COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Report No. 25

PAPERS ON TERTIARY MICROPALAEONTOLOGY

BY

I. CRESPIN, F. M. KICINSKI, S. J. PATTERSON
and D. J. BELFORD.

**Issued under the Authority of Senator the Hon. W. H. Spooner,
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LIST OF REPORTS

1. Preliminary Report on the Geophysical Survey of the Collie Coal Basin.—N. G. Chamberlain, 1948.
2. Observations on the Stratigraphy and Palaeontology of Devonian, Western Portion of Kimberley Division, Western Australia.—C. Teichert, 1949.
3. Preliminary Report on Geology and Coal Resources of Oaklands-Coorabin Coalfield New South Wales.—E. K. Sturmfels, 1950.
4. Geology of the Nerrima Dome, Kimberley Division, Western Australia.—D. J. Guppy, J. O. Cuthbert and A. W. Lindner, 1950.
5. Observations of terrestrial magnetism at Heard, Kerguelen, and Macquarie Islands, 1947-48. (Carried out in co-operation with the Australian National Research Expedition, 1947-8.).—N. G. Chamberlain, 1952.
6. Geology of New Occidental, New Cobar and Chesney Mines, Cobar, New South Wales.—C. J. Sullivan, 1951.
7. Mount Chalmers Gold and Copper Mine, Queensland.—N. H. Fisher and H. B. Owen, 1952.
8. The Ashford Coal Province, New South Wales.—H. B. Owen, G. M. Burton and L. W. Williams, 1955.
9. The Mineral Resources of Papua and New Guinea.—P. B. Nye and N. H. Fisher, 1954.
10. Geological Reconnaissance of South-West Portion of Northern Territory.—G. F. Joklik, 1952.
11. The Nelson Bore, Victoria; Micropalaeontology and Stratigraphical Succession.—I. Crespin, 1955.
12. Stratigraphy and Micropalaeontology of the Tertiary Marine Rocks between Adelaide and Aldinga, South Australia.—I. Crespin, 1955.
13. Geology of Dampier Peninsula, Western Australia.—R. O. Brunnschweiler (in press).
14. A Provisional Isogonic Map of Australia and New Guinea, showing Predicted Values for the period 1955-65.—F. W. Wood and I. B. Everingham, 1953.
15. Progress Report on the Stratigraphy and Structure of the Carnarvon Basin, Western Australia.—M. A. Condon, 1955.
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18. Petrology and Petrography of Limestones from the Fitzroy Basin, Western Australia.—J. E. Glover, 1956.
19. Heard Island Magnetic Report.
20. Micropalaeontological Investigations in the Bureau of Mineral Resources, 1927-52.—I. Crespin.
21. Macquarie Island Magnetic Report.
22. Occurrence and Distribution of Oil in Glauconitic Sandstone at Lakes Entrance, Victoria.—R. F. Thyer and L. C. Noakes, 1955.
23. Seismic Survey, Darriman, Victoria.—M. G. Garrett.
24. Sedimentary Control of Uranium Deposition in Northern Territory.—M. A. Condon and B. P. Walpole, 1955.

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DEPARTMENT OF NATIONAL DEVELOPMENT

Minister—Senator the Hon. W. H. Spooner.
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FOREWORD

The papers contained in this publication were prepared at various times between 1952 and 1954 for the 'Records' series of the Bureau. Records are designed for a very limited circulation, and the opportunity has been taken to extract from them papers of a wide general interest and to publish the selected papers to give them a wider distribution.

Some attempt has been made to bring them up to date; but it has been thought unnecessary to attempt a thorough revision, because they are in fact reprints of earlier papers, to which reference has been made in literature.

Many short communications, particularly in palaeontology, have been relegated to the 'Records' series for lack of a suitable medium for publication: it is hoped that this Report, and others planned to follow it, will make them available to a wider audience.

Of Miss Crespin's four papers, two are syntheses of known information and two are reports of particular investigations: all deal with Tertiary faunas.

Dr. Kicinski's papers report the results of micropalaeontological examination of material from Papua, Bougainville and Manus.

P. B. Nye,
Director.

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MIGRATION OF FORAMINIFERA IN TERTIARY TIMES IN AUSTRALIA

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INTRODUCTION

The distribution of marine Tertiary rocks in Australia is restricted to the western and southern coastal areas of the continent. The rocks represented are of Palaeocene, Eocene, Miocene and Pliocene ages.

Considerable material has been collected in stratigraphical sequence from many Tertiary localities in recent years, and the detailed examination of the foraminiferal content of the rocks has yielded many unexpected discoveries. Until the last few years samples have been collected haphazardly with the result that there has been little opportunity to obtain definite information of the stratigraphical sequence, and the vertical range of the foraminifera could not be propprly established because of insufficient stratigraphical information. Attempts are now being made to correct this state of affairs by systematic collection of samples, and already much new light has been thrown on varying foraminiferal assemblages in the different Tertiary Basins.

Considerable migration of foraminifera faunas took place in Tertiary times throughout the world, but evidence of such migration is gradually being discovered in Australia. It is now known that Palaeocene faunas exist in Australia, and marine lower Eocene deposits are very probably represented in Western Australia. Probable middle Eocene deposits are widespread, chiefly in subsurface deposits in south-eastern Australia, but definite upper Eocene beds occur in Western Australia, South Australia, and Victoria. Up to the present no definite marine Oligocene has been discovered; but limestones whose age is equivalent to "e" stage of Indo-Pacific Tertiary stratigraphical subdivision, and probably representing Aquitanian of Europe, are known in North-West Australia. These beds are regarded as low in the lower Miocene. Miocene and Pliocene deposits are widely distributed.

Two types of foraminifera are used in stratigraphical correlation in the Tertiary - the large species and the small species. The large foraminifera are extremely valuable for regional correlation such as in the Miocene in the Indo-Pacific region. The small forms, especially the pelagic foraminifera, are now proving of considerable value as long-distance age determinants because of their abundance and rapid and widespread dispersal in the seas. It is difficult, however, to suggest the direction of migration to Australia of the small forms; this would involve the study of the probable direction of currents during the Tertiary epoch.

In studying migration of foraminiferal species in the Tertiary of Australia, two points are outstanding:

1. The presence of widely distributed European and American species in the Palaeocene and Eocene.

2. The predominance of species restricted to the Indo-Pacific region in the Miocene and Pliocene.

As regards the first point, the small species of the Palaeocene and lower Eocene of Europe and America have been found in North-West Australia. Large foraminifera of European species occur in the middle to upper Eocene of North-West Australia with possible migration route through the Middle East and India. The assemblage of small species in the upper Eocene of Western Australia and south-eastern Australia contain many small European, American, and New Zealand species as well as certain species which are indigenous to Australian upper Eocene. The lower Oligocene species from parts of the United States of America closely resemble upper Eocene and Miocene species of Australia, and this similarity of species has led to some confusion regarding the age of some of our Tertiary deposits.

As regards the second point, the assemblages in the Miocene and Pliocene of Australia are dominated by Indo-Pacific species, that is species which are found primarily throughout the Indo-Pacific region and which are characteristic of shallow warm water and thrive under ecological conditions such as are found associated with coral reefs. Where the waters have been more temperate, and more open-sea conditions prevailed, the smaller species are abundant and many of those present have a wide lateral distribution and long stratigraphical range.

DISCUSSION OF FORAMINIFERA AND FORAMINIFERAL ASSEMBLAGES.

In this paper it is planned to discuss briefly certain foraminiferal species from the Palaeocene, Eocene, Miocene, and Pliocene deposits of Australia and to show the limits of their migration in Tertiary times in Australia. It will be shown that certain pelagic species that are restricted to certain formations and stages outside Australia have longer stratigraphical ranges in Australia.

Palaeocene.

About six years ago, the writer discovered an assemblage of small foraminiferal species in the Carnarvon Basin, Western Australia, which closely resembled an upper Eocene assemblage described by the late W.J. Parr in 1938 from the King's Park Bore, Perth. However, systematic collection of samples in the Giralia area more recently has revealed that the samples examined earlier came from beds stratigraphically below the upper Eocene limestones containing *Discocyclina* and overlying the Upper Cretaceous. The assemblage was also compared with those described from the Midway of Texas by Mrs. Plummer in 1926 and from the Palaeocene of Sweden described by Brotzen in 1948. Species from both these widely separated areas were found in the Western Australian beds. The presence of Parr's upper Eocene species indicate the long stratigraphical range of these forms in Australia, for they are found in *Hantkenina*-bearing deposits in south-eastern Australia. An Upper Cretaceous species which persists in the Palaeocene assemblage is *Verneuilina parri*, which was described by Cushman from Gin Gin, about 60 miles north of Perth. With the incoming of the Palaeocene the genera *Globorotalia* and *Globigerina* become well represented. *Globorotalia* is represented in Western Australia by such species as *G.spinulosa*, *G.membranacea* and *G.wilcoxensis*. The number of species of *Globigerina* is less than in the Upper Cretaceous, and the commonest species are *Globigerina triloculinoides* Plummer and *G.mexicana* Cushman.

A widely distributed form in the Palaeocene is one related to *Pulvinulina exigua* Brady var. *obtusa* Burrows and Holland (now placed in the genus *Alabamina*) which was originally described from the Thanet beds in England, which are most probably Palaeocene. Dr. Glaessner in 1937 recorded this species from the Upper Cretaceous and Palaeocene in the Causasus. Mrs. Plummer recorded it from the Midway of Texas, and Brotzen renamed it Alabamina midwayensis. Parr discovered a related form in the upper Eocene of Perth, which he called Pulvinulinella obtusa var. westraliensis, and which has also been found in the Palaeocene beds at Giralia.

Eocene.

Present evidence suggests that beds of marine lower Eocene occur in Western Australia; middle and upper Eocene deposits are fairly widespread, especially in south-eastern Australia, with a considerable thickness of probable middle Eocene.

The Eocene is represented by two main lithological types in Australia, the calcareous type and the arenaceous type. The foraminiferal assemblages are controlled by ecological or facies conditions represented by these lighological types.

1. Calcareous rock types. Calcareous rocks of Eocene age crop out in Giralia-Cardabia area and at Cape Cuvier in North-West Australia; at Christie's Beach and in cliffs near the mouth of the Onkaparinga River, Port Noarlunga, along the Onkaparinga River at Noarlunga, in the cliffs at Maslin Beach, Blanche Point, and Aldinga, and the Mt. Gambier area, in South Australia; at Portland, Johanna River, Brown's Creek and Castle Cove in south-western Victoria, and from Bell's Headland east to Torquay in Victoria. Calcareous rocks are also found in subsurface sections as in the Carnarvon Basin and around Perth, in bores in the Mt. Gambier area, and at Portland; and the so-called "Micaceous series" in the Gippsland bores in south-eastern Victoria will probably be included in this group of Eocene rocks.

The calcareous rocks contain both large and small foraminifera. The microfauna in the limestones in the Giralia-Cardabia area and at Cape Cuvier in North-West Australia shows a marked difference from that found in the limestones in south-eastern Australia. In the Carnarvon Basin, the assemblage is dominated by large foraminifera with which are associated numerous small species. Large genera such as Discocyclina, Asterocyclina, Actinocyclina, Alveolina, and Nummulites have not yet been found in Australia outside the Carnarvon Basin.

The species recognised indicate chiefly an upper Eocene age, but some of the limestones may be equivalent to "a -b" stage of the Indo-Pacific "letter" classification; that is, middle to upper Eocene. The presence of forms similar to European species in the Middle East, India, Indonesia, and North-west Australia suggests that species imigrated eastward. Few European species of the larger foraminifera occur in America, but the American species Actinocyclina aster is apparently present in the Carnarvon Basin. Alveolina and Nummulites are not common in North-West Australia, but the species that are present are closely allied to Indo-Pacific forms.

From the evidence available at the moment, it appears that these genera of large foraminifera do not occur in south-eastern Australia. Consequently no proper correlation could be made between the Eocene beds of the Carnarvon Basin and those of south-eastern Australia. However, quite recently two moderately large forms, of the smaller foraminifera Victoriella plecte and Crespinella sp. nov., which occur rather abundantly in upper Eocene deposits in south-eastern Australia, have been found in the Carnarvon Basin in association with the above-mentioned larger foraminifera. They now form the link for correlation of these widely separated areas. It is also known that both Victoriella plecte and Crespinella sp. nov. occur in south-eastern Australia, in Eocene beds at Hohanna River together with the widely distributed American upper Eocene species Hantkenina alabamensis Cushman. The new and most interesting fact established through recent work, therefore, is the proof that in the Eocene beds of the Carnarvon Basin, although their fauna is dominated by Indo-Pacific forms, a transition has taken place from the Indo-Pacific province to the typical south-eastern Australia province. A similar transition is established for the south-eastern Australia province between the Australian forms, such as Victoriella plecte and Crespinella sp. nov. and North American forms represented by Hantkenina alabamensis.

Victoriella plecte was described by Chapman in 1921 from a bore near Bird Rock, Torquay. It is most important as a zonal species for the upper Eocene in Australia because of its adaptability to varying ecologic conditions. It apparently thrived in warm, clear waters in which limestones were deposited, as well as in more temperate and more turbid waters in which calcarenites were laid down. Crespinella sp. nov. has also been found in both limestone and calcarenites. Both forms are most probably indigenous to the Australian Eocene; but the adaptability of Victoriella plecte permitted it to migrate as far as Gippsland in south-eastern Victoria, whereas Crespinella sp. nov., so far, has not been found east of the Torquay area. It is understood that V.plecte has been found in New Zealand in beds of middle Oligocene age. (Hornibrook, pers. comm.).

Small foraminifera occur abundantly in the upper Eocene calcarenites in the bores at Perth and in surface outcrops in south-western Victoria. They are common in the limestones in South Australia and in the Carnarvon Basin. Many species are referable to Eocene and a few to lower Oligocene species of America and Europe, and upper Eocene species from New Zealand are also widely distributed. The most characteristic assemblage of species is that described by Parr from the King's Park Bore, Perth (Parr, 1938). This assemblage is widespread in South Australia, where it is found in bores in the Adelaide Basin, at localities at Port Noarlunga, and in cliffs at Maslin Beach, Blanche Point, and Aldinga Bay. In Victoria it is present in the calcarenites at Johanna River, Brown's Creek, and Castle Cove in the Otway area, and in the Bird Rock/Point Addis section to the east. Species described by Parr from the King's Park Bore, Perth, and found in widely separated areas include Cibicides umbonifer, C.pseudoconvexus, Bolivinopsis crespinae, Buliminella westralensis, Guembelina venezuelana var. rugosa, Globorotalia chapmani, Anomalina perthensis, Angulogerina subangularia and Alabamina obtusa var. westraliensis. Amongst the interesting pelagic species described from New Zealand and America and found in the Australian upper Eocene are Globigerina triloculinoides Plummer, G.pseudobulloides Plummer, Globigerina mexicana Cole, Globigerinoides index Finlay, "Globigerinella" micra (Cole), and Hantkenina alabamensis Cushman. All these forms are known to exist in the Eocene of America and the Middle East (Grimsdale, 1951). Hantkenina is also recorded from East Borneo (Thalmann, 1942). It is impossible at present to suggest any one direction of migration. G. triloculinoides and G. pseudobulloides were described by Mrs. Plummer from the Midway (Palaeocene) of Texas and seem to range stratigraphically higher in Australia than elsewhere.

The migration of Hantkenina alabamensis is of considerable importance because it occurs in upper Eocene deposits in so many parts of the world with little change in shape. Bronniman (1950) thinks that the variety compressa instituted by Parr for the Victorian form at Johanna River, Brown's Creek, and Hamilton Creek, is only a slight variant of the type species, but suspects that another American species H.primitiva is also present. The discovery of the species at Maslin Beach, Blanche Point, South Australia, by the late W.J. Parr shortly before his death, and the more recent discovery at Bird Rock, Torquay, Victoria, (Raggatt & Crespin, 1952) have done much to confirm an upper Eocene age for the beds in these localities, which previously had been regarded as either Oligocene or Miocene. Another small but distinctive upper Eocene assemblage occurs at Bird Rock and includes Massilina torquayensis (Chapman), Dimorphina janjukensis Crespin, Quinqueloculina ornithopetra Crespin, Q.singletoni Crespin, Lamarckina glencoensis Chapman and Crespin, and Victoriella plecte (Chapman). Except for Victoriella plecte, which has already been discussed, there is no evidence as yet of migration of any of these species beyond south-eastern Australia.

2. Arenaceous rock types. Lignitic sandstone and siltstone occur at the bottom of some of the bores in the Perth area, Western Australia; in bores at Moorlands and in the Mt. Gambier areas in south-eastern South Australia; in the Nelson Bore and Dartmoor bores in south-western Victoria, and in bores in the Mallee and in Gippsland. Outcrops occur in the Anglesea and Dartmoor areas; all these occurrences are most probably middle Eocene in age.

In all occurrences, except in the Moorlands Brown Coal deposits, the foraminiferal assemblage is dominated by the genus Cyclammina. One well-known species, Cyclammina incisa, is widely distributed; it is found in New Zealand and America. The beds containing Cyclammina are approximately 4,300 feet thick in the Nelson Bore on the Glenelg River in south-eastern Victoria.

The lignitic sandstone in the Moorlands Bores contains a genus having affinities with Eoannularia, a genus described by Storrs Cole and Bermudez (1944) from the middle Eocene of Cuba. This genus is also present in the calcarenites at Johanna River, at Point Addis, at Rocky Point, and at Fisherman's Steps, in south-western Victoria; and at Port Noarlunga, and in a bore on S.A. Ivimey's property at Warradale, Adelaide Basin, South Australia.

Miocene.

According to present knowledge, no marine deposits of definite Oligocene age occur in Australia, but Miocene rocks are widely distributed. The Miocene foraminiferal assemblages are dominated by species which occur in assemblages throughout the Indo-Pacific region and which are found in deposits which have been laid down in warm shallow clear waters associated with coral reefs. The writer has discussed this problem in different publications (Crespin, 1948, 1950). Stratigraphical work on measured sections in the Cape Range, North- West Australia, during the last three years has helped to clarify some of the problems that had confronted the writer, and it is now possible to trace the easterly migration of certain species of the large and small foraminifera from the western Indo-Pacific region to the south-eastern corner of Australia. It is essential when studying the Miocene stratigraphy of Australia that one should be conversant with the Miocene stratigraphy of the Indo-Pacific region in general. In the study of the larger foraminifera it is possible to apply the "letter" classification.

A migration of Indo-Pacific species from Indonesia south-eastward is suggested by the distribution in Australia of the following foraminifera:

1. Eulepidina
2. Nephrolepidina, Trybliolepidina, Cycloclypeus, Miogypsina and Flosculinella
3. Austrotrillina howchini
4. Many small foraminifera.

1. In Australia, the well-known Indo-Pacific "e" stage foraminifera Eulepidina has only been found so far in the Carnarvon Basin, Western Australia. Limestones containing Eulepidina badjirraensis Crespin, which with E.dilatata Michelotti var. tidoenganensis Van der Vlerk is one of the largest Lepidocyclines in the Indo-Pacific region, are to be placed in "e" stage. It is now known that E.badjirraensis is present in limestones on Cebu Island, Philippines. Associated with Eulepidina badjirraensis is Cycloclypeus eidae Tan, an Indo-Pacific species

which has not been found in Australia outside the Carnarvon Basin. The absence of Eulepidina and Cycloclypeus eidae elsewhere in Australia indicates that either the Oligo-Miocene seas did not extend, in Australia, beyond the Carnarvon Basin or these typical Indo-Pacific forms have reached the limit of the distribution in the south-eastern direction in the Carnarvon Basin.

2. Nephrolepidina is present with Eulepidina in the Carnarvon Basin, but it appears in abundance only in the overlying "f_1" limestones, where also the first Trybliolepidina makes its appearance. Trybliolepidina has not been found so far in any locality between the Carnarvon Basin and south-eastern Australia. It is very common at Hamilton in Western Victoria. From there to the south-eastern portion of Victoria, it occurs in many localities in surface and subsurface sections. Nephrolepidina, however, appears to be restricted to the Carnarvon Basin. The foraminiferal fauna in Victoria is dominated by Trybliolepidina. The Indo-Pacific species L.(N) ferreroi, L.(N) angulosa, L.(N.) borneensis, and L.(T)martini are found in the Carnarvon Basin but in Victoria they are replaced by L.(T) gippslandica, L.(T) howchini, and L.(T) batesfordensis, although L.(T) gippslandica has also been found in the Cape Range limestones. As far as can be ascertained the subgenus Eulepidina dominated the Lepidocyclina assemblage in the Oligocene and the lower part of the Miocene both in Europe and the Indo-Pacific. The subgenus Nephrolepidina dominated the Miocene assemblages in Europe but the subgenus Trybliolepidina is apparently restricted to Indo-Pacific Miocene assemblages and became the exclusive subgenus when Indo-Pacific bathymetric and climatic conditions reached south-eastern Australia.

As regards Cycloclypeus in "f" stage rocks, the Indo-Pacific species C.indopacificus Tan which is found in the Carnarvon Basin is replaced in Victoria and in South Australia by C.victoriensis Crespin. And it is of some importance that the "f_1" stage genera Flosculinella and Miogypsina do not appear in any assemblage beyond the Carnarvon Basin. Miogypsina occurs in New Zealand, but the writer is inclined to think that this important Indo-Pacific genus migrated to New Zealand via New Guinea.

In the Lepidocyclina horizon in Victoria, it is found that although the species have many of the specific characters of the Indo-Pacific form, in the long migration from the Carnarvon Basin, Western Australia, to south-eastern Australia, some of these distinctive characters were lost; and it is noticable that when one compares the Lepidocyclinae of New Zealand with those of Australia the influence of Indo-Pacific ecological conditions did not extend very markedly beyond south-eastern Australia.

3. Probably the most interesting species of the Miocene assemblages is Austrotrillina howchini, described by Schlumberger in 1893 from Clifton Bank, Hamilton, Victoria, which has become an important zonal species throughout the Indo-Pacific region. Although it is recognised in "e" stage limestones in Java and Borneo, it has not yet been found below "f_1" stage in Australia. Further work in Victoria may show that it ranges a little higher in the south-eastern part of the continent. The most easterly known occurrence of A.howchini in Australia is in Skinner's section along the Mitchell River above Bairnsdale in south-eastern Gippsland, where it occurs sparingly in association with Lepidocyclina and Cycloclypeus. It has not been found in the numerous bores in Gippsland which passed through the Lepidocyclina horizon. It occurs in some abundance in some of the Mallee bores in western Victoria which are included in the "old Murray Gulf" area, the eastern limit of which marks the most easterly extension in Australia of typical Indo-Pacific assemblages. (Crespin, in Gloe, 1947).

4. In "e" and "f" stage rocks in Australia small foraminifera are very common. In the Carnarvon Basin, species described by LeRoy and others from localities in Indonesia and other parts of the western Indo-Pacific region intermingle with those described by Chapman, Howchin, Parr, and Heron-Allen and Earland from south-eastern Australia. Species described from Indonesia and the western Indo-Pacific region are exceedingly rare in south-eastern Australian assemblages, but such forms as Gypsina howchini, Planorbulinella plana, Calcarina cerriculata, Cibicides victoriensis, Crespinella umbonifera, and Loxostomum hentyanum, which are common in the Lepidocyclina horizon at either Batesford, Hamilton or Gippsland, are well represented in the Carnarvon Basin assemblages. It is notable, however, that Crespinella umbonifera and Calcarina verriculata as well as Austrotrillina howchini decrease in abundance as the eastern margin

of the Miocene sea is reached in Australia. A. howchini and C.verriculata are very scarce in the Gippsland deposits and so far Crespinella umbonifera has not been found east of Batesford.

In the Carnarvon Basin an assemblage of Austrotrillina howchini, Marginopora vertebralis, and numerous small miliolidae is found in a cream coloured limestone (Trealla Limestone, Crespin, 1953) which is regarded as between top "f_1" and basal "f_2" stages. This assemblage occurs in hard limestone, of similar lithological character to that in the North-West Basin, at localities on the Nullarbor Plains, in the moderately friable cream limestone in sub-surface deposits in the Adelaide Basin, and in sandy limestones which become rather sandy, in bores in the Mallee, western Victoria. This association is not found east of the area last mentioned, which, as already stated, most probably forms the eastern limit of typical Indo-Pacific Miocene conditions in south-eastern Australia.

The wide dispersal of small species which are apparently indigenous to Australian Miocene assemblages is further demonstrated by the occurrence of some of them in the Miocene of New Zealand. Such forms as Planorbulinella plana, Cibicides victoriensis, Pavonina triformis, and Tubulogenerina mooraboolensis are found in New Zealand.

Pliocene.

Indo-Pacific climates strongly influenced the Pliocene as well as the Miocene assemblages in North-West Australia and in the Adelaide Basin, but the Pliocene deposits in Victoria suggest more temperate but still shallow-water conditions. Warm shallow-water forms such as Marginopora vertebralis, Sorites marginalis, and Peneroplis planatus are not found in Pliocene assemblages east of the Adelaide Basin; this marked change in the assemblage of species indicates that the warm Indo-Pacific waters did not reach beyond that area. Some Victorian Pliocene (Kalimnan) species such as the restricted species Flintina intermedia, and longer ranging species such as Massilina lapidigera and Clavulinoides multicamerata, are found in the assemblages in the Adelaide Basin and to the west, but for the most part the species in the Victorian deposits are much smaller in size than those in the calcareous sandstones of the Adelaide and

and Carnarvon Basins.

This regression of warm-water faunas in the Pliocene is marked by a further regression to the west in Pleistocene and Recent assemblages.

CONCLUSIONS.

The conclusions regarding migration of foraminifera in Australia are:

1. There is definite evidence of world-wide dispersal of small species of foraminifera in the Palaeocene and Eocene assemblages, with a limited migration of larger foraminifera. Species of *Discocyclina* and *Asterocyclina* appear to be world-wide in their distribution, but species of *Pellatispira* and *Alveolina* are more closely related to Indo-Pacific forms.

2. The world-wide distribution of small pelagic species in the upper Eocene is indicated by the recent discoveries of the American species *Hantkenina alabamensis* at several localities in south-western Victoria and its known occurrence in the Middle East and East Borneo; and of other species such as *Globigerina triloculinoides*, *G.dissilimis*, *G.pseudobulloides*, *Globigerinoides* index, and *Globorotalia wilcoxensis* in the Palaeocene and upper Eocene of Australia.

3. Certain species such as *Victoriella plecte* and *Crespinella* sp. nov. are apparently restricted to Australian upper Eocene deposits, but *V. plecte* is recorded from beds of middle Oligocene age in New Zealand.

4. Indo-Pacific climatic and bathymetric conditions have affected Miocene and Pliocene foraminiferal assemblages throughout Australia. The eastern boundaries of such influences can be traced throughout the Miocene deposits in Australia and a regression of these conditions is noticeable in the Pliocene and even in Pleistocene and recent times.

5. The restriction of the occurrence of *Eulepidina*, the important "e" stage genus, and *Cycloclypeus eidae*, a species restricted to "e" stage, to the Carnarvon Basin indicates the limit of the transgression of "e" stage larger forminifera in Australia.

6. *Nephrolepidina* is restricted to the Carnarvon Basin whereas *Trybliolepidina* is widely distributed in the Carnarvon Basin and in south-eastern Australia; specific characters in *Lepidocyclina* and *Cycloclypeus* differ only slightly between the Carnarvon Basin and south-eastern Australia.

7. *Austrotrillina howchini* makes its first appearance in "f_1" stage in North-West Australia rather than in "e" stage as in the Indo-Pacific region to the west, and may range into "f_2" stage in south-eastern Australia. *A.howchini* is common in the Carnarvon Basin and in the Adelaide Basin and in the Mallee and Wimmera of western Victoria, but scarce in south-eastern Victoria.

8. The south-eastern boundary of typical Indo-Pacific conditions in the Miocene in Australia is along the eastern margin of the old Murray Gulf which runs in a more or less northerly direction through the Wimmera and Mallee areas. This fact has been proved by borings.

9. The south-eastern boundary of typical Indo-Pacific warm shallow water conditions in the Pliocene is in the Adelaide Basin and in the deposits southward to Aldinga. There is a marked regression of the warm shallow water conditions of the Pliocene, westward from the Mallee and Wimmera areas to the Adelaide Basin and the area to the south.

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CHANGES IN IDEAS OF AGE OF CERTAIN BEDS IN THE AUSTRALIAN TERTIARIES

by

I. CRESPIN

(Records 1953/80)

CONTENTS

CHANGES IN IDEAS OF AGE OF CERTAIN BEDS IN THE AUSTRALIAN TERTIARIES

by

I. CRESPIN

INTRODUCTION

Since the writer presented a paper at the Eighth Pacific Science Congress in New Zealand in 1949 (Crespin, 1950), ideas of the age of certain of the marine Tertiary deposits in Australia have changed drastically. Intensive investigations of the microfaunas both in North-West Australia and in south-eastern Australia have revealed genera and species of the foraminifera which are regarded as indicators of age in other parts of the world. Furthermore, the prevailing ideas in Indo-Pacific Tertiary stratigraphy as to the lower Miocene age of the upper part of the Aquitanian stage of Europe and its equivalence to the upper part of "e" stage of the Indo-Pacific, and the placing of "f_1" stage in the lower Miocene, had to be considered in their application to Australian Tertiary deposits. It is interesting to note that the age ascribed by palaeontologists in the latter half of the last century to certain beds in south-eastern Australia is now proving substantially correct.

One of the most important discoveries in the last few years has been that of the Eocene pelagic foraminiferal genus Hantkenina at different localities in south-eastern Australia. This Lower Tertiary form is proving to have world-wide distribution, and its value as an age determinant and for zonal correlation is undoubtedly of outstanding importance.

In the Middle Tertiary, the larger foraminifera continue to be of considerable value in long-distance correlation in the Indo-Pacific region, and the upward stratigraphical range of several forms such as the subspecies of Lepidocyclina - Eulepidina - and Austrotrillina howchini seems to have been more or less accurately determined.

Ideas of age of the beds in the Upper Tertiary have undergone little change.

The recent re-determinations of the age of the Australian marine Tertiary deposits have brought the stratigraphical sequence into line with that used throughout the Indo-Pacific region. Marine Oligocene seems to be almost completely absent in the Australian region, and the major stratigraphical break at the top of the lower Miocene or "e" stage in western Australia is a condition found in other parts of the Indo-Pacific region (Crespin, 1953). The age of the beds immediately above the Lepidocyclina horizon in south-eastern Australia may be middle Miocene; but characteristic larger foraminifera are absent and little research has been done on the smaller foraminifera in the sediments.

PALAEOCENE AND LOWER EOCENE

There is considerable discussion at present as to whether beds of Palaeocene age are represented in Australia. The problem in North-West Australia can only be solved by the decision as to what is "Danian". In that area the foraminifera in the beds under discussion have a Tertiary aspect whereas the larger fossils have affinities with the Upper Cretaceous. The abundance of the foraminiferal genus Globorotalia in surface and subsurface deposits in the Carnarvon Basin suggests that lower Eocene deposits are present in the Carnarvon Basin.

The Palaeocene-Lower Eocene problem is also to be found in south-eastern Australia. The Pebble Point Beds bear Princetown, south-western Victoria, are regarded as Palaeocene to lower Eocene in age. Some of the macrofossils have Upper Cretaceous affinities and they have been discussed by Teichert (1943), Singleton (1943), and Baker (1943); Glaessner and Parr (1943) briefly discussed the microfauna. Recently Kenelly (1951) discovered deposits of similar lithology, containing a similar macrofossil fauna to that in the Pebble Point Beds, in the cliff sections on the Glenelg River, south of Casterton, western Victoria. It is quite possible, too, that the unfossiliferous beds in the Nelson Bore, on the Glenelg River, Western Victoria, below the depth of 5,503 feet may be of similar age (Crespin, 1955). The Eastern View Coal Measures and the Boonah Sandstone recently studied by Raggatt and the writer (Raggatt and Crespin, 1952) are possibly associated with the Palaeocene/lower Eocene problem, and also that of the "Anglesean Stage" of south-eastern Australia introduced by Singleton (1941).

MIDDLE EOCENE

Deposits now suspected to be of middle Eocene age are widespread in south-western and south-eastern Victoria; they consist of carbonaceous siltstone containing abundant Cyclammina. They had previously been regarded as Oligocene. Cyclammina in itself cannot be an age indicator as the genus ranges from Mesozoic to Recent; but the stratigraphical position of the beds containing it and their relationship with known upper Eocene deposits suggests that they are of middle Eocene age.

Raggatt and Crespin (1952) have taken the type section for the so-called Anglesean Stage of Singleton (1941), which consists of carbonaceous siltstone with abundant Cyclammina, as the type for their Demon's Bluff Formation, and it has been found now that this lithology with its characteristic microfaunal assemblage occurs at several localities in south-western Victoria (Baker, 1953). Similar beds with Cyclammina are widespread in subsurface sections in that area, and it is known that at least 4,000 feet of carbonaceous sandstone containing Cyclammina are present in the Nelson Bore (Crespin, 1955). They are also widespread in south-eastern Victoria.

Middle Eocene beds are probably present in North-West Australia where larger foraminifera such as Discocyclina are present. The problem there is again closely bound up with Indo-Pacific stratigraphy.

UPPER EOCENE

It is now known that upper Eocene deposits are much more extensive in Australia than had been thought since the beginning of the century - palaeontologists of the latter half of the last century had considered many deposits in south-eastern Australia to be Eocene, but these had come to be regarded as lower Miocene; they are now found to be upper Eocene (Crespin,1952). Cushman (1922) commented on the close relationship between the lower Oligocene and upper Eocene foraminiferal species of America and those of the Miocene of the Indo-Pacific; and it is interesting that some of the beds to which he referred are now placed in the upper Eocene.

There are two distinct lithologies in the upper Eocene of Australia, and as a result there is a difference in the microfaunal assemblage. In North-West Australia, in the Giralia and Cape Cuvier areas, the predominant rock type is limestone and the microfauna, with its assemblage of larger foraminifera, is typical of the upper Eocene elsewhere in the Indo-Pacific region. In southern Western Australia, as in the bores around Perth, the rocks are mostly argillaceous and the small species described from those bores by Parr (1938) and Coleman (1952) and referred to the upper Eocene are to be found in deposits of similar lithology throughout south-eastern Australia.

The upper Eocene age of the beds in south-eastern Australia has been confirmed by the discovery of the typical upper Eocene species _Hantkenina alabamensis_ Cushman subspecies _compressa_ Parr at several localities such as at Maslin Beach, South Australia by Parr (Glaessner, 1951, Crespin, 1952a), at Brown's Creek, Johanna River and Hamilton River, south-western Victoria, (Parr, 1947), and at the base of Bird Rock Cliff, Torquay, Victoria, (Crespin, 1952; Raggatt and Crespin, 1952). This last locality is the "type area" for the Janjukian stage of Victorian stratigraphy and has been regarded as lower Miocene for many years (Crespin, 1950).

In the absence of _Hantkenina_ in certain deposits a reliable species for age determination is _Victoriella plecte_. This form was found associated with _Hantkenina_ at the base of Bird Rock cliff, Torquay, and at Johanna River farther to the west. It occurs without _Hantkenina_ at other localities, but in association with an assemblage of species that is now known to be typically upper Eocene.

Victoriella has proved of value as an age determinant because of its adaptability: it thrives under either calcareous or argillaceous conditions. It is very common in many limestones in south-western Victoria. It is also valuable for long distance correlation, for it also occurs in limestones in North-West Australia where it is associated with the definite Eocene genus _Discocyclina_. A new species of Parr's genus _Crespinella_ is also useful for this purpose. It is common in the Maslin Beach section south of Adelaide, South Australia, in beds in which Parr found _Hantkenina_, and it is also associated with _Victoriella_ in _Discocyclina_-bearing rocks in North-West Australia.

OLIGOCENE

Previous statements by the writer (Crespin, 1950, 1950a) that Oligocene or "d" stage rocks were present in North-West Australia have recently been proved to be incorrect, and in south-eastern Australia many deposits such as those included in the "Anglesean" stage formerly regarded as Oligocene are now considered to be Eocene. Evidence seems to suggest a period of prolonged denudation throughout the Oligocene in North-West Australia where upper lower Miocene rocks are known to overlie the Eocene. In south-eastern Australia there is evidence of denudation and probable terrestrial deposition during that epoch.

MIOCENE

In discussing the change of age of certain of the Australian Tertiary deposits, one is immediately involved in the question of correlation with European stages such as the Aquitanian and Burdigalian. The writer puts forward here her view that it is unwise to carry correlation over such a long distance, especially when species of foraminifera, especially the larger ones, are not the same in the Indo-Pacific area as in the Aquitanian and Burdigalian. Few species of Eulepidines, so important in the Aquitanian and in "e" stage in the Indo-Pacific, are common to both regions; and it has been shown that none of the species of Lepidocyclina of the Burdigalian and Vindobonian are similar to those found in "f" stage of the Indo-Pacific region. The Nephrolepidines in Europe with a symmetrical arrangement of chambers are replaced by species in which rayed features are characteristic, and the embryonic apparatus of the subgenus itself is replaced by an apparatus which is almost trybliolepidine in character. This distinctive feature was commented upon by Dr. Tan Sin Hok when the writer studied the Victorian Lepidocyclina with him in Java in 1939, and it is an important feature of the Lepidocyclina assemblages at the top of the lower Miocene and the middle Miocene in the Indo-Pacific Region. Exact correlation of Indo-Pacific Tertiary deposits with those of Europe by means of the foraminifera seems to be ineffective, especially above the Eocene. Van der Vlerk's concluding remark in his paper to the International Geological Congress in 1948 stresses the point of the individuality of the microfaunas of the Tertiary in the Indo-Pacific region when he states that "the fact that genera and subgenera such as Biplanispira, Austrotrillina, Flosculinella, Miogypsinoides, Trybliolepidina, Katacycloclypeus, Radiocycloclypeus and a number of species are restricted to the Far East is too important to doubt of the autochthony of this district."

Rocks equivalent to the upper part of stage "e", namely stage "e_5", and "f_1" - "f_2" (van der Vlerk, 1950) occur in the Cape Range area. Field and palaeontological evidence suggests that a major stratigraphical break occurs between the upper Eocene and the lower Miocene. Two new species of Eulepidina from the "e_5" beds at Cape Range have been described by the writer (Crespin, 1952). One of the species, L.(E) badjirraensis, is amongst the largest Lepidocyclinae described from the Indo-Pacific. Chapman (1927) determined it as L.(E.) dilatate Micheloti, and placed the beds in the Oligocene; it has recently been determined by the writer in the Philippines. The writer (Crespin, 1950, 1950a) also referred to the deposits as Oligocene, but recent investigations (Crespin, 1953) have proved this to be incorrect. These lower beds of the Mandu Formation are now regarded as the equivalent of "e_5" stage and represent the lower part of the lower Miocene. Whether they are equivalent in age to the top of the Aquitanian will still remain a matter for discussion. Small foraminifera are abundant in the chalky limestones of the Mandu Formation and the species include those described by LeRoy from the Miocene of Java and Sumatra (1944), and by Chapman (1910), Chapman and Parr (1938), Chapman, Parr and Collins (1934), and others, from beds in south-eastern Australia, which are now regarded as lower Miocene.

"f_1" stage is represented by the Tulki Calcarenite and "f_1"-?"f_2" stage by the Trealla Limestone in the Cape Range area (Crespin, 1953). Typical Indo-Pacific Lepidocyclinae are common in the Tulki Limestone and Austrotrillina howchini is found in the Tulki and Trealla; it is common in the latter formation. The writer (Crespin, 1950, 1950a) put these beds in the middle Miocene, but present investigations show that they must be placed in the lower Miocene.

In 1936, the writer regarded the Lepidocyclina-bearing beds of south-eastern Australia, from which A.howchini was originally described by Schlumberger (1893), in the lower Miocene, but in 1943, to conform with the then current opinion of the age equivalent for "f_2" stage, she transferred them to middle Miocene. Recent views, however, indicate an upper lower Miocene age, although the writer is not completely convinced that Austrotrillina howchini does not occur stratigraphically higher in south-eastern Australia than in other parts of the Indo-Pacific region.

The decision to limit the stratigraphical range of Austrotrillina howchini to the upper lower Miocene has necessitated reconsideration of the age of the Lepidocyclina-bearing beds in south-eastern Australia, and it also means that the Balcombian Stage of the Victorian Tertiary stratigraphy, of which the Lepidocyclina beds apparently form a part, is most probably lower Miocene rather than middle Miocene, (Crespin, 1943).

The acceptance of the Lepidocyclina horizon as lower Miocene or the equivalent of "f_1" stage has rather complicated the age of the beds overlying the horizon and extending up to the Pliocene in south-eastern Victoria, where bore sections pass through a considerable thickness of bryozoal sediments before penetrating that horizon. Larger foraminifera are absent and the smaller foraminifera are dominantly the same as in the lower beds, and until intensive study is undertaken of the foraminiferal assemblages in these higher beds, no definite decision can be given.

PLIOCENE

A major stratigraphical break occurs at the top of the lower Miocene or of "f_1"-"f_2" stage in the areas in which Indo-Pacific Miocene foraminiferal assemblages are present in the sediments, that is in North-West Australia and in the Adelaide Basin, and in deposits in the old Murray Gulf of eastern South Australia, western Victoria and south-western New South Wales (Crespin, 1947). The writer is convinced that Pliocene beds overlying the lower Miocene in these areas are referable to the lower Pliocene Kalimnan Stage of Victoria. This view is supported by recent work on the mollusca of the Pliocene beds in the Adelaide Basin by B.C. Cotton (1947), Crespin and Cotton (in Miles, 1952), and Cotton (1952).

The beds constituting the Yardie Formation in North-West Australia are very probably of the same age, but unfortunately there is little molluscan evidence to support this view.

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FOSSILIFEROUS ROCKS FROM THE NULLARBOR PLAINS

by

I. CRESPIN

(Records 1954/25)

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FOSSILIFEROUS ROCKS FROM THE NULLARBOR PLAINS

by

I. Crespin

INTRODUCTION

In 1944, while Mr. H. B. Owen, geologist of the Bureau of Mineral Resources, was travelling by road from Port Lincoln, South Australia, to Norseman, Western Australia, he collected specimens of the Tertiary rocks for micropalaeontological examination. No detailed report on these samples has been put on record, but as the area is now being investigated for the possibility of oil accumulation, the samples have been examined and this report prepared. Some interesting observations made by Mr. Owen during the trip are incorporated here.

From Port Lincoln, the road across the Nullarbor Plains follows the coast closely as far as Eucla, on the border between Western Australia and South Australia. From there it follows a westerly course but the coast trends south of west. The eastern-most exposure of Tertiary rocks was observed near Colona Homestead in South Australia and the westernmost between Balladonia and Norseman in Western Australia, a distance westward from Colona of 550 miles. Sand and travertine cover the greater part of the surface over the intervening distance and opportunities to collect specimens from the Tertiary limestones were few. The accompanying map (Plate 1) shows the localities from which specimens were taken. Some were derived from spoil dumps of wells or other excavations and others from natural outcrop or road cuttings. Included also in this report is a sample collected by M. H. Johnstone from Madura Pass.

The most important results of the micropalaeontological examination of these limestones are:

1. The discovery of extensive deposits of upper Eocene age both in outcrop and in sub-surface sections.
2. The similarity of the stratigraphical sequence from upper Eocene to lower Miocene in the coastal area of the Nullarbor Plains to that found in part of the Carnarvon Basin, Western Australia, in the Adelaide Basin, South Australia, in north-western Victoria, and in

the Torquay area, central southern Victoria.

DESCRIPTIONS OF LOCALITIES AND FOSSIL CONTENT OF THE LIMESTONES

The sample numbers are those shown in Plate I.

A. Fowler's Bay/Yalata Section

Sample 1 came from a ridge immediately north of the old Yalata Homestead. The bed consists of a shelly travertinous limestone about 15 feet thick.

The following foraminifera were recognised:

Marginopora vertebralis Blainville

Peneroplis pertusus (Forskal) (common)

Sorites marginalis Lam.

Spiroloculina sp.

The age of this rock is most probably Pleistocene.

B. Colona

The first Tertiary limestones were collected at two localities near the Colona Homestead.

Sample 2 came from a spoil dump of a well 1 mile south-east of Colona Homestead. The well, which was dry, was about 140 feet deep. Two rock types were present in the sample bag.

1. Moderately friable calcareous sandstone with poorly preserved foraminifera.

   Calcarina verriculata (Howchin & Parr)

   Operculina victoriensis Chapman & Parr

   Sigmomorphina subregularis Howchin & Parr

   The age of this rock is lower Miocene (f_1-f_2 stage)

2. Hard bryozoal limestone with small foraminifera.

   Ammobaculites sp.

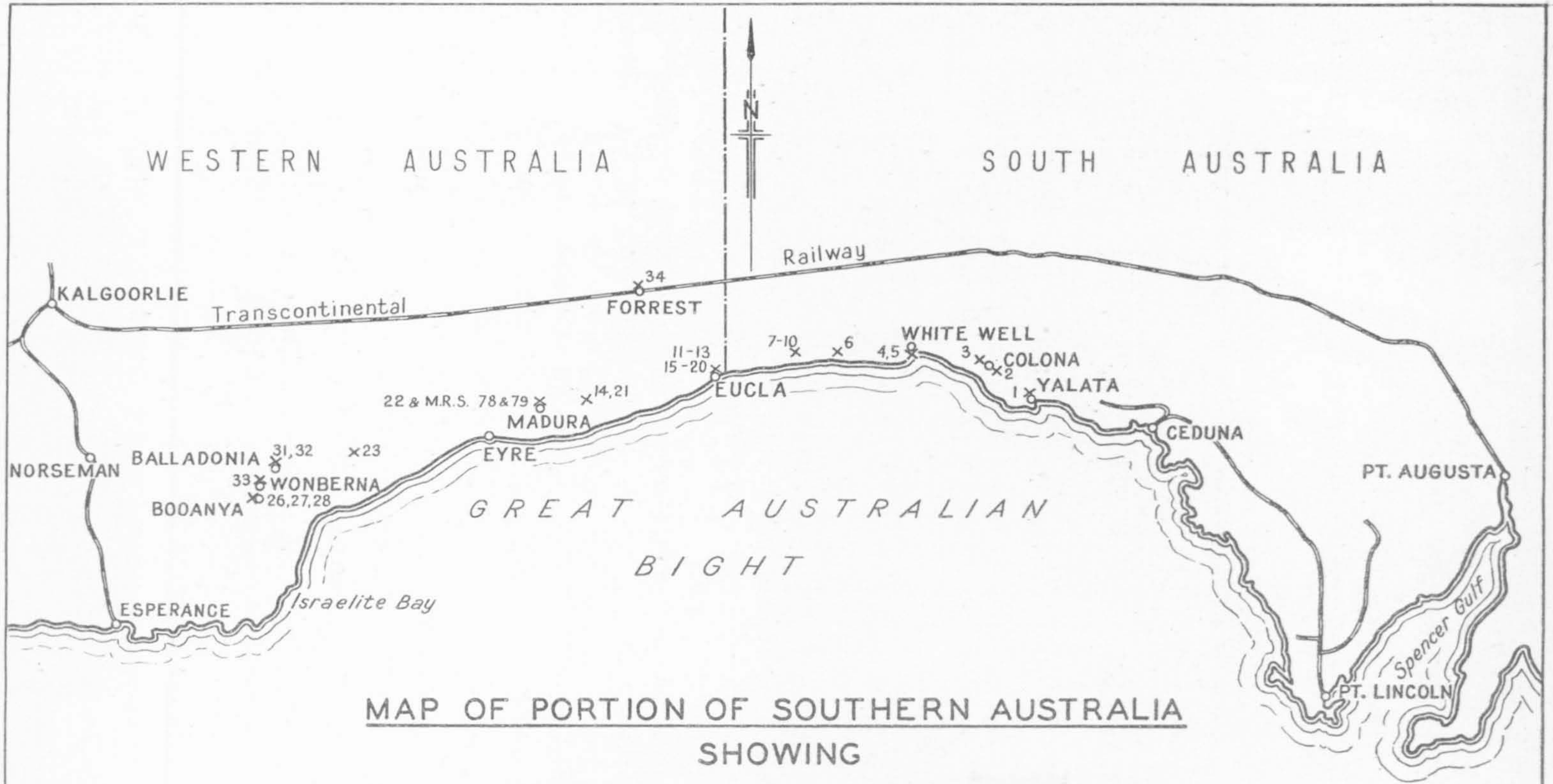
   cf. *Guembelina*

   Guttulina sp.

   Nodosaria sp.

   Planorbulina sp.

   Pseudoglandulina sp.



MAP OF PORTION OF SOUTHERN AUSTRALIA

SHOWING

LOCALITIES OF SPECIMENS

COLLECTED FOR MICROPALAENTOLOGICAL EXAMINATION

Scale

100 0 100 200 300 400 500 Miles

Mineral Resources Survey. 20·9·44. Geologist H.B.Owen

WA 52-1
MK

PLATE I

The age of this rock is most probably upper Eocene.

Sample 3 was collected from a dump of a well about 9 miles northwest from Colona Homestead. This well was also dry and was about 250 feet deep. The rock was a moderately friable bryozoal limestone with numerous fairly well preserved foraminifera, siliceous sponge spicules, and ostracoda.

Foraminifera:

Angulogerina cf. *cooperensis* Cushman
Angulogerina sp. 1
Angulogerina spp.
Angulogerina subangularis Parr
Anomalina perthensis Parr
Anomalina subnonionoides Finlay
Anomalina westraliensis Parr
Bolivina aff. *dilatata* Reuss
Cassidulina armosa Bandy
Cassidulina inconspicua Hussey
Cassidulina subglobosa d'Orb
Cibicides pseudoconvexus Parr
Cibicides umbonifer Parr
Cibicides vortex Dorreen
Cibicides sp. 2
Cibicides spp.
Cyclammina cf. *rotundata* Chapman & Crespin
Dorothia cf. *parri* Cushman
Discorbis bertheloti (d'Orb) var.
Discorbis sp.
Eponides toulmini Brotzen
Gaudryina (Pseudogaudryina) crespinae Cushman
Globigerina mexicana Cushman
Globigerina triloculinoides Plummer
Guttulina cf. *irregularis* d'Orb
Gyroidina scrobriculata Finlay
Gyroidina soldanii d'Orb
cf. *Karreria fallax* Rzehak
Lagena favosopunctata Brady
Lagena striata d'Orb
Lamarckina vicksburgensis Cushman
Nonionella hantkeni Cushman & Applin
Patellina cf. *corrugata* Williamson
Pseudoglandulina clarkei Parr
Pullenia bulloides d'Orb
Pullenia quinqueloba d'Orb
Reusella sp.
Robulus cf. *limbosus* (Reuss) var *hockleyensis* (Cushman & Applin)
Robulus sp.
Spirillina sp.
Spiroplectammina sp.
Sigmomorphina jacksonensis Cushman
Stomatorbina torrei Cushman & Bermedez
Uvigerina gracilis Reuss
Verneulina sp.

The age of this rock is upper Eocene.

C. White Well Outstation and Head of Great Australian Bight.

From Colona to White Well there were no exposures of fossiliferous rocks and the surface is covered with sandy soil and sometimes travertine at least 3 feet thick. At White Well, which is at the head of the Bight, a well in Tertiary limestone stuck a small supply of salt water at the depth of 200 feet; the well shaft passed through a cave. Another bore was sunk to 700 feet: it encountered water under pressure which rose to about 200 feet from the surface. It is considered that this bore penetrated clay and a lignitic bed, but definite information was not available. No spoil samples were available.

Mr. Owen visited the cliffs forming the coast west of the head of the Bight and found that the cliffs actually facing the Southern Ocean are consolidated dune-sands piled up against the face of an old sea-cliff composed of fossiliferous Tertiary limestone. Specimens (Sample 4) of the limestone exposed near the top of the cliffs and for 200 yards inshore were taken; they represent a vertical thickness of 30 feet. Other specimens (Sample 5) were collected at a point where the limestone is covered by sand hills just inshore from the end of the sandstone cliffs, and represent a lower horizon than Sample 4.

Sample 4. About 5 miles west from head of Bight; sample represents 30 feet vertical cliff face.

Hard yellowish crystalline limestone with foraminifera.

Austrotrillina howchini (Schlumberger)

Marginopora cf. vertebralis Blainville

Operculina cf. victoriensis Chapman & Parr

Numerous small miliolids

Sample 5. About 4 miles west of head of Bight; lowest exposure of limestone above sand-cover.

Hard yellowish crystalline limestone with foraminifera.

Austrotrillina howchini (Schlumberger)

Marginopora cf. vertebralis Blainville

Numerous small rotalines and miliolids

The age of Samples 4 and 5 is topmost lower Miocene (f_1-f_2 stage).

D. Between White Well and the Border.

The first outcrop of Limestone along the road is at 57 miles west of White Well: sample 6 was collected from this locality.

At 82 miles west from White Well a blowhole occurs near the road. Heaps of spoil indicated that it has been cleaned out at some time, probably to give access to caves so as to deepen it for water. Samples 7, 8 and 9 were taken from the spoil dump, and Sample 10 from the limestone outcrops. This blowhole is within two or three miles of the Albala Karoo Bore, which according to Jack (1930) reached bedrock at 950 feet after penetrating 600 feet of bryozoal limestone and 350 feet of bluish clay and shale.

Sample 6. Limestone outcrop 57 miles west of White Well.
Hard cream to yellowish limestone with foraminifera.

Austrotrillina howchini (Schlumberger)
Flosculinella cf. *bontangensis* (Rutten)
Marginopora cf. *vertebralis* Blainville
Operculina victoriensis Chapman & Parr
Textularia sp.
Numerous small rotalines.

The age of this rock is topmost lower Miocene ("f_1""f_2" stage)

Sample 7. Spoil Dump, 82 miles west of White Well.
White chalky bryozoal limestone with numerous moderately well preserved foraminifera.

Alabamina obtusa var (B. & H.) *westraliensis* Parr
Angulogerina sp. nov.
Asterigerina adelaidensis Howchin
Anomalina perthensis Parr
Anomalina westraliensis Parr
Bolivinopsis crespinae Parr
Bulimina aff. *tarda* Parker & Bermudez
Carpenteria rotaliformis
Cassidulina cf. *inconspicua*
Cassidulina subglobosa Hussey var *horizontalis* Cushman
Ceratobulimina sp.
Discorbis cf. *turbo* (d'Orb)
Eponides repandus (F.& M.) var.
Gaudryina (Pseudogaudryina) crespinae Cushman
Globigerina triloculinoides Plummer
Globigerinella micra (Cole)
Globigerinoides index Finlay
Gyroidina scobriculata Finlay
Gyroidina soldanii (d'Orb)
Lagena laevis (Montf.)
Lagena favosopunctata Brady
Lagena sulcata (W. & B.)
Lamarckina sp.

Cibicides cf. perlucida Nuttall

Cibicided pseudoconvexus Parr

Cibicides umbonifer Parr

Cibicides sp.

Crespinella sp. nov.

Dentalina cf. soluta (Reuss)

Discorbinella sp. 1

Notorotalia stachei Finlay

Palellina cf. corrugata Williamson

Pullenia cf. quinqueloba d'Orb

Spirillina sp.

Stomatorbina torrei Cushman & Bermudez

Sample 8. Same locality as No. 7.

Hard yellowish bryozoal chalky limestone with foraminifera.

Anomalina cf. perthensis Parr

Cibicides cf. pseudoconvexus Parr

Globigerina cf. cretacea d'Orb.

Globigerina pseudobulloides Plummer

cf. Guembelina

The age of Samples 7 and 8 is upper Eocene.

Sample 9. Same locality as Nos. 7 and 8 but probably stratigraphically below those samples.

Friable grey sandstone with glauconite and a few fragments of bryozoa (derived).

Age - uncertain.

Sample 10. Limestone outcrop 82 miles west of White Well.

Hard cream limestone with foraminifera.

Bolivina sp.

Elphidium sp.

Globigerina sp.

Marginopora cf. vertebralis Blainville

Operculina cf. victoriensis Chapman & Parr

Sigmoidella elegantissima (P. & J.)

Numerous small miliolids.

The age of this rock is topmost lower Miocene (f_1-f_2 stage).

E. Eucla, Western Australia (See Plate 2).

Eucla is separated from the sea by a belt of sand hills about 400 feet wide and is about 2½ miles south of Hampton Scarp. From Eucla the ground

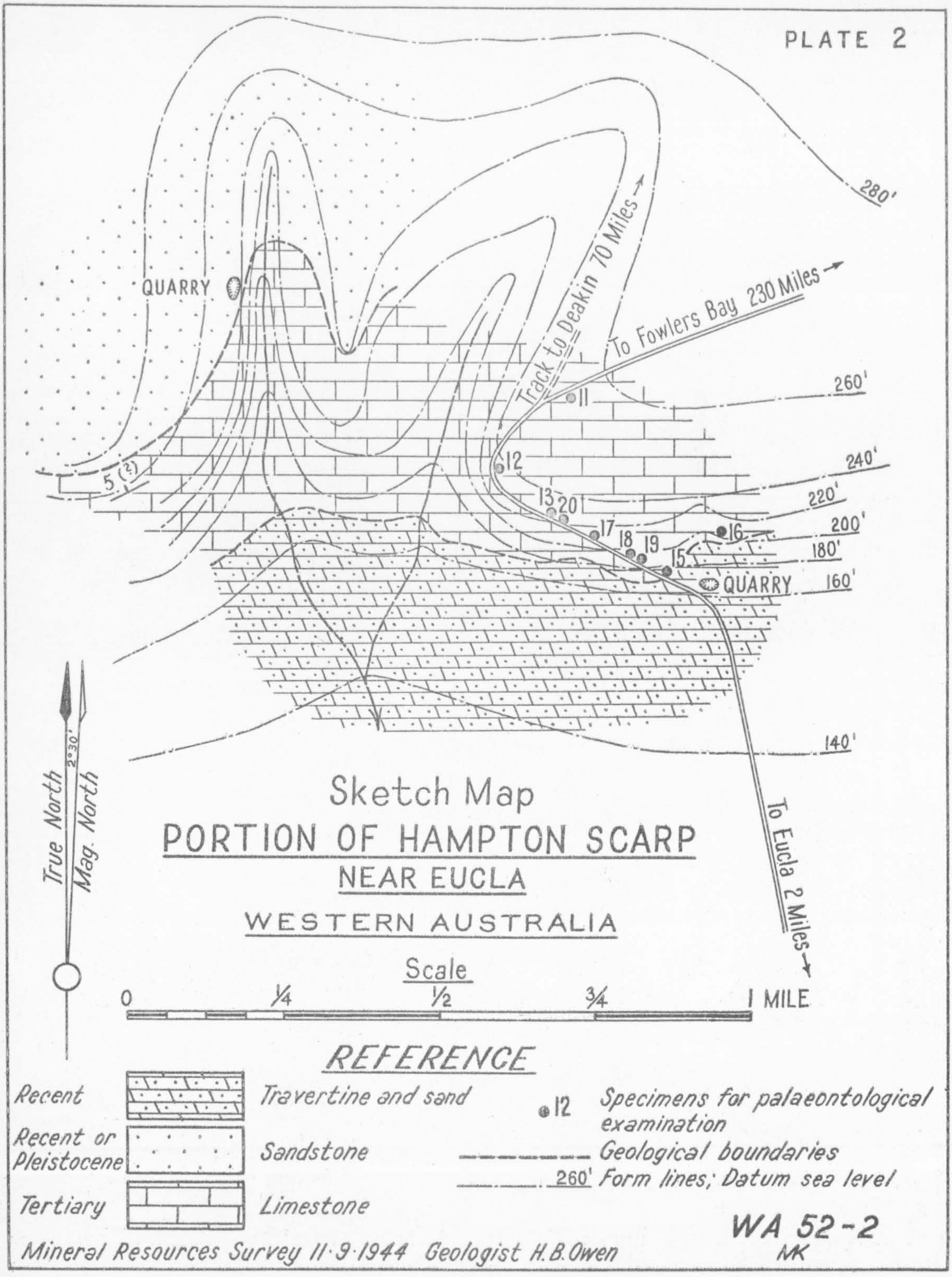


PLATE 2
QUARRY
Track to Deakin 70 Miles
To Fowlers Bay 230 Miles
280'
260'
240'
220'
200'
180'
160'
140'
11
12
13
20
17
18
19
15
16
QUARRY
5 (?)
True North
2°30'
Mag. North
To Eucla 2 Miles
Sketch Map
PORTION OF HAMPTON SCARP
NEAR EUCLA
WESTERN AUSTRALIA
Scale
0
¼
½
¾
1 MILE
REFERENCE
Recent
Travertine and sand
12
Specimens for palaeontological examination
Recent or Pleistocene
Sandstone
Geological boundaries
260'
Form lines; Datum sea level
Tertiary
Limestone
WA 52-2
MK
Mineral Resources Survey 11·9·1944 Geologist H.B. Owen

level gradually rises to about 160 feet above sea level at the foot of the scarp. The scarp rises abruptly to 260 feet, which is the level of the plateau. At the point where the road descends the scarp to the coastal plain, road cuttings and natural exposures reveal a vertical thickness of 90 feet of Tertiary limestone. Samples were collected throughout the section.

Sample 11. 2½ miles north of Eucla.

Hard cream crystalline limestone with a few foraminifera.

Elphidium sp.
Textularia sp.
Valvulina cf. *fusca* Williamson
Small rotalines.

Sample 12. 20 feet down scarp, 2½ miles north of Eucla.
Hard cream crystalline limestone with a few foraminifera.

Carpenteria sp.
Valvulina cf. *fusca* Williamson
Small foraminifera

The age of Samples 11 and 12 is topmost lower Miocene ("f_1"-"f_2" stage).

Sample 13. 40 feet down scarp, 3¼ miles north of Eucla.
Hard cream crystalline limestone with abundant small indeterminate foraminifera in a chalky matrix.

Sample 16. Lowest point on scarp at which limestone outcrops.
Chalky white bryozoal limestone with a few foraminifera.

Cibicides pseudoconvexus Parr
Nodosaria sp.
Pseudoglandulina sp.
Small rotalines

Sample 15. 30 feet below No. 16 and 150 yards south-west from it. 100 yards from 444 mile peg and about 15 feet above level of road quarry.

Yellowish bryozoal limestone with small indeterminate foraminifera chiefly rotalines.

Sample 17. Exact locality label missing (See Plate 2)

Pinkish to cream bryozoal limestone partially recrystallized, with a few indeterminate small foraminifera.

Sample 18. Road cutting 70 yards east from No. 17.

Pinkish to cream bryozoal limestone with indeterminate small foraminifera.

The age of Samples 13, 15, 17 and 18 is probably upper Eocene.

F. Between Eucla and Madura Pass.

Sample 14. East of Madura, 95 miles west of Eucla.

Bryozoal limestone with indeterminate foraminifera.

Sample 21. Scarp 95 miles west of Eucla.

Bryozoal limestone with a few small foraminifera.

The age of Samples 14 and 21 is probably upper Eocene.

G. Madura Pass.

Sample 22. Cutting, west side of road, 110 miles west from Eucla.

Hard pinkish crystalline limestone with foraminifera, Ditrupa tubes, and abundant calcareous algae.

Austrotrillina howchini (Schlumberger)

Calcarina cf. verriculata (Howchin & Parr)

Flosculinella cf. bontangensis (Rutten)

Gypsina howchini Chapman

Marginopora cf. vertebralis Blainville

Rotorbinella cf. cycloclypeus (Howchin & Parr)

Operculina cf. victoriensis Chapman & Parr

Numerous small foraminifera especially miliolids.

Sample collected at Madura Pass by M.H. Johnstone (MHJ.1)

Hard cream to pink crystalline limestone with calcareous algae and foraminifera.

Austrotrillina howchini (Schlumberger)

Carpenteria sp.

Marginopora cf. vertebralis Blainville

Operculina cf. victoriensis Chapman & Parr

Rotorbinella cf. cycloclypeus (Howchin & Parr)

Textularia sp.

Valvulina cf. fusca Williamson

Numerous miliolids.

The age of Sample 22 and MHJ.1 is topmost lower Miocene ("f_1"-"f_2" stage).

H. Balladonia, 100 miles east of Norseman.

Sample 23. Outcrop 64 miles west of 250 mile Hut and east of Balladonia, and 186 miles east of Norseman.

Hard pinkish limestone with most organisms filled with brown glauconite, a few small indeterminate foraminifera, and fragments of Marginopora.

Sample 32. Outcrop ¼ mile south of Balladonia Homestead Outcamp. Fragmental limestone with quartz grains, calcareous algae, and foraminifera, most tests infilled with glauconite.

Flosculinella cf. bontangensis (Rutten)

Marginopora cf. vertebralis Blainville

Rotorbinella cf. cycloclypeus (Howchin & Parr)

Numerous miliolids and rotalines.

The age of Samples 23 and 32 is topmost lower Miocene ("f_1"-"f_2" stage).

Sample 31. ¼ mile south of Balladonia Homestead Outcamp, from underground tank excavation.

Whitish bryozoal chalky moderately friable limestone with numerous foraminifera.

Alabamina obtusa (B.& H.) var westraliensis Parr

Anomalina perthensis Parr

Anomalina subnonionoides Finlay

Cassidulina armosa Bandy

Cassidulina inconspicua Hussey

Cibicides umbonifer Parr

Guttulina regina (B.P. & J.) aff.var. chappeli Parr & Collins

Guttulina cf. trigonula (Reuss)

Gyroidina soldanii (d'Orb.)

Lagena favosopunctata Brady

Lagena sulcata (W.& B.)

cf. Lamarckina sp.

Cibicides vortex Dorreen

Cibicides sp.

Crespinella sp. nov.

Dorothia parri Cushman

Eponides repandus (F.& M.) yar.

Eponides sp.

Globorotalis crassata (Cushman)

Globigerina triloculinoides Plummer

Globigerina cf. angipora Stache

Guttulina irregularis d'Orb

Guttulina cf. jarvisi Cushman & Ozawa

Guttulina problema d'Orb.

cf. Mississippina sp.

Parrella sp. nov. aff mexicana (Cushman)

Pseudoglandulina clarkei Parr

Sigmoidella bortonica Finlay

Spiroplectammina mississippiensis Cushman

Spiroplectammina cf. nuttalli Lalicker

Spiroplectammina sp.

Stomatorbina torrei Cushman & Bermudez

Textularia adalta Cushman

Victoriella cf. plecte (Chapman)

The age of this rock is upper Eocene

I. Booanya. 27.5 miles south from Balladonia.

Samples 26, 27 and 28 come from a dump at Booanya Well which is 60 feet deep. Booanya Well is 0.4 miles from big granite rock on bearing 210°M and about 0.25 miles from granite boundary.

Sample 26 has been lost.

Sample 27. Hard pinkish bryozoal limestone with foraminifera, club-shaped echinoid spines, and small brachiopoda.

Asterigerina sp. nov

Crespinella sp. nov.

Robulus cf. alabamensis Cushman

Planorbulina sp.

Sample 28. Moderately hard bryozoal limestone with numerous foraminifera, many tests encrusted with calcite.

Asterigerina sp.	Lagena cf. orbignyana Seg.
Anomalina subnonionoides Finlay	Miliolinella oblonga (Montagu)
Bolivinella sp. nov.	cf. Nodobaculariella
Cancris sp.	Pullenia bulloides d'Orb.
Crespinella sp. nov.	Pyrgo bulloides (d'Obr.)
Eponides toulmini Brotzen	Pyrgo sp.
Discorbis cf. turbo (d'Orb)	Pseudoglandulina clarkei Parr
Discorbis cf. patelliformis (Brady)	Parrella sp.
Dorothia parri Cushman	Reussella cf. finlayi Dorreen
Frondicularia sp.	Reussella cf. eocena (Cushman)
Gaudryina (Pseudogaudryina) crespinae Cushman	Robulus sp.
	Spiroplectammina sp.
Guttulina irregularis d'Orb	Stomatorbina torrei Cushman & Bermudez

The age of Samples 27 and 28 is upper Eocene.

J. Wonberna. 12.3 miles from Telegraph Station at Balladonia.

Sample 33. 100 yards north of granite outcrop.

Hard fragmental limestone with foraminifera.

Austrotrillina howchini. (Schlumberger)

Flosculinella cf. bontangensis (Rutten)

Marginopora cf. vertebralis Blainville

Numerous miliolids.

The age of this rock is topmost lower Miocene ("f_1"-"f_2" stage).

THE FORAMINIFERAL ASSEMBLAGES AND THE AGE OF THE LIMESTONES.

The collection is the most systematic so far made in the Nullarbor Plains region, and Mr. Owen's notes have helped to elucidate the Tertiary problems there. The foraminiferal assemblages present in these limestones from the Nullarbor Plains have yielded valuable information, based on recent work on the Tertiaries of Western Australia and south-eastern Australia, regarding their age. It would seem that, in the light of present evidence as to the age of certain beds in south-eastern Western Australia, earlier collections of limestones such as that from the "Plantagenet Series" described by Chapman and Crespin (1934) should be re-examined.

Sample 1, taken from a ridge immediately north of the old Yalata Homestead, was the only one collected which is younger than Tertiary. The foraminiferal assemblage is regarded as most probably Pleistocene in age. The species present are typical of shallow warm water, and are found living in the seas along the west coast of Western Australia. The youngest known occurrences of the foraminifera as fossils eastwards from Western Australia is in deposits of Pleistocene age in the Adelaide Basin, South Australia. The limestones at Yalata seem to be equivalent in age.

The Tertiary limestones collected west from Yalata are represented by hard foraminiferal crystalline limestone, bryozoal crystalline limestone, and white to pinkish chalky limestone. The foraminifera in these rocks indicate two ages - topmost lower Miocene ("f_1"-"f_2" stage), and upper Eocene ("b" stage). The remarkable feature of the hard foraminiferal limestone and the bryozoal limestone is their lithological and faunal similarity to limestones in the Carnarvon Basin, Western Australia, the former type with the Trealla Limestone and the latter with the Giralia Calcarenite(Condon et al., 1953). The third type of limestone with its chalky lithology seems to be characteristic of the Nullarbor Plains region.

(1) Hard foraminiferal crystalline limestone.

This rock is widespread, both in outcrop and immediately underlying the travertine deposits, on the Nullarbor Plains. The samples included under this heading are Nos. 2 (1), 4,5,6,10,11,12,22,23,33, and MHJ.1. The best sections are at Madura Pass and on the Hampton Scarp near Eucla. The limestone contains an assemblage of foraminifera which is found in the Trealla Limestone of the Carnarvon Basin and is typical of "f_1"-"f_2" stage in Indo-Pacific Tertiary stratigraphy. It is equivalent in age to the upper part of the lower Miocene. The characteristic foraminifera include Austrotrillina howchini, Marginopora cf. vertebralis, and Valvulina cf. fusca, together with numerous miliolids. The presence in Sample 22 of Flosculinella cf. bontangensis, Calcarina verriculata, and Gypsina howchini, as well as the species mentioned above, suggests that these rocks may be slightly lower stratigraphically than the rocks without those three forms.

This microfaunal assemblage extends as far eastward as the "old Murray Gulf" in north-western Victoria and south-western New South Wales, where it is well developed in subsurface sections. Moderately hard limestone with the same microfauna is also found in some of the Adelaide Metropolitan bores, where it is referred to as the "Oakland Limestone" (Crespin, 1955).

2. Hard bryozoal limestone.

Rocks of this lithology and faunal assemblage are samples Nos. 2 (2), 8, 13, 15, 16, 17, 18 and 21. In the Eucla section, they directly underlie the hard foraminiferal limestones described above. Small foraminifera are difficult to determine in thin section, but forms such as *Anomalina* cf. *perthensis*, *Cibicides* cf. *pseudoconvexus*, *Globigerina pseudobulloides*, and *Globigerina* cf. *cretacea* have been identified. Bryozoa are exceedingly common. The lithology is characteristic of that found in the Giralia Calcarenite in the Carnarvon Basin. The occurrence of similar bryozoal limestones in such widely separated areas suggests the widespread influence of Indo-Pacific Tertiary conditions of sedimentation as far east as western South Australia. There is little doubt that these rocks are upper Eocene in age.

3. White and pinkish moderately friable chalky limestone.

This rock is represented in samples Nos. 3, 7, 16, 27, 28 and 31. Many of the limestone samples are rich in foraminifera, the majority of the tests being well preserved and unusually large. Many well known upper Eocene species are represented. Some have been described from the King's Park Bore, Perth, (Parr, 1938) and others from Eocene deposits in America and elsewhere. Some species are new, although they have been recorded from upper Eocene deposits in the Carnarvon Basin and in the Maslin Beach section in South Australia. Very common in the assemblage is a new species of *Crespinella* recently recorded in some abundance at Maslin Beach (Crespin, 1955). It has also been found associated with *Discocyclina* in the Carnarvon Basin. Another important form is *Asterigerina adelaidensis*, which is represented by beautifully preserved specimens. It was described by Howchin from the basal part of the section in No. 2 Bore, Kent Town, Adelaide (1891), and is now recognised as an important zonal form for the upper Eocene; it also occurs in the upper Eocene deposits of south-western Victoria. A small specimen of Victoriella cf. plecte Chapman was discovered in sample No. 31. It has been found with Crespinella sp. nov. and Discocyclina in the Carnarvon Basin. Large tests of a new species of Bolivinella are common in sample No. 28 from Booanya Well.

Small upper Eocene species include Alabamina obtusa var. westraliensis Parr, Anomalina perthensis Parr, Anomalina westraliensis Parr, Angulogerina subangularis Parr, Bolivinopsis crespinae Parr, Cassidulina inconspicua Hussey, Cassidulina armosa Bandy, Cibicides umbonifer Parr, Cibicides pseudoconvexus Parr, Eponides toulmini Brotzen, Globigerina mexicana Cushman, Globigerinoides index Finlay, Globigerinella micra (Cole), Pseudoglandulina clarkei Parr and Sigmomorphina jacksonensis Cushman.

A feature of the limestone from Booanya Well is the presence of a large number of club-shaped echinoid spines, to which Chapman and Cudmore (1934) make reference (985 specimens were made available to them from this locality.) It is interesting to note that all the localities from which these authors recorded this form are now regarded as upper Eocene in age.

CONCLUSIONS

The following points have been brought out by this investigation of the limestones in the coastal region of the Nullarbor Plains.

1. The lithological similarity of the limestones to those of the same age in the Carnarvon Basin.

   (a) The widespread distribution in the Nullarbor Plains region of the same lithological type as the Trealla Limestone of the Carnarvon Basin of Western Australia.

   (b) The similarity of the bryozoal limestone lithology, especially in the Eucla section, to parts of the Giralia Calcarenite of the Carnarvon Basin.

2. The similarity of the faunal content of the limestones in the Nullarbor Plains region to that in limestones in the Carnarvon Basin, and in the Adelaide Basin and the Aldinga area (Maslin Beach), South Australia, as well as in north-western Victoria and south-western New South Wales.

(a) The "f_1"-"f_2" foraminiferal assemblage with Austrorillina howchini in the hard foraminiferal limestone is identical with that found in the Trealla Limestone of the Carnarvon Basin (Condon et el, 1953) and in the Oaklands Limestone (Crespin, 1955) of subsurface deposits in the Adelaide Basin, South Australia, and in subsurface deposits of north-western Victoria and south-western New South Wales (Chapman, 1916).

(b) The foraminiferal fauna in the hard bryozoal limestone is identical with that found in the Giralia Calcarenite of the Carnarvon Basin, which is upper Eocene in age.

(c) The microfauna of the chalky limestone with its abundant Crespinella sp. nov. is correlated with deposits at Maslin Beach (Blanche Point Limestone, Crespin, 1955) South Australia, and with certain beds in the Giralia Calcarenite. A further link with the Adelaide-Aldinga Tertiary deposits is the occurrence of Asterigerna adelaidensis. Numerous small foraminifera also indicate an upper Eocene age for the beds.

3. The stratigraphical sequence of upper Eocene and lower Miocene is similar to that found in the Giralia Anticline in the Carnarvon Basin, in the Adelaide Basin, and even as far east as the Torquay section in central southern Victoria.

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NOTES ON A LEPIDOCYCLINA - BEARING ROCK FROM CEBU, PHILIPPINES.

by

Irene Crespin.

During a visit by the writer to the Philippines in November, 1953, specimens of a large Lepidocyclina of paper-like thinness from the island of Cubu were handed to her for comment. External characters immediately suggested Lepidocyclina (Eulepidina) badjirraensis Crespin, from Badjirrajirra Creek, Cape Range, Exmouth Gulf, North-West Australia (Crespin, 1952). Thin sections prepared at the Bureau of Mines, Manila, confirmed this determination. A special visit was made by the writer to Cebu to collect specimens from the locality at Mantalongan. In company with Mr. Robert Grey and other members of the staff of the Bureau of Mines, she set out from Cebu City for the locality, but owing to heavy rain, which brought about a sudden rise in the height of the river to be crossed, it was not reached. However, it was promised that a collection would be made at the earliest opportunity and forwarded to Canberra. These samples were received from the Director of Mines, Manila, on 28th July, 1954.

The collection was made at Barrio Magalambac, Mantalogon, and consisted of tests of both the megalospheric and microspheric generations (Forms A and B) of the species Lepidocyclina (Eulepidina) badjirraensis, flatly lying and closely matted together. The average diameter of the microspheric form measured 55 mm., the largest being 60 mm. The thickness at the peripheral edge was 0.5 mm. The megalospheric form showed an almost uniform diameter of 20 mm. This species is amongst the largest Lepidocyclinae known from the Indo-Pacific region. It is apparently the species referred to by Corby et al. (1951, p.117) as Lepidocyclina cf. dilatata Michelotti. The writer has little doubt also that L.(E) saipanensis Cole (Cole & Bridge 1953) is referable to this species. Professor Storrs Cole's specimens from Saipan were examined at Cornell University in 1951 and the suggestion was made to him that the species from Saipan and from the Cape Range, Western Australia, were identical.

Associated with this species in Cebu are species of foraminifera similar to those found in the Cape Range. The "e" stage form Cycloclypeus eidae

Tan is present, together with Lepidocyclina (Nephrolepidina) bornëensis and large and small tests of Operculina which have been referred to O.victoriensis Chapman and Parr. It has also been possible to obtain a small but interesting assemblage of smaller foraminifera from the matrix attached to the large tests. Most of these forms were found associated with L.(E.) badjirraensis in the Cape Range material. The complete list of foraminifera recognised is as follows:

Amphistegina lessonii (d'Orb.)
Anomalina glabrata (Cushman)
Anomalina sp.
Anomalinella rostrata (Brady)
Bolivina cf. antiqua d'Orb
Cancris auriculus (F. and M.)
Cibicides dorsopustulosus Le Roy
Cibicides cf. fijiensis (Cushman)
Cibicides lobatulus (W. and J.)
Cibicides refulgens (Montf.)
Cornuspira crassisepta Brady
Cycloclypeus eidae Tan
Cycloloculina sp.
Dentalina insecta Schwager.
Dentalina spp.
Eponides cf. praecinctus (Karrer)
Globigerina cf. baroemeonensis Le Roy
Globigerina bulloides d'Orb
Globigerinoides trilocularis (d'Orb.)
Hemicristellaria sumatrica LeRoy.
Lagena sulcata (W. & B.) var. apiculata Cushman
Lagena sp.
Lepidocyclina (Eulepidina) badjirraensis Crespin (Forms A & B)
Lepidocyclina (Nephrolepidina) bornëensis (Provale).
Liebusella rudis (Costa)
Miogypsina cf. kotoi Hanzawa
Nodosaria sp.
Operculina victoriensis. Chapman and Parr (Forms A & B)
Patellina corrugata (Williamson)
Reophax cf. scorpiurus Montf.
Reussella decorata (Heron-Allen and Earland)
Saracenaria italica Defr.
Spiroloculina canaliculata d'Orb.
Spiroplectammina arenacea LeRoy.

The stratigraphical horizon at which L.(E) badjirraensis is found in Cebu is almost certainly equivalent to that in which it occurs in the Cape Range, North-West Australia, and the age of the bed is regarded as near the top of "e" stage. The occurrence in the field is apparently similar in both localities, where the tests of the two generations are flatly lying and are crowded together so as to give the bed a stratified appearance. In Badjirrajirra Creek, Cape Range, the bed containing these crowded tests is only 2 feet thick and occurs in the type section of the Mandu Limestone (Condon et al., 1953), 169 feet above the base of the exposed section of the Formation and 94 feet below the base of the overlying Tulki Formation in which Eulepidina is absent. The Tulki Limestone is overlain by the Trealla Limestone, the age of both these formations being low in "f" stage. The base of the Mandu Limestone is not exposed in the Cape Range, but the stratigraphy of the area suggests that it overlies limestones of Eocene age which in turn overlie the Cretaceous.

The limestone bed within the Malubog Formation which overlies the Cebu Limestone is also of interest. The writer collected a sample of this limestone on the Cebu-Toledo road about 15 kilometres from Toledo. This limestone has two outstanding characteristics:

1. The abundance of the species Austrotrillina howchini (Schlumberger)
2. The remarkable similarity in lithology to the limestone in the lower part of the Trealla Formation in the Cape Range area.

Austrotrillina howchini was described by Schlumberger from a Lepidocyclina limestone at Clifton Bank, near Hamilton, Western Victoria, Australia, which is most probably equivalent to basal "f_2" and uppermost lower Miocene. This form was not found associated with L.(E) badjirraensis at the type locality, but is present in the limestone of the Tulki Formation and common in the Trealla Limestone. It is noteworthy that "e" stage beds with Eulepidina have been found in Australia only in North-West Australia.

The writer takes this opportunity to correct errors relating to the Tertiary stratigraphical sequence in Australia shown on Plate 48 of the Corby publication (1951). Considerable work has been done in this country on the

Tertiary sequence since Chapman and Singleton put forward their views in 1925 (not 1930 as quoted on the plate). The term "Barwonian" has been abandoned, and the Balcombian Stage has been proved to overlie the Janjukian, not underlie as previously thought. The Balcombian is most probably the equivalent in age of basal "f_2" and the Janjukian is upper Eocene.

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AN ACCOUNT OF THE GEOLOGY AND PETROLEUM PROSPECTS OF THE CAPE VOGEL BASIN, PAPUA.

by

S.J. Paterson and F.M.Kicinski

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SUMMARY

This paper is an attempt to organize the available data on the geology and petroleum prospects of the Cape Vogel Basin. The geotectonic position of the Basin is discussed and it is shown that it lies between the Morobe Arc and Owen Stanley Folded Zone (of Glaessner, 1950) and the D'Entrecasteau Arc. The stratigraphy of the area is treated in three sections -Southern, Northern and Central- and it is shown that in the Southern and Northern sections the basal rocks are predominantly of volcanic origin and that in the Northern section non-volcanic deposits are only of minor importance. In the Central section - the Cape Vogel Peninsula - some 14,000 ft. of dominantly arenaceous sediments are exposed. These have been assigned ages ranging from middle Miocene to Recent. The structure is discussed and it is indicated that a major anticline exists in the Cape Vogel Peninsula area. An account of the work of the Vogel (Papua) Oil Company is included. The extensive development of shallow non-marine sediments and their predominantly arenaceous character, the absence of any surface indications of oil and of any proven occurrence of oil in the three test wells, and the long history of volcanic activity, lead to the conclusion that the area has only slight petroleum prospects, and does not justify exploration at this stage.

INTRODUCTION

GENERAL

In 1953 the New Guinea Survey Unit of the Land Research and Regional Survey Section of C.S.I.R.O. (of which one author (S.J.P.) is a member) conducted a resources survey of the Buna-Kokoda area of Papua. This area lies in the northern section of the Cape Vogel Basin. Publication of the geological and geomorphological report on this area is delayed until photography of the area is complete and final maps are draughted. In view of the present activity in the search for oil in Papua the writers believe that a short account of the geology of the Buna-Kokoda area and of the known geology of the Cape Vogel Basin together with a view of the petroleum prospects of this area is opportune at this stage.

LOCATION

The Cape Vogel Basin lies in the Northern Division of Papua between the north-eastern slopes of the Owen Stanley Range and the D'Entrecasteau Islands. The greater part of the basin is at present covered by the sea; the exposed section extends from East Cape (approximately 10°14'S, 150°51'E) in the south to Hercules Bay (approximately 07°55'S, 147°42'E) in the north. The location of the area is shown on Figure 1.

PREVIOUS INVESTIGATION AND SOURCE MATERIAL

The Cape Vogel Peninsula was first visited and examined by Stanley, Papuan Government Geologist, in 1914 (Stanley, 1919a). He reported the occurrence of arenaceous strata and igneous rocks and recommended further investigation, as the area seemed to possess petroleum prospects analogous to those of the Vailala River area. The area was again traversed in 1924 by Dolton and Lyne (1924) and the Vogel (Papua) Oil Syndicate was formed in 1925. Papp and Nason-Jones of the Anglo-Persian Oil Company (1930) made a detailed examination of part of the Cape Vogel Peninsula in 1928. Observations by Stanley (1923) on the geology of the southern section of the Basin are contained in his report on the Geology of Papua.

GEOTECTONIC POSITION

The geotectonic position of the Cape Vogel Basin is shown in Figure 1. The basin is a linear belt lying between two metamorphic arcs - the Morobe Arc and Owen Stanley Folded Zone (of Glaessner, 1950) and the D'Entrecasteau Arc - the metamorphic and igneous rocks of which form the basement rocks of the geosyncline.

MOROBE ARC AND OWEN STANLEY FOLDED ZONE

The Morobe Arc and Owen Stanley Folded Zone was described by Glaessner (1950). The northern section of the arc consists of low-grade metamorphics - Fisher's (1943) Kaindi "Series" - some of which contain an assemblage of molluscs which Glaessner (1950) regards as being Cretaceous, probably Aptian to Albian, age. The metamorphics are intruded by the granodiorite of the Morobe Batholith and other intrusions which must be of late Mesozoic or younger age.

The central section of the arc consists of low to medium grade metamorphics - the Owen Stanley Metamorphics. These rocks are almost certainly much older than the Kaindi "Series" and resemble the pre-Permian Omung Metamorphics of Central Highlands described by Rickwood (1954). The metamorphics are intruded by the peridotites, dunites, gabbros, norites, and dolerites of the Ajura Kiljala Complex. The age of the intrusion is not definitely known but it appears to be late Mesozoic or early Tertiary.

Little is known of the south-eastern section of the arc but reports by Stanley (1923) indicate that the Owen Stanley Range has the same general features in that direction.

D'ENTRECASTEAU ARC.

The D'Entrecasteau Arc is also formed of metamorphic rocks. Stanley (1920) recognised slightly altered phyllites and quartz schists resting unconformably on highly metamorphosed granite gneisses on Fergusson Island. The metamorphic rocks are intruded by granites. Age relationships of the D'Entrecasteau Arc are not known.

CAPE VOGEL BASIN.

The Cape Vogel Basin is typical of Kay's (1947) eugeosynclines. It is an orogenically and volcanically active linear belt of long-continued subsidence, characterised by volcanic rocks, tuffaceous sandstones, cherts, and dark shales. Sediments were apparently derived from the island arcs. The greater part of the geosyncline is at present covered by the sea.

STRATIGRAPHY.

The stratigraphy of the Cape Vogel basin is incompletely known, but the general features are apparent. The summarized stratigraphy is shown on Table I. The lack of detailed stratigraphical and palaeontological examination allows only broad correlations, and for this reason the stratigraphy of the basin is treated in three parts, the southern, northern, and central sections.

SOUTHERN SECTION.

Lower Tertiary rocks (probably Eocene and Oligocene) are reported by Montgomery, Osborne, and Glaessner (1950) south of Goodenough Bay and Cape Vogel Penninsula. These rocks are similar in lithology to those in the Port Moresby area: cherts, green tuffs, shales, and bands of sandstones.

NORTHERN SECTION.

Part of the Northern Section was examined by Paterson (1955) during the Buna-Kokoda Resources survey carried out by C.S.I.R.O. in 1953.

The Buna-Kokoda area included part of the Morobe Arc and Owen Stanley Folded Zone, composed of metamorphic rocks of the Owen Stanley Range which are in intruded by igneous rocks of the Ajura Kiljala Complex. The Tertiary of this part of the Cape Vogel Basin consists of a thick sequence of lower Burdigalian (lower "f_{1-2}" stage of the Dutch classification) and possible Aquitanian ("e" stage) volcanic deposits and tuffaceous sediments, a thin veneer of Burdigalian ("f_{1-2}" stage) limestones, isolated outcrops of Pliocene sandstones and mudstones, and thick Quaternary deposits from the dormant or extinct Hydrographer Range Volcano and the active volcano, Mt. Lamington.

Metamorphic Rocks: Owen Stanley Metamorphics.

The Owen Stanley Range, part of the main cordillera of New Guinea, is almost entirely composed of metamorphic rocks. Stanley (1919b) described the rocks south of the Kokoda-Yodda Valley as "highly altered biotite schists and gneisses of igneous origin, epidote and chlorite schists and gneisses, associated with numerous quartz veins." Stanley also recorded the occurrence of crystalline limestone below Oivi Village and west of the Kumusi River. In the same area Paterson (1955) described muscovite-chlorite gneisses, glaucophane-cordierite schists, calc schists, and garnetiferous calc silicate rocks.

According to the metamorphic facies and grade concepts of Eskola (1920) and Tilley (1924) (extended by Turner and Verhoogen, 1951), the rocks may be assigned to the greenschist facies (muscovite-chlorite subfacies) and to the albite-epidote-amphibolite facies (chloritoid-almandine subfacies), indicating metamorphism under conditions of low to moderate temperature, mostly low hydrostatic pressure, and moderate to high directed pressure. The extent of the Owen Stanley Metamorphics and the localised nature of the intrusion of the Ajura Kiljala Complex substantiate the conclusion that the metamorphics are dominantly the result of low to medium grade regional metamorphism, though within the sphere of influence of the intrusion contact or local metamorphic features are seen in rocks of the actinolite-epidote-hornfels subfacies (low-temperature contact metamorphism).

The metamorphic rocks are strongly folded; much microfolding exists within the major structures and the effects of shearing are nearly always pronounced. The rocks are regarded as being older than Fisher's (1943) Kaindi "Series" of the Morobe Districts and comparable in age with the pre-Permian Omung Metamorphics of the Central Highlands described by Rickwood (1954).

Plutonic and Hypabyssal Rocks: Ajura Kiljala Complex.

Serpentinized peridotites and dunites, olivine gabbros, olivine-hypersthene gabbros, hornblende gabbros, augite norites and hypersthene dolerites - the Ajura Kiljala Complex - intrude the Owen Stanley Metamorphics in the Buna-Kokoda Area. The main mass of the complex forms the Ajura Kiljala Range, which lies to the north of the Kokoda-Yodda Valley. This mass which is elongated in a north-north-west direction, extends from near the Kumusi River-Oivi Creek junction to north of the Chirima-Mambare River Junction and is about 40 miles by 12 miles. Peridotites and dunites also occur in the Guaya Range, on the southern side of the Mamama River, south of Mt. Lamington. The ages of the intrusions are not definitely known but they are thought to be of late Mesozoic or early Tertiary age.

Tertiary.

Lower Burdigalian and possibly Aquitanian: Iauga Formation - The Iauga Formation forms the base of the Tertiary sequence in the northern part of the Cape Vogel Basin. The formation is typically developed in the Iauga Plateau, which lies between the mouths of the Mambare and Opi Rivers (approximately between latitudes 8°02'S and 8°19'S at longitude 148°05'E). Similar rocks are found in the foothills along the northern slopes of the Ajura Kiljala Range.

The thickness of the formation is unknown but it is estimated to be over 2,000 ft. The formation is conformably overlain by the Burdigalian and possibly Aquitanian Robinson Bay Limestone.

The volcanics are predominantly basaltic, ranging from olivine and augite basalts to augite andesites and quartz microdiorite. These are accompanied by agglomerates, andesitic tuffs and tuffaceous sandstones. Olivine and augite basalts and agglomerates containing boulders of these lavas are dominant on the northern coast of the Iauga Plateau. The eastern and southern sections of the plateau are composed of similar lavas, but these are accompanied by a greater development of andesite, andesitic tuff, and tuffaceous sandstone. The foothills zone along the northern slopes of the Ajura Kiljala Range is dominantly composed of agglomerate, andesitic tuff, and calcareous tuffaceous sandstones.

The only fossiliferous sample (No. 83), a tuffaceous sandstone collected from the uppermost part of the formation, yielded:

Miogypsina kotoi Hanzawa
Lepidocyclina cf. *verbeeki* Newton & Holland
Amphistegina sp.

As will be seen from the distribution chart of larger foraminifera (Table 3) this fauna does not differ from that of the over-lying limestones. At least the uppermost beds of the Iauga Formation are assigned to Burdigalian; the rest of it belongs possibly to older stages.

Burdigalian: Robinson Bay Limestone - Algal-foraminiferal detrital limestone, ranging in colour from white or grey to pale pink, conformably overlies the Iauga Formation. It is in turn disconformably overlain by Pliocene Mamama Sandstone and Mudstone. The limestone is massive and very poorly bedded.

The limestone was examined on the northern arm of Robinson Bay (08°07'S, 148°09'E), on the eastern slopes of the Iauga Plateau. The section contains 60 feet of limestone and grades from a tuffaceous limestone through limestone containing small percentages of tuffaceous material, such as clino-pyroxenes, plagioclase and zeolites, to pure limestone. With the exception of Armit Caves, near Ioma Administration Station, where some 400 ft. of limestone is estimated as outcropping, the limestone only occurs as thin cappings on hills of Iauga Formation in a zone extending from the mouths of the Mambare and Gira Rivers to the northern slopes of the Ajura Kiljala Range.

The limestone is very fossiliferous and the more important larger foraminifera determined by Kicinski (Appendix C to Paterson, 1955) are listed in Table 3.

Two main assemblages are distinguished.

Assemblage of sample No. 78 contains:

"Assilina" cf. orientalis Douville

Borelis (Neoalveolina, Silvestri) haueri (d'Orb.)

B. pygmea Hanzawa

Miogypsinoides dehaarti Van der Vlerk

Flosculinella bontangensis (Rutten)

Alveolinella fennemai Checchia-Rispoli

Lepidocyclina (N) rutteni lauensis Cole

Borelis haueri is generally speaking a lower Miocene form. In Western Papua it occurs mainly in the "e" stage. Borelis pygmea also is associated only with the "e"-stage assemblages in Western Papua, and this seems to be the first occurrence in the "f" stage in that country. Elsewhere it ranges from Oligocene to Miocene (and perhaps Recent). Flosculinella bontangensis is known from the "f" stage only in the Dutch East Indies. Miogypsinoides dehaarti is believed to be restricted to "e" and "f_{1-2}" stages in East Indies and Papua. Lepidocyclina (N) rutteni lauensis was described by Cole from the "f" stage of Fiji. ?Assilina sp.indet. could not be studied in detail owing to the lack of oriented sections. It is believed, however, that it is an indigenous and not a derived form.

This assemblage is considered to be definitely older than that of the remaining samples, but, lacking distinctive forms of the "e" stage (as Spiroclypeus, Eulepidina, etc.), is placed at the base of the "f" stage.

The fauna of the remaining samples forms the second assemblage. Only 5 samples were taken in a stratigraphical sequence. These are (in ascending order) nos. 45, 50, 47, 48, 49, representing a 60-foot section.

Following is the list of the diagnostic foraminifera determined:

Borelis haueri (d'Orb.)

Miogypsina kotoi Hanzawa

Austrotrillina howchini (Schlumberger)

Lepidocyclina (N) ferreroi Provale

L.(N.) verrucosa Scheffen

L. (N) angulosa Provale

L. (N) cf. verbeeki Newton and Holland

L. (N) sumatrensis Brady

L. (N) rutteni Van der Vlerk

L. (N) inflata Provale

Linderina sp. indet.

Miogypsina kotoi is restricted to lower "f" stage in Dutch East Indies and Papua. Austrotrillina howchini is a typical "e"-stage and lower "f"-stage form of the Indo-Pacific region. Lepidocyclina (N) ferreroi, L.(N) verrucosa, L.(N) angulosa, L.(N) sumatrensis and L.(N) inflata are common "f_{1-2}"-stage forms of Dutch East Indies and Papua, although they occur also in the upper "e" stage. Summarising, the assemblage is clearly of "f_{1-2}" age correlated with Burdigalian (Glaessner, 1943) of the Standard European Classification.

New in this assemblage is Linderina sp. indet., which shows no indications of being derived. The genus is commonly known from Eocene only, but unidentified species have been reported from the Miocene of Borneo and Pemba Island. Its occurrence in the Miocene of New Guinea has been already noted in unpublished reports of some oil companies. It is known from the Northern coast of Eastern New Guinea, associated with Lepidocyclina (N) cf. verbekki, and from Western Papua, where it was found with the "e"-stage fauna. The form is being studied by one of the writers (F.M.K.) and the results are expected to be published elsewhere.

Pliocene: Mamama Formation - Sediments of the Mamama Formation only crop out in two isolated localities.

The outcrop in a small tributary of the Muro River (9°02'S, 148°10'E), a major tributary of the Mamama River, was first described by Stanley (1919). These beds consist of greyish mauve mudstone, laminated shale with plant remains, and fine and coarse conglomerates containing pebbles of serpentinized peridotites and basalts. The beds rest unconformably on rocks of the Owen Stanley Metamorphics. The outcrop is 42 feet thick.

Similar rocks form bars in the Mambare River, near the villages of Sia and Bebewa (approximately 8°10'S, 148°01'E). Here some 100 ft. of fine-grained loosely compacted sandstone and carbonaceous mudstone crop out in a small gently dipping anticlinal structure. These rocks disconformably overlie Robinson Bay Limestone, and are unfossiliferous. Because of their similarities to Pliocene rocks from various parts of New Guinea they are regarded as being of Pliocene age.

Quaternary

Pleistocene: Hydrographer Range Volcanics - Deposits of the Hydrographer Range Volcano appear to rest unconformably upon the Pliocene Mamama Formation and, in common with the deposits of other extinct or dormant volcanoes in New Guinea, are regarded as being of Pleistocene age.

The Range is composed of tuffs overlain by basalt, andesite, and agglomerates containing basalt and andesite boulders. Columnar lava flows and agglomerate beds predominate and the deposits are about 6,000 ft. thick.

Pleistocene to Recent: Kokoda Conglomerate - Lacustrine deposits of the Kokoda-Yodda Fault Trough Lake consist of poorly consolidated coarse conglomerate, sand and mud. The material was derived from the igneous rocks of the Ajura Kiljala Complex and from the Owen Stanley Metamorphics. About 150 ft. of lacustrine material was deposited in the lake 25 miles long by 3 to 4 miles wide.

Pleistocene to Recent: Alluvial Deltaic Deposits - Extensive low, flat, alluvial-deltaic plains - the Kumusi-Mambare Lowlands- form a wide belt extending from the base of the Mt. Lamington and Hydrographer Range volcanoes to the Gira River.

The material consists of unconsolidated gravel, sand and silt derived from a wide variety of metamorphic and igneous rocks. Beach ridges are found along parts of the coastline where the plains are advancing towards the sea. These contain concentrates of augite, and hornblende and magnetite.

Recent: Mt. Lamington Volcanics - In common with the deposits of other active volcanoes in New Guinea the deposits of Mt. Lamington are regarded as having been laid down within Recent time.

The Volcanics consist of andesitic ash and agglomerate deposits with an aggregate thickness of 3,500 feet overlain by lave flows and coulees of hypersthene-augite-biotite andesite, hornblende-biotite andesite, hornblende-augite andesite, and lamprophyric andesite.

CENTRAL SECTION.

A sequence of over 14,000 ft. of sediments has been described from the Cape Vogel area by Papp and Nason-Jones in the report of the Anglo-Persian Oil Company (1920-1929). These sediments have been assigned ages ranging from middle Miocene to Recent. Papp and Nason-Jones subdivided the geological sequence on stratigraphical and lithological characteristics. No detailed palaeontological examination of specimens was made and only fragmentary fossil material was supplied to Chapman, who assigned the various ages to the formation. This work needs revision, but for the purposes of this paper it has to be accepted at its face value since the material is not available to the writers for examination.

Tertiary.

Middle Miocene: White Marl "Group."-

The oldest rocks within the confines of the mapped area are micaceous, saponaceous thin-bedded creamy or white marls. These beds are more than 800 ft. thick and the junction with the overlying sediments is apparently conformable. Abundant fossil fragments were examined by Chapman (A.P.O.C. 1930) who identified the following genera:-

Lucina sp.
Lucina ovum Reeve
Tellina cf. *gracilis* Sow
Uca sp.
Linthia sp.

These beds were assigned a middle Miocene age.

Upper Miocene: Lower Arenaceous "Group".

The rocks are composed predominantly of coarse and fine-grained sandstone part of which is current bedded and contains lenses of hard white marl, brown and white marl, and brown marl containing plant remains and shell fragments. These are intercalated with volcanic tuff, agglomerate, conglomerate, and breccia. The thickness of the strata is at least 8,000 ft. Chapman (A.P.O. C.1930) identified the following fossils:-

Palunina angularis Miller

P. burroughiana Lea

P. sp.

Neritina auriculata Lam.

Papp and Nason-Jones state 'The fossils clearly indicate that the sediments of the Lower Arenaceous "Group" were deposited largely in shallow fresh water, but the collected and observed specimens do not, unfortunately, provide sufficient evidence to determine the precise geological age of the "Group".' However, on the map accompanying their report, the rocks are assigned an upper Miocene age.

Mio-Pliocene: Upper Arenaceous "Group".

The sediments of the previous "Group" are conformably overlain by a formation of more or less similar lithological characteristics with a total thickness of 4,600 ft. The rocks are subdivided as follows:-

Sub-Group A - This, the lowest Sub-Group, is mainly composed of soft brown sandstone and marl, grit and ferruginous gravelly sandstone, with a measured thickness of 3,700 ft.

The following fossils were identified by Papp and Nason-Jones (A.P.O. C. 1930).

Tapes sp.

Ervili sp.

Modiolus sp.

Congeria sp. (small)

Melanopsis sp.

Shark-teeth (small)

<u>Sub-Group B</u> - Sub-Group B, which has a measured thickness of 500 ft. conformably overlies Sub-Group A and consists of thin-bedded white laminated siliceous marl and occasional hard thin grey limestone bands containing shell fragments, fish scales, and carbonised plant remains and foraminifera. These pass upwards into grey and brown marl and conglomerate of silicified marl pebbles and beds of grey marl breccia.

<u>Sub-Group C</u> - The rocks of Sub-Group C, totalling 400 ft. and more in thickness, conformably overlie Sub-Group B. These beds consist of sandstone and marl with plant remains, molluscs and gastropods, ill-consolidated conglomerate, occasional tuffs, and gravelly sandstone containing igneous pebbles. The following fossils have been identified from this Sub-Group by Chapman (A.P.O.C. 1930):-

<u>Corbula</u> sp. nov.
<u>Mytilus</u> sp. nov.
<u>Carcharias</u> cf. <u>dijki</u> Martin
<u>Turbonilla</u> cf. <u>semarangana</u> Martin
<u>Phos</u> cf. <u>woodwardianus</u> Martin
<u>Melania</u> sp.
<u>Paludina</u> sp.

The beds of the Upper Arenaceous Group have been assigned a Mio-Pliocene age.

<u>Pliocene to Recent: Raised Coral Limestone</u>.

Well-bedded calcareous sandstone, alternating with hard, compact, and porous limestone, forms terraces and broad upland plateaux and lies unconformably as outliers on igneous rocks in the Cape Vogel area. The beds have a thickness of about 240 ft. and the following foraminifera were identified by Chapman (A.P.O.C. 1930):

<u>Amphistegina</u> sp.
<u>Heterostegina</u> sp.
<u>Orbiculina</u> sp.
<u>Biloculina</u> sp.

(The last two forms are probably <u>Sorites</u>? sp. and <u>Pyrgo</u> sp)

Quaternary: Coral Limestone and Alluvium.

Practically the whole of the coastline of the Cape Vogel Peninsula is fringed with unconformable coral reef platforms. Along the lower parts of the major rivers and along the low lying swampy coast extensive alluvial deposits have formed. The alluvium is composed of clays, sands, muds and gravels derived from the rocks of the hinterland.

Igneous Rocks.

The igneous rocks are intrusive and extrusive, and are confined to the northern and southern parts of the area mapped by Papp and Nason-Jones. The igneous rocks were divided into two groups:-

(a) Andesitic, basaltic, trachytic, and porphyritic lavas.

(b) Volcanic agglomerates, conglomerates, breccias, green and white volcanic tuffs, perlite, lapilli, obsidian, pumice, etc.

Volcanic tuffs, agglomerates,and lapilli-beds are interbedded with members of the Lower Arenaceous "Group" and Papp and Nason-Jones state that this indicates "that the primary volcanic activity took place before and during the Upper Miocene Period." They also state that "the baked, brecciated and indurated character of parts of the Lower and Upper Arenaceous Groups is sufficient evidence to suggest the continuation of volcanic and post-volcanic activity until the end of Pliocene times."

STRUCTURE.

FOLDING.

The basement rocks - the Owen Stanley Metamorphics - are closely folded and micro-folding is common. The effect of shearing is nearly always pronounced.

The Iauga Formation and conformable Robinson Bay Limestone and Mamama Formation are dominantly broadly folded, and steep dips and close structures are only found in the neighbourhood of major faults.

In the Cape Vogel area the dominant structural feature is the Garabuna-Tabana-Guduguduwanu Range of igneous rocks, which, with the flanking and overlying Lower Arenaceous "Group" sediments, form the core of a major anticlinal structure.

Papp and Nason-Jones describe this structure as "symmetrical and some 8 miles in length, with a short northern limb having a span of only 1 or 2 miles, and a southern limb, outcropping over a distance of 6½ miles, in which appear the whole of the sediments lying above the White Marl Group ..... The Strike direction of the main feature is in general east and west .... both flanks are undulating and have developed several minor anticlines and synclines."

FAULTING.

Several major faults are situated in the Buna-Kokoda area. Two major fault troughs are associated with the Kokoda and Yodda, and Sia and Bebewa, Faults, and the Baru Fault has important topographic expression in the Iauga Plateau.

In the Cape Vogel area very few faults have been observed apart from the principal fault-lines along which the ancient volcanic activity occurred. These faults are considered to be mostly secondary and of little tectonic importance.

AGE OF FOLDING AND FAULTING MOVEMENTS.

The age of the gentle folding and faulting of the rocks of the Buna-Kokoda area is post-Pliocene, possibly early Pleistocene. Movements in the Cape Vogel area are probably of similar age.

OIL POSSIBILITIES.

REGIONAL GEOLOGY.

The known stratigraphical record of the Cape Vogel geosyncline indicates that it is a typical eugeosyncline in which volcanic rocks are important stratigraphically. In the northern and southern sections of the eugeosyncline the basal rocks are exposed, and these are dominantly volcanic. The volcanic rocks in the northern section are lower Burdigalian ("f_{1-2}" stage of the Dutch classification) and possibly Aquitanian ("e" stage). In the Cape Vogel area volcanic activity is considered to have taken place before and during the upper Miocene and continued to the end of Pliocene time. Pleistocene and Recent volcanic activity has been centred on Mt. Dayman, the Hydrographer Range, Mt. Victory, Mt. Trafalgar, and the Goropu Mountains and Mt. Lamington.

The disconformity between the Burdigalian ("f_{1-2}" stage) Robinson Bay Limestone and the Pliocene Mamama Formation indicates that the northern section was part of a land surface from middle Miocene to Pliocene time. Pliocene sediments only measure approximately 100 ft. The Central Section, the Cape Vogel Peninsula, where a total thickness of over 14,000 ft. of sediments is exposed, is the only area which warrants discussion from the aspect of petroleum prospects.

CAPE VOGEL PENINSULA AREA.

Source Rocks.

Within the Cape Vogel Peninsula area the Lower Arenaceous "Group", totalling 8,000 ft. of sediments, and the Sub-Groups B and C of the Upper Arenaceous "Group", totalling 900 ft. of sediments, were deposited largely in a shallow non-marine environment, for the sediments contain numerous carbonised plant remains and fragments of fresh and brackish water molluscs. The remainder of the sediments are composed of sandstones and white and cream marls. Thus, within the area, no sediments rich in organic matter have been deposited in the comparatively deep parts of the eugeosyncline under conditions favouring reducing and excluding oxidizing chemical processes, and thus none of the sediments can be considered to be source rocks. Source beds may occur in the deeper parts of the basin which are at present covered by the sea.

Reservoir Beds.

The numerous arenaceous beds of the Lower and Upper Arenaceous "Groups" interspersed with marls could be considered reservoir beds if a suitable structure could be located.

Oil Indications and Previous Drilling.

No indications of oil were found within the area by members of the Anglo-Persian Oil Company survey team.

Three test wells were drilled on a monocline near the former village of Kukuia by the Vogel (Papua) Oil Company.

According to the drilling log of the first well, gas and oil traces were observed at a depth of 147 feet. The well was abandoned at 180 ft. because a driller poured oil into the hole.

The second hole was drilled close to the first, and was abandoned at 1,018 ft. owing to fishing troubles. This well started 8,000 ft. below the top of the sedimentary series and finished at least 4,000 ft. above the base of the Lower Arenaceous Group. According to the drilling log gas was located between 221-232 ft., 391-396 ft, 457-461 ft, 472-568 ft, and at 609 ft, while traces of light violet oil were observed between 568 and 605 ft and again at 622 ft. No samples of oil were collected and Papp and Nason-Jones of the Anglo-Persian Oil Company (1920-1929) were unable to verify the reports by soxhlet extraction of bore samples.

The third well was drilled at a distance of 500 ft. to the south-west of the former site. The object was to establish the bona fides of oil-traces reported in the second well. The depth reached was 217 ft. and the presence of gas was reported at 150 ft.

CONCLUSIONS.

The thick development of non-marine sediments and their predominantly arenaceous character; the absence of any surface indications of oil; the absence of any proven occurrence of oil in the three test wells; and the long history of volcanic activity; all lead to the conclusion that the area has only slight petroleum prospects and does not justify exploration at this stage.

ACKNOWLEDGEMENTS

The authors wish to express their thanks to the Officer in charge of Land Research and Regional Survey Section, C.S.I.R.O., for allowing them to use information collected during survey of Buna-Kokoda Area, of North-eastern Papua, in preparation of this paper.

They are also indebted to Dr. M.F. Glaessner for comments on faunal determinations, reading the manuscript and helpful suggestions.

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TABLE I.

STRATIGRAPHY OF THE CAPE VOGEL BASIN

NORTHERN SECTION

Buna - Kokoda Area.

Age.	Formation	Description	Approximate thickness
Recent	Mt. Lamington Volcanics.	Poorly consolidated andesitic ash and agglomerate, hornblende-augite andesite, hornblende-biotite andesite, hypersthene-augite-biotite andesite and lamprophyric andesite flows and coulees.	5,000 ft.
Recent to Pleistocene		Alluvial-deltaic deposits - unconsolidated gravel, sand and silt with beach ridges containing concentrates of augite, hornblende and magnetite.	
Pleistocene	Hydrographer Range Volcanics.	Andesitic tuff and agglomerate, augite basalt, augite andesite, augite-hypersthene andesite, biotite-hypersthene andesite and lamprobolite andesite flows.	6,000 ft.
		A N G U L A R U N C O N F O R M I T Y.	
Pliocene	Mamama Formation	Greyish mauve carbonaceous sandstones, mudstones and laminated shale; fine and coarse conglomerates containing pebbles of basalt and serpentinized peridotite.	100 ft.
		D I S C O N F O R M I T Y.	
Miocene "f_{1-2}" (Burdigalian)	Robinson Bay Limestone	White, grey and pale pink, massive algal and foraminiferal detrital limestones containing: Austrotrillina howchini, Borelis pygmea, B. haueri, Miogypsina kotoi, Miogypsinoides dehaarti, Lepidocyclina (N) ferreroi, L. (N) angulosa, L. (N) sumatrensis, L. (N) inflata, L. (N) verrucosa, L. (N) rutteni, L. (N) verrucosa, L. (N) cf. verbeeki, Flosculinella bontangensis, Alveolinella fennemai, Linderina sp. indet.	400 ft.

TABLE I (Cont'd)

Age.	Formation	Description	Approximate thickness
Miocene "f_{1-2}" (Burdigalian) possibly also Pre-Burdigalian	Iauga Formation	Olivine and augite basalts, augite andesite, quartz microdiorite, agglomerate, andesitic tuffs, and tuffaceous sandstone.	2,000 ft.
		A N G U L A R U N C O N F O R M I T Y	
Mesozoic ?	Ajura Kiljala Complex.	Peridotite, dunite, olivine gabbro, olivine-hupersthene gabbro, hornblende gabbro, augite norite and hypersthene dolerite.	
Palaeozoic ?	Owen Stanley Metamorphics.	Quartz-muscovite-chlorite gneiss, garnetiferous calc-silicate rock, calc-silicate rock, calc schist, glaucophane-cordierite schist.	

TABLE II

STRATIGRAPHY OF THE CAPE VOGEL BASIN

CENTRAL SECTION

Cape Vogel Peninsula.

After Papp and Nason-Jones.

Age	Formation	Description	Approximate thickness
Recent to Pleistocene		Fringing reef-platforms and alluvial deposits.	
		ANGULAR UNCONFORMITY	
Pleistocene to Pliocene		Well bedded calcareous sandstone alternating with hard and compact and sometimes porous limestone forming terraces and broad upland plateaux and lying unconformably as outliers on igneous rocks.	240 ft.
		UNCONFORMITY	
Pliocene to Miocene	Upper Arenaceous "Group" Sub-Group C.	Sandstone and marl with plant remains, mulluscs and gastropods, ill-consolidated conglomerate, occasional tuff and gravelly sandstone containing igneous pebbles.	400 ft.
	Sub-Group B	Thin bedded white laminated silicified marl and few hard, thin grey limestone bands containing ill-preserved shell remains, fish scales, plant remains passing upwards into grey and brown marl and conglomerate of silicified white marl pebbles, together with beds of grey marl breccia.	500 ft.
	Sub-Group A.	Soft yellow and brown sandstone and marl containing brackish and fresh water gastropods, molluscs, plant remains and shark teeth, together with concretionary marl and brown marl containing igneous and green tuff pebbles and grey marl nodules.	3,700 ft.
Upper Miocene	Lower Arenaceous "Group"	Predominantly coarse and fine grained sandstone, often current bedded and containing lenses of hard white marl, with intercalated tuff and agglomerate, breccia, conglomerate, soft brown and white sandy marl rich in plant remains and shell fragments, blue,blue-grey marl and dark-grey and brown marl rich in plant remains and freshwater gastropods with occasional thin bands of lignite. Laminated silicified marl at the base.	8,000 ft.

TABLE II (Cont'd)

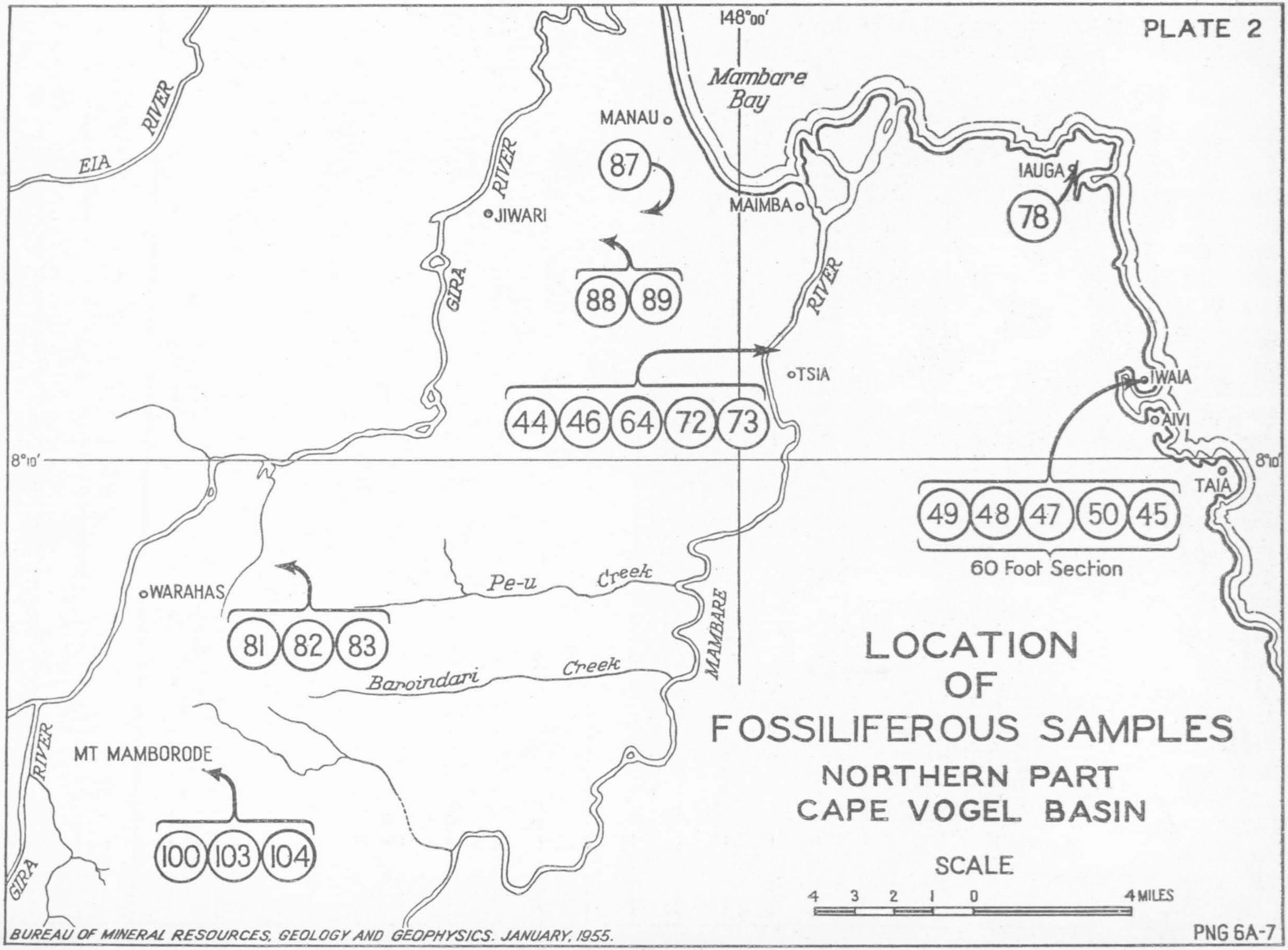
Age	Formation	Description	Approxima[te] thicknes[s]
Middle Miocene	White Marl "Group"	Thin bedded white and cream. soft, saponaceous marls containing molluscs, crab and fish scales and well preserved echinoids.	800 ft.
	INTRUSIVE AND EXTRUSIVE		
Late Tertiary		Andesitic, basaltic, trachitic and porphyritic lavas, volcanic agglomerate, complomerate, breccia, green and white tuff, perlite and lapilli.	

TABLE III
DISTRIBUTION CHART OF LARGER FORAMINIFERA IN THE NORTHERN PART OF CAPE VOGEL BASIN

Sample No.

Foraminifera	78	83	82	81	100	103	104	45	50	47	48	49	44	46	64	72	73	87	88	89
"Assilina" cf. orientalis Douville	f																			
Borelis haueri (d'Orb.)	f					r	f													
B. pygmea Hanzawa	r																			
Miogypsinoides dehaarti Van der Vlerk	v																			
M. sp. indet	v																			
Miogypsina kotoi Hanzawa		r	v	f	r			f	f	f	c	f	r		f	a	f	f	r	r
Austrotrillina howchini (Schlumberger)						v	v					v	v			v				
Flosculinella bontangensis (Rutten)	v																			
F. sp. indet	v																			
Alveolinella fennamai Checchia-Rispoli	r																			
Operculinella sp. indet.	f														v					
Linderina sp. indet.								v	v	v	v	v								v
Sorites sp. indet.																v	v			
Lepidocyclina (N) verrucosa Scheffen								v								r				
L.(N) ferreroi Provale								v					v		v	v	v			
L.(N) angulosa Provale								v								v				
L.(N) cf. verbeeki New & Holland		r								r									f	
L.(N) sumatrensis Brady			v							v	v	v							v	
L.(N) cf. rutteni Van der Vlerk		v																		
L.(N) rutteni lauensis Cole	v																			
L.(N) inflata Provale												v								
L.(N) sondaica Yabe & Hanzawa												v								
L.(N) melanesiana Hanzawa									r			r								
Cycloclypeus spp.	r			r					r	v	r	r			r					r
Amphistegina spp.	r	r	r	r	v					f	f	c	v	r	r	r	f	r	r	v
Carpenteria sp. indet.					r			f	f	r	r				r					

v - very rare; r - rare; f - frequent; c - common; a - abundant.


148°00'
PLATE 2
Mambare Bay
MANAU
87
EIA
RIVER
RIVER
JIWARI
GIRA
MAIMBA
IAUGA
78
88
89
RIVER
TSIA
44
46
64
72
73
IWAIA
AIVI
8°10'
8°10'
TAIA
49
48
47
50
45
60 Foot Section
WARAHAS
Pe-u
Creek
MAMBARE
81
82
83
Baroindari
Creek
LOCATION
OF
FOSSILIFEROUS SAMPLES
NORTHERN PART
CAPE VOGEL BASIN
RIVER
MT MAMBORODE
GIRA
100
103
104
SCALE
4 3 2 1 0 4 MILES
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS. JANUARY, 1955.
PNG 6A-7

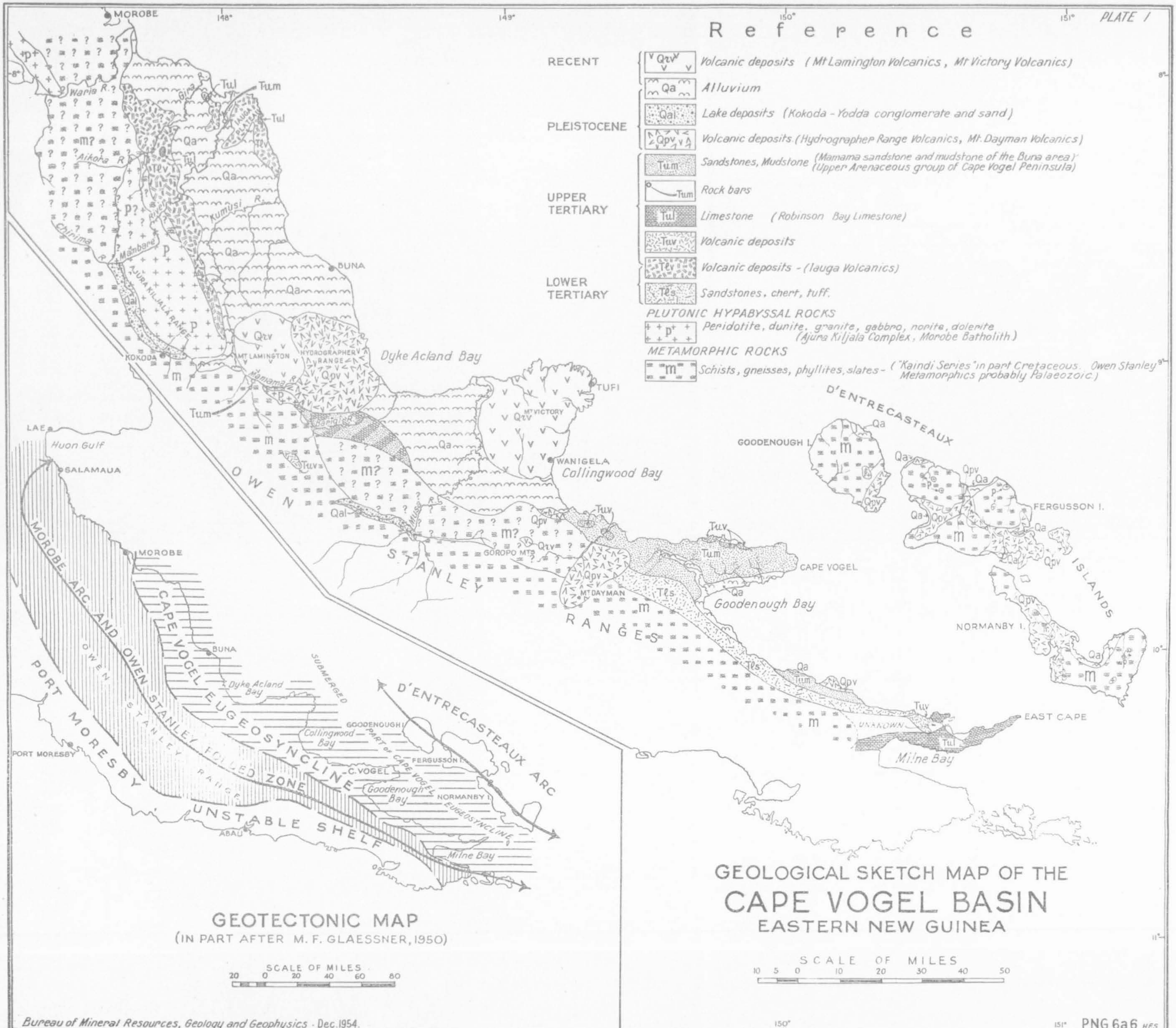


PLATE I
Reference
RECENT
Qtv Volcanic deposits (Mt Lamington Volcanics, Mt Victory Volcanics)
Qa Alluvium
PLEISTOCENE
Qal Lake deposits (Kokoda - Yodda conglomerate and sand)
Qpv Volcanic deposits (Hydrographer Range Volcanics, Mt Dayman Volcanics)
UPPER TERTIARY
Tum Sandstones, Mudstone (Mamama sandstone and mudstone of the Buna area) (Upper Arenaceous group of Cape Vogel Peninsula)
Tum Rock bars
Tul Limestone (Robinson Bay Limestone)
Tuv Volcanic deposits
LOWER TERTIARY
Tev Volcanic deposits - (Iauga Volcanics)
Tes Sandstones, chert, tuff.
PLUTONIC HYPABYSSAL ROCKS
p Peridotite, dunite, granite, gabbro, norite, dolerite (Ajura Kiljala Complex, Morobe Batholith)
METAMORPHIC ROCKS
m Schists, gneisses, phyllites, slates - ("Kaindi Series" in part Cretaceous. Owen Stanley Metamorphics probably Palaeozoic.)
MOROBE
148°
149°
150°
151°
8°
9°
10°
11°
Waria R.
Aikora R.
Chirima R.
Mambare R.
Kumusi R.
AJURA KIJALA RANGE
IAUGA PLATEAU
BUNA
KOKODA
MT LAMINGTON
HYDROGRAPHER RANGE
Dyke Acland Bay
TUFI
MT VICTORY
WANIGELA
Collingwood Bay
LAE
Huon Gulf
SALAMAUA
OWEN STANLEY RANGES
GOROPO MTS
MT DAYMAN
CAPE VOGEL
Goodenough Bay
D'ENTRECASTEAUX ISLANDS
GOODENOUGH I.
FERGUSSON I.
NORMANBY I.
EAST CAPE
UNKNOWN
Milne Bay
MOROBE
BUNA
PORT MORESBY
ABAU
MOROBE ARC AND OWEN STANLEY FOLDED ZONE
CAPE VOGEL EUGEOSYNCLINE
OWEN STANLEY RANGE
PORT MORESBY UNSTABLE SHELF
SUBMERGED
D'ENTRECASTEAUX ARC
PART OF CAPE VOGEL EUGEOSYNCLINE
Dyke Acland Bay
Collingwood Bay
GOODENOUGH I.
FERGUSSON I.
C. VOGEL
Goodenough Bay
NORMANBY I.
Milne Bay
GEOTECTONIC MAP
(IN PART AFTER M. F. GLAESSNER, 1950)
SCALE OF MILES
20 0 20 40 60 80
GEOLOGICAL SKETCH MAP OF THE
CAPE VOGEL BASIN
EASTERN NEW GUINEA
SCALE OF MILES
10 5 0 10 20 30 40 50
Bureau of Mineral Resources, Geology and Geophysics - Dec. 1954.
PNG 6a6 HES

NOTE ON THE TERTIARY SUCCESSION AND FORAMINIFERA OF MANUS ISLAND.

by

F. M. Kicinski and D.J. Belford

During the reconnaissance survey carried out in 1952 by Mr. J.E. Thompson, Senior Geologist of the Bureau of Mineral Resources, four traverses were made across the Island and established the following sequence (in descending order):

Raised coral reefs
Volcanic tuffs and flows
Marine tuffaceous siltstones with volcanic tuffs and flows
Hinterland Limestone
Plutonic basement

Because of the lack of good exposures, and unreliable dips, no stratigraphical thicknesses could be obtained.

Samples of the limestones and tuffaceous siltstones were subsequently sent to Canberra and their microfauna examined by the authors.

Following is the list of the faunal determinations:

Sample No. R.5952 (M2) from Kawaliap

Dense fine-grained algal and foraminiferal limestone
Miogypsina kotoi Hanzawa
Lepidocyclina sp.
Gypsina globulus Reuss
Operculinella sp.
Amphistegina sp.
Planorbulinella sp.
Carpenteria sp.

Sample No. R.5953 (M3) from Tawi

Fine-grained detrital limestone
Lepidocyclina cf. *sumatrensis* Brady
Gypsina globulus Reuss

Planorbulinella sp.

Cycloclypeus sp.

Amphistegina sp.

Operculinella sp.

Sample No. R.5954 (M4) from Kawaliap

Coarse detrital limestone

Miogypsina kotoi Hanzawa

Lepidocyclina cf. martini Schlumberger

Gypsina globulus Reuss

Lepidocyclina ferreroi Provale

Amphistegina sp.

Carpenteria sp.

Planorbulinella sp.

Operculinella sp.

Four samples of tuffaceous siltstone, Nos. R.5955-5958 (M5-M8), were examined, and the faunal assemblage found to be similar in each. Species identified are as follows:

Abundant large tests:
- Orbulina universa d'Orbigny
- Globigerina triloba Reuss
- Globigerinoides sacculiferus (Brady)
- Globorotalia menardi d'Orbigny

G. scitula (Brady)

Allomorphina trigona Reuss

*Bolivinita quadrilatera (Schwager).

Cassidulina crassa d'Orbigny

C. laevigata d'Orbigny

C. murrhyna (Schwager).

C. pacifica Cushman.

*C. subglobosa Brady

*Cibicides pseudoungerianus (Cushman)

Eponides umbonatus (Reuss)

*Gyroidina soldanii d'Orbigny

G. cf. orbicularis d'Orbigny

Osangularia culter (Parker and Jones)

*Planulina wullerstorfi (Schwager).

Pleurostomella brevis Schwager

Pullenia bulloides d'Orbigny

Pulleniatina obliquiloculata (Parker and Jones)

*Sigmoilina schlumbergeri Silvestri

Siphogenerina dimorpha (Parker and Jones)

S.striata (Schwager)

*Siphonina tubulosa Cushman

*Sphaeroidina bulloides d'Orbigny

Sphaeroidinella seminulina (Schwager)-

*Uvigerina crassicostata Schwager

U.proboscidea Schwager

The distinctive fauna of the limestones is as follows:

Miogypsina kotoi Hanzawa. Originally described from Taiwan, Formosa (Kaizan Beds), and assigned to the "f-3" stage of the Dutch "letter" classification. Tan Sin Hok (3), considering the occurrences of the species in East Indies, is of the opinion that its range is lower "f" stage. This is confirmed by the range of this form in Western Papua (unpublished reports of the Australasian Petroleum Co., and Island Exploration Co.), where it is associated with Austrotrillina howchini Schlumberger, Lepidocyclina (N.) sumatrensis Brady, Lepidocyclina (N.) angulosa Provale, and L.(N) ferreroi Provale.

Lepidocyclina (N.) ferreroi Provale. Occurs commonly in lower "f" and uppermost "e" stages and in lower "f" stage in Papua.

Summarising, the fauna of the Hinterland Limestone appears to indicate clearly the lower "f" stage (=Burdigalian of the European Standard Classification).

The species of smaller foraminifera marked with an asterisk in the above list have a local correlative value in the Upper Purari Era River Area in Papua, where they occur in assemblages of the "f3" stage (middle Miocene), although they are not restricted to this stage, occurring also in "g" stage and even higher. In view of the distance between these two areas it is not intended to make any precise correlation, but it is suggested that this fauna may be placed within the boundaries of the "f_3" and "g" stages of the Dutch "letter" classification.

Two species, namely <u>Cassidulina murrhyna</u> (Schwager) and <u>Sphaeroidinella seminulina</u> (Schwager), are listed by Glaessner (1, p.68) as restricted to Miocene in the Indo-Pacific Region.

There are no field observations regarding the nature of the contact between Hinterland Limestone and the overlying siltstone. The abrupt disappearance of the larger foraminifera (<u>Lepidocyclina</u> and <u>Miogypsina</u>, which extend up to the top of the "f_3" stage elsewhere) suggests a faunal break. A period of non-deposition and probably denudation may justifiably be postulated at the end of "f_{1-2}" stage and early "f_3" stage.

In conclusion the following stratigraphical succession of the Manus Island Cainozoic is suggested.

QUATERNARY		Raised Coral Reefs Volcanic Tuffs & Flows ?
PLIOCENE		Non deposition ? ?
	"g" stage (Pontian, Sarmatian)	Marine tuffaceous siltstones with volcanic tuffs & flows ?
	"f_3" stage (Tortonian, Helvetian)	
	"f_{1-2}" stage (Burdigalian)	Suggested non deposition ? Hinterland Limestone
PALAEOZOIC (?)		Plutonic basement

The writers are indebted to Mr. J.E. Thompson for permission to publish his geological map of Manus Island and to Dr. M.F. Glaessner for valuable comments.

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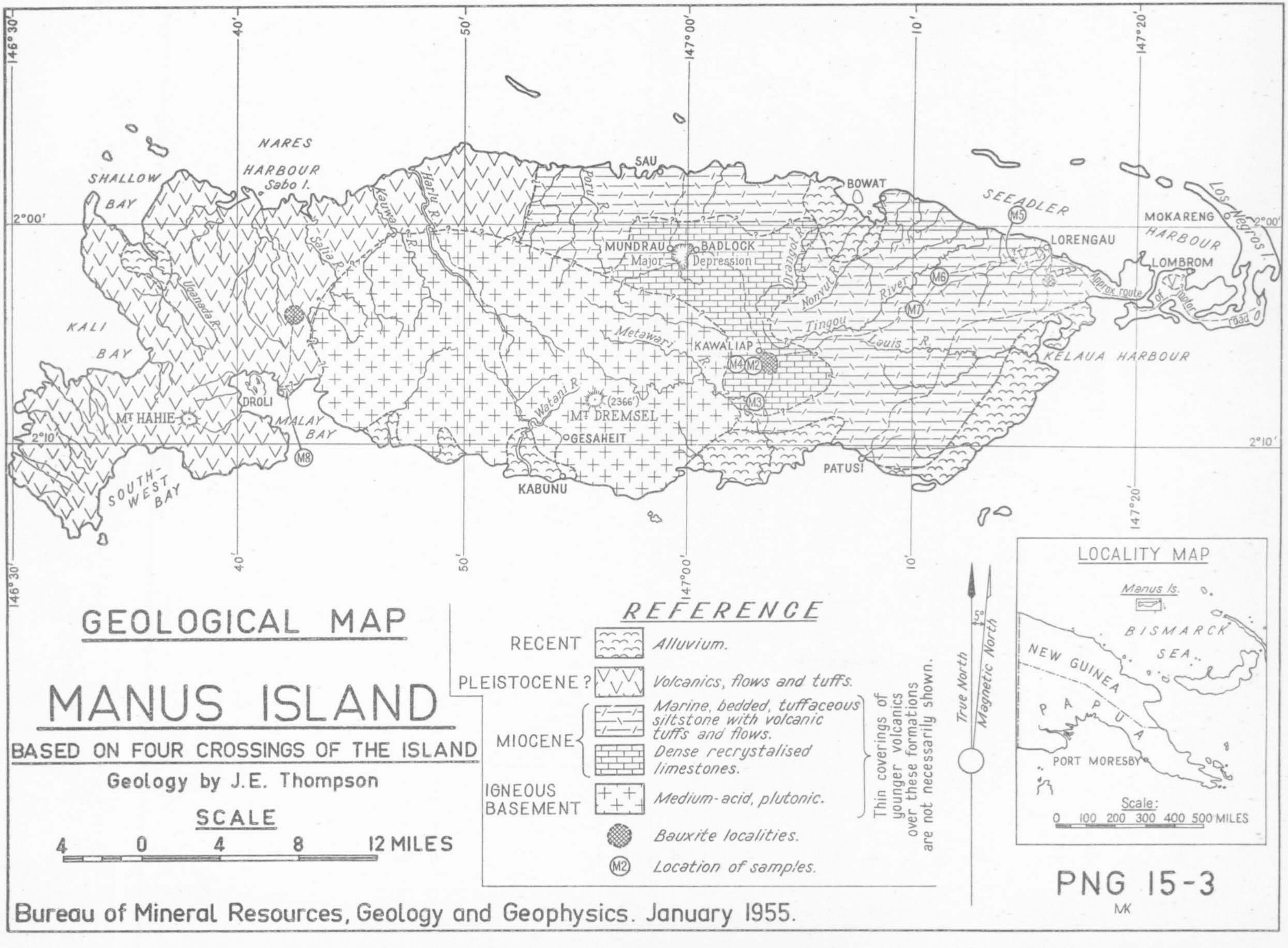
GEOLOGICAL MAP
MANUS ISLAND
BASED ON FOUR CROSSINGS OF THE ISLAND
Geology by J.E. Thompson
SCALE
4 0 4 8 12 MILES
REFERENCE
RECENT
Alluvium.
PLEISTOCENE ?
Volcanics, flows and tuffs.
MIOCENE
Marine, bedded, tuffaceous siltstone with volcanic tuffs and flows.
Dense recrystalised limestones.
IGNEOUS BASEMENT
Medium-acid, plutonic.
Bauxite localities.
M2
Location of samples.
Thin coverings of younger volcanics over these formations are not necessarily shown.
True North
Magnetic North
5°
LOCALITY MAP
Manus Is.
BISMARCK SEA
NEW GUINEA
PAPUA
PORT MORESBY
Scale:
0 100 200 300 400 500 MILES
PNG 15-3
MK
Bureau of Mineral Resources, Geology and Geophysics. January 1955.
146°30'
40'
50'
147°00'
10'
147°20'
2°00'
2°10'
NARES HARBOUR
Sabo I.
SHALLOW BAY
KALI BAY
SOUTH-WEST BAY
MALAY BAY
DROLI
Mt HAHIE
M8
Uganda R.
Salia R.
Kauwa R.
Harlu R.
Poru R.
SAU
BOWAT
SEEADLER HARBOUR
M5
LORENGAU
MOKARENG
LOMBROM
Los Negros I.
MUNDRAU Major
BADLOCK Depression
Drangot R.
Nonvut R.
M6
M7
Tingou River
Louis R.
Approx. route of motor road
KELAUA HARBOUR
Metawari R.
KAWALIAP
M4
M2
M3
Watani R.
(2366')
Mt DREMSEL
GESAHEIT
KABUNU
PATUSI

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NOTE ON THE OCCURRENCE OF SOME TERTIARY LARGER FORAMINIFERA ON BOUGAINVILLE ISL. (SOLOMON ISLANDS).

by

F. M. Kicinski

During the two trips to Mt. Balbi (Bougainville) made in 1950 by Mr. G.A. Taylor, Vulcanologist of the Bureau of Mineral Resources, and in 1951 by the late Mr. A.K.M. Edwards, Senior Geologist, a few limestone samples were collected which added to the knowledge of the distribution of Tertiary Indo-Pacific Foraminifera.

The sample collected by Mr. Edwards from the Wakunai River Est of Mt. Balbi (No MF 969), a compact pink limestone, yielded:

- Spiroclypeus sp. indet. (abundant)
- Lepidocyclina (N) perornata Douville (abundant)
- Lepidocyclina (N) cf. verbeeki Newton & Holland (abundant)
- Miogypsinoides sp. indet.

Spiroclypeus ranges in the Indo-Pacific Region from "b" to "e" stages (of the Dutch "letter" classification) inclusive. Miogypsinoides is known only from "e" and "f_{1-2}" stages, and the same range is given by Caudri (1939) for Lepidocyclina preornata.

This fauna belongs to "e" stage (Aquitanian).

Three samples collected by Mr. Taylor (Nos R6686-6688) on the track between the Sisivi and Lesopaia villages (11 miles South-East from Mt. Balbi) are grey compact silty limestones containing:

- Lepidocyclina (N) verrucosa Scheffen (frequent)
- Gypsina globulus Reuss (frequent)
- Elphidium craticulatum Fichtel & Moll (v.rare)
- Operculinella sp. indet (common)

The only diagnostic form in this assemblage is Lepidocyclina verrucosa. It was described from Java, where it ranges from the upper "e" to "f_2" stage inclusive. In Eastern Borneo and Papua it occurs abundantly in the "f_2" stage associated with L.(N) angulosa Provale, L.(N) inflata Provale and L.(N) sumatrensis Brady.

This assemblage most likely represents the lower "f" stage (Burdigalian).

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