1	1	1			10.
<i>Supercytis digitata</i>	5	3	1	4		7.4.
<i>Heteropora nodulosa</i>	1	1		1		4.
<i>Heteropora pisiformis</i>	1	1	1			
<i>Lichenopora</i> sp.	2	2	2			3.4.
<i>Lichenopora australis</i>	4	1		4		7.
<i>Lichenopora reticulata</i>	2	1	2			4.
<i>Arachnopusia liversidgei</i>	12	6	5	5	2	7.4.
<i>Ramphonotus lusorius</i>	12	6	6	5	1	7.4.
<i>Cranosina coronata</i>	13	3	8	2	3	11.
<i>Membranipora</i> spp	20	9	9	9	2	12.
<i>Membranipora cyclostoma</i>	1	1		1		11.
<i>Membranipora elliptica</i>	1	1	1			10.
<i>Membranipora fossa</i>	5	2	1	4		6.
<i>Membranipora incurvata</i>	5	1	1		4	2.
<i>Membranipora perfragilis</i>	1	1	1			10.
<i>Membranipora striata</i>	2	2	2			8.10.
<i>Synaptacella</i> sp.	5	2	5			4.
<i>Macropora</i> sp.	2	2	2			11.
<i>Lunulites angulipora</i>	1	1	1			7.

	No/units	biofacies	No. of times			Most common Biofacies
			Rare	Common	Abundant	
Lunulites canaliculata	3	1	3			7.
Lunulites parvicella	7	5	4	3		10.
Lunulites rutella	1	1	1			8.
Caleschara denticulata	1	1	1			8.
Selenaria concinna	3	2	3			8.
Cellaria crassimarginata	6	2		1	5	7.
Cellaria cucullata	1	1		1		7.
Cellaria rigida perampla	6	3	4	2		5.
Melicerita angustiloba	20	6	6	10	4	7.
Caberea sp.	1	1	1			9.
Corbulipora evevata	1	1	1			11.
Corbulipora ornata	1	1		1		4.
Lepralia perforata	1	1	1			2.
Lepralia abdita	7	6	5	2		6.
Lepralia corrugata	1	1	1			11.
Lepralia filiformis	1	1	1			9.
Lepralia rotunda	1	1	1			9.
Adeona grisea	58	9	6	6	46	10.11.
Adeonellopsis mucronata	5	3	5			8.9.
Adeonellopsis obliqua	8	3	7	1		8.9.
Trigonopora moniliferum	1	1	1			10.
Catenicella spp	2	1	1	1		8.
Ditaxipora internodia	3	2		3		4.
Schiznopora sp.	3	2	2	1		2.
Schiznopora coronopus	38	10	11	21	6	11.12.

	No/units	biofacies	No. of times			Most common Biofacies
			Rare	Common	Abundant	
Schiznopora biradiata	1	1	1			11.
Schiznopora modesta	1	1	1			10.
Sphaeropora fossa	1	1	1			11.
Cucullipora tetrasticha	3	3	3			8.9.3.
Tetraplaria australis	1	1		1		7.
Bipora sp.	1	1	1			4.
Conescharcellina cancellata	1	1	1			9.
Lekythopora hystrix	2	1	2			11.
Lekythopora mooraboolensis	1	1	1			7.
Microporella sp.	1	1	1			9.
Microporella ciliata	2	2	1	1		8.7.
Smittina oculata	1	1	1			10.
Smittina ordinata	1	1	1			10.
Smittina tatei	2	2	2			8.4.
Porina gracilis	23	10	11	12		12.6.
Prostomaria gibbericolis	1	1	1			10.
Retepora sp.	23	7	11	12		12.7.
Retepora permunita	1	1	1			9.
Retepora porcellana	11	1		11		11.
Retepora rimata	12	3	6	6		10.4.
Retepora schapperensis	1	1		1		10.
Retepora tessellata	1	1	1			10.
Schizo sertella beaniana	2	1	2			9.

	No/units	biofacies	No. of times			Most common Biofacies
			Rare	Common	Abundant	
<i>Sertella aciculifera</i>	1	1	1			10.
<i>Chiastocella daedala</i>	2	2	2			9.
<i>Schizoporella convexa</i>	1	1	1			10.
<i>Schizoporella fenestrata</i>	2	2	1	1		9.
<i>Schizoporella lata</i>	2	1	1	1		3.
<i>Schizoporella macgillivrayi</i>	4	3	3	1		3.
<i>Schizoporella quadrata</i>	1	1	1			4.
<i>Schizoporella subsinuata</i>	1	1	1			8.
<i>Schizoporella submersa</i>	2	2	1	1		7.
Asteroid plates	3	3	2	1		6.
<i>Stereocidaris</i> sp.	10	3	7	3		9.10.
<i>Phyllacanthus duhcani</i>	1	1	1			4.
<i>Delocidaris prunispindsa</i>	5	1	2	3		8.
<i>Psammechinus woodsi</i>	1	1	1			4.
Large radiolos (Regular echinoids)	44	11	15	29		6.7.
<i>Monostychia australis</i>	4	1	2	2		1.
<i>Scutellinoides patella</i>	2	2	2			14.2.
<i>Fibularia gregata</i>	11	1	2		9	1. .
<i>Pericosmus</i> sp.	12	2	3	9		6.7.
<i>Pericosmus gigas</i>	2.	1	2			4.
<i>Maretia anomala</i>	3	2	3			1.2.
<i>Lovenia forbesi</i>	1	1	1			2.
Sharks teeth	5	3				4.
Bone	3	2	1	2		3.
Otoliths	7	5	7			10.11.

CHAPTER 3

THE BIOFACIES

The fossils have been grouped into assemblages, termed biofacies. Because there are a relatively large number of species in relatively few units, it was impossible to recognise recurrent assemblages by a direct comparison of the species lists. Eradication of the less important species in the units was not found to be helpful as it failed to distinguish between the major compositional trends of the fossil assemblages and it was found that most of the commoner species occurred in a large number of units.

Accordingly, the divisions into assemblages were based upon the broadest changes in the biota. For each unit, the number of species representing each of the major groups of fossils (e.g. sponges, gastropods, brachiopods) were tabulated as simple histograms. Common species were listed above a median line, rare species below it. The grouping of units into biofacies was then accomplished by visual comparison of the histograms. This procedure was particularly useful for the correlation of very fossiliferous units with those in which fossils were rare.

The descriptions of the biofacies comprise:-

(i) The number of units in which the biofacies occurs, and the number of coarse-fractions examined (some samples were too indurated to sieve). The microfossils are absent from those units from which a coarse fraction was not obtained, so the figures for their abundance must be related to the latter. The formation in which the biofacies occurs and the rock types represented are also given.

(ii) The list of the species present is limited to the more characteristic species. These include all abundant and most common species

and those rare species that occur frequently. The number of times the species occurs has been indicated. In the case of common species the first figure refers to common occurrences (and if underlined it refers to abundant occurrences), the second to rare occurrences.

(iii) A summary of the environment and a discussion of the composition of the fossil assemblage follows.

Histograms of the total number of species in the biofacies in each of the fossil groups comprise figures 3.1 - 7. They include common species (to the left of the median line) and rare species (to the right of the median line).

Figure 3.B gives biotal analyses for each of the biofacies. These consist of percentages of the species belonging to particular forms (e.g. thick-shelled) or having particular habits (e.g. carnivorous). The following forms and habits are taken to indicate various environmental conditions in the biofacies.

Form

Thick Shelled/Thin Shelled:- Within one Recent genus, thick shells generally indicate environments towards the shallower and warmer ends of the range. Many of the genera that are present in deep water in the Flindersian and Peronian provinces have thick shelled equivalents in the shallow waters of Queensland and the South Pacific. Thick shells tend to occur in areas of high current activity. Thin shelled species conversely, indicate the deeper and cooler ranges of particular genera, or areas away from high current activity.

Flattened:- In the case of attached epibionts this is taken to indicate gentle or unidirectional currents, and in the case of inbionts, a soft organic rich substrate allowing deep burrowing.

Elongate:- Elongate inbionts are generally deep burrowers in organic rich sediments, or in the case of epibionts indicate unidirectional currents.

Smooth Shell/Costate:- Smooth shelled species of particular genera indicate rather lower energy conditions than costate ones, either in deeper waters or in burrows deeper within the sediment.

Erect Bryozoa:- Erect bryozoa indicate good oxygenation and gentle to strong current activity.

Articulated Bryozoa:- An algal substrate is required by these forms, generally in areas of moderate to strong current activity within the photic zone.

Aragonitic shells:- Shells composed of aragonite tend to be in - bionts or vagrant epibionts. The latter may be partly composed of calcite.

Calcitic Shells:- Calcite shelled species are either attached or cemented epibionts. The latter may be partly composed of aragonite.

Vagrant Epibionts:- These indicate stable substrates in areas of gentle to strong current activity in which deposition is slow or does not take place. Frequently the substrate is rich in algae.

Attached Epibionts and Swimmers:- An abundance of both indicates stable substrates in areas of gentle to strong current activity where little deposition is taking place. An abundance of organic matter in the water is obligatory.

Endobionts:- Endobionts are common in sediments deposited by gentle or moderate currents at variable, but generally slow to moderate rates. The sediment or the overlying waters are rich in organic matter.

Suspension Feeders:- This type of feeding habit is typical of organic-rich waters in areas of gentle to strong current activity. An abundance of suspension feeders indicates very slow or non-deposition.

Deposit Feeders:- These occur in organic rich substrates in which the depositional rate is moderate and the current activity weak.

Scavengers and Herbivores:- Both indicate algal rich substrates in areas of gentle to high current activity in which the depositional rate is slow or non-existent.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	⊙	●	△	◐	30%	⊗	⊕	▲	⬢	⬠	⬡	⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
thick-shelled	56	54	88	36	45	39	34	30	36	44	27	41	8	70	42	26	50	100	44
thin-shelled	19	10	7	36	45	13	19	20	12	19	35	24	58	17	32	42	25		22
flattened	50	44	22	43	60	48	47	25	30	25	42	40	42	50	40	37	44		11
elongate		10	7	7	15		11	11	16	22		18		4	28	21	16	25	
smooth	62	49	44	43	55	48	49	39	33	41	35	38	56	43	52	95	66	37	22
costate	6	34	37	26	30	13	30	25	30	41	24	32		30	40	10	25	62	11
planktonic	6		4	2		4	2	8	6	7	3	4	42	4	8	26	16		
epibionts	37	15	44	14	20	22	21	28	27	30	22	14	25	13	36	32	44	37	22
attached epibionts	37	63	33	60	65	61	64	22	30	29	44	39	33	48	36	53	25	37	22
swimmers		10	4				8	5	3	12	13	8		13	4		16		11
burrowers	12	20	7	2	25	4	2	44	26	28	11	17		9	24	16		37	22
borers																		12	
aragonite-shelled	6	29	55	26	45	4	21	66	48	56	24	35	50	9	52	42	8	37	33
calcite-shelled	94	73	45	71	50	96	76	21	33	42	62	65	66	86	44	74	92	62	55
suspension feeders	37	82	44	76	70	61	68	33	40	56	77	67	75	78	50	69	50	50	44
deposit feeders					5		2	1	1	1		6			2			12	11
herbivores			26					11	12	13		6			10	10	8		
carnivores			14	2	5		6	33	23	22		4			18	16		25	
scavengers	56	15	11	19	20	35	23	6	7	8	22	14	25	13	22	26	44		22
erect bryozoans	6	25	14	38	45	39	34	7	12	13	35	7	25	9	12	42	8		
articulated bryozoans					20	4		1	2							10			
Catenicelliform				5	5	4	2	2	2		2								
Cellariform			4	7	20	4	6	4	1	1	2	2			2	5			
Lunulitiform				2				2	1	2	2								
Reteporiform		5	4	2	5		2		2	4	2	2		4					
Adeoniform						4		5	5	2	2	2	25		2	5			
Celleporiform				5	5		2				2	2		4	2				
Vinculariform		15	7	7	15	4	6			4	5	2							
Eschariform			11	12	10	4	6		3	1	13				4	10			
Membraniporiform	6	10	7	5	5	4	8					2			4				
Cyathostomes	6	10	4	17	5	17	13			2	9	4		4	4	21			

Biotal analysis of the biofacies

Carnivores:- A high percentage of Carnivores indicates the presence of a rich biota of molluscs, ascidians, sponges etc.

The Lower Maude Limestone Biofacies (figure 3. 1)

(1) The Fibularia Biofacies

This occurs in 13 units, and is restricted to the calcareous sands of the Lower Maude Limestone. In all cases a coarse fraction was examined. The most characteristic species are:-

Common species: Fibularia gregata (9.2)
Cibicides thiara (7.3)
Discorbinella papillata (5.2)
 Sponge spicules (5.1)
 Calcareous algae (5)
Isis sp. (2.3)
Baggina phillipinensis (2.2)
Monostychia australis (2.2)
Idmonca spp (1.3)

The biota is predominantly thick-shelled, and very largely epibiontic (74%). The most common species are vagrant or burrowing and though many are suspension-feeders (37%), the majority are scavengers. The calcareous sands in which the biofacies occurs are silt-free and were laid down under conditions of moderate to strong current activity. Thus, the substrate was too unstable to support a fixed epibiontic population.

The most abundant species, Fibularia gregata indicates depths of deposition of at least 25 metres, a figure which fits in well with the ecology of the other species. The environment represented probably lay off an open coast from which little or no clastic material was being supplied, all the material being derived from erosion of previous rocks on the sea floor.

SPECIES PROFILES OF LOWER MAUDE LIMESTONE BIOFACIES

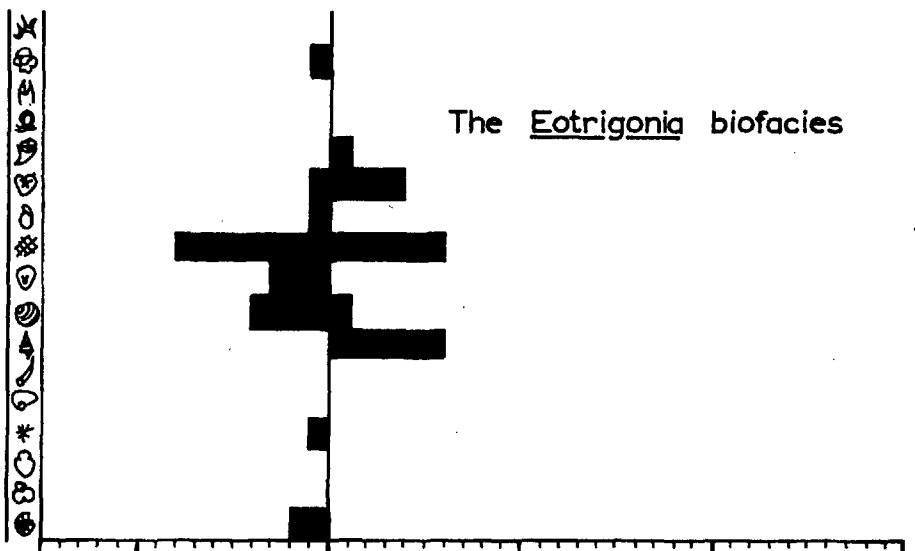
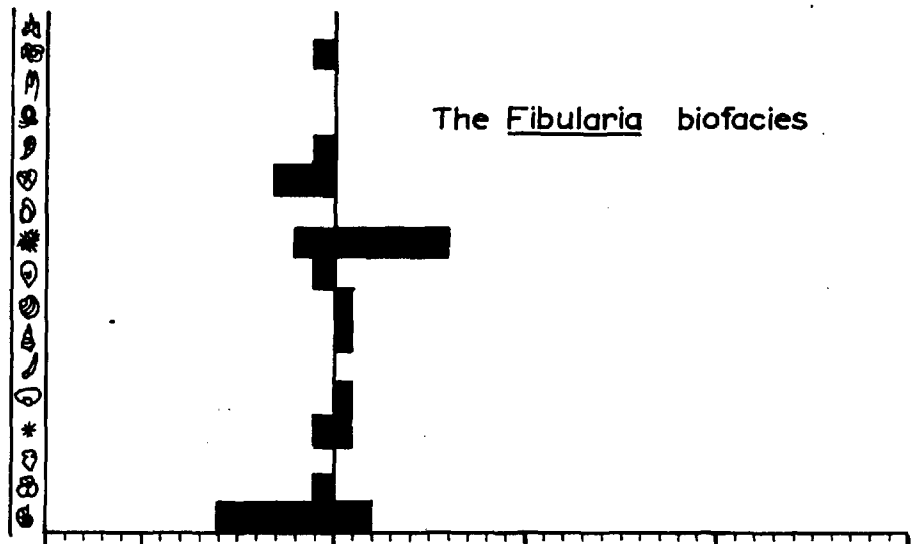


Figure 3.1

(2) The Eotrigonia Biofacies

This biofacies is found in seven sand and silty sand units in the Lower Maude Limestone. In all cases coarse fractions were examined. The most characteristic species are:-

Common species:- Membranipora incurvata (4.1)

Idmonea trigona (4)

Cibicides thiara (2.2)

Amphistegina lessonii (2)

Dosinia johnstoni (1.1)

Eotrigonia intersitans (1.1)

Schiznopora sp. (1.1)

Ostrea sp. (1.1)

Porina gracilis (1.1.)

Rare species:- Hornera sp. (3)

Though related to the Fibularia biofacies, the biota is much more varied in this biofacies, and includes a number of species of bivalves, gastropods and bryozoans. There are fewer scavengers and more suspension-feeders, attached epibionts and burrowers.

The environment was probably much more stable and subject to much more gentle currents than the Fibularia biofacies, as the sediments in which it occurs contain much silty material. Deposition took place in a similar depth range, probably between 20 and 30 metres.

The Upper Maude Limestone Biofacies (figure 3.2)

(3) The Subninella Biofacies

This biofacies occurs in seven aphanitic limestone units at the base of the Upper Maude Limestone. In no cases were coarse fractions examined. The more characteristic species are:-

Common species:- Calcareous algae (6)

Subninella grangensis (4.1)

Cerithium flemingtonensis (4)

Cantharidus serratulus (3.2)

Astele millegranosa (2.2)

Cypraea leptorhynchia (2.2)

Triloculina sp. (2.1)

Rare species:- Terebratula sp. (3)

Pinnate and encrusting calcareous algae are abundant in this bio - facies, many being in life position, but the striking feature is the high percentage of vagrant epibionts. Most species are thick shelled (88%) reflecting strong current activity. The percentage of aragonitic shells is high for a biofacies with so many epibionts, but is a result of the quantity of vagrant herbivores and carnivores. A large number of the species present require an algal substrate for both food and attachment.

Gastropods are abundant, and though none of the genera present are restricted to the intertidal zone at the present day, all of them can live there. Large numbers of turbate forms occur in shallow keep - covered rockpools on the open coasts of Victoria today, and it is this sort of environment that was represented by this biofacies. The lack of limpets and barnacles suggests that there was little or no exposure and that most or all of the deposition was subtidal. Pinnate calcareous algae grow in sheltered areas in very shallow waters, and clearly the rock pools provided such an environment. The current activity was high and the depositional rate very slow. As with the other biofacies there is no indication of any brackish water influence.

(4) The Calcareous Algae - Schizomopora Biofacies

This biofacies is found in twelve units, in the silty sandy limestones, sandy silts and aphanitic limestones of the middle part of the Upper Maude Limestone. In ten cases coarse fractions were examined. The more characteristic species are:-

SPECIES PROFILES OF UPPER MAUDE LIMESTONE BIOFACIES

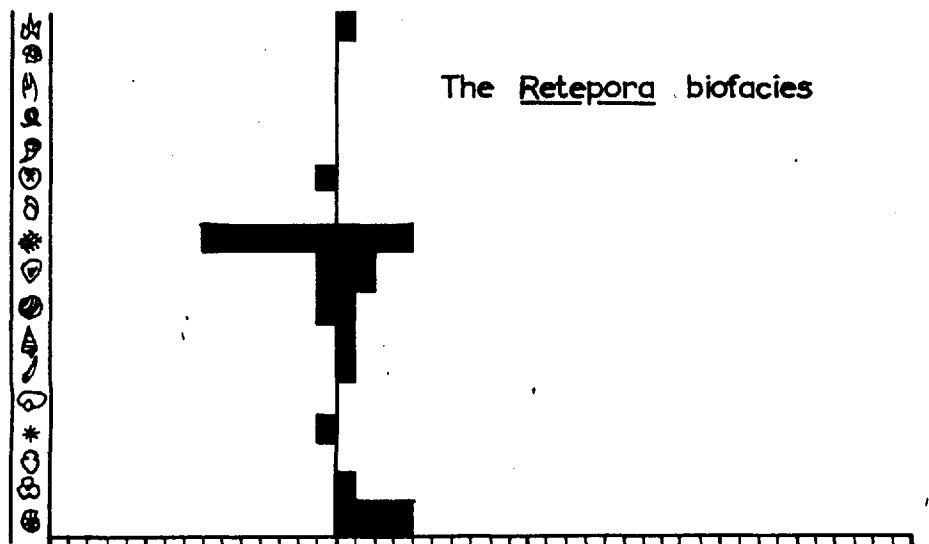
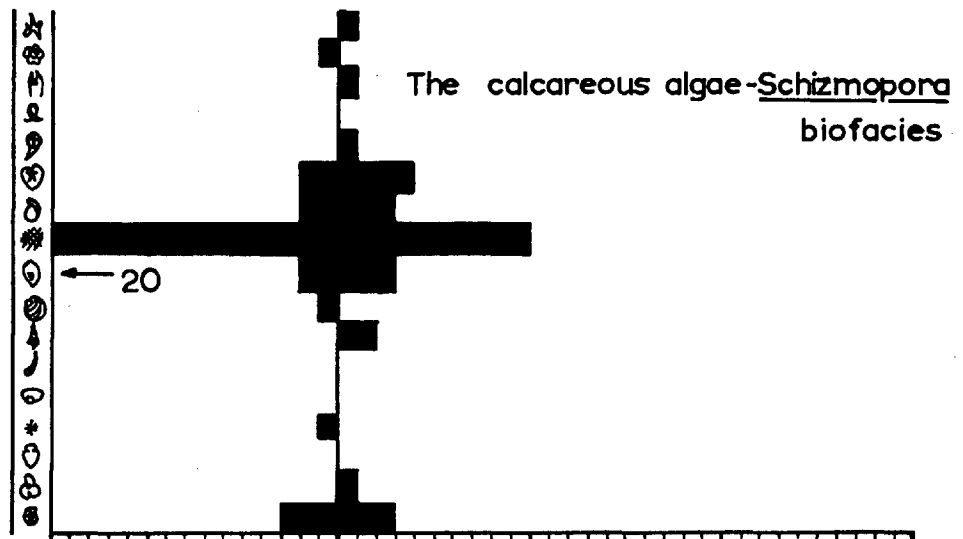
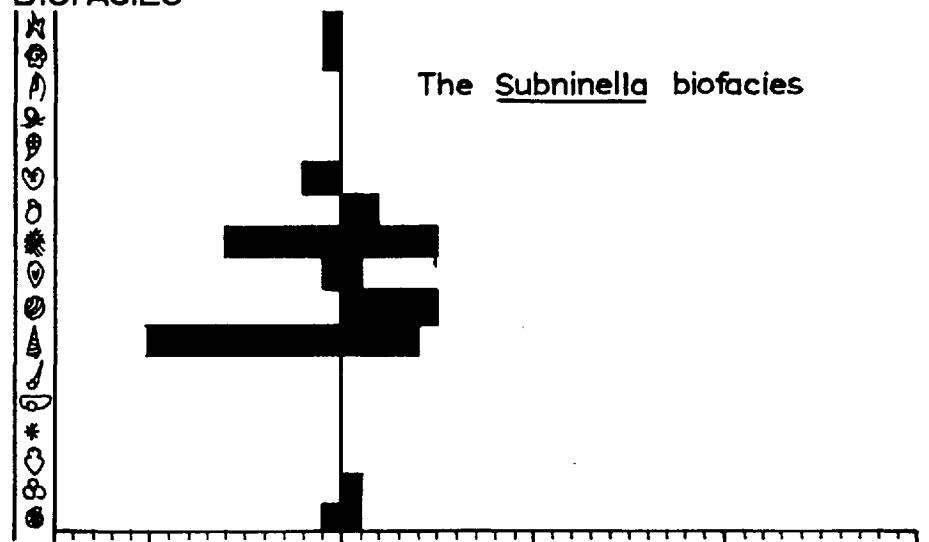


Figure 3.2

Common species:- Calcareous algae (7.2)

Melicerita angustiloba (6.1)

Schizomopora coronopus (5.1)

Idmonea sp. (5)

Hornera frondiculata (4.1)

Ostrea sp. (4.4)

Cidarid radioles (4.4)

Ramphonotus lusorius (4.1)

Amphistegina lessonii (4)

Cellaria longipora (4)

Entalophora longipora (4)

Retepora rimata (3.3)

Pecten polymorphoides (2.5)

Tretocalia pezica (2.3)

Porina gracilis (2.2)

Terebratulina scoulari (1.5)

Rare species:- Globigerina sp. (5)

Bolivina sp. (4)

Pecten foulchari (4)

There is a close relation between the biota of this biofacies and the Subninella biofacies. However, the percentage of attached epibionts is higher, and the vagrant herbivores and carnivores are reduced. Most of the calcareous algae fragments are pinnate, and a generally rich algal population is indicated by the high percentage of species that require an algal substrate.

The dominant bryozoan forms are cyclostomatous and all the important genera like Schizomopora, Cellaria and Melicerita live today in intertidal or very shallow subtidal water.

The biofacies occurs in the sections in units above the Subninella biofacies and is characterised by the smaller gastropod population.

The units in which it occurs are much more rich in clastic material and probably represent sand and silt flats that developed above the infilled rock pools in intertidal or very shallow subtidal environments. The abundance of fragments of pinnate calcareous algae indicates that rock pool environments were present in the neighbourhood.

(5) The Retepora Biofacies

This biofacies is found in eleven units, largely silty sandy limestones, at the top of the Upper Maude Limestone. In ten cases a coarse fraction was examined. The characteristic species are:-

Common species:- Retepora sp (4.1)

Ostrea sp (3.1)

Arachnopusia liversidgei (2.2)

Cellaria rigida var perampla (2.1)

Melicerita angustiloba (2)

Frondipora palmata (1.2)

Chione sp. (1.1)

Rare species:- Schiznopora coronopus (4)

Amphistegina lessonii (4)

Catenicella spp (4)

Dimya dissimilis (4)

Ramphonotus lusorius (3)

Cibicides thiara (3)

Anomalina sp (3)

This biofacies is very similar to the calcareous algae - Schiznopora biofacies and usually overlies it in the sections. It does not, however, contain any recognisable calcareous algae, and is richer in quiet water genera, like Retepora. Burrowing species total 25% and cyclostomatous bryozoans are replaced by shallow water cellari - form types.

The sedimentary environment was much more stable and the current activity gentle to moderate only. Deposition took place in the inter-tidal or very shallow subtidal zones but the rock pool Subninella environment was absent from the area and the supply of calcareous algae fragments lessened.

The Batesford Limestone Biofacies (figure 3.3)

(6) The Calcareous Algae - Pericosmus Biofacies

This biofacies occurs in six calcarenite units in the lower part of the Batesford Limestone. In five cases coarse fractions were examined. The more characteristic species are:-

Common species:- Calcareous Algae (6)

Sponge Spicules (5)

Cidarid radioles (5)

Membranipora fossa (4)

Cellaria sp. (3.1)

Pericosmus sp. (3.3)

Idmonea sp. (3)

Cibicides sp. (2.1)

Amphistegina lessonii (2.2)

Entalophora verticellata (2)

Operculina victoriensis (1.4)

Rotalia calcar (1.2)

This biofacies is dominated by fragments of pinnate and encrusting calcareous algae, and contains a limited number of species, mainly echinoids and bryozoa. They are largely epibiontic suspension-feeders, though there are some epi- and inbiontic scavengers. 12% of the species require an algal substrate, though the absence of herbivorous species suggests that the cover was not great.

SPECIES PROFILES OF BATESFORD LIMESTONE BIOFACIES

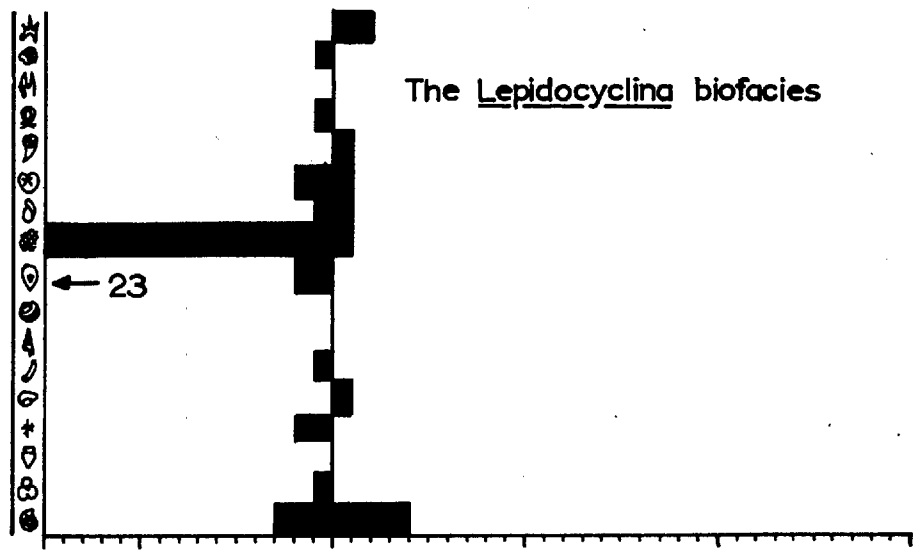
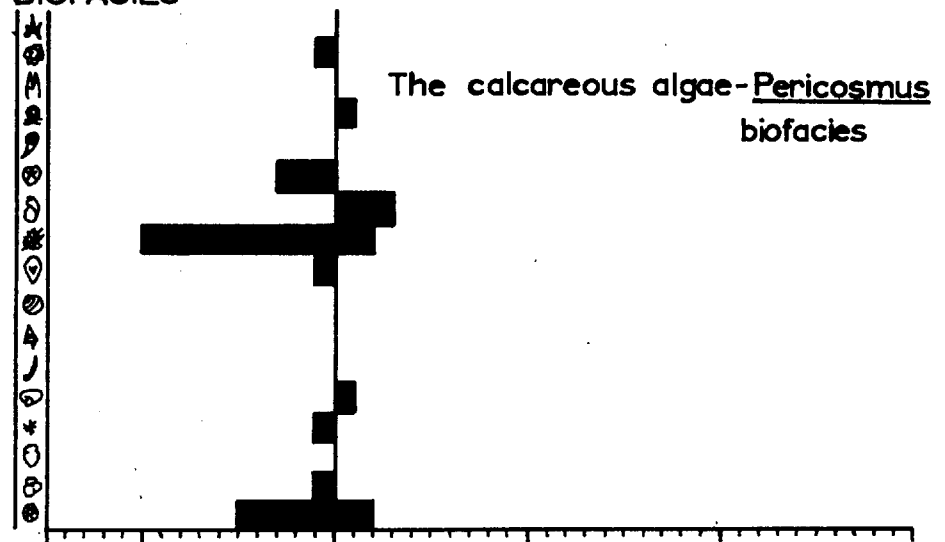


Figure 3.3

The current activity was moderate to strong, winnowing out all the material finer than sand grade, and supporting the high percentage of suspension feeders. None of the fragmentary material is in life position, and the only complete forms, the echinoids, provide the best indication of the environment. Pericosmus indicates depths greater than four metres and down to about thirty metres.

(7) The Lepidocyclina Biofacies.

This biofacies is found in twelve units, and characterises the calcarenites at the top part of the Batesford Limestone. Coarse fractions were examined in seven cases. The most characteristic species are:-

Common species:- Lepidocyclina howchini (11)

Calcareous Algae (11)

Cidarid radioles (8)

Idmonea spp (6)

Pericosmus sp. (6)

Entalophora longipora (5)

Cellaria crassimarginata (5)

Hornera frondiculata (5)

Membranipora spp (5)

Melicerita angustiloba (4)

Sponge Spicules (4)

Lichenopora australis (4)

Adeona sp. (3.2)

Amphistegina lessonii (2.2)

Pecten murrayanus (1.5)

Rare species:- Rotalia calcar (5)

Gypsina howchini (5)

The abundance of Lepidocyclina howchini crowding the bedding differentiates this biofacies from the calcareous algae-Pericosmus biofacies. The biota is slightly more variable, including rare carnivores and deposit feeders, but is very similar in all other respects. The passage from sediments without Lepidocyclina to those crowded with it, is very sharp and suggests that its presence is not due to evolution within the area, but to a sudden influx from outside.

Temperature was probably the controlling factor. Dorman (1966) recorded a palaeotemperature high in oyster and clam shells from the Lepidocyclina - bearing Batesford Limestone, and its equivalent in Gipsland, the Longford Limestone. The figures, recording temperatures throughout the Tertiary, were obtained from Ostrea hyotoidea and Ostrea arenicola and a variety of pectinids, including Chlamys murrayanus. Throughout the lower part of the Batesford Limestone, represented by the calcareous algae - Pericosmus biofacies, there were temperatures in the range of 19°C to 20°C, but during the period in which Lepidocyclina was present there was a sharp increase to 20°C to 26°C. The overlying clays of the mixed calcareous algae - gastropod biofacies are typified by much lower palaeotemperatures (14°C - 17°C).

Lepidocyclina, a tropical and subtropical genus, reached world wide distribution between latitudes 40° north and south during the Miocene and occurrences in Victoria and North Island, New Zealand, mark its farthest southward extension. It is most likely, therefore, that it could only exist in the period of temperature high recorded by Dorman.

As with the calcareous algae - Pericosmus biofacies, only part of the biota is complete and unfragmented. Thus the well-preserved Lepidocyclina howchini and Pericosmus are probably the only representatives that indicate the true environment. Probably deposition took place in depths of 4 to 30 metres in areas of moderate to strong current activity.

The Fyansford Clay Biofacies (figures 3, 4, 5, 6.)

(8) The Maoricolpus Biofacies

This occurs in ten units in the lower part of the Fyansford Clay, and is restricted to silts and clays. In nine cases a coarse fraction was examined. The more characteristic species are:-

Common species:- Cibicides spp (8.1)

Globigerina spp (8.1)

Anomalina sp. (7)

Adeona grisea (6)

Dentalium mantelli (5)

Maoricolpus murrayana (4)

Orbulina universa (5)

Nuculana chapmani (3.3)

Stereocidaris radioles (3.2)

Limacina tertiaria (3.1)

Notocallista eburnea (3.1)

Venericardia latissima (2.3)

Sponge Spicules (1.5)

Dentalium aratum (1.3)

Cypraea leptorhyncha (1.3)

Limopsis maccoyi (1.3)

Nassa tatei (1.3)

Rare species:- Porina gracilis (5)

Bullinella exigua (4)

Cerithium cibarioides (4)

Adeonellopsis obliqua (4)

This biofacies is dominated by Cibicides spp, Globigerina spp, Anomalina sp. and Adeona grisea. There is a very large number of gas-tropod species together with bivalves and bryozoans. Thirty three percent of the species are carnivorous, indicating that a large number

of soft bodied animals (e.g. gastropods and ascidians) were present. The higher percentage of inbionts than epibionts indicates that sedimentation was fairly continuous though slow, for there is a high percentage of suspension-feeders (33%). The epibionts largely comprise bryozoans that prefer gentle currents. Sixteen percent of the fauna is herbivorous, or requires an algal substrate.

The substrate consisted of silts and clays, variably calcareous and or sandy dependant upon the rate of deposition and current activity. The deposition was in the range of 40 to 80 metres (possibly as deep as 100 metres) and the salinity normal marine. The latter is taken to be equivalent to the mean salinity of the surface waters of the New South Wales and Victorian coasts at the present day - 35.5⁰/oo.

Deposition took place on the open shelf. Rich biotas are present on the clayey sea-floor of the Australian shelf seas at the present day, in contrast to the poor biota present in coastal bays such as Port Phillip (Port Phillip survey 1957 - 1963, 1966).

(9) The Gastropod - Orbulina biofacies

This biofacies also occurs in ten units in the lower part of the Fyansford Clay, and is restricted to clays. In seven cases a coarse fraction was examined. The more characteristic species are:-

Common species:- Adeona grisea (7.2)

Orbulina universa (6)

Cibicides sp. (6)

Globigerina sp. (5.1)

Vaginella eligmotoma (5)

Anomalina sp. (5)

Nuculana chapmani (4)

Limopsis maccoyi (4)

SPECIES PROFILES OF FYANSFORD CLAY BIOFACIES

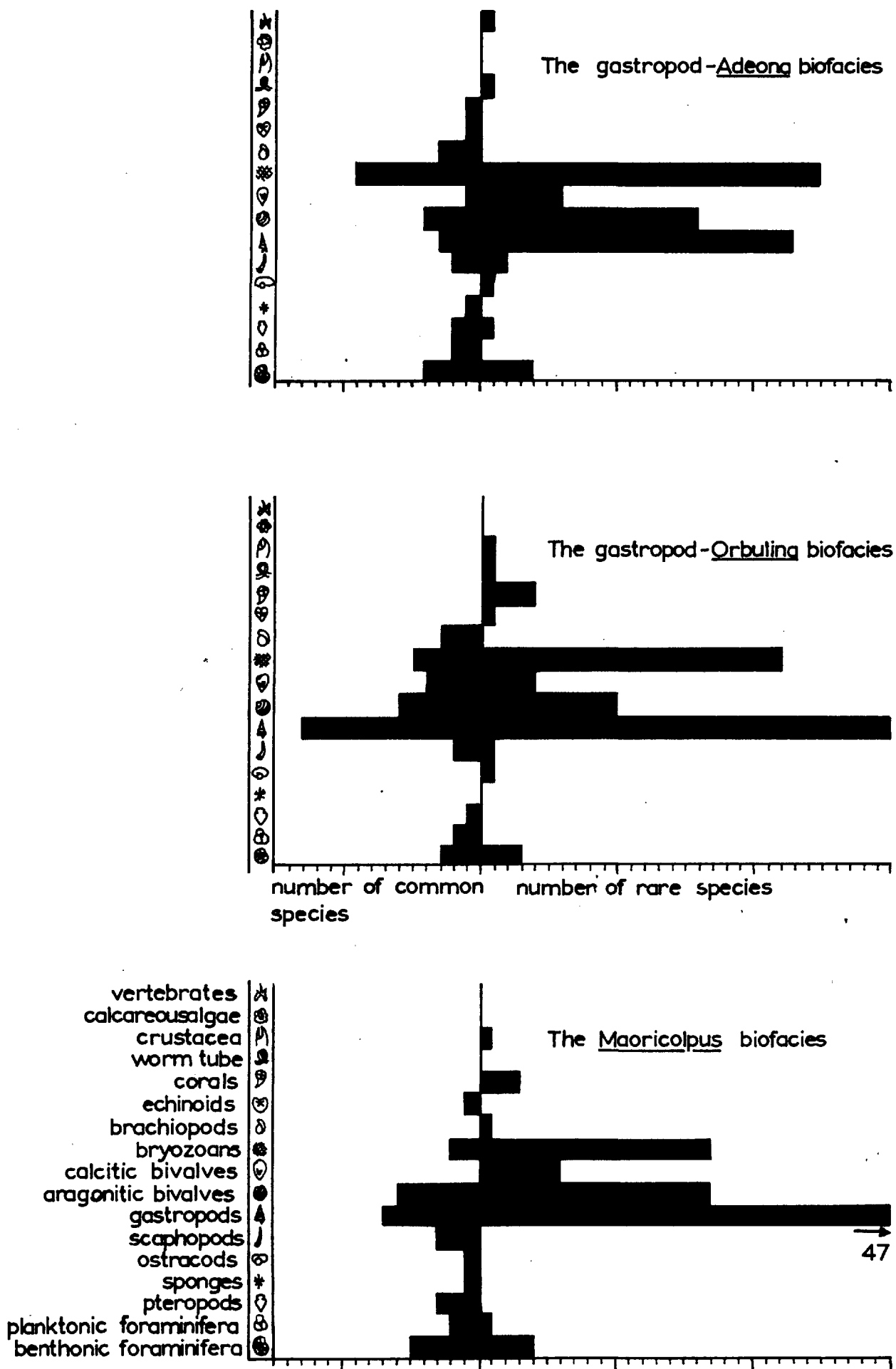


Figure 3.4

Marginella micula (3.3)

Bullinella exigua (3.1)

Ostrea sturtiana (1.3)

Rare species:- Colpospira tristira (7)

Stereocidaris radioles (5)

Barbatia celleporacea (4)

This biofacies is very similar to the Maoricolpus biofacies but the planktonic species are more abundant (Orbulina universa and Vaginella eligmotoma). There are fewer sponge spicules and aragonite-shelled bivalves, but generally more bivalves and bryozoans, reflected in the higher percentages of attached epibionts (30%) and calcite shelled species (25%).

The higher percentages of epibionts and planktonic species indicate a slower rate of deposition, but otherwise rather similar environmental conditions to the Maoricolpus biofacies.

(10) The Gastropod-Adeona biofacies

This biofacies is found in twelve units, also towards the lower part of the Fyansford Clay, but mainly occurs in sandy silty clays. In nine cases coarse fractions were examined. The more characteristic species are:-

Common species:- Adeona grisea (10)

Cibicides sp. (6.2)

Triloculina sp. (5.1)

Proxichione subtilicostata (5.1)

Anomalina sp. (4)

Sponge spicules (3.1)

Notocallista eburnea (3.3)

Dentalium subfissura (3.2)

Retepora rimata (3.2)

Orbulina universa (3.1)

Melicerita angustiloba (2.3)

Maoricolpus murrayana (1.3)

Rare species:- Cypraea spp (4)

Cardita delicatula (4)

Ostrea sp. (4)

Calcareous worm tubes. (4)

This biofacies is also similar to the Maoricolpus biofacies, but is much richer in bryozoans. Generally there are more thick-shelled, suspension-feeding epibionts and fewer burrowers (28%). Concomittantly there is a drop in the percentage of aragonitic-shelled forms (56%) and an increase in calcitic-shelled forms.

A. slower rate of deposition in the same bathymetric range as biofacies 1 and 2 is indicated. There is no predominant bryozoan form, all preferring gentle currents in areas of moderately slow deposition.

Most of the units in which the biofacies occurs contain sand grains, marking periods of very slow deposition when currents prevented clay-grade sedimentation.

(11) The Adeona Biofacies

This is found in seventeen units, in the middle part of the Fyansford Clay. It mainly occurs in sandy-silty-clays, and in thirteen cases a coarse fraction was examined. The more characteristic species are:-

Common species:- Adeona grisea (11)

Retepora porcellana (11)

Magellania corioensis (9.1)

Globigerina spp (8.2)

Schizmopora coronopus (8.1)

Cellaria spp (7.1)
 Sponge Spicules (6)
Cibicides spp (5)
Anomalina spp (4.5)
Orbulina universa (4.4)
Cranosina coronata (3.3)
Triloculina sp. (3.3)
Cidarid radiolites (2.3)

The Adeona biofacies is rich in epibionts (66%), most of which are attached, many to algae. The biota is largely suspension-feeding (77%), with a few scavengers. The high percentage of flattened species indicates the presence of gentle to moderate currents. Burrowers are rare (11%) reflecting the relative stability or hardness of the substrate.

Though the current activity was clearly higher than in the other biofacies, it was still only moderate, allowing deposition of silt-grade material to take place. Periods of slow or non-deposition are indicated by the high percentage of suspension feeders. The biota indicates depths between 20 and 60 metres in normal marine salinities with good oxygenation.

(12) The Adeona-Bivalve Biofacies.

Found in twenty two units towards the top of the Fyansford Clay sections, this biofacies occurs in sandy silty clays and calcareous sandy clays. In eighteen cases coarse fractions were examined. The more characteristic species are:-

Common species:- Adeona grisea (11.2)
Schismopora coronopus (6.1)
Dentalium mantelli (5.1)
Cellaria spp (4.1)
Retepora sp. (4.4)

SPECIES PROFILES OF FYANSFORD CLAY BIOFACIES

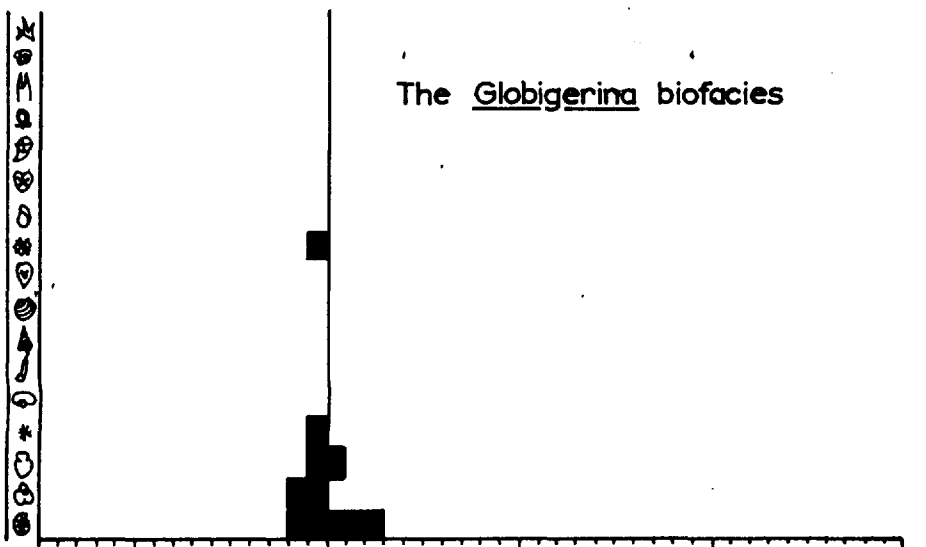
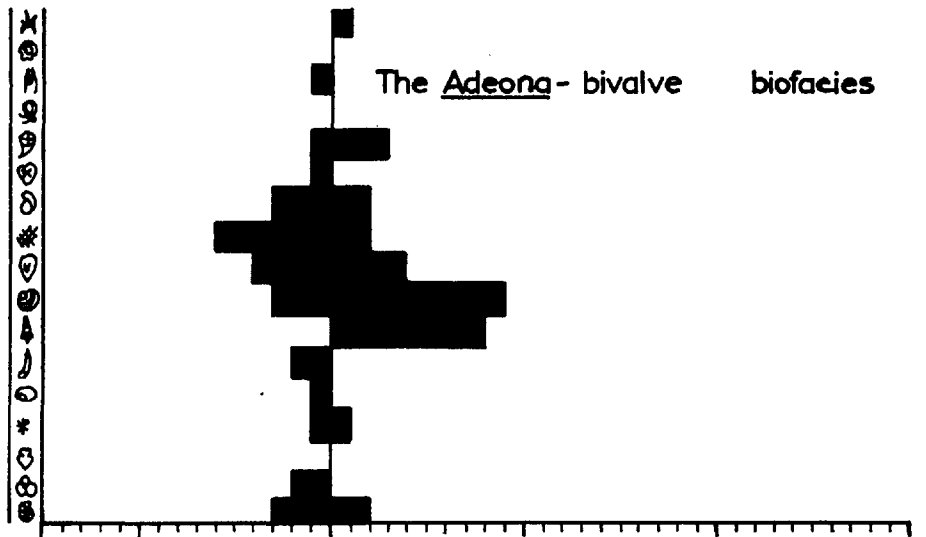
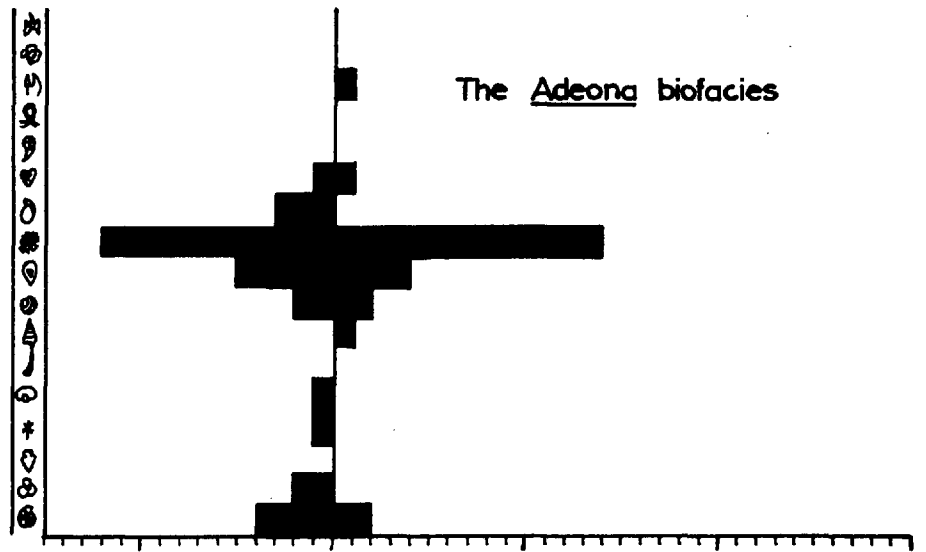


Figure 3.5

Magellania corioensis (4.2)

Ostrea hyotis (3.1)

Pecten sp. (3.1)

Placotrochus deltoideus (3.1)

Cidarid radioles (2.3)

Venericardia sp. (1.6)

Stethothyris insolita (1.3)

Anomalina sp. (1.3)

Spondylus gaderopoides (1.3)

Rare species:- Triloculina sp. (4)

Corbula ephamilla (4)

The composition of the biota is intermediate between that of the Maoricolpus and the Adeona biofacies. There is a high percentage of calcite-shelled suspension-feeding and scavenging epibionts, but more endobionts than in the Adeona biofacies. The substrate must have been rather less hard and richer in organic matter (and depositional rate rather higher) than in the latter, but otherwise the environment was probably very similar.

(13) The Globigerina Biofacies

This only occurs in five units in the middle part of the Fyansford Clay. It is found in silty clays and in all cases a coarse fraction was examined. The more characteristic species are:-

Common species:- Globigerina spp (4.1)

Orbulina universa (3)

Anomalina sp. (2.1)

Sponge Spicules (2)

Cibicides sp. (1.2)

Rare species:- Lingulina sp. (3)

The striking feature of this biofacies is the high percentage of planktonic species, the most common being Globigerina spp and Orbulina universa. There are no inbionts and a great reduction in benthonic species altogether. The composition of the biota is due to this marked reduction, and reflects considerable dilution of the benthonic population. Many authors have taken the increase in percentage of planktonic species to indicate relative distance from the shoreline, but this cannot be the case here, as the biofacies occurs in sections geographically closer to the Miocene land than the biofacies already considered (6 -12). Probably the scarcity of benthonic species is due to local unfavourable conditions or to rapid deposition.

(14) The Hinnites Biofacies

The Hinnites biofacies occurs in seven units at the very top of the Fyansford Clay in the south near Geelong, and overlying the Upper Maude limestone in the north. It is mainly found in sandy silty limestones and calcareous sandy silts, and in five cases a coarse fraction was examined. The more characteristic species are:-

- Common species:- Ostrea angasi (3.1)
Schiznopora coronopus (2)
Dimya dissimilis (2)
Anomalina nonnoides (2)
Cibicides victoriensis (2)
Placunanomia sella (1.2)
Magellania corioensis (1)
Proxichione sp. (1.1)
Serripecten yahlensis (1)
Hinnites corioensis (1)
Austrothyris grandis (1)
Ostrea ingens (1)

Rare species:- Pecten foulcheri (3)
Globigerina sp. (3)
Propeanmusium zitteli (2)
Retepora sp. (2)

This biofacies includes a high percentage of thick-shelled epibionts indicating moderate to strong currents and a cohesive substrate. The shells are largely calcitic (82%) suspension feeders, and there are very few aragonitic burrowers (10%).

The rate of deposition was very slow - nearly all the sediments are calcareous - and the depth of deposition indicated by the fossils was between 5 and 30 metres.

(15) The Mixed calcareous algae - gastropod Biofacies

Found in eight units, this biofacies is restricted to the clayey limestones and clays immediately overlying the Batesford Limestone and interbedded with the latter. In six cases coarse fractions were examined. The most characteristic species are:-

Common species:- Globigerina sp. (6)
Adeona grisea (5.1)
Orbulina suturalis (5)
Idmonea spp (5)
Cidarid radioles (4.2)
Anomalina sp. (4.1)
Cibicides sp. (4.1)
calcareous algae (3.1)
Sponge Spicules (3)
Dentalium subfissura (3)
Triloculina sp. (2.3)
Ostrea sp. (2.2)
Cypraea gigas (1.4)

4

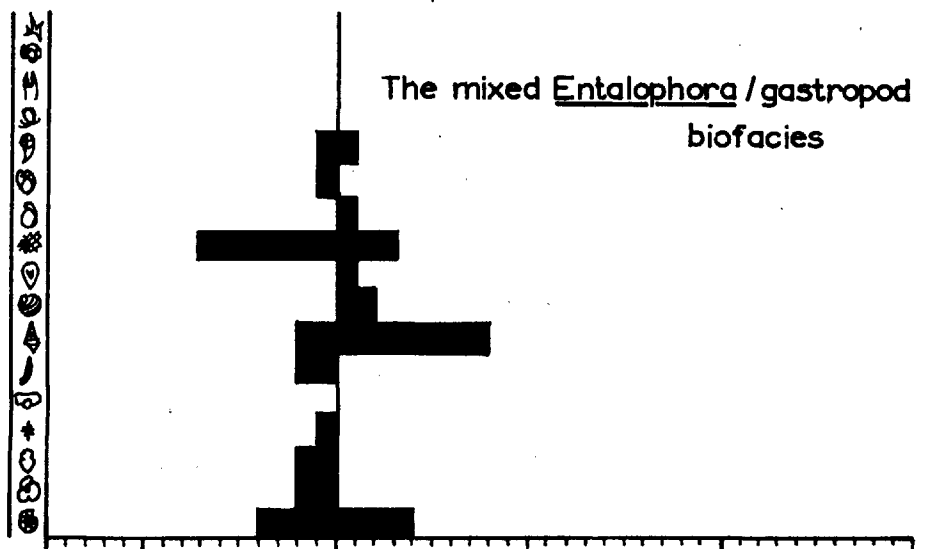
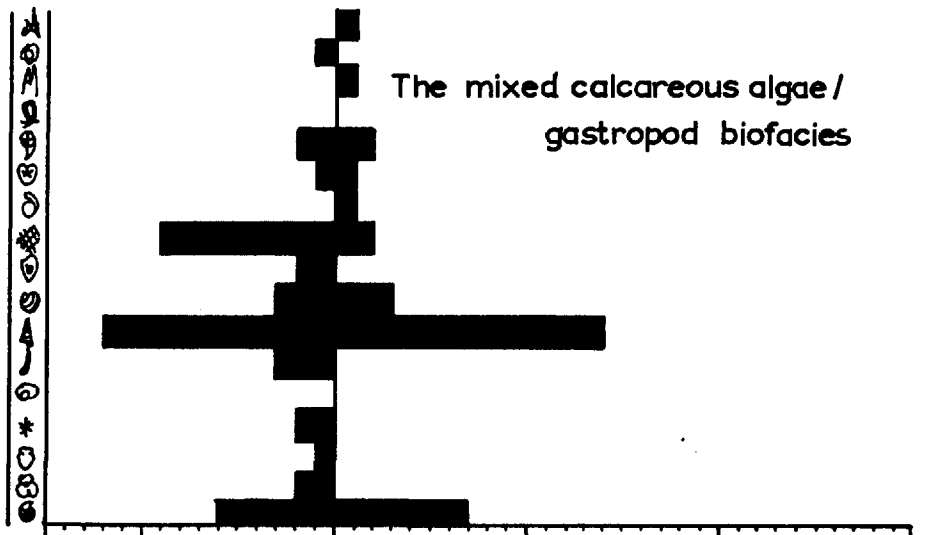
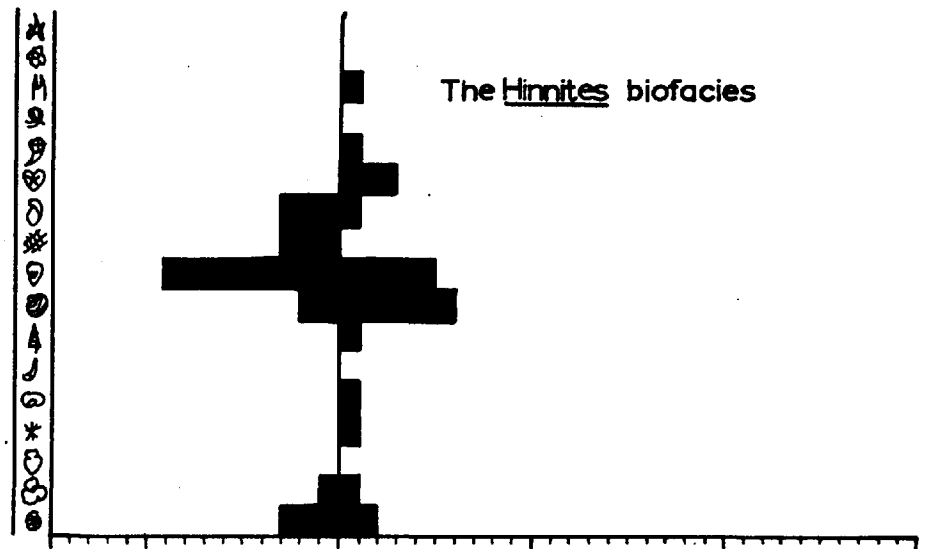


Figure 3.6

Pecten murrayanus (1.3)

Rare species:- Stephanotrochus australis (4)

Triphoris wilkinsoni (3)

Bolivina alata (3)

This biofacies, marking the transition between the Fyansford Clay and the Batesford Limestone, contains a biota similar to the Maoricolpus biofacies with the addition of fragments from the Lepidocyclina biofacies. It forms a mixed biofacies with many species represented by one or two specimens only.

The biofacies therefore represents an environment within the general framework of the Maoricolpus biofacies into which there were periodic influxes of material derived from the Batesford Limestone biofacies.

(16) The Mixed Entalophora - gastropod Biofacies

This biofacies, found in six units, also forms part of the transition between the Batesford Limestone and the Fyansford Clay. It generally overlies the mixed calcareous algae - gastropod biofacies in the sections and occurs in clays, clayey limestones and sandy silty limestones. Coarse fractions were examined in every case and the more characteristic species are:-

Common species:- Globigerina sp. (5.1)

Orbulina suturalis (3)

Idmonea sp. (3)

Astronion sp. (3)

Cibicides thiara (2.1)

Entalophora sp. (2)

Triloculina sp. (2)

Anomalina macraglabra (1.3)

Cidarid radioles (1.2)

Dentalium subfissura (1.1)

Dentalium mantelli (1.1)

This biofacies is similar to the mixed calcareous algae - gastropod biofacies but does not contain either calcareous algae or Lepidocyclina. In fact fragments derived from the Batesford Limestone are rather uncommon, and subtraction of them leaves a profile similar to that of the gastropod - Adeona biofacies.

The environment represented is similar to that of the gastropod - Adeona biofacies but includes material derived from the Batesford Limestone.

The Moorabool Viaduct Sand Biofacies (figure 3.7)

(17) The Ostrea angasi biofacies

This biofacies occurs in ten units in silty sandy limestones and calcareous sands throughout the Moorabool Viaduct Sands. Coarse fractions were examined in eight cases. The characteristic species are:-

Common species:- Ostrea angasi (4.2)

Mimachlamys asperimus (2.3)

Globigerina sp. (2.1)

Orbulina universa (1.1)

Rare species:- Elphidium chapmani (2)

Rotalia beccarii (2)

The biofacies contains many species that are still living on the coast of Victoria. Most of those that are not (including Orbulina universa, Elphidium chapmani and Rotalia beccarii) are limonitised and remanent.

The biota is one that occurs today in shallow bays and exposed beaches down to 10 or 15 metres. Most of the species are epibionts but only 50% are suspension feeders, 44% being scavengers and 8% being herbivores. Probably therefore the substrate had a cover of algae or

marine grass. Of a total of seventeen living species collected from the Moorabool Viaduct Sands by various authors (Dennant, Mulder, Coulson), eight inhabit the Tasmanian coast. It seems unlikely therefore, that there has been much temperature change in the water since the deposition of these beds. The average surface water temperature recorded from the Victorian coast is 14.4°C .

(18) The Zeacumantis Biofacies

This biofacies is restricted to the outcrops of the Moorabool Viaduct sands on either side of the Viaduct, and occurs in silty sandy limestone and sandy ironstone. No coarse fractions were examined, and the most characteristic species are:-

Common species:- Zeacumantis diemenensis (2)

Pholas australasiae (1.1)

Ostrea manubriata (1)

Polinices sordidus (1)

Ostrea angasi (1)

Balanus sp. (1)

Rare species:- Corbula stolata (2)

The fauna of this biofacies is related to that of the Ostrea angasi biofacies, but contains abundant gastropods. As the fossils are rather rare, the collections of Dennant (at the locality east of the Viaduct) and Mulder, Coulson, Dennant and of the National Museum of Victoria (from the locality on the west side of the Viaduct - section 8) were examined and included in the analysis of the biofacies.

The most important species, Zeacumantis diemenensis and Pholas australasiae, are both found at the present day in sheltered bays from low in the intertidal zone down to about six metres in the Flindersian province. Only 50% of the species are suspension-feeders, the others being carnivorous, herbivorous and deposit feeding. An algal or grassy substrate is indicated, therefore. There is no sign of reduced salinity.

SPECIES PROFILES OF MOORABOOL VIADUCT SANDS BIOFACIES

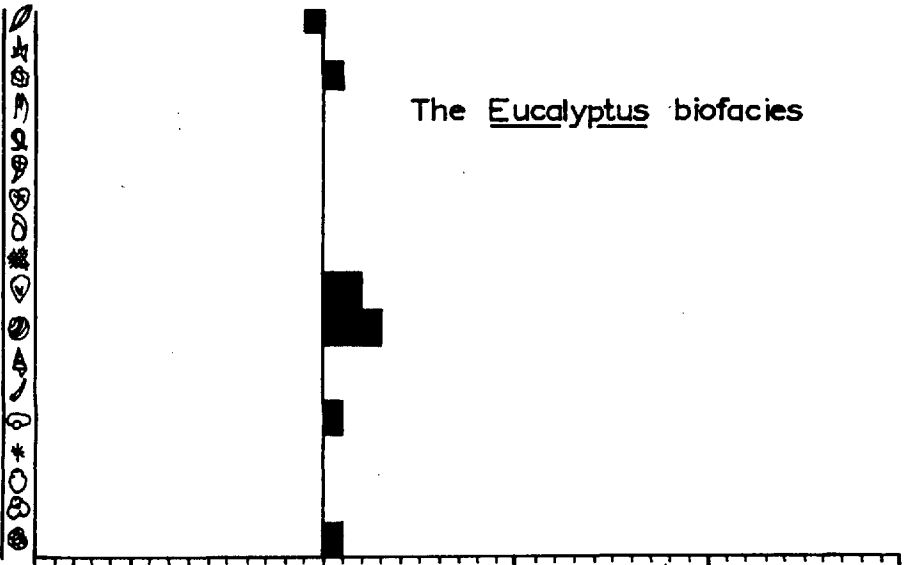
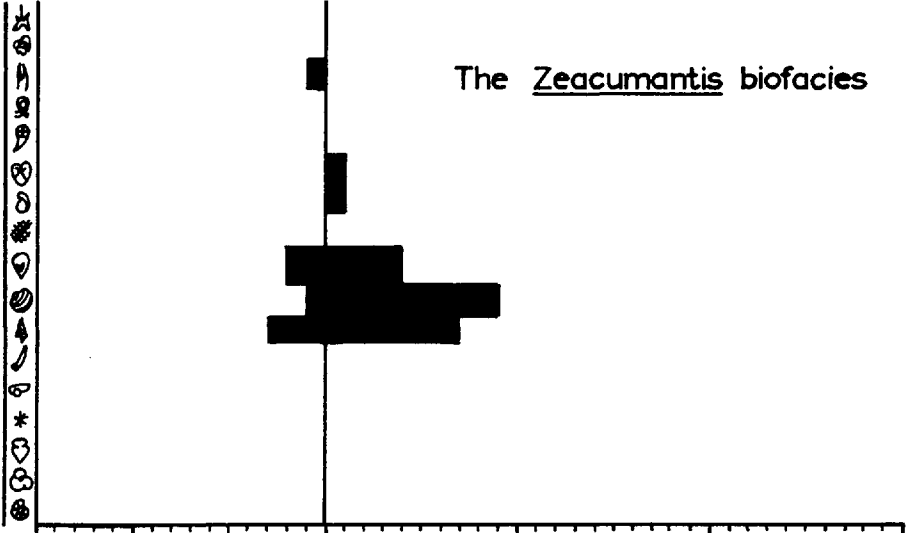
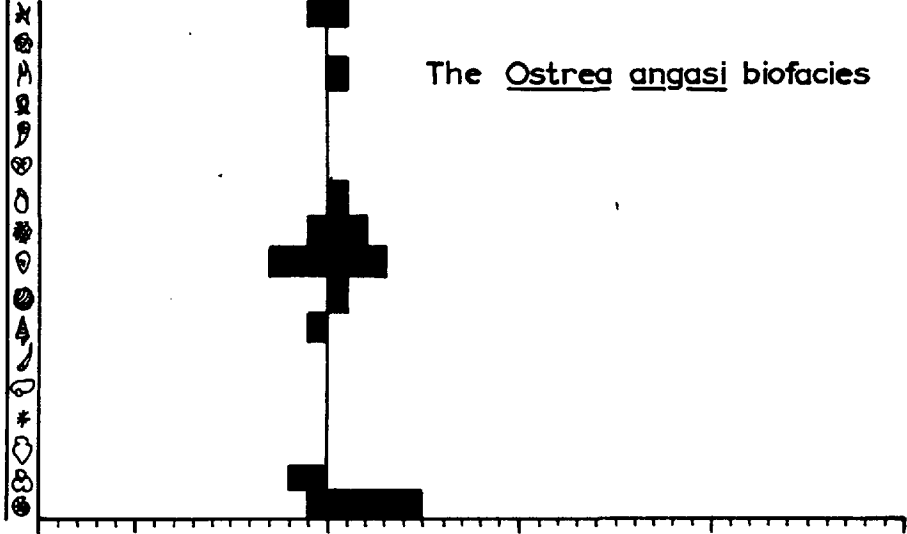


Figure 3.7

(19) The Eucalyptus Biofacies

This biofacies was only found in one unit, though Bowler (1963) recorded leaf-beds from poorly exposed parts of the Moora - bool valley sections between Lowndes Bridge and the Viaduct. He thought the beds were located at the top of the Fyansford Clay, but the biota is much more closely related to the Moorabool Viaduct Sands. The characteristic species are:-

Common species:- Eucalyptus sp.

Rare species:- Pecten sp.

Ostrea sp.

Corbula stolata

Diplodonta sp.

Notocallista sp.

Foraminifera (recorded by Bowler)

Ostracoda (recorded by Bowler)

Calcareous Algae (recorded by Bowler)

The biota is dominated by poorly preserved ferruginous leaves of Eucalyptus sp. They occur in a silty sandy limestone crowding many bedding planes without preferred orientation.

The environment indicated was similar to that of the Zeacumantis biofacies, but deposition probably took place in the intertidal zone where plant material was contributed to the marine sediments.

CHAPTER 4

THE BIOTURBATION

Burrows occur in all of the formations examined. The poverty of exposure, however, made it difficult to obtain a great deal of data on them. Burrow types with various morphologies in different types of sediment such as were recognised in the Zelten area (Libya) were not encountered, probably because the sediments in which each type occurs are much more uniform.

Considerable caution had to be exercised in the collection of data, as the surface of the exposures, often down to about 2 metres was penetrated by empty, or sand, clay and lignite filled tubes belong to Recent grasses, shrubs and insects. These could be differentiated by their attitude, content and distribution.

Most of the burrows have very similar structures and are distinguished only by their pattern. To a great extent therefore, they are morphotypes, and it is probable that some at least were created by more than one organism.

All of the burrows are cylindrical and may be divided into:-

(A) Branching burrows:

(i) walled: Thalassinoides (diffuse wall)

Capsites (thin silty wall)

Rosselia (concentric wall structure)

(ii) unwalled: Eurydichmus (regular plexus)

Daedalichnus (0.1 to 0.4 cm in diameter.
forms an irregular plexus.)

Needlechnus (0.2 to 0.4 cm in diameter.
irregular branches)

(B) Unbranched burrows:

- (i) walled: Phaedrella (0.2 to 1.7 cm in diameter).
- (ii) unvalled: Vertillichnus (0.03 to 0.3 cm in diameter
straight)

Batesfordichnus (irregular 2.0 cm in diameter)

For each of the burrows, a list of the sediment types and associated burrows is given together with a description of its distribution.

BIOTURBATION	no. of units	% distribution in							% association with biofacies and each other						
		clay	snd clay	silty snd lst	calc snd	lst	snd	der- ived	over 90	80-90	70-80	60-70	50-60	40-50	30-40
Thalassinoides	22	28	40		14	9	10	11							Euryd.
Capsites	14	21			35	28	14							Vert.	Thalass
Rosselia	31	26	58			6	10								Euryd.
Eurydichnus	48	69	27			4									
Daedalichnus	18		25		12		63							Phaed	Thalass
Needlechnus	12				20		80				Fibularia				Phaed.
Phaedrella	23	53				4	39	4							
Vertilichnus	5	60			40								Capsites		
Batesfordichnus	5	80				20							MC		

Occurrence of the bioturbation structures

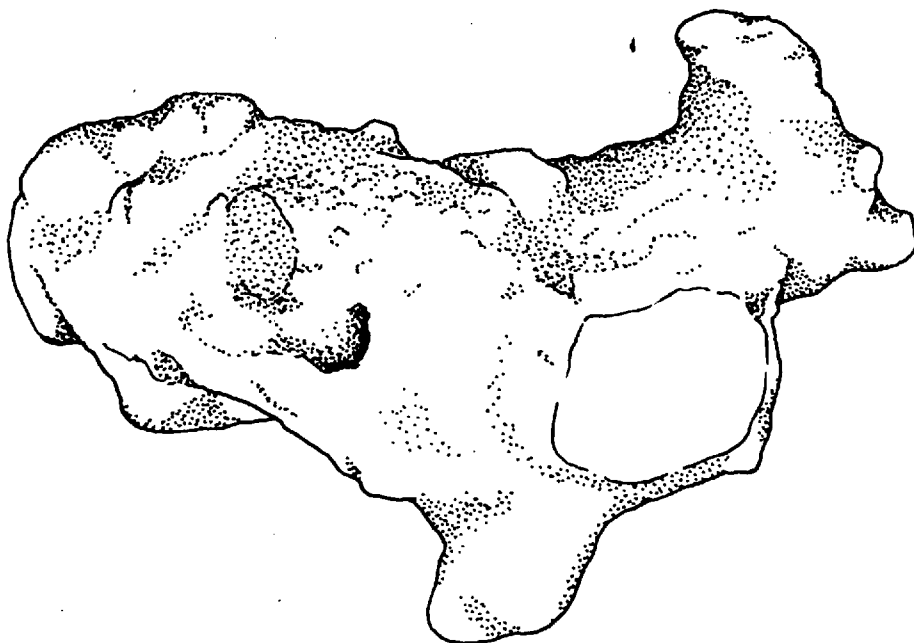
Thalassinoides Ehrenberg (figure 4.1)

Description: The burrows consist of thick-walled vertical and horizontal cylindrical tubes, mostly between 3.0 and 7.0 cms in diameter (especially 4 to 5 cms). Short, blindly ending branches may be less than 1.0 cm in diameter (figure 4.1a)

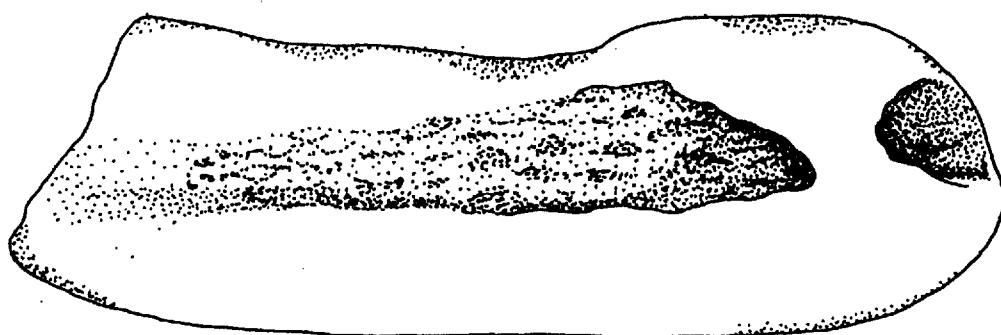
Straight, unbranched vertical components are connected to rather irregularly Y-branching components. The morphology of the outer surface is irregular, and dependant upon the composition of the host rock. The fill may be wholly uncemented but typically consists of carbonate-cemented host-rock in which there is a tendency for the shells and shell-fragments to become concentrically aligned around the centre. As a result of this distribution of material and limonitisation, which frequently occurs, spreiten or multiwalled-structures often appear to be present.

The central area of the burrow is indistinctly separable from the wall, and usually contains large fragments of fossils up to 3.0 cms in diameter arranged concentrically around the centre. It may be filled with soft silty sediment, however, as in a specimen from Maude (section 16). In the latter case, an 0.1 to 1.5 cm wide central tube has irregular elongate ridges running parallel to the length of the burrow.

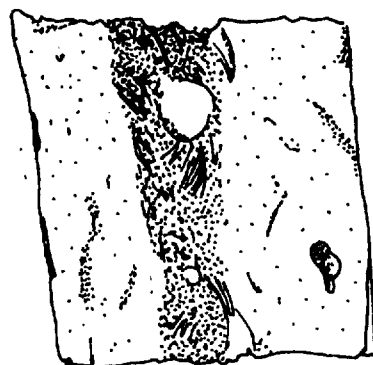
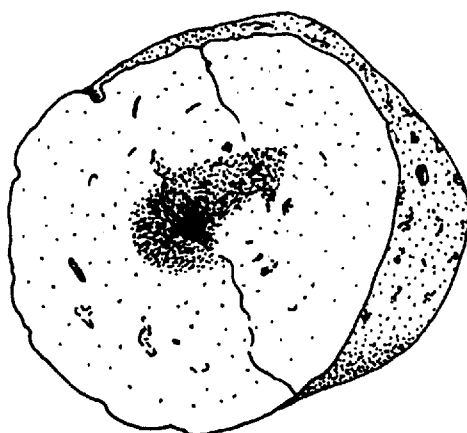
Well-worn and rounded elongate pebbles 4.3 to 7.0 cms in diameter in the phosphate nodule bed at the base of the Moorabool Viaduct Sands (Coulson 1932) show the characters of those burrows - either 4.5 cm. wide tubes filled with concentrically-arranged decalcified shell-fragments up to 2.0 cm. in diameter (figure 4.1c), or else burrows with central tubes and elongate ridge marks on the inner surfaces of the walls (figure 4.1b)



a Thalassinoides Ehrenberg. Branching specimen (x0.5) Section 1



b Thalassinoides with discrete inner tube with longitudinal ridges.
Derived pebble from the phosphate nodule bed, section 7 unit 9



c Thalassinoides with diffuse central areas and aligned shells
in transverse and longitudinal section.(x1) Section 7 unit 9

Figure 4.1

Distribution: Those burrows are present in many different sediments and formations, though they are mainly found in the calcareous sandy silts and clays near the top of the Ryansford Clay. They are associated with nearly all of the biofacies and indicate a wide range of environments.

Interpretation: These Thalassinoides burrows represent the activity of organisms that secrete material into the sediment to form large calcareous structures, resembling concretions. Though two types seem to be present, they proved to be inseparable. Burrows with diffuse central areas were sometimes found to pass along their length into forms which the central area was clearly differentiated. The burrowing pattern and morphology of the burrows closely resembles those of Thalassinoides thought to be created by decapod crustaceans.

The only decapod remains common in the area are those of a crab, Ommatocarcinus corioensis Creswell. This was recorded by Keble (1932) as abundant in the "phosphatic nodules" (actually pebbles) in the conglomerate at the base of the Moorabool Viaduct Sands. Well-preserved chela and complete carapaces have been recorded from many of these pebbles, which almost exclusively represent derived Thalassinoides burrows. Hall (1905) suggested that the excellent preservation of the specimens of O. corioensis he described indicated that they had probably been entombed in their burrows when they died. Probably, therefore the derived burrows in the phosphate nodule bed were excavated by Ommatocarcinus corioensis. The presence of elongate ridges representing scratch marks characteristic of crustaceans' burrows, supports the correlation of those structures with arthropods.

Decapods of the genus Callianassa are known to secrete amorphous calcium phosphate (Collophanite) into the walls of their burrows to bind them (Weimer and Hoyt 1964), and it is possible that the derived

phosphatic "nodules" were primarily rich in phosphate before they were eroded and redeposited. Coulson (1932) recorded between 12.15 and 24.60% P_2O_5 in nodules from the Geelong district. He added that Howitt and others had seen "concretionary phosphatic nodules" - almost certainly representing Thalassinoides burrows, in the Fyansford Clay at Western Beach, Geelong (section 2). Analysis of these by Doyle indicated between 11.01 and 24.74% P_2O_5 , while the microscopic structure was seen to be identical with that of the derived phosphate nodules. The P_2O_5 content of the surrounding sediment was found to be less than 1%. Coulson (1932) regarded the phosphate of the pebbles as a replacement mineral, and concluded that it was in part oolitic and in part interstitial. The oolites he saw were probably the sand balls seen in the thin section from the pebble bed in section 7 (photo 4.2a).

The burrows that are in situ have not yielded O. corioensis but their similarity with the derived specimens in the nodule bed suggests that they were created by the same animal.

Hall and Keble both noted that O. corioensis was closely related to the living species O. macgillivrayi White, a species found on the mud flats of Port Curtis, Queensland, and in waters down to about 20 metres off the coast of North Island, New Zealand.

Capsites nom. nov. (figure 4.2.a)

Derivation of name: Refers to the in silty case present in this burrow.

Description: These are 0.4 cm. to 2.1 cm. diameter frequently branching and anastomosing cylindrical burrows (figure 4.2.a(i)). Typically the branching is Y-fashion, the internodes varying, but generally between 3 and 10 cms long. The burrows are disposed horizontally or are gently inclined, and horizons up to 15 cms thick are bioturbated. Some of the horizontal components cross each other but do not interfere, the later burrow passing up and over the earlier one.

On weathered surfaces the outer surface of the burrow is often divided from the surrounding sediment by an 0.1 cm. wide groove. This represents limonitic silty material that has been removed by erosion. This thin case of silty material may be seen in a few specimens.

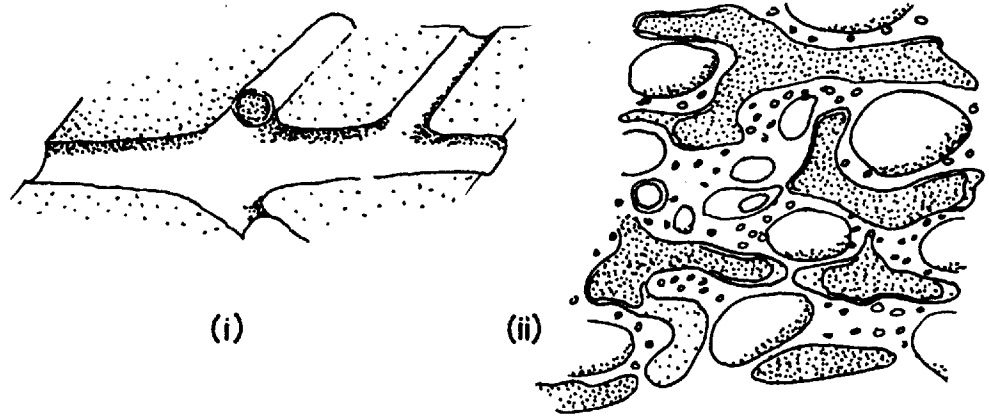
The burrow fill consists of sand or skeletal or limonitic sand of similar composition to the host rock.

The pattern of burrowing is very flexible. In an exposure near the Moorabool Viaduct, where a plexus of burrows is developed in a gritty conglomerate, the organisms excavate the matrix material between the intraclasts avoiding the coarser grit and pebbles (figure 4.2.a(ii)). On horizontal bedding planes horizontal members are often straight for up to 20 cms, giving off branches dichotomously or trichotomously every few centimetres.

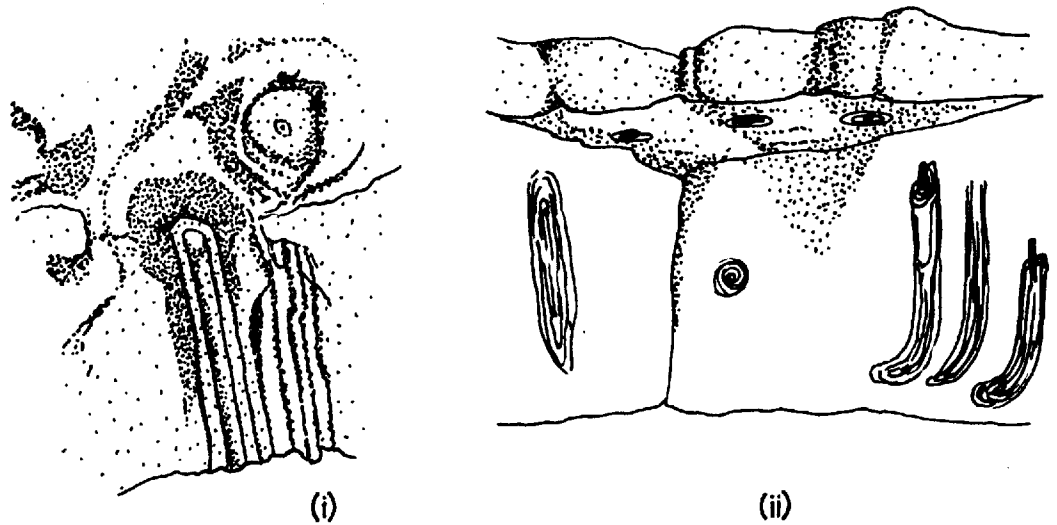
Distribution: This burrow occurs very largely in sands and calcareous sands, though a few specimens occur in limestones and silts. It is most closely associated with the Retepora biofacies.

Interpretation: Irregularly branching burrow systems bioturbating thick levels in the sediment may be caused by a variety of deposit feeders in a variety of depths of water at the present day. Polychaetes

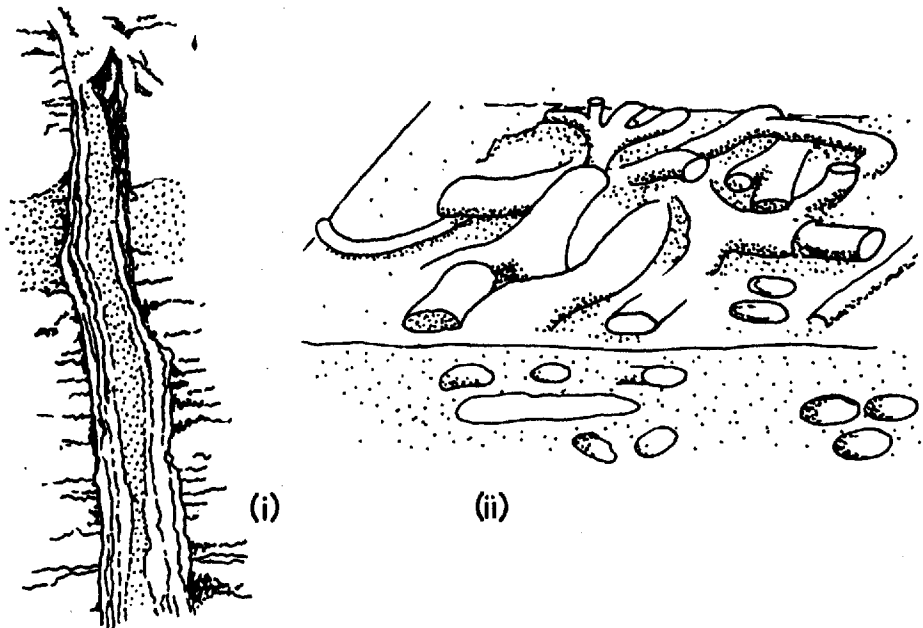
produce such structures in intertidal and subtidal deposits (Schafer 1962, Reineck 1967), and the thin silty or calcareous case around the burrow suggests that it was lined with mucus, such as polychaetes produce (Reineck 1967). The biofacies with which these burrows are associated indicate areas of moderate to strong current activity in depths of 0 to 25 or 30 metres



- a** (i) Capsites. Branching specimen. Section 16 unit 13 (x1)
 (ii) Capsites. Branching plexus between pebbles. (x1) On road near Moorabool Viaduct, (352047).



- b** (i) Rosselia Dahmer. Two adjacent specimens showing concentric walls. (x1) Section 1 unit 2
 (ii) Rosselia. Rooting from sandy unit, burrowing in clay. (x0.1) Section 7 units 4 and 5



- c** (i) Multiwalled Nereis diversicolor burrow, from Jade Bay tidal flat, North Sea. (x1) After Reineck 1967.
 (ii) Eurydichnus. Irregular ramifications in U. Maude Lst (x1)

Figure 4.2

Rosselia Dalmer (1937) (figure 4.2b)

Description: This type comprises unbranched and generally straight cylindrical burrows, 1.0 to 2.7 cms in diameter, often with a multiple wall composed of concentric shells parallel to the length, alternately richer in silty or sandy material. In the centre is an 0.3 to 0.5 cm. diameter, often depressed, hard and limonitic core that weathers out in isolated lengths approximately 3.0 cms long. The multiwall structure weathers out as a series of elongate shells, each 0.01 to 0.08 cms diameter. In silty units the thicker components of the shells are composed of silt with sand grains, and are separated by bands composed of limonite-coated sand grains only. In sand units the thicker components are composed of sand grains. The burrows typically occur in a concentration of 3 per 10 cm. of vertical section.

Vertical burrows 40 cms long are found in sandy silty clays. At their bases, some specimens show a tendency to swing towards the horizontal. Several specimens at Fyansford, section (3), are parallel to one another and separated by 3.3 cm. Their burrow pattern suggests they may be U-shaped. Adjacent parallel tubes often differ in structure - one is very much less complex, being composed of a soft limonitic core 0.3 cm diameter without a concentric wall. At section (1) in the calcareous sandy silt bands where the burrows are much more complicated, parallel tubes are often adjacent to one another and show vertical spreiten patterns. Large specimens 7.0 cms in diameter at section 3 also show spreiten.

Distribution: Rosselia is typical of the sandy clays and calcareous sandy silts of the Fyansford Clay and is very closely associated with the Fyansford Clay biofacies. It frequently occurs with Eurydichmus, Thalassinoides and Phaedrella.

Interpretation: As was pointed out by Goldring (1962), concentric wall patterns composed of alternating layers of silty and sandy material can arise in a number of ways. The persistence of these layers for up to 15 cms vertically in unlaminated sediment suggests that the organism cemented material to the wall, rather than that it was due to constant excavation of the burrow or to migration through interlaminated sediment. Examples of living organisms that line their burrow wall with sand grains to produce a concentric structure are common in the Recent. Burrows of Nereis (Reineck, 1967), Echiurus (Reineck et al, 1967) and Mya (Schafer 1962) are good examples (figure 4.2c(i)).

Nereis produces rather irregular branching multiwalled burrows in tidal flats e.g. these on the Norfolk coast. Mya burrows in much the same environment, but no shells were found associated with these burrows so it is considered improbable that they were produced by molluscs.

The best correlation of these burrows is with the multiwalled U-shaped burrows of Echiurus echiurus which have been recorded by Reineck et al (1967) from depths of 25 to 35 metres off the Weser and Elbe estuaries. The long straight vertical unbranched components particularly resemble the fossils.

It is concluded that these burrows were excavated by worms, possibly echiuroid, and that the multiwalled structure was caused by cementation of sand grains with mucus. The association of the burrow with the Fyansford Clay biofacies suggests that it preferred depths of 5 - 60 metres in areas of slow deposition where the currents were gentle to moderate and the salinity was normal marine.

The concentric wall structure and hard central tube of this burrow are very similar to those forming the funnel of Rosselia Dahmer (1937). The specimens from Victoria have a much more

extensive concentric wall structure than the specimens described by Dalmer, but it is not present throughout the burrows. Clearly, only part of the burrow was lined in each case.

Eurydichnus nom. nov. (figure 4.3a)

Derivation of name: Refers to Eurydice, who was called down into the underworld.

Description: These are predominantly horizontal meandering burrows, typically between 0.4 and 0.6 cm. diameter, forming a compact and close knit plexus on some bedding planes. Smooth-walled and occasionally Y-branching tubes, with internodes of at least 5 cms are linked to other horizontal planes by low angled inclined tubes, so that a total thickness of between 2 and 4 cms of sediment may be burrowed from any one horizon (figure 4.3a(ii)). They commonly occur in clays and are nearly always depressed into an elliptical shape as a result of compaction. Economical coverage of horizontal surfaces is demonstrated by a "helminthoid" pattern sometimes exhibited (figure 4.3a(i)). In these cases, the meandering course of one burrow is closely followed for a few centimetres by another. In the clay beds the fill is often characterised by shrinkage cracks which occur approximately every 0.5 cm. along the length of the burrow.

In the sandy silts the pattern is much less regular. The burrows are often more closely spaced and though they never burrow through one another, they occasionally pass over the top of an earlier burrow. The gentle meandering is lost, and both the diameter and the branching become much more variable. The latter is both Y-shaped and right angled and may be dichotomous or trichotomous, leading to a radiating pattern. The diameter may be as little as 0.15 cm. or as great as 0.7 cm. (figure 4.2.c(ii)). The fill in these burrows may be coarser than in the host rock in general. A few specimens have a thin, 0.1 cm. diameter calcareous or limonitic case.

Distribution: Eurydichnus occurs in the Fyansford Clay and the Upper Maude Limestone. It is found mainly in clays and calcareous silty clays but is also common in sandy silts and calcareous sandy silts. It is closely associated with a number of marine biofacies, the most

important of which are the Maoricolpus, the gastropod-Adeona, Adeona and Adeona-bivalve biofacies.

Interpretation: The burrows were caused by deposit feeding animals that excavated organic rich bands in the sediment. The economical coverage of horizontal surfaces is a characteristic of such a habit. Those occurring in the deeper water silts and silty clays are much more regular than those in the shallower silty limestones. This is a reflection of the difference in energy levels between the two environments. In the deeper waters where the sedimentation is relatively uninterrupted the distribution of organic matter within the sediment is much more even than in the more variable shallower waters where it tends to occur in isolated pockets.

The fine-grained burrow fill suggests that the burrower did not retain an open burrow system, but excreted material as it passed through the sediment.

The patterns of burrowing and associations with the biofacies suggest that the type found in the Fyansford Clay burrowed in organic-rich silts and clays in depths of 4 - 80 metres, while the type found in the Upper Maude Limestone burrowed in shallow water and intertidal conditions.

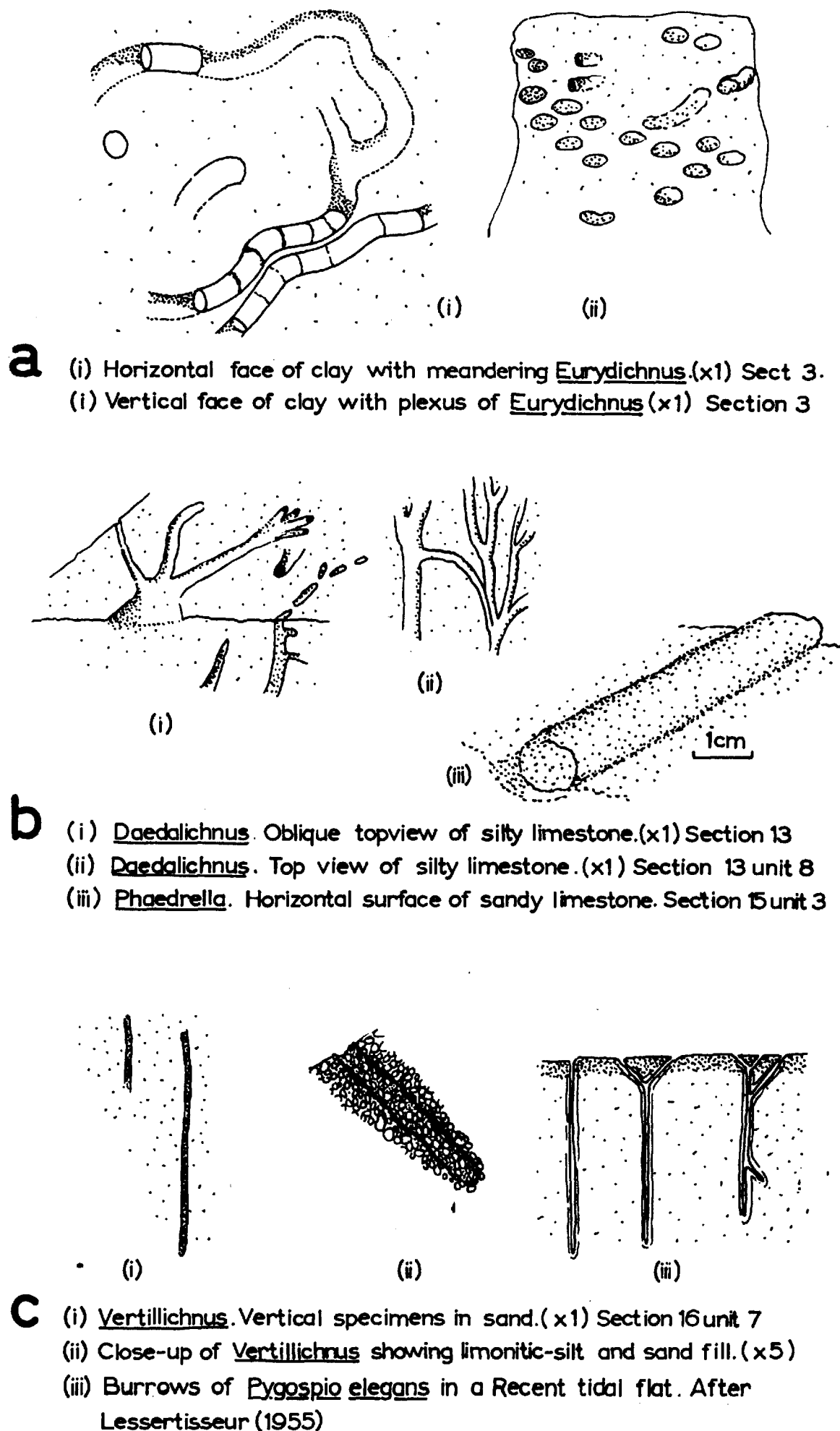


Figure 4.3

Daedalichnus nom. nov. (figure 4.3b)

Derivation of name: Refers to Daedalus, who designed the great labyrinth at Knossos.

Description: This burrow consists of meandering round burrows 0.1 to 0.4 cms in diameter, without any casing. In the dominantly horizontal burrows branching is very frequent and mainly random. The most common sized branches, 0.15 cm. diameter often Y-branch irregularly twofold, threefold or even fourfold (figure 4.3.b(ii)). The internodes are variable, but on average are 1.0 cm. long. The predominantly vertical or steeply inclined types radiate outwards and downwards through about 3 cms of sediment. Slightly meandering components on bedding planes give rise to downward directed bundles of tubes often indicating four- or fivefold branching. These may give rise to horizontal branches at various levels (figure 4.3.b(i)).

The fill may be host rock, uncemented sand or calcareous sandy silt. Occasionally it is composed of 0.05 cm. diameter egg-shaped silty pellets with a cohesive limonitic case. At section 7 unit 4 consists almost entirely of clay pellets in bundles 0.5 cm. large.

In a few specimens a transverse annulation marked by constrictions every 0.1 cm is developed.

Distribution: Daedalichnus occurs in sands and calcareous sandy silts and is associated with a number of biofacies, especially the Retepora, gastropod-Adeona, Fibularia and Eotrigenia biofacies, and many of the burrow types.

Interpretation: The irregularity of size and pattern of the horizontal members distinguishes this type from Eurydichnus. They are, however, closely related in that they branch, are uncased and produce complex burrow systems in beds. The habit is that of a deposit-feeder and they represent a rather similar environment to the other deposit

feeders present. They are closely associated with Phaedrella and Thalassinoides.

The bundles of balled-up silt pellets associated with these burrows may represent faecal material. Their egg shape suggests they are probably not the faecal material of crustaceans - (the latter produce rod-shaped faecal pellets). Probably these burrows were caused by deposit feeding worms.

Needleichnus nom. nov. (photo 4.1)

Derivation of name: Refers to the needle-like appearance of these burrows.

Description: These comprise 0.2 to 0.4 cm. diameter vertical, horizontal and meandering branching burrows forming simple or complex patterns in sands and calcareous sands.

The internodes are very variable, being as little as 1 cm. long or persistent through a length of 5 cms. Branching usually takes place at 90°, and is especially common at some highly bioturbated horizons.

The burrows are sand or calcareous sand filled and have no silty or calcareous casing or wall.

Distribution: These burrows are restricted to the sands and calcareous sands of the Lower Maude Limestone, where they are almost invariably associated with the Fibularia biofacies. Phaedrella occurs quite commonly with this type.

Interpretation: Needleichnus burrows closely resemble their counterparts from Libya, and the burrows produced in sandy tidal flats at the present day by the deposit feeding polychaete Scoloplos armiger (Reineck 1967). Simple sand filled tubes or dense plexi are produced by the latter depending upon the concentration of organic matter within the sediment. The associated biofacies indicates that the depth of deposition was in the range of 25 - 40 metres in waters where the current activity was high.

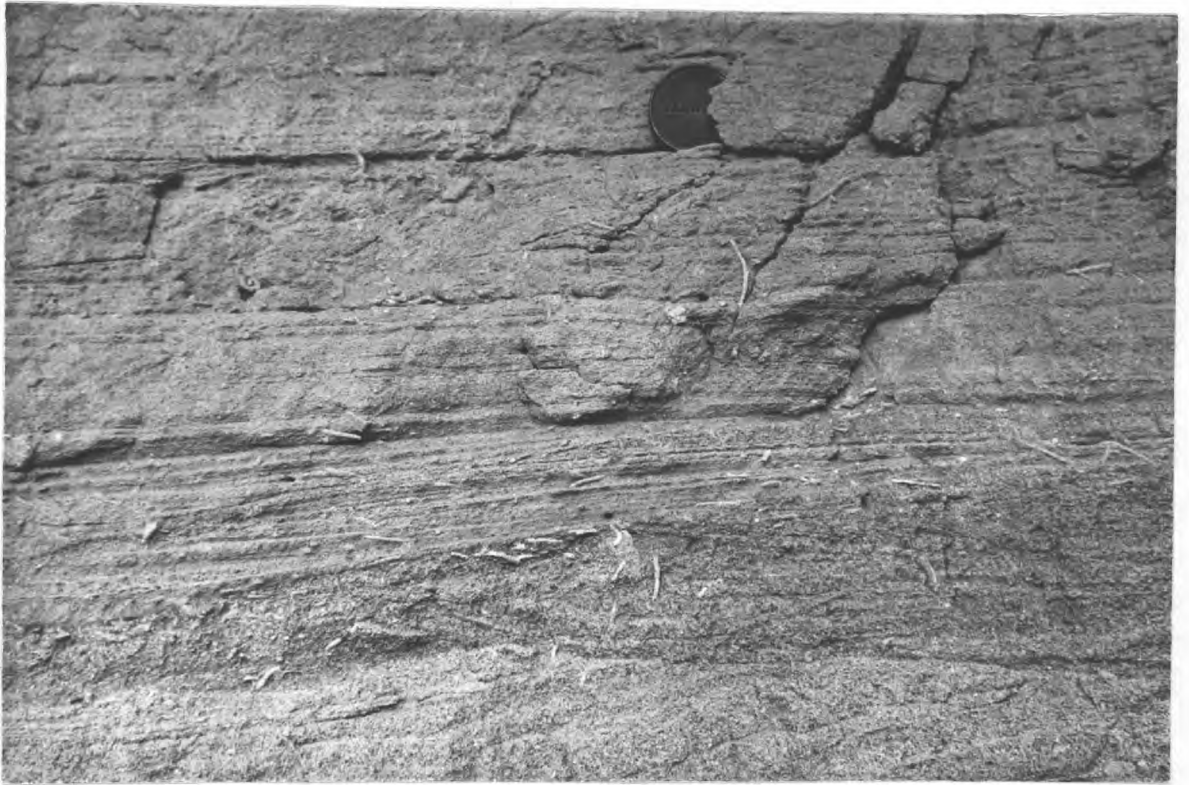


Photo. 4.1a Vertical face of calcareous sand with Needleichnus.
Lower Maude Limestone. section 18.

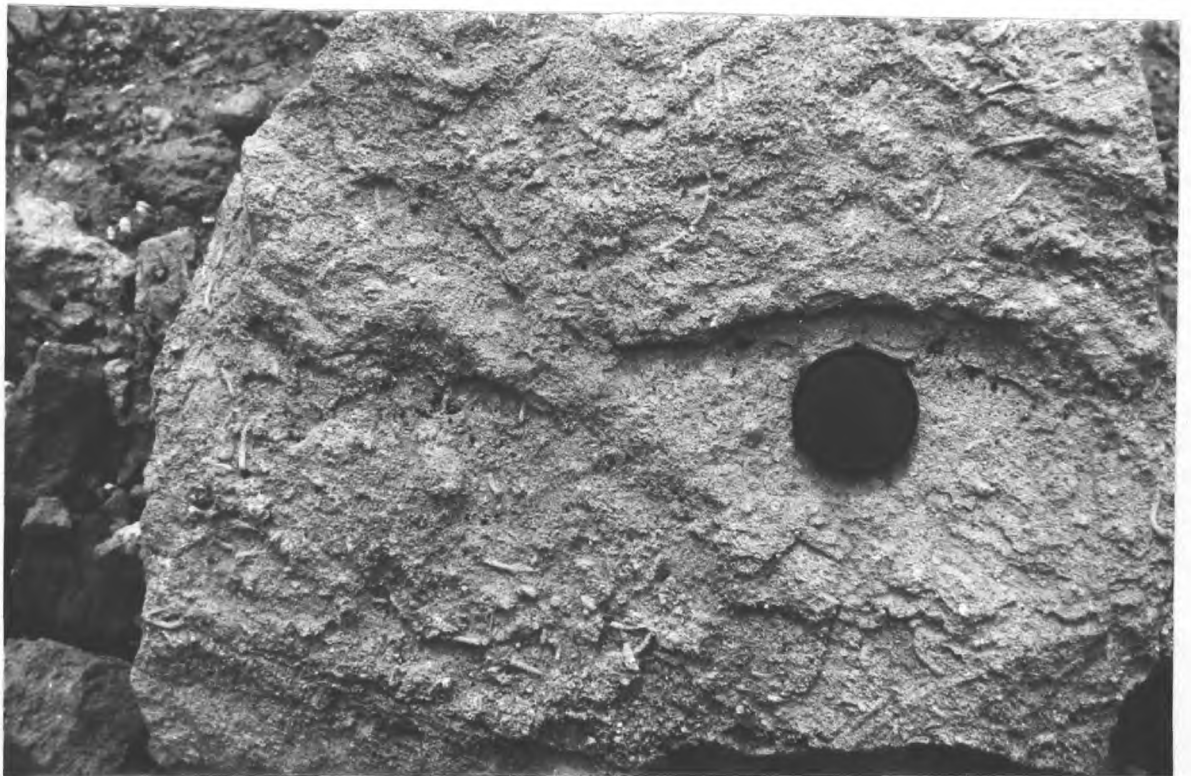


Photo. 4.1b. Horizontal face of calcareous sand with Needleichnus.
Lower Maude Limestone, section 18.

Phaedrella nom. nov. (figure 4.3.b(iii)).

Derivation of name: Refers to Phaedra, one of the daughters of Minos, who had the great labyrinth of Knossos excavated.

Description: These comprise cylindrical unbranched burrows 0.2 to 1.7 cm. diameter. Most are between 0.5 and 1.0 cm. diameter and horizontal or vertical, though a few are inclined. They are either straight or meandering. A thin casing is often present, especially in the vertical and inclined components, but is never more than 0.1 cm. in diameter. The case is very diffuse, being composed of limonitised silty material finer than the burrow fill, or else of light coloured sand. The fill is usually the same as the host rock, and may be sand, silty sand or silt, but generally skeletal material is less abundant than in the host rock. Horizontal burrows follow horizons rich in shelly fragments. A few have a meniscus fill structure, composed of septa of silty material continuous with the wall, alternating with more sandy material.

Distribution: These burrows occur in clays, calcareous silts and sands associated with a number of biofacies, especially to the Fibularia, Ostrea angasi and Adeona-bivalve biofacies, and with burrows, especially Daedalichmus and Rosselia.

Interpretation: These burrows represent the activity of deposit feeding worms that excavated organic rich bands within the sediment and reduced the grade of calcareous material. They secreted a mucus that bound silty material to form a rudimentary casing. Mucus-cemented walls have been described from burrows in the North Sea by Reineck (1967). A meniscus fill indicates that there was active back-fill of the burrow, periodically cemented by mucus secretion and that the organism did not retrace its path. The burrows occur in a variety of environments but indicate slow or moderate deposition where the currents were not strong enough to winnow out the organic matter in the sediment. The biofacies it is associated with indicate depths of 0 - 50 metres in normal salinities.

Vertillichmus nom. nov. (figure 4.3.c)

Derivation of name: Refers to the vertical habit of these burrows.

Description: These burrows are 0.05 to 0.3 cms in diameter and are always straight. Most are vertically disposed, reaching up to 10 cms in length. They are usually grouped in clusters in which there may be six burrows per cm^2 of horizontal section. Some swing gently towards the horizontal at their bases, and a few have horizontal branches (figure 4.3.c(i)).

The fill consists of silt with host-rock sand grains or of sand alone, and is usually stained with limonite. Occasionally the outer part is slightly cemented with limonite (figure 4.3.(ii)).

Distribution: There are only five occurrences of this burrow, in silts, calcareous silts and calcareous sands. It always occurs with biofacies, especially the Retepora, gastropod-Adeona and Adeona biofacies, and is closely associated with Eurydichnus and Needlechnus.

Interpretation: Straight, vertical burrows of these proportions have been described from the Recent by, amongst others, Lessertisseur (1955). He figured burrows of Pygospio elegans and Corophium volutator. (Pallas) from Recent tidal flats. The simple vertical shafts 3 - 7 cms long and 0.1 cm. in diameter formed by P. elegans are particularly similar, but only represent one form of the burrow and the constancy of structure of the fossil burrows is marked (figure 4.3.c(iii)).

Corophium volutator burrows may be U-shaped or straight and again are rather variable in structure. Straight vertical burrows are also produced around the siphons of bivalves, but the absence of any shells or moulds of the latter suggest that they were not responsible. The associated biofacies and burrows indicate depositional depths between about 0 and 40 metres in calm or agitated waters. Probably more than one

burrower is represented here, one in the shallow waters of the Retepora biofacies, and one in the deeper waters of the gastropod-Adeona and Adeona biofacies. It is impossible to attribute this burrow type to any species or group of animals. As no signs of truncation of any structures within the sediment were seen it was assumed that these structures were not borings.

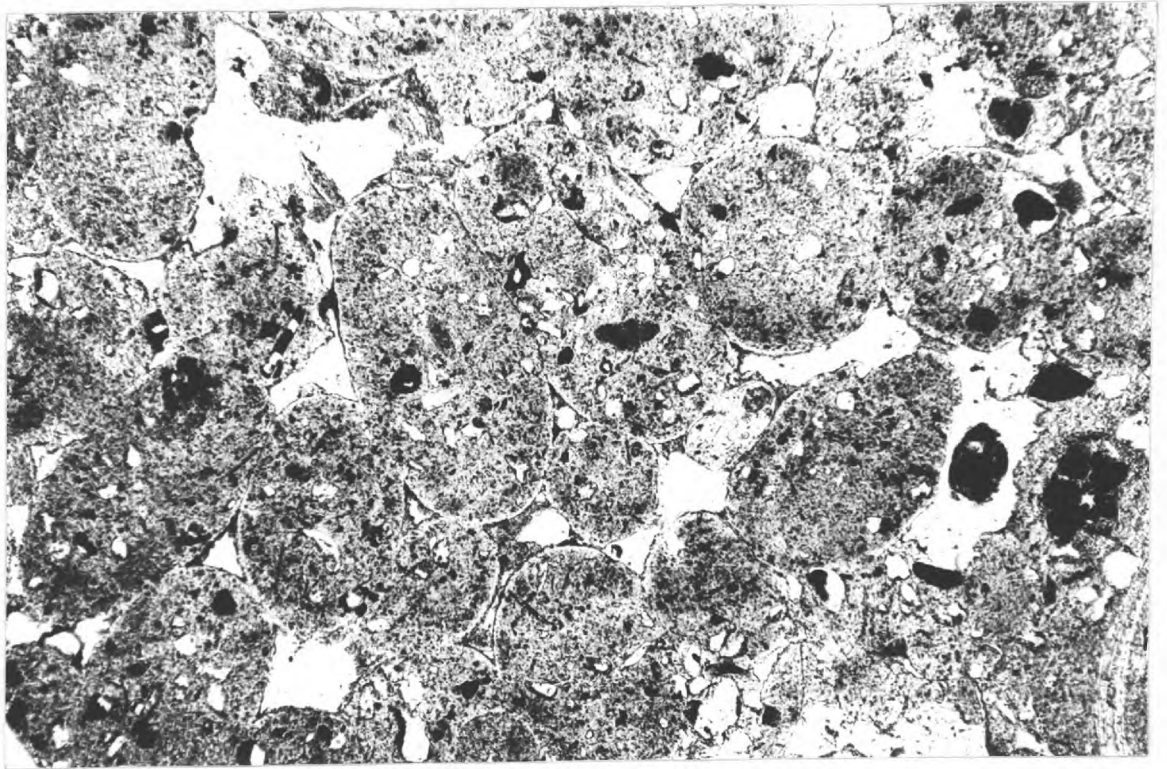


Photo. 4.2a Thin section of remanie Thalassinoides from the Phosphate Nodule Bed, with sand balls. Section 7 unit 9.

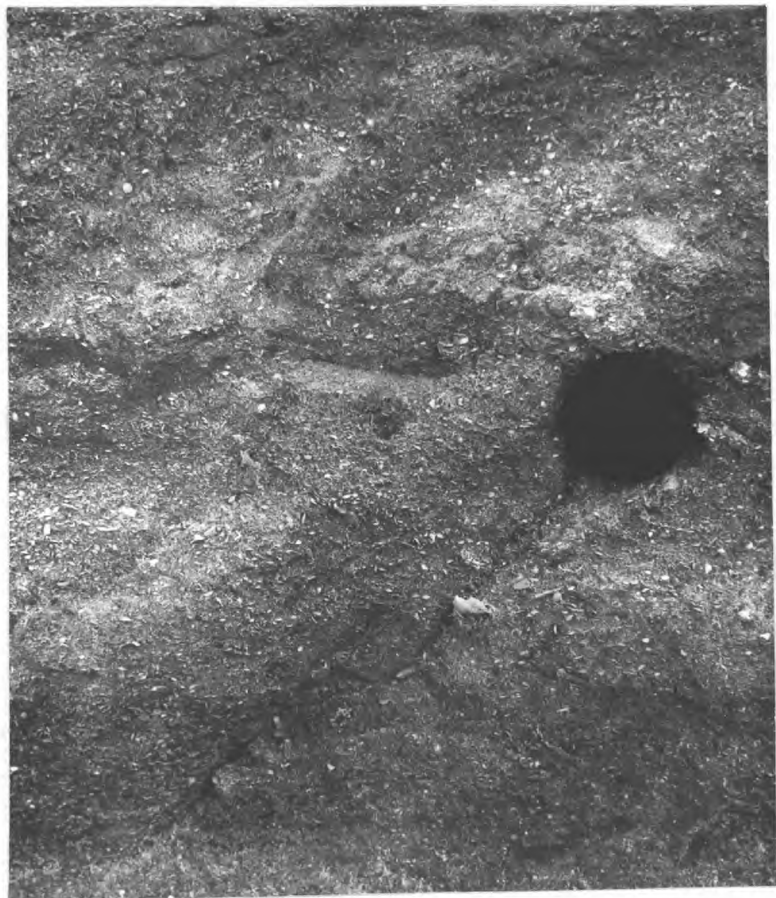


Photo. 4.2b. Batesfordichnus in vertical face of clay rich in calcareous fragments from the Batecford Limestone. Section 5, basal Fyansford Clay.

Batesfordichnus nom. nov. (photo 4.2.b)

Derivation of name: These burrows are found only at Batesford Quarry.

Description: This burrow is very diffuse and rather variable in diameter (usually about 2 cms). It occurs in clays rich in shells.

The burrows consist of simple, rarely-branching irregular tubes filled with more clayey material than the surrounding shell-rich sediment. The few remaining shells in the fill are rudely oriented parallel to the sides. The burrows may be vertical, inclined or horizontal and usually meander. They may double back upon themselves (photo. 4.2b). The concentration is never more than $1/\text{metre}^2$ of vertical section.

Distribution: These burrows are restricted to the clays with shelly debris above the Batesford Limestone, and in the thin associated limestone interbeds. They are associated with the mixed calcareous algae-gastropod and mixed Entalophora-gastropod biofacies.

Interpretation: The clay-rich fill differentiates these burrows from the surrounding sediment. The burrower clearly fed on organic material associated with the shells and crushed the latter up to a fine powder.

Similar structures are produced at the present day at all depths by burrowing echinoids such as Echinocardium, (Reineck et al (1967)), but no tests were found associated with them. More probably they were formed by deposit-feeding worms that excavated organic-rich layers in the sediment and excreted material from their gut as they passed through the sediment (in much the same way as Eurydichnus).

The biofacies with which the burrows are associated indicate depths of 30 - 80 metres in areas of low but periodically high current activity.

CHAPTER 5

THE SEDIMENTS (enclosure 1)

The sediments of the area were divided into a number of formations by Hall and Pritchard (1892, 1895, 1897). They were studied in detail by Bowler (1963) who proposed the following rock units (oldest first):

Lower Maude Formation:-

Sutherlands Creek Sands member

Lower Maude Sand and Gravel member

Lower Maude Limestone

Maude Basalt

Upper Maude Limestone

Batesford Limestone

Fyansford Clay

Moorabool Viaduct Sands.

The sedimentary and biotal composition of these formations will now be considered, and their environment and age deduced.

The Lower Maude Formation (figure 5.2)

Introduction: Bowler (1963) defined this as including all Lower Tertiary sediments which lie between the Maude Basalt and the basement Ordovician slates. It outcrops in the northern part of the area near Maude, and has been examined in sections 14 to 18.

Bowler recognised three subdivisions of the Lower Maude Formation, two cropping out in the Moorabool valley and one in Sutherlands Creek to the east. The latter, the Sutherlands Creek sands were not fossiliferous and have not been examined. Bowler described them as well sorted and well rounded pure quartz sands and orthoquartzites, often extensively

Figure 5.1

Hall and Pritchard 1902	Chapman 1914 Chapman/Singleton 1923	Singleton 1941	Carter 1964	faunal units	Continental stages (Carter 1964)	formations
Werrikooian	Werrikooian	Werrikooian				Moorabool Viaduct Sand
		Adelaidean				
Kalimnan	Kalimnan	Kalimnan	Kalimnan		Pliocene	
		Cheltenhamian	Mitchellian & Cheltenhamian			
		Balcombian	Bairnsdalian	11	Tortonian	Fyansford Clay
Balcombian	Janjukian (with Batesfordian)	Balcombian	Balcombian	10	Helvetian	
		Batesfordian	Batesfordian	9	Burdigalian	Batesford Limestone
				8		
			Longfordian	7	Aquitania	
				6		
Janjukian	Balcombian	Janjukian	Janjukian	5		
				4	Oligocene	

Correlation of the formations

cemented by secondary silica. They vary in thickness from almost nothing in the north to approximately 100' about one and a half miles southeast of Maude. Bowler concluded that they were deposited in a beach environment.

Description of sections The sediments present in the sections in the Moorabool Valley comprise two divisions:

(i) The Lower Maude Sand and Gravel member

This crops out at the bases of sections 16, 17 and 18 and lies between the steeply dipping Ordovician basement and the Lower Maude Limestone. At section 18 a 15' thick basal conglomerate composed of unrounded quartz pebbles about 3 cms in diameter in a matrix of fine quartzite with grit grains, passes up into 55' of fine white sands with scattered quartz grains and carbonate rich areas. The latter are secondary, the material being derived from above. Poor exposure at section 17 prevents a comparison of thicknesses but there is a marked reduction, the whole of the Lower Maude Formation totalling only 60'. At section 16 the Lower Maude Sand and Gravel is 20' thick (though where Bowler measured his section (15) it is 30' thick), the basal part of which comprises a well bedded white illsorted gravelly sand rich in quartz grains and clay pellets. It grades upwards through fine light coloured sands with Daed. alichnus into the Lower Maude Limestone.

One and a quarter miles to the south, the member is completely absent, and the overlying Lower Maude Limestone directly overlies the Ordovician rocks. Within two and a half miles therefore there is a reduction in thickness from 70' to nothing.

Bowler regarded these beds as equivalent to the Sutherlands Creek sands and to gravels up to 159' thick exposed beneath the Maude basalt farther to the north near Steiglitz. He concluded that they were non marine sediments deposited before the main marine transgression. This accords well with the illsorted nature of most of the sediment and with

Facies and interpretation of the Lower Maude Formation

- n Needichnus
- d Daedalichnus
- p Phacarella
- F Eibularia biofacies
- E Eotrigonia biofacies

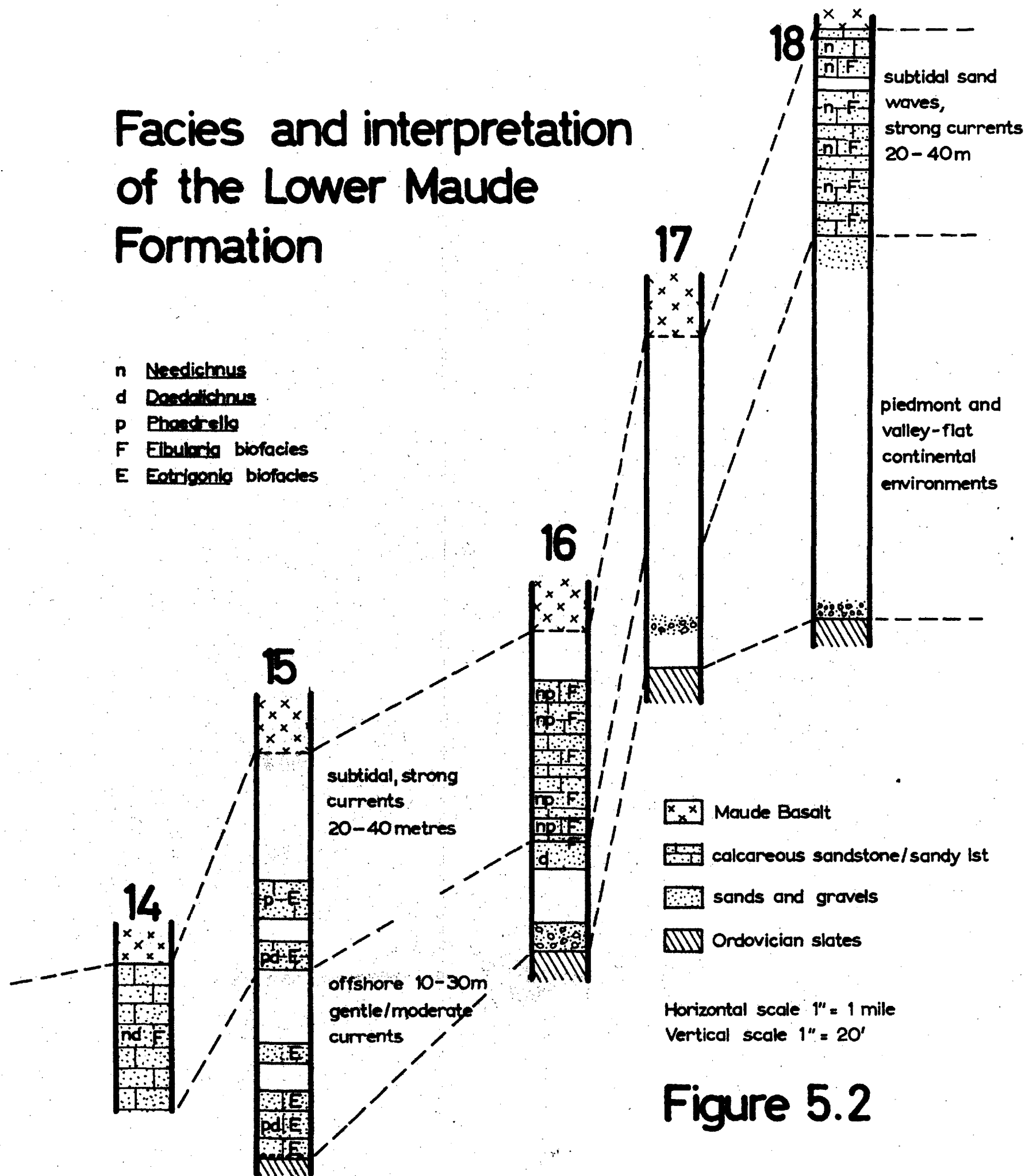


Figure 5.2

the lack of carbonate. The lack of exposure prevents a confident estimation of the compositional variation, but there seems to be a gradual reduction in grain size up the succession.

(ii) The Lower Maude Limestone

This calcareous sandstone and sandy limestone overlies the Lower Maude Sands and Gravels in sections 16 and 18 and lies directly on the Ordovician at section 15 and probably 14. Horizontal bedding is very common and a few units are planar cross stratified. The roundness, especially of the coarser grade material is good, quartz grains being polished. Units towards the base, especially in the sections that lie directly upon the Ordovician contain some silty material, but in general the sorting is good or very good.

At section 18, 37' of horizontally bedded calcareous sandstone, near the top often gritty and cross stratified, contain the Fibularia biofacies and Needleichmus. These indicate a marine environment of high current activity in depths of about 25 metres. Bowler (1963) concluded that the figures for skewness (both positive and negative) indicated that deposition took place "in an inshore shallow marine environment, but not a beach zone".

The Lower Maude Limestone is not exposed at section 17, but 38' of calcareous sandstones are seen in section 16. At the base, a thinly bedded horizon passes up into planar cross-bedded and horizontally bedded fine or very fine calcareous sands and sandy limestones. They contain the Fibularia biofacies and Phaedrella, Daedalichmus and Needleichmus throughout and indicate a similar environment to that of the calcareous sandstone of section 18.

One and a half miles to the south the Lower Maude Limestone directly overlies steeply dipping green siltstones of the Ordovician. The plane of unconformity is extremely irregular; in a section 50 yards

long it varies through a thickness of 6'. The beds consist of an alternation of well bedded, often planar cross stratified, partially decalcified silty sandstones rich in well rounded cobbles and pebbles of the underlying Ordovician and of quartzite. The fossils in these beds belong to the Eotrigonia biofacies and are jumbled and broken. They indicate an environment of moderate to strong current activity in depths of 20 to 30 metres. This locality corresponds to TM3 of Wilkinson (sheet 19SW, 1865 Geological Survey of Victoria), and was the one from which Hall and Pritchard (1895) collected large numbers of well-preserved specimens of Eotrigonia intersitans and Glycimeris cainozoicus in a white silt. Though both species were found by the author, neither was collected in abundance and it seems likely that decalcification of aragonitic shells has taken place in all but a few localities.

At section 15, (TM1 of Wilkinson, 1865) the Lower Maude Limestone is probably about 70' thick, but lack of exposure prevents an examination of the top 23'. The beds are exclusively horizontally-bedded and consist of slightly silty fine calcareous sands rich in skeletal material. The unconformity at this section is again angular and is marked by a quartz conglomerate which passes up into a 3' bed with cobbles of Ordovician siltstone. The Eotrigonia biofacies is present throughout the section and there is bioturbation by Phaedrella and Daedalichnus (photo 5.1a).

I am indebted to Tom Darragh of the National Museum of Victoria who established the presence of Eotrigonia from calcareous silts and sands from this locality northwards (personal communication 1967), towards TM3.

At section 14, 25' of slightly silty sands with the Fibularia biofacies is exposed between the Maude Basalt and river level.

Discussion of the Lower Maude Formation (figure 5.3)

Though the beds seem to have no dip, they are carried from high in section 18 to below river level near section 14. In the distance of four miles between the sections, the top surface of the Lower Maude Limestone falls from 507'OD to 215'OD. This represents an inclination of 1 in 75 or an angle of $0^{\circ}46'$. Bowler attributed this partly to "initial dip of sediment wedging out against a rising shoreline of Ordovician slates" and partly to subsequent tectonic uplift to the north. Taken in its entirety, however, the Lower Maude Formation is of fairly constant thickness between sections 15 and 17.

section 18 : 107'

section 17 : approx 60'

section 16 : 58'

section 15 : 71'

section 14 : > 25'

Throughout the sections the Fibularia biofacies occurs in the Lower Maude Limestone where sands and gravels underly it, while the Eotrigonia biofacies occurs in those sections where the sands and gravels are absent. It is possible therefore that the Eotrigonia-bearing Lower Maude Limestone is older than the Fibularia-bearing portion, and is in part the equivalent of the Lower Maude Sands and Gravels. Although the Fibularia biofacies is never seen overlying the Eotrigonia biofacies, the upper parts of the formation in section 15 (units 6 and 7) possibly belong to the former. The units are very poorly fossiliferous and the fossils they do contain are equally referable to either. (They are only referred to the Eotrigonia biofacies because they were insufficiently different to the units below to justify separation). The constancy of thickness of the formation between sections 15 and 17 supports the suggestion that the lower part of the limestone is equivalent to the Lower Maude Formation in part.

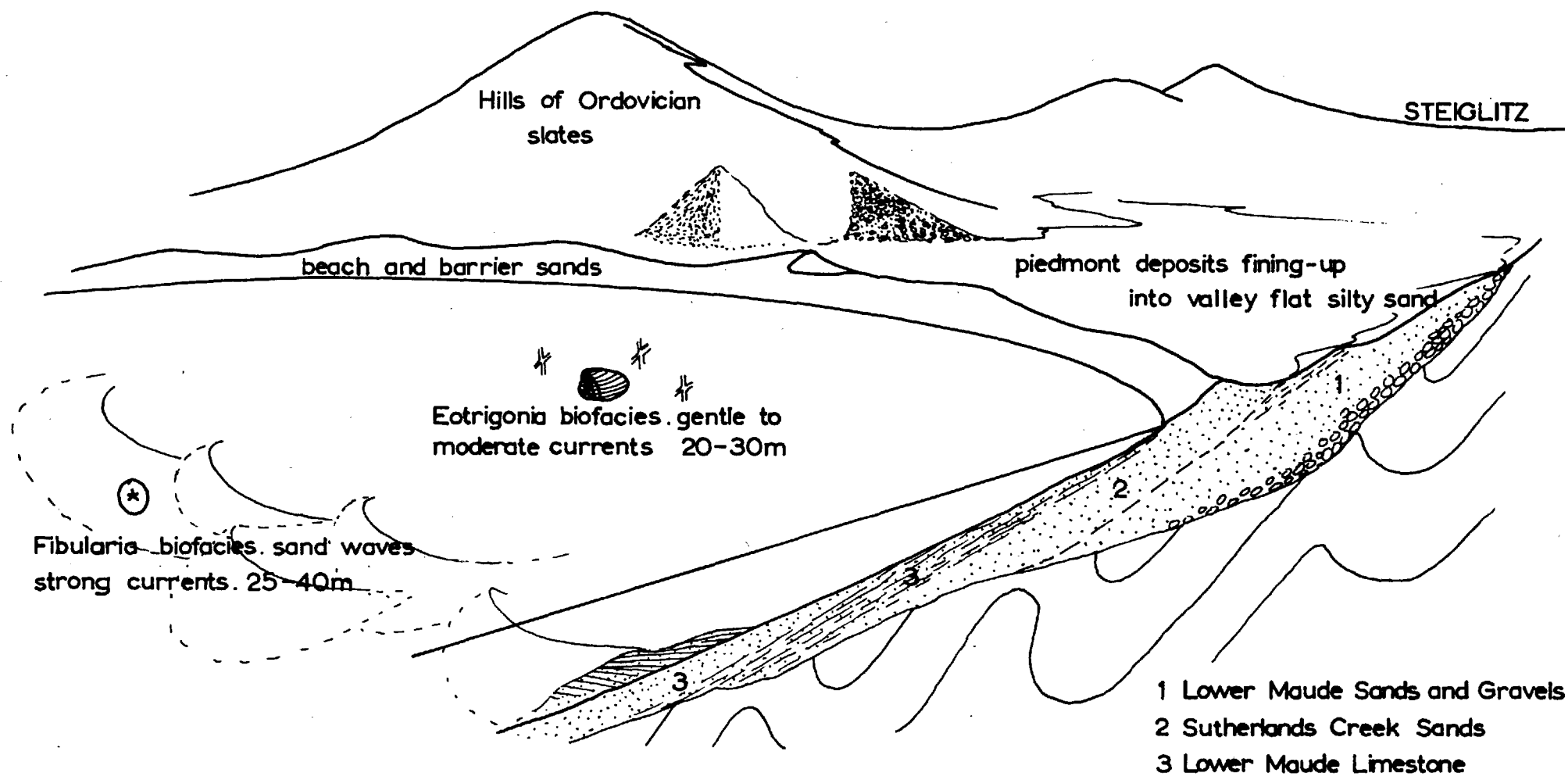
Clearly the thick white sands of section 18 are not equivalent to the limestone, their lack of carbonate and illsorted nature indicating that they are probably continental. However, the presence of bioturbation at the top of the Lower Maude Sands and Gravels at section 16 suggests that it is in part marine there.

The Lower Maude formation commences with widespread continental deposits or an irregular erosional surface of Ordovician siltstones. Everywhere where the contact is exposed there is a basal conglomerate, which passes up into white sands and gravels. Bowler has correlated the 70' thick sands and gravels of section 18 with gravels farther to the north near Steiglitz described by Harris and Thomas (1949). The latter, which lie between the Ordovician and outliers of Maude Basalt, are composed of a basal conglomerate (with boulders up to 2' in diameter) overlain by coarse, poorly-sorted gravels and eventually by finer sands and clays, reaching 150' three miles northwest of Maude. They are often partly silicified and, according to Bowler, pass without break into the Sutherlands Creek sands also. Some of these beds contain ferruginous wood fragments (Wilkinson and Murray, sheet 19SW 1865).

Thus there is a complex of gravels and sands, all overlying Ordovician rocks, and united by the presence of upward-fining sequences, covering much of the area around Steiglitz, Maude and the northern part of Sutherlands Creek. Those in the latter area are silicified and much better sorted than the rest. Those in the Moorabool Valley thicken northwards towards Steiglitz, but then die out.

Though correlation between these beds in the sections is very difficult due to the lack of exposure, the general picture that emerges is of widespread continental and marine deposition along the margin of a shallow sea. Up to 150' of conglomerates, grits, sands and clays were deposited on what was clearly a very irregular surface in fluvial environments related both to piedmont and valley-flats (Twenhofel 1950).

Figure 5.3



Depositional environments in the Lower Maude Formn.

These passed transitionally southwards into variably thick barrier or beach sands (represented by the Sutherlands Creek Sands), and into thin offshore calcareous sands with the Eotrigrionia biofacies and Phaedrella and Daedalichmus deposited in depths of 20 - 30 metres. There followed a slight marine transgression during which no further fluvial deposition took place and during which little clastic material was introduced into the sea. In these conditions extensive reworking of the earlier deposits on the floor of the sea produced sand waves with the Fibularia biofacies like those described by Stride (1963) from the North Sea. This is represented by the upper part of the Lower Maude Limestone. The general constancy of thickness of the marine portions of the Lower Maude Formation suggests that the dip of the beds is not original, but entirely tectonic.

The Age of the Lower Maude Formation (figure 5.1)

Hall and Pritchard (1902) were the first to suggest an age for these beds. They considered them to be equivalent in age to the Tertiary beds at Torquay (40 miles southwest of Maude), and that both of them belonged to the Eocene Janjukian stage. Subsequently Chapman (1914) realised that most of the rocks previously regarded as Eocene were in fact Oligocene or Miocene. He considered that the Lower Maude beds belonged to the Miocene. Subsequent workers have accepted this: Singleton (1941) for instance noted that whilst many of the species present in these beds were restricted to the locality, at least two (including Eotrigrionia intersitans) were also present at Torquay.

The zonal scheme proposed by Carter (1964) divided the Janjukian (as defined by Singleton 1941) into two. The lower part, equal to his faunal units 4 and 5 was named the Janjukian, while the upper part, equal to his faunal units 6, 7 and 8 was defined as the Longfordian. The microfossils present in the Lower Maude Limestone include species



Photo. 5.1a Unconformity between the Ordovician siltstones and the Miocene calcareous sands of the Lower Maude Limestone. Section 15.

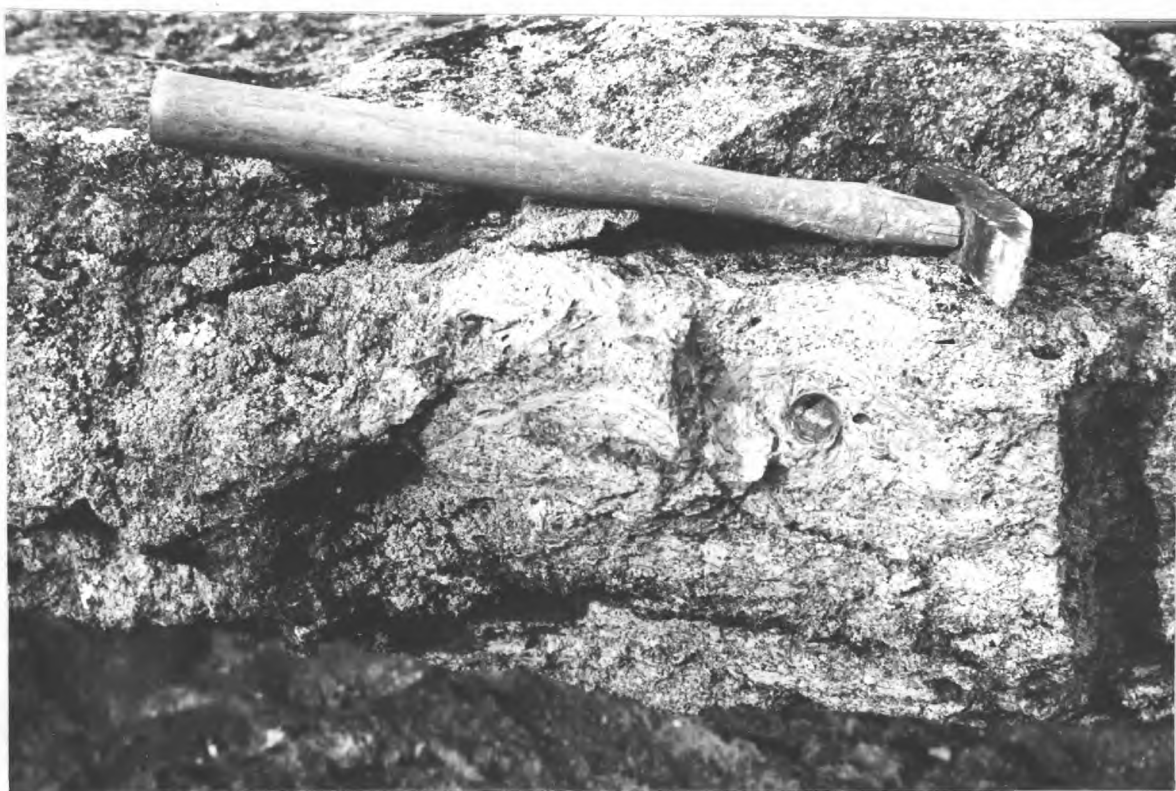


Photo. 5.1b: Encrusting calcareous algae in life position. Base of the Upper Maude Limestone. Section 16.

that first appear in faunal units 5,6 and 7.

Cibicides thiara and Amphistegnia lessonii occur in the Eotrignia biofacies while both these and Discorbinella papillata and Globigerinoides triloba occur in the Fibularia biofacies. The first two appear in faunal unit 5 (Janjukian), the last two in 6 and 7 (Longfordian). Probably, therefore both stages are present - the former represented by the Lower Maude Sands and Gravels, the Sutherlands Creek Sands and the lower part of the Lower Maude Limestone, the latter by the upper part of the Lower Maude Limestone.

The Maude Basalt

The Maude Basalt separates the Lower Maude Formation from the later Tertiary beds. It is present in sections 12 to 18, and has been described in detail by Bowler (1963). He defined it as a normal labra - dorite, olivine, augite basalt and noted that columnar jointing, present in a quarry half a mile north of Russell's Bridge, indicated that at least as far south as that the basalt had been extruded subaerially. Half a mile to the south pillow structures can be seen in the lava and suggest subaqueous extrusion.

The basalt is of very variable thickness, reaching 132' at section 15. If it is assumed that the lower portion was extruded onto more or less flat lying surface - as is suggested by the constant thickness of the Lower Maude Limestone, then the top surface varied through 72' at least. South of section 14 the basal surface is not seen, but it probably thins, since it is absent from the Bannockburn bore, located two miles south of Lowndes' Bridge.

Clearly considerable erosion excavated a deep profile of the top surface of the basalt prior to the deposition of the overlying strata, and this coupled with the evidence of the columnar jointing suggests

that it was to a certain extent extruded subaerially. The author, however, does not agree with Bowler (1963), that this indicates a regression after the deposition of the Lower Maude Limestone. The quarry in which Bowler saw columnar jointing indicative of subaerial conditions (half a mile north of Russell's Bridge) is clearly near the top of the basalt - it is at approximately 200'OD.

Both Bowler and the author agree that there was no significant erosion of the Lower Maude Limestone before the extrusion of the basalt, so the extrusion of at least 132' of it was quite sufficient to raise the area above sea level. The biofacies in the top part of the Lower Maude Limestone indicate depths of only 25 - 40 metres, i.e. 75' - 120'. In the absence of any other good exposures of basalt structure, except for the one near Russell's Bridge, where there are pillow structures, it is unjustified to assume a regression to account for the features.

The Upper Maude Limestone (figure 5.4)

Introduction: The Upper Maude Limestone has been defined by Bowler as the "fossiliferous and calcareous sediment lying directly on Maude Basalt and continuing vertically to (the) top of bed D in section 15 near the Maude School," and corresponds to the Upper Maude beds or upper beds at Maude of earlier authors. It occurs in sections 12 to 17 and is of variable thickness and lithology. Generally, a 3' to 6' aphanitic limestone unconformably overlying Maude Basalt, rich in boulders of the latter and containing a very shallow water rocky biota passes up into thicker and highly bioturbated alternations of sands and calcareous sands. The junction with the basalt is nearly always strongly discordant.

Description of sections: At section 17, the plane of unconformity between the limestone and the basalt is so steep that between 5 and 30' of the former occurs. Successive limestone horizons die out against an 11° southward dipping surface of basalt. The limestone, which is of calcarenite grade at the base, passes upwards into well-bedded cal -

Facies and interpretation of the Upper Maude Limestone

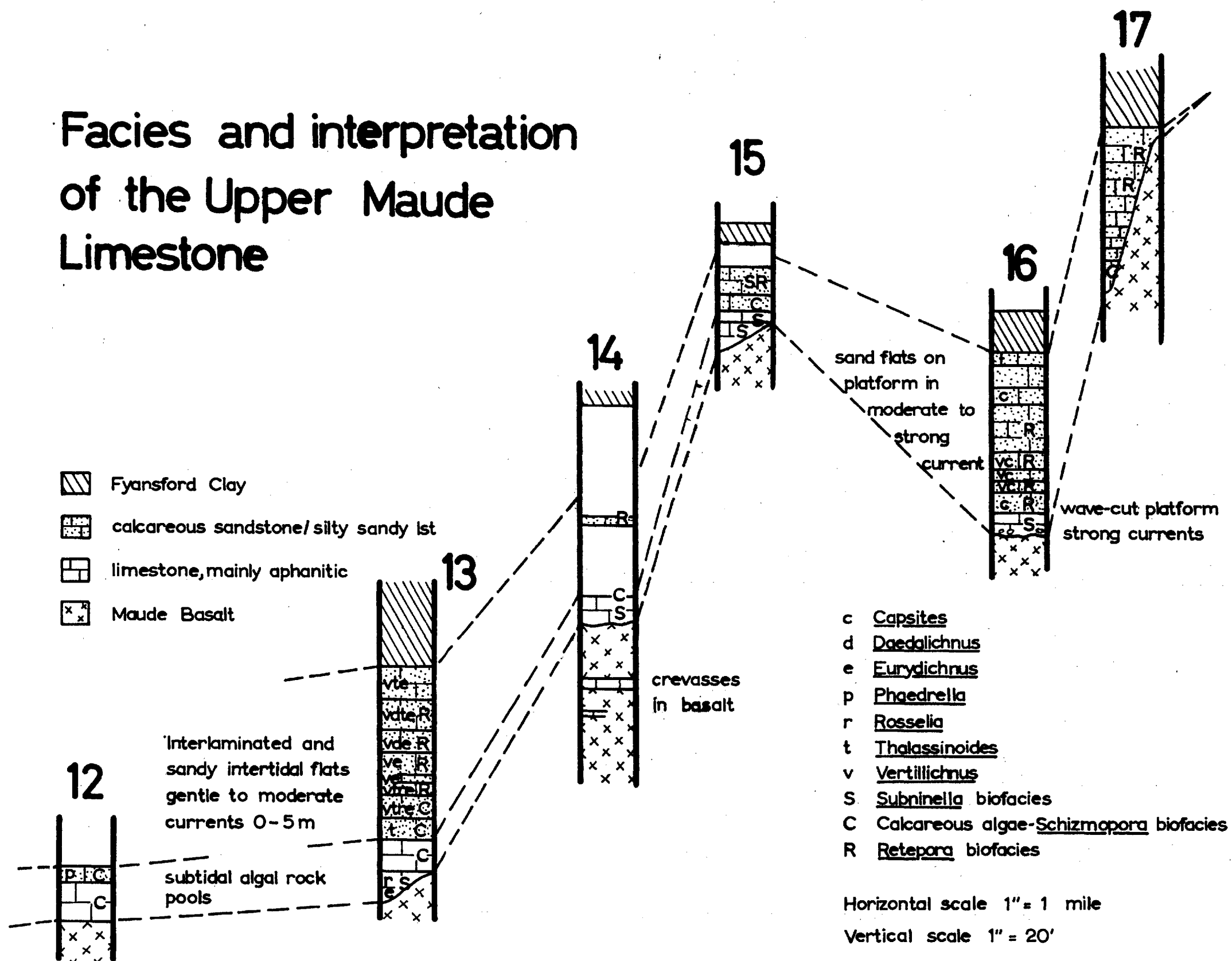


Figure 5.4

careous sandstones: Bowler records a carbonate percentage of 89.1% at the base, falling to 51.2% at the top. Throughout, skeletal-rich bands containing fossils occur. They are highly fragmented and belong to the calcareous algae-Schiznopora and Retepora biofacies.

Section 16 at which Bowler defined the limits of the formation (his section 15) contains 34' of Upper Maude Limestone. At the base is a 4' thick aphanitic limestone with the Subnabella biofacies rich in well rounded and highly spherical pebbles of basalt and quartz grains (photo 3.2a). Encrusting calcareous algae in growth position (photo 5.1b) or in jumbled blocks or fragments occurs throughout. In thin section the skeletal fragments can be seen to be composed largely of pinnate and encrusting calcareous algae, bryozoa and benthonic foraminifera. The rest of the formation is composed of alternations of gritty and sandy calcareous silts and silty sandy limestones with the Retepora biofacies and Capsites, Vertillichnus and Thalassinoides.

In an exposure by the Knights Bridge road near Maude (235180) festoon-bedded limestone overlies an extremely irregular surface of basalt. As at section 16 there is a high percentage of well-rounded and spherical quartz grains, but there is little matrix. This is the outcrop at which Wilkinson and Murray mapped a thin limestone band near the top of the basalt, for Chapman (1914) maintained it could be seen there. No other authors have been able to locate it, however, and Singleton (1941) attributed Chapman's interpretation to the extremely irregular nature of the upper surface of the basalt.

At section 15 the unconformity is also very irregular, varying through at least 11 feet. Very large basalt boulders up to 4' in diameter infill topographic lows in the surface and lead to disturbed structures in the intervening sediment. Throughout the basal few feet of the formation the limestone is aphanitic being composed of a micrite

matrix with skeletal fragments. It is richly fossiliferous and broken or complete specimens belonging to the Subninella biofacies and at the top, the calcareous algae-Schiznophora biofacies are abundant. Towards the top of the formation the micrite matrix becomes less important and the limestone becomes a clastic rich ooquina. It is characterised by the calcareous algae-Schiznophora biofacies but contains scattered basalt boulders, around which the Subninella biofacies occurs.

At section 14 the Upper Maude Limestone is poorly exposed but a succession composed of an aphanitic limestone with basalt boulders containing the Subninella biofacies passing up into sandier beds with first the calcareous algae-Schiznophora and then the Retepora biofacies occurs. 10' below the top surface of the underlying Maude Basalt there is a 2' thick limestone band. A second band 15' below the surface of the basalt is very impersistent. It is composed of wispy alternations of finely granular limestone and cryptocrystalline material.

The upper band is more persistent and well-bedded however, and consists of alternations of bands 1" - 2" thick of:

(i) A microcrystalline crystalline sparry calcite matrix rich in angular and subrounded quartz grains and cloudy algal fragments. All the material is of strictly fine sand grade, though a few larger bryozoan fragments are present.

(ii) A similar matrix, partly micritic, rich in well rounded ferruginised pellets and quartz grains up to 4 cms diameter.

Though the junction between these two zones is sharp it is not erosional. The band is interpreted as the infilling of a crevasse in the basalt: vertical limestone-filled clefts are closely associated.

As Bowler (1963) pointed out this is more probably the band that Wilkinson and Murray mapped and took as evidence of a second period of basalt extrusion.

The best exposure of the Upper Maude Limestone is seen at section 13, where the formation reaches a maximum of 39' thick. The basal 5' characterised by the Subninella biofacies is locally absent due to the relief of the basalt, but where present consists of an aphanitic limestone rich in basalt boulders and pebbles as before. Throughout ferruginised rounded pellets 0.1 to 0.3 cm. diameter that Bowler described as limonitic are abundant. In thin section (photo 5.2b) a specimen is seen to be composed of four zones through a thickness of 2.5 cm.

(i) At the base is 0.4 cm. of black highly ferruginous micrite rich in subangular medium sand grains. This is separated by a sharp junction from....

(ii) A zone 1.3 cm. thick of micrite matrix rich in shelly fragments. Throughout, 0.1 to 0.2 cm. diameter well rounded and spherical highly ferruginous pellets riddled with algal borings occur. They are composed of worn skeletons of calcareous algae, bryozoa, echinoid radioles, foraminifera and fragments of micrite rock containing parts of their skeletons. There are also a few non-ferruginous less well rounded pellets of calcareous algae and bryozoa in the same size range. This zone is separated from (iii) by a very irregular junction.

(iii) An 0.5 cm. zone of strongly ferruginised micrite, rich in subangular quartz grains, rather like (i) except that 0.03 cm. thick anastomosing filaments of calcareous algae are persistent across the slide and are clearly in growth position. This zone is followed by a sharp junction, truncating algal filaments and even quartz grains.

(iv) This zone is rather similar to (ii) but contains filamentous calcareous algae.

The presence of multiple planes of truncation that affect sediment and quartz grains similarly indicates that the limestone was very rapidly lithified. The zone in which the filaments of calcareous algae and which contains no pellets is the area of strongest ferruginisation,

while the zones rich in pellets have micrite matrixes relatively free of iron. Clearly, there were alternations of:

(a) Periods of slow deposition during which algal mats developed and when iron-rich solutions from the basalt stained the sediment that was being deposited, that were followed by contemporaneous or precontemporaneous lithification.

(b) Periods of erosion during which the lithified ferruginous limestone was eroded and redeposited rapidly as well rounded pellets in a non-ferruginous micrite matrix.

The next 3'6" of the section is composed of an unconsolidated rubble of skeletal material 0.25 to 0.5 cm. diameter, with abundant ferruginous pellets, but the rest of the Upper Maude Limestone is dominated by clastic material. Rippled calcareous sands with thinner silty horizons and interlaminated calcareous sands and silts are typical. In the thicker sandy beds planar cross stratification is common, while bioturbation by Eurydichnus, Rosselia, Thalassinoides and Daedalichnus is abundant throughout. At the base the calcareous algae-Schiznophora biofacies occurs but is replaced upwards by the Retepora biofacies. Fossils are present largely in scattered rippled bands up to 1" thick composed of skeletal fragments.

In an exposure south of Lowndes Bridge (261108), a horizontal erosion surface in aphanitic limestone can be traced for 20' before it disappears below basalt boulders, some of which are 12' long. A quarry half a mile south of Lowndes Bridge (261106) exposes the lower part of the Upper Maude Limestone, in which limonitic pellets are particularly abundant. They occur in a sandy silt matrix and are associated with fresh skeletal fragments. Limonitised echinoid radioles and other elongate pellets and fragments are nearly all oriented in an arc between 50° and 120° , most commonly about 85° . Many of the limonitised pellets are composed of fossils that are also present in a fresh condition in



Photo. 5.2a. Basalt conglomerate at the base of the Upper Maude Limestone. Section 16

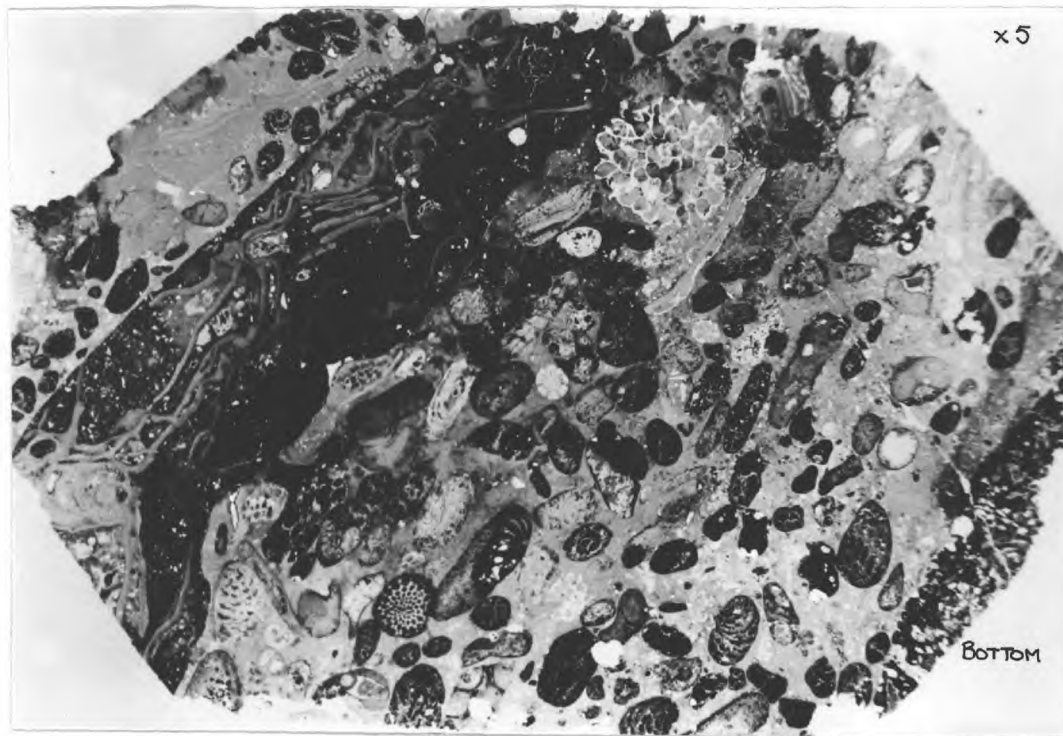


Photo. 5.2b. Thin section of aphanitic limestone from the base of the Upper Maude Limestone at section 13. (refer to text).

the bed but many are composed of limonitised rock. The latter were examined by Bowler who dissolved out the limonite and was left with a "residual mould of clay-like material, very finely divided and with low birefringence". He was uncertain about the origin of this material but suggested that it represented material, possibly from the Lower Maude Limestone, exposed to subaerial weathering before deposition of the Upper Maude Limestone. The present author suggests that the pellets represent eroded bands of ferruginised aphanitic limestone such as are present in the thin section from the base of section 13. Probably some represent amygdalae eroded out of the basalt, for in the highly limonitised crust many of the basalt boulders have, the amygdalae take on an appearance very like that of the pellets.

At section 12 a dense pink aphanitic limestone with the calcareous algae Schiznophora biofacies occurs at the base of the sequence. There are a few limonitic fragments at the very base but otherwise no evidence of the limonitic pellets so abundant one mile to the west. It passes up into planar crossstratified and rippled calcareous sands with the calcareous algae-Schiznophora biofacies concentrated in bands.

In summary, the typical succession seen in the Upper Maude Limestone commences with a conglomeratic aphanitic limestone containing the Subnina - ella biofacies.

In the northern sections this is rich in well-rounded quartz grains and may be calcarenitic. In many of the sections in the southern part of the outcrop, limonitic pellets are abundant. The overlying beds rapidly become rich in clastics and consist of an alternation of highly bioturbated calcareous sandstones and calcareous silty sands. Throughout rippled bands or beds rich in skeletal material reflect an upward passage from the calcareous algae-Schiznophora to the Retepora biofacies.

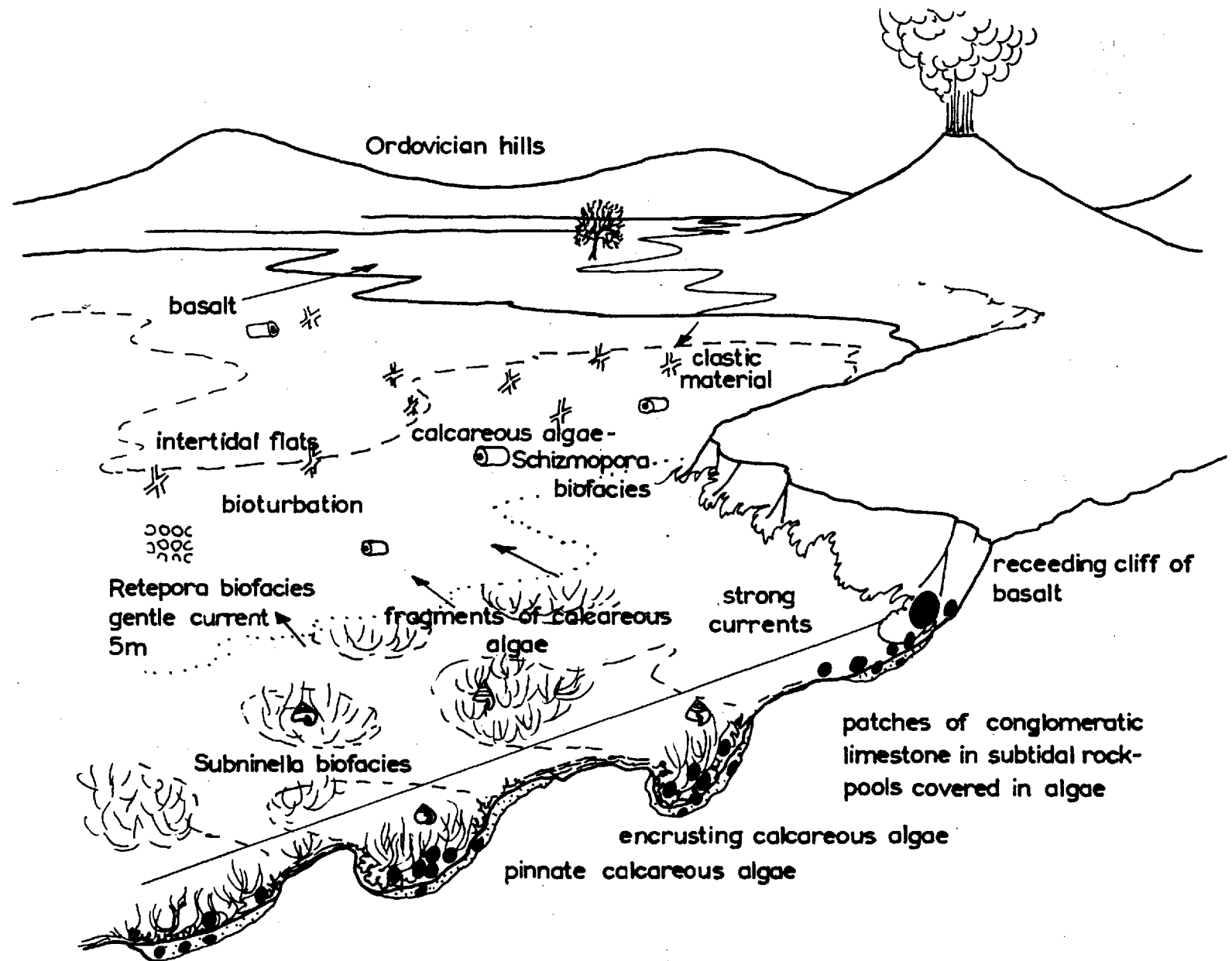
Discussion of the Upper Maude Limestone (figure 5.5)

Like the Lower Maude Formation and the Maude Basalt, the Upper Maude Limestone is carried from high in the sections north of Maude down to near river level farther south, and eventually disappears completely by reason of the downthrow of the Rowsley fault. It is of extremely variable thickness, varying for instance from 1' to 30' across the outcrop of section 17. Except at section 18, it separates Maude Basalt from Fyansford Clay and is distinguished from the latter by its sandier and more calcareous composition.

The Subnivalia biofacies, characteristic of the basal horizons, indicates the high energy conditions of intertidals and very shallow subtidal wave cut platforms and rock pools. Both encrusting and pinnate calcareous algae representing both exposed and protected environments associated with cliffs and rock pools occur. Lithification of the limestone took place very rapidly and thin mats of calcareous algae encrusted the hard surfaces produced.

In the sections in the south the basalt surface is extremely irregular and the basal limestone is rich in ferruginised pellets and basalt boulders. As pointed out by Bowler (1963), this indicates strongly acid conditions. The biofacies and general topography of the surface indicate that deposition took place in deep, subtidal rock pools. In these conditions, where due to the presence of abundant algae, the waters are not easily renewed, considerable diurnal variations in the PH take place. During the day time plants extract CO_2 during photosynthesis and raise the PH. The concentration of CO_2 in the water is reduced until it balances the Ca content, and combines with it to form CaCO_3 . This is precipitated as limestone cement. During the night, the plants respire and give off their CO_2 . The PH falls and dissolution of the limestone takes place. Under these sorts of conditions it is possible to produce rapidly lithified limestones, as well as providing the acid

Figure 5.5



Depositional environments of the Upper Maude Lst

conditions necessary for the extraction of ferruginous material from the basalt. Deep rock pools in which diurnal variations in PH occur were described by Emery (1946).

In the more northerly sections in which the limonitic pellets are absent, there are usually abundant quartz grains in the basal limestone. They are derived from the Lower Maude Formation, and, being well rounded probably largely represent Sutherlands Creek Sands. The Maude Basalt does not occur farther north than section 16 so this part of the outcrop was close to exposed Lower Maude Sands and Gravels and Sutherlands Creek Sands. The absence of limonitic pellets and the presence of local festoon-bedded calcarenites indicates that deposition took place in the higher energies of a wave-cut platform close to the shore.

Throughout the sections of the Upper Maude Limestone, deposition remained intertidal or very shallow subtidal. As the slow transgression, indicated in beds farther to the south, took place more and more of the Lower Maude Formation was exposed and sedimentation become more clastic. The presence of highly bioturbated rippled interbedded calcareous sands and silty sands suggests that intertidal flats, rather similar to those described by Klein (1964) from the bay of Fundy intertidal zone developed. In the latter case, wave-cut benches developed on part on basalt are covered with a thin veneer of rippled or megarippled sand with in basalt fragments.

Basalt boulders present in clastic beds towards the top of the outcrop in section 15 are surrounded by a Subninella biota, identical to that at the base of the section. This indicates that other than the general absence of a hard substrate the conditions did not change through the thickness of the formation.

The upward passage from the calcareous algae-Schiznophora to the Retepora biofacies indicates that the conditions gradually became more stable and that wave action decreased as the shore profile changed from

a cliff to an intertidal flat. The calcareous algae-Schizmopora bio-facies with fragmentary calcareous algae indicates that hard substrates were still in existence in the area, but the Retepora biofacies contains barely recognisable fragments only. These have been eroded from beds lower in the sequence and indicate that nearly the whole of the basalt outcrop was covered by sand flats.

Age of the Upper Maude Limestone (figure 5.1)

Singleton (1941) regarded the Upper Maude Limestone as a littoral facies of the Fyansford clay. He noted, however, that many of the skeletal rich horizons present near the base resembled the Batesford Limestone. Bowler (1963) figured a thin section of a Lepidocyclina from the basal bed from Maude school and concluded that the Upper Maude Limestone was in fact equivalent to the Batesford Limestone and Batesfordian. However, the very variable thickness of the formation and its transitional relationship with the overlying Fyansford Clay indicates that it is, as Singleton suggested, in part the littoral equivalent of the latter. There are no fossils diagnostic of the Balcombian (Fyansford Clay), but many species are common to the Fyansford Clay and Upper Maude Limestone.

The Batesford Limestone (figure 5.6)

Introduction: The Batesford Limestone, a poorly-cemented, pure coquina has a very restricted distribution in the area. It "includes all limestone, sandy limestone and calcareous sands which overlies Palaeozoic granite and diabase on the flanks of the Dog Rocks and underlie the Fyansford Clay" (Bowler 1963). At the present it is only known to occur on the southeastern flank of the hill south of Batesford, known as Dog Rocks. It is exposed in a large quarry owned by Australian Cement Ltd., where it has been studied.

Description of Sections: The most detailed section was measured on the eastern side of the quarry below the foremans office. At this locality, the floor is 72' below sea level, and an uninterrupted section of 115' of limestone is exposed in a vertical face. Throughout, the beds are poorly cemented coquinas with variable amounts of terrigenous material. At the base poorly bedded biocalcarenite comprising fragments of fossils belonging to the calcareous algae-Pericosmus biofacies contain 2-3" thick bands every 2 or 3 feet rich in quartz grains and mica flakes. The carbonate percentage is about 95%, but is often only 65% in the terrigenous-rich bands. The shelly fragments, comprising calcareous algae, bryozoa and foraminifera are surrounded by a thin zone of sparry calcite. They are unrounded and usually less than 0.3 cms in diameter. Complete radioles of regular echinoids are often concentrated on bedding horizons, while thin-shelled tests of irregular echinoids are scattered here and there and a few with aboral surfaces upwards may be in life position. In places the bedding is disturbed and contains intraclasts up to 1' in diameter. Bioturbation by Capsites is only seen when it disturbs the terrigenous beds, but is absent from the disturbed horizons.

There is a gradual increase in silty material up the section and coincident with a decrease in the grain size of the sand-grade material, the sorting improves (Bowler 1963). Sixty feet above the base of the quarry there is a sharp junction with beds crowded with Lepidocyclus howchini, the characteristic species of the Lepidocyclus biofacies, which persist to the top. Bedding is horizontal and bioturbation and complete echinoid tests are absent. Most fragments are of the same grade as those near the base, but Lepidocyclus specimens are nearly always complete. Silty-clay interbeds are fairly common, and 110' above the base (38'OD) the rock becomes a clayey limestone. This junction corresponds to a change in the heavy mineral suite from garnet-chlorite-biotite to tourmaline-zircon (Bowler 1963).

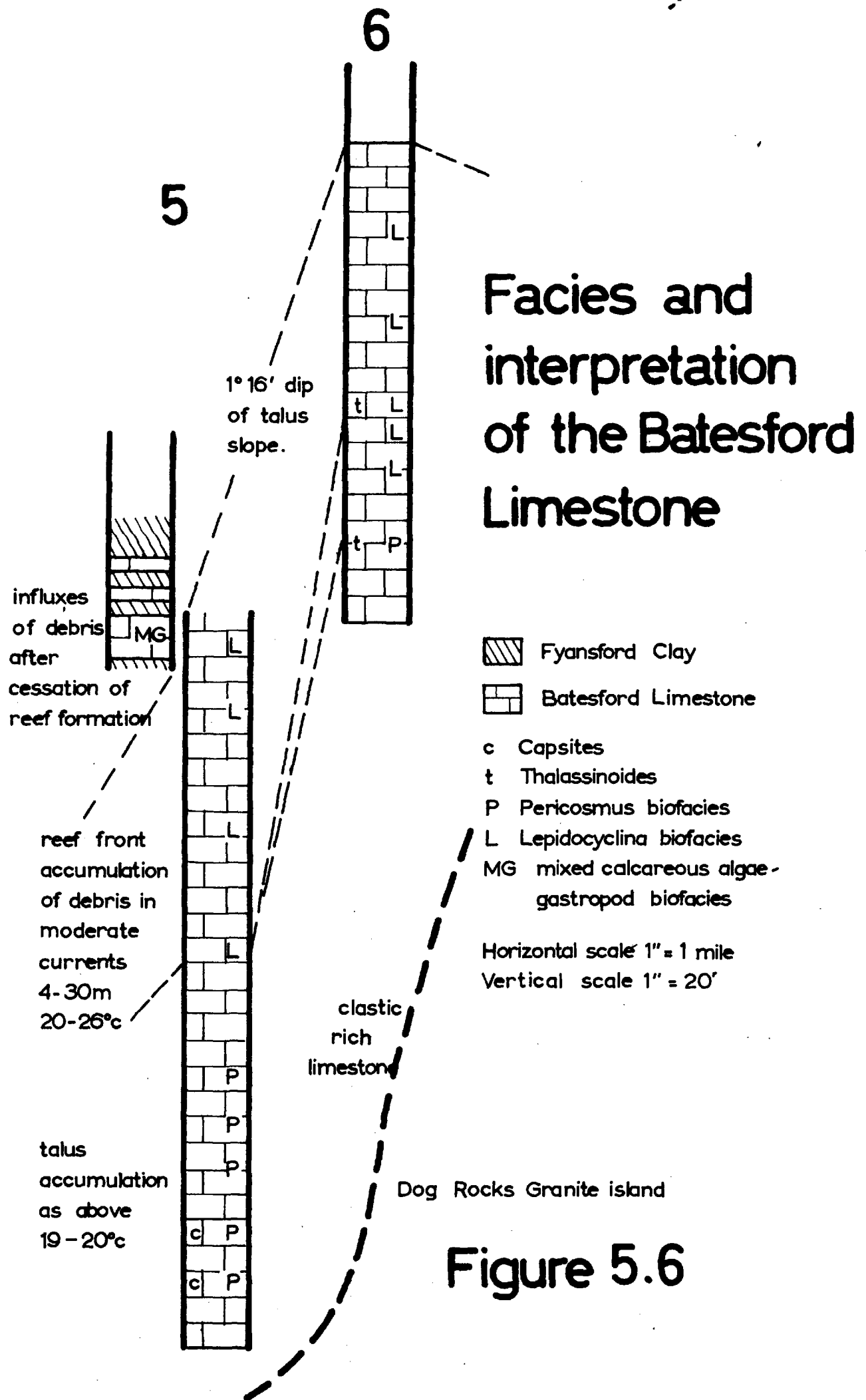


Figure 5.6

A gentle southeasterly dip of between 1 and 2° evident in weathered outcrop carries unit 9 down to the horizon at the base of the conveyor belt section, at 21'OD. Alternations of Capsites-burrowed argillaceous coquina limestones and more clay-rich beds about 10' thick occur, both with abundant Lepidocyclina. Through 35' of section, the basal 10' of which is equal to unit 9 of the other section, there is a marked increase in argillaceous material, so that unit 6 is a clay rich in calcareous fragments. The Lepidocyclina biofacies characteristic of the lower three units, gives way to the mixed calcareous algae-gastropod biofacies in which Lepidocyclina is very much less abundant, in the upper three units.

In the southeast corner of the quarry interbedded argillaceous limestones and calcareous clays occur at the same level, and pass rapidly up through calcareous clays into stiff black Fyansford Clay. The mixed calcareous algae-gastropod biofacies passes up into the mixed Entalophora-gastropod biofacies.

At the western side of Batesford quarry the limestone has a much greater percentage of terrigenous material. Quartz and biotite occur throughout rather than being concentrated in bands towards the base only. Aggregates of granitic material as well as pebbles 1" - 2" in diameter occur

Bowler (1963) recorded an increase in clastic material westwards as well as an increase in the grain size and a decrease in the sorting capacity.

At the section on the north side of the quarry (360 007) the beds are at a much higher topographic level, the base being at 51'OD. The limestone is exposed between this level and 126' OD, where talus slopes probably corresponding to the junction with the Fyansford Clay begin. The lower part of the limestone, between 51' and 83' OD is characterised by the calcareous algae-Pericosmus and Lepidocyclina biofacies. It

consists of massive and well-bedded coquinas with bands rich in echinoid radioles and clastic material. At 83'0D there is a sharp junction with a coarse coquina crowded with Lepidocyclina howchini - the equivalent of the horizon 60' above the base of the foremans office section. In this section, however, Lepidocyclina enters at least 10' below this level. Towards the top of the section impure wavy clayey inter-beds enter, and show up extensive Thalassinoides bioturbation.

Discussion of the Batesford Limestone (figures 5,8,9)

The Batesford Limestone occurs to the southeast of the outcrop of the Dog Rocks granite. Its top surface is exposed in sections between about 40' and 126' above sea level, while its characteristic biofacies indicate depths of between about 10 and 100' (4 - 30 metres) only. In the absence of any faulting the present topographic height of the granite hill - about 325' indicates that it must have stood out of the sea as an island during the deposition of these beds.

The limestone consists of an accumulation of fragments of calcareous algae, bryozoa, echinoids and foraminifera. Of these the only groups that show any signs of being in the environment in which they lived are the echinoids and the foraminiferans. Other than complete delicate tests of Pericosmus spp, some still in life position, and complete and unworn Lepidocyclina howchini crowding bedding planes, there is no evidence that any of the fragments originated in the environment in which they occur. Nearly all of the calcareous algae and bryozoans represent a talus accumulation of fragments derived from shallower waters.

The drop in topographic level of the top of the limestone, from 126' (in the section to the north of the quarry) to about 40' (near the foremans office) in about 0.7 of a mile represents a southeasterly inclination of about 1:45 ($1^{\circ}16'$) consistent with a talus slope. The area of limestone genesis was in very shallow or intertidal waters where

a calcareous algae reef or ledge developed around the granite island. It is never seen owing to lack of exposure or subsequent erosion, and all that remains is a thick pile of talus composed of carbonate fragments. There is a great similarity between the Batesford Limestone and the sediments being deposited on the Seychelles bank at the present day, which are developed as a thin veneer on a shallow water bank, rarely deeper than 20 metres, proximal to granite islands. Locally coral and algal reefs occur. Lewis and Taylor (1966) divided the sediments there into groups based upon the organic content and the presence or absence of quartz.

The Batesford Limestone, characterised by the calcareous algae-Pericosmus and Lepidocyclina biofacies particularly resembles the deposits of the forereef of the Mahé reefs. The latter comprises a talus accumulation to the seaward of isolated reefs. Gastropods and bivalves are abundant, but coral and algal debris form the bulk of the sediment. Echinoids, bryozoans, crustaceans and green algae are also important, and benthonic foraminifera are locally abundant. The absence of gastropods and bivalves from Batesford is probably due to diagenesis, since no aragonitic shells are present in the limestone, while the absence of reef corals indicates that the reef or ledge was entirely algal.

The forereef of the Seychelles passes laterally into the sediments of the bank, in which benthonic foraminifera, especially Amphistegina are abundant. The slower rate of deposition is reflected in an increase of planktonic species, but fragments of calcareous algae, bryozoans, echinoid plates and spines, become rather less important than on the talus slope. The sediments of both the forereef and the Seychelles bank proximal to the islands may be rich in quartz grains.

Drawing a strict parallel, it might be concluded that the upper part of the Batesford Limestone, characterised by an abundance of benthonic foraminifera, especially Lepidocyclina, represented a period of

slower deposition during which the reef was not so active. However, as has been indicated in Chapter 3 the entry of Lepidocyclus is attributed to an increase in the temperature of the water. Lepidocyclus is assumed to have lived on the talus slopes of the reef, and has thus not been transported from shallower water. It is thought to be depth-restricted for two reasons:-

(i) It is well preserved and abundant in the talus accumulation of the Batesford Limestone.

(ii) It is very rare in the intertidal and shallow subtidal equivalent of the Batesford Limestone:- the Upper Maude Limestone.

Its entry into the section at the foremans office is very sharp and probably follows a period of scour. Periods of scour occurred throughout the period of deposition, and are represented by lags of regular echinoid radioles. Influxes of talus material were clearly fairly constant, but in a few places disturbed bedding due to slumping may be seen (foremans office section, units 3,4,5). Clasts of cemented rock are occasionally seen, and indicate that rapid lithification of the substrate took place during periods of non-deposition. Penecontemporaneous lithification of carbonates has been described from subtidal deposits at the present day by Milliman (1966) and Berger (1967).

Decrease in the quantity of clastic material both eastward, away from the granite island, and upwards through the sections, were described by Bowler (1963). He located an outcrop, west of the present quarry, in which limestone was observed resting directly upon granite (It is probably now like both the "Upper" and "Filter" quarries of earlier authors, covered by tips). It was a very impure limestone and contained large clasts of quartz and felspar in a reddish subopaque lime-mud matrix. As in the Seychelles, therefore, the quantity of terrigenous material becomes less abundant away from the island.

The reef evidently continued to form throughout the period during which the Dog Rocks granite was exposed as an island. It seems very unlikely that any deposition of clay took place around the reef during this period since the time lines, as indicated by the marked disconformity in the middle of the limestone, are parallel to the top surface. Once flooding of the granite island took place - marked by a change in the heavy mineral assemblage at the top of the limestone (Bowler 1963) - and the reef ceased to develop, clay deposition, marking the onset of the Fyansford Clay, started. It gradually mantled the surface of the reef, but during the period represented by the basal beds was subjected to influxes of carbonate material derived by current activity from the reef and talus slopes. This period is represented by approximately 50' in the section in the southeast corner of the quarry, but is necessarily much thinner in the section on the north side, the true Fyansford Clay biofacies entering not more than 30' above the top of the limestone. Clearly, the mantling of the reef by clay took place from the bottom upwards, so that it was covered at the top much later than at the base. The lowermost clays of the Fyansford Clay are, therefore, characterised by the mixed calcareous algae-gastropod biofacies in which Lepidocyclina occurs in the reef-derived debris. The later clays, however, with the mixed Entalophora-gastropod biofacies (without Lepidocyclina) were deposited when most of the talus slopes had been mantled, and only the top of the reef, originally deposited in water shallower than Lepidocyclina existed in, was exposed to current activity.

The Age of the Batesford Limestone (figure 5.1)

The most exhaustive study of the fauna of the Batesford Limestone was by Chapman (1909) who listed a large number of Foraminifera and Ostracoda from the upper and filter quarries. Singleton (1941) noted that both of these quarries were now no longer visible, but both contained

limestone rich in Lepidocyclina and so they obviously belonged to the top part of the present section. The brownish colour of the limestone from the upper quarry (near the position of the section on the north side) is due to ferruginous staining from the beds above. The section at the filter quarries, towards the west of the position of the present quarry was measured by Chapman (1909).

Pale blue clay 14'

Polyzoal rock with few Lepidocyclina

Friable cream Lepidocyclina 22'

This represents a similar section as can be seen at the top of the limestone on the eastern side of the quarry.

Until recently the floor of the quarry was not low enough to expose limestone without Lepidocyclina, so that Singleton (1941) defined the Batesfordian stage as "the interval of time represented by the deposition of the Lepidocyclina-bearing limestones of the Batesford quarries, as well as those represented therein by non-deposition or erosion". Previously, the Lepidocyclina-bearing Batesford Limestone had been referred to the Janjukian by Chapman (1914), and to the Balcombain by Hall and Pritchard (1902). Singleton (1941) regarded the Batesfordian as a stage immediately antecedent to the Balcombain, while admitting that the fossils of the former were strongly environment-controlled and that it might represent a facies of the latter.

Carter (1959) agreed that the Batesfordian represented a distinct stage represented by his faunal unit 9 and that it was present only at the tops of the Batesford sections. He recognised a Longfordian fauna from sample (1) on the quarry floor. Bowler (1963) also regarded the Batesfordian as a stage preceeding the Balcombain but thought that the upper part was to some extent equivalent to the lower part of the Eyansford Clay. However, his figure 13 (p. 100) indicates that he considered that clay deposition took place throughout the period

represented by the Batesford Limestone.

The present author considers that deposition of the whole of the Batesford Limestone took place before the deposition of the overlying Fyansford Clay, partly because the time lines within the limestone seem to follow its upper surface, and partly because he considers it improbable that a reef talus consisting of clean washed carbonate debris could develop at the same time as significant offshore muddy sedimentation was taking place. The interdigitations of limestone in the clay at the top are regarded as representing influxes of talus material after the reef had ceased to develop actively. The author is therefore in close agreement with Singleton and Carter that the Batesfordian represents a distinct stage prior to the Balcombian.

The Fyansford Clay (figure 5.7)

Introduction: This has been described by Bowler (1963) as including "... all clays, argillaceous limestone, marl and argillaceous silts situated above the stratigraphic level of the Batesford limestone and below the disconformable contact with the Moorabool Viaduct Sands".

The most complete section occurs in road cuttings at Fyansford, but most of the sections between Geelong and Maude contain significant thicknesses. Owing to the soft nature of much of the sediment, exposures are often obscured by hill slopes.

Description of Sections: The section at Fyansford (section 3) in the Orphanage Hill locality of earlier authors (Singleton 1941), and includes 103' of fairly continuous section. Throughout, it consists of well bedded blue silty clays in units between 2' and 3'6" thick alternating with brown limonitic and more calcareous sandy silty clays. As pointed out by Bowler (1963) the variation in colour is largely due to weathering, since in fresh exposure the silty clays appear black, and the sandier more calcareous beds appear light grey. In many of the

Facies and interpretation of the Fyansford Clay

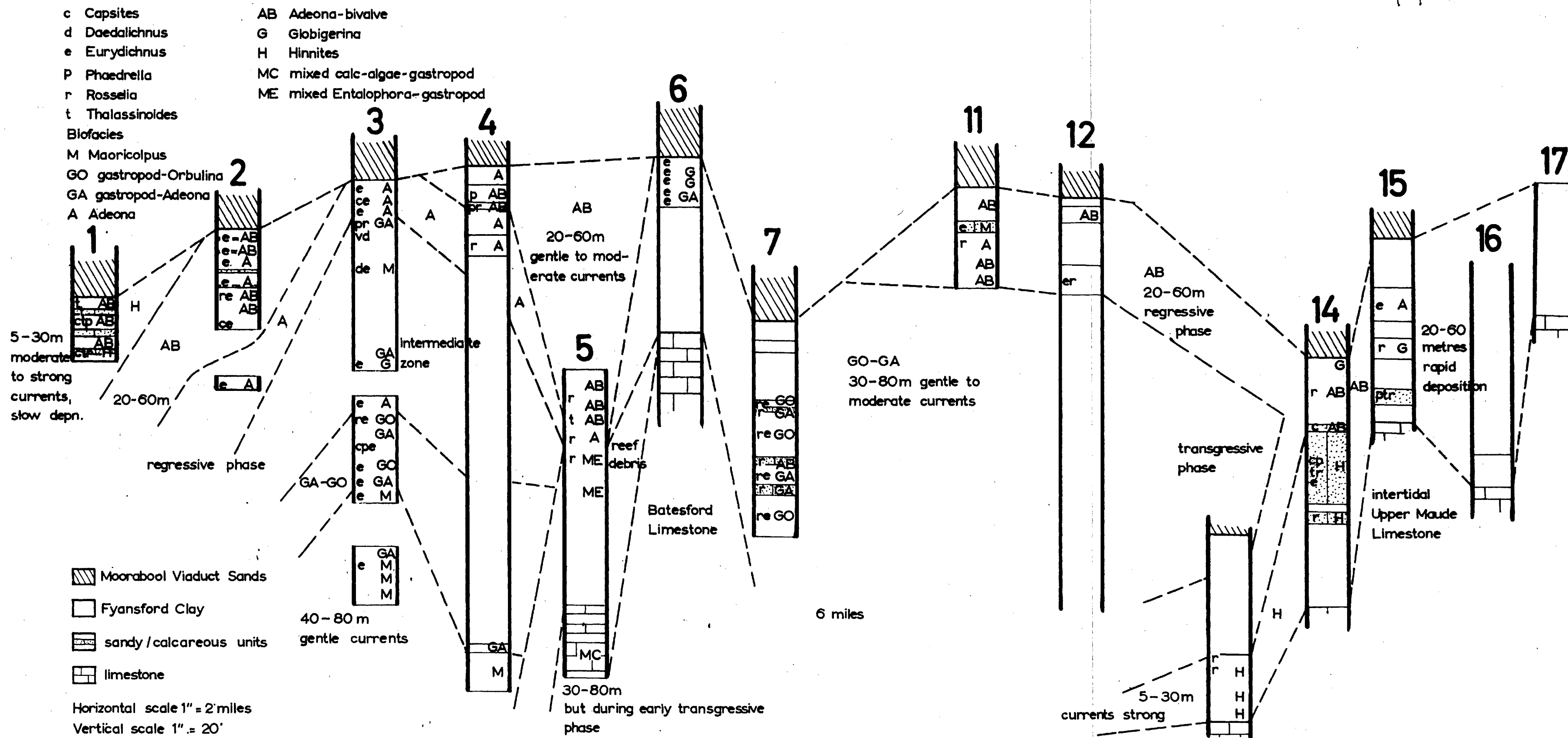


Figure 5.7

units the proportion of sand is very low (see Bowler), but in some of the limonitic beds it may reach 10%. The carbonate percentage is usually about 7% but may rise to 20% or even 30%. In the silty clay beds almost all of the coarse fraction consists of shell fragments, but in the limonitic beds the latter are usually subordinate to quartz grains. The clastic material in the coarse fraction consists largely of fresh or limonite-coated unrounded quartz grains of fine sand grade, muscovite and chloritised biotite. Bowler (1963) also recorded magnetite and ilmenite, and the heavy minerals zircon, tourmaline and rutile. Fossils are abundant in nearly all of the units. They are extremely well preserved and usually complete or only slightly broken. Many of the bivalves are articulated and lie like most of the scaphopods, vertically within the sediment. Both are interpreted as being in life position, but the rest of the biota, being largely epibiontic, is less obviously so. Large zoaria of Adeona grisea occur on many bedding planes, but in the main they are broken up into fragments about 1" long. Many of the shells are concentrated in bands within the sediment, reflecting the presence of current activity. However, the fine grade of the sediment indicates that this was very gentle, and not capable of transporting shells far. The biofacies present in each unit are regarded as being more or less autochthonous, therefore.

Towards the top of the section, limonitic and calcareous sandy silty clays become more common than at the base, and these changes are reflected in the succession of biofacies. At the base the Maoricolpus biofacies is typical, but this gives way to the gastropod-Orbulina and the gastropod-Adeona biofacies and towards the top to the Adeona biofacies. There is thus a passage upwards from environments of deposition in depths of 40 to 80 metres in which the deposition was continuous, through gradually shallowing water into depths of 20 to 60 metres where the current activity is much greater and the deposition slower

and less continuous. Throughout the section Eurydichnus is abundant, but a variety of other forms enter towards the top (Rosselia, Phaedrella, Daedalichnus, Capsites).

At section 2, on the seafront at Western Beach, Geelong, about 40' of Fyansford Clay, overlain by Moorabool Viaduct sands, is exposed. The succession consists of sandy silty clays in which concretionary limestone bands appear towards the top. Nearly all of the units are horizontally bedded, and bioturbation by Eurydichnus is abundant throughout. The Adeona biofacies, present at the base is replaced upwards by the Adeona-bivalve biofacies. The beds continue the trends apparent at the top of the Fyansford section - becoming more sandy and calcareous upwards. A low northward dip carries these beds below those exposed in the cliff at North Shore, Geelong (section 1). Only 15' of Fyansford Clay, represented by alternations of sandy silts and then silty sandy limestone bands occurs. The Adeona bivalve biofacies, present in the silts, alternates with the Hinnites biofacies, present in the limestones. The Hinnites biofacies represents very slow or non-depositional conditions in depths of 5 to 30 metres in areas of gentle to strong current activity. Bioturbation is present throughout. Though Rosselia, Thalassinoides, Phaedrella and Capsites are present, the most common is Thalassinoides represented by light coloured mottling of the sediment.

The biofacies present in these two sections indicate a gradual shallowing of the environments, a slower rate of deposition and an increase in current activity. The conditions are reflected in a concomitant increase in the sand and carbonate percentages in the sediments. Probably, therefore, they represent a sensible upward succession - the sediments of section 2 continuing from the top of section 3, and those of section 1 overlying those of section 2.

In a bore-hole at Coghills, north of Fyansford, Bowler indicated that 300' of Fyansford clay occurs. In the outcrop there (section 4),

scattered exposures through a thickness of 127' were examined. At the base silty clays and sandy silts characterised by the Maoricolpus and the Gastropod-Adeona biofacies respectively occur, and may be correlated with the base of section 3, at Fyansford. At the top, alternations of highly bioturbated sandy silts and silty sandy limestones with the Adeona and Adeona-bivalve biofacies are clearly related to section 2 at Geelong.

The junction between the base of the Fyansford Clay and the Bates - ford Limestone in section 5 has been dealt with in the description of the latter. The mantling of the talus slopes by stiff black clays and calcareous clays (with talus-derived debris) took place after the reef had ceased to form. The absence of large quantities of granitic material in the clay indicates that flooding of the granite island had already taken place. The mantling of the reef took place from the base upwards, though the depositional surface was not horizontal, but slightly concave upwards. This is reflected in a southeasterly dip of 2° visible in the clay at the north side of Batesford, and accounts for the rapidity with which the Lepidocyclina-bearing talus slopes were covered.

In the section at the conveyor belt, the biofacies characterising the stiff black clays rich in shelly matter is the mixed calcareous algae-gastropod biofacies. This indicates a large influx of talus-derived debris, including Lepidocyclina within the general environment of the Maoricolpus biofacies. In the section on the south side of the quarry, where shelly sands are subordinate to clays, the mixed calcareous algae-gastropod biofacies passes up into the mixed Entalophora-gastropod biofacies. The latter represents an environment within the general framework of the gastropod-Adeona biofacies but containing reef-derived debris (without Lepidocyclina).

The same upward transition is evident in the southeast corner of the quarry, where the mixed Entalophora-gastropod biofacies is completely within the Fyansford Clay. In this section it is overlain by sandy

silts with the Adeona-bivalve biofacies.

In section 6, on the north side of Batesford, alternations of clays and sandy clays with the gastropod-Adeona and Globigerina biofacies, occur at the top, while at section 7 the lower units contain Eurydichmus, Rosselia and the gastropod-Orbulina and gastropod-Adeona biofacies. The upper units, however, are unfossiliferous.

In sections 11 and 12 highly Eurydichmus and Rosselia bioturbated sandy silts with concretionary limestone bands are typified by the Adeona and Adeona-bivalve biofacies.

The sediments lying on the Upper Maude Limestone in section 13 consist of grits and fine sands passing up into silts. A basal massive illsorted calcareous grit with pebbles of fine sand is overlain by Rosselia burrowed fine sands and grits. Sandy silts at the top are bioturbated also by Rosselia. Throughout the Hinnites - biofacies is characteristic, indicating water slightly deeper than that of the underlying Upper Maude Limestone.

In section 14, 23' of interbedded calcareous sandy silts and silty clays, characterised by the Hinnites biofacies and a variety of burrow types overlie the Upper Maude Limestone. The remainder of the section, composed of Rosselia-bioturbated blue silty clay is characterised by the Adeona-bivalve and Globigerina biofacies. At the base, a sandy silt is crowded with worn limonitised Amphistegnia lessonii. This is almost certainly the horizon described by Bowler (1963) as representing a "marl facies near Lethbridge". He identified the limonitised foraminifera as Lepidocyclina, but a prolonged search failed to produce any specimens with a convincing equatorial plane.

At section 15 scattered outcrops of bioturbated calcareous silts and fine sands occur, characterised by the Adeona and Globigerina biofacies. At this locality there is not more than 44' of Fyansford Clay present. Maximum thicknesses for the other northern sections are:-

section 12	:	160'
13	:	46'
14	:	60'
15	:	44'
16	:	93'
17	:	32
18	:	1'

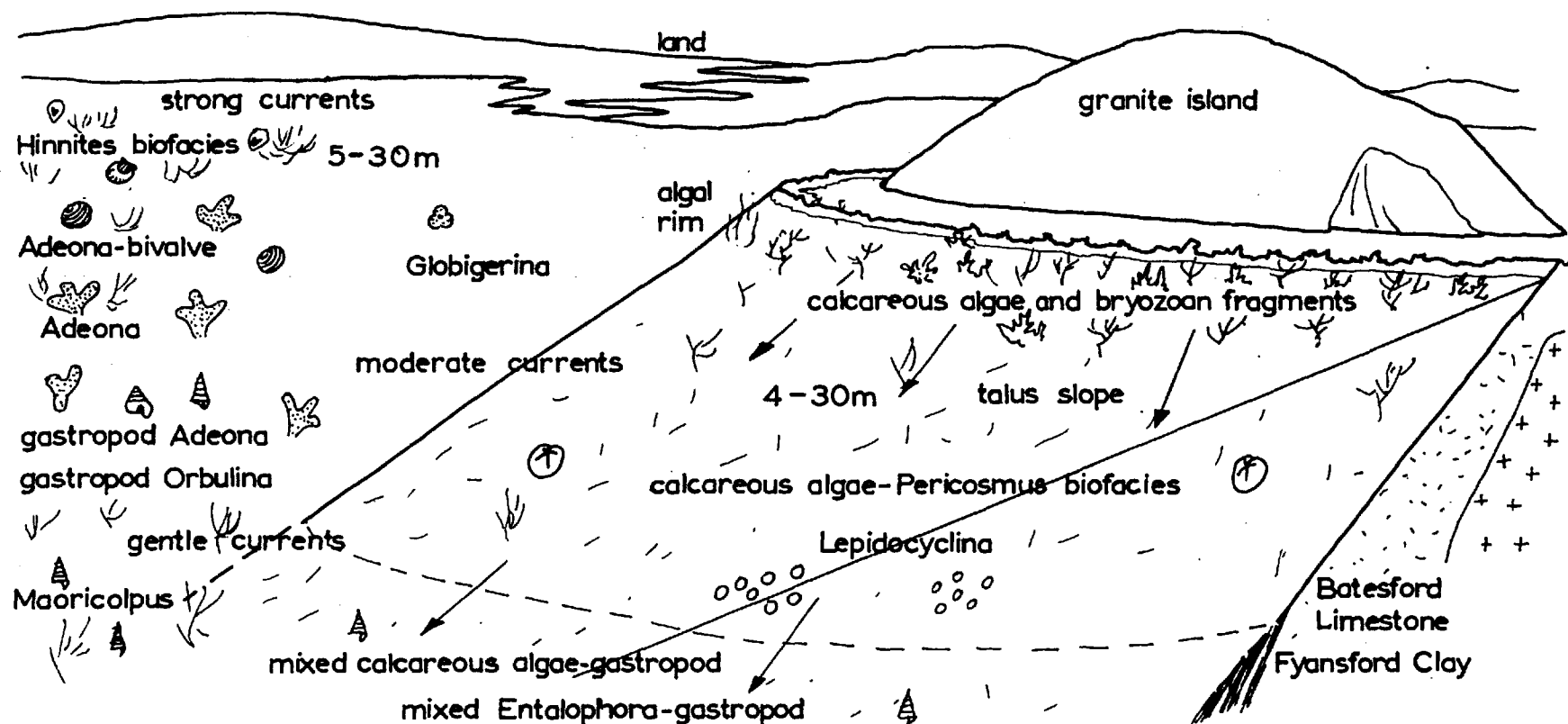
The great variations in thickness reflect the irregularity of the development of the Upper Maude Limestone and the variation in the top surface of the Maude Basalt.

The Fyansford Clay in sections 16,17 and 18 did not yield any fossils. It is represented by sandy silts and silty sands but is poorly exposed. In section 18 it is reduced to a 1' thick band of black sandy clay between the Maude Basalt and the Newer Basalt.

Discussion of the Fyansford Clay (figures 5,8,9)

The Fyansford Clay represents deposition on an open shelf during and after the phase of maximum transgression of the Tertiary sea in this area. Clay and sandy silty clay, derived from a river draining areas of low topography deposited a thick sequence of sediments over a wide area of the shelf of southern Victoria. The transgression that flooded the Dog Rocks Granite and its associated reef also flooded the shallow water and intertidal deposits of the Upper Maude Limestone. Deposition of the Fyansford Clay, in the northern sections represented by highly bioturbated sands and sandy silts, took place. Probably the rate of sedimentation was rather rapid in many places for many of the units are unfossiliferous. In many cases, however, the Hinnites bio-facies characterises the lowermost beds, indicating very slow deposition in shallow subtidal zones (5 - 30 metres) with moderate or strong currents. The overlying sediments, contain the Adeona and Adeona-bivalve biofacies, which indicate rather deeper waters and less strong currents.

Figure 5.8



Depositional environments in the Batesford Limestone and Fyansford Clay

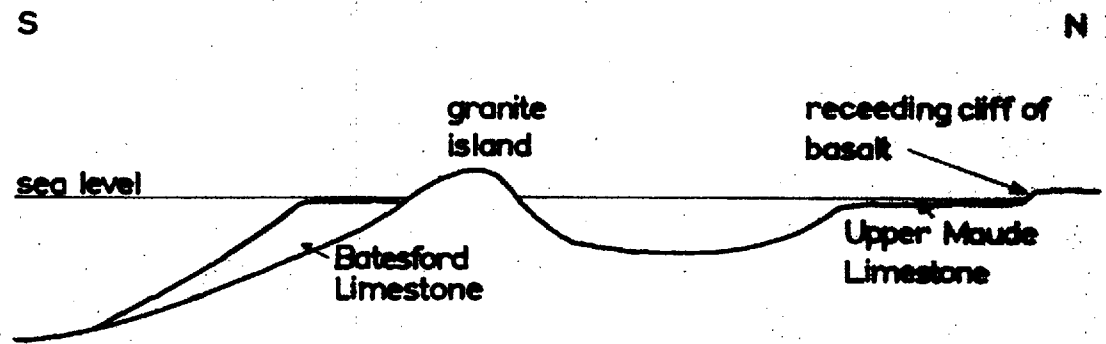
The phase of transgression must have come to an end fairly rapidly however, for in all of the rest of the sections, the succession of bio-facies indicate a regression. The fact that no Fyansford Clay occurs northwards of section 18 (the position at which all the earlier marine deposits died out) suggests that the transgression was not the result of eustatic movements, but of downwarp southward of a strandline axis. Bowler also arrived at this conclusion, citing as evidence the sharp drop in the Basement from Maude to Bannockburn.

As indicated before, the succession of biofacies in section 3 at Fyansford indicates a regression, or upward shallowing, which is continued in sections 2 and 1. In the latter, the Hinnites biofacies occurs, representing a return to very shallow water conditions like those of the early part of the transgressive phase in the northern sections. The Hinnites biofacies of the regressive phase contains a different biota (including Hinnites corioensis and Ostrea ingens) than those of the transgressive phase, though the biofacies pattern and environment are the same.

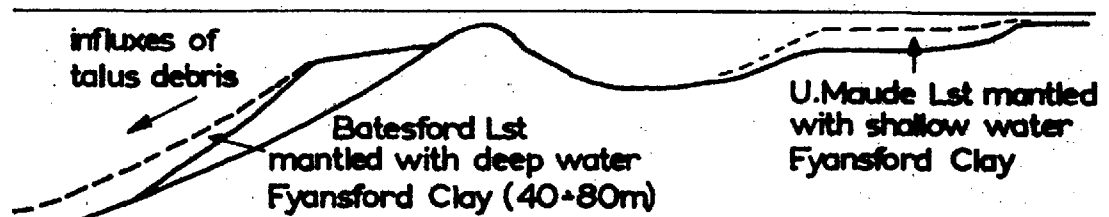
The regressive succession of biofacies can be recognised throughout the sections (figure 5.8.) and consists of:-

Top	<u>Hinnites</u> biofacies	
	<u>Adeona</u> -bivalve biofacies	5-30 metres depth
	<u>Adeona</u> biofacies	
	Transition zone.	
	Gastropod- <u>Orbulina</u> and gastropod- <u>Adeona</u> biofacies	30-80 metres depth
Bottom	<u>Maoricolpus</u> biofacies	

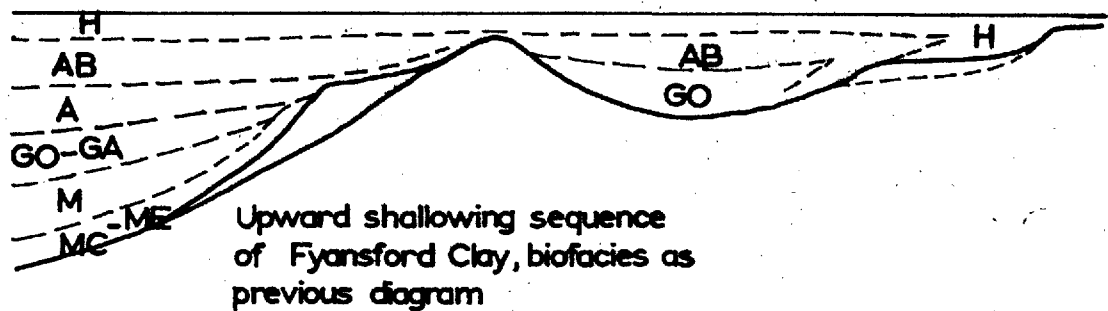
At Batesford (section 5), the lowest two zones are represented by the mixed calcareous algae-gastropod and mixed Entalophora-gastropod



1 BATESFORDIAN



2 BALCOMBIAN (transgression)



3 BAIRNSDALIAN (regression)

Sequence of depositional events during the Batesfordian to Bairnsdalian period

Figure 5.9

biofacies which represent the environments of the Maoricolpus and gastropod-Adeona biofacies with talus-derived debris respectively. They were probably deposited rather earlier, however, as is discussed in the section on age. In the northern sections, the transgressive phase with the Adeona-bivalve biofacies is probably in part the equivalent of the upper zones of the regressive phase.

The lines of correlation, following zones of influence of biofacies in the sections indicate that gentle folding took place before erosion and deposition of the Moorabool Viaduct sands. They closely follow the correlation lines of Bowler (1963), arrived at on the basis of independent evidence. Correlation by successions of biofacies, providing they follow a coherent pattern is a valuable tool in the classification of formations through which there is little apparent vertical change in the overall species content.

The Age of the Fyansford Clay (figure 5.1)

The age of the Fyansford Clay was discussed at length by Bowler (1963) who concluded that there was a disparity between the microfaunal and macrofaunal evidence.

Singleton (1941) equated the clays of the Fyansford section with those of his type Balcombian at Balcombe Bay. O.P. Singleton (1954) recognised two divisions of the latter:- a lower Balcombian stage, and an upper Bairnsdalian stage, and regarded the sediments at North Shore, Geelong (section 1), characterised by Hinnites corioensis, as characteristic of the latter. Carter (1963) recorded Orbulina universa throughout the Fyansford section and thus regarded the whole as belonging to his faunal unit 11, the Bairnsdalian. Faunal unit (10), characterised by Orbulina suturalis, and the equivalent of the Balcombian of Singleton, he recorded only from the 30' of clays overlying the Batesford Limestone at Batesford. The macrofaunas of the clays at Batesford and Fyansford do not differ, though, and both are represented at Balcombe Bay, so

the author accepts Carter's correlation.

Both the mixed calcareous algae-gastropod and mixed Entalophora-gastropod biofacies contain Orbulina suturalis without O. universa and so represent faunal unit 10, the Balcombian of Carter. Probably they are the equivalent of Fyansford Clay below the base of sections 3 and 4 (at Fyansford and Coghills). As indicated by Bowler (1963) 300' of clay occurs there, nearly 175' being below river level.

It is concluded that the lower part of the Fyansford Clay, represented at Batesford by about 30' of clay, and probably also in the northern sections (though no diagnostic foraminifera occur) is Balcombian. The bulk of the regressive portion of the Fyansford Clay, including the whole of the Fyansford section is Bairnsdalian, belonging to faunal unit 11 of Carter. The Bairnsdalian is thus regarded as a much more important stage than the Balcombian.

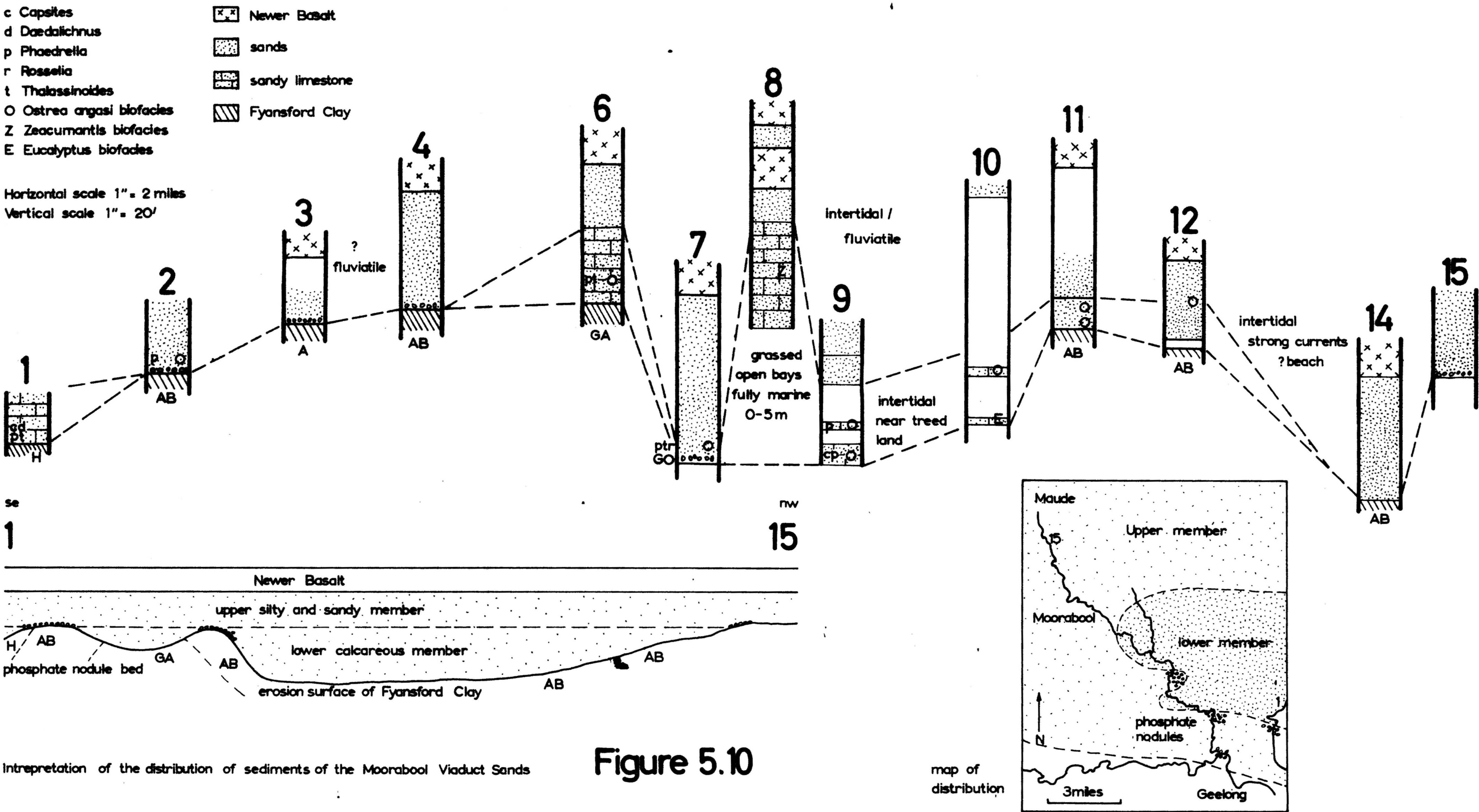
The Moorabool Viaduct Sands (figure 5.10)

Introduction: The Moorabool Viaduct Sands comprise a relatively thin, but persistent formation overlying the Fyansford Clay. They were defined by Bowler (1963) as including "... all the arenaceous sediments stratigraphically situated above the disconformable contact with the Fyansford clay and underlying Newer Basalt". There is considerable range in the lithology.

Description of sections: The formation was examined by earlier workers, notably Hall and Pritchard 1897, Mulder 1902, and Singleton 1941, in scattered outcrops near the Moorabool Viaduct, one mile north of Batesford.

At this locality, section 8, sands occur both below and above basalt flows. An upper flow about 15' thick, the Newer Basalt, overlies a thin bed of soft white, unconsolidated sand with red limonitic concretions. From this bed Hall and Pritchard (1897) recorded a leaf

Facies and interpretation of the Moorabool Viaduct Sands



impression, and regarded it as probably of fresh water origin. The topographically lower basalt 10' thick which is younger than the Newer Basalt, and separates this bed from the underlying sands, is present on both sides of the valley, but has a very local distribution. It was interpreted by Bowler (1963) as the fill of a valley excavated after the extrusion of the Newer Basalt in the position of the present Moora - bool river.

At the top of the lower part of the succession 8' of massive unconsolidated sands are exposed. They are well sorted and ironstained, but unfossiliferous. They are underlain by about 25' of alternating sands and calcareous sandstones, with frequent conglomeratic and gritty bands. Individual beds are about $\frac{1}{2}$ " to 1" thick, but bedding appears to be on a larger scale as there are zones about 1' thick of predominantly calcareous beds, alternating with non-calcareous zones of similar thickness. Quartz grains in the gritty bands are well rounded and often have a high degree of sphericity. The Zeacumantis biofacies is characteristic, though fossils are not common. Mulder (1902) recorded a large fauna from this locality, and his collection has been incorporated into the assemblage upon which the biofacies is based. On the road leading down to the river $\frac{1}{2}$ mile north of the Viaduct (353047) two exposures of similar gritty and conglomeratic sands and calcareous sandstones occur. The upper one is at the same topographic level as at section 8 and includes rippled sands rich in grit particles and flattened pebbles of sandstone (representing eroded sandy interbeds). Thalassinoides and Capsites are present, and the Ostrea angasi biofacies is represented by limonitised foraminifera. The lower exposure consists of very similar sediment but occurs between 127' and 132' above sea level. On the west side of the river around 346041, between about 110 and 140'OD (i.e. at the same topographic height as the lower exposure on the road)

boulders of an extremely ferruginous sandy grit litter the hill slope. The rock contains well rounded quartz grains and pebbles and Bowler (1963) recorded that it contains an unusually high proportion of kaolin - ised felspar. Ferruginisation has been so extensive that the rock largely consists of ironstone. Fossils are rare now, but were abundant in the past. Dennant collected a fauna similar to that of Mulder, i.e. belonging to the Zeacumantis biofacies.

The Moorabool Viaduct Sands in this part of the valley are in the region of 80' thick and reach almost down to river level. This represents their maximum development, as they thin northwards and southwards.

At section 9, scattered outcrops in a steep slope show bioturbated silty sandy limestones with the Ostrea angasi biofacies passing upwards into pebbly ferruginous sands and festoon-bedded white sands, alternating with grey sandy silts. At section 10 very scattered outcrops through a thickness of 60' expose the same succession. Silty sandy limestones occur at two levels, but both are very doubtfully in position. Outwash blocks of the lower, found 20' above an outcrop of granite in the river bed, are very rich in ferruginised leaves of Eucalyptus sp. characteristic of the Eucalyptus biofacies. The upper limestone contains the Ostrea angasi biofacies as at section 9. In situ exposures of ferruginous sand occur at 186 OD.

A similar section, though much thinner overlies Fyansford Clay at section 11. At the base, bioturbated calcareous silty sands and sandy silts 7' thick with a basal quartz pebble conglomerate are characterised by the Ostrea angasi biofacies. Specimens of Pholas australasiae in life position occur in the middle of the bed. Quartz pebbles also occur in the 18' thick overlying coarse grey argillaceous sand.

Farther to the north, the calcareous lower part of the formation is absent. At sections 11, 14 and 15 for example coarse red sandstones rich in grit particles and shale pellets directly overlie Fyansford

Clay. A few scattered oyster shells indicate the environment was still that of the Ostrea angasi biofacies. Moorabool Viaduct Sands are not exposed north of section 15, though Bowler indicated that there might be a very thin development at Maude school (section 16).

Traced southwards from the outcrops at the Viaduct the formation thins sharply, so that at section (7) two fifths of a mile to the south, it is only 40' thick. The calcareous lower portion is absent here, the poor exposures all being in illsorted red sandstone. At the base, overlying the Fyansford Clay is a 1' conglomerate composed of polished and algal-bored cobbles and pebbles of phosphatic sediment. Most are rather elongate, and as has been considered elsewhere (see Chapter 4), nearly all represent eroded Thalassinoides burrows, originally excavated by Ommatocarcinus corioensis. The decalcified faunas within the burrows, indicate a Balcombian or Bairnsdalian age, the composition falling into the pattern of biofacies of the gastropod-Orbulina.

Bowler (1963) recorded poorly preserved molluscan moulds, presumably originally aragonitic (and probably belonging to the Zeacumantis biofacies), from illsorted white sands just below the Newer Basalt in a road cutting at Batesford (356019). These are at the same stratigraphic level as white sands with calcareous concretions at the top of section 6 on the north side of Batesford. Separating the latter from the underlying Fyansford Clay is 18' of poorly-sorted horizontally bedded and planar cross stratified alternations of sands and calcareous sandstones. Shelly horizons containing Ostrea angasi and Mimachlamys asperimus occur throughout. Thalassinoides and Phaedrella are also present. At section 4 the calcareous horizon is absent, the whole of the Moorabool Viaduct Sands being represented by soft illsorted white sands with limonitic concretions and with a gritty layer at the base. A zone immediately below the Newer Basalt is reddened.

At Fyansford mottled red and yellow sands overlie a gritty bed with phosphatic pebbles (as at section 7). Sixty per cent of the pebbles here are recognisable as derived burrows. Towards the top of the section clay appears and persists to the base of the basalt.

At section 2 a basal phosphate pebble conglomerate characterised by the Ostrea angasi biofacies, is overlain by illsorted, festoon-bedded sands, the foresets dipping to the northwest. Thirteen feet of highly bioturbated calcareous sands with Thalassinoides, Phaedrella, Daedalichmus and Capsites overlie the youngest known Fyansford clays. Bowler (1963) recorded rare mollusc moulds and oyster shells from railway cuttings near the International Harvester Works at North Shore.

Discussion of the Moorabool Viaduct sands (figure 5.11)

From the foregoing, the Moorabool Viaduct Sands are clearly divisible into two members:-

(i) a lower calcareous member, exposed in sections 1,6,8,9,10 and 11, and characterised by bioturbation and the Ostrea angasi, Zeacumantis and Eucalyptus biofacies,

(ii) an upper sandy and silty member, exposed in sections 2,3,4, 6,7,8,9,10,11,12,14 and 15. Generally fossils are not preserved, though the Ostrea angasi biofacies has been recorded, and there are reports of moulds of molluscs and leaves at various localities.

The lower member is present in an east-west trending area stretching from North Shore and Batesford in the south to section 11 in the north west. In the southern part it consists of rippled sands and calcareous sands with pebble and grit layers characterised by the Ostrea and Zeacumantis biofacies. Both indicate deposition in grassed fully saline open bays in intertidal or shallow subtidal waters down to about five metres.

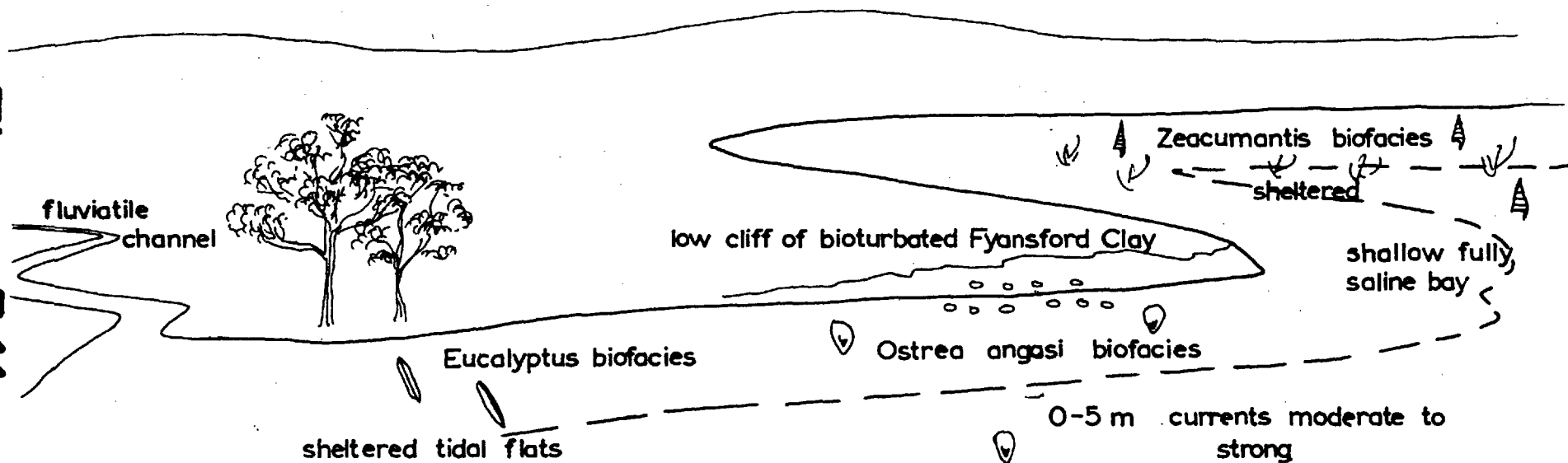
Farther north there is a considerable amount of silty material present and the conglomeratic bands are absent. Thus, though the Ostrea angasi biofacies indicates a similar environment to that farther south, there was less exposure and the conditions were much more sheltered. Proximity to the shoreline is indicated by the presence of the Eucalyptus biofacies.

These leaf-beds were located by Bowler between sections 9 and 12 in loose blocks on the valley slopes. Though uncertain as to their stratigraphic position, which he recognised was near the disconformity between the Fyansford Clay and the Moorabool Viaduct Sands, he attributed them to the former. He described them as a facies variation under the title of "leaf beds near Greenbanks", and regarded them as a non-marine or near shore environment indicative of a regressive phase at the end of the Fyansford Clay. However, the sediments in which the leaves occur closely resemble deposits of the Moorabool Viaduct Sands in sections 8 and 9, and contain a marine fauna with affinities to the Zeacumantis biofacies. Bowler did not find any marine shells in the leaf beds he examined, though he mentioned that unidentifiable foraminiferal and ostracod tests occurred.

The upper member consists of variable white, red and mottled sands and grey silts and clays that cover the whole of the area as far north as section 15. Most of the reddening is due to ferruginisation from the overlying basalt, as can be seen at section 4. Fossils are rare, but where present belong to the Ostrea angasi biofacies. The predominantly gritty or sandy composition of the deposit and the frequency of festoon bedding in some of the better exposed outcrops indicates rather higher energies than those of the lower group.

In the southern part of the area, in those localities where this member directly overlies Fyansford Clay, a conglomerate, frequently composed almost entirely of phosphatic pebbles occurs. As already

Figure 5.11



Depositional environments of the Moorabool Viaduct Snd.

suggested, these pebbles represent burrows, probably primarily rich in phosphate, eroded out of Thalassinoides burrowed Fyansford Clay. In the north, where poor exposure prevents examination of the junction, Bowler recorded the presence of phosphatic pebbles at the base of the sands in section 15 (his section 14). The localisation of these conglomeratic beds suggests that phosphatic burrows were only preserved after erosion out of the Fyansford Clay in areas where the energy was high, and both erosion and deposition rapid. In addition, Thalassinoides burrowed Fyansford Clay occurs only in the zones of the Hinnites and Adeona-bivalve biofacies. Phosphatic pebbles were located in sections in which the unconformity directly overlies the Adeona and Adeona-bivalve biofacies.

The presence of a marine fossil fauna suggests that these deposits were laid down in a marine environment. The local presence of illsorted festooned sands overlain by clays, the characteristic successions of fluvial channels (Allen 1965) however, indicates that in many places the environment may have been non-marine. The leaf collected by Hall and Pritchard (1897) at section 8 may be significant in this respect.

The Age of the Moorabool Viaduct Sands (figure 5.1)

The large numbers of living species present in these beds indicates that they are much younger than the rest of the sediments. Out of thirteen species collected by Mulder (1902), Tate regarded twelve as still living today. Singleton (1941) recorded the formation as Werrikooian, i.e. Upper Pliocene. However, in the map on page 30 he marked the locality on the west side of the Viaduct with the letter K, representing Kalimnan (middle Pliocene). The fauna collected by Dennant from this locality contains the same species as have been recorded by Mulder (1902), Coulson and the present author, from the outcrop on the eastern side (section 8), and there seems no reason to separate them. The author does not accept the correlations of Bowler (1963), who suggested that a considerable time elapsed between the deposition of the lower horizon at

the viaduct (on the west side) and the upper horizon (on the east side).

Tertiary geological history of the area

Janjukian (Oligocene)

The oldest tertiary sediments exposed in the area occur in the north, where a widespread phase of non-marine, beach-sand and nearshore marine deposition is represented. The continental sediments, the Lower Maude Sands and Gravels, representing piedmont and valley-flat environments occur to the north of Maude, while the variably thick barrier-beach sands are best developed in Sutherlands Creek. Offshore calcareous sands belonging to this period were deposited in depths of 20 to 30 metres. They constitute the lower part of the Lower Maude Limestone.

Longfordian (uppermost Oligocene - Aquitanian)

The onset of a marine transgression at the base of the Longfordian lead to the cessation of fluvial deposition. Little clastic material was added to the marine area and extensive reworking of the Janjukian deposits took place. This produced sand waves that migrated over the sea floor in depths of about 25 to 40 metres, and were eventually deposited as the Lower Maude Limestone (upper part). The fact that the shoreline did not change position suggests that the transgression was due to strandline downwarp, as farther up in the succession.

Farther to the south, on the southeast flanks of a granite island, a reef developed on the open shelf. Talus slopes of reef-derived debris accumulated in about 4 to 30 metres of water to produce the lower part of the Batesford Limestone.

Batesfordian (Burdigalian)

This period was marked by the extrusion of a basalt in the north, which built up to sea level and lead to a regression in the sea of about six miles. It was rapidly dissected by streams and with the continuation of the transgression begun in the Longfordian was slowly flooded by the sea. Deposition at first took place in inlets and in the rock pools of a wave-cut platform seaward of a receding cliff. Subsequently this phase gave way to intertidal flat deposition in the upper part of the Upper Maude Limestone.

At Batesford, the period was marked by the influx of the warmer water species Lepidocyclina howchini, but otherwise the development of the reef-talus limestone was not interrupted. At the close of the Batesfordian, the granite island was flooded and the reef ceased to develop.

Balcombian (Helvetian)

The transgression continued during the Balcombian, a period marked by the onset of clay deposition throughout the area. This is marked in the north by a deepening sequence of Fyansford Clay overlying the Upper Maude Limestone. At Batesford it is represented by Fyansford Clay mantling the Batesford reef talus slopes, and deposited in deeper water (30 to 80 metres) than the underlying limestone.

Bairnsdalian (Tortonian)

The transgression ceased at the beginning of the Bairnsdalian and a regressive sequence of thick clays - the main part of the Fyansford Clay - were deposited. At the base the depths of deposition were in the region of 40 to 80 metres, while at the top they were between about 5 and 30 metres. With the gradual infilling of the sedimentary area, the deposition became slower and more and more rich in sandy material.

Mitchellian, Cheltenhamian and Kalimnan (Lower and Middle Pliocene)

During this period no deposition took place, and the sediments were subjected to slight folding. Probably the present topography, in which the Barrabool Hills west of Geelong became elevated, was instigated during this period. The sea probably retreated completely from the area for at least part of the time, for the next deposits have a rather restricted distribution, of similar trend to the present topography.

Werrikooian (Upper Pliocene)

The first deposits of this period were laid down in a shallow bay with an east west trend, protected from the sea to the south by the Barrabool Hills, and probably the Otway ranges. The Upper Werrikooian sands, comprising a complex of probably beach and fluviatile deposits were laid down over a much wider area, and indicate that the sea transgressed over the limits of the shallow bays.

Pleistocene

The whole complex of sediments were overlain by a thick flow of the "Newer Basalt", and subsequently uplifted to the present level. Associated movements on the Rowsely fault and Lovely Banks monocline took place and lead to the present topographic relief. Subsequent basalt flows infilled early valleys cut into the Newer Basalt and their underlying sediments.

In the Mornington area on the east side of Port Phillip Bay, Gostin (1966) described the sequence of Oligocene and Miocene strata,

At the bottom of the sequence non-marine sediments lie below, above and interdigitated with Older (Flinders) Basalt (probably in part the equivalent of the Maude Basalt). Gostin regarded them as spanning the Janjukian to Longfordian stages. They are the equivalent of the Lower Maude Formation but are non-marine throughout and were never subject to a transgression of the sea.

During much of the Longfordian and Batesfordian little or no deposition seems to have been taking place, the transgression not having reached the area. In the late Batesfordian impersistent shallow marine, intertidal and fluviatile deposition took place (the Mt. Martha Sand Beds and the Harmon Rocks Sand Bed), and full y marine, offshore conditions were not operative until the Balcombian- Bairnsdalian when the Balcombe Clay (=Fyansford Clay) was deposited.

The regressive sequence noted in the Fyansford Clay is probably present in the Balcombe Clay, as deposition of the latter culminates in a phase of shallow marine Bairnsdalian- Michellian deposits, the Marina Cove Sand.

There follows a break in deposition, fluviatile Baxter Sandstones (probably in part the equivalent of the Moorabool Viaduct Sands) overlying an unconformity.

Throughout the period deposition took place in environments much closer to land than in the Moorabool and marine sediments were only developed after a considerable period of transgression had passed.

List of References Consulted

(See also Volume I)

Allan, Joyce.

1950: Australian Shells. 470 p. Georgian House, Melbourne.

Bandy, O.L.

1964: General Correlation of foraminiferal structure with environment. In Imbrie, J. and Newell, N.D. (eds) Approaches to Palaeoecology. pp 75-90. J. Wiley and Sons, Inc.

Berger, W.H.

1967: Foraminiferal Ooze: Solution at depths. Science, 156 pp. 383-385.

Bittner, A.

1892: Über Echiniden des Tertiärs von Australien. Sber. preuss. Akad. Wiss (Math. Naturw cl.) 57 (1). pp 331-371 Tables I-IV.

Bowler, J.M.

1963: Tertiary Stratigraphy and Sedimentation in the Geelong-Maude area, Victoria. Proc. R. Soc. Vict. 76(1). pp 69-137. plates XV - XVIII.

Canu, F., and Bassler, R.S.

1935: New Species of Tertiary Choilostome Bryozoa from Victoria, Australia. Smithson. Misc. Collns. 93. (9). 54p, 9 plates.

Carter, A.N.

1964: Tertiary Foraminifera from Gippsland, Victoria, and their stratigraphical significance. Mem. Geol. Surv. Vict. 23. Dept. Mines. Melbourne. 154 p., 17 plates.

Chapman, F.

- 1909: A study of the Batesford Limestone. Proc. R. Soc. Vict. 22 (2)
pp 263-314. plates LII-LV.

Chapman,

- 1922: New or little-known fossils in the National Museum XXVI -
Some Tertiary Mollusca. Proc. R. Soc. Vict. 35(1)
pp 202-205. Plates 1-3.

Chapman, F., and Gabriel, C.J.

- 1923: A revision and description of the Australian Tertiary
Patelloididae, Cocculinidae and Fissurellidae. Proc. R.
Soc. Vict. 36 (1) pp 22-40. plates 1-3.

Chapman, F., Parr, W.J., and Collins, A.C.

- 1934: Tertiary Foraminifera of Victoria, Australia - the
Balcombian deposits of Port Phillip. Part IV. J. Linn.
Soc. Lond - Zool. 38. pp 553-577 plates 8 - 11.

Chapman, F., and Singleton, F.A.

- 1925: The Tertiary deposits of Australia. Roc. Pan-Pacific
Sci. Congr., Aust. 1923 (1) pp 985-1024.

Chapman, F., and Singleton, F.A.

- 1925: A Revision of the Cainozoic species of Glycimeris in
Southern Australia. Proc. R. Soc. Vict. 37 (1) pp 18-60.

Chapman, F., and Singleton, F.A.

- 1927: Descriptive notes on Tertiary Mollusca from Fyansford and
other Australian localities. Part I. Proc. R. Soc. Vict.,
39 (2). pp 113-124. plates X-XI

Clark, H.L.

- 1946: The Echinoderm fauna of Australia, its composition and its origin. Carnegie Inst. Wash. Publ. 566. Echinoidea pp 277-382.

Cossmann, M.

- 1897: The gastropods of the Older Tertiary of Australia - Les Opisthobranches. Trans. R. Soc. S.Aust. 21 (1) pp 1-21. plates 1-2.

Cotton, B.C.

- 1959: South Australian Mollusca: Archaeogastropoda. Govt. Printer., Adelaide 449p.

Cotton, B.C.

- 1961: South Australian Mollusca: Pelecypoda. Govt. Printer., Adelaide. 263p.

Cotton, B.C., and Godfrey, F.K.

- 1942: Echinodermata of the Flindersian region, Southern Australia. Rec. S. Aust. Mus. VII (2). pp 193-234. plate XII.

Coulson, A.

- 1932: Phosphatic nodules in the Geelong district. Proc. R. Soc. Vict. 44. (II). pp118-126, plate XV.

Coulson, A.

- 1938: The basalts of the Geelong district. Proc. R. Soc. Vict. 50. pp 251-257.

Coulson, A.

- 1960: Some structural features of the Barrabool Hills. Proc. R. Soc. Vict. 72. pp45-52.

Crespin, Irene.

- 1943: The genus Lepidocyclina in Victoria. Proc. R. Soc. Vict.
55. (2). pp 157-180. plates 3-9.

Dahmer, G.

- 1937: Lebensspuren aus dem Taunus - Quartzeit und den Siegener
Schichten (Unterdevon). Jahrb. nass. geol. Landesanst.,
Bd. 57. p 523.

Darragh, T.A.

- 1965: Revision of the species of Eucrassatella and Spissatella
in the Tertiary of Victoria and Tasmania. Proc. R. Soc.
Vict. 78 (1) pp 95-114 plates 12-15.

Darragh, T.A.

- 1965: Proxichione (Pelecypoda: Veneridae) from the Tertiary of
South-Eastern Australia. Proc. R. Soc. Vict. 79 (1).
pp 165-174. plates 21-24.

Dennant, J.

- 1904: Recent corals from the South Australian and Victorian
coasts. Proc. R. Soc. Vict. 28. pp 1-11. 2 plates.

Dennant, J., and Kitson, A.E.

- 1903: Catalogue of the described species of fossils (except
Bryozoa and Foraminifera) in the Cainozoic fauna of Australia,
South Australia and Tasmania (with locality plan). Rec.
Geol. Surv. Vict. 1 (2). pp 89-147.

Dennant, J. and Mulder J.F.

- 1896: Probable Miocene age of a conglomerate at Shelford. Proc.
R. Soc. Vict., 9. pp 174-182.

Deschet, Y.,

- 1966: Études sur des Trigoniidae cénozoïques travaux du laboratoire de Paléontologie. Univ. Paris. Fac. Sci. D'Orsay.

Dorman, *h*

- 1966: Australian Tertiary Palaeotemperatures.
J. geol., 74, (1), pp 49-61.

Duncan, P.M.

- 1870: On the fossil corals (Madreporia) of the Australian Tertiary deposits. Quart. J. geol. Soc. Lond. 26. pp 284-318, plates XIX-XXI.

Duncan, P.M.

- 1875: On some fossil Alcyonaria from the Australian Tertiary deposits. Quart. J. geol. Soc. Lond. 31 pp 673, 674.

Duncan, P.M.

- 1877: On the Echinodermata of the Australian Cainozoic (Tertiary) deposits. Quart. J. geol. Soc. Lond. 33. pp 42-73.
plates III, IV.

Emery, K.O.

- 1946: Marine solution basins. J. geol. 54 (4) pp 209-228. 15 figs.

Etheridge, R.

- 1878: A catalogue of Australian fossils. Camb. Univ. Press. 232 p.

Finckh, A.E.

- 1904: Biology of the Reef-forming organisms at Funafuti Atoll.
in, The Atoll of Funafuti, pp 125-150. Rep. Coral reef
Comm. R. Soc., R. Soc. Lond., Harrison and Sons.

Finlay, H.J.

- 1926: New specific names for Austral Mollusca. Trans. N.Z. Inst.
57. pp 488-533.

Gostin, V.A.

- 1966: Tertiary stratigraphy of the Mornington district, Victoria.
Proc. R. Soc. Vict. 79 (2) pp 459-512 plates 51, 52.

Hall, T.S.

- 1897: On the occurrence of the anchoring tubes of Adeona in the
older Tertiaries of Victoria with an account of their
structure. Proc. R. Soc. Vict. (9)., pp 1-4, plate 1.

Hall, T.S.

- 1905: A description of Ommatocarcinus coriocoensis, Creswell sp.
from the Lower Tertiary of Victoria. Proc. R. Soc. Vict.
17 (2). pp 356-360.

Hall, T.S. and Pritchard, G.B.

- 1892: Notes on the Lower Tertiaries of the southern portion of
the Moorabool Valley. Proc. R. Soc. Vict. 4. pp 9-26.

Hall, T.S. and Pritchard, G.B.

- 1895: The Older Tertiaries of Maude, with an indication of the
sequence of the Eocene rocks of Victoria. Proc. R. Soc.
Vict. 7. pp 180-196.

Hall, T.S. and Pritchard, G.B.

- 1897: Geology of the Lower Moorabool. Proc. R. Soc. Vict. 10
(1). pp 43-56.

Hall, T.S. and Pritchard, G.B.

- 1902: A suggested nomenclature for the marine Tertiary deposits of southern Australia. *Proc. R. Soc. Vict.* 14 (2). pp 75-81.

Harris, W.J. and Thomas, D.E.

- 1949: Geology of the Meredith area. *Min. geol. J. Melbourne.* 3 (5) 43-51.

Hinde, G.J.

- 1900: On some remarkable calcsponges from the Eocene strata of Victoria (Australia). *Quart J. geol. Soc. Lond.* 56 pp 50-66. plates III-V.

Iredale, T. and McMichael, D.F.

- 1962: A reference list of the marine Mollusca of New South Wales. *Mem XI of Aust. Mus. Sydney.*

Keble, R.A.

- 1932: Notes on the faunas of the Geelong nodule beds. *Proc. R. Soc. Vict.*, 44. pp 129-133.

Klein, G. de V.,

- 1963: Bay of Fundy intertidal zone sediments. *J. sedim. Petrol.* 33. pp 844-854.

Lagaaij, R. and Gauthier, Y.V.

- 1965: Bryozoan assemblages from the marine sediments of the Rhone Delta, France. *Micropalaeontology.* 11 (1) pp 39-58.

Lewis, M.S., and Taylor, J.D.

- 1966: Marine sediments and bottom communities in the Seychelles. *Phil. Trans. R. Soc. Lond. (A)* 259, pp 279-290.

McCoy, F.

- 1874-1879: Prodromus of the Palaeontology of Victoria. Geol. Surv. Vict. spec. publ. Decade I, 1874, Decade II, 1875, Decade III, 1876, Decade IV, 1876, Decade V, 1877, Decade VI, 1879.

MacGillivray, P.H.

- 1895: A Monograph of the Tertiary Polyzoa of Victoria. Trans. R. Soc. Vict. IV. pp 1-166. 22 plates.

Macpherson, J. Hope, (editor).

- 1966: Port Phillip Survey 1957-1963. Part I. Mem. Nat. Mus. Vict. Melbourne. 27. 384 p.

Macpherson, J. Hope, and Gabriel, C.J.

- 1962: Marine molluscs of Victoria. Melbourne Univ. Press. 475 p.

Maplestone, C.M.

- 1898-1913: Further descriptions of the Tertiary Polyzoa of Victoria. Proc. R. Soc. Vict. 11-25. Parts referred to:
 Part I Vol 11 (1) pp 14-22 1898. plates 1,2.
 Part II Vol 12 (1) pp 2-13 1899. plates 1,2.
 Part III Vol 12 (2) pp 162-169 1900. plates 17,18.
 Part IV Vol 13 (1) pp 1-9 1900. plates 1,2.
 Part V Vol 13 (2) pp 189-190 1901. plates 13,14.
 Part VI Vol 13 (2) pp 204-213 1901. plates 34,35.

May, W.L., revised by Macpherson, J. Hope,

- 1958: An illustrated index of Tasmanian shells. Govt. Printer Hobart. 114 p.

Milliman, J.D.

- 1966: Submarine lithification of Carbonate Sediments. Science., 153. pp 994-997.

Mulder, J.F.

1897: The Eocene deposits of Coris Bay. Geelong Nat. 6 pp 12-17.

Mulder, J.F.

1902: Newer Pliocene strata on the Moorabool River. Proc. R.Soc. Vict., 14. pp 82-84.

Phleger, F.B.

1960: Ecology and distribution of Recent Foraminifera. John Hopkins Press, Baltimore. 297 p.

Pritchard, G.B.

1895: A revision of the fossil fauna of the Table Cape Beds, Tasmania, with descriptions of the new species. Proc. R. Soc. Vict. 8. pp 74-150. 4 plates.

Pritchard, G.B.

1895-1903: Contributions to the Palaeontology of the Older Tertiary of Victoria. Lamellibranchs.
Proc.R. Soc. Vict. 7,14,15. 3 plates.
Part I Vol 7., pp 225-231, 1895. 3 plates.
Part II Vol 14 (1)., pp 22-31, 1901. 2 plates.
Part III Vol 15 (2) pp 87-103, 1903. 2 plates.

Pritchard, G.B.

1898-1904: Contributions to the Palaeontology of the Older Tertiary of Victoria. Gastropods. Proc. R. Soc. Vict. 11-17.
Part I. Vol 11 (1)., pp 96-111, 1898. 2 plates.
Part II. Vol 17 (1)., pp 320-337, 1904. 2 plates.

Pritchard, G.B.

1903: On some Australian Tertiary Pleurotomarias. Proc. R. Soc. Vict. 16 (1) pp 83-91. 1 plate.

Singleton, F.A.

- 1932: Studies in Australian Tertiary Mollusca. Part I. Proc. R. Soc. Vict. 44 (2) pp 289-308.

Singleton, F.A.

- 1941: The Tertiary Geology of Australia. Proc. R. Soc. Vict. 53 part 1. (n.s.). pp 1-125, 3 plates.

Stach, L.W.

- 1936: Correlation of zoarial form with habitat. J. geol. 44. pp 60-65. 1 fig.

Stach, L.W.

- 1937: The application of the Bryozoa in Cainozoic stratigraphy. Aust. N.Z. Assoc. Adv. Sci., Rept 23d meeting. Auckland. pp 80-83.

Stride, A.H.

- 1963: Current-swept sea floors near the southern half of Great Britain. Quart. J. geol. Soc. Lond. Vol 119. pp 175-99. plates 13-18, 13 figs.

Tate, R.

- 1878: The Fossil Marginellidae of Australasia. Trans. Phil. Soc. Adelaide (1877-78) pp 90-98.

Tate, R.

- 1880: On the Australian Tertiary Palliobranchs. Trans. R. Soc. S. Aust. 3. pp 140-170.

Tate, R.

- 1884-1886: The Lamellibranchs of the Older Tertiary of Australia. Trans. R. Soc. S. Aust. Part I Vol 8 (1884-5) pp 96-158. plates II-XII. Part II Vol 9 (1886) pp 142-189, 196-200 plates XIV-XX.

Tate, R.

- : 1886: Supplemental notes on the Palliobranchs of the Older Tertiary of Australia, and a description of a new species of Rhynchonella. Trans. R. Soc. S. Aust. 8 pp94-95 1 plate.

Tate, R.

- 1887-1893: The Gastropods of the older Tertiary of Australia.
Trans. R. Soc. S. Aust.
Part I Vol. 10 pp 91-176 (1886-7) plates I-XII.
Part II Vol. 11 pp 116-174 (1889) plates II-X.
Part III Vol 13 (2) pp 185-235, (1890) plates V-XII.
Part IV Vol. 17 (2) pp 316-345 (1893) plates IV-X.

Tenison Woods, J.E.

- 1877: On some Australian Tertiary Corals. J.R. Soc. N.S.W. 11.
pp 183-195. plates I and II.

Tenison Woods, J.E.

- 1878: On some Tertiary fossils from Muddy Creek, Western Victoria.
Proc. Linn. Soc. N.S.W., 3. (3). pp 222-240 plates 20,21.

Tenison Woods, J.E.

- 1878: On some Australian Tertiary fossil Corals and Polyzoa.
J.R. Soc. N.S.W. 12. pp 57-61. 1 plate.

Tenison Woods, J.E.

- 1878-9: On some Tertiary fossils. Proc. Linn. Soc. N.S.W., 4(1)
pp 1-20.

Tenison Woods, J.E.

- 1880: On some new Corals from the Australian Tertiaries. Trans.
R. Soc. S. Aust. 3. pp 99-101.

Twenhofel, W.H.

1950: Principles of sedimentation. McGraw Hill. Inc. 673 p.

Walton, W.R.

1964: Recent foraminiferal ecology and palaeoecology. In: Imbrie, J. and Newell, N.D. (eds), Aspects of Palaeoecology, pp 151-237. John Wiley and Sons. Inc.

Addendum

Saidova, Kh. M.

1960; Raspredelenie foraminifer v donnykh otlozheniyakh Okhotskogo Morya., Akad Nauk SSSR, Instituta Okeanologii, Trudy. 32 pp 96-157, figs 1-28. (Distribution of Foraminifera in the bottom sediments of the Okhotsk Sea.)

