# A REVISION OF THE STARFISH GENUS *UNIOPHORA* (ASTEROIDEA; ASTERIIDAE)

## BY S. A. SHEPHERD*

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## INTRODUCTION

The genus *Uniophora* is a prominent and distinctive representative of the seastars of temperate Australian waters having a distribution around the coast of the southerly half of the continent from Collaroy Reef near Sydney on the east coast to Lancelin Island in Western Australia.

The members of the genus are extremely variable and have long been a source of perplexity to taxonomists. Lamarck (1816) described *Asterias granifera* from Tasmania and Gray (1841) created the genus *Uniophora* naming *U. globifera* from New South Wales. Perrier (1875) described *Asterias nuda* from Pt. Lincoln, South Australia, *Asterias fungifera* from "Nouvelle Hollande" and *Asterias sinusoida* from Hobart, Tasmania. The species of Lamarck and Perrier were all subsequently placed in the genus *Uniophora*. In 1923 Clark added *U. dyscrita* from Western Australia and in 1928 *U. gymnonota, U. multispina, U. obesa* and *U. uniserialis* all from Spencer or St. Vincent Gulfs, South Australia. Subsequent shore collecting (Cotton and Godfrey, 1942) showed that of the ten species, certainly eight and probably nine were to be found in the gulfs of South Australia.

This paper is largely the result of collecting by the author with SCUBA diving apparatus over a number of years. The examination of the considerable material so gathered shows that the supposed speciation of the genus in the South Australian gulfs does not exist, and it is believed that there are only two species in South Australian seas.

The collections of the Australian Museum, the National Museum of Victoria and the Western Australian Museum have been examined; the forms from Victoria, New South Wales and Tasmania are considered conspecific with *U. granifera* but the Western Australian form *U. dyscrita* is regarded as specifically distinct. Differences between the several forms are discussed and spine

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counts are used to determine statistical differences between population samples. This method is believed to be novel in the study of asteroids. Geographical and ecological notes are also given and a map showing the distributions of the various forms in the gulf regions is added.

In this paper the following abbreviations are used: A.M., Australian Museum; N.M.V., National Museum of Victoria; S.A.M., South Australian Museum. W.A.M., Western Australian Museum.

### UNIOPHORA GRANIFERA Lamarck

*Asterias granifera* Lamarck, 1816, p. 560.
*Uniophora globifera* Gray, 1840, p. 288.
*Asterias fungifera* Perrier, 1875, p. 337.
*Asterias sinusoida* Perrier, 1875, p. 338.
*Uniophora sinusoida* Clark, 1928, p. 411.
*Uniophora obesa* Clark, 1928, p. 409.
*Uniophora uniserialis* Clark, 1928, p. 413.
*Uniophora multispina* Clark, 1928, p. 407.
*Uniophora multispina multispina* Stach, 1938, p. 332.
*Uniophora multispina uniserialis* Stach, 1938, p. 332.

*Material Examined.* "Granifera" group. S.A.M. (117 specimens) K174-6, K191, K597-8, K600, K629-K641. A.M. (16 specimens) from N.S.W. J.127-8, J.144, J.7444, J.6884, J.7008. From Tas. J.141, J.143, J.168-9, J.5410-5414. N.M.V., 5 specimens labelled Port Phillip Survey. "Multispina" group (98 specimens) S.A.M. K181-3, K185, K187-9, K190, K193. K520-1, K601-2, K605, K628, K635, K643-651.

In 1875 Perrier (1875, p. 342) noted the puzzling diversity of the specimens before him and considered them to comprise four distinct species. Later Fisher (1923, p. 597) referred Gray's *globifera* to the species *granifera*. It is now clear that there is only one species which shows considerable morphological variation both between and within its component populations. The differences in morphology relate principally to the frequency, size and regularity of arrangement of the dorsal spines. The populations examined fall into two groups each of which has its own preferred habitat and finds a distinctive phenotypic expression. One group is called "granifera" as specimens of it have predominantly the characteristics formerly ascribed to *U. granifera* and the other group is termed "multispina" to indicate a similar relationship with the former species *U. multispina.*

### "Granifera" Group

This group is polymorphic and falls into three more or less conspicuous forms. Historically these forms have been treated as three species, namely, *Uniphora granifera, U. sinusoida* and *U. fungifera.* A given population of the group may contain representatives of all three forms but usually there is a preponderance of one form with a few representatives of one or both of the other forms. Where two of the forms are represented in a population there are usually numbers of specimens of intermediate form, and on occasions specimens of one form have been seen with a regenerated arm of another form.

The form first described as *U. globifera* is most commonly encountered and is characterised by swollen and capitate carinal spines. A typical specimen is figured by Clark (1928, p. 404). The carinal series of plates carries up to 25 enlarged capitate spines, frequently placed singly at the apex of each zigzag formed by the outline of the plates. Interspersed between these enlarged spines are a variable number of much smaller capitate spines either singly or in small groups. The dorso-lateral plates have numerous spines of varying size usually

about as large as the smaller spines of the carinal series and these are often irregularly placed. Here and there the spines of the supero-marginal plates are as large as those along the carinal lines.

Specimens from New South Wales which have this form are remarkable for the size of their enlarged capitate carinal spines which are larger than those seen in South Australian specimens. They also differ from the latter in possessing a larger number of smaller capitate spinelets dorsally and on the intermarginal plates. The actino-lateral spines are quite variable; sometimes they are typical but at others more like those in "multispina" group. The specimens were all taken apparently on rocky bottoms and are either from Long Reef, Collaroy, or Sydney Harbour.

A second form which was formerly designated *U. sinusoida* possesses a markedly zigzag carinal series of plates bearing spines which are capitate but not nearly as conspicuous as the globose spines of the previous form. In some specimens it is difficult to detect a carinal series of plates at all and dorsally the spines appear to form the margins of a series of discontinuous polygonal papular areas. The figures of Clark (1928, p. 412) and Stach (1938, p. 382) are quite typical of this kind of specimen.

A number of such specimens have been examined from Port Phillip Bay, Victoria and have less conspicuous dorsal spines than the South Australian specimens while several rather resemble those in "multispina" group. Specimens from the Australian Museum taken in Tasmania are placed in this group with some hesitation. The arrangement of the spines and the general appearance of these specimens are typically *sinusoida*-like but the dorsal spines of some specimens, particularly those taken in D'Entrecasteaux Channel, Tasmania, are fine and pointed as is sometimes the case in "multispina" group.

In some localities there commonly appears a third form which is remarkable for the proliferation of spines dorsally. Instead of enlarged capitate spines occurring singly or in groups of two or three along the carinal series, there are groups of 10 to 20 small and closely appressed, capitate spines, often with the central one much larger than the surrounding ones. These groups of spines are usually contiguous and together appear to form an almost flat dorsal surface. In other respects the specimens do not differ significantly from those previously mentioned. These specimens conform to such a striking degree with Perrier's description of *Asterias fungifera* (1875) that no doubt this form, or something very close to it, is that which is so described. It is to be noted also that Fisher (1926, p. 198) who compared the type specimens of *Asterias fungifera* and *Asterias sinusoida* thought the latter to be a "slenderer and stouter spined example of the same species".

I have only observed "granifera" populations on reefs and rocky bottom. Stach (1938) however, reports several specimens from *Posidonia* beds in the Sir Joseph Banks Group, Spencer Gulf, South Australia, but it is possible that these specimens came from a granitic reef nearby. Some of the specimens from Port Phillip Bay, Victoria, and also from D'Entrecasteaux Channel, Tasmania, also appear to occur on sandy bottom but as indicated previously these specimens are atypical. The form ranges from low water down to about 20 m in depth but is found in greatest abundance in depths between 5 and 10 m; in favourable conditions where the wave action is moderate but not severe two or three specimens may occur to the square metre.

The favourite diet is a small tunicate which abounds on shallow reefs. Very frequently the seastar is found with its rays encircling the tunicate and

protuding its everted stomach into the animal's oral aperture. How it achieves this is not known. Its tube feet clearly could not exert the same force on the tunicate as they could upon the shells of a bivalve. In the latter case the force exerted by each tube-foot on the shell would be cumulative; whereas in the former case, the aperture appears to be controlled by musculature immediately surrounding it and the seastar could bring very few of its tube feet to bear upon these muscles, and hence would exert little force on them. It is possible that the animal discharges a stomach enzyme or toxin which paralyses or narcotizes its prey so enabling it to gain entry. Certainly when the starfish is removed the tunicate is unusually sluggish in closing its aperture. To a lesser degree the seastar has been observed to feed on reef-dwelling univalves and bivalves and on various encrusting ascidians. Specimens taken from shallow water are usually brick-red in colour but occasional ones are seen in which the papular areas are a dark blue. Specimens from deeper water between 15 and 20 m are usually more brightly coloured, ranging from bright red to orange. Orally specimens are red to orange.

### *"Multispina" Group*

Specimens from these populations are distinguishable from those of "granifera" populations by the comparatively regular arrangement of the carinal and dorso-lateral plates and the spines on them. The carinal series carries from 1 to 4 rather small capitate spines to each plate and the series forms a straight line medially on the dorsal surface with a tendency in some specimens to zigzag distally. On each side of this series and parallel with it are two regular dorso-lateral series carrying similar but smaller spines. In some populations the latter series bear spines only sporadically and the supero-marginal series bear them irregularly. The spines themselves vary considerably from being capitate or bluntly pointed to being fine and sharp. Where "multispina" and "granifera" populations intergrade, as is not uncommonly the case, the characteristic differences tend to become obscured.

The forms described by Clark as *U. obesa* and *U. uniserialis* are both well within the range of variability shown by "multispina" races and there can be no doubt as to their synonymy. The figures of Clark (1928, pp. 407, 410 and 412) indicate the remarkable diversity existing in the appearance of specimens.

"Multispina" populations are abundant on the angiosperm beds of *Cymodocia antarctica* Endlicher, *Posidonia australis* Hooker, and *Zostera muelleri* Irmisch characteristic of the coastal margins of the South Australian Gulfs particularly in the less exposed regions. Their principal diet is bivalves and univalves which are abundant in the sand among the fibrous angiosperm roots. Most specimens are dark red in colour but some are lighter, tending to become fawn. This form is commonly found down to 10 m but occasionally specimens have been taken from deeper water and there is an unusual record of 3 specimens from 30 m taken by Mr. R. C. Sprigg off Carickalinga Head in St. Vincent Gulf, South Australia.

### *UNIOPHORA NUDA* Perrier

*Asterias nuda* Perrier, 1875, p. 335.

*Uniophora gymnonota* Clark, 1928, p. 405.

*Material Examined.* S.A.M. (80 specimens) K178-9, K522, K599, K636, K642, K652.

Perrier's type was stated to have come from "Port Lincoln, (detroit de Torres)". A series of specimens taken off Cape Donnington just outside Pt.

Lincoln Harbour, South Australia conforms exactly with Perrier's description and confirms Clark's view (1928, p. 417) of the place of origin of the species.

The species is distinguishable from the "multispina" group by the very small number and size of its spines, and many specimens, save for the adambulacrals, are quite denuded of spines. It is without exception, covered by a thick skin which tends to conceal the existing spines but does not obscure the prominent plates forming the carinal, dorso-lateral and marginal series.

Examination of Clark's type of *U. gymnonota* shows no significant differences between it and the specimens from Cape Donnington. Clark purported to distinguish *U. nuda* from *U. gymnonota* on the ground that the latter did not have any pedicellariae corresponding to those observed by Perrier in the ambulacral groove and which he described in these terms "droit, court, large, en forme de triangle". . . . However there are similar pedicellariae in Clark's type and in many other specimens from the north coast of Kangaroo Island and Spencer Gulf, South Australia and it is concluded that Clark's differentiation was in error.

This species has a greater depth range and diversity of habitat than *U. granifera*. The specimens from Cape Donnington were taken in 16 m from thick beds of the hammer oyster *Malleus meridianus* Cotton. Several specimens were observed feeding on the oyster and this no doubt constituted their principal diet. In Nepean Bay near Kingscote, South Australia in 5-8 m there are large colonies inhabiting the beds of the angiosperms *Zostera* sp. and *Halophila ovalis* (R. Brown) Hooker. There it feeds on bivalves and on small tunicates which find a ready attachment to debris and rocks scattered on the bottom. It also occurs in deeper water off the north coast of Kangaroo Island and in Backstairs Passage, South Australia, in 20 to 40 m on rocky or shellgrit bottoms. In colour the species varies from reddish brown to fawn, the specimens from deeper water being invariably the lighter in colour.

## *UNIOPHORA DYSCRITA* Clark

*Uniophora dyscrita* Clark. 1923, p. 244.

A total of 15 specimens have been examined from the private collection of Dr. E. P. Hodgkin all of which are referred to this species. There are 5 juvenile specimens numbered U.D. 9-13 from deep water (120 to 200 m) and the remainder are from shallow water. The specimens show considerable diversity and one or two approach *U. granifera* (sinusoida form) in appearance; but in the main the species is quite distinctive.

In four specimens numbered U.D. 1-4 from Rockingham and Woodman's Point near Fremantle, Western Australia, the spines on the carinal series are stout at the base and conically pointed. These spines are often 2-3 mm long and 0·5-0·7 mm in diameter at their base, and number from 25-30 along the carinal line. There are also 20 or more much smaller spinelets along the same line. Elsewhere on the dorsal surface there are many fine spinelets up to 0·5 mm long on the plates. One of these (U.D. 1) is shown in Plate 1. These specimens conform to Clark's description except that the carinal series is more evident than appears to be so in the type. In four other specimens numbered U.D. 5-8 from Woodman's Point, Cockburn Sound and Carnac Island, Western Australia, the dorsal spines on the carinal series and elsewhere are predominantly capitate and globose. A few of the spines are rather bluntly pointed. Apparently there is considerable variation in colour in the species. The colour dorsally ranges from dark red to fawn and in some specimens the papular areas are a greenish-brown. Below the colour is orange. Most of the specimens were taken on rocky bottom but several are reported from muddy or sandy bottom.

Two specimens numbered U.D. 14 and 15 present some difficulty by reason of their extraordinary spinulation. One of these, U.D. 14 is shown in Plate 1. They were both taken at the Naval Base, Cockburn Sound, Western Australia. These specimens differ from those described earlier in having few stout spines but many more fine bluntly pointed spinelets often about 1 mm long and 0·5-0·6 mm in diameter, some of which are slightly flattened at their distal ends and somewhat chisel-like. The carinal plates are very sinuous and obscure and with the dorso-lateral plates enclose large polygonal areas devoid of spines. The spines on the carinal plates number from 80-100 on each arm. The marginal spines and actino-lateral spines are not as flattened or as chisel-like as the specimens described above. A few of the actino-lateral spines are divided into two or three short branches but this is not a distinctive feature of the species as Clark asserts (1928, p. 417). It is not considered that the differences in these two specimens are of sufficient magnitude to justify separation and in view of the diversity shown by the other specimen, they are believed to represent at most a variant form. They were reported to have been taken at 3 m depth on *Pinna* from which it may be inferred that their habitat is a sandy or muddy bottom.

The juvenile specimens, the largest of which has $R/r = 22/4$ mm were all dredged off Rottnest Island, Lancelin Island or Cape Naturaliste, Western Australia. It is noteworthy that in one specimen (U.D. 9) the innermost series of actinal plates nearest the adambulacral armature carries 3 spines on each plate. In the other 4 specimens there are only 2 to each such plate. Otherwise there are no notable differences other than those one would expect from juvenile specimens.

The absence of adult specimens from deep water off Western Australia as for South Australia lends credence to the view that this is a shallow water species and that the specimens from deep water are expatriates which having settled there as larvae, do not find favourable conditions for survival to maturity.

The adult specimens show considerable variation in the character of the spines but there is no doubt that they are conspecific. Having regard to their diversity which at one extreme approaches *U. granifera* "granifera" group there exists some doubt whether this form should be given specific status. Taken individually, none of the characters used by Clark (1923, p. 244 and p. 246) in creating the species are reliable and each of them is shown at least in some degree by one or other of the South Australian forms. On the other hand the overall appearance of the majority of specimens is unlike that of any seen from South Australia or elsewhere. The occurrence in some specimens of larger and relatively long pointed spines on the rays and disk is distinctive and the clusters of fine and pointed spinelets on the carinal and dorso-lateral plates in others are unique in the genus. On the whole the species is considered valid.

An endemic distribution in the temperate waters of the lower west coast of Western Australia is indicated from the present material. No specimens have been recorded from the Great Australian Bight. From the brief notes accompanying the specimens the species shows some variability in habitat and may occur on rock, sand, or muddy bottom in depths to 20 m.

### Distribution in the South Australian Gulfs

*Uniophora granifera* is seldom found on exposed coastlines; it prefers protected waters and occurs predominantly along the coastal fringe of gulfs and bays down to about 15 m. Occasionally juveniles with R up to 10 mm have been taken in deeper water of 40-50 m but this environment is apparently unsuitable as larger specimens have never been taken at such depth despite extensive collecting and dredging.

*Uniophora nuda* is found in the protected parts of more open waters but so far has not been taken in St. Vincent Gulf.

Figure 1 indicates the distribution of the species in the Gulfs.

Populations of "granifera" group occur in abundance on the reefs of the eastern coastal margin of St. Vincent Gulf southwards from Glenelg. These reefs are not continuous and colonies of the seastar are geographically separated by

Fig. 1. The distribution of the species in Spencer and St. Vincent Gulfs showing the occurrence of the dominant forms.

stretches of sandy bottom. There are not many representatives of the "sinusoida" form here; the "fungifera" form is dominant at Glenelg, in Holdfast Bay and Halletts Cove but further south the "globifera" form is more common. The population samples are not sufficient to assess accurately the proportions in which the three forms occur. It is noted however that the specimens of the dominant form from any one locality are fairly homogeneous and that there are minor but recognizable morphological differences when a population sample from one place is compared with one from an adjacent colony. The inter-population differences do not appear to follow any pattern of variation and no clines have been detected. The distribution of populations of "multispina" group corresponds with the extent of the beds of *Posidonia* and *Cymodocia* on the coastal margins of St. Vincent Gulf. It is found along much of the western margin of the Gulf but on the eastern margin it is common only to the north of Holdfast Bay; specimens are seldom taken to the south.

Some intergradation between *U. nuda* and "multispina" forms of *U. granifera* has been observed on the north coast of Kangaroo Island near Cape Marsden and about Eastern Cove (Clark, 1928, p. 411) but its extent is not known. The evidence does not suggest that it is at all frequent or widespread. No intergradation has been observed anywhere between *U. nuda* and any forms of "granifera" group even where the two species are found in the same geographical area, although in different ecological niches.

The distribution in Spencer Gulf is still sketchily known. Despite extensive diving no specimens have been taken around the Gambier Islands, the Neptunes, or Thistle Island but they seem to be common enough in the quieter waters further north. In the Sir Joseph Banks Group it appears that *Uniophora granifera* occurs commonly both with the "granifera" and "multispina" kind of spinulation (Stach, 1938, p. 329), and *U. nuda* has also been dredged in deeper water off Spilsby Island.

No specimens of *U. granifera* have been taken west of Spencer Gulf but as little collecting has been done on the west coast of Eyre Peninsula its discovery in suitable localities along that coast would not be surprising. As yet only *U. granifera* "granifera" group has been taken off the coasts of New South Wales, Victoria and Tasmania.

### Differences in Uniophora Colonies

The forms differ basically from each other in the number and nature of the spines, notably those dorsally on the rays. Spine counts therefore seem to offer the best method of presenting the differences statistically despite the irregularity of arrangement of the spines. The spines along the plates of the carinal series from the base of the ray to the tip were counted and the results are expressed in spines per cm to compensate for size variations.

Because of the unpredictable local occurrence of colonies there are not many collections which are sufficiently comprehensive to give reliable statistical definitions of the several populations. For the sake of completeness even small series are analysed so that the data in the following table and Figure 2 comprise the figures for all series of five or more specimens.

The purpose of the statistical record is firstly to show the close relationship between the several forms and secondly to determine the variability within a population and so complete the empirical description of the material. Analysis of the larger population samples shows that the spine-counts follow a normal distribution curve and a comparison of population samples indicates a gradual

## TABLE 1

Geographical occurrence of Uniophora colonies sampled.

| Form | Locality + Depth (in metres) | No. of specimens | Mean size of sample (R) in cm. |
|---|---|---|---|
| (1) *U. nuda* | Cape Donnington—15m. | 5 | 8·3 |
| (2) ,, | Sir Joseph Banks Group—30m. | 6 | 4·3 |
| (3) ,, | Kingscote—Nepean Bay   5m. | 57 | 4·5 |
| (4) ,, | Backstairs Passage—30m. | 5 | 8·8 |
| (5) *U. granifera* ("multispina" group) | Edithburgh—5m. | 28 | 4·5 |
| (6) ,, | Outer Harbour—5m. | 10 | 4·7 |
| (7) ,, | Semaphore—10m. | 17 | 10·2 |
| (8) ,, | Pt. Turton—7m. | 14 | 6·8 |
| (9) *U. granifera* ("granifera" group) | Glenelg Breakwater—5m. | 17 | 7·5 |
| (10) ,, | Halletts Cove—7m. | 7 | 6·0 |
| (11) ,, | Pt. Noarlunga—7m. | 34 | 4·6 |
| (12) ,, | Pt. Willunga—8m. | 21 | 4·0 |
| (13) ,, | Snapper Rock off Cape Donnington—5m. | 6 | 6·4 |
| (14) ,, | Pt. Hughes—5m. | 6 | 4·6 |
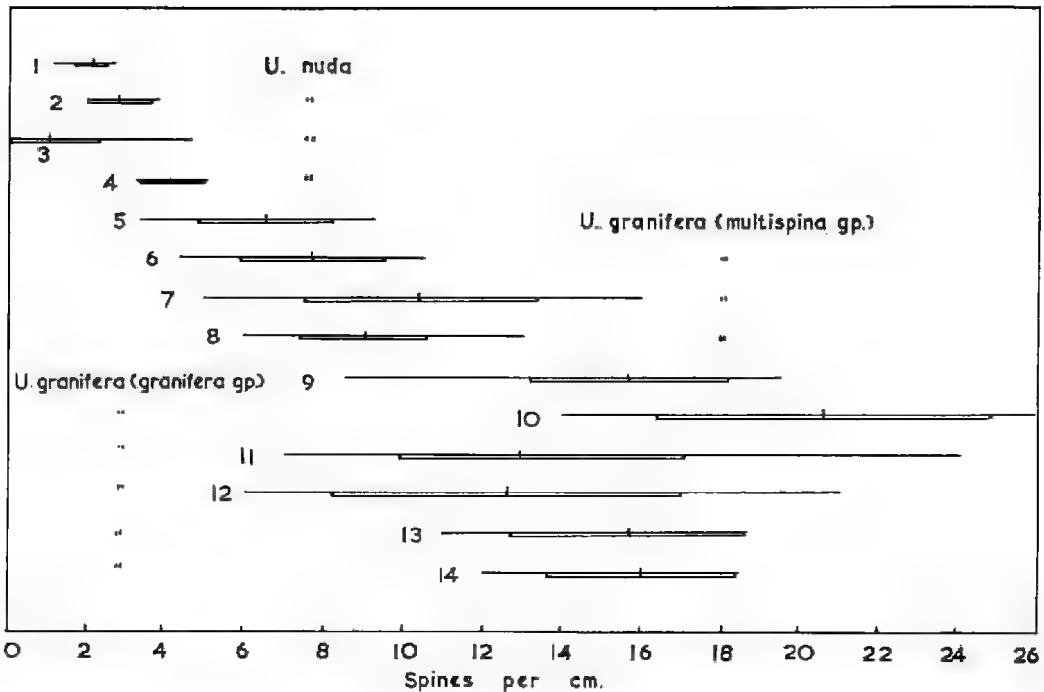


Fig. 2. The graph is a summary of Uniophora carinal spine-counts. In each case the single line represents the range, the rectangle in block one Standard Deviation on either side of the mean, and the vertical line the mean.

increase in spine counts from *U. nuda* to *U. granifera*. Despite the slight overlap between *U. nuda* and *U. granifera* it is considered that the combination of the differences between the two is sufficient to justify specific differentiation. Table 2 summarises the characters which are useful in discriminating between the forms. It is evident at once, that there are no diagnostic characters which can be relied upon as absolute determinants; the characters are all variable and can be used only in conjunction with others to distinguish the forms. Even then the degree of overlap may in some cases cause difficulty. Another problem is that Table 2 is based primarily on the South Australian material so that when the specimens from other States are examined it is found that the character combinations are not quite the same and intermediate degrees of relationship exist. Other characters are referred to in the literature which have been used from time to time as determinants, for example the presence of pedicellariae and pebbled areas in the intermarginal plates, but these are now ignored as they have not been found to be of any significance.

TABLE 2

Major differences between Uniphora species.

| | U. dyscrita | U. nuda | U. granifera | |
| | | | "granifera" gp. | "multispina" gp. |
|---|---|---|---|---|
| Carinal series. i.e. central series of plates dorsally on rays | Zig-zag | Straight, sometimes zig-zag distally | Zig-zag sometimes irregular | Straight, sometimes zig-zag distally |
| Carinal spines Frequency (per cm.) | Capitate or bluntly pointed 9-15 | Inconspicuous fine and pointed 0-5 | Capitate, singly or in groups 8-25 | Capitate sometimes bluntly pointed singly or in groups 4-13 |
| Dorso-lateral spines | Irregularly arranged, often in groups, Smaller and finer than carinals | Absent | Irregularly arranged, or arranged to form polygonal papular areas | Form 1 or 2 regular series each side of carinals |
| Supero-marginal spines | Capitate or flattened terminally | Rare or absent | Capitate | Slightly capitate. Often in groups of 2-3 |
| Actino-lateral spines | Present | Rare or absent | Present | Present |

The considerable increase in spine numbers per cm along the carinal line in "granifera" group as shown in Figure 2 is due partly to the exaggerated development of the characteristic zigzag carinal plates and partly to the increase in spines on the plates. Of the series from St. Vincent Gulf it is noteworthy that the specimens from Port Noarlunga southwards are generally smaller and have fewer and more capitate spines than those further north. The series from Halletts Cove and Glenelg Breakwater shows some intergradation with "multispina" group.

Table 1 also shows the variation in the mean size of adult specimens from the populations sampled. The reason for the diversity in size is not known. It does not appear to be related directly to age as there is no difference in maximum size of specimens collected in one locality at different times of the year and in different years. The seastars are sedentary in habit and it is probable that the type and quantity of food available is an important factor. It is noted for example that the specimens of *U. nuda* from the rich hammer oyster beds off Cape Donnington are considerably larger than the specimens of the same species from the quiet waters of Nepean Bay, Kangaroo Island.
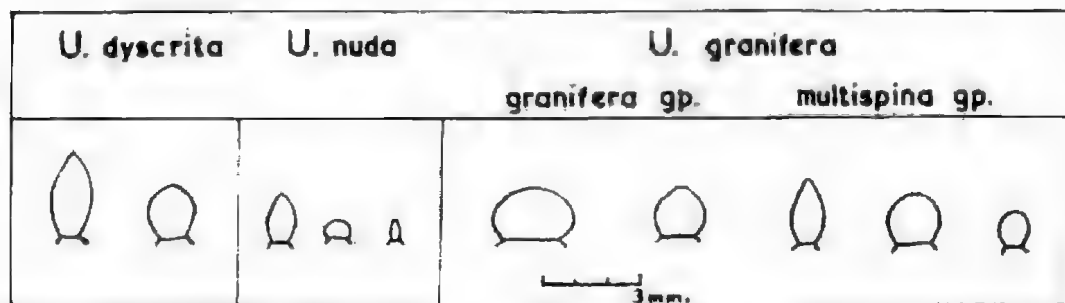


Fig. 8.   Lateral view of prominent carinal spines on rays.

## CONCLUSION

The greater amount of material now available reveals that in the South Australian Gulfs there are two species of *Uniophora*. One of these *U. granifera* contains two component groups of populations, each of which has some peculiarities of behaviour, distribution and morphology. The populations called "granifera" are found on rocky bottom along coasts of moderate wave action whereas "multispina" populations occur on sandy bottom and in calmer water. Specimens having characteristics of both "granifera" and "multispina" have been taken on bottoms of a mixed character. The interesting problem is raised whether the differences in morphology are genetically or ecologically determined, but this cannot be resolved without experimental work.

The existing evidence suggests that *U. nuda* is a distinct species but this view may require reconsideration should intermediate populations be discovered. Whatever the case is, the two species have succeeded in occupying a variety of habitats and so been able to flourish in the Gulf regions in an abundance, which is without rival among the asteroids. There is no evidence of the species achieving the same success elsewhere on the Australian coast.

*Uniophora dyscrita* must be retained as a valid species for the present. There is no record of the species from the Great Australian Bight. It is quite likely that the exposed coasts and long stretches of sandy shore of that region constitute a natural barrier sufficient to prevent gene flow between the South Australian and Western Australian species. (See Womersley and Edmonds, 1958, p. 221, and Jennings, 1963, p. 45.) In view of the known ecological requirements of the species much of this coast would not provide favourable conditions for survival. The differences already visible indicate genetic variation and hence the evolution of separate species.

## ACKNOWLEDGMENTS

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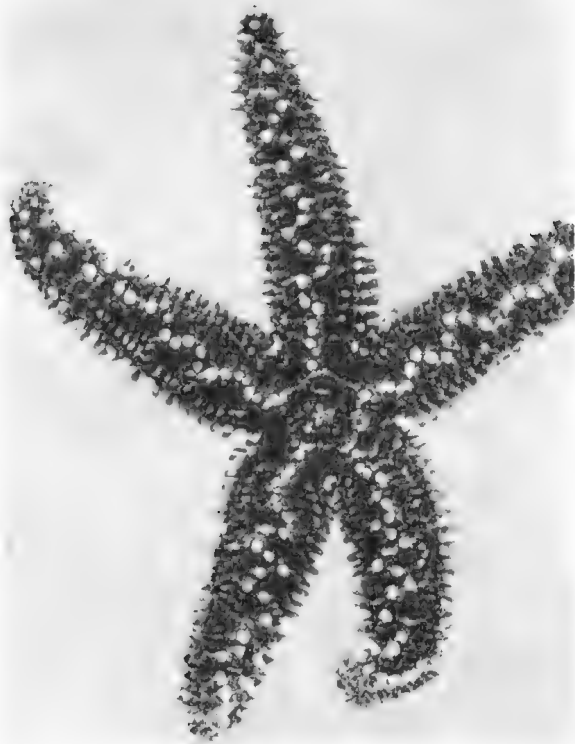WOMERSLEY, H. B. S., and EDMONDS, S. J., 1958. Aust. J. Mar. Freshw. Res., 9, pp. 217-260.

PLATE 1

(1) Dorsal view of specimen of *Uni-ophora dyscrita* numbered U.D. 1 R = 54 mm. Collected R. Howlett on muddy, sandy bottom. Depth 25 ft. Palm Beach Jetty 3/3/60. Rockingham, W.A. (Photo E. P. Hodgkin.)

(2) Dorsal view of specimen of *Uni-ophora dyscrita* numbered U.D. 14 R = 55 mm.
Collected Stn. 61 Naval Base, Cockburn Sound, W.A., among Pinna 10 ft. deep by Marine Gp W.A. Naturalists 10/4/60. (Photo E. P. Hodgkin.)

# PRELIMINARY PALAEOMAGNETIC RESULTS FROM THE ADELAIDE SYSTEM AND CAMBRIAN OF SOUTH AUSTRALIA

*BY J. C. BRIDEN**

## Summary

The natural remanent magnetization (NRM) of some sediments from the Adelaide System and Cambrian of South Australia is reported. In some of the formations, which were studied, notably the Cambrian sequence on Kangaroo Island and the Billy Creek Formation in the Flinders Ranges, directions were consistent with an NRM of Mesozoic or early Tertiary age. It is suggested the NRM in the Cambrian of Kangaroo Island was acquired during a period of slightly elevated rock temperatures and stabilised by cooling to near present day temperatures. In the Marinoan and Cambrian sediments of the Flinders Ranges, the secondary NRM may be due to a surface effect, which resulted in increased grain size of the magnetic fraction.

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by J. C. Briden[*]

(*Communicated by B. Daily*)

[Read 12 September 1967]

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## INTRODUCTION

The natural remanent magnetization (NRM) of some sediments from the Adelaide System and Cambrian of South Australia is reported. In some of the formations which were studied, notably the Cambrian sequence on Kangaroo Island, and the Billy Creek Formation in the Flinders Ranges, directions were consistent with an NRM of Mesozoic or early Tertiary age. It is suggested that the NRM in the Cambrian of Kangaroo Island was acquired during a period of slightly elevated rock temperatures, possibly connected with early Tertiary igneous activity, and was stabilised by cooling to near present-day temperatures. In the Marinoan and Cambrian sediments of the Flinders Ranges, the secondary NRM may be due to a surface effect which resulted in increased grainsize of the magnetic fraction. Results from other formations, in which NRM is weak in intensity and scattered in direction, are reported in brief, because consistency of direction was evident in isolated portions of the sequences; although their significance cannot be assessed with such limited data, they may be important in the light of further work which is in progress in the State.

## SURFACE COLLECTIONS

The procedure in the field was to collect from 1 to 6 *samples* from each *site*. Up to 4 *specimens* were cut from each sample, in which direction and intensity of NRM were measured in the laboratory using an astatic magnetometer. Direction is quoted in terms of declination ($D$) and inclination ($I$, regarded as positive downward from the horizontal) relative to two sets of axes: (1) relative to the present horizontal and meridian ("uncorrected") and (2) after unwinding

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the folding of the beds on the assumption that each phase of folding has been purely rotational ("corrected"). Directions are analysed by the method of Fisher (1953). Stability of NRM is assessed (1) by comparison of the uncorrected mean direction with the present field, (2) by comparing the estimate of precision ($k$) of grouping of directions before and after correction for folding (if corrected directions are more precise, then NRM may be presumed to be older than the folding), and (3) by interpreting the thermal demagnetization characteristics of specimens in the laboratory.

TABLE 1

Summary of palaeomagnetic measurements in the Adelaide System.

| Series | Formation | Locality | Number of Samples | Comments |
|--------|-----------|----------|-------------------|----------|
| MARINOAN | Pound Quartzite equivalent | Railway cuttings through South Hummocks Ranges | 14 | Weak and widely scattered NRM with negative inclinations relative to the present horizontal |
| | ABC Range Quartzite equivalent | | 3 | |
| | Upper Glacial Sequence' | | 5 | |
| | Sandstones and arkoses | Hallett Cove (14 sites) | 35 | 3 sites near middle of sequence consistent. Corrected mean after cleaning at 400°C $D = 191°, I = +39°, k = 5$ |
| | Sandstones | Reynella Quarries (5 sites) | 10 | 4 sites consistent, initial corrected mean $D = 7°, I = +11°, k = 35$ |
| STURTIAN | Brighton Limestone | Reynella Quarries Happy Valley | 3 / 2 | Weak and widely scattered NRM with negative (upward) inclinations relative to the present horizontal |
| | Tapley Hill Slates | Tapley Hill Mt. Barker Road | 5 / 5 | |
| | Sturt Tillite | Lockler Road Quarry | 1 | |
| TORRENSIAN | Stonyfell Quartzite | Greenhill Quarries | 2 | No detectable NRM |

*Adelaide System:* Results are summarised in Table 1. Only in isolated portions of the sections were NRMs consistent. In a small face at the east end of Reynella Quarries, 4 sites in about 5 m of the lowest Marinoan sandstones have a mean direction $D = 7°, I = 11°$ after correction with $k = 32$. A fifth site, only a few metres away in another face, was not in agreement. The coastal section north and south of Hallett Cove was sampled thoroughly, but only at three sites near the northern end of the cove were directions consistent. The increase in precision after thermal cleaning at 400°C and correction for folding ($D = 191°, I = +39°, k = 5$) compared with the uncorrected mean direction of total NRM ($k = 1$) suggests that a relic of stable NRM which is older than the folding may have been preserved.

*Cambrian*: Twenty-three sites were sampled in the Cambrian sequence on the north coast of Kangaroo Island (Daily, 1957). The distinction between the Emu Bay Shale and the equivalent of the White Point Conglomerate near Emu Bay depends on the recognition of a *Redlichia* horizon which also occurs in the Flinders Ranges, not far below the base of the Billy Creek Formation. Because the author did not find the *Redlichia* horizon, 3 sites included with the White Point Conglomerate might strictly belong to the overlying formation. In this context, the distinction is not important because the palaeomagnetism of the Kangaroo Island Group does not vary from formation to formation. All site mean directions except one (near Point Marsden) were significant with 95 per cent probability. Before correction for folding all inclinations were steep, and at all except three sites were directed upwards (in the same sense as the present field, and referred to as "normal"). At 2 sites, however, in the Emu Bay Shale in its eastern section, steep downward inclinations were observed (called "reversed"), and at a third site, nearby, both normal and reversed samples were found. The mean direction after adjustment for the reversed directions, is slightly steeper than the present field (Figure 1) and is more precisely defined than when correction is made for folding (Table 2).

TABLE 2

Analysis of NRM directions in Cambrian sediments from Kangaroo Island.

| | B | D | I | k | n | pole ϕ | λ |
|---|---|---|---|---|---|---|---|
| uncorrected | 22 | 357 | -75 | 27·5 | 6 | 39W | 64N |
| corrected | 22 | 289 | -73 | 7·9 | 11 | — | — |

*B* is the number of significant sites (95 per cent probability);
*a* is the semi-angle of the 95 per cent cone of confidence; (ϕ, λ) is the palaeomagnetic pole.

Initial directions of NRM in the Billy Creek Formation are steeply upwards (Figure 2.) Upon thermal demagnetization, direction changes at most sites (at the north of Lake Torrens, in the Copley-Mount Scott district and between Wirrealpa and Martin Well) are irregular, but tend in general towards a southwesterly direction. At Balcoracana Creek (Figure 3) directions change systematically until, after heating to 500°C and correcting for folding, the mean is horizontal and southwesterly, which is in agreement with that found in other Cambrian rocks in Australia by Irving and Green (1958). This suggests that, although the dominant component of NRM is secondary, in at least part of the formation a relic of more stable NRM is preserved, and it is possible that this is of Cambrian age.

## BORECORE SAMPLES

Measurements of NRM of borecore samples are limited by lack of azimuthal orientation; *inclination* but not *declination* can be measured. Nevertheless such measurements are useful for estimating inclination in areas where rocks at the surface have been remagnetized, since it is possible that primary magnetization might have been preserved at depth. Briden and Ward (1966) devised a method of estimating mean inclination and Fisherian precision from a collection of borecores, which has been used in analysing results from South Australia and the Northern Territory (Table 3). A vertical mark was made on each sample, and two discs were cut from each, so that consistency of NRM direction within a sample could be tested; when differences exceeded 30°, results were discarded.

TABLE 3

Analysis of inclination of NRM in borecores.

$B$ is the number of consistent samples; $\lambda_p$ is the palaeolatitude.

| Borehole and location | | Age | $B$ | $I$ | $k$ | $\lambda_p$ |
|---|---|---|---|---|---|---|
| BMR/GRG No. 7 (136·1°E, 22·3°S) | | Upper Cambrian | 8 | −15 | 85 | 9 |
| BMR/GRG No. 5 (135·2°E, 21·3°S) | | Upper Cambrian | 8 | −42 | 21 | 24 |
| Minlaton No. 1 (137·7°E, 34·8°S) | | Lower Cambrian | 13 | −55 | 5 | 35 |
| Wilkatana No. 1 (138·0°E, 32·2°S) | 1340-1750 ft. | Upper Marinoan | 21 | −85 | 25 | 80 |
| | 1750-1845 ft. | | 5 | −41 | 20 | 24 |
| Clarence River No. 1 (136·5°E, 31·1°S) | | Lower Marinoan | 23 | −36 | 6 | 20 |



(a)

(b)
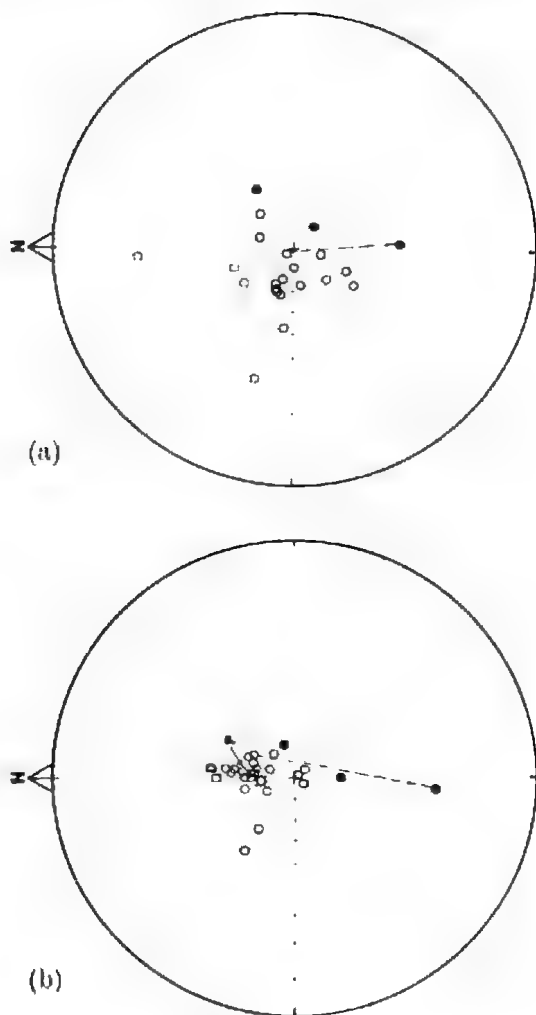
Fig. 1. Site mean directions and thermal demagnetization of NRM in Cambrian sediments from Kangaroo Island. (a) Stereographic projections of uncorrected (left) and corrected (right) directions. At one site where polarity is mixed, the means of both normal and reversely magnetized samples are shown, and are joined by the broken line. The mean NRM direction is denoted by a star, with the circle of 95 per cent confidence around it. The directions of the present and axial dipole fields are denoted by $P$ and $D$. (b) Thermal demagnetization curves of samples KI5, KI19, KI57; intensities (m) are normalized by dividing by the total NRM intensity ($M_0$). Open symbols denote upward and solid symbols downward inclinations.

In the Wilkatana No. 1 bore, there is an abrupt change in inclination at about 1,750 ft, so the groups above and below that level have been analysed separately. In Clarence River No. 1, inclinations are in two groups (Figure 4) with moderate positive and negative inclinations respectively. This suggests not merely a large scatter of directions, but rather that some of the cores have been marked the wrong way up. (An alternative explanation in terms of reversals of NRM is not considered plausible because there is no discernible stratigraphic pattern in the distribution of the two groups.) From the mean inclinations, the palaeolatitude ($\lambda_p$) of each borehole is calculated on the assumption of a geocentric dipole field from the relation

$$\tan I_b = 2\tan\lambda_p$$

and the results are compared on a map of palaeomagnetic poles (Figure 5) with results from other Australian rocks.
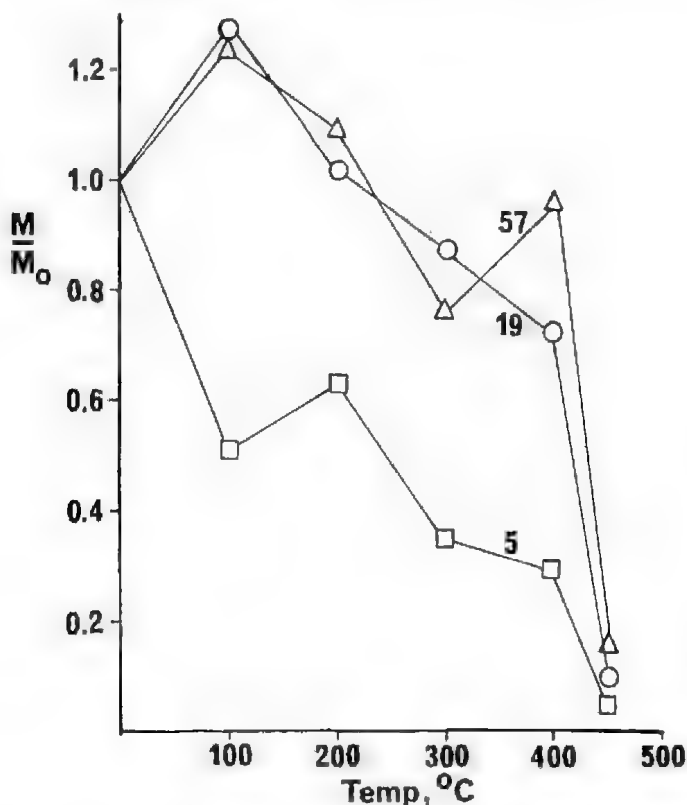


## DISCUSSION OF THE ORIGIN OF SECONDARY NRMs

Thermal demagnetization curves of the Billy Creek Formation and Emu Bay Shale (Figures 1 and 3) are similar to those of ancient secondary magnetizations in the Bloomsburg red beds (Irving and Opdyke, 1965) and the Old Red Sandstone (Chamalaun, 1964). The hypothesis which is proposed for their origin is that they were acquired in the Earth's field over a long period (say $10^4$ years) after which the effective relaxation times of the magnetic grains were increased. This has the effect of "freezing-in" the NRM so that it may be stable over millions of years at normal temperatures. Increase in relaxation time may
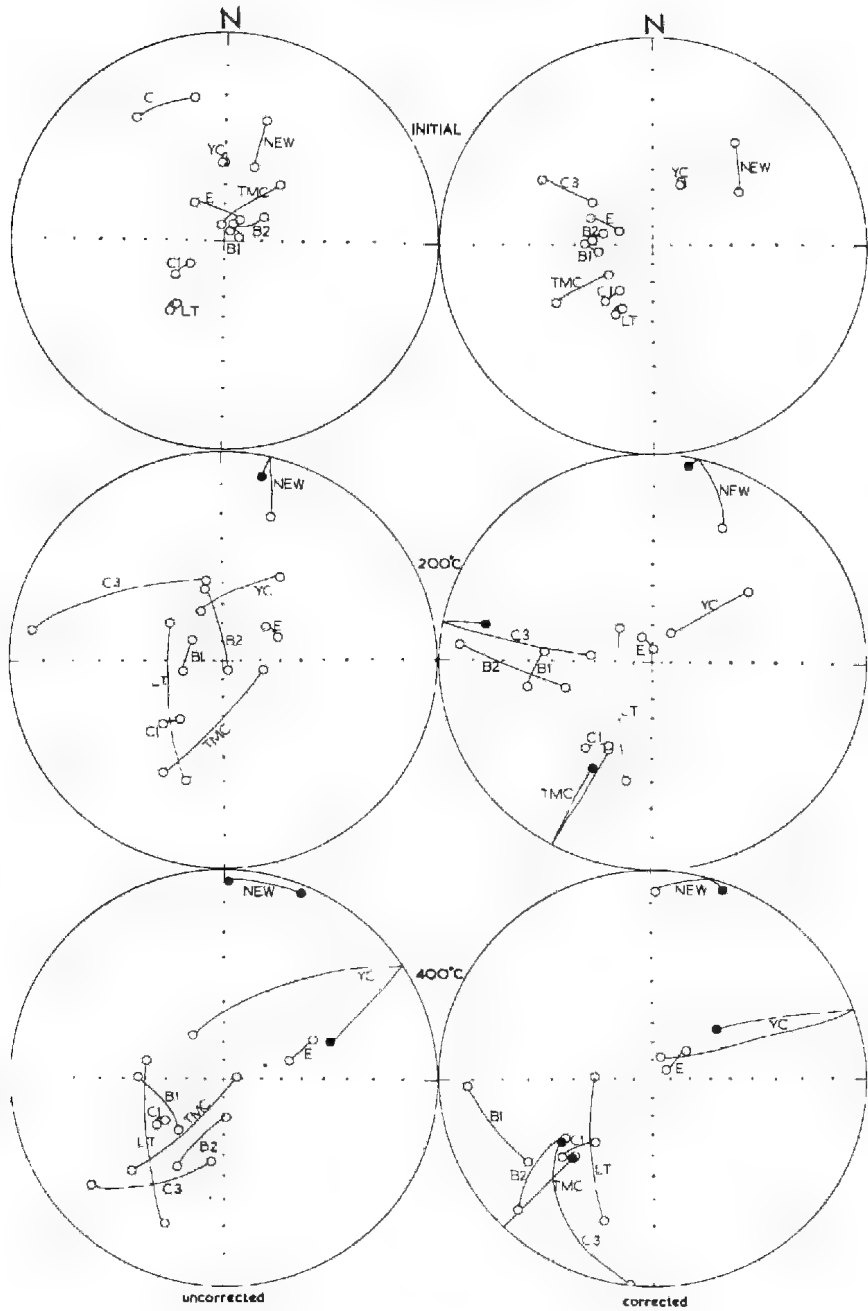
Fig. 2. Thermal cleaning of Billy Creek Formation. Initial directions. and directions after heating to 200°C and 400°C, both before and after correction for folding. Sites are NEW (northeast of Wirrealpa); YC (Yarra Wurta Creek); LT (edge of Lake Torrens); C1 and C3 (Copley-Mount Scott); B1 and B2 (Balcoracana Creek); TMC (Ten Mile Creek) and E (Eregunda Creek). Open symbols denote upward and solid symbols downward inclinations.
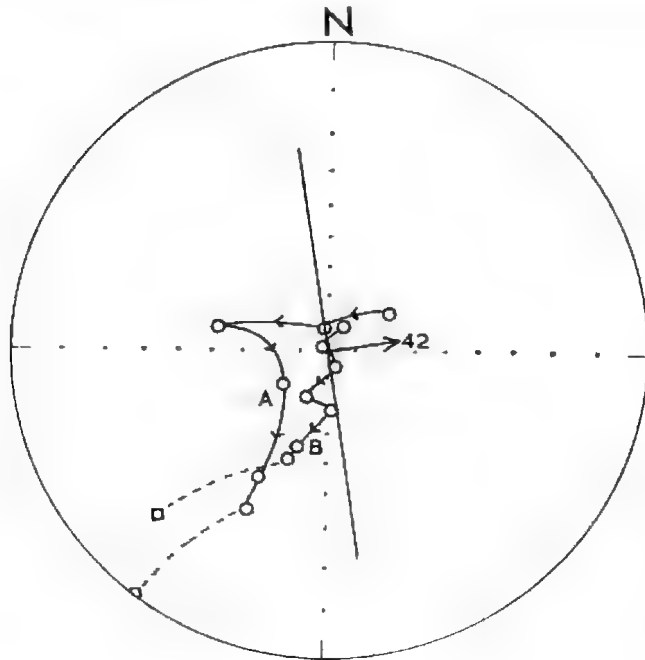
Fig. 3. Thermal demagnetization of two specimens from Balcoracana Creek, in steps, at room temperature, 100°C, 200°C, 300°C, 400°C, 450°C, and 500°C. The stereogram (above) shows the change of uncorrected directions (circles) with progressive demagnetization in the sequence indicated by the arrows, and (squares) after demagnetization to 500°C and correction for the tilt of the beds, which is also shown. The demagnetization curves (below) show vectorial mean intensity of the two specimens. Open symbols denote upward and solid symbols downward inclinations.
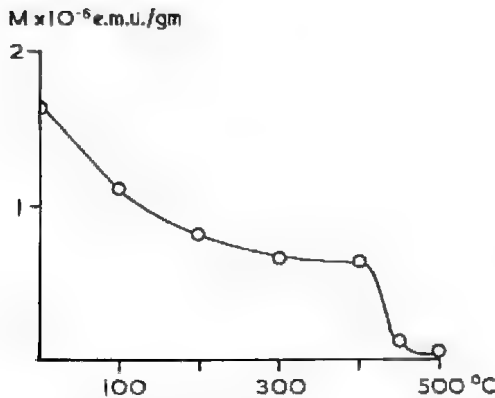
be due to fall in temperature, (due to uplift during folding, or at the close of a phase of igneous activity), change in grainsize, or chemical change. For the Bloomsburg Formation and the Old Red Sandstone, fall in temperature has been proposed.

On Kangaroo Island, Lower Tertiary basalts outcrop on the low hills inland from the palaeomagnetic sampling sites. It is not unreasonable to suppose that they were formerly more extensive, and that temperatures in the Cambrian rocks were elevated at the time of their extrusion. The mean direction of NRM in these rocks is similar to that found in early Tertiary rocks in Australia (Irving, 1964) and hence the NRM may be the same age as the basalts. The most reasonable interpretation is that only the reversed rocks retain their NRM from that time, and that the normal rocks have NRM of recent origin.
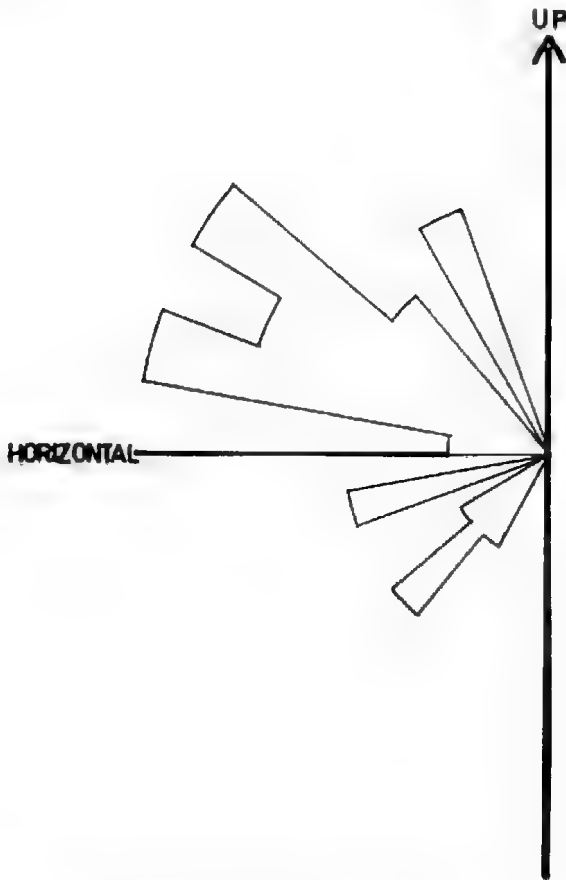
Fig. 4. Inclinations of NRM in Clarence River No. 1 (Woomera) bore.

The inclinations in borecore samples are, for the most part, not inconsistent with NRM of comparable age to their host rocks. But in the Wilkatana No. 1 bore, the upper part of the sequence appears to have been remagnetized in a direction steeper than the present field. This may be due to a surface effect operative in the Mesozoic or early Tertiary (Figure 5), and it is possible that this was a regional effect which involved the Billy Creek Formation also. There is no geological evidence of elevated temperatures in these rocks, and it may be that chemical or grainsize changes were responsible for stabilising the NRM.

The acquisition of viscous magnetization (which increases with the time of application of a magnetic field) at various temperatures by specimens of Billy Creek Formation and Emu Bay Shale has been investigated in the laboratory and is described by Briden (1965).

## ACKNOWLEDGMENTS

Dr. B. Daily gave me the benefit of his detailed knowledge of the Kangaroo Island Group. The Director, Bureau of Mineral Resources, Geology and Geophysics, Canberra, allowed me access to the cores from the Georgina basin.
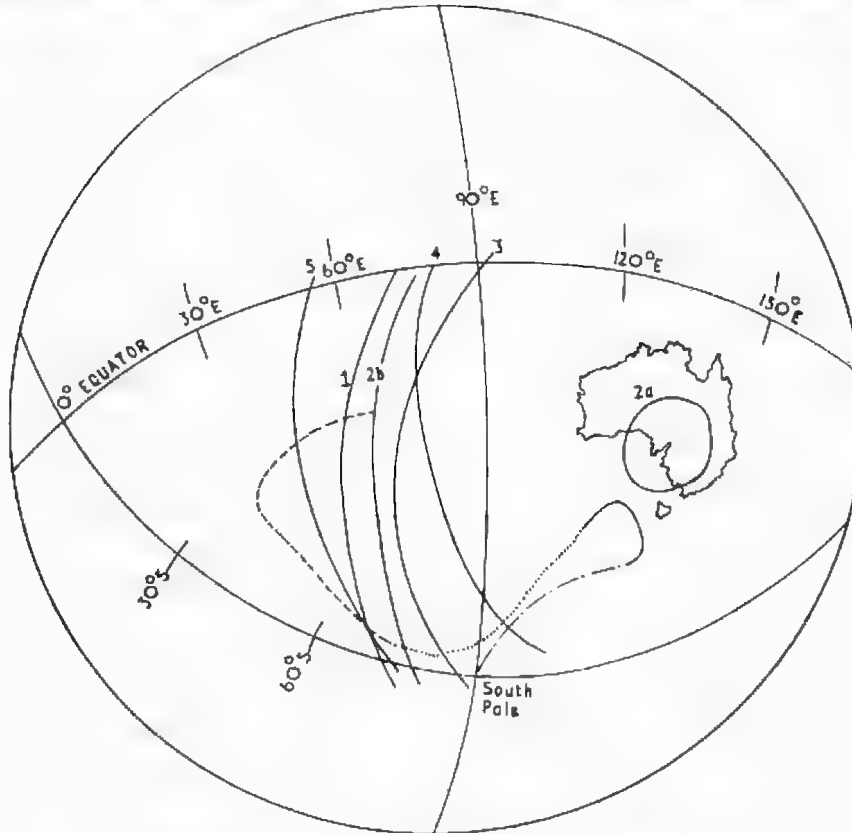


Fig. 5. Loci of palaeomagnetic poles, calculated from borecore measurements, by drawing circles of radius $\lambda_{ll}$ centred on the drilling sites. 1: Clarence River. 2: Wilkatana (a = upper, b = lower). 3: Minlaton. 4: GRC5. 5: GRC7. The curve is the approximate polar wandering curve for Australia, constructed from the A-group data of Irving (1964); dashes for late Precambrian to Devonian, dots for the Carboniferous, solid line for the Mesozoic and dot-dash for the Cainozoic.

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# ON THE RADIOACTIVITY AND RELATED FLUORESCENT PROPERTIES OF SEDIMENTARY AUSTRALIAN ZIRCONS

*BY I. A. MUMME\**

## Summary

The natural radioactivity of sedimentary zircons from various placer deposits in Australia was investigated with a gamma-ray spectrometer.

The radioactivity of the zircon samples was generally weak, and was shown to be due to uranium series; however, in one sample traces of thorium series were also detected.

Under ultraviolet light many of the colourless to lemon brownish zircons fluoresced with a brilliant yellow colour which was attributed to the presence of uranium in solid solution.

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[Read 11 May 1967]

## INTRODUCTION

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The radioactivity of the zircon samples was generally weak, and was shown to be due to uranium series; however, in one sample traces of thorium series were also detected.

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## OCCURRENCE AND NATURE OF RADIOACTIVITY OF ZIRCONS

Zircon is widely distributed in Australia as an accessory constituent of igneous and metamorphic rocks being especially common in the granitic rocks and only occurring sparingly in the basic rocks. It is one of the earliest minerals to crystallize out of a magma.

It is apparently more abundant in plutonic than volcanic rocks.

By disintegration of these rock types it is concentrated by the action of water in sedimentary deposits along with other characteristic minerals including magnetite, garnet, ilmenite, corundum.

As the mineral zircon ($ZrSiO_4$) may contain uranium and thorium as substitution solid solutions up to $0 \cdot 1$ per cent and even higher amounts as crystal inclusions, the radioactivity of sedimentary zircons from various placer deposits in Australia was measured with a gamma-ray spectrometer, and the uranium and thorium contents estimated by calibration with standard samples.

## THE GAMMA-RAY SPECTROMETER

The gamma-ray spectrometer offered a rapid and accurate method of analysis of the uranium and thorium contents of the zircon concentrates.

The spectrometer employed an electronic means of differentiating between the energies of the various intercepted gamma-rays.

Essentially the gamma-ray spectrometer consisted of a scintillation detector which converted an intercepted gamma-ray to an electrical impulse, the voltage of which was proportional to the energy of the absorbed gamma-ray.

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This impulse was amplified and passed through an electronic gating circuit which allowed only pulses of a specific voltage to actuate a scaler.

Gamma-rays emitted by radioactive nuclides are of characteristic energies and the intensity of the gamma-radiation emitted by a specific nuclide is proportional to the quantity of the nuclide present in the sample.

The gamma-ray spectrum graphs were obtained by sweeping the spectrum with a pulse height analyser.

The individual samples of zircon concentrates were weighed and packed in perspex cups and counted close to the face of a thallium activated sodium iodide scintillation crystal which was shielded by a lead castle.

## RESULTS OF THE RADIOMETRIC INVESTIGATIONS

An examination of the gamma-ray spectra for the various zircon samples investigated showed that the uranium series were in equilibrium in each case.

This is to be expected as the zircons resist alteration to a marked degree, and also the age of the zircons are greater than $3 \cdot 5 \times 10^5$ years—the time required for radioactive equilibrium to be set up by the contained uranium.

The results of the radiometric measurements are presented in Table 1.

TABLE 1

| Locality | Uranium content ($\% \ U_3O_8$) | Thorium content ($\% \ ThO_2$) |
|---|---|---|
| 1. Rocky River, Uralla (15662) N.S.W. | 0·101 | 0·01 |
| 2. Anakie, Queensland (D21364) | 0·037 | <0·001 |
| 3. Strangway's Range, Central Australia (D40180) | 0·0021 | <0·001 |
| 4. Hanging Rock Head of Duncan's Creek, 4 miles along Niangula Road (D40400) N.S.W. | 0·0108 | <0·001 |
| 5. Inverell (D16261) N.S.W. | 0·0124 | <0·001 |
| 6. 100 miles N.W. of Augathella (D40162) | 0·0071 | <0·001 |
| 7. Bald Nob Creek, Glen Innes (D16314) | 0·0054 | <0·001 |
| 8. Oban (12 miles S.E.) (D27764) N.S.W. | 0·0241 | <0·001 |
| 9. Sapphire, Inverell (D26298) N.S.W. | 0·0153 | <0·001 |
| 10. Back Creek, 27 miles from Armidale (D19355) N.S.W. | 0·087 | <0·001 |
| 11. Oban (D16257) N.S.W. | 0·057 | <0·001 |
| Tingha (D37997) N.S.W. | 0·047 | <0·001 |
| 13. Trunkey (D10108) N.S.W. | 0·043 | <0·001 |

## RESULTS OF THE ULTRAVIOLET LAMP TESTS

As zircons are frequently fluorescent, the samples were tested for this property with an ultraviolet lamp. The sedimentary zircon samples show a wide variation of luminosity from fluorescence under ultraviolet light ranging from very weak fluorescence to brilliant yellow hues. The activator for the yellow fluorescence is attributed to the presence of uranium.

The details of these tests are brought together in Table 2.

## TABLE 2

1. Rocky River, Uralla (D15662). Crystals water worn reddish colour, 0·5 cm average diameter, fluorescence dull yellow.
2. Anakie, Queensland (D21364). Crystals water worn pale reddish colour; 0·6 cm average diameter, one crystal vivid red; fluorescence yellow, few crystals bright yellow.
3. Strangway's Range. Central Australia (D40160). Crystal fragments angular up to 3 cm diameter. Grey lemon to pale reddish colour; fluorescence generally dull yellow with patches of bright yellow.
4. Hanging Rock (D40400). Water worn crystals up to 1 cm diameter. Brown-lemon colour; fluorescence bright yellow.
5. Inverell (D16261). Water worn crystals, pale lemon, few deep red; 0·5 cm average diameter, few 1·5 cm diameter. fluorescence bright yellow hue.
6. Augathella Region (100 miles NW of Augathella) (D40162). Water worn crystals, colourless, brownish-yellow, associated with black sapphires; fluorescence bright yellow and spotty yellow.
7. Bald Nob. Glen Innes (D16314). Reddish zircons few colourless, average diameter 0·4 cm, associated with black sapphires; fluorescence dull to bright-yellow hues.
8. Oban (D27764) (12 miles SE of Oban). Water worn crystals. deep red colour, translucent, up to 2 cm diameter. fluorescence few bright yellow.
9. Sapphire. Inverell district (D26298). Colourless, reddish and deep red, up to 1 cm, fluorescence bright yellow.
10. Back Creek (27 miles from Armidale) (D19355). Colourless. lemon and pale reddish zircons up to 0·5 cm diameter; associated with blue and black sapphires; fluorescence bright yellow.
11. Oban (D16257). Deep red crystals water worn 0·3 cm diameter (on average); not fluorescent.
12. Tingha (D37997). Crystals water worn; colourless, yellowish, reddish and deep red; some crystals tetragonal square prisms, most crystals water worn. Diameter up to 1·5 cm; fluorescence bright-yellow.
13. Trunkey (D10108). Crystals water worn. Translucent red, one crystal bright red, average diameter 0·5 cm, one crystal fluorescent bright yellow, rest of crystals non-fluorescent.

## CONCLUSIONS

Gamma-ray spectrometry measurements on zircon samples from a number of sedimentary deposits in Australia showed that they were all weakly radioactive. The radioactivity was shown to be due to the presence of contained uranium series in solid solution. The zircon concentrates from Uralla (Rocky River) were considerably more radioactive than the other samples and were also shown to contain detectable amounts of the thorium series.

In samples containing both colourless to yellow-brown zircons and red zircons, the latter were considerably more radioactive than the former group.

The red colour apparently has resulted from alpha radiation damage from the contained uranium series held in solid solution, for on heating the red zircons, the red colour disappeared very rapidly.

Under the ultraviolet lamp it was observed that the colourless to yellowish brown zircons fluoresced brightly with a brilliant yellow colour, whereas the red zircons were non-fluorescent or only weakly so. The decolourized zircons, however, did not regain their fluorescent properties.

## ACKNOWLEDGMENT

# CRUSTAL THICKNESS MEASUREMENTS IN THE SOUTH EAST OF SOUTH AUSTRALIA BASED ON THE REGIONAL GRAVITY VALUES

*BY* I. A. MUMME

## Summary

In the course of this project, regional gravity stations were established along the main highway from Adelaide to Bordertown. In most cases, these stations were close to gravimeter stations previously occupied by the South Australian Department of Mines, and the Commonwealth Bureau of Mineral Resources.

The gravimeter measurements were conducted with a Carter Y2 gravimeter, and the gravity values determined on this traverse are based on an absolute gravity value of 979·7237 gals at the gravity base station in the New Observatory, which is located in the grounds of the University of Adelaide (Mumme, 1960; Dooley and Williams, 1960).

The results of this survey were applied to various equations and graphical methods relating crustal thickness, and Bouguer anomaly, or elevation. Based on this data, an average crustal thickness of 33 kilometres was determined for this general region investigated.

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## PREVIOUS GEOPHYSICAL WORK

Regional gravity work had previously been conducted in this general area by the Geophysical Section of the South Australian Department of Mines (O'Driscoll, 1961), and also a gravity traverse had been run by the Bureau of Mineral Resources between Adelaide and Melbourne (Marshall and Narain, 1954). Before commencing the survey, the writer calibrated the gravimeter by measuring the gravity interval between the New Observatory and the Mount Lofty gravity station which was established by Muckenfuss on behalf of the Wood's hole Oceanographic Institute while carrying out world wide gravimeter observations with a geodetic Worden gravimeter.

## METHODS USED

The Carter Y2 gravimeter was calibrated by measuring the dial interval (allowing for instrumental drift) between the New Observatory and the Mount Lofty gravity station, assuming a gravity interval of 0·1326 gals, and hence a factor of 0·0809 milligals per division for the sensitivity factor. Gravity differences between the New Observatory gravity station and the gravity stations occupied were obtained by establishing a number of intermediate gravity stations, measuring the gravity intervals between successive stations, and thus obtaining the total gravity interval between the New Observatory gravity station and the particular gravity station measured. Repeat readings were taken in measuring the gravity intervals, and curves drawn up to allow for instrumental drift.

The gravity stations were generally occupied close to railway stations or railway crossings for which accurate reduced level data was available from the Records section of the Department of Railways. Levels were transferred from the Railway survey data to the site of the gravity stations with an Abney clinometer and staff. The Railway datum levels were based on a datum level 100 ft below Low Water Ordinary Spring Tide, and a correction of 105·7 ft were subtracted to correct the levels to mean sea level.

## REDUCTION OF RESULTS

The observed gravity values for the gravity stations were reduced to mean sea level by applying the following corrections; namely, an elevation correction and a topographic correction.

### (1) *Elevation Correction*

There are two components in the elevation correction, namely the free-air correction and the Bouguer correction.

(a) *The Free Air Correction*: This correction does not consider the gravity effect of topography but only the increased distance from the centre of the earth of the gravity station. Due to this effect, gravity decreases by $0·00009406$ $(1 + 0·0071 \cos^2 \phi)$ milligals per foot above the surface of the earth providing there is nothing but air between the earth's surface and the point where gravity is measured (Heiland, 1964). Thus, the elevation correction merely compensates the gravity readings without altering their sites.

(b) *Bouguer Correction*: This correction allows for the attraction of the material between the reference station, viz mean sea-level, and that of the actual gravity station. The term "Bouguer correction" is used here in a restricted sense to designate the correction for the attraction as approximated by considering the material as an infinite horizontal slab. The attraction due to gravity for a point on the surface of such a slab is $0·01276\sigma$ h milligals, where $\sigma$ is the density of the rock between the reference level (which is mean sea-level) and the gravity station under consideration, and h is the elevation of the gravity station.

### (2) *Topographic Correction*

A gravity graticule devised by Sigmund Hammer (1939) was used to correct for the actual topographic features associated with each gravity station occupied along this traverse. The 1930 International Gravity Formula was used to obtain the theoretical gravity value Go for each gravity station at mean sea-level. where $Go = 978·049 (1 + 0·0052884 \sin^2 \phi - 0·0000059 \sin^2 \phi)$ gals.

Bouguer anomalies for the gravity stations were calculated by subtracting theoretical gravity values, for the gravity stations, from the reduced gravity values obtained by applying elevation and topographic corrections. As the gravity measurements were conducted on a regional scale, an elevation correction of 0·060 milligals per vertical foot was used (which corresponds to a density of 2·67 grammes per cc) for the following reasons; (a) for this type of investigation geological effects appear as random disturbances, (b) there is no need for a high degree of refinement in the method of data reduction in so far as the elimination of these effects is concerned, (c) a value of 2·67 grammes per cc would appear to be a reasonable value over the entire length of the traverse for the density of the rock material occurring above mean sea-level. The results are given in Tables 1 and 2.

## GEOLOGY OF THE AREA

Between Murray Bridge and Bordertown, the gravimeter traverse passes over a veneer of Quaternary and recent deposits generally masking any evidence of subsurface structure. The structural pattern of this area is complicated and bore hole data suggest that the area north of the traverse forms part of the Murray Basin Proper, while the area south of a line between Kingston and Naracoorte belongs to the Gambier Sunklands with a zone of structural highs between the two areas known as the Padthaway Horst comprising metamorphic rocks. A broad belt of Palaeozoic granitic rocks outcropping along the north-west to southeast ridge of the Padthaway Horst from Murray Bridge to Bordertown includes granites of 3 types.

### TABLE 1

| Latitude | Longitude | Location | Elevation ft. | Observed gravity |
|---|---|---|---|---|
| 34° 55·2′ | 138° 36·3′ | New Observatory | 108 | 979·7237 gals |
| 35° 0·6′ | 138° 42·5′ | Mount Lofty station | 1613 | 979·6448 |
| 34° 58·5′ | 138° 42·7′ | Mount Lofty Tower | 2334 | 979·5911 |
| 35° 0·0′ | 138° 44·0′ | Aldgate | 1386·8 | 979·6627 |
| 35° 2·2′ | 138° 54·4′ | Nairne | 1238·6 | 979·6681 |
| 35° 7·0′ | 139° 16·2′ | Murray Bridge | 46·5 | 979·7376 |
| 35° 15·5′ | 139° 27·1′ | Tailem Bend | 55·7 | 979·7625 |
| 35° 17·7′ | 139° 39·1′ | Moorlands | 32·4 | 979·7795 |
| 35° 28·8′ | 139° 40·4′ | Coomandook | 33·3 | 979·7977 |
| 35° 34·7′ | 139° 45·6′ | Kiki | 85·3 | 979·8034 |
| 35° 42·4′ | 139° 50·2′ | Coonalpyn | 66·0 | 979·8058 |
| 35° 49·3′ | 139° 55·5′ | Culburra | 57·3 | 979·8131 |
| 35° 53·4′ | 140° 0·5′ | Tintinara | 54·0 | 979·8152 |
| 35° 57·8′ | 140° 10·5′ | Coombe | 87·3 | 979·8295 |
| 36° 6·2′ | 140° 20·2′ | Keith | 94·3 | 979·8566 |
| 36° 12·6′ | 140° 40·1′ | Wirrega | 202·3 | 979·8183 |
| 36° 18·8′ | 140° 45·2′ | Bordertown | 261·7 | 979·8347 |

### TABLE 2

| Elevation Correction (milligals) | Topographic Correction (milligals) | Reduced Gravity (gals) | Theoretical Gravity (gals) | Bouguer Anomaly (gals) |
|---|---|---|---|---|
| 6·48 | 0·19 | 979·7304 | 979·7394 | −0·0090 |
| 96·78 | 1·30 | 979·7429 | 979·7469 | −0·0040 |
| 200·40 | 3·14 | 979·7342 | 979·7441 | −0·0099 |
| 82·21 | 0·78 | 979·7467 | 979·7472 | −0·0005 |
| 74·32 | 0·85 | 979·7434 | 979·7498 | −0·0064 |
| 2·79 | 0·07 | 979·7405 | 979·7562 | −0·0157 |
| 3·34 | 0·05 | 979·7659 | 979·7682 | −0·0023 |
| 1·94 | 0·04 | 979·7815 | 979·7713 | 0·0102 |
| 2·00 | 0·01 | 979·7997 | 979·7871 | 0·0126 |
| 5·12 | 0·01 | 979·8085 | 979·7955 | 0·0130 |
| 3·96 | 0·01 | 979·8098 | 979·8065 | 0·0033 |
| 3·44 | 0·02 | 979·8165 | 979·8164 | 0·0001 |
| 3·24 | 0·02 | 979·8184 | 979·8223 | −0·0039 |
| 5·24 | 0·02 | 979·8347 | 979·8381 | −0·0034 |
| 5·66 | 0·02 | 979·8623 | 979·8388 | 0·0235 |
| 12·14 | 0·02 | 979·8304 | 979·8488 | −0·0184 |
| 15·70 | 0·02 | 979·8504 | 979·8587 | −0·0083 |

## INTERPRETATION OF RESULTS

The regional Bouguer anomaly shows a gravity low at Murray Bridge which is possibly due to the presence of the Murray Bridge granite, which has a relatively lower density than the intruded country rock, or due to structural effects (Mumme, 1963). A large regional gravity anomaly occurs between Murray Bridge and Coombe with a maximum value occurring at Kiki. This is probably due to basement structures associated with igneous intrusions. Another important feature of the plan is a sharp gravity anomaly centred on the township of Keith. It is of interest to note that the gravity highs along this traverse roughly correspond to magnetic highs (O'Driscoll, 1960) (Fig. 7), and suggest that they are due to basement highs in the Archaean metasediments whereas the gravity lows are due to granitic intrusions and possibly increased depths of the surface Tertiary sediments.

On the basis of an elementary concept of isostasy, the following equation holds:

Bouguer Anomalies equal —gravitational attraction of the topography

—constant C (Marshall and Narain, 1954).

Assuming that the topography could be regarded as an infinite, level plane at the altitude of the gravity station, we have:

Bouguer anomalies equal —0·034 h —constant C.

The observed regression curve of Bouguer anomaly against elevation h for the area investigated (Fig. 1) suggests that the following relationship holds:

Bouguer anomalies equal —0·0375 h —constant C.

This equation does not differ very much from the theoretical equation and this then suggests that the general area is isostatically compensated in a regional sense.

The average Bouguer anomaly obtained for this traverse was —0·00112 gals. and the average elevation approximately 456 ft.

The Bouguer anomaly values were then applied in various equations and by graphical methods relating elevation and crustal thickness, and gravity anomaly and crustal thickness with the following results:

(1) Applying the equation relating gravity anomaly and crustal thickness used by the Russian and Chinese seismologists, namely

$$H = 35(1 + \tan h\ 0 \cdot 0037\ \triangle g)$$

where H is the crustal thickness and $\triangle g$ the gravity anomaly, we obtain

$$H = 35(1 + \tan h\ 0 \cdot 0037(-1 \cdot 1))$$
$$= 35(1 - 0 \cdot 0041)$$
$$= 35 \text{ kilometres.}$$
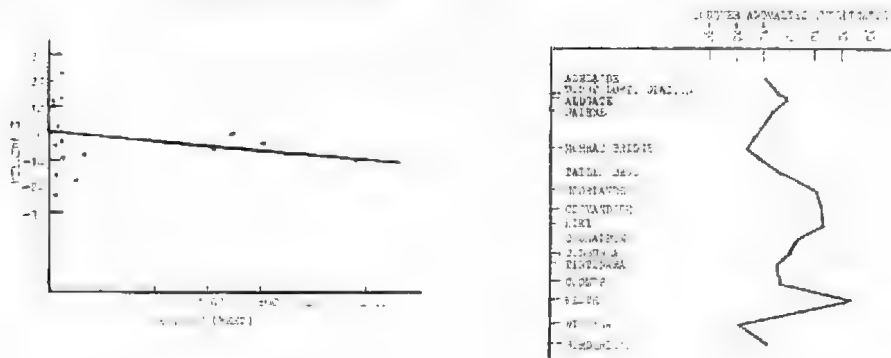
(2) Applying the equation relating gravity anomaly and elevation used by the Russian and Chinese seismologists, namely

$$H = 33 \tan h(0 \cdot 38 \triangle h - 0 \cdot 18) + 38$$

where H is the crustal thickness and $\triangle h$ is the elevation

$$H = 33 \tan h(0 \cdot 38 \times 0 \cdot 16 - 0 \cdot 18) + 38$$
$$= 33 \tan h(-0 \cdot 12) + 38$$
$$= -3 \cdot 96 \div 38 = 34 \text{ kilometres.}$$

(3) Applying Andreev's formula, namely

$$H = -0 \cdot 1 \triangle g + 30$$
$$= -(0 \cdot 1)(-1 \cdot 1) + 30$$
$$= 30 \text{ kilometres.}$$

(4) Applying Woollard's graphical method relating depth of the Mohorovicic discontinuity as a function of the Bouguer anomaly, we obtain a value of the crustal thickness of 32 kilometres.

(5) Applying Woollard's graphical method relating depth of the Mohorovicic discontinuity as a function of elevation, we obtain a value of the crustal thickness of 32 kilometres.

From these various methods an average value of 33 kilometres for the crustal thickness is obtained. Now according to Cooke (1962) the average crustal thickness for a region can be expressed in the form;

$$H = -62 \cdot 9 + 0 \cdot 435 \triangle g + 15 \cdot 65 <V>$$

where $<V>$ is the mean crustal velocity, $\triangle g$ is the average Bouguer anomaly and H is the crustal thickness.

Applying the values of 33 kilometres, and $-1 \cdot 1$ milligals for H and $\triangle g$, we obtain a value for $<V>$ of $6 \cdot 16$ kms/sec.

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# AN AEROLITE FROM COCKBURN, SOUTH AUSTRALIA

BY J. E. JOHNSON* AND D. H. McCOLL†

**Summary**

A small aerolite, found in deflated sandy country near Cockburn, on the New South Wales - South Australian border, is described and classified as an olivine-hypersthene chondrite.

# AN AEROLITE FROM COCKBURN, SOUTH AUSTRALIA

by J. E. Johnson* and D. H. McColl†

[Read 13 April 1967]

## SUMMARY

A small aerolite, found in deflated sandy country near Cockburn, on the
New South Wales - South Australian border, is described and classified as an
olivine—hypersthene chondrite.

This meteorite was found during 1952 by the senior author on an aboriginal
campsite on Ophara Blocks Station (now abandoned), at a point where the
Cockburn-Egebek road crosses Ophara Creek. This is just inside New South
Wales (latitude 32°8'S., longitude 141°4'E.) and is approximately six miles
southeast of Cockburn, South Australia. Hence, in accordance with the estab-
lished practice of naming meteorites after the nearest landmark to appear on
current survey maps, it has been called the Cockburn meteorite. The locality
is typical of many such aboriginal campsites, located in a region of low sand-
hills which in places have been wind eroded, leaving a residuum of australites,
aboriginal artifacts, and indeterminate chalcedonic flakes probably also originat-
ing from aboriginal occupation.

## DESCRIPTION

The meteorite has the form of a bipyramid based upon what was probably
a near-trapezoid shape, from which one corner has been recently broken away,
probably by aboriginals, so as to remove an estimated 20 per cent of the mass
of the meteorite. The length along the long diagonal of the trapezoid is 2·78
centimetres, the breadth when unbroken, across the short diagonal is estimated
to have been 2·0 centimetres, and the thickness between the apices of the
pyramids is 1·48 centimetres.

The faces of the steeper pyramid are all slightly concave, in contradistinc-
tion to those of the flatter pyramid which are convex, showing that the latter
was the anterior surface and the former the posterior during oriented transit
through the atmosphere.

The mass of the meteorite, prior to study, was 10·13 grams and when
entire it would have been little more than 12 grams. The overall specific gravity
is 3·47 which, although within the range for such meteorites, is rather low
indicating the weathering that has taken place.

The surface bears the weathered remains of a fusion crust, now almost
entirely converted to limonite. The thickness of this crust varies from 0·1 to
1·0 millimetres, and is thickest over the convex anterior surface. Extent and
depth of weathering is further indicated by scattered warty excrescences of

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limonite up to $1 \cdot 3$ millimetres in diameter, through the fusion crust. These seem where observable to coincide with underlying grains of troilite and/or nickel-iron.

## MICROSCOPIC

*Transmitted Light*: The meteorite is composed of an aggregate of grains of olivine, orthopyroxene, plagioclase and opaques. The chondritic texture is present although much obscured by brecciation and recrystallisation. Weathering has also stained the more permeable parts with limonite.

*Olivine*: Is present as clear colourless grains to the extent of 30 to 40 per cent of the total. The composition of it estimated by X-ray diffraction measurement of the 130 d-spacing is $25 \pm 3$ mol. per cent of $Fe_2SiO_4$.

*Orthopyroxene*: Occurs as slightly turbid, often yellow stained grains comprising approximately 40 per cent of the total. The value of 2V was estimated only with difficulty as between $60°$ and $70°$, corresponding to 25 to 30 mol. per cent. $FeSiO_3$.

*Plagioclase*: Constitutes no more than 5 per cent of the meteorite, occurring as colourless, clear, untwinned crystals, filling spaces between the other silicates. It has a very low refractive index, some orientations being less than balsam, indicating it to be in the albite-oligoclase range.

*Reflected Light*: The opaque minerals are shown to be nickel-iron, troilite, minor iron oxides (including chromite), and veins of secondary goethite penetrating along zones of weathering. The nickel-iron shows regular graphic intergrowths of kamacite and taenite (i.e. plessite), indicating a nickel content of 10-15 per cent, which is typical of this class of meteorite. From this section, which covered the entire cut face of the specimen, a micrometric estimation was made of the percentage composition, counting at 20 micron intervals. This gave the following results.

|  | | | Percentage (Area) | | Calculated Percentage by Weight |
|---|---|---|---|---|---|
| Silicates | .. | .. | 89.14 | | 82.5 |
| Nickel-iron | ... | ... | 3.87 | | 8.3 |
| Troilite | ... | ... | 5.45 | | 7.1 |
| Iron oxides | ... | ... | 1.54 | | 2.1 |
| | | | | Total | 100.0 |

## CONCLUSION

All evidence obtained concerning the composition of this meteorite places it among the olivine-hypersthene chondrites (Classification of Mason, 1962),[2] the most common classification of the aerolites.

That this stone may be related to the Silverton meteorite,[3] is a possibility, as they are similar in composition and appearance, and were found about twenty miles apart. They differ only in degree of weathering and cohesion of constituent minerals, which effects may be related and consequent upon the sixty years which intervened between their discoveries.
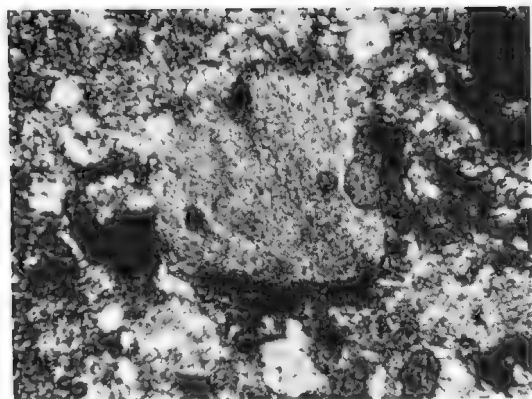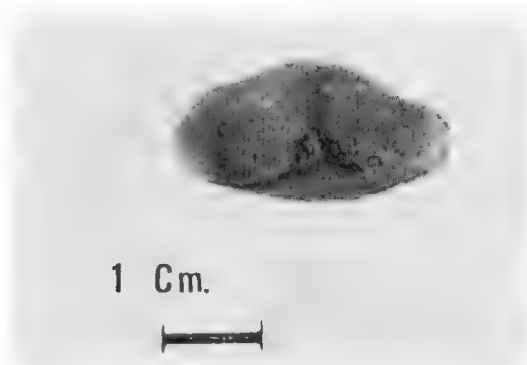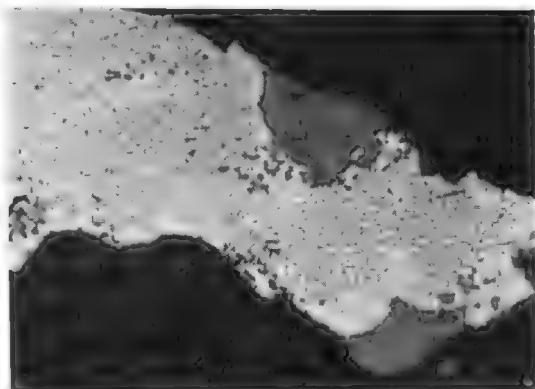
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A. General view of Cockburn Meteorite. B. Thin section in polarised light to show chondrule and silicate texture (x 60). C. Polished section showing troilite (grey) and plessitic structure in the nickel-iron (white) (x 250).

# *PARACANTHORHYNCHUS GALAXIASUS*, A NEW GENUS AND SPECIES OF ACANTHOCEPHALA FROM A FISH. AUSTRALIAN ACANTHOCEPHALA NO. 12.

*BY S. J. EDMONDS**

## Summary

About 40 specimens of a fish *Galaxias attenuatus* (Jenyns) that were collected in some fresh water streams and pools on the property of Mr. B. S. Hyde near Port Lincoln, South Australia, were brought to me for identification by Dr. P. G. Martin of the University of Adelaide. The fish were found to be heavily infested with acanthocephalans which differ from previously described genera and species. If one uses Golvan's key (Golvan, 1960b: 713) they fall into the class Palaeacanthocephala and the family Cavisomidae.

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## Paracanthorhynchus n.g.

Diagnosis: Acanthocephala with characteristics of the subfamily Vancleaveinae Golvan, 1960a. Parasitic in small intestine of fresh water fish. Body small. Trunk subcylindrical or fusiform. Body spines restricted to a small triangular area on the anterior and ventral surface of the trunk. Arrangement of body spines same in both sexes. Introvert of short to moderate length, cylindrical and with hooks that are not differentiated dorso-ventrally. Hooks with simple rooting processes. Sheath double-walled and cerebral ganglion placed in its middle. Lemnisci as long as or a little longer than the sheath. Male organs occupy posterior half or two-thirds of the trunk. Testes ellipsoidal and placed behind each other. Four cement glands, short and pyriform. Eggs slender with polar prolongations of the middle shell. Type species: *Paracanthorhynchus galaxiasus.*
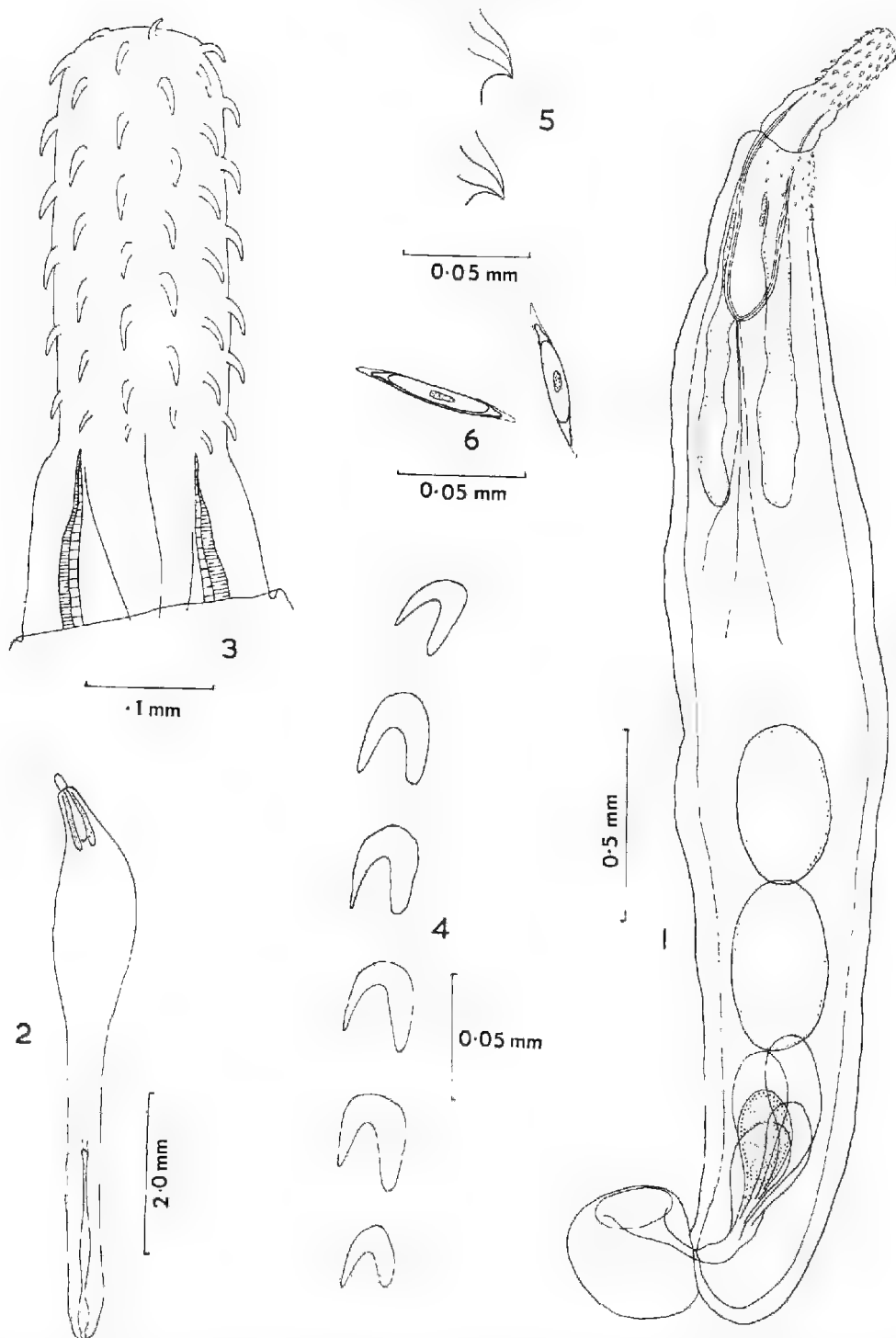
## Paracanthorhynchus galaxiasus n.g., n.s.p.: figs. 1-6

Small slender worms. Trunk subcylindrical with maximum width in the anterior third of worm. Body of preserved specimens may be straight but body of living specimens usually slightly S-shaped. Female noticeably larger than male and the posterior part of its trunk more slender.

Trunk: Length of male 2·7-4·2 mm and maximum width 0·5-0·6 mm; length of female 4·5-8·0 mm and maximum width 0·5-0·9 mm. Small triangular area of body spines on anterior ventral region of trunk of both sexes, the spination scarcely extending to the dorsal surface of the trunk. Spines comparatively large, 0·2-0·3 mm long. No genital spines.

Introvert: Cylindrical and not long. Length of armed section in male 0·32-0·36 mm and maximum width 0·12-0·15 mm. Corresponding measurements in female are 0.32-0.38 mm and 0·13-0·18 mm. Unarmed truncated collar or neck

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Figs. 1-6.   *Paracanthorhynchus galaxiasus.*   1 male, 2 female, 3 introvert, 4 some hooks from the introvert, 5 body spines, 6 eggs.

0·10-0·15 mm long. Armed with 12 rows of 7 hooks per row, the size and shape of some of the hooks is shown in Fig. 4. Last hook of each row is smallest. No marked difference observed in size of hooks on dorsal and ventral surfaces of introvert.

Sheath: Arises just posterior to introvert hooks. Double walled. Length about 0·6-0·8 mm and maximum width 0·19-0·23 mm. Ganglion present in mid-region of sheath.

Lemnisci: Rather stout, about one to one and a half times as long as sheath.

Male structures: Testes, ellipsoidal, 0·35-0·45 mm long and in tandem.

Cement glands: Four, club-shaped and pressed closely together.

Male aperture: Appears to be subterminal in some but terminal in fully extended specimens.

Female structures: Uterine bell about 0·4 mm long and uterus and vagina about 2·0-2·5 mm long.

Eggs: Slender. Outermost covering very thin and collapses easily 55-67 $\mu$ long and 7-11 $\mu$ wide with polar prolongations of the middle shell.

Type host: *Galaxias attenuatus* (Jenyns).

Type locality: Coomunga, near Port Lincoln, South Australia.

Holotype and paratypes: Australian Museum, Sydney.

Manter (1955: 67) reported the presence of acanthocephalans of the genus *Acanthocephalus* from *Galaxius attenuatus* in New Zealand. Parasites of this genus possess six cements glands and lack body spines. Consequently Manter's specimens must be different from the South Australian specimens.

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# SUBDIVISION AND STRUCTURE OF THE PRECAMBRIAN (WILLYAMA COMPLEX AND ADELAIDE SYSTEM), WEEKEROO, SOUTH AUSTRALIA

BY J. L. TALBOT*

## Summary

The basement complex at Weekeroo can be subdivided into 6 major units of schists and gneisses. Only one of these units shows undoubted sedimentary features although other of the units may be sedimentary in origin. The basement complex has been deformed at least twice prior to the deposition of younger Precambrian sediments. High grade metamorphism with associated pegmatites and granites accompanied the first phase of deformation and a lower grade of metamorphism appears to have been imposed in the second phase of deformation. The younger Precambrian sediments consist of the Burra Group overlain unconformably by the glacial Umberatana Group. The sediments and the underlying basement were deformed in the Palaeozoic orogeny and metamorphosed to the biotite grade.

# SUBDIVISION AND STRUCTURE OF THE PRECAMBRIAN (WILLYAMA COMPLEX AND ADELAIDE SYSTEM), WEEKEROO, SOUTH AUSTRALIA

by J. L. Talbot[*]

[Read 13 April 1967]

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## INTRODUCTION

In the Olary region of South Australia two distinct sequences of Precambrian rocks are exposed (Fig. 1), an older basement of schists and gneisses named the Willyama Complex (Mawson, 1912) and younger Precambrian sediments referred to the Torrensian and Sturtian Series of the Adelaide System (Campana and King, 1958). The Olary Province (Campana, 1956; Glaessner and Parkin, 1958) is one of a number of areas within the Adelaide geosyncline in which the basement is exposed. The age of these basement outcrops is unknown but granitic rocks within them have ages ranging from 1,700-1,400 million years (Compston *et al.*, 1966).

This paper describes the geology of a small area in the Olary Province. Detailed mapping was undertaken to investigate the relationships between the basement and overlying sedimentary mantle. The results of this mapping are summarised in Fig. 2 which shows the distribution of rock units in the area studied. A considerable modification of the rock units and structure reported by Campana and King (*op. cit.*), is suggested as a basis for extension of the mapping to other areas.

*General Relationships*

The distribution of rock types in Fig. 2 shows the younger Precambrian Burra Group resting with marked unconformity on a folded sequence of schists and gneisses. The structure in the Willyama Complex is dominated by a large antiform[*] in the central outcrop and a series of antiforms in the western outcrop. On the two simplifying *assumptions* that the units recognised in the Willyama Complex reflect original sedimentary units and that the central antiform is in

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[*] Campana and King interpreted this central antiform as a syncline and hence concluded that the gneisses were younger than the schists. (Antiform is a descriptive term for an arch-like structure. It does not contain the stratigraphic implications of anticline.)

fact an anticline, a succession can be erected for the Willyama Complex in which the "leucogneiss" is the lowest and the "bedded mica schist" the highest recognisable unit. Six mappable units have been recognised, their relationships being shown in the map and legend of Fig. 2. A discussion of the validity of the assumptions and hence the origin and significance of the rock units is given in the final section of this paper.
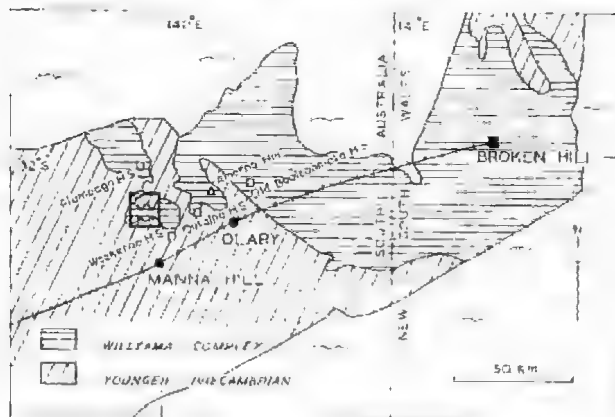


Fig. 1. Locality Map. Area mapped outlined in solid black, north of Mannahill.

The younger sequence occurs in four prominent tongues protruding into the outcrop of the Willyama Complex. The structure of the tongues is complex but the north-south trends are in marked contrast to the ENE trends of the Olary Arc in this general region. Explanations for this anomaly may be sought in the relationships to the basement structures but such a discussion is beyond the scope of this paper.

### The Willyama Complex

The six units of the Willyama Complex consist of 4 lower units which are essentially gneissic and 2 upper units which are schistose. Each unit is quite variable but an attempt is made to describe the essential characteristics by which the unit may be recognised in other areas. The lowest unit is described first.

### Layered and Foliated Leucogneiss

The lowermost structural unit is exposed in the core of the antiformal structure which dominates the southern central outcrop of the Willyama Complex. The unit is composed of a lower sequence of massive to macro layered leucogneisses, granofels* and migmatites, a middle group of more migmatitic gneisses and an upper series of layered gneisses. These layered gneisses show remarkably planar layering 1-10 cm thick and form a distinctive marker horizon. The base of the unit is not exposed.

The mineralogical composition of the leucogneisses is simple, consisting essentially of acid plagioclase with less quartz and with accessory to minor pale-olive biotite. Muscovite may also occur in minor amounts and some rocks with a granitic appearance also contain microcline. The pegmatitic segregations in the migmatites also show abundant microcline. The preferred orientation of micas is normally parallel to the layering but in the cores of some small folds is parallel to the axial surface of the folds. The layering in the upper part consists of alternations of plagioclase-quartz-minor biotite layers with coarser layers of plagioclase-biotite with minor muscovite. (Plate 1, Fig. 1.)

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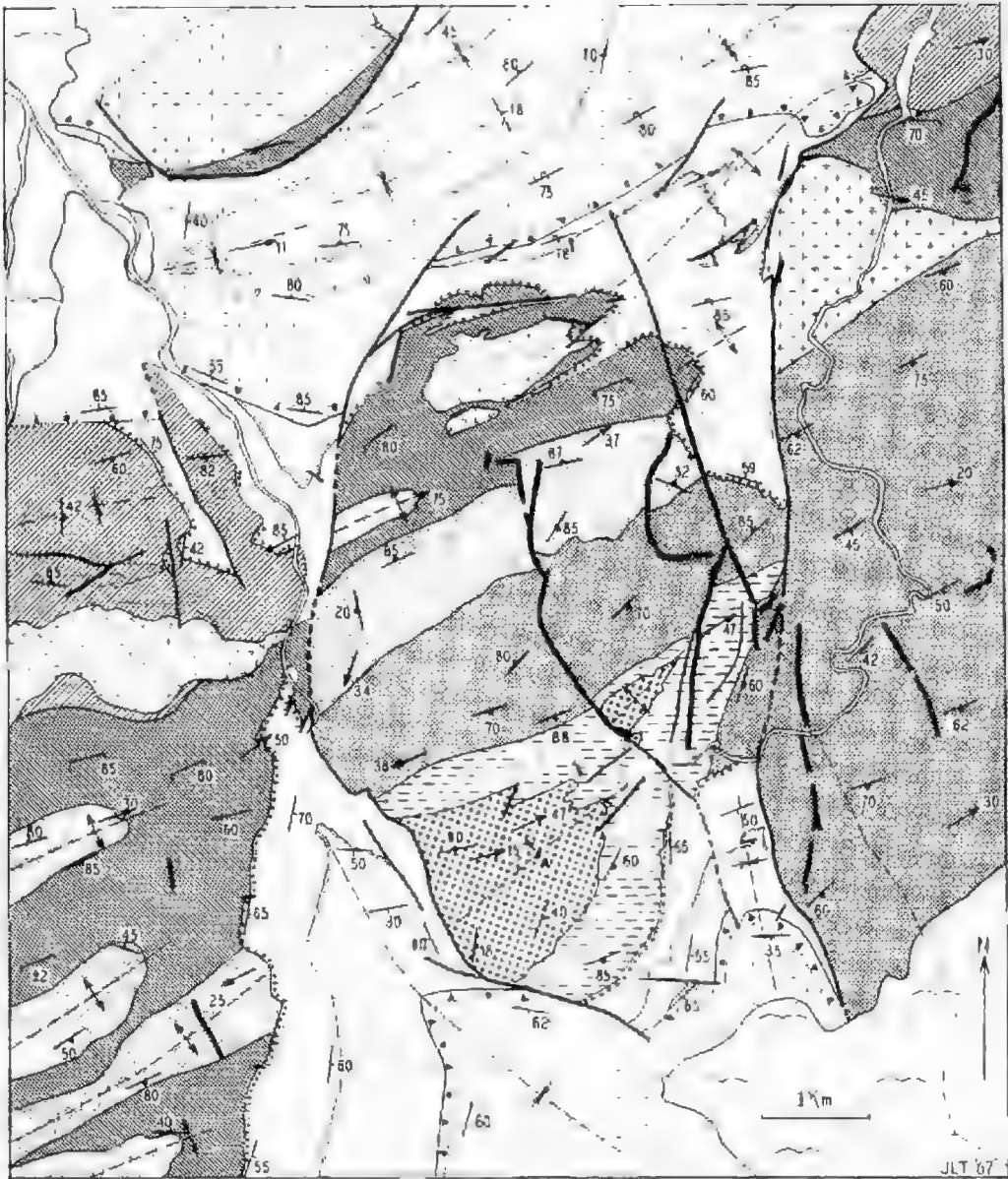* Granofels. Medium to coarse metamorphic rock with no obvious foliation (Goldsmith, 1959).

Fig. 2. Simplified geologic map of portion of Weekeroo and Morialpa Stations, South Australia. The boundaries of the area are Longitudes 139° 55' to 139° 59'E and Latitudes 32° 10' to 32° 16'S.

## Migmatitic Schist

Structurally overlying the layered gneiss is a quartz-feldspar-mica schist crowded with pegmatitic schlieren. The pegmatites are commonly only a few centimetres wide, are lensoid and generally parallel to the foliation. Small isoclinal folds in the pegmatites are common even in the cores of the large folds, and a crenulation cleavage is developed parallel to their axial surfaces.

Compositional layering within the migmatitic schists is comparatively rare and where observed is thin and parallel to the cleavage. There are, however, two bands of calc-silicate schists about 25 m thick which show well developed layering. The layering in these schists conforms to the large scale structures, the layering commonly being at a high angle to the cleavage. The relationship between the structures shown by the calc-silicate schists and the migmatitic schists is shown schematically in Fig. 3. The layering in the migmatitic schists is said to be transposed (e.g. Turner and Weiss, 1963, p. 94).
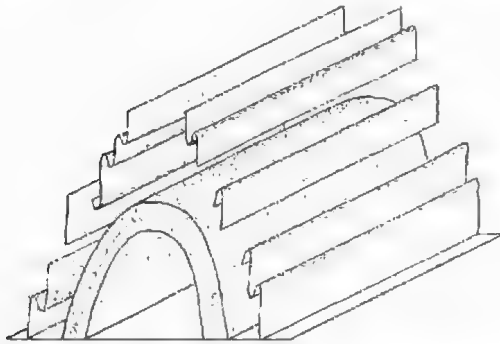


Fig. 3. Sketch showing the relationship between the transposed migmatitic schist unit (lined) and gneiss band (stippled).

The uppermost part of the migmatitic schist unit consists of a distinctive layered biotite-gneiss 20 m thick.

In thin section the migmatitic schists show coarse relics of quartz, microcline, muscovite and biotite in a highly foliated sericitic matrix. Plagioclase appears to be uncommon in these schists but the presence of large amounts of sericite may indicate that any original plagioclase may have been completely replaced. The calc-silicate schists vary from layered two-mica schists to dark-brown biotite schists with up to 30% epidote. A blue-green hornblende and calcite occur in some sections.

## Granitoid Gneiss

Granitoid gneisses occur in the central part of the area and along most of the eastern border. A wide variety of rock types have been included in this unit; weakly foliated granofels, gneissic migmatites, layered leucogneiss and some minor schists. The lack of characteristic markers within this unit makes correlations across faults and the delineation of macroscopic structures extremely difficult. The gneisses along the eastern margin are particularly unsatisfactory in these respects. A number of mappable sub-units can be distinguished in this area but they are sufficiently repetitious to make it impossible to decide whether a major structure corresponding to the central antiform is present in this region. Similarly a definite correlation between these gneisses and those of the central region must be regarded as tentative. An extension of the mapping to the east may solve some of these problems.

The mineralogy of the gneisses is relatively simple, quartz and plagioclase (An 15) being the most important constituents with small amounts of biotite and/or muscovite. Microcline occurs in some specimens and sphene and opaques are ubiquitous accessories.

### Layered gneisses and schists

In contrast with the non-layered nature of the previous unit the next highest unit is layered on all scales. Macroscopic layering is clearly visible on aerial photographs and is an expression of alternations of leucocratic poorly layered gneisses with layered mica-gneisses and schists. The rocks are also well layered on a small scale and where sufficient biotite is present a foliation parallel to the lithologic layering is well developed. In a number of localities the more leucocratic phases of the gneisses grade laterally into dense, unlayered "aplitic" and pegmatitic rocks. Campana and King (1958, p. 30) interpreted these changes as a result of "blastic recrystallization" of pre-existing feldspathic rock.

The leucogneisses are composed of varying proportions of quartz and plagioclase with small amounts of K feldspar in some specimens. Trains of accessory sphene, zircon and apatite commonly outline the only layering visible in the rocks. Variable amounts of mica may be present in the rocks and forms an essential constituent of the schistose phases.

### Mica Schist and Bedded Mica Schist

The four units described above are predominantly gneissic with some granitic and minor schistose phases. Micas do not average above 20% in these units and normally are considerably lower. In marked contrast to these gneisses is a group of brown and grey mica-schists which crop out in the northern and western part of the mapped Willyama Complex. These schists have been referred to as the Weekeroo-Schists by Campana and King (1958). In this study these schists have been subdivided into a lower "Mica-Schist" unit and an upper "Bedded Mica-Schist" and are described separately. Campana and King (1958) recognised an Ethiudna Calc-Silicate Group between the gneiss units already described and these schist units. The present author does not recognise this as valid regional unit for reasons to be discussed later.

### Mica Schists

The contact of the Weekeroo Schists with the structurally lower gneisses is gradational. The thickness and number of leucogneiss bands decreases rapidly over a distance of 50 m to a dominant rock type of silky muscovite-rich schist. Most of the "Mica Schist" outcrops are monotonous unlayered quartz muscovite schists with muscovite commonly making up over 50% of the rock. Some of the outcrops contain abundant layers of quartz-rich schist which may be transposed sedimentary layers. These layers are however never sufficiently thick or persistent to outline large scale structures.

The most common mineral assemblage of the schists is quartz-muscovite with minor feldspar, biotite and/or chlorite. Garnet occurs in some specimens and a light brown to blue pleochroic tourmaline is a common accessory. Some localities show large white porphyroblasts with a tetragonal outline. Although these porphyroblasts are now predominantly composed of a white mica, relict andalusite occurs in some. Rarely, staurolite and chloritoid occur within the porphyroblasts and in one specimen sillimanite occurred with them. No mutual replacement textures were observed between these three minerals although all three appear to be replacing the andalusite.

### Bedded Mica Schists

To the north of the "Mica Schists" are a sequence of schists and granofels which show macrosopically folded layering visible on aerial photographs. The macroscopic layering is parallel to a small scale layering which in places shows cross-bedded ripple structures (Plate 1, Fig. 2). There appears to be little doubt therefore that the layering in this unit represents bedding. Consistent foreset truncations indicate that the bedding and structures north of the western amphibolite are right way up. It is probable therefore that the "Bedded Mica Schist" unit is younger than the "Mica Schist" unit unless there is some unsuspected structural complication.

The mineral assemblages of the bedded mica schists are similar to those in the "Mica Schist" unit. Garnet and andalusite are however rare. The rocks are finer grained and contain more quartz.

### Older Precambrian Metamorphism and Igneous Activity

There are a number of metamorphic episodes affecting the Willyama Complex and there are considerable problems in outlining a metamorphic history. The general appearance of the rocks, especially the gneisses, suggests the metamorphic grade was quite high. Abundant migmatites, pegmatites and foliated granites are suggestive of at least lower amphibolite facies. Relicts of sillimanite and andalusite in the schists confirm this impression.

Most of the rocks however contain assemblages which are consistent with the greenschist facies, that is, muscovite-chlorite-garnet in the schists and albite-muscovite in the gneisses. It appears therefore that an earlier phase of higher grade metamorphism has been overprinted by a later phase of lower grade metamorphism.

Structural evidence supports this hypothesis, and suggests the second phase of metamorphism occurred before the deposition of the Adelaide System rocks. An early phase of tectonism resulted in an essentially planar or at least isoclinal attitude of layering with a foliation parallel to this layering. The large development of migmatites and pegmatites also appear to be associated with this phase of tectonism.

The pegmatites which are commonly parallel to the foliation vary in thickness from a few centimetres to over 100 metres. The distribution of pegmatites shows a high degree of correlation with rock type, pegmatites being most abundant in the migmatitic schist and layered gneiss units and somewhat less abundant in the mica schist unit. On a smaller scale bands of mica schist and calc-silicate schist within the migmatitic schist unit are remarkably free of pegmatite although the surrounding schists are crowded with pegmatites. Such field occurrences suggest an intimate genetic relationship between the formation of the pegmatites and metamorphism rather than an introduction of material from outside. Such processes are typical of the middle or upper amphibolite facies rather than greenschist facies.

The second phase of metamorphism is related to the second phase of deformation of the rocks in the Willyama Complex. This phase of folding has resulted in the general outlines of the large scale structures now visible in the Willyama Complex. The pegmatites are folded conformably with the lithologic layering. During this phase of deformation most of the rocks were recrystallized and the present mineral assemblages established. Most direct evidence of the previous higher grade of metamorphism appears to have been obliterated during this tectonic episode.

The granites marked on the map (Fig. 2.) are foliated to some degree but differ from the granitic gneisses in their lack of marked compositional variation across the bodies. The granites are composed of varying proportions of quartz, microcline, albite, muscovite and biotite. A weak preferred orientation of the micas defines a poor foliation in some specimens.

The texture is coarse-grained hypidiomorphic and the minerals show abundant strain shadows in thin section. These textural features contrast strongly with the unstrained granular texture of most of the gneisses.

Amphibolites are quite common in the Willyama Complex, the more important bodies being indicated in Fig. 2. Large amphibolites occur within the schist sequences at several localities. The rocks are massive amphibole-albite-epidote rocks with no well pronounced foliation. Although metamorphosed, relict igneous textures are common. It seems clear therefore that they represent altered basic igneous rocks. Some structural features are suggestive of a volcanic origin (Jones, Talbot and McBriar, 1962) but more recent work has brought to light intrusive contacts and breccias and the rocks are more reasonably interpreted as dolerite plugs. Albitization of the surrounding country rock is also a characteristic feature of these amphibolites.

Campana and King (*op. cit.*) interpreted these amphibolites as sedimentary and equivalent to the Ethiudna Calc-Silicate Group. The present author, however, can find no evidence of sedimentary amphibolites in the Weekeroo area although other types of calc-silicate occur within the migmatitic schist unit. Another group of dark green amphibolites occur as long, narrow nearly vertical dykes generally with a north-south trend. In a number of localities the dykes are folded on a large scale and in many places the margins of the dykes are now chlorite schists with the foliation parallel to the dyke margins. In some instances the dykes follow faults. None of these dykes cut the Adelaide System rocks and a number of them are cut off by the unconformity.* The dykes, however, cut across the large folds in the Willyama Complex and are therefore later than the second phase of deformation. It is not known whether the dykes are related to the large amphibolite bodies but the generally massive nature of the latter suggests they were formed after the metamorphism associated with the second deformation.

## The Younger Precambrian Metasediments

Lying with marked unconformity upon the Willyama Complex are metamorphosed sediments of the Adelaide System. Two sequences are represented, a lower group believed to be the equivalent of the Burra Group (Torrensian) and an upper group which is correlated with the Umberatana Group of Sturtian age (for a discussion of correlations within the Adelaide Geosyncline see Thomson, 1966).

The original sedimentary nature of the younger sequence of rocks is readily apparent. The rocks are well-layered and show an abundance of small scale sedimentary features such as ripple marks, cross bedding and convolute laminations, and in the basal beds rare suncracks. Facies changes in many horizons can be distinguished easily and original variations in the quartzites and glacial horizons are particularly prominent. The macroscopic structures are relatively simple and individual marker horizons can be followed for comparatively large distances.

* A single example of a light green uralitized dolerite is seen cutting the folded Burra Group in the northeast tongue. This dyke has not been distinguished on the map from the Precambrian amphibolite dykes but it is clearly later.

Many of the original sedimentary features, however, have been modified by deformation and the overall simplicity of the large scale structures is somewhat misleading. Bedding in the schist units is largely subparallel to the foliation and is heavily transposed (Plate 1, Fig. 3). Thinning of the schist units is also readily apparent (Plate 1, Fig. 4) and so calculated sedimentary thicknesses are unreliable. Tectonic thinning or thickening has not been allowed for in construction of the fence diagram in Fig. 4 so the thicknesses can only be regarded as relative.

## Burra Group

A generalised stratigraphic column for the Burra Group in the northeastern outcrops is shown in Fig. 4. The relative positions of prominent marker beds in the other three outcrop areas is also shown. Detailed columns could not be constructed in these other areas on account of poor outcrops. No attempt has been made to subdivide the sequence into formations as the dominant rock type, mica schist, is similar throughout the sequence.
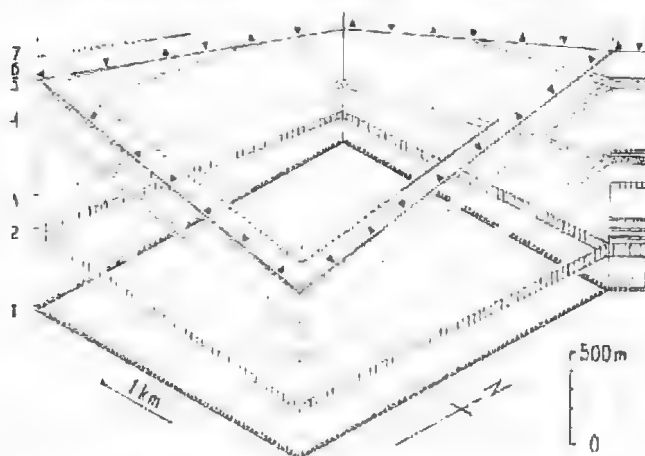


Fig. 4. Stratigraphic column for the Burra Group of the northeast tongue (right hand pillar) and fence diagram to show variations over the whole area. The other three uprights represent sections measured in the other three tongues of the Burra Group. The numbered marker beds are:— 1. Basal conglomerate 2. Major dolomite 3. White quartzite 4. Cross bedded silty sandstone 5. Sandstone 6. Tillite 7. Festoon ripple sandstone. Markers 1-4 are in the Burra Group and 5-7 in the Umberatana Group.

The contact between the Burra Group and the Willyama Complex is well exposed over most of the area mapped and along all western contacts of the Burra Group tongues is an unsheared sedimentary contact.

The rocks lying directly above the unconformity are for the most part metamorphosed conglomerates. In a few localities impure quartzites rest on the Willyama rocks. The conglomerate is quite variable in particle size, composition and thickness, and these variations show a correlation with variations in the underlying Willyama Complex.

The maximum thickness of the conglomerate is about 15 m and the maximum pebble size about 10 cm diameter. In general the thicker, coarser conglomerates are found in contact with the more schistose rock types of the Willyama Complex; conglomerate may be absent altogether in contact with the more massive gneisses. These differences appear to represent lows and highs respectively in the unconformity surface.

The composition of the basal beds varies sympathetically with the rocks in the underlying Willyama Complex. In all the outcrops pebbles of vein quartz are prominent. Adjacent to the gneisses, pebbles of quartz-feldspar gneiss are very common and pebbles of quartz-feldspar-biotite gneiss are also present. Adjacent to the schists, gneiss pebbles are less common and vein quartz pebbles

predominate, but as might be expected schist pebbles are not abundant. Pebbles of amphibolite and albite rock are found in the conglomerate resting on the amphibolite and in some exposures epidote (from the amphibolite) is abundant in the matrix.

The conglomerate is interpreted as a reworked regolith. The correlation of pebble type with underlying rock type in the Willyama Complex suggests that there has been little transportation of the pebbles.

The higher beds of the basal unit consist of fairly uniform impure quartzites, metagreywackes, minor conglomerates and interlayered mica schists. The quartzites commonly show cross-bedding, heavy mineral laminations, and ripple marks; suncracks were observed in two localities.

Above this basal sequence the rocks are predominantly mica schists. The most common mineral assemblage is quartz-biotite-chlorite (muscovite) and quartz-biotite-actinolite (dolomite, chlorite). Most of the rocks have a pronounced preferred orientation of biotites although in many specimens a schistosity is not obvious on casual inspection.

In the lower part of the sequence, bands of dolomite marble are common, and sedimentary magnesite occurs in some horizons. The most common assemblages are quartz-dolomite, quartz-dolomite-talc. The assemblage quartz-dolomite-tremolite occurs in a number of localities.

Metasandstones are also common throughout the sequence, two prominent horizons being a white ripple marked quartzite in the middle of the sequence and a finer grained impure sandstone near the top of the sequence. In the two southern tongues a light grey quartzite with festoon cross-bedding occurs directly beneath the Umberatana "tillite".

*Umberatana Group*

Rocks of the Umberatana Group rest with apparent conformity on the Burra Group over much of the area but a distinct angular unconformity of up to 40° occurs in the northwestern part of the area. In this latter region the Umberatana Group overlaps all parts of the Burra Group and rests directly on the Willyama Complex. Where an unconformity cannot be recognised the base of the Umberatana Group has been placed at the first appearance of large boulders in the schists. The incoming of large boulders also corresponds to a general change in the appearance of the mica schists. In contrast with the schists of the Burra Group which are soft and show a good schistosity, the schists of the Umberatana Group are hard dense brown rocks commonly with only a poorly developed schistosity.

The basal unit of the Umberatana Group, interpreted as a tillite by Campana and King (*op. cit.*) is a quartz-rich biotite granofels with large boulders and with bedding completely absent in most outcrops. The horizon is very variable, containing numerous large boulders in some parts and being almost free of boulders in other parts. The boulders range in size up to 50 cm diameter and are most commonly well-rounded, although boulders less than 5 cm diameter tend to be sub-angular. The composition of the boulders is very variable, in some outcrops boulders from the Willyama Complex are dominant, whist in others dolomites and quartzites from the Burra Group predominate. The matrix of the "tillites"* is a characteristic dark grey structureless fine-grained biotite

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* The sedimentary term "tillite" is used to describe this rock as no satisfactory metamorphic term is available.

granofels which no longer shows sedimentary characteristics. Orginal grains larger than 0·1 mm are however still preserved. These grains, mostly of quartz but also of aggregates of dolomite or quartz (and feldspar) vary from rounded to sub-angular and show a wide variation in grain size. The reconstituted matrix in which these fragments occur has a grain size varying from 0·02-0·05 mm and consists essentially of quartz, olive-green biotite and carbonate, with accessory muscovite and granular opaques.

The rocks above the basal "tillite" are dominantly fine-grained quartz-rich mica schists and granofels with minor dolomite marbles and quartzites. Scapolite occurs as porphyroblasts up to 0·5 cm in diameter in some horizons in the mica schists in the northern part of the area. Scattered boulders (most commonly granite) up to one metre in diameter occur in all parts of the sequence but are uncommon in the upper part. Sedimentary structures, such as convolute laminations and small scale cross-bedding, are common in the quartz-rich mica schists.

In contrast to rocks of the Burra Group, biotite shows a rather poor preferred orientation in the Umberatana Group rocks, with a consequent lack of foliation in most outcrops. This lack of foliation is not regarded as a fundamental metamorphic difference between the two groups but rather due to differences in lithology.

### Palaeozoic Metamorphism and Igneous Activity

The mineral assemblages in the Adelaide System rocks are indicative of biotite grade (middle greenschist facies) of metamorphism. No granitic rocks or pegmatites are found within the Adelaide System rocks and the only evidence of large scale metamorphic differentiation is the presence of quartz veins in some localities. Quartz in pebbles and in quartzites show strong preferred orientations which are related symmetrically to the axial plane schistosity (Talbot, 1962). The metamorphism and large scale folding and deformation appear therefore to be related and correlation with the major orogeny which affected the whole of the Adelaide Geosyncline, indicates it to be Palaeozoic in age.[*] A single light green dyke occurs cutting the folded Burra Group NNW from the Weekeroo Station shearing shed. The rock is now largely an assemblage of albite, chlorite, epidote and magnetite, showing relict lathes of plagioclase. It therefore appears that this dyke was intruded after the peak of the Palaeozoic metamorphism and certainly after folding had ceased.

### Structural History

A detailed analysis of the structural geology is beyond the scope of this paper and only a brief outline of the structural history will be presented here.

As noted previously the overall distribution of rock types within the Willyama Complex is largely the result of the second recognizable tectonic event. This period of deformation affected rocks which already possessed a well defined schistosity and which were already high grade metamorphic rocks, that is, gneisses and migmatites. Large scale folds were formed with a new foliation, a crenulation cleavage, parallel to the axial surface. The trend of this steep foliation is roughly NE to ENE and the associated large scale folds commonly plunge at moderate angles to the NE although a wide range of plunges has been observed. The majority of the amphibolite dykes were intruded after this phase of deformation and it is also possible that the large amphibolite bodies were also formed at this time.

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[*] Latest information suggests the age of the metamorphism of the Adelaide Geosyncline rocks is 490 m. years. (Compston *et. al.*; 1966.)

The younger Precambrian sequence was deposited on the already multiple deformed Willyama Complex. Some movements must have occurred after the deposition of the Burra Group but the next major tectonic episode is the lower Palaeozoic orogeny which affected the whole Adelaide Geosyncline. The major trends of this Palaeozoic folding in the Olary region are ENE-WSW but highly divergent trends are apparent in the vicinity of the areas of basement outcrop. Only minor modifications of the fold patterns in the Willyama Complex have occurred during the Palaeozoic orogeny but a number of large vertical slip faults have altered the distribution of rock types.

## Nomenclature and correlation

The area mapped appears to be critical to a discussion of the stratigraphic relationships in both the older and younger Precambrian. Campana and King (op. cit.) recognized four main groups of rocks in the Willyama Complex, namely "Archaean Metasediments As"; "Feldspathised Archaean Metasediments Af"; "Migmatites and Granite Gneisses Am" and "Anatectic Granites, Granodiorites and Granulites Ag". The last group does not occur in the area mapped and is not discussed further. Campana envisaged the first three units as representing different stages of granitization of similar sediments and his map shows cores of Am surrounded by zones of Af and finally As, although a number of important exceptions do occur (e.g. near Old Boolcoomata Homestead).

The "metasediments" were divided into a lower group (Weekeroo Schists) a Middle Group (Ethiudna Calc-silicate Group) and an Upper Group (Outalpa Arkosic quartzites passing to granite gneisses)* (Campana and King, 1958, p. 21). The Ethiudna Group is said to occupy "a well defined stratigraphic horizon within the schistose succession". The relationship between the "Weekeroo Schists" and the "Outalpa quartzites" can be seen in a number of localities, e.g. Weekeroo, Old Boolcoomata and Ameroo Hill, where schists are in contact with gneisses, the contact being parallel to the layering in the gneisses. The middle or Ethiudna Group is shown by Campana to lie within the schist sequence in all localities shown on the map except in the type locality of Ethiudna Mines. In this locality, near Plumbago Head Station, the group consists of calc-silicates and dolomites in an isolated gneissic terrain whose "stratigraphic" position is unknown. The "stratigraphic" position of the Ethiudna Group as the Middle Group of metasediments is however determined by the position of amphibolites at Weekeroo, Ameroo Hill and Old Boolcoomata. In none of these localities do the rocks resemble the Ethiudna rocks and in fact in two of them the calc-silicates are intrusive igneous rocks. In addition, calc-silicates occur in other parts of the section (e.g. in the migmatitic schist unit at Weekeroo) and it is considered unwise to make long range correlations of this sort in gneissic terrains.

It is therefore proposed that use of the term Ethiudna Calc-silicate Group as a regional unit be discontinued.

The remaining rock types in the Weekeroo section were grouped by Campana and King into "Migmatite and Granitic Gneiss unit Am" with the genetic implication that they are more altered than the "Archaean Metasediments As". These have been subdivided in this study into 3 units which are recognised as part of the overall sequence and not as more metasomatized rocks.

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* On Campana's map of the Weekeroo region this unit is included with the "Migmatites and Granitic Gneisses Am", instead of with the "Metasediments As". This is clearly a drafting error.
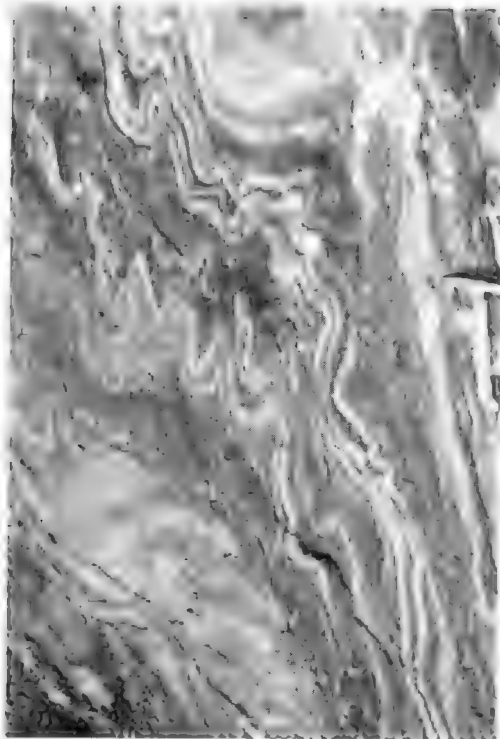
PLATE 1



Fig. 2.

Fig. 4.

Fig. 1.

Fig. 3.

A comparison of Campana and King's units and the units proposed for this study is shown in Table 1. The sequence proposed for this paper is not necessarily a sedimentary sequence although many of the rocks are sedimentary in origin. The origin of the layering and of the boundaries of the gross lithologic units is of special importance to this problem. In all the schist units except the bedded mica schist unit, layering, whether originally sedimentary or not, is now heavily transposed parallel to the second generation cleavage. Hence stratigraphic relationships within these units have been completely destroyed. Nevertheless, the gross relationship between the major lithologic units has not been profoundly altered by this second phase of deformation which resulted in the large scale folds now visible in the Willyama Complex.

TABLE 1

*Willyama Complex Sequence*

| | Sequence of Campana & King (1958)* inverted | Informal sequence used in this Paper |
|---|---|---|
| "Archaean" Metasediments (As) | Weekeroo Schist | Bedded mica schist. Mica Schist |
| | Ethiudna Calc-Silicate Group | |
| | Outalpa Quartzites† | Layered gneiss |
| Migmatites and Granite-Gneisses (Am) | Undifferentiated‡ | Granitoid gneiss Migmatitic schist Leucogneiss |

* Campana's sequence has been inverted as the evidence from the present study suggests that the schists are the youngest part of the Willyama Complex sequence.

† This unit is called "Arkosic Quartzites, Passing to Granite-Gneisses" in the text (Campana & King 1958 p.18) but is referred to by name in the map legend and also in Campana (1957).

‡ This unit was not recognised by Campana as a "stratigraphic unit" but as rocks in a particular state of alteration.

In contrast to the schist units the more massive gneissic units show relatively little transposition parallel to the new cleavage and even where folded show a foliation parallel to visible layering in the rocks. (Exceptionally a new foliation is developed in some rocks parallel to the axial surface of small folds.) In the more massive gneisses the foliation is discontinuous or defined by a preferred orientation of micas. In the layered gneisses foliation is well developed in the mica rich portions and is invariably parallel to the layering. In the quartzo-feldspathic layers trains of accessory minerals such as zircon and sphene are observed parallel to the gross lithological layering.

The evidence suggests that although the foliation is parallel to layering the presence of layering is not a necessary condition for the formation of the foliation. It seems unlikely therefore that the foliation represents a simple "bedding plane foliation" imposed on relatively undisturbed planar bedding. It is more likely that the gneissic units have been heavily deformed and that the parallelism of foliation and layering are the result of large scale isoclinal folds with possibly large amounts of transposition on a small scale. This phase of

deformation resulted in an essentially planar attitude of layering and foliation and was accompanied by high grade metamorphism and the formation of pegmatites. This planar layering was then folded by the second phase of deformation to give the observed major folds.

The succession of units in the Willyama Complex may not therefore have any stratigraphic significance (with exception of the bedded mica schist. This unit appears anomalous in the general context of the Willyama Complex and it was entertained that there could be an unconformity between it and the remaining units. No direct evidence could be found to support this suggestion)

The present study confirms the recognized stratigraphic relationships of the overlying Adelaide System. Campana emphasized the transgressive nature of the Umberatana Group and in the Weekeroo area an angular unconformity between the Burra and Umberatana Group is now well established. Recent mapping by the S.A. Mines Department has demonstrated this unconformity in many other parts of South Australia. Differences of interpretation however arise with structure and metamorphism. The differences in structural interpretation are of limited interest but the failure by Campana to recognise the metamorphism in the Adelaide System rocks may lead to an incorrect assessment of the economic potentialities of the younger group of rocks. Recognition that the rocks have been metamorphosed to the biotite grade also removes some of the limitations to the tectonic interpretation of the area, and also imposes strict limitations to age determinations in the Willyama Complex.

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## EXPLANATION OF PLATE

### PLATE 1

Fig. 1. Banding in gneiss near top of leucogneiss unit. Lat. 32° 13·7'S Long. 139° 56·8'E.

Fig. 2. Truncated laminations and scour and fill structure in granofels of the bedded mica schist unit. Lat. 32° 12·6'S Long. 139° 54'E.

Fig. 3. Transposed layering in the uppermost beds of the Burra Group. Arrows point to Fold closures. Lat. 32° 10·5'S Long. 139° 58·1'E.

Fig. 4. Bulk strain of the Umberatana Tillite as indicated by deformed dolomite erratics. 100 metres N of locality of Plate 1, Fig. 3.

# PHERETIMA TUMULIFACIENS (OLIGOCHAETA, MEGASCOLECIDAE) A NEW SPECIES OF EARTHWORM FROM THE SEPIK DISTRICT, NEW GUINEA

*BY* K. E. LEE*

## Summary

*Pheretima tumulifaciens,* a new species of earthworm, belonging to the family Megascolecidae, is described. It was found in the Sepik River Valley, northern New Guinea, where it is associated with unusual forms of micro relief that have been attributed to the earthworms' burrowing and casting. The species is most closely related to *P. sangirensis* (Michaelsen), from Indonesia, but in some respects resembles *Megascolex.* The inadequacy of generic distinctions and of the criteria for distinction of groups of genera are discussed.

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[Read 8 June 1967]

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## INTRODUCTION

Haantjens (1965) recorded micro-relief in the form of irregular pits, trenches, mounds and ridges, not unlike some periglacial phenomena, from the humid tropical grass-covered plains bordering the Sepik River valley, south of Wewak, in New Guinea. Populations of a large earthworm species were always associated with the micro-relief and Haantjens (1965) considered that they were responsible for the formation of the micro-relief features.

In October, 1965, the author visited four sites in the vicinity of Yangoru, where Haantjens had observed micro-relief features, to collect earthworms and examine the relationship between their activities and the micro-relief features attributed to them. At each of the sites, large earthworms belonging to an undescribed species of *Pheretima* Kinberg were collected. The earthworms were closely associated with the micro-relief features, as recorded by Haantjens, but it seemed unlikely that they were directly responsible for the micro-relief. A discussion of the micro-relief features and their possible origin will be published elsewhere (Lee (in press)). The large earthworm associated with the micro-relief features has been named *Pheretima tumulifaciens*, and is described below.

### *Pheretima tumulifaciens* n.sp.

*Collection Data.* (1) About 1½ mi S of Kworo Village, 20 mi SW of Yangoru, District, New Guinea; 0-33 cm in soil under kunai grassland; 2 clitellates; K.E.L. 22/10/65. (2) About ½ mi SW of Watibi no. 2 Village, 15 mi SW of Yangoru; 0-30 cm in soil under secondary forest; 1 aclitellate; K.E.L. 22/10/65. (3) About 1 mi N of Watibi no. 2 Village, 14 mi SW of Yangoru; 0-55 cm in soil at edge of deep trenches, under kunai grassland; 1 clitellate; K.E.L. 22/10/65. (4) About 1 mi SW of Haripmor Village, 15 mi SE of Yangoru; 0-45 cm in and under low mounds and ridges covered by kunai grassland; 6 clitellates; K.E.L. 23/10/65.

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* Division of Soils, C.S.I.R.O., Adelaide.

*Type Material.* Holotype and two syntypes lodged in South Australian Museum.

*Dimensions.* Mature specimens are 500-600 mm in length, 9-10 mm in diameter (in ethyl alcohol) and have 550-600 segments. Detailed measurements of the holotype are: Length 590 mm; segments 587; diameter 10·5 mm at vii, 9·5 mm at xiii, 9·5 mm at clitellum, tapering gradually to 6 mm at about half length and fairly uniform to posterior end. Posterior to iii the segments have secondary annulations, two to five per segment.

*Colour.* Pale greyish-brown with pale brownish-red clitellum.

*Chaetae.* Absent on i, otherwise about 140 per segment, evenly spaced on a slight ridge around each segment, nearer the anterior than the posterior margin of the segments; without a mid-dorsal gap, but with a small mid-ventral gap, about twice the normal chaetal interspace; a few chaetae missing immediately adjacent to each male pore, on xviii, and across the mid-ventral line adjacent to the female pores, on xiv.

*Prostomium* prolobous.

First dorsal pore at 10/11.

*Clitellum* covering entire body surface from slightly posterior to the chaetal ring on xiii to the line of the chaetal ring on xvii.

*Spermathecal pores*: one pair, at 7/8, each on a prominent, transversely elongate papilla, about 2 mm x 1 mm, the pores each about 3 mm from the ventral mid-line.

*Female pores*: one pair of small pores on xiv, about 0·75 mm apart, one each side of the ventral mid-line, surrounded by a pale elliptical area, in line with the chaetal ring.

*Male pores*: ventral on xviii, one on each side, each about 3·5 mm from ventral mid-line, in line with chaetal ring, not on papillae; each pore medial to a deep longitudinal groove, overhung by a prominent ventro-lateral ridge that runs longitudinally from xvii to xix (Figs. 1, 2).

*Tubercula pubertatis*: two pairs of prominent, flattened papillae, a pair on xvii and a pair on xix, each papilla about 3 mm diameter, forming, together with the prominent ventro-lateral ridges on xviii, the edges of a deep depression that occupies the ventral surface of xviii (Figs. 1, 2).

*Septa* v/vi, vi/vii, vii/viii and viii/ix are thickened and strongly muscular. Thick muscle fibres arise from the body wall in segments vi-ix and run forward to an insertion on the posterior surfaces of the muscular septa; some of the fibres are attached anteriorly to the pharynx and not to the septa. Similar muscles have been observed previously in many earthworms, especially in large species; their purpose is apparently to produce unusually powerful contractions of the anterior segments, probably to facilitate burrowing and provide the traction necessary to move the large bulk of the earthworm's body. In most species of *Pheretima*, septa viii/ix or ix/x, or both of them, are absent or greatly reduced in size. This is not so in *P. tumulifaciens*.

The *pharynx* occupies most of i-iv, and has a diffuse glandular coating, with many fine muscle fibres attached to the body wall. In v-vii the alimentary canal is a thin-walled tube with large finely lobate salivary glands lying beside it and opening by narrow ducts into the pharynx. *Gizzard* strongly muscular, in viii. *Oesophagus* extends from ix to xv where it expands abruptly into the *intestine*, close to the anterior end of xv. There is no typhlosole. Many species of *Pheretima* have a pair of rounded or conical intestinal caeca, arising in xvi
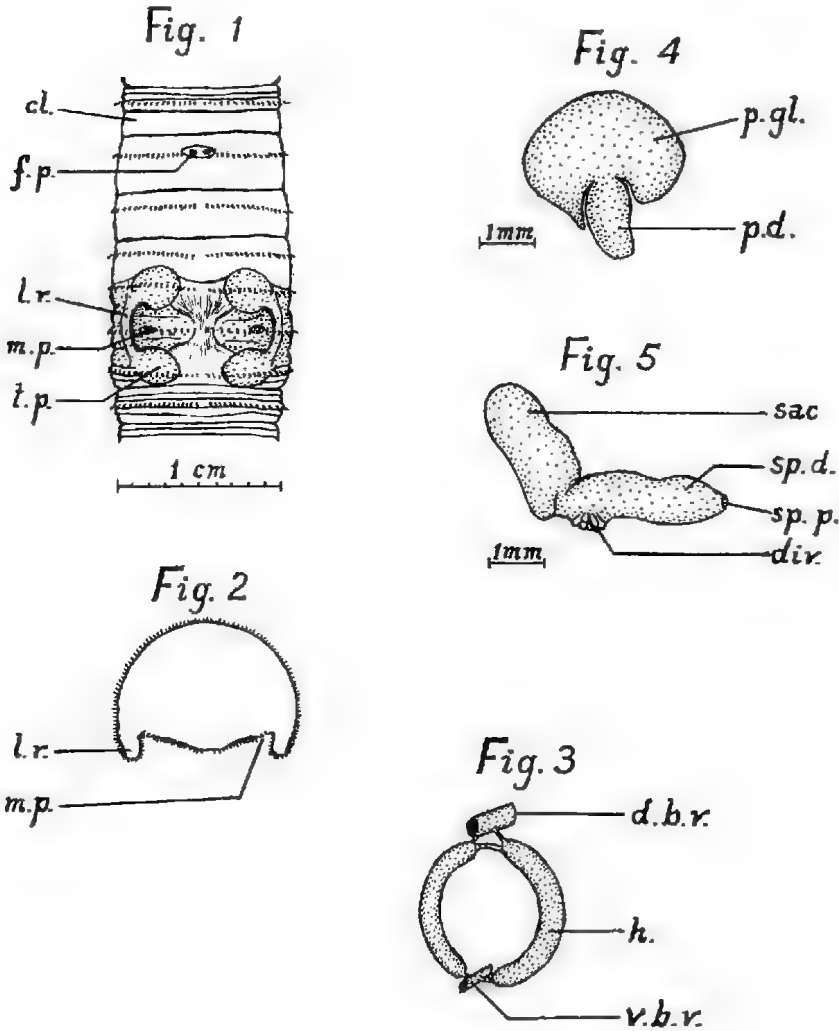
Fig. 1. *Pheretima tumulifaciens*, ventral aspect, segments xiii-xx.

Fig. 2. *P. tumulifaciens*, diagrammatic transverse section at segment xviii, to show position of male pores in relation to ventro-lateral ridges.

Fig. 3. *P. tumulifaciens*, arrangement of hearts of segment xiii in relation to dorsal and ventral blood vessels (diagrammatic).

Fig. 4. *P. tumulifaciens*, left prostate, medial aspect.

Fig. 5. *P. tumulifaciens*, left spermatheca, medial aspect.

ABBREVIATIONS

cl. = clitellum; d.b.v. = dorsal blood vessel; div. — spermathecal diverticulum; f.p. = female pore; h. = heart; l.r. = ventro-lateral ridge; m.p. — male pore; p.d. = prostatic duct; p.gl. = prostatic gland; sac = spermathecal sac; sp.d. = spermathecal duct; sp.p. = spermathecal pore; t.p. = tuberculum pubertatis; v.b.v. = ventral blood vessel.

or thereabouts, and projecting forwards, sometimes through several segments, usually pressed tightly against the ventro-lateral or lateral aspects of the intestine. There are no such caeca in *P. tumulifaciens*.

*Dorsal blood vessel* unpaired; it can be traced forward to the posterior end of the pharynx, where it divides into several branches. Stout commissural vessels (*hearts*) in x-xiii, one pair in each segment, connecting the dorsal and ventral blood vessels; the two vessels of each pair have a short transverse connection across the oesophagus, independent of the connection of the two vessels to the dorsal vessel (Fig. 3). There is no independent supra-intestinal vessel connecting the hearts longitudinally. In vii-ix similar lateral vessels arise from the dorsal vessels, but divide into a number of branches leading to segmental organs and are not "hearts". The *testes* are in x, xi; those of xi are in testis sacs that occupy much of the coelomic cavity in the segment. *Ovaries* in xiii. One pair of small, racemose *vesiculae seminales*, in ix. *Prostates* in xviii, one on each side; laminar glandular portion with branching ducts, all discharging into a short, stout, strongly muscular prostatic duct (Fig. 4). *Spermathecae* in viii, one pair, each discharging through a thick, muscular duct at the anterior margin of the segment; the sac is cylindrical, a little wider than the duct, projecting backwards into the segment and set off from the line of the duct; a cluster of small diverticula opens into the duct close to its junction with the sac (Fig. 5). *Micronephridia* are small and numerous in each segment, irregularly scattered over the peritoneum.

## DISCUSSION

*P. tumulifaciens* differs from most species of *Pheretima* in having well-developed, strongly muscular septa in the segments adjacent to the gizzard, a characteristic shared with many large megascolecid earthworms, especially those which, like *P. tumulifaciens*, make extensive burrow systems going down to considerable depths. In most species of *Pheretima* the anterior septa are not thickened and septa viii/ix or ix/x or both of these are absent, or much reduced. The absence of intestinal caeca also distinguishes *P. tumulifaciens* from many other species of the genus. The only character that decisively places this species in *Pheretima* is the position of the gizzard, in viii. If the gizzard were in v, vi, or vii, it would be placed in the genus *Megascolex*. There is need for a thorough re-examination of the criteria on which generic distinctions in megascolecid earthworms are based. Revised groupings of genera have been proposed by Gates (1959), Lee (1959) and Omodeo (1958). The proposed new groupings are based on slightly different bases, but none of the proposals has contributed greatly to the improvement of the state of confusion that has developed over the years since Michaelsen (1900) and Stephenson (1930) defined the genera and grouped them into sub-families and families on the basis of a supposed "family tree" of generic relationships, derived from a study of only a few anatomical characters. Sims (1966) has attempted to clarify the relationships between genera, using a computer to assess the affinities of 30 species, belonging to 29 megascolecid genera, on the basis of 48 attributes of each species. The results of his study favoured the scheme of classification proposed by Gates (1959) for taxonomic categories above the level of genera. Computer techniques may make a useful contribution to megascolecid taxonomy, as they make it possible to assess relationships on the basis of a larger number of attributes than can be handled by traditional taxonomic methods. However, if computer techniques are to be used, it is at the level of definition of genera that they can probably contribute most, and Sims' study assumes that the genera are adequately defined.

*P. tumulifaciens* shows closest affinities to *P. sangirensis* (Michaelsen), an Indonesian species. Similarities and differences between the two species are summarised below.

|                          | *P. tumulifaciens*                      | *P. sangirensis*                    |
|--------------------------|-----------------------------------------|-------------------------------------|
| Spermathecal pores       | 1 pair, at 7/8                          | 1 pair, at 7/8                      |
| Female pores             | paired, close to ventral mid-line       | unpaired, median ventral            |
| Septum viii/ix           | present, muscular                       | present, membranous                 |
| First intestinal segment | xv                                      | xv                                  |
| Intestinal caeca         | absent                                  | sometimes present, very short       |
| Vesiculae seminales      | 1 pair, in ix                           | 2 pairs, in xi, xii                 |
| Spermathecal diverticula | cluster of small diverticula            | 1 ellipsoidal diverticulum          |

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# PERMIAN DEPOSITS OF SOUTH AUSTRALIA AND THEIR FAUNA*

*BY N. H. LUDBROOK†*

## Summary

Lower Permian sediments occur in all the main sedimentary basins of South Australia. The Cape Jervis Beds are described, and the Lake Phillipson Beds and Stuart Range Beds formally named. In general, the formations follow a sequence of boulder clay overlain by sands and clays mostly of marine origin, with a widely distributed fauna of arenaceous foraminifera of which *Hyperammina*, *Ammodiscus*, and *Hemidiscus* are the most common. Twenty-three species, of which four are new, are recorded or described. The most varied fauna occurs in the Stuart Range Beds from which the gastropod *Peruvispira* was recovered.

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## by N. H. Ludbrook[†]

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## INTRODUCTION

As recently as 1955, Permian sedimentation in South Australia was so imperfectly known as, on a map of Australia showing regions of Permian sedimentation (Hill, 1955), to be restricted to glacial deposits in a southeast-northwest trough south of Adelaide, extending from Encounter Bay to western Yorke Peninsula. While this is still recognized as the main area of outcropping Permian glacigene sediments, Lower Permian sands and clays have been proved by exploratory drilling to occur widely in all the main sedimentary basins. Moreover, as reservoir beds for natural gas accumulation in the Great Artesian Basin, Permian rocks have assumed an economic importance not foreseen a decade ago (Sprigg, 1966).

Until foraminifera were discovered in the Permian section of Minlaton Stratigraphic Bore (Ludbrook, 1956), the depositional environment of most of the Permian sediments in South Australia was misunderstood. It was generally believed that the sandy nature of most of the deposits indicated a fluvio-glacial origin, and that "fluvio-glacial depositions in ponded waters are but rarely met with in our Permo-Carboniferous strata and marine depositions of this age are entirely absent" (Mawson, 1926). The ubiquity of foraminifera in the Lower Permian in all the main sedimentary basins, except that part of the Great Artesian Basin, including the Cooper's Creek Sub-basin, occurring in the northeast of the State, disproves this belief.

After initial over-deepening by ice, marine incursions in fjords or narrow troughs took place in two main and widely-separated areas following the general southeast-northwest trend. The southeastern area includes the Murray and St. Vincent Basins and the northwestern area the part of the Great Artesian Basin lying between the Peake and Denison Ranges, Stuart Range, and Margaret Creek.

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Localities from which Permian marine sediments have been proved in surface sections or by drilling are shown in Fig. 1.

All material and figured specimens are housed in the collections of the Geological Survey of South Australia, except those lent by the Geology Department, University of Western Australia (UWAGD).
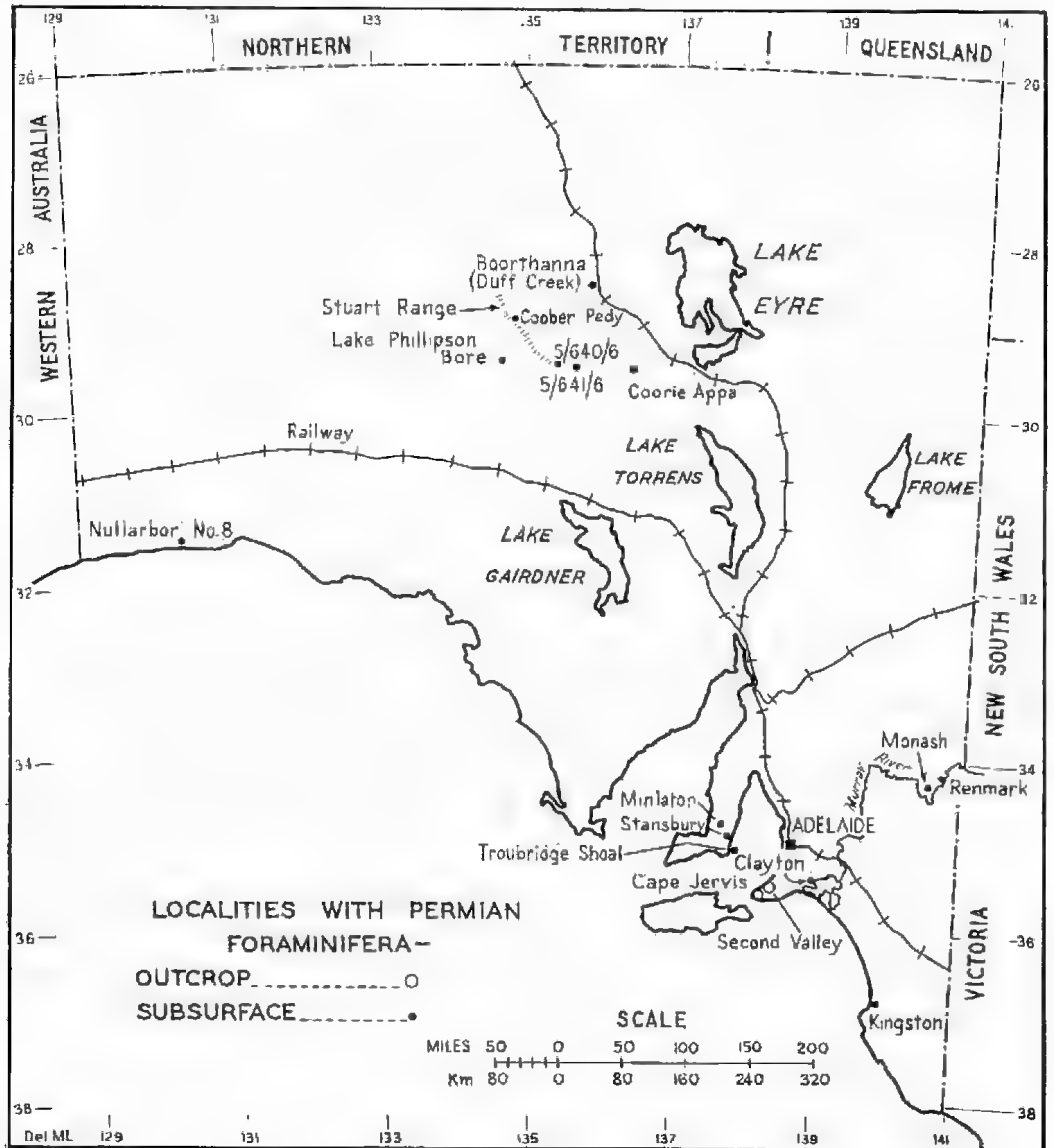
Fig. 1.   Map showing localities with Permian foraminifera.

## ST. VINCENT BASIN AND ADJACENT AREAS

Since Selwyn's recognition in 1859 of glacial features in the valley of the Inman River, there has accumulated a considerable volume of descriptive literature on the Permo-Carboniferous or Permian glaciation and glacial deposits in

the St. Vincent Basin and adjoining areas to the east on Fleurieu Peninsula and
to the west on Yorke Peninsula. The papers of Howchin (1926) and Campana
and Wilson (1955) may be consulted for historical reviews and comprehensive
lists of references.

Without designating any standard section, Howchin described most if not
all of the known exposures of Permian deposits in the area between Adelaide
and Kangaroo Island. The sequence at Hallett Cove he referred to as the
"Hallett's Cove beds" (1895, p. 65), while the glacigenes of Inman Valley were
variously designated "Inman Valley Shale" (1895, p. 68) and the "Inman River
Beds" (1926, p. 102). Unfortunately, neither of the names Hallett Cove nor
Inman is now available for stratigraphic purposes as they have been applied
to other units.

The most complete outcropping sequences described by Howchin are those
at Hallett Cove, Cape Jervis (David and Howchin, 1897) and King's Point,
near Victor Harbor (1910a). Of these David and Howchin recognized the
section at Cape Jervis as "the most extensive development of glacial till that
has been up to the present observed in South Australia" (1897, p. 64). The
section was illustrated but not redescribed by Campana and Wilson (1953, 1955).

The Cape Jervis exposure is here described by R. B. Wilson and the writer
as the holostratotype section of the Permian deposits of St. Vincent Basin and
the adjoining areas:

*Cape Jervis Beds* (Fig. 2).

*Type Section*: Jervis 1-mile geological sheet.

On coast, extending for one mile (1·609 km.) northeast of Cape Jervis
Lighthouse, Hundred of Yankalilla, sections 212, 211, 3009, 3010.

*Thickness*: 98 feet (29·87 m.).

The Cape Jervis Beds are unconformable upon easterly dipping greywackes
of the Cambrian Kanmantoo Group. They are overlain by kunkar. The type
section is described as follows:—

| Unit | Lithology | Thickness feet | metres |
|------|-----------|------|--------|
| 6 | Poor outcrop, grass covered slopes, probably clay as below, boulders on surface | 23·5 | 7·2 |
| 5 | Clay shale—grey-brown, fissile, gritty with scattered boulders, becoming red-grey mottled toward top | 29·5 | 9·0 |
| 4 | Sandstone—yellow-white, cross-bedded, with scattered calcareous pebbles | 5 | 1·5 |
| 3 | Sandstone—gritty sandstone and grit with boulders and thin interbeds of laminated fissile grey clay | 13 | 3·9 |
| 2 | Till—dark grey boulder till with clay-shale bands | 5 | 1·5 |
| 1 | Till—sandy till with boulders of all sizes, principally Kanmantoo greywacke and Victor Harbor Granite. Thin (6 inches to 1 foot; 0·15 − 0·3 m.) limestone bands | 22 | 6·7 |
| BASE | | | |
| | Total measured thickness of Cape Jervis Beds unconformably overlying Cambrian Kanmantoo Group | 98 | 29·8 |

The fossil locality number is 5/837/2 (Jervis 2). The grey clay and over-
lying red and grey gritty clay of bed 5 are fossiliferous, arenaceous foraminifera
being present in samples C.J. 7 and C.J. 8. Abundant tests of *Recurvoides
wilsoni* Ludbrook sp. nov. accompanied in decreasing order of abundance by

*Hyperammina coleyi* Parr, *Ammovertella howchini* Ludbrook sp. nov., *Digitina recurvata* Crespin and Parr, *Ammodiscus oonahensis* Crespin and *Hyperammina acicula* Parr.

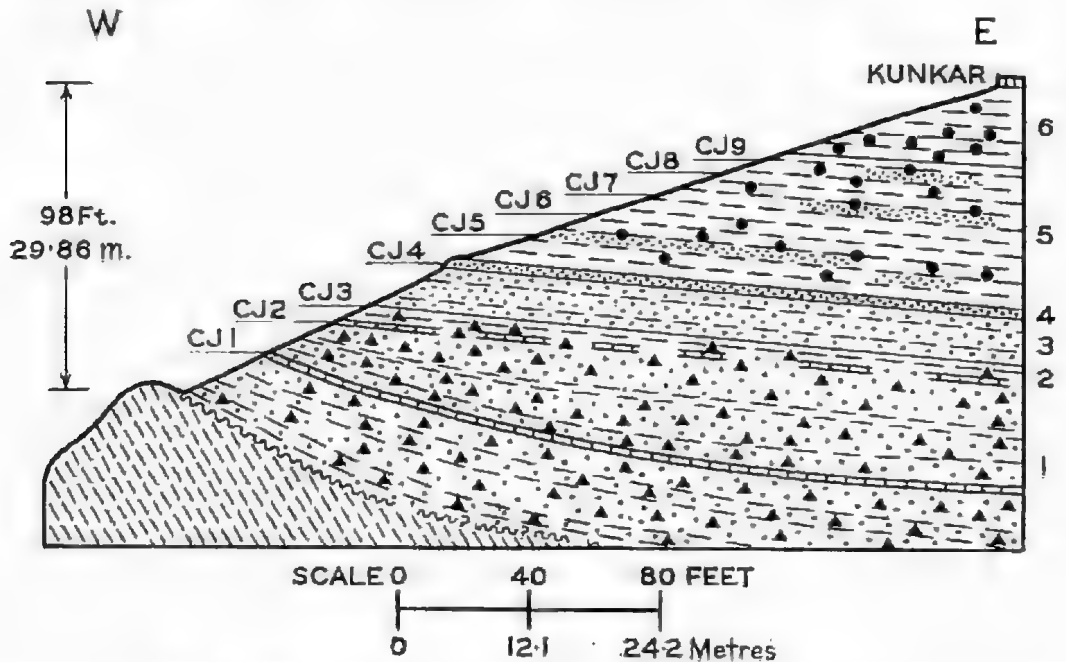The Cape Jervis Beds are extensively developed on Jervis and Yankalilla 1-mile sheets.



Fig. 2.   Sketch of type section of Cape Jervis Beds, Cape Jervis.

A southerly view of the Cape Jervis section showing the Cape Jervis Beds (C.J.) overlying Kanmantoo greywacke (K) is shown on plate 1, figure 1.   Fig. 2 illustrates the lower part of the section to the sandstone ledge at 40 feet (12 m.) above the base; the interbedded nature of the sandstone and clay and the tendency for the boulders to be bedded in some parts of the section is also shown at the position of the hammer.   Fig. 3 illustrates the dip (probably depositional) and bedding of the same part of the section as figure 2, viewed south.   Fig. 4 is that of a striated boulder on boulder clay at the most northerly end of the exposure.

The Cape Jervis Beds are very subject to gully erosion which is illustrated in plate 2, figure 1 of the northern part of the exposure.

The section at Cape Jervis provides confirmatory evidence of marine incursion in the Adelaide region following initial overdeepening by glaciation in the late Carboniferous to early Permian.   Previously a few broken fragments of *Hyperammina* were recovered from clay collected by B. P. Thomson from Second Valley (locality Jervis 1, 5/837/1), but no other foraminifera had been observed in Permian glacigenes between Adelaide and Kangaroo Island.

Parastratotype sections of the Cape Jervis Beds are exposed at Hallett Cove where the formation rests on striated pavements now declared a national reserve, and at King's Point west of Rosetta Head, on Encounter Bay, where the sequence

of moraine, glacial till, and sandstone described and illustrated by Howchin in 1910 is still undisturbed (plate 2, figure 3).

At Selwyn's Rock (plate 2, figure 2) the southern bank of the Inman River has recently been considerably eroded at the position of the large erratic in boulder clay overlying the striated pavement.

Exposures, however, nowhere attain any great thickness, and Permian sedimentation in the Adelaide region consists for the most part of infilling of overdeepened glacial valleys and basins as those of Fleurieu Peninsula (Campana and Wilson, 1953, 1955) and Kangaroo Island where a bore at Kingscote in 1909-1910 intersected 950 feet (289 m.) of typical Permian sequence before bottoming in slate. Leaf impressions were collected in 1953 by R. C. Sprigg, then of the Geological Survey of South Australia, in Permian sediments three miles (4·8 km.) southwest of Penneshaw. Their fragmentary nature precluded identification at the Australian Museum other than that they were possibly portions of equisitaean stems.

In the St. Vincent Basin and adjoining areas only the lower part of the Permian sequence appears to be represented. The absence of coals and of good microflora-bearing clays demonstrates that the Artinskian and upper part of the Sakmarian are missing in this area. On the other hand, the occurrence of Permian megaspores in the lower Tertiary of the St. Vincent Basin suggests that the absence of the upper part of the sequence may be due to erosion rather than to non-deposition.

The Permian is 776 feet (236 m.) thick on Yorke Peninsula where it provides the clay pans for the salt lagoons which are exploited for commercial salt production. The sequence was completely intersected in Minlaton and Stansbury Bores (Ludbrook, 1966a). In Beach Petroleum Troubridge Shoal No. 1 Stratigraphic Well, 750 feet (228 m.) of Permian sediments were cut between 850 feet and the total depth of the well. Foraminifera occurring sporadically between 1,010 and 1,550 feet (307·8 and 472·4 m.) permit close correlation with the marine interval in Stansbury Bore. Here also the upper Sakmarian-Artinskian carbonaceous sediments are absent.


## MURRAY BASIN

Presumed Permian glacigene sediments were proved by drilling in the Murray Basin in South Australia at Renmark, Monash and Clayton. A.O.C. North Renmark No. 1 entered at 3,245 feet (989 m.) blue-grey boulder clay irregularly interbedded with calcareous sandstone in irregular lenticles and laminae. Slump structures were common, while erratic pebbles and grains of quartz, granite, grey metamorphic rocks and dark pink feldspar were variously scattered throughout the groundmass. Faceted pebbles were recovered at 3,431 feet (1,045 m.). At 3,788 feet (1,154 m.) (Core 15) there was a calcareous pyritic quartz sandstone, and at 3,884 feet (1,184 m.) (Core 16) blue-grey shale irregularly interbedded with lenses of calcareous sandstone containing pink feldspar, biotite and pink garnet. The well bottomed in sandstone with scattered coal fragments and conglomerate bands, small slump structures and swirls of fine clay. Foraminifera occurred in almost all the cuttings between 3,410 and 4,000 feet (1,039 and 1,219 m.), but as none were recovered from cores their persistence does not necessarily indicate marine environment for the lower part of the interval.

Similar sediments with a few foraminifera were intersected in Beach Petroleum Monash No. 1 Well between 2,930 and 3,320 feet (893 and 1,011 m.). The formation was conglomeratic at 3,285 feet (1,001 m.).

A considerable thickness of at least 1,600 feet (487 m.) of Lower Permian sands and shale was intersected in W.G. Goyder Donna No. 1 Well drilled at Clayton, 5½ miles south-southwest of Milang, near the southwestern margin of the Murray Basin. At 500 feet (152 m.) the well passed into brownish mudstone with fine muscovite and some carbonaceous matter. This was a thin bed overlying pyritic sand with subangular to subrounded quartz and pink garnet grains, grading to sandstone and sand with some interbeds of fine-grained calcareous sandstones. The quartz grains were more or less rounded, with pitted surfaces; pink garnet was common and pyrite usually present with accessories of muscovite, feldspar and lithic grains. A few foraminifera, either *Ammodiscus* or *Hemidiscus*, were present in most samples between 540 and 1,050 feet (161 and 320 m.).

Without the evidence of foraminifera these sediments would be regarded as "fluvio-glacial". In Donna No. 1 Well there is less evidence of boulder clay, while the sands for the most part are worn and of reasonably uniform size. The section therefore corresponds to the Lower Sakmarian marine sediments in the Yorke Peninsula bores. Owing to drilling difficulties good bottom cores were not obtained to prove the base of the sequence.

Sediments of possible Permian age with a species of *Trochammina* not known from other Permian sediments in South Australia occur below 255 feet (77 m.) in a water bore at Blackford on section 500, Hundred of Murrabinna.

## GREAT ARTESIAN BASIN
### *Western Part — Lake Phillipson and Boorthanna Troughs*

Following the recognition of 2,000 feet of Permian sediments in Lake Phillipson Bore (Balme, 1957), the sequence of Lower Permian rocks underlying the western part of the Great Artesian Basin was described by Ludbrook (1961), and the history of their deposition and geological setting reviewed by Wopfner (1964). The Lake Phillipson and Boorthanna Troughs between Lake Phillipson and the Peake and Denison Ranges contain the most complete succession identified by Balme as Sakmarian-Artinskian, consisting in upward sequence of a maximum of 2,974 feet of glacial till and boulder clay, marine mudstones and siltstones, overlain by *Glossopteris-* and *Gangamopteris-*bearing freshwater silts and clays with sandstone and coal interbeds now described from the Arckaringa Sub-basin as the Mount Toondina Beds (Freytag, 1965). All but the uppermost coal beds were recently intersected between 490 feet (149 m.) and the total depth of 2,043 feet (623 m.) in Stuart Range No. 3 Bore, drilled by the South Australian Mines Department in search of additional underground water supplies for Coober Pedy Opalfield. The marine formation below the Mount Toondina Beds in this well provided the most significant fauna so far recovered from the South Australian Permian. Stratigraphic, lithological, and palaeontological details of this well are in press (Ludbrook, 1967).

Except for the Mount Toondina Beds, the Permian sediments in the Lake Phillipson and Boorthanna Troughs have not been formally named. Balme (1964) informally used the names "Lake Phillipson Coal", "Lake Phillipson Glacials", in tabulating the stratigraphic position of pre-Tertiary micro-floras, and the names "Coober Pedy Beds" and "Stuart Range Beds" on a locality map of Permian localities from which palynological data were available. It is here

proposed to formalize the names Lake Phillipson Beds for the glacigenes at the base of the sequence and Stuart Range Beds for the mudstones and silt-stones, marine in part at least, between the glacigenes and the Mount Toondina Beds, using Lake Phillipson Bore (Ludbrook, 1961) as the standard subsurface section.

The *Lake Phillipson Beds* are so named to avoid further duplication of stratigraphic names for the glacigene boulder clays or till at the base of the Permian sequence. It is recognized that the boulder beds occur in outcrops on the Oodnadatta and Warrina 1:250,000 sheets from which a type section might be selected to comply with the Australian Code of Stratigraphic Nomenclature. The relationship of these outcrops to the Lake Phillipson Beds or to the Crown Point Formation of the Northern Territory is not, however, firmly established. Scattered occurrences of Permian(?) tillite were briefly described and mapped in the Peake and Denison Ranges west of Mount Dutton, 45 miles (7·2 km.) north-northeast of Warrina, three miles (4·8 km.) northeast of Duff Creek Siding and three miles (4·8 km.) northeast of Box Creek Siding (Reyner, 1955).

In the standard section, the Lake Phillipson Beds occurring between 2,357 feet (718 m.) and 3,140 feet (957 m.) overlie granite basement and consist of the sequence already described (Ludbrook, 1961) of 783 feet (238·7 m.) of grey boulder clay with some limestone and calcareous sandstone.

The Lake Phillipson Beds were intersected in Stuart Range No. 3 Bore between 1,660 feet (505 m.) and the total depth 2,043 feet (623 m.) in which the formation consisted of 100 feet (30·4 m.) of pinkish sandstone with scattered coarse quartz grains, red feldspar, pyrite, biotite, pink garnet, granite pebbles and 283 feet (86·2 m.) of boulder conglomerate with granite and other boulders of heterogeneous rock types.

The formation was also intersected in Coorie Appa and Margaret Creek Bores (Ludbrook, 1961).

*The Stuart Range Beds* overlie the Lake Phillipson Beds. So far they have not been recognized in outcrop. They are 1,613 feet (491·6 m.) thick between 744 feet (226·7 m.) and 2,357 feet (718 m.) and were described (Ludbrook, 1961) as a sequence of 88 feet (26·8 m.) of blue-grey mudstones with foraminifera, overlain by 1,525 feet (464·8 m.) of sandstones and siltstones. Only the lower unit in Lake Phillipson Bore appears to contain foraminifera.

The Stuart Range Beds are well distributed in the Coober Pedy-Stuart Range area of the Lake Phillipson Trough and in the Boorthanna Trough. They were intersected between 910 feet (277 m.) and 1,660 feet (505 m.) in E. & W.S. Stuart Range No. 3 Bore where they contained an abundant and persistent fauna of foraminifera with rare molluscs, ostracodes and vertebrate remains. They are represented in samples of grey clay collected from spoil from three bores on Balta Baltana Station on Billa Kalina 1:250,000 sheet, Balta and Ware 1-mile sheets. The depths at which the Stuart Range Beds were intersected are not known accurately, but they are known to underlie the Lower Cretaceous Marree Formation. Localities of the bores Balta Baltana No. 1 (Ware 5, 5/641/5), No. 2 (Ware 3, 5/641/3), No. 3 (Balta 6, 5/640/6) are shown on Map 8 Billa Kalina (Ludbrook, 1966b). All contained foraminifera which were abundant at locality 5/641/5. In the Boorthanna Trough the beds appear to attain their greatest thickness of 1,903 feet (580 m.) in Boorthanna (Duff Creek) Bore, thinning out to the south to 240 feet (73 m.) in Coorie Appa Bore and rapidly disappearing to the east of a line between Boorthanna, Anna Creek and Coorie Appa.

It may be anticipated from seismic data (Moorcroft, 1964; Freytag, 1965) and the Permian isopach map of Kapel (1966) that over 3,000 feet (914 m.) of similar sediments occur in the Arckaringa Sub-basin southwest of Oodnadatta and north of the Boorthanna Trough.

### Northern South Australia: Simpson Desert

Lower Permian sections were intersected in two wells, Witcherrie No. 1 and Purni No. 1 of French Petroleum Company (Australia) Pty. Ltd., located in the north of South Australia on the southern margin of the Simpson Desert. The sequence consisted of an upper unit 41 feet (12 m.) thick of dark shale with coal and a lower unit consisting of 290 feet (88 m.) of sandstone and shale and 241 feet (80 m.) of siltstone and shale with quartzite pebbles (Canaple and Smith, 1965). The upper unit which has been compared with the coal sequence in Lake Phillipson Bore presumably belongs to the Mount Toondina Beds, while the lower unit is regarded by Canaple and Smith as equivalent to the Crown Point Formation.

### Northeastern South Australia: Cooper's Creek Sub-basin

In the Permian of the Cooper's Creek Sub-basin to the northeast of South Australia gas discoveries have been made on the Gidgealpa and Moomba structures. The sequence of three disconformably transgressive units has been named (Kapel, 1966) the Gidgealpa Formation.

The Permian sediments were described by Greer (1965) as sandstones, lignitic shales and coals which accumulated in alternating coastal swamps, brackish lagoonal and shallow-water marine environments. In Gidgealpa No. 1 Well, the Permian is "underlain by 400 feet of Permo-Carboniferous marine shales and sands". Kapel (1966) subdivided the Gidgealpa Formation into three subunits: a lower of sandstone, shale and coal; a middle of shale, siltstone and minor coal; a top subunit of sandstone minor shale and coal. Wopfner (1966) divided the Formation into a lower Permian unit of conglomerate and sedimentary breccia in black or dark grey silty matrix, and carbonaceous shale interbeds, and an upper Permian unit of light grey fine- to very coarse-grained sandstone, dark grey carbonaceous shale and coal seams.

The Formation therefore has yet to be formally defined. The highly carbonaceous nature of most of the sequence is in contrast to the low carbon content of the light grey claystones and sandstones containing foraminifera which occur over the boulder clays elsewhere in South Australia.

Upper Permian carbonaceous siltstone, silty sandstone, conglomerate and arkosic crossbedded sandstone with coal and plant remains were intersected in Delhi-Frome-Santos Innamincka No. 1 Well in the northeast of the State.

## EUCLA BASIN

Knowledge of Permian sediments in the Eucla Basin is limited to the single occurrence of Artinskian fossiliferous clay in Nullarbor No. 8 (Yangoonabie) Bore (Harris and Ludbrook, 1966).

## FAUNA AND AGE OF THE PERMIAN DEPOSITS

The fauna contained in the Cape Jervis Beds, the Stuart Range Beds, and their equivalents, is sparse, indicative of a restricted environment of low temperatures or low salinity. With two exceptions, the faunal assemblage consists

only of 23 species of arenaceous foraminifera, of which species of *Hyperammina*, *Ammodiscus*, and *Hemidiscus* are the most common and ubiquitous. *Hippocrepinella biaperta* Crespin and *Reophax thomasi* (Crespin) are distributed in small numbers in all the sedimentary basins; *Lagenammina ampulla* (Crespin) and *Glomospirella nyei* Crespin are restricted to the Lake Phillipson trough; *Thuramminoides sphaeroidalis* Plummer, *Ammovertellina* (?) *glomospiroides* Ludbrook sp. nov., *Glomospira adhaerens* Parr, *Tolypammina undulata* Parr, *Recurvoides wilsoni* Ludbrook sp. nov., are well distributed frequently in abundance. As the foraminiferal fauna is almost entirely endemic it provides no reliable basis for correlation. *Thuramminoides sphaeroidalis* described from the American Pennsylvanian is known to have a range of Middle Silurian to Permian, while (?)*Hyperammina expansa* (Plummer) was described from the Middle Pennsylvanian Strawn Group of Texas.

The most significant fossil so far recovered is the gastropod *Peruvispira* in Stuart Range No. 3 Well at 1,285-1,305 feet. This genus, known only from Lower to Middle Permian marine rocks, confirms the Permian age of the Stuart Range Beds determined by Balme (1957) from microfloral evidence. In Stuart Range No. 3 Well the single specimen of *Peruvispira* was associated with a fragment of ? *Conularia*. Other sparse elements of the fauna include ostracodes and vertebrate remains which have not been identified.

## SYSTEMATIC DESCRIPTIONS
### Order FORAMINIFERIDA
#### Superfamily AMMODISCACEA
#### Family ASTRORHIZIDAE
#### Subfamily RHIZAMMININAE
#### Genus HIPPOCREPINELLA Heron-Allen and Earland, 1932
#### Hippocrepinella biaperta Crespin
pl. 3, fig. 1

1958. *Hippocrepinella biaperta* Crespin, 37, pl. 1, figs. 1-18.

*Description.* Test free, broadly elongate, consisting of a single tube open at both ends, sides parallel, ends constricted, the greatest constriction towards the aperture which is surrounded by a more or less thickened lip, aboral end open, less thickened when it is preserved, but usually broken off; wall thick, wrinkled, agglutinating, consisting of quartz grains in a siliceous matrix.

*Dimensions.* Hypotype Ff379, length 1·05, width 0·25 mm.

*Type Locality.* Oonah, Tasmania; Quamby Mudstone.

*Material.* Hypotype G.S.S.A. Ff379; 51 specimens.

*Distribution.* Minlaton Bore, Stuart Range No. 3 Bore, Fossil localities Ware 5 (5/641/5) and Balta 6 (5/640/6), Nullarbor No. 8 Bore, A.O.C. North Renmark No. 1 Bore.

*Stratigraphic Range.* Lower Permian.

#### Subfamily HIPPOCREPININAE
#### Genus HYPERAMMINA Brady, 1878
#### Hyperammina acicula (Parr)
pl. 3, fig. 7

1942. *Hyperamminoides acicula* Parr, 105, pl. 1, figs. 4, 5; pl. 2, fig. 4.
1958. *Hyperammina acicula*; Crespin, 44, pl. 5, fig. 11; pl. 6, fig. 7 (synonymy).

*Hyperammina acicula* is a large tapering species with a thick smoothly finished wall with much cement. Fragments only have been recovered in South Australia, but they compare with paratype material.

*Dimensions.* Holotype length 11 mm., greatest diameter 1·3 mm., paratype on UWAGD slide 20767 length 11 mm., greatest diameter 1·2 mm.; the figured hypotype GSSA Ff370 is only 1 mm. long.

*Material.* UWAGD 20767 five paratypes, 20770 three paratypes, 20771 one paratype, 20772 four paratypes. 195 fragments in South Australian samples.

*Distribution.* Stansbury and Minlaton Bores; locality Balta 6 (5/640/6), Boorthanna, Coorie Appa and Stuart Range No. 3 Bores; Goyder Donna No. 1 Bore; Nullarbor No. 8 Bore.

*Stratigraphic Range.* Lower Permian.

### Hyperammina coleyi Parr
pl. 3, figs. 8, 9

1942. *Hyperammina coleyi* Parr. 104, pl. 2, fig. 3; 1958. Crespin. 46, pl. 6. figs. 5, 6; pl. 7, figs. 3-5; pl. 33, figs. 1-2.

*Hyperammina coleyi* is a large species with a subglobular proloculus and a slender tubular chamber of lesser diameter than the proloculus. The wall is thick, firmly but not smoothly cemented as in *H. acicula*; the surface is rough.

*Dimensions.* The type series ranges in length to 9 mm., the proloculus diameter 0·5-1 mm., tubular chamber diameter 0·5 mm. Figured hypotype GSSA Ff371 proloculus diameter 0·55, diameter of tube 0·45 mm.

*Material.* UWAGD 20766 three paratypes, 20769 one paratype, 20770 two paratypes, 20771 four paratypes, 20772 one paratype; 100 fragments in South Australian samples.

*Distribution.* Cape Jervis; Stuart Range No. 3, Stansbury and Nullarbor No. 8 Bores.

*Stratigraphic Range.* Lower Permian.

### (?) Hyperammina expansa (Plummer)
pl. 3, fig. 10

1945. *Hyperamminoides expansus* Plummer. 223, pl. 16, figs. 1-6.
1958. *Hyperammina expansa*; Crespin, 49, pl. 4, figs. 9-11.

Short flaring specimens with a thick wall and apparently wide aperture in undamaged specimens belong to the species referred by Crespin (1958, p. 49) to *Hyperamminoides expansus* Plummer. As the genus *Hyperamminoides* has been synonymized by Loeblich and Tappan (1964) with *Hippocrepina*, and Conkin (1961, p. 261) has noted similarities between *H. expansa* and the microspheric form of *Hyperammina casteri* Conkin the specific identification and affinities of the Australian species must remain in doubt.

*Dimensions of Figured Specimen.* Height 0·4, diameter 0·4 mm.

*Type Locality.* Algerita, Texas, U.S.A.; Strawn Group, Middle Pennsylvanian.

*Material.* Hypotype GSSA Ff372; 11 specimens.

*Distribution.* Stansbury, Coorie Appa, Stuart Range No. 3 and AOC North Renmark No. 1 Bores.

*Stratigraphic Range.* Middle Pennsylvanian; ?Lower Permian.

## Hyperammina hebdenensis Crespin
pl. 3, figs. 2-6

1958. *Hyperammina hebdenensis* Crespin, 52, pl. 6, figs. 8-12.

*Description.* Test free, small, broad, straight, consisting of a globular proloculus followed by a nearly straight tubular second chamber; wall agglutinating, moderately thin, with fine quartz grains in much cement. The cement is usually siliceous but some specimens have calcareous cement. Aperture a large circular opening at the end of the tube.

*Dimensions.* Hypotype GSSA Ff375 length 0·75, proloculus diameter 0·25; hypotype GSSA Ff376 length 1·26, diameter 0·6 mm.

*Type Locality.* Hebden, N.S.W., Mulbring Subgroup.

*Material.* 526 fragments.

*Distribution.* Ubiquitous in South Australian material.

*Stratigraphic Range.* Lower Permian.

*Observations.* It is not always easy to distinguish *H. hebdenensis* from *H. coleyi* when they usually occur as tubular fragments. In this study the two have been differentiated by the wall thickness with relatively little cement in *coleyi*; the smaller size, relative smoothness of the wall finish and the fact that the tube diameter is only a little less than that of the proloculus in *H. hebdenensis*.

## Family SACCAMMINIDAE
### Subfamily SACCAMMININAE
### Genus LAGENAMMINA Rhumbler, 1911
### Lagenammina ampulla (Crespin)
pl. 3, fig. 14

1958. *Pelosina ampulla* Crespin, 42, pl. 2, figs. 1-3.

*Description.* Test free, consisting of a single flask-shaped globular chamber; wall agglutinating, consisting of very fine quartz grains in much siliceous cement; aperture usually oval, terminal, at the end of a short neck.

*Dimensions.* Hypotype length 1·00, width 0·8 mm.

*Type Locality.* Oonah, Tasmania; Quamby Mudstone.

*Material.* Hypotype GSSA Ff387; 7 specimens.

*Distribution.* Locality Ware 5 (5/641/5), Stuart Range No. 3 Bore.

*Stratigraphic Range.* Lower Permian.

*Observations.* Conkin (1961, p. 248) noted the obscurity of the affinities of *Proteonina* Williamson, 1858, *Lagenammina* Rhumbler, 1911, and *Saccammina* Sars, 1869. *Pelosina ampulla* Crespin possesses the diagnostic features of *Lagenammina* rather than those of *Pelosina* as it has been redefined by Loeblich and Tappan (1964, p. C200).

## Genus SACCAMMINA M. Sars in Carpenter, 1869
### Saccammina orca Ludbrook sp. nov.
pl. 3, figs. 11-13

*Description.* Test free, large, solid, consisting of a single globular chamber of somewhat variable shape; it is commonly barrel-shaped with irregular annular constrictions but may be flatly spherical without apertural neck, or flask-shaped with a broad neck; wall thick, consisting of an inner pseudochitinous layer and

an outer layer of quartz grains held together by calcareous cement; exterior roughly finished; aperture oval, usually without neck, but may be at the end of a broad, short neck.

*Dimensions.* Holotype Ff384 length 1·8, diameter 1·1; paratype Ff385 length 1·15, diameter 0·75; paratype Ff386 length 1·2, diameter 1·1 mm.

*Type Locality.* E. & W.S. Stuart Range No. 3 Bore, 1,305 feet 8 ins.-1,327 feet.

*Material.* 368 specimens.

*Distribution.* Stansbury Bore; locality Balta 6 (5/640/6), Boorthanna, Lake Phillipson, Stuart Range No. 3 and Nullarbor No. 8 Bores.

*Stratigraphic Range.* Lower Permian.

The specific name is taken from the Latin noun *orca*, a jar or pot.

## Genus SACCULINELLA Crespin, 1958
### Sacculinella australae Crespin

One specimen doubtfully referable to this species was recovered from A.O.C. North Renmark No. 1, 3,410-3,415 feet. *Sacculinella* Crespin has been synonymized with *Brachysiphon* Chapman by Loeblich and Tappan, but there seems to be insufficient support for this view from the material available.

## Genus THURAMMINOIDES Plummer, 1945
### Thuramminoides sphaeroidalis Plummer
pl. 3, figs. 15, 16

1945. *Thuramminoides sphaeroidalis* Plummer, 218, pl. 15, figs. 4-10; Crespin, 1958, 40, pl. 3, figs. 9-11; pl. 31, figs. 1-2; Conkin, 1961, 243, pl. 17, figs. 1-10; pl. 18, figs. 1-4; pl. 26, figs. 1-3.

*Description.* An amended description of the species has been given by Conkin (1961). South Australian specimens are always preserved as deflated or flattened discs. The wall is finely arenaceous with agglutinated quartz grains cemented by siliceous material in some tests and calcareous material in others. Of 162 tests examined 38 had calcareous cement; these all came from Stuart Range No. 3 Bore with the exception of one specimen from Ware 5, locality 5/641/5, and three from Stansbury Stratigraphic Bore. The development of protuberances on some of the tests is similar to that on Texas specimens.

*Dimensions.* The species shows a considerable range in diameter as shown by Conkin (1961, p. 247), with whose measurements (in mm.) those from the different South Australian localities may be compared.

| | |
|---|---|
| Locality 5/641/5 | 0·6 (1 specimen) |
| Stansbury Stratigraphic Bore | 0·4-0·5 (14 specimens) |
| Minlaton Stratigraphic Bore | 0·4-0·7 (8 specimens) |
| Boorthanna Bore | 0·4-0·75 (10 specimens) |
| Lake Phillipson Bore | 0·25-0·65 (4 specimens) |
| Stuart Range No. 3 Bore | 0·5-2·25 (69 specimens) |
| Nullarbor No. 8 Bore | 0·5-1·0 (47 specimens) |

The South Australian specimens are on the whole of medium size. The largest specimens with diameter of 1·75 mm. or more are smooth specimens with protuberances (pl. 3, fig. 16).

*Wall Structure.* The problem of the cementing material and the possible replacement by silica of original calcite is not resolved in the present study.

Some tests of both *Thuramminoides sphaeroidalis* and *Hyperammina hebdenensis* have calcareous cement in certain samples. Both species occurring in Ware locality 5/641/5 and at depths of 1,225 to 1,367 feet in Stuart Range No. 3 Bore have both calcareous and siliceous tests in the same sample. Tests of *Thuramminoides sphaeroidalis* have siliceous cement at depths of 740 to 1,225 feet and calcareous cement below 1,367 feet in Stuart Range No. 3 Bore, while all the tests in Minlaton, Boorthanna, Lake Phillipson, Stansbury, and Nullarbor No. 8 had siliceous cement. On the other hand, some tests of *Hyperammina hebdenensis* from Nullarbor No. 8 have calcareous cement.

*Australian Species of* Thuramminoides. Conkin (1961, p. 243) has placed *Crithionina teicherti* Parr, which was transferred by Crespin to *Thuramminoides*, in synonymy with *Thuramminoides sphaeroidalis*. The two species are, in the opinion of the present writer, specifically and generically distinct from each other. Seven slides containing some of Parr's original type material were kindly lent by the Department of Geology, University of Western Australia. While the holotypes so far cannot be located slides 20768 and 20772 contain topotypes of *Crithionina teicherti* from Parr's original material. Slide 20768 has seven mounted specimens which, with one exception 1·8 mm. in diameter, range from 2·0 to 2·5 mm. in diameter. They are spherical and uncrushed with a loosely cemented wall 0·2 mm. thick. The otherwise smooth outer surface of the wall is marked irregularly by small openings of the irregular canals contained in the thick wall. The inner surface is strongly and irregularly punctured with larger openings.

From the limited amount of material available the genus *Oryctoderma* Loeblich and Tappan, 1961 (type species *Crithionina rotundata* Cushman) is to be preferred for *Crithionina teicherti*. The test wall is relatively thinner than that of either the type species or of *O. palaeozoica* (Conkin), but the spongy wall texture may be seen where there has been limonitic infilling, and the small round or polygonal openings on the exterior surface are not characteristic of *Thuramminoides*. The wall texture differs also from that of South Australian specimens of *Thuramminoides sphaeroidalis*. *Oryctoderma teicherti* has not so far been recognized in the South Australian Permian.

*Type Locality.* *Thuramminoides sphaeroidalis* was described from the Middle Pennsylvanian lower Strawn Shale, east of San Saba, Texas, U.S.A.

*Material.* Hypotypes GSSA Ff377, Ff378; 162 specimens.

*Distribution.* The species is widely distributed in Stansbury, Minlaton, Boorthanna, Lake Phillipson, Stuart Range No. 3 and Nullarbor No. 8 Bores and locality Ware 5 (5/641/5).

*Stratigraphic Range.* Middle Silurian to Permian.

## Family AMMODISCIDAE
### Subfamily AMMODISCINAE
### Genus AMMODISCUS Reuss, 1862
### Ammodiscus oonahensis Crespin
pl. 3, figs. 17, 18

1958. *Ammodiscus oonahensis* Crespin, 69, pl. 12, figs. 10, 11.

*Description.* Test free, depressed in the centre, consisting of a small proloculus and long undivided second chamber closely planispirally wound in about 6 volutions with occasional growth constrictions; sutures distinct, slightly depressed; chamber in last volution broad; aperture at end of second chamber, slightly arched.

*Dimensions.* Hypotype, greatest diameter 0·825, thickness 0·20 mm.

*Type locality.* Oonah, Tasmania; Quamby Mudstone.

*Material.* Hypotypes GSSA Ff402, 403; 215 specimens.

*Distribution.* W.G. Goyder Donna No. 1, A.O.C. North Renmark No. 1, Stansbury, Minlaton, Beach Petroleum Troubridge Shoal No. 1, Boorthanna, Coorie Appa, Stuart Range No. 3 and Nullarbor No. 8 Bores; localities Balta 6 (5/640/6) and Ware 5 (5/641/5).

*Stratigraphic Range.* Lower Permian.

<div align="center">

Genus HEMIDISCUS Schellwien, 1898

**Hemidiscus balmei** Ludbrook sp. nov.

pl. 3, figs. 19-21

</div>

*Description.* Test fairly large, irregularly discoidal, depressed in the centre, consisting of a proloculus and an undivided tubular second chamber at first planispirally wound like *Ammodiscus* then coiling unevenly so that later whorls lap over the earlier whorls on one side; there are about five volutions in a specimen of diameter 2·4 mm.; growth constrictions may occur at the former positions of the aperture; diameter of second chamber increasing very gradually; sutures distinct, slightly depressed; aperture at the open end of the tubular chamber.

*Dimensions.* Holotype Ff399 diameter 1·3 mm.; paratype Ff400 diameter 0·7 mm.; paratype Ff401 diameter 2·4 mm.

*Type Locality.* Stuart Range No. 3 Bore, 1,225 feet 3 ins.-1,246 feet depth.

*Material.* Holotype GSSA Ff399; paratypes GSSA Ff400, 401; 212 specimens, including 61 topotypes.

*Distribution.* Common in W.G. Goyder Donna No. 1 Well between 600 and 2,073 feet; Stansbury, Beach Petroleum Troubridge Shoal No. 1, Boorthanna, Coorie Appa, Stuart Range No. 3 and Nullarbor No. 8 Bores.

*Stratigraphic Range.* Lower Permian.

The specific name acknowledges the contribution made by Mr. B. E. Balme to understanding the South Australian Permian.

<div align="center">

Genus AMMOVERTELLINA Suleymanov, 1959

**Ammovertellina(?) glomospiroides** Ludbrook sp. nov.

pl. 3, figs. 22-26

</div>

1958. *Ammovertella inclusa* Crespin, 72, pl. 18, fig. 5 (*non* Cushman and Waters).

*Description.* Test free, fairly small, consisting of a proloculus followed without any distinct separation by an undivided tubular second chamber of uniform diameter throughout; flatly streptospirally coiled in the initial stages then more or less planispiral; in the final stages the tube swings over and embraces the earlier coils at right angles to its previous plane of coiling. Wall thick, agglutinating, consisting of quartz grains well cemented in siliceous cement; aperture arched, at the end of the final coil.

*Dimensions.* Holotype greatest diameter 1·0 mm., diameter of chamber 0·25 mm.

*Type Locality.* Stuart Range No. 3 Bore, 1,265-1,285 feet.

*Material.* Holotype GSSA Ff396, paratypes GSSA Ff397, 398; 230 specimens.

*Distribution.* Locality Ware 5 (5/641/5), Stansbury, Minlaton, Boorthanna, Lake Phillipson, Stuart Range No. 3 and Nullarbor No. 8 Bores.

*Stratigraphic Range.* Lower Permian.

*Observations.* This is the species identified by Crespin with *Ammovertella inclusa* (Cushman and Waters). Unlike *A. inclusa* the species is not attached nor when sectioned does it show the planispirally coiled early portion figured by Conkin (1961, pl. 23, fig. 8) or the planispiral zig-zag type of coiling illustrated by Ireland (1956, text fig. 5, 6-14). The type of coiling differs from that of *Ammovertellina* in that in the final stage the tubular chamber does not uncoil. The mode of coiling, however, is irregular when compared with that of *Glomospira* or *Glomospirella*. It appears to represent a style of coiling intermediate between *Glomospira* and *Ammovertellina*. In many respects the species is close to *Glomospira articulosa* Plummer, which coils in a haphazard, but compact, fashion.

## Genus GLOMOSPIRA Rzehak, 1885
### Glomospira adhaerens Parr
pl. 4, figs. 1-4

1942. *Glomospira adhaerens* Parr, p. 103, pl. 1, fig. 2; 1958, Crespin. 70, pl. 13, figs. 6. 7.

The South Australian specimens are attached to quartz grains, coiled in *Glomospira* fashion, the wall is thick, with agglutinated quartz grains in a siliceous matrix.

*Dimensions.* Hypotype Ff391 diameter 0·75, diameter of tube 0·15 mm. near the end.

*Type Locality.* "Lingula beds", south side of Minilya River, near Coolkilya Pool, Wandagee Station; Quinnanie Shale.

*Material.* Hypotypes GSSA Ff391, Ff392, Ff393; 64 specimens.

*Distribution.* Stuart Range No. 3 and Boorthanna Bores.

*Stratigraphic Range.* Lower Permian.

## Genus GLOMOSPIRELLA Plummer, 1945
### Glomospirella nyei Crespin
pl. 4, fig. 13

1958. *Glomospirella nyei* Crespin, 70, pl. 13, figs. 1-5.

Only the specimens from Lake Phillipson Bore are small and within the range of the type series described by Crespin. There seems to be no criterion but size to distinguish the specimens from Stuart Range No. 3 Bore from *G. nyei*.

*Dimensions.* Hypotype diameter 1 mm., diameter of tube 0·15 mm.

*Type Locality.* Cundlego Crossing, Minilya River, Western Australia; Cundlego Formation.

*Material.* Hypotype GSSA Ff394; 100 specimens.

*Distribution.* Locality Ware 5 (5/641/5), Lake Phillipson and Stuart Range No. 3 Bores.

*Stratigraphic Range.* Lower Permian.

## Subfamily TOLYPAMMININAE
## Genus TOLYPAMMINA Rhumbler, 1895
### Tolypammina undulata Parr
pl. 4, figs. 5, 9

1942. *Tolypammina undulata* Parr, 104, pl. 2, fig. 2; 1958, Crespin, 72, pl. 19, figs. 7, 8.

The South Australian specimens are all small, about 0·5 mm. diameter overall, commonly adherent to quartz grains or to tubes of *Hyperammina hebdenensis*, as noted by Crespin.

*Type Locality.* "*Lingula* beds", south side of Minilya River, near Coolkilya Pool, Wandagee Station, Western Australia; Quinnanie Shale.

*Material.* Hypotypes GSSA Ff380, Ff381; 134 specimens.

*Distribution.* Locality Balta 6 (5/640/6), Stansbury, Minlaton, Boorthanna, Stuart Range No. 3 and Nullarbor No. 8 Bores.

*Stratigraphic Range.* Lower Permian.

## Genus AMMOVERTELLA Cushman, 1928
### Ammovertella howchini Ludbrook sp. nov.
pl. 4, figs. 6-8

*Description.* Test attached, consisting of a small proloculus followed by a long narrow tubular second chamber which at first winds back and forth in zig zag fashion and later winds irregularly over the surface of attachment; wall agglutinated with fine angular quartz grains in a small amount of siliceous cement; aperture at the open end of the tubular second chamber.

*Dimensions.* Holotype Ff414 diameter 1 mm. x 0·8 mm.; hypotype Ff415 diameter 0·65 x 0·625; hypotype Ff416 diameter 0·9 x 0·8 mm. Size of the tests is variable. The initial portion is usually about 0·5 mm. in diameter, but the total area covered by a single specimen may be as much as 2 mm. or more; diameter of tube 0·075 mm.

*Type Locality.* Cape Jervis; Cape Jervis Beds.

*Material.* The holotype Ff414, paratypes Ff415, 416, and 52 other specimens.

*Distribution.* Stuart Range No. 3 and Stansbury Bores; a pebble 36 mm. in diameter from Stansbury Bore is extensively covered with many encrusting individuals.

## Superfamily LITUOLACEA
## Family HORMOSINIDAE
### Subfamily HORMOSININAE
## Genus REOPHAX Montford, 1808
### Reophax subasper Parr
pl. 4, fig. 15

1942. *Reophax subasper* Parr, 108, pl. 1, fig. 12; 1958, Crespin, 64, pl. 11, figs. 10, 11.

South Australian specimens have calcareous cement.

*Dimensions.* Hypotype length 0·8, width 0·4 mm.

*Type Locality.* "*Lingula* beds", east of Coolkilya Paddock, Wandagee Station, Quinnanie Shale.

*Material.* A single paratype on UWAGD slide 20770; hypotype GSSA Ff388, and 4 other specimens.

*Distribution.* Stansbury and Stuart Range No. 3 Bores.

*Stratigraphic Range.* Lower Permian.

### Reophax (?) thomasi (Crespin)
pl. 4, figs. 16, 19, 20

1958. *Lugtonia thomasi* Crespin, 65, pl. 7, figs. 6, 7.

*Description.* Test free, straight, flaring slightly, consisting of as many as six chambers in a rectilinear series; sutures distinct, straight, depressed; wall very thick, agglutinating, with close set fine quartz grains in a small amount of calcareous cement, leaving very reduced chamber cavities connected by necks; aperture circular, terminal, surrounded by a thickened lip.

*Dimensions.* Hypotype (incomplete) length 1·2, width 0·5 mm.

*Type Locality.* 1¼ miles southwest of Nalbia Dam, Wandagee Station, Western Australia; Bulgadoo Shale.

*Material.* Hypotypes Ff389, Ff440; 30 specimens.

*Distribution.* A.O.C. North Renmark No. 1, Stansbury, Minlaton, Coorie Appa, Stuart Range No. 3, Nullarbor No. 8 Bores.

*Observations.* Conkin (1961, p. 276) has discussed the anomalous position of this reophacid species in the genus *Lugtonia* Cummings, which was placed by its author in the *Earlandiidae.* Crespin (1958, p. 35) states that the Western Australian specimens of *R. thomasi* have siliceous cement; South Australian specimens have calcareous cement. In thin section no evidence can be seen of the domed chamber form of *Lugtonia*, although most of the tests are poorly preserved and distorted. The thin section figured (pl. 2, fig. 20) shows the unusually thick wall and reduced chamber cavity, while the nature of the initial part of the test is somewhat doubtful. For these reasons the genus *Reophax* is used with caution until sections can be made of a wider range of undistorted specimens.

### Reophax tricameratus Parr
pl. 4, fig. 14

Five specimens, some complete, occur in Nullarbor No. 8 Bore, 1,280-1,290 feet. The species is large; the wall of South Australian specimens consists of coarse quartz grains in calcareous cement.

*Dimensions.* Hypotype length 2, diameter 1·4 mm.

*Type Locality.* "Lingula beds", south side of Minilya River, near Coolkilya Pool, Wandagee Station, Western Australia; Quinnanie Shale.

*Material.* Paratype on UWAGD Slide 20772, hypotype GSSA Ff390; five specimens.

*Distribution.* Nullarbor No. 8 Bore, 1,280-1,290 feet.

*Stratigraphic Range.* Lower Permian (Artinskian).

### Family LITUOLIDAE
Subfamily HAPLOPHRAGMOIDINAE
Genus RECURVOIDES Earland, 1934
### Recurvoides wilsoni Ludbrook sp. nov.
pl. 5, figs. 1-10, 15

*Description.* Test free, subovate to flatly globose, asymmetrical, streptospiral; first whorl is planispiral but later whorls in different planes; periphery more or less oval, lobulate, chambers numerous, about seven in the final whorl increasing very gradually in size as added, inflated unless flattened during fossilization, with pseudochitinous lining; sutures distinct, depressed, nearly straight; wall coarsely arenaceous with coarse angular quartz grains in a siliceous matrix; aperture interio-areal apparently a small low arch, with a lip.

*Dimensions.* Holotype Ff405, greatest diameter 0·60, thickness 0·4 mm.; paratype Ff407, greatest diameter 1·25, thickness 1·0 mm.; paratypes are in the range of greatest diameter 0·75-1·25 mm.

*Type Locality.* Cape Jervis, Cape Jervis Beds.

*Material.* The holotype Ff405, paratypes Ff406-Ff413, Ff441; 348 specimens.

*Distribution.* Cape Jervis, Balta 6 (5/640/6); Stansbury, Minlaton, Beach Petroleum Troubridge Shoal No. 1, Boorthanna, Stuart Range No. 3 Bores.

*Observations.* The genus *Recurvoides* has not previously been recorded from rocks older than Oligocene. The streptospiral test of *Recurvoides wilsoni* is very variable in shape and when fully developed is most closely related to the Recent *R. turbinatus* Brady, *R. contortus* Earland and *R. trochamminiforme* Höglund. The axis of coiling in *R. wilsoni* as in *R. trochamminiforme* continues to change throughout the development of the test. Immature specimens are planispiral and similarly coiled to the genus *Adercotryma*.

Both *R. contortus* and *R. trochamminiforme* inhabit cold waters or fjords. The relatively abundant numbers of *R. wilsoni* at Cape Jervis in beds deposited in an over-deepened valley or fjord appear to parallel the occurrence of *R. trochamminiforme* in Gullmar Fjord. *R. contortus* occurs off South Georgia and in Antarctic waters.

Species of both *Adercotryma glomeratum* (Brady) and *Recurvoides turbinatus* have been described from Arctic waters. Both species occur together at several stations off Greenland, at depths of between 31 and 91 metres and also off Humboldt Glacier at 201·2 metres (Loeblich and Tappan, 1953).

Sectioning of the test shows (pl. 5, fig. 15) the interior of the chambers to be conspicuously lined with pseudochitinous material. *R. obsoletum* (Goës) and *R. higginsi* Bronnimann from the Cruse and Lengua Formations of Trinidad have been described (Bronnimann, 1953, p. 98) as having the interior of the chambers coated with a brown or thin ?chitinous film.

*Specific Name.* The species is named for Mr. R. B. Wilson of Geosurveys of Australia Ltd. who collaborated with the writer in selecting and describing the type section of the Cape Jervis Beds.

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Subfamily LITUOLINAE

Genus AMMOBACULITES Cushman, 1910

**Ammobaculites woolnoughi Crespin and Parr**

pl. 4, fig. 17

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1941. *Ammobaculites woolnoughi* Crespin and Parr. 304, pl. 12, figs. 2a, b, 3a, b; 1958. Crespin. 75, pl. 14, figs. 10, 11 (synonymy).

The three specimens from South Australia are poorly preserved and identification is doubtful. One specimen was recovered from Minlaton Bore, 554-560 feet, and one from Stuart Range No. 3 Bore at depths of 1,205 feet 5 ins. - 1,225 feet 5 ins. and 1,265-1,285 feet.

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Family TEXTULARIIDAE

Subfamily TEXTULARIINAE

Genus TEXTULARIA Défrance in de Blainville, 1824

**Textularia bookeri Crespin**

pl. 4, fig. 18

</div>

1941. *Textularia eximia* Crespin and Parr. 305, pl. 13, figs. 7a-c. 8a-c; 1947. Crespin. pl. 2, figs. 23, 24 (non Eichwald).

1956. *Textularia* "exima Eichwald" of Crespin and Parr. Cummings, 214.

1958. *Textularia bookeri* Crespin, 77, pl. 15, figs. 1-7.

South Australian specimens are usually distorted during fossilization and the arrangement of the early chambers is difficult to determine.

*Dimensions.* Hypotype Ff383, length 1·1, width 0·8 mm.

*Type Locality.* Four chains west of Farley Railway Station, Hunter River District, New South Wales; Dalwood Group.

*Material.* 40 specimens.

*Distribution.* Locality Ware 5 (5/641/5), Stansbury, Boorthanna and Stuart Range No. 3 Bores.

*Stratigraphic Range.* Lower Permian.

### Family ATAXOPHRAGMIIDAE
### Subfamily GLOBOTEXTULARIINAE
### Genus DIGITINA Crespin and Parr, 1941
### Digitina recurvata Crespin and Parr
pl. 4, figs. 10-12

1941, *Digitina recurvata* Crespin and Parr, 306, pl. 13, figs. 9a, b, 10a. b; 1958, Crespin, 79, pl. 15, figs. 10, 11.

*Description.* Test free, moderately elongate, flaring, of moderate size, consisting of a minute trochospiral stage with about 4 chambers in the initial whorl, followed by a triserial portion with about 9 inflated globular chambers increasing fairly rapidly in size, then becoming irregularly biserial and finally uniserial. Sutures distinct, depressed; wall coarsely agglutinated with coarse angular quartz grains in a thin matrix; aperture interio-areal, a very small arched slit near the base of the apertural face. In the figured hypotype (F1418) and two other specimens from Stuart Range No. 3 Bore, in which the uniserial stage has developed, the aperture is subterminal, as it appears to be in the holotype (Crespin and Parr, pl. 13, figs. 9a-b).

*Dimensions.* South Australian specimens are relatively short and broad, adult specimens from Stuart Range No. 3 Bore attaining a length of 1·0, width 0·7 mm; most Cape Jervis specimens come within the range length 0·4-0·625, width 0·325-0·45 mm.

*Type Locality.* Foot of Victoria Pass, Mitchell Highway; Capertee Group.

*Material.* 29 specimens.

*Distribution.* Cape Jervis, Stuart Range No. 3 Bore, 1,285-1,367 feet.

*Observations.* The genus *Digitina* has been retained here only because no specimens of *Mooreinella* Cushman and Waters, 1928, are available for comparison. Cummings (1956, p. 214) suggested the possibility of the synonymy of *Digitina* with *Mooreinella* which was rejected by Crespin (1958, p. 36) on the basis of apertural differences. Although the aperture is usually, as Crespin emphasizes, at the base of the final chamber, in fully adult specimens with a uniserial final chamber, the aperture is, like that of *Mooreinella*, subterminal. However, no description of *Mooreinella* mentions the triserial stage, through which *Digitina* passes so conspicuously that the immature specimens from Cape Jervis with poorly preserved initial portions appear to belong to *Eggerella* (pl. 4, figs. 11, 12).

### Phylum MOLLUSCA
### Class GASTROPODA
### Genus PERUVISPIRA Chronic, 1949

The single minute incomplete specimen 1 mm. diameter (pl. 5, fig. 13) is not sufficiently well preserved for its specific identity to be established, but with its generic range of Lower to Middle Permian, it is an important element in the fauna. The specimen was recovered from 1,285-1,305 feet in Stuart Range No. 3 Bore.

Gastropod indet. A minute steinkern of a protoconch also occurred in Stuart Range No. 3 Bore at 1,327-1,349 feet.

## Phylum COELENTERATA
### Class SCYPHOZOA
### Genus ? CONULARIA Sowerby, 1821

The fragment figured (pl. 5, fig. 14) of a pyritized cast appears to be that of a *Conularia*, from Stuart Range No. 3 Bore, 1,327-1,349 feet.

## OTHER ORGANIC REMAINS

Two species of ostracodes (pl. 5, figs. 11, 12) were recovered from Stuart Range No. 3 Bore, 1,327-1,349 feet, together with vertebrate teeth and bones.

## ACKNOWLEDGMENTS

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# EXPLANATION OF PLATES

## PLATE 1

Fig. 1.   Cape Jervis Beds (C.J.) overlying Kanmantoo greywacke (K) at south end of type section, view southerly.

Fig. 2.   View upwards through units 2 and 3 of Cape Jervis Beds to sandstone ledge of unit 4, showing inter-bedded sandstone and clay of unit 2, and boulders in layers.

Fig. 3.   Southerly view of same part of section as Fig. 2, showing dip in lower part of section and bedding of boulders.

Fig. 4.   Striated boulder on tillitic clay at northern end of type section.

## PLATE 2

Fig. 1.   Gully erosion in Cape Jervis Beds, north end of type section.

Fig. 2.   Erratic in boulder clay overlying Selwyn's rock (lower left), Inman River.

Fig. 3.   King's Point, Encounter Bay; boulders on shore at foot of point overlain by boulder till, with sandstone at top right.

Fig. 4.   Burrowings in sandstone at top of section, King's Point. This part of the sequence is doubtfully of Permian age.

## PLATE 3

### All Figures X 30

Fig. 1.   *Hippocrepinella biaperta* Crespin. Ff379, Minlaton 500-530 feet.

Figs. 2-6.   *Hyperammina hebdenensis* Crespin. 2, Ff374a, with siliceous cement; 3, Ff374b, with calcareous cement, both locality 5/641/5; 4. Ff373, with siliceous cement, Stansbury 845 feet; 5, Ff375, with calcareous cement, Nullarbor No. 8 1290-1300; 6, Ff376, with siliceous cement, North Renmark No. 1 3755-3760 feet.

Fig. 7.   *Hyperammina acicula* (Parr). Ff370, Stuart Range No. 3, 1205.5-1225.5 feet.

Figs. 8, 9.   *Hyperammina coleyi* Parr. Ff371a; b, Cape Jervis CJ8.

Fig. 10.   *Hyperammina expansa* Plummer. Ff372, North Renmark No. 1, 3785-3790 feet.

Figs. 11-13.   *Saccammina orea* Ludbrook. 11. holotype Ff384; 12. Ff386, paratype both from Stuart Range No. 3, 1305 feet 8 ins.-1327 feet; 13, paratype Ff385, Stuart Range No. 3, 1827-1349 feet.

Fig. 14.   *Lagenammina ampulla* (Crespin). Ff387, Stuart Range No. 3, 1305 feet 8 ins.-1327 feet.

Figs. 15-16.   *Thuramminoides sphaeroidalis* Plummer. 15. Ff377, with siliceous cement, Stansbury 830 feet; 16, Ff378, with calcareous cement, Stuart Range No. 3, 1305 feet 8 ins.-1327 feet.

Figs. 17-18.   *Ammodiscus oonahensis* Crespin. 17. Ff402, North Renmark No. 1, 3900-3905 feet; 18, Ff403, Stuart Range No. 3, 1020-1040 feet.

Figs. 19-21.   *Hemidiscus balmei* Ludbrook. 19, holotype, Ff399, Stuart Range No. 3, 1225 feet 3 ins.-1246 feet; 20, paratype, Ff400, Nullarbor No. 8, 1320-1335 feet; 21, Ff401, Donna No. 1, 870-880 feet.

Figs. 22-26.   *Ammovertellina glomospiroides* Ludbrook. 22, holotype, Ff396, Stuart Range No. 3, 1265-1285 feet, the aperture can be seen at the top of the Figure; 23, holotype, reverse side; 24, paratype, Ff397, Stansbury, 210-215 feet. 25, 26, two views of paratype Ff398, Stansbury, 775 feet.

## PLATE 4

### All Figures X 30

Figs. 1-4.   *Glomospira adhaerens* Parr. 1, 2, two views of Ff391, Stuart Range No. 3, 1225-1246 feet, the quartz grain to which the specimen is adhering occupies the central half of Fig. 2; 3, Ff392, Stuart Range No. 3, 1182-1205.5 feet; 4, Ff393, Stuart Range No. 3, 1367-1400 feet, wound around quartz grain.

Figs. 5, 9.   *Tolypammina undulata* Parr. 5, Ff381, Minlaton, 500-530 feet, adhering to *Hyperammina hebdenensis*; 9, Ff380, Stansbury, 775 feet, adhering to quartz grain.

Figs. 6-8.   *Ammovertella houchini* Ludbrook. 6, holotype, Ff414, Cape Jervis; 7, paratype, Ff415, Cape Jervis, showing aperture at the end of the tube on the right-hand side of the Figure; 8, paratype, Ff416, Stuart Range No. 3, 1020-1040 feet.

Figs. 10-12. *Digitina recurvata* Crespin and Parr.   10, Ff418, Stuart Range No. 3, 1305 feet 8 ins - 1327 feet; 11, 12, Ff417a, b, Cape Jervis.
Fig. 13.      *Glomospirella nyei* Crespin.   Ff394, Stuart Range No. 3, 1265-1285 feet.
Fig. 14.      *Reophax tricameratus* Parr.   Ff390, Nullarbor No. 8, 1280-1290 feet.
Fig. 15.      *Reophax subasper* Parr.   Ff388, Stuart Range No. 3, 1349-1367 feet.
Figs. 16, 19, 20. *Reophax thomasi* (Crespin).   16, 19, Ff389a, b, Stuart Range No. 3, 1040-1060 feet; 20, Ff440, thin section, North Renmark No. 1, 3785-3790 feet.
Fig. 17.      *Ammobaculites woolnoughi* Crespin and Parr.   Ff395, Stuart Range No. 3, 1265-1285 feet.
Fig. 18.      *Textularia bookeri* Crespin. Ff383, Stuart Range No. 3, 1060-1120 feet.

## PLATE 5

### All Figures X 30

Figs. 1-10, 15. *Recurvoides wilsoni* Ludbrook.   1, holotype, Ff405, Cape Jervis; 2, paratype, Ff407, Stuart Range No. 3, 1182-1205.5 feet, spiral view; 4, Ff407, apertural view, showing large quartz grain on apertural face; 4, Ff409; 7, Ff412; 9, Ff410; 10, Ff411, showing change in plane of coiling; 5, Ff406, showing apertural lip; 6, Ff408; 8, Ff413, showing position of aperture; 15, Ff441, Stuart Range No. 3, 1205.5 - 1225.5 feet, thin section, showing pseudochitinous lining of early chambers.
Figs. 11, 12. Ostracodes, Stuart Range No. 3, 1327-1349 feet.
Fig. 13.      *Peruvispira* sp., M3180, Stuart Range No. 3, 1285-1305 feet.
Fig. 14.      ? *Conularia* sp. Cr.3, Stuart Range No. 3, 1327-1349 feet.
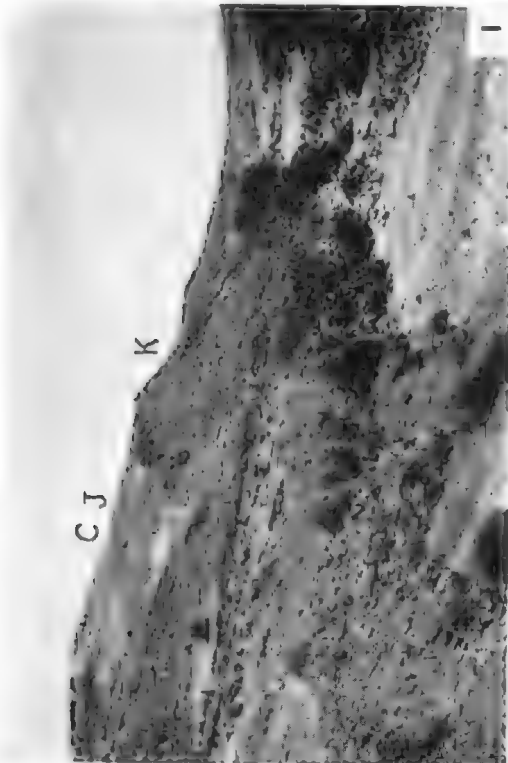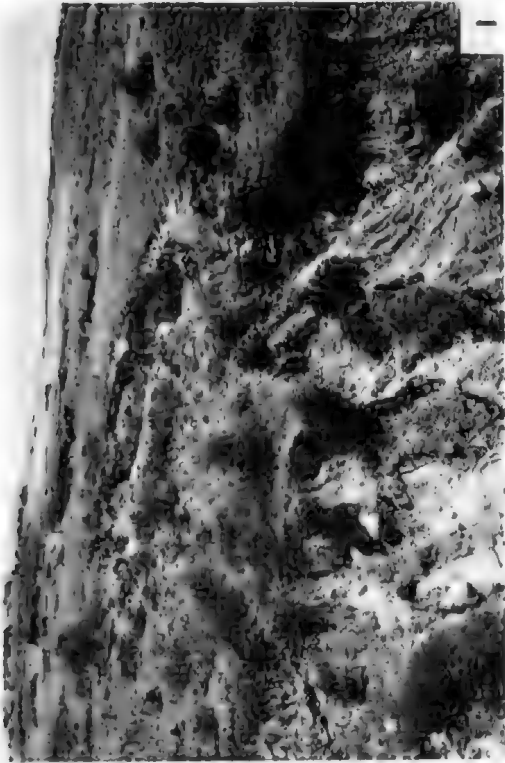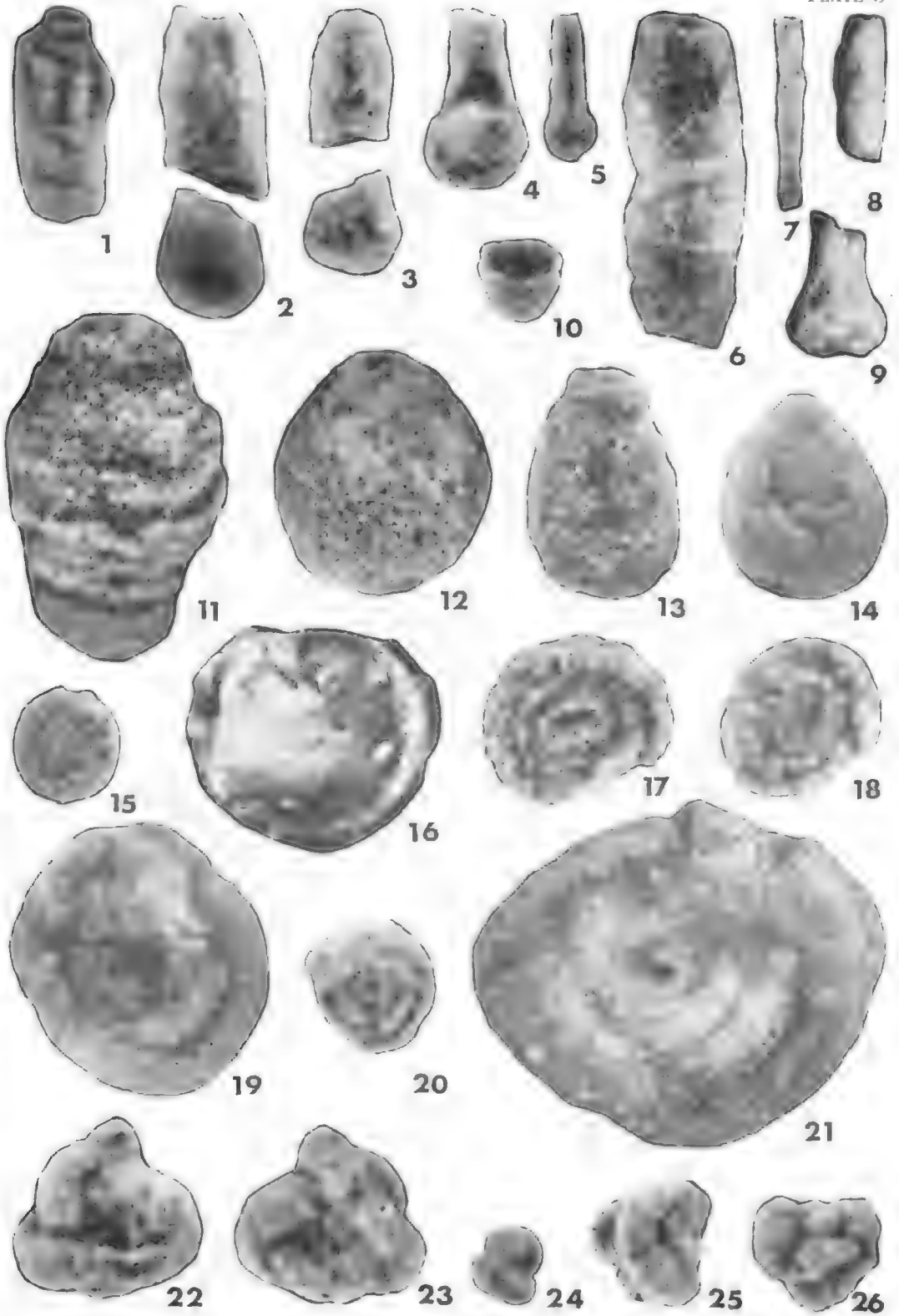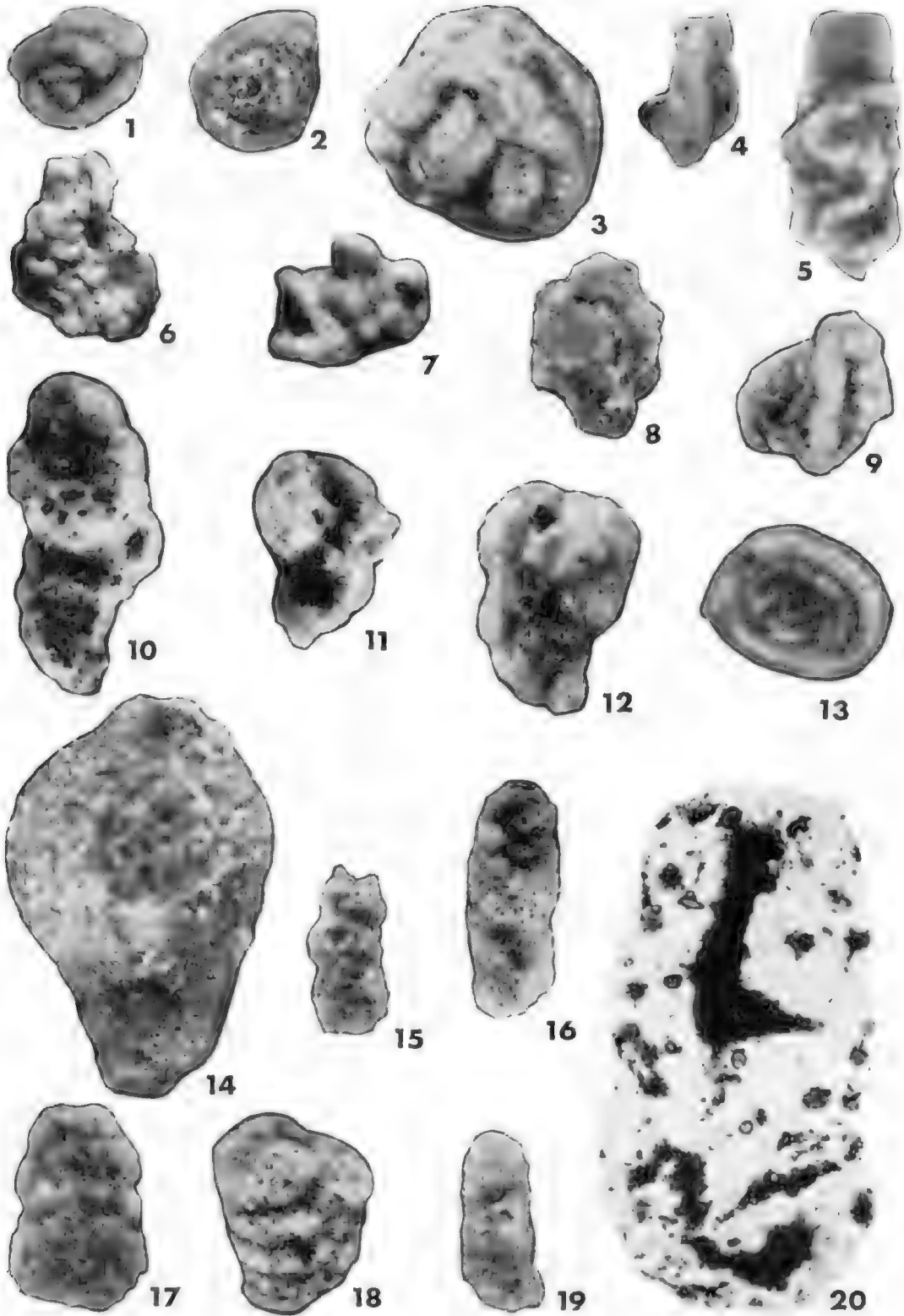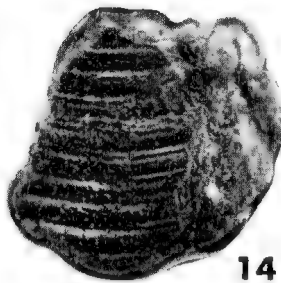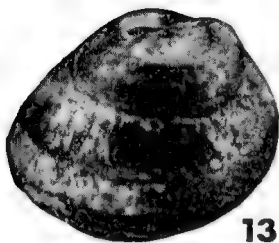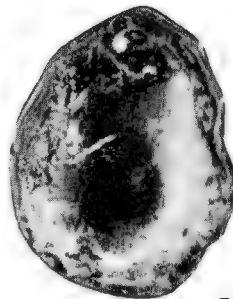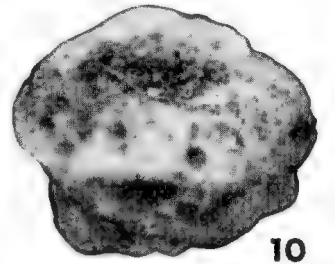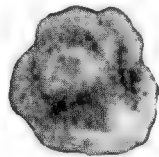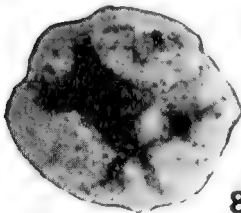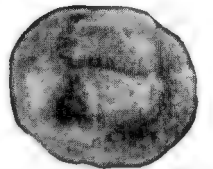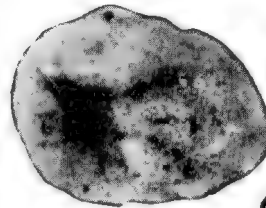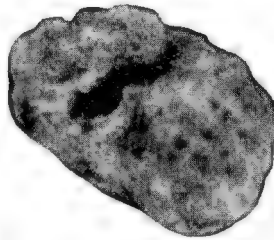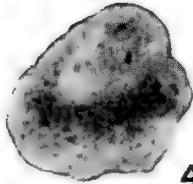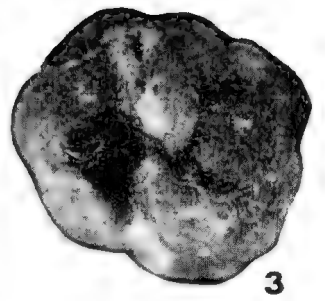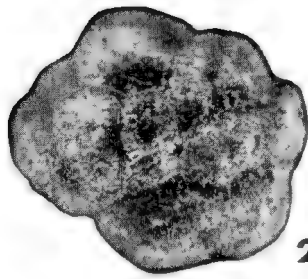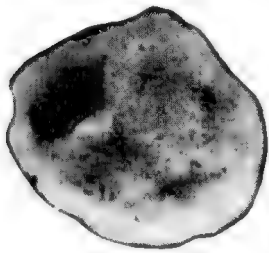
Plate 1

Plate 2

PLATE 8

Plate 5

# FORAMINIFERA AND STRATIGRAPHY OF THE TYPE SECTION OF PORT WILLUNGA BEDS, ALDINGA BAY, SOUTH AUSTRALIA*

*BY J. M. LINDSAY†*

## Summary

The type section 20 miles (32 km) south of Adelaide has been reexamined. Comprising about 107 feet $(32^1/_2$ m.) of bryozoal calcarenitic impure limestones, sands, silts, and clays, it is informally subdivided into three apparently conformable successions of beds, the middle interval characterized by horizons with spicular cherty nodules. Equivalents of these three intervals are present in the Willunga Bore W.B.1, and in bores in the Adelaide Plains Sub basin. The top of the Eocene Aldingan Stage is represented by the top of a hard grey marker bed at the base of the siliceous interval about 45 feet (14 m.) above the base of the formation.

Planktonic and benthonic foraminifera indicate that the age of the section ranges from Upper Eocene to Oligocene. Four informal planktonic zones are recognized, using successive extinctions of *Turborotalia aculeata* (Jenkins), *Globigerina linaperta* (Finlay), *Chiloguembelina cubensis* (Palmer) and *Guembelitria stavensis* Bandy. These zones span Aldingan to lower Janjukian Stages, and can be related to a planktonic zonal scheme recently proposed for New Zealand.

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by J. M. Lindsay[†]

[Read 13 July 1967]

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The type section 20 miles (32 km.) south of Adelaide has been re-examined. Comprising about 107 feet (32½ m.) of bryozoal calcarenitic impure limestones, sands, silts, and clays, it is informally subdivided into three apparently conformable successions of beds, the middle interval characterized by horizons with spicular cherty nodules. Equivalents of these three intervals are present in the Willunga Bore W.B.1, and in bores in the Adelaide Plains Sub-basin. The top of the Eocene Aldingan Stage is represented by the top of a hard grey marker bed at the base of the siliceous interval about 45 feet (14 m.) above the base of the formation.

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## INTRODUCTION

Rocks referred to Port Willunga Beds comprise a significant part of the Tertiary sequence in the St. Vincent Basin and its sub-basins. Investigation of the type exposure of Port Willunga Beds has therefore been a necessary step towards an understanding of the place of the formation in sequences elsewhere, especially in the Adelaide Plains Sub-basin.

The type section of the formation at Aldinga Bay, 20 miles (32 km.) south of Adelaide (Fig. 1), forms part of the coastal exposure of the Cainozoic rocks in the Willunga Sub-basin of the St. Vincent Basin. Following interest in the sequence over a period of at least 75 years by geologists and palaeontologists, it was mapped, described, and formally subdivided and named by Reynolds (1953). The Port Willunga Beds consist of a bryozoal calcarenitic series of variable hard and soft rocks including impure limestones, sands, silts, and clays, with an interval characterized by horizons of siliceous nodules. The beds, which are well exposed in low coastal cliffs around the central part of Aldinga Bay, have gentle southerly dips of up to 3° but are in part slightly folded and faulted (see Fig. 2). They are now estimated to be about 107 feet (32½ m.) thick which is close to Reynolds's figure. Following Ludbrook (1956, p. 17), the basal bed is taken to be the thin gravelly sand (sample 119-66 of the present series) which overlies with minor disconformity the green fossiliferous clay

bed (118-66) included by Reynolds in Port Willunga Beds, but now regarded as the top unit of Chinaman's Gully Beds. The Port Willunga Beds are overlain by Pliocene Hallett Cove Sandstone with mild angular unconformity.
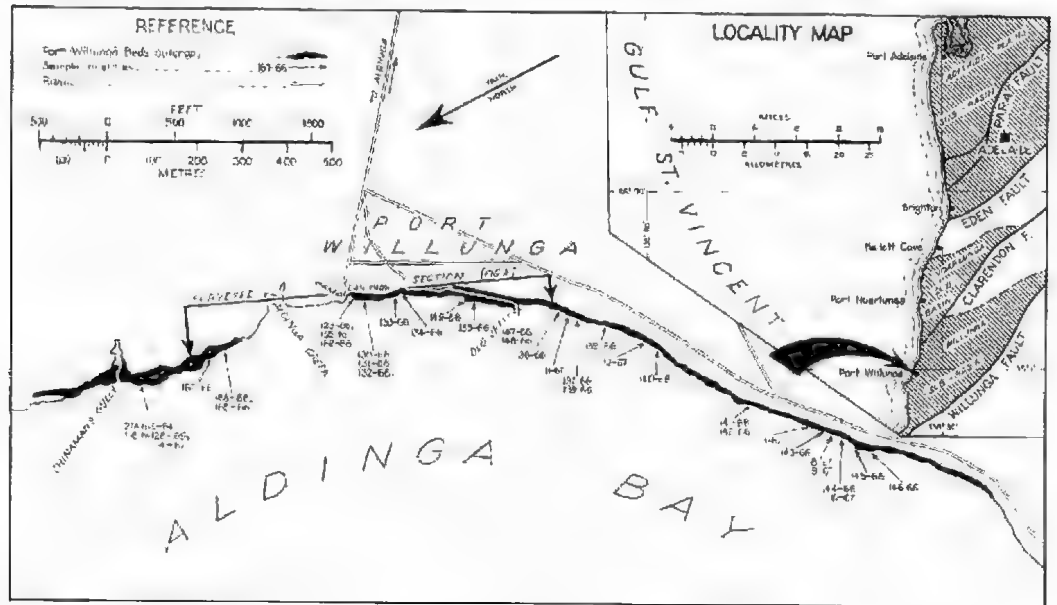


Fig. 1.   Locality map and plan showing position of samples taken from stratotype Port Willunga Beds.

## METHODS

Fig. 1 shows the localities at which samples were taken and Fig. 2 their stratigraphic positions. Included are samples from a pit dug at the site of 129-66, and also tube samples from a "Wacker" hammer hole sunk from the bottom of the pit until stopped in hard sandstone. Washed and unwashed samples and microfaunal preparations, are held in the Palaeontology Section of the Geological Survey of South Australia.

The photographs of planktonic foraminifera in Plate 1 were taken with a Leitz Laborlux microscope, using a Leitz Ultropak lighting unit in combination with a 6.5X objective and relief condenser. Adox KB 12 film was used, and prints were made on Agfa Brovera paper.

## CORRELATION ACROSS ALDINGA CREEK

The exposed Port Willunga Beds are divided into a northern and a southern portion by the sand-covered and alluvium-filled entrance to Aldinga Creek, as shown in Fig. 1. In order to consider the sequence as a whole, it is therefore necessary to determine the stratigraphic relationship between the northern and southern sections across the distance of more than 800 feet (244 m.) which separates them. There are several reasons why this is not a simple matter. Firstly, some of the beds are observed to vary laterally in thickness and lithology. As early as 1878, Tate noted their "most diversified character — clays, limestones, and sands rapidly replacing one another in horizontal and vertical

Fig. 2.  Foraminiferal log, lithology, and stratigraphy of stratotype Port Willunga Beds.

extension". Secondly, minor folding and faulting are apparent in parts of the
sequence as shown in Fig. 2. It is likely that the concealed section has been
affected by one or more of these factors. In addition, matching of the sections
immediately north and south of Aldinga Creek is rendered more difficult by the
limited thicknesses available for examination.

Glaessner (1951, p. 275), recording the measurement by Dolling in 1949
of 25 feet (7½ m.) of "polyzoal sands and clays" north of Aldinga Creek, and
97 feet (30 m.) of "polyzoal sandy marls" south of it, listed these thicknesses
as consecutive and did not discuss the relationship between the two sections.
Reynolds did not explicitly state the thickness of beds common to both exposed
sections. In his Fig. 1, this thickness is apparently drawn as nine feet (2·7 m.).
In his more detailed and definitive Fig. 2 it is shown to be little more than two
feet (0·6 m.). However, in both of these representations the total thickness of
the formation is 111½ feet (34 m.). Glaessner and Wade (1958) produced
from these data a composite section with the same total thickness.

At the time that Ludbrook and Lindsay (1966) recorded their preliminary
notes on the range of *Globigerina linaperta* and the extent of the Aldingan Stage
within the formation, the writer accepted Reynolds's correlation of beds either
side of Aldinga Creek as shown in his Fig. 2. However, the ranges of *Turboro-
talia aculeata* in the northern and southern sections suggested that more of the
beds than he indicated in Fig. 2 are common to the two sections.

Later in 1966, during a discussion with Mr. W. Stewart of the Geology
Department, University of Adelaide, it became apparent that further measure-
ments should be made to check the thickness common to both sections. In a
brief stadia survey, several marker beds near Aldinga Creek were traced by
the writer, and the results are presented slightly diagrammatically in Fig. 2.
The green clay with white limy nodules, which was used as a marker bed by
Reynolds and from which his sample A.211 and the writer's sample 132-66 were
taken, is matched with one of the green clays north of the creek as shown.
Both beds contain the uppermost occurrence of *Turborotalia aculeata* in their
respective sections. This correlation is considered to be reasonably consistent
with the lithological, structural, and microfaunal data, but it is certainly desir-
able that the depth to Chinaman's Gully Beds should be proved south of Aldinga
Creek by drilling.

The type section of Port Willunga Beds as now re-measured, is therefore
approximately 26 feet (8 m.) thick north of Aldinga Creek, and 89 feet (27 m.)
thick south of it, with nearly 8 feet (2½ m.) of overlap between the sections,
yielding a total thickness of about 107 feet (32½ m.).

## LITHOLOGICAL UNITS

Reynolds, in his Fig. 2, distinguished 29 lithological units in the type section.
His basal bed, a green fossiliferous clay, is now considered to be the top unit
of Chinaman's Gully Beds. The remaining 28 units may be grouped into three
lithological subdivisions which are recognizable elsewhere in the Willunga and
Adelaide Plains Sub-basins. For the present, these three subdivisions are simply
referred to as the lower, middle, and upper sequences, but future work may
show that they merit formal stratigraphic status.

Numbering Reynolds's 28 units from the bottom up, the lower sequence
contains units 1 to 12 and is by present measurement and correlation about 43

feet (13 m.) thick. It consists of a thin basal gravelly sand followed by cream cross-bedded bryozoal calcarenitic sandy limestones, calcareous sandstones and sands, green-grey clays (often with white limy nodules) and fawn, brown, or pale grey, impure calcarenitic limestones, silts and marls. This variable succession extends up to the base of the first hard bed which has some siliceous cementation — the "hard consolidated grey marly bed to be seen in the caves below Port Willunga" (Reynolds, Fig. 2).

The middle sequence consists of most of the remainder of the type section, up to and including the lower part of unit 28. It is about 52 feet (16 m.) thick, and is characterized by the sporadic development of a hard spicular cherty phase typically occurring as bands of fawn and grey fossiliferous cherty nodules in softer fawn to pale grey impure limestones, silts, and marls, all calcarenitic and sandy. At the base of this interval is the hard marker bed noted above, which has some siliceous phase but is mostly limestone to calcareous siltstone and sandstone. The base of the lowest bed with prominent siliceous nodules is from 4 to 5 feet (1·3 to 1·5 m.) above the top of the marker bed. This middle, siliceous, interval in Port Willunga Beds is distinct from the older siliceous beds developed in Blanche Point Banded Marls. The two are separated by about 107 feet (32½ m.) of Blanche Point Soft Marls, Chinaman's Gully Beds and Aldingan Port Willunga Beds in the exposures at Maslin and Aldinga Bays.

The upper sequence comprises the upper part of unit 28 to the top of the exposed section. It is about 12 feet (3½ m.) thick, consisting of yellow-brown, fawn, and pale grey bryozoal beds including hard limestone bands, softer impure limestones, silty sands, and at the top of the exposure cross-bedded calcarenitic sandstones.

Reynolds did not define the top of Port Willunga Beds but simply noted that the top of the formation is not revealed in the type section. Three and a half miles (5½ km.) inland, the Willunga Bore W.B.1. (Glaessner and Woodard, 1956; Ludbrook, 1956; Lindsay, 1966) penetrated, above the stratigraphic level of the top of the type section, more than 160 feet (49 m.) of calcareous sands, sandstones, and sandy limestones, which are evidently also Port Willunga Beds. They extend up beyond the level of Janjukian (Oligocene) beds at the top of the type section into beds which are Longfordian (Lower Miocene). The three lithological subdivisions of the type section can also be recognized in broad outline in the bore, despite changes there in lithofacies due to deposition under more marginal and restricted conditions.

Calcarenitic limestones, sands, and clay, which may be included within the scope of Port Willunga Beds, are widespread in the St. Vincent Basin (Glaessner and Wade, 1958). In the Adelaide Plains Sub-basin Miocene beds up to Balcombian Stage, including the Munno Para Clay Member, are known from bores (Lindsay and Shepherd, 1966), and in one locality the presence of *Heterolepa victoriensis* (Chapman, Parr and Collins) suggests Bairnsdalian Stage (Lindsay, 1965). It has been recently demonstrated (Lindsay, 1967) that equivalents of the three lithological subdivisions of the type section are recognizable in deeper bores in the Adelaide Plains. The middle, siliceous, interval is well-developed at least as far north as Hundred of Dublin, but the lower interval is difficult to separate from Blanche Point Soft Marls. and Chinaman's Gully Beds usually cannot be distinguished. The whole succession of Port Willunga Beds attains a maximum known thickness of 874 feet (267 m.) in the Croydon Bore, where, in the lower part of this succession, equivalents of the type section are 440 feet (125 m.) thick,

## CORRELATION WITH AUSTRALIAN AND NEW ZEALAND STAGES

After tracing the usage of the stage name Aldingan, Ludbrook and Lindsay redefined the term "in the restricted time-rock sense as representing the time interval required for the deposition at Aldinga and Maslin Bays of the Tortachilla Limestone, the Blanche Point Marls, the Chinaman's Gully Beds, and the lower half of the Port Willunga Beds". The upper boundary of the stage was drawn at a level of natural subdivision, involving both an important microfaunal event — the top of the range of *Globigerina linaperta* — and an important lithological development — the commencement of the middle, siliceous, interval of Port Willunga Beds. The end of the Aldingan Stage is now further defined as being represented by the top of the hard grey marker bed which is the basal unit of the middle interval as described above. By present measurement and correlation the boundary is at approximately 45 feet (14 m.) above the base of the formation.

Raggatt and Crespin (1955), followed more recently by Carter (1964), have restricted the Janjukian Stage in a time-rock sense to represent the time interval required for the deposition of the Jan Juc Formation in the Bell's Headland-Torquay area of southern Victoria. The most diagnostic planktonic event at present available to link the type sections of Jan Juc Formation and Port Willunga Beds, is the extinction of *Chiloguembelina cubensis* which takes place near the base of the former and near the top of the latter. This event is a feature of Carter's Faunal Unit 4, in the lower episode of the Janjukian. From available data on the range of the species in both sequences it may be inferred that less than 20 feet (6 m.) of Port Willunga Beds, at the top of their type section, are early Janjukian. Most of the middle, siliceous, interval appears to be strictly pre-Janjukian and it is post-Aldingan as at present defined. Further description of the Jan Juc Formation and its planktonic foraminifera will be necessary to further clarify the relation between Aldingan and Janjukian Stages.

Comparison of the ranges of several planktonic species in Port Willunga Beds with their ranges as recorded by Jenkins for New Zealand, suggests correlation with the Kaiatan, Runangan, and Whaingaroan Stages as shown in Fig. 2.

## AGE OF THE TYPE SECTION

Eocene age was recently ascribed to the lower, Aldingan, part of the type section by Ludbrook and Lindsay, the writer having recognized in it a foraminiferal succession, apparently unaffected by reworking, containing *Globigerina linaperta* and associated Eocene species. Although in earlier years considered all of Eocene age by Tate (1879, 1899) and Tate and Dennant (1896), the type section was more recently considered to be of Oligocene to Lower Miocene age. The foraminiferal evidence now available suggests an Oligocene age for the post-Aldingan part of the section.

## PLANKTONIC ZONES

Lithologies and microfaunas suggest that stratotype Port Willunga Beds, as indeed most of the marine Tertiary of the St. Vincent Basin, were deposited under conditions of somewhat restricted access from the open ocean. This environment does not favour the presence of the tropical or temperate planktonic foraminifera which have been chosen to diagnose planktonic zones in standard sequences of comparable age elsewhere. For example, of the zonal species of

Blow and Banner (1962), only *Globigerina ampliapertura* Bolli has been found. Zonal species of Jenkins (1965) not yet encountered include *Globorotalia inconspicua* Howe, and *Globigerina brevis* Jenkins. *Globigerapsis index index* (Finlay), key species of the *index* zone or zone 2 of Carter (1964, p. 46) followed by Wade (1964), occurs only very rarely and as immature specimens. *Globigerina angiporoides angiporoides* Hornibrook, another of Jenkins's zonal species, although very rare, is typical and persistent within the range of G. *linaperta* s.str. Above this, however, only occasional doubtful specimens are present at the level of the *angiporoides angiporoides* zone in New Zealand, and the zone is thus not suitable for local use. G. *euapertura* Jenkins is present, but not well-developed in the type section. Jenkins, however, defined the lower boundary of his *euapertura* zone by the extinction of G. *angiporoides angiporoides*, and as noted above this is not a suitable criterion at Aldinga Bay.

The *linaperta* zone of Carter (1964) followed by Wade (1964), was equated by them with Carter's Faunal Unit 3, which is characterized by the microfauna of the upper part of the Castle Cove Limestone, and the "Lower Glen Aire Clays", containing "a form of *Globigerina linaperta* with swollen chambers" (Carter, 1958, p. 21). Examination of available material leaves little doubt that this is G. *angiporoides angiporoides*, and not G. *linaperta* s.str. Jenkins records similar upward ranges for both G. *linaperta* and *Globigerapsis index index* in New Zealand. Faunal Unit 3, or the "linaperta zone" in this sense, has not been used in the present study due to some uncertainty as to the planktonic content and stratigraphic position of the beds used to define it.

Jenkins defined a different zone of G. *linaperta* in the Upper Eocene of New Zealand, between the extinction of *Globorotalia inconspicua* and the initial appearance of *Globigerina brevis*. Neither of these species is known from Port Willunga Beds but his zone is adapted for local use as described below.

The most useful characteristic of Carter's Faunal Unit 4, the final appearance of *Chiloguembelina cubensis*, is utilized as the upper limit of a zone of G. *cubensis* which follows the zone of G. *linaperta*. *Guembelitria stavensis* is associated with G. *cubensis* at the level of Faunal Unit 4 and ranges a little higher. This relationship is used to define a zone of G. *stavensis*, which occurs at the top of the type section.

Despite their usefulness at a certain stage in the development of Australian Tertiary stratigraphy, Carter's Faunal Units or Zones are for various reasons proving unsuitable or difficult to use (at least in the Eocene and Oligocene) as a framework for planktonic zonation. The recent work of Jenkins in New Zealand has provided the basis for an alternative approach and it is therefore proposed to define from stratotype Port Willunga Beds, informal local planktonic zones which may be useful within the St. Vincent Basin, and may also be related to zones elsewhere via more diverse planktonic sequences from southern Australia and New Zealand.

The lowest such zone in the type section is that of *Turborotalia aculeata* (= *Globorotalia inconspicua aculeata* Jenkins) which extends below Port Willunga Beds, and whose upper limit is marked by the top of the range of the species. Jenkins recorded the same extinction level for both of the forms he regarded as subspecies of G. *inconspicua*. If *T. aculeata* has a similar range in South Australia, the basal 22 feet (6·7 m.) of Port Willunga Beds containing the species, correlate with part of the Kaiatan Stage of New Zealand at the top of the zone of G. *inconspicua*. Species associated with *T. aculeata* in the *aculeata* zone at Aldinga Bay include *Globigerapsis index index*, *Globigerina*

*linaperta, G. angiporoides angiporoides, G. ampliapertura, Turborotalia incre-*
*bescens* (Bandy), *Chiloguembelina cubensis,* and *Cassigerinella* sp. cf. *C. chipo-*
*lensis* (Cushman and Ponton). Below Port Willunga Beds, the sequence at
Aldinga and Maslin Bays is not at present known to have other planktonic
events suitable as a basis of zonation until *Hantkenina alabamensis compressa*
Parr is encountered in the lower part of Blanche Point Transitional Marls.

A zone of *Globigerina linaperta* has its lower boundary defined by the top
of the local range of *Turborotalia aculeata* and its upper by the top of the range
of *G. linaperta* s.str. This is comparable with the G. *linaperta* zone of Jenkins in
the upper Kaiatan and Runangan of New Zealand, but there he shows the final
appearance of *G. linaperta* to be contained within the basal part of his *brevis*
zone which is not yet recognized in Australia. Species associated with G. *lina-*
*perta* in this adapted *linaperta* zone include *Chiloguembelina cubensis, Cassi-*
*gerinella* sp. cf. *C. chipolensis, Turborotalia increbescens, Globigerina amplia-*
*pertura, G. angiporoides angiporoides,* and, at the top, *Guembelitria stavensis*
and *Globigerina euapertura.* The zone of *G. linaperta* is present in the upper-
most part of the Aldingan.

The zone of *Chiloguembelina cubensis* has its lower boundary defined by
the top of the local range of *G. linaperta* and its upper boundary by the final
appearance of *C. cubensis.* Species associated with the zonal species include
*Guembelitria stavensis, Cassigerinella chipolensis, Globigerina euapertura,* and
very rare and doubtful specimens of *G. angiporoides angiporoides.* Also occur-
ring towards the top of the zone in the type section are *Globigerina bulloides*
d'Orbigny, *G.* sp. cf. *G. ciperoensis ciperoensis* Bolli, *G. labiacrassata* Jenkins,
and *Globorotaloides testarugosa* (Jenkins). A specimen of *Globanomalina* sp. cf.
*G. naguewichiensis* (Myatliuk) was recovered from the top of the zone. The
zone of *C. cubensis* is post-Aldingan, and its uppermost part, at least, is early
Janjukian. The zone is likely to be synchronous with most of the *brevis* zone,
the whole of the *angiporoides angiporoides* zone, and the basal part of the
*euapertura* zone of Jenkins.

The zone of *Guembelitria stavensis* has its lower boundary defined by the
top of the local range of *Chiloguembelina cubensis,* and its upper boundary by
the final appearance of the zonal species, the latter event almost certainly
occurring stratigraphically higher than the top of the type section of Port Wil-
lunga Beds. In the Willunga Bore W.B.1, and generally in the Adelaide Plains
Sub-basin, *G. stavensis* ranges up above *C. cubensis* (Lindsay, 1966, 1967, cited
above). At the top of the type section the zonal species is associated with
*Cassigerinella chipolensis* and *Globigerina bulloides.* The zone would no doubt
occupy an interval in the lower part of Jenkins's *euapertura* zone (though Jenkins
does not record *G. stavensis*), in uppermost Whaingaroan and perhaps basal
Duntroonian.

## FORAMINIFERA

### PLANKTONIC SPECIES

Throughout the type section, planktonic species are mostly small and re-
stricted in variety, although at times abundant. No reworking is apparent. The
local ranges of more significant species are plotted in Fig. 2.

*Globigerina praebulloides* (many comparable with subsp. *leroyi* Blow and
Banner), *G. angusthumbilicata* Bolli, *G. officinalis* Subbotina, and *G. ouachitoensis*
Howe and Wallace, range through the sequence, comprising an association of
small, apparently tolerant, species related to the *Globigerina bulloides* Lineage
which was discussed by Wade. They often form the most obvious and abundant

planktonic component of the samples examined and appear to be typically present in Upper Eocene and Oligocene sequences elsewhere. Because of their long ranges, however, they are omitted from Fig. 2.

### Guembelitria stavensis Bandy
Pl. 1, Fig. 1

1949. *Guembelitria stavensis* Bandy. Bull. Am. Paleont., 32 (131), pp. 124-125, pl. 24, figs. 5a-b.

1964. *Guembelitria* sp.; Wade, Micropaleontology 10 (3), pp. 286-287, pl. 1, figs. 12a-b.

The South Australian species of *Guembelitria* which occurs in the uppermost Eocene and Oligocene, has been compared with the types of *G. stavensis* kindly loaned by the University of Indiana. At Port Willunga, the species commences its range about 7 feet (2 m.) below the extinction of *Globigerina linaperta* and continues up to the top of the section beyond the highest occurrence of *Chiloguembelina cubensis*, this latter part of its range comprising the basal part of the zone of *G. stavensis*. The species has a wide distribution in the St. Vincent, Murray and Otway Basins.

### Chiloguembelina cubensis (Palmer)
Pl. 1, Figs. 2-3

1934. *Giimbelina cubensis* Palmer. Mem. Soc. Cubana Hist. Nat., 8 (2), pp. 74-75, text figs. 1-6 (*fide* Ellis and Messina, 1940 *et seq.*).

1957. *Chiloguembelina cubensis*; Beckmann, Bull. U.S. Natn. Mus., 215, pp. 84, 89, pl. 21, fig. 21, text fig. 14 (5-8).

1964. *Chiloguembelina rugosa*; Wade, Micropaleontology, 10 (3), pp. 286-287, pl. 1, fig. 2.

Beckmann (1957) commented on the stratigraphic usefulness of *Chiloguembelina*, particularly in samples containing mainly a benthonic fauna, and his remarks are supported by the writer's experience of both *Chiloguembelina* and *Guembelitria* in the Upper Eocene and Oligocene of the Murray and St. Vincent Basins in South Australia.

Reynolds (p. 129) was the first to note the presence of "*Gumbelina*" in type Port Willunga Beds, from sample A.114, 18 feet above the base of the formation (Carter, 1958, p. 25). It is now known that *C. cubensis* ranges almost throughout the section, appearing to approach extinction towards the top in basal Janjukian equivalents, where it becomes very rare and sporadic. The last-appearing specimen is figured.

Besides Carter's record of the last appearance of the species in Faunal Unit 4 low in the Jan Juc Formation at Bell's Headland (Carter, 1964, p. 42, fig. 14), Taylor (1966), records *C. cubensis* above *G. linaperta* from Esso Gippsland Shelf No. 1 Well in his Zonule J which he compares with Faunal Unit 4. Jenkins puts the extinction of *C. cubensis* within the basal part of his *cuapertura* zone, high in the Whaingaroan of New Zealand. He has recently (1966) made this extinction the eleventh in a series of twenty-nine homotaxial datum planes chosen by him for the Pacific and Trinidad Tertiary. In Trinidad, *C. cubensis* makes its final appearance in the *opima opima* zone. The occurrence of this datum plane near the top of stratotype Port Willunga Beds is thus of considerable importance. Although the planes are described by Jenkins as homotaxial and not necessarily isochronous, he accepts the extinction of *C. cubensis* as an Oligocene event.

### Globanomalina sp. cf. G. naguewichiensis (Myatliuk)
Pl. 1, Figs. 4-5

1950. *Globigerinella naguewichiensis* Myatliuk, Trudy vses. neft. nauchno-issled. geol.-razv. Inst. (VNIGRI). Mikrofauna S.S.S.R., sb. 4, vyp. 51, 281, pl. 4, figs. 4a-b (*fide* Ellis and Messina, 1940, *et seq.*).

1962. *Pseudohastigerina naguewichiensis*; Blow and Banner (University Press, Cambridge). p. 72.

Loeblich and Tappan (1964, p. C 665) are followed in regarding *Pseudo-hastigerina* as a synonym of *Globanomalina*. A solitary small planispiral specimen with six chambers in the final whorl was recovered from the top of the *cubensis* zone. It is *Globanomalina*, apparently less akin to G. *micra* (Cole) than to G. *naguewichiensis* (*fide* Ellis and Messina, 1940, *et seq.*). The extinction of Myatliuk's species, as the last-surviving species of *Globanomalina*, marks the lower boundary of the basal Neogene zone N.1 of Banner and Blow (1965). Too much importance cannot be attached to a single specimen, but the occurrence does provide some support for the widely-held view that the extinction of G. *cubensis* occurred in the Palaeogene and Oligocene.

## Cassigerinella chipolensis (Cushman and Ponton)
### Pl. 1, Fig. 6

1932. *Cassidulina chipolensis* Cushman and Ponton, Bull. Fla. St. geol. Surv. No. 9, p. 98, pl. 15, figs. 2a-c (*fide* Ellis and Messina, 1940 *et seq.*).
1962. *Cassigerinella chipolensis*; Blow and Banner (University Press, Cambridge). pp. 81, 83, pl. XV (M, N) (synonymy).
1964. *Cassigerinella chipolensis*; Wade, Micropaleontology, 10 (3), pp. 286-287, pl. 1, fig. 22.

Specimens with well-developed biserial enrolling and prominent aperture, occur through the *cubensis* and *stavensis* zones. The species ranges as high as the Balcombian Munno Para Clay in the Adelaide Plains Sub-basin, and up to Bairnsdalian Pata Limestone in the Murray Basin of South Australia.

## Cassigerinella sp. cf. C. chipolensis
### Pl. 1, Figs. 7-9

Blow and Banner did not find any forms referable to the genus *Cassigerinella* in the Eocene of the Lindi area, Tanganyika. However, in stratotype Port Willunga Beds, forms from the upper part of the *aculeata* zone, and the *linaperta* zone, are referable to *Cassigerinella* and are compared with C. *chipolensis*. Eleven such specimens have been recovered. They usually have a distinct planispiral early stage, but also display the biserial enrolling of *Cassigerinella*. In some examples the aperture tends to be more restricted and slit-like than is the case with C. *chipolensis*, but the earliest form (pl. 1, figs. 7-8) has a distinctly open oval aperture. The lowest sample south of Aldinga Creek with C. sp. cf. C. *chipolensis* (155-66) also contains immature but characteristic *Globigerapsis index index* besides *Turborotalia aculeata*. The earliest C. sp. cf. C. *chipolensis* in the type section is from sample 123-66 north of Aldinga Creek, and is associated with the latest *Maslinella chapmani* Glaessner and Wade. Todd (1966, p. 14) has recently discussed the possibility that *Cassigerinella* occurs in the Eocene. The evidence from Port Willunga Beds seems to confirm that it does.

## Turborotalia aculeata (Jenkins)
### Pl. 1, Figs. 10-11

1965. *Globorotalia inconspicua aculeata* Jenkins, N.Z. J. geol. geophys., 8 (6), pp. 1118, 1120, fig. 13, nos. 119-125.

In the present study, non-keeled Globorotaliinae are assigned to *Turboro-talia* following Loeblich and Tappan (1964, p. C 668). This distinctive finely spinose species described from the Bortonian and Kaiatan Stages of New Zealand, is present, at times abundantly, in the basal 22 feet (6½ m.) of the type section, in the *aculeata* zone. Its differences from *Globorotalia inconspicua* Howe, noted by Jenkins, appear to suffice for its transfer from a subspecies of

*G. inconspicua* to a distinct species in *Turborotalia*. Both north and south of Aldinga Creek, the highest occurrence of *T. aculeata* is in a green clay with white limy nodules, supporting the equivalence of these two beds as shown in Fig. 2. The species is known from the Eocene of the St. Vincent, Murray, and Otway Basins of southern Australia.

### Turborotalia increbescens (Bandy)
Pl. 1, Fig. 12

1949. *Globigerina increbescens* Bandy, Bull. Am. Paleont., 32 (131), pp. 120-121, pl. 23, figs. 3a-c.
1962. *Globorotalia (Turborotalia) increbescens*; Blow and Banner (University Press, Cambridge), pp. 118-119, pls. XIII (T-V), XVII (D, K), fig. 9 (xiii-xv).
1965. *Turborotalia increbescens*; Reed, Bull. Am. Paleont., 49 (220), pp. 86-87, pl. 14, figs. 11-13.

The species has been found only in two samples straddling the top of the *aculeata* zone north of Aldinga Creek. This is somewhat higher than the range recorded by Jenkins from New Zealand, but is within the lower part of the range recorded by Blow and Banner from Lindi (*op. cit.*, Fig. 20).

### Turborotalia opima continuosa (Blow)
Pl. 1, Figs. 13-14

1959. *Globorotalia opima continuosa* Blow, Bull. Am. Paleont., 39 (178), pp. 218-219, pl. 19, figs. 125a-c.
1965. *Globorotalia continuosa*; Jenkins, N.Z. J. geol. geophys., 8 (6), fig. 2 (range chart).

Only two examples have been recognized, both from sample 145-66 at the top of the *cubensis* zone, from a level near the bottom of the range of the species as recorded for New Zealand by Jenkins. The specimen figured agrees closely with Blow's diagnosis of the subspecies, which by the criteria of Loeblich and Tappan belongs to *Turborotalia* rather than to *Globorotalia*.

### Globigerina ampliapertura Bolli
Pl. 1, Fig. 17

1957. *Globigerina ampliapertura* Bolli, Bull. U.S. Natn. Mus., 215, p. 108, pl. 22, figs. 4a-7b.
1962. *Globigerina ampliapertura ampliapertura*; Blow and Banner (University Press, Cambridge), pp. 83-84, pls. XI (A-D), XVII (C), fig. 12b.

The species has been seen only in the Aldingan portion of the type section, mostly in the *linaperta* zone, where it is small with a relatively high arched aperture. This is comparable with the basal part of the range of the species in New Zealand as recorded by Jenkins.

### Globigerina angiporoides angiporoides Hornibrook
Pl. 1, Fig. 25

1965. *Globigerina angiporoides* Hornibrook, N.Z. J. geol. geophys., 8 (5), pp. 834-838, figs. 1 (a-i), 2 (synonymy).
1965. *Globigerina angiporoides angiporoides*; Jenkins, N.Z. J. geol. geophys., 8 (6), pp. 1092, 1096, fig. 2 (range chart).

Through the *aculeata* zone this form occurs typically and consistently but mostly very rarely. It ranges into the *linaperta* zone and occasional doubtful examples are present nearly to the top of the *cubensis* zone. Taylor (op. cit.) recorded this species (as *G. angipora* Stache) only from his Zonule K of uppermost Eocene age in Esso Gippsland Shelf No. 1 Well, associated with *G. linaperta*. *G. angiporoides angiporoides* is abundant in the "Lower Glen Aire Clays", and as was noted above, there is little doubt that it is the form referred to by Carter as "*G. linaperta* with swollen chambers", the characteristic species of his Faunal Unit 3 or "*linaperta* zone".

## Globigerina bulloides d'Orbigny

### Pl. 1, Fig. 16

1941. *Globigerina bulloides* d'Orbigny; Cushman, Contr. Cushman Lab. foramin. Res., 17 (2), pp. 38-39, pl. 10, figs. 1-13 (synonymy).

1959. *Globigerina bulloides*; Blow, Bull. Am. Paleont., 39 (178), pp. 175-176, pl. 9, figs. 38a-c.

There has been some disagreement among micropalaeontologists over the age of earliest *G. bulloides*, varying for example from middle Miocene (Blow, 1959, p. 175) to Upper Eocene (Wade, op. cit., p. 278). Jenkins recorded earliest *G. bulloides* in New Zealand from middle Whaingaroan Stage (Oligocene), and comparable with this, in type Port Willunga Beds, forms attributable to *G. bulloides* enter high in the *cubensis* zone and are prominent within the Janjukian interval.

## Globigerina sp. cf. G. ciperoensis ciperoensis Bolli

### Pl. 1, Fig. 18

1954. *Globigerina ciperoensis* Bolli, Contr. Cushman Fdn. foramin. Res., 5 (1), pp. 1-2, text figs. 3, 3a, 4, 4a-b, 5, 5a-b, 6.

1957. *Globigerina ciperoensis ciperoensis* Bolli, Bull. U.S. Natn. Mus., 215, p. 109, pl. 22, figs. 10a-b.

At a similar level to that recorded by Jenkins for New Zealand, the *ciperoensis* form is emerging as an offshoot from the *G. angustiumbilicata* population at the top of the *cubensis* zone in Port Willunga Beds, as it develops a more highly trochospiral, five-chambered whorl, a slightly hispid test, and a more open centrally-situated umbilical aperture tending to lose its lip. The specimen most similar to *G. ciperoensis ciperoensis* is figured, but its umbilicus is still relatively small, and an apertural lip is still slightly developed.

## Globigerina euapertura Jenkins

### Pl. 1, Fig. 15

1960. *Globigerina euapertura* Jenkins. Micropaleontology, 6 (4), p. 351, pl. 1, figs. 8a-e.

1962. *Globigerina ampliapertura euapertura*; Blow and Banner (University Press, Cambridge), p. 84, pl. XI (E-G).

Commencing its range near the top of the Aldingan, *G. euapertura* occurs most frequently in the Janjukian interval. The rather low, rimmed, widely-arched aperture and depressed final chamber, are distinctive features. Blow and Banner discussed *euapertura* as a subspecies of *G. ampliapertura*, and showed its emergence from that lineage near the top of their *turritilina turritilina* zone (uppermost Eocene) at Lindi. Similarly in New Zealand, Jenkins records the commencement of the range of *G. euapertura* near the Runangan-Whaingaroan boundary. At Port Willunga, sample 147-66 from just below the top of the Aldingan Stage contained the specimens figured of the earliest definite *G. euapertura* and the latest *G. ampliapertura* seen.

## Globigerina labiacrassata Jenkins

### Pl. 1, Figs. 20-22

1965. *Globigerina labiacrassata* Jenkins, N.Z. J. geol. geophys., 8 (6), pp. 1102, 1104, 1106, fig. 8, nos. 64-71.

A few examples of the species have been recovered from samples 9-67 and 13-67 in the upper part of the *cubensis* zone, at a level equivalent to the middle of its range in New Zealand. The forms have moderately thickened apertural rims, and variable size and height of aperture, as compared with the more typical figured specimen from the Otway Basin.

### Globigerina linaperta Finlay
#### Pl. 1, Figs. 23-24

1939. *Globigerina linaperta* Finlay. Trans. R. Soc. N.Z., **69** (1), p. 125. pl. 13. figs. 54-57.
1962. *Globigerina linaperta linaperta*; Blow and Banner (University Press, Cambridge), pp. 85-87, pl. XI (H) (synonymy).

The apparent environmental tolerance of this species makes it stratigraphically important in Eocene correlation. Blow and Banner demonstrated its extinction at Lindi at the top of their *turritilina turritilina* zone, in beds still Eocene on the evidence of diagnostic larger foraminifera such as *Discocyclina* sp. For New Zealand, Jenkins recorded both *G. linaperta* and *Globigerapsis index index* as having become extinct at the top of the Runangan, and accepted this as the Eocene-Oligocene boundary. McTavish (1966, p. 16) maintained that *G. linaperta* "persisted into the Oligocene in Australia", while acknowledging its general extinction at the close of the Eocene. However, it seems likely from present studies that Australian records of *G. linaperta* from the Oligocene refer either to *G. angiporoides angiporoides* or to forms not conspecific with *G. linaperta* but comparable with it in some aspects. The specimens figured from Port Willunga Beds show the diagnostic features of the species, and in particular the specimen from sample 148-66, the uppermost recovered, is very comparable with New Zealand material examined.

### Globorotaloides testarugosa (Jenkins)
#### Pl. 1, Fig. 26

1960. *Globorotalia testarugosa* Jenkins, Micropaleontology, **6** (4), p. 368. pl. 5. figs. 8a-c.
1965. *Globorotaloides testarugosa*; Jenkins. N.Z. J. geol. geophys., **8** (6), p. 1092, fig. 2 (range chart).

Good examples are present very rarely at the top of the *cubensis* zone, equivalent to the middle of the range recorded by Jenkins from New Zealand. He described the species from the base of the Lakes Entrance Oil Shaft in Victoria at the top of its range. The form has also been recorded by Taylor (op. cit.) from Esso Gippsland Shelf No. 1 Well. The figured specimen shows the characteristic coarsely pitted wall and relatively straight tangential sutures on the spiral side.

### Globigerapsis index index (Finlay)
#### Pl. 1, Fig. 19

1939. *Globigerinoides index* Finlay. Trans. R. Soc. N.Z., **69** (1), p. 125, pl. 14. figs. 85-88.
1957. *Globigerapsis index*; Bolli. Bull. U.S. Natn. Mus., 215, p. 165, pl. 36, figs. 14a-18b.
1965. *Globigerapsis index index*; Jenkins, N.Z. J. geol. geophys., **8** (6), pp. 1091, 1094. fig. 2 (range chart).

Immature examples with wide single apertures, as shown in the figured specimen, occur very rarely within the *aculeata* zone. Jenkins does not record *Globigerapsis tropicalis* Blow and Banner from New Zealand and ranges both *G. index index* and *Globigerina linaperta* to the top of the Runangan. *G. index index* is evidently more affected by adverse environment than is *G. linaperta* and its usability as a zonal indicator is thereby lessened. However, its occasional presence within the bottom 16 feet (5 m.) of the type section of Port Willunga Beds confirms the Upper Eocene age of this interval.

### BENTHONIC SPECIES

The benthonic foraminifera have not been studied in detail and many of the species are as yet undescribed. A few of more immediate stratigraphic significance will be noted here.

An interesting assemblage is present as a numerically minor constituent of the microfauna in the basal 20 feet (6 m.) of the type section, within the Upper Eocene *aculeata* zone. The members of this assemblage are: *Crespinina kingscotensis* Wade, *Linderina* sp., *Halkyardia* sp. cf. *H. bartrumi* Parr., *Maslinella chapmani* Glaessner and Wade, *Reussella finlayi* Dorreen, and a genus close to *Bolivinella*. Their ranges within the type section are plotted in Fig. 2.

All South Australian specimens of *Crespinina kingscotensis* recorded by Wade in her description of the species (1955), came from Eocene beds. It has in addition been recorded by Ludbrook from Buccleuch A and B in the Murray Basin (1961, Table X), and at Aldinga Bay (1956, p. 17) from as high as basal Port Willunga Beds. In South Australia it is thus only known as an Eocene species.

*Linderina* sp., and *Halkyardia* sp. cf. *H. bartrumi*, have been recorded by Ludbrook, and the latter figured, from Buccleuch A (1961). She has also noted them (1963, pp. 8, 9) from other calcareous sediments in the Upper Eocene of South Australia.

*Maslinella chapmani* is only known from the Eocene. Glaessner and Wade (1959) described South Australian occurrences from Upper Eocene beds at Maslin Bay, Port Noarlunga, Kingscote (Kangaroo Island), and Moorlands. Ludbrook noted the species from Buccleuch A in the Murray Basin (1961), and in 1963, in Middle and Upper Eocene microfaunas from South Australia, including the Eucla Basin. A few examples have now been recovered from the *aculeata* zone in type Port Willunga Beds north of Aldinga Creek.

A genus closely related to *Bolivinella* was recorded and figured by Ludbrook (1961) from Upper Eocene Buccleuch A in the Murray Basin, and noted by her (p. 86) to occur associated with *Hantkenina alabamensis compressa* in Blanche Point Transitional Marls at Maslin Bay. A few glauconitic internal casts of the form have now also been found at the top of Chinaman's Gully Beds in sample 118-66, and typical examples occur low in Port Willunga Beds. In a few of the specimens some coiling of the initial chambers has been observed. This species is only known from the Eocene of South Australia.

As with the planktonics, these benthonics do not appear to have been reworked from older beds. Occasional specimens show slight wear, interpreted as due to the kind of contemporaneous abrasion which might be expected in beds such as the basal cross-bedded bryozoal sands.

The assemblage noted above thus supports the planktonic evidence for an assignment of Upper Eocene age to the *aculeata* zone in type Port Willunga Beds.

*Cibicides pseudoconvexus* Parr, 1938, ranges throughout the section but occurs only occasionally above the *aculeata* zone, the uppermost example being found at the top of the *cubensis* zone. The species was reported by Carter to be present as high as Faunal Unit 4 (1958, Table 3; 1964, Table 3).

Although miliolids are scarce in the type section, a single good example of *Massilina torquayensis* (Chapman, 1922), was found at the top of the *cubensis* zone, within the Janjukian interval. A comparable finely striate siliceous internal cast was recovered from low in the *cubensis* zone. This is a characteristic species of the Jan Juc Formation and its South Australian correlatives. A specimen from the Ettrick Formation has been figured by Ludbrook (1961, Pl. 11, Fig. 3).

Placed for the present in *Notorotalia*, a species which is probably new appears in the Janjukian near the top of the *cubensis* zone. It ranges up into

the *stavensis* zone, and elsewhere into the basal Miocene of the Murray and St. Vincent Basins. More robust, and somewhat larger than *Notorotalia howchini* (Chapman, Parr and Collins), it has a more or less prominent but flush umbilical plug. It is quite distinct from *Porosorotalia crassimura* (Carter), which is present throughout the type section.

*Pseudopolymorphina rutila parri* Cushman and Ozawa, 1930, has only been seen from the top of the *cubensis* zone. It was described from the Jan Juc Formation and occurs sparsely in Janjukian correlatives in the Murray and St. Vincent Basins.

*Sherbornina atkinsoni* Chapman occurs throughout the type section, preferring calcareous sandy facies, but S. *cuneimarginata* Wade is not present.

Notably absent from even the Upper Eocene part of Port Willunga Beds are *Asterigerinella adelaidensis* (Howchin) and a distinctive, striate, *Pseudopolymorphina* sp. (of Ludbrook, 1961, Pl. 1, Fig. 1). In the St. Vincent Basin the former is not known from above Blanche Point Marls and the latter ranges no higher than the Blanche Point Transitional Marls Member.

*Victoriella conoidea* (Rutten) has not been seen in the type section, and in any case use of the *Victoriella conoidea* zone (Carter, op. cit.; "V. plecte" zone of Glaessner, op. cit.) would be inappropriate for a scheme of planktonic zonation. The *cubensis* and *stavensis* zones of the present scheme are used instead for all but the uppermost part of the zone of *Victoriella conoidea*. The species has been found by the writer recently for the first time in the Adelaide Plains in the Croydon Bore where it occurs in Port Willunga Beds at 1,040-1,045 feet (317-319 m.) in pale brownish-grey limestone, 25 feet (7·6 m.) above the top of the *stavensis* zone, and associated in an upper Janjukian microfauna with *Cibicides psuedoconvexus*, *Globigerina* sp. cf. *G. angulisuturalis* Bolli, *Massilina torquayensis*, *Sherbornina atkinsoni* and *Sherbornina cuneimarginata*. This is above the level of the type section of Port Willunga Beds, and must be close to the Oligocene-Miocene boundary.

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## EXPLANATION OF PLATE

PLATE 1 (*all figures* X 110)

All from type section of Port Willunga Beds except Fig. 22.

Fig. 1. *Guembelitria stavensis* Bandy. Hypotype Ff419, sample 145-66, top of *cubensis* zone, Oligocene.

Fig. 2-3. *Chiloguembelina cubensis* (Palmer). Hypotype Ff420, sample 145-66, as above. 2. Side view. 3. Oblique view showing aperture.

Fig. 4-5. *Globanomalina* sp. cf. *G. naguewichiensis* (Myatliuk). Hypotype Ff421, sample 145-66, as above. 4. Side view. 5. Apertural view.

Fig. 6. *Cassigerinella chipolensis* (Cushman and Ponton). Hypotype Ff422, sample 144-66, high in *cubensis* zone, Oligocene. Side view, showing aperture.

Fig. 7-9. *Cassigerinella* sp. cf. *C. chipolensis* (Cushman and Ponton). 7, 8. Hypotype Ff423, sample 123-66, *aculeata* zone, Upper Eocene. 7. Apertural side view. 8. Oblique apertural view. 9. Hypotype Ff424, sample 126-66, top of *aculeata* zone, Upper Eocene. Side view.

Fig. 10-11. *Turborotalia aculeata* (Jenkins). Hypotype Ff425, sample 163-66, *aculeata* zone, Upper Eocene. 10. Umbilical view. 11. Spiral view.

Fig. 12. *Turborotalia increbescens* (Bandy). Hypotype Ff426, sample 127-66, basal *linaperta* zone, Upper Eocene. Umbilical view.

Fig. 13-14. *Turborotalia opima continuosa* (Blow). Hypotype Ff427, sample 145-66, top of *cubensis* zone, Oligocene. 13. Side view showing the "comma-shaped aperture" noted by Blow. 14. Umbilical view.

Fig. 15. *Globigerina euapertura* Jenkins. Hypotype Ff428, sample 147-66, near top of *linaperta* zone, uppermost Eocene. Umbilical view.

Fig. 16. *Globigerina bulloides* d'Orbigny. Hypotype Ff429, sample 145-66, top of *cubensis* zone, Oligocene. Umbilical view.

Fig. 17. *Globigerina ampliapertura* Bolli. Hypotype Ff430, sample 147-66, near top of *linaperta* zone, uppermost Eocene. Umbilical view.

Fig. 18. *Globigerina* sp. cf. *G. ciperoensis ciperoensis* Bolli. Hypotype Ff431, sample 145-66, top of *cubensis* zone, Oligocene. Umbilical view.

Fig. 19. *Globigerapsis index index* (Finlay). Hypotype Ff432, sample 161-66, *aculeata* zone, Upper Eocene. Umbilical view showing single aperture of immature specimen.

Fig. 20-22. *Globigerina labiacrassata* Jenkins. 20. Hypotype Ff433, sample 9-67, high in *cubensis* zone, Oligocene. Umbilical view showing relatively small aperture with thick rim. 21. Hypotype Ff434, sample 13-67, *cubensis* zone, Oligocene. Umbilical view showing larger aperture and thick rim. 22. Hypotype Ff435, Oil Development N.L. Mount Salt Structure Hole No. 3, 560-570 feet, Gambier Limestone, Oligocene, Otway Basin, 10 miles (16 km.) south-west of Mount Gambier. Umbilical view showing typical apertural features.

Fig. 23-24. *Globigerina linaperta* Finlay. 23. Hypotype Ff436, sample 120-66, *aculeata* zone, Upper Eocene. Umbilical view. 24. Hypotype Ff437, sample 148-66, top of *linaperta* zone, uppermost Eocene. Umbilical view.

Fig. 25. *Globigerina angiporoides angiporoides* Hornibrook. Hypotype Ff438, sample 21E-64, high in *aculeata* zone, Upper Eocene. Umbilical view.

Fig. 26. *Globorotaloides testarugosa* (Jenkins). Hypotype Ff439, sample 145-66, top of *cubensis* zone, Oligocene. Spiral view.
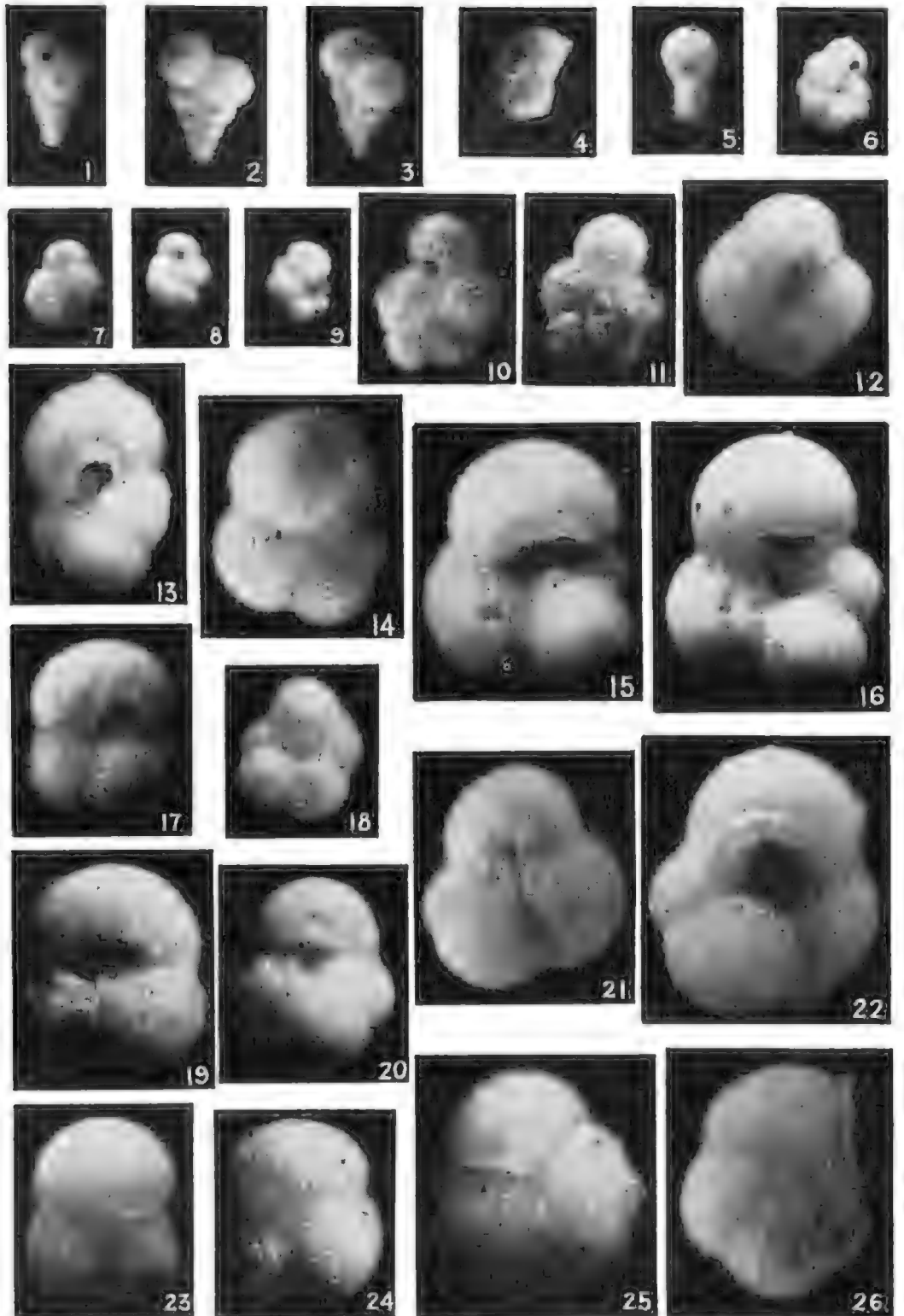
# A NEW SPECIES OF EREMOPHILA FROM SOUTH AUSTRALIA

*BY ELIZABETH A. SHAW**

## Summary

In this paper is described *Eremophila hillii,* a species so far known only from two collections made near Ooldea, South Australia. It belongs to the section *Stenochilus* (R.Br.) Benth., but differs markedly from the other species placed herein by its small obovate to suborbicular crenate leaves.

# A NEW SPECIES OF EREMOPHILA FROM SOUTH AUSTRALIA

by Elizabeth A. Shaw*

[Read 13 July 1967]

## SUMMARY

In this paper is described *Eremophila hillii*, a species so far known only from two collections made near Ooldea, South Australia. It belongs to the section *Stenochilus* (R.Br.)Benth., but differs markedly from the other species placed herein by its small obovate to suborbicular crenate leaves.

### Eremophila hillii E. A. Shaw, sp. nov.

Section *Stenochilus* (R.Br.)Benth., Fl.Austr.5(1870)27.

*Frutex* usque ad 70 cm altus, intricate ramosus, habitu cumulatus, pilis erectis, albidis vel griseis, multiramosis vel stellatis vel ± plumosis vestitus. *Rami* plerumque cicatricibus foliorum delapsorum praediti; iuniores dense tomentosi sed vestutiores glabrescentes. *Folia* matura ca. 7-10 mm x 4-8 mm, dense tomentosa, spiraliter disposita ut videtur, versus apices ramorum dense conferta, obovata ad obtrullata vel suborbicularis, sessilia vel in petiolum brevissimum angustata, plerumque ad apicem rotundata vel subacutata raro acutata, raro integra plerumque crenata. *Flores* singulatim in axillis foliorum summorum dispositi; pedicelli ca. 2-3 mm longi dense tomentosi. *Sepala* 5 imbricata, post anthesin probabiliter non aucta; exteriora 3 ca. 5·2-7·0 mm longa x 2·5-3·4 mm lata, ovata ad deltata ad apicem rotundata vel subacutata, in superficiebus ambabus dense tomentosa; interiora 2, ca. 4·5-5·5 mm longa x 1·8-2·6 mm lata, plerumque ovato-lanceolata subacutata, extus dense tomentosa sed intus basem versus glabrescentia. *Corolla* ca. 3·0-3·5 cm longa in vivo rubra, in sicco cinnabarina ad lateritia vel interdum flavida, in statibus ambabus intus pallidior; extus pilis brevibus glandulosis sparsis aequaliter praedita, intrinsecus pilis glandulosis irregulatim sparsis, utrinque basem versus (sub segmentis calycis) glabrescens; supra ovarium corolla subglobosa expansa deinde parum contracta et supra denuo ampliata et leviter arcuata; lobi labii superioris 4 consimiles longitudine, ca. 2·0-3·5 mm longi, triangulares (ei laterales interdum oblique triangulares) acuti; labium inferius ca. 12-16 mm longum, loratum reflexumque, plerumque subacutum. *Stamina* 4, inter se non valde diversa, ca. 3·0-4·5 mm, longe exserta, filamentis complanatis et pilis glandulosis aspersis praecipue ad basem vestitis. *Ovarium* ca. 2·5-3·5 mm longum, glabrum ovoideum, biloculare ovulis 2 in quoque loculo; stylus ca. 3·8-4·5 cm longus gracilis et glaber. *Fructus* ignotus. *Semina* ignota.

Holotypus: ca. 5 km north of Ooldea; 20.9.1960; *P.Wilson* 1795. Sandhills. Rounded bush 2 ft. high, flower red. Leaves whitish. — AD 96131130!

*Shrub* to ca. 70 cm in height, intricately branched and mounded in habit, covered with white or pale grey many-branched, stellate or ± plumose erect

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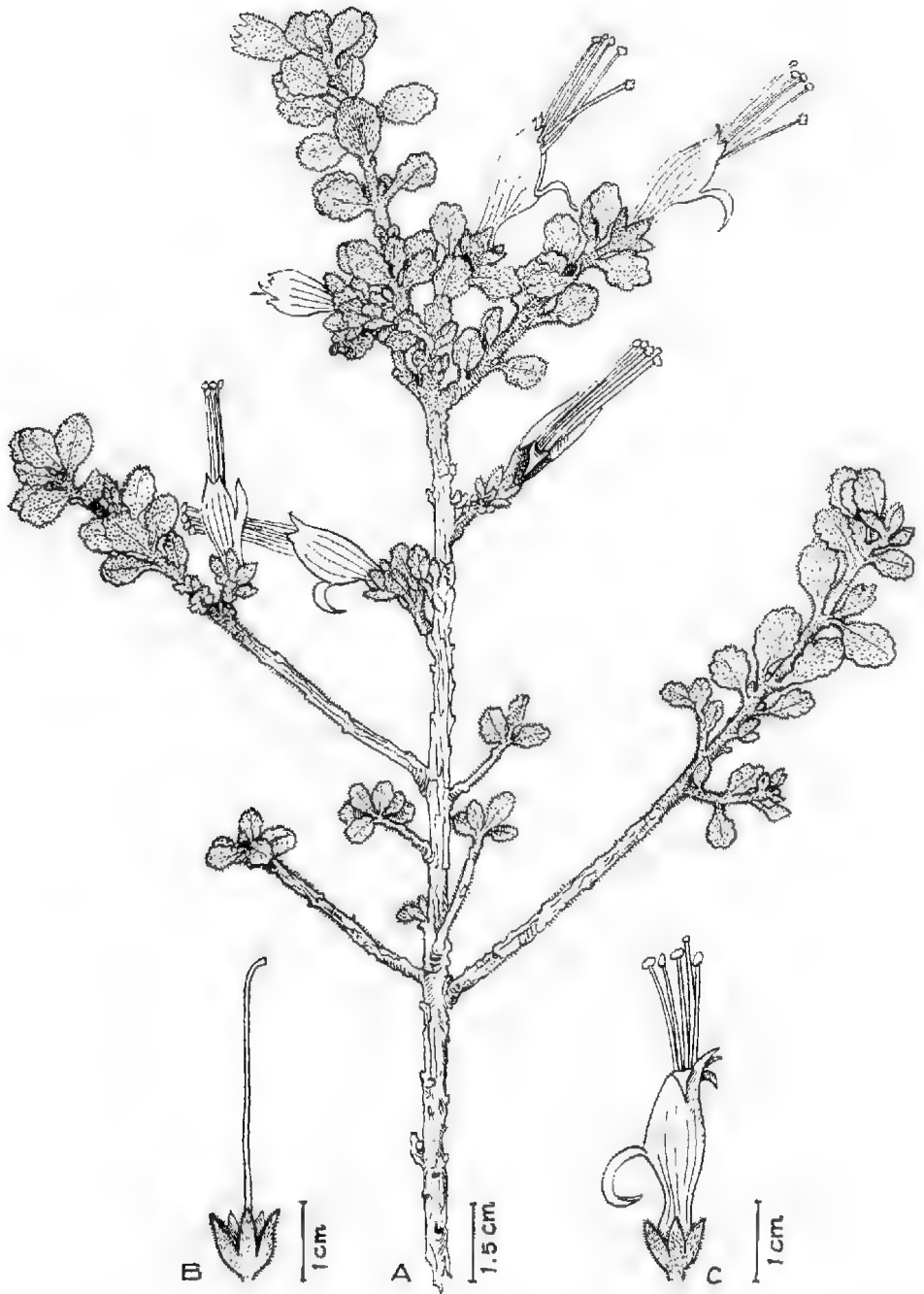
* State Herbarium of South Australia, Adelaide.

Fig. 1. *Eremophila hillii* E. A. Shaw. A, flowering branch; B. flower with corolla removed; C, entire flower—(all ex Wilson 1795).

hairs. *Branches* usually with rather conspicious leaf scars, the younger ones densely tomentose, but the older ones glabrescent. *Leaves* ca. 7-10 mm x 4-8 mm when mature, densely tomentose, apparently in a spiral sequence, very densely crowded towards the branch tips, obovate to obtrullate to suborbicular, apex usually rounded to subacute, rarely acute, sessile or tapering into a very short petiole, rarely entire usually crenate; midrib not visible above, slightly raised abaxially. *Flowers* single, in the axils of upper leaves; pedicels ca. 2-3 mm long, densely tomentose: *Calyx segments* 5, quincuncial, probably not enlarged after flowering; 3 outer sepals ca. 5·2-7·0 mm long x 2·5-3·4 mm wide, ovate to deltate, at apex rounded to subacute, densely pubescent on both surfaces; 2 inner sepals shorter and narrower, ca. 4·5-5·5 mm long x 1·8-2·6 mm wide, usually ovate-lanceolate, subacute, abaxially densely pubescent, but on the inside glabrescent towards the base. *Corolla* ca. 3·0-3·5 cm long, *in vivo* bright red, *in sicco* deep pink to brick-red or sometimes yellowish, in both states paler on the interior; exterior with sparsely and evenly scattered short glandular hairs, glabrescent towards the base (under calyx), interior with scattered glandular hairs, glabrescent towards the base; corolla expanded over the ovary, then contracted and again expanded and slightly flared and curved above, 5-lobed; the 4 lobes of the upper lip all ± the same length, ca. 2·0-3·5 mm long, triangular (the lateral ones sometimes obliquely so) and acute; the lower lip ca. 12-16 mm long, deeply cut into the tube, ligulate and usually subacute, reflexed. *Stamens* 4, all ± the same length, ca. 3·0-4·5 mm, much exserted, slightly flattened and bearing scattered glandular hairs, especially near the base. *Ovary* ca. 2·5-3·5 mm long, glabrous, ± ovoid, bilocular with 2 ovules per locule; style ca. 3·8-4·5 cm long, slender and glabrous. *Fruit and seeds* unknown.

*South Australia*: ca. 5 km north of Ooldea; 20.9.1960; *P.Wilson* 1795. Sandhills. Rounded bush 2 ft. high, flower red. Leaves whitish. — AD 96131130 (*holotypus*): 2 km south of Ooldea; 21.9.1960; *D. J. E. Whibley* 753 — AD 96104227.

*Distribution*: *E. hillii* is so far known only from these two collections made at Ooldea on the Transcontinental rail line. When these specimens were found during a routine sorting of *Myoporaceae* I thought it possible that they had somehow been introduced from Western Australia, but they belong to none of the described species from that State. It is likely that *E. hillii* may be found to the north of the rail line; this is an area in which very few collectors have worked.

*Discussion*: *E. hillii* belongs to Sect. *Stenochilus* of *Eremophila*, a rather small group; Kränzlin (1929) who treated it as a genus, *Stenochilus* R.Br., distinct from *Eremophila*, included only 15 species. They are well distinguished from other species of *Eremophila* (s.l.) by having the lowest segment of the 5-lobed perianth cut much more deeply into the tube (4-6 times) than do the others so as to form a narrow tongue which is usually reflexed. *E. hillii* differs most markedly from all these 15 species cited by Kränzlin by having small obovate to suborbicular crenate leaves.

So far as I know, there has been described since 1929 only one species of *Eremophila* belonging to this section. This species, *E. virens* C. A. Gardner (1942) from Western Australia, differs from *E. hillii* in several respects, for example, height (3-5 m), leaf shape and size (generally lanceolate and up to 7·2 cm long), and corolla colour and size (green, 1·3 cm long). *E. macgillivrayi* J.M.Black (1926), included under section *Stenochilus* in the key to *Eremophila* in Black's Flora of South Australia (1957), was not known to Kränzlin, but differs from *E. hillii* in having much longer (1·5-6 cm) narrow-lanceolate leaves, smaller floral organs, and calyx segments valvate rather than quincuncial.

*E. hillii* seems to be most closely related to *E. glabra* (R.Br.) Ostenf.; in its usually accepted delimitation *E. glabra* includes quite a wide range of forms, many of which have a tomentum like that of *E. hillii* and flowers practically indistinguishable from those of the Ooldea plants.  However, plants of *E. glabra* generally have leaves which are ± lanceolate and 1·5-5 cm long; I have seen none which approach the crenate, obovate to suborbicular leaves of *E. hillii* and I believe that the recognition of the latter as a distinct species is warranted.

This species is named in honour of Mr. Ronald Hill of the Botanic Garden, Adelaide, who has a wide knowledge of this genus and a keen interest in it.

## ACKNOWLEDGMENTS

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# A CONTRIBUTION TO OUR KNOWLEDGE OF SOME MAMMALS FROM INLAND AUSTRALIA

*BY C. M. PHILPOTT\* AND D. R. SMYTH\*‡*

## Summary

We record the positive results of 24 weeks of field work on the mammals of northern South Australia and adjoining areas. Localities, notes on the natural history and some discussion of the taxonomy of the species located are given.

We found the rare rabbit bandicoot, *Macrotis lagotis* Reid, in two areas. The marsupial mouse, *Sminthopsis crassicaudata* (Gould), was moderately common near Birdsville and Oodnadatta. There is evidence that it is more active in the early part of nights without moonlight. Two other rarer species of *Sminthopsis* and *Antechinomys spenceri* Thomas were taken as solitary specimens.

We located the two rock wallabies *Petrogale lateralis* Gould and *P. xanthopus* Gray.

Near Oodnadatta, we found a native rodent, either *Pseudomys (Pseudomys) minnie* Troughton or *Ps. (Ps.) rawlinnae* Troughton. Two groups of specimens of *Pseudomys* (sub-genus *Leggadina*) were obtained, but not specifically identified. *Ps. (Leggadina) hermannsburgensis* Waite and the northern hopping mouse, *Notomys alexis* Thomas, were moderately plentiful in and near northwestern South Australia. *N. cervinus* (Gould) and a solitary specimen of *N. fuscus* (Wood-Jones) from in and near south-west Queensland, were recorded.

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by C. M. Philpott*† and D. R. Smyth*‡

[Read 10 August 1967]

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## INTRODUCTION

As early as 1925, Wood-Jones documented the alarming decline of populations of many South Australian mammals (Wood-Jones, 1923-5). Finlayson (1961) surveyed the Central Australian mammal fauna, and his conclusions showed that this decline was continuing. Calaby (1963) suggested that six marsupials and several native rodents from Australia were already extinct, and that as many as fifty species were either close to extinction, or so little known that no definite statement could be made.

It is generally agreed that if many of Australia's mammals are to be kept from extinction, urgent measures to conserve them must be undertaken. It is also agreed that knowledge of their distribution and natural history is a prerequisite to their conservation.

With the aim of contributing to this knowledge, we surveyed the mammal fauna of parts of arid Australia. In particular, we sought information on the following seven rare marsupials: *Myrmecobius fasciatus rufus* Wood-Jones, *Macrotis lagotis* Reid, *M. leucura* (Thomas), *Chaeropus ecaudatus* (Ogilby), *Bettongia pencillata* Gray, *Caloprymnus campestris* (Gould), and *Onychogalea lunata* (Gould). We also obtained information about other mammals during the search for these seven rare species.

## METHODS

The areas involved in this survey are vast, and our time was limited. This forced up to rely particularly on information from local people. The aboriginal people, and in particular the older men from the large reserves in the north-west of South Australia and Central Western Australia, gave us valuable information.

Several rodents, and the fat-tailed marsupial mouse, *Sminthopsis crassi-caudata* (Gould), were readily found and caught at night. The procedure we adopted was to drive along roads or over other accessible country at about 25 miles per hour, with the lights of our truck on low beam. Small mammals within about 30 yards (27 metres) of the truck could often be seen. They usually ran away from the lights, but when followed with a spotlight trained on them, they often sought refuge in depressions or behind grass tussocks. Here they would crouch motionless, and could readily be approached on foot. They were then caught with a net or by hand. This method was particularly effective for *S. crassicaudata*, which cannot run quickly.

Observation of sign in the form of burrows, tracks and droppings is an obvious method of locating some species. The form of a burrow is often a clue to the species which made it. "Runs" of the northern hopping mouse, *Notomys alexis* Thomas, and the sandy inland mouse, *Pseudomys* (*Leggadina*) *hermannsburgensis* Waite, often led to burrows. Aboriginals are particularly adept at digging these out. This is a practical method for obtaining alive such burrowing species as the rabbit bandicoot, *Macrotis lagotis* Reid. Several species of *Notomys*, *Pseudomys*, and *Sminthopsis* were taken in this way. We did not use traps. However, it is possible that the setting of a large number of traps on many nights may have revealed the presence of rarer, more cryptic species.

The older aboriginals of the Pitjantjatjara tribe (from the Blackstone Range to the Musgrave and Everard Ranges), and the Nga:nyatjara tribe (from the vicinity of the Warburton Ranges), have specific names for the mammals of their country. We found that the use of these names amongst them created immediate interest, and helped us obtain information on localities and the natural history of many species. The aboriginal names of some of the species considered below are recorded. They are spelt phonetically following Douglas (1964). Measurements of lengths of head and body, tail, hind-foot (pes), and ear of all specimens were taken using the methods described in Wood-Jones (1923). All dead specimens secured on this survey are preserved in the South Australian Museum under the registered numbers used below.

## RESULTS

Between April and December, 1966, we spent 24 weeks in the field. Fig. 1 shows the route we followed. Special attention was given to the following areas: near Birdsville (3 weeks), south of the Blackstone, Mann and Musgrave Ranges (5 weeks), and near the Warburton Range (3 weeks).

We obtained information on the distribution and natural history of the following species of mammals. Where no mention is made of a species previously recorded from inland Australia, it may be assumed that no positive records of it were obtained.

## Order Ornithodelphia

*Tachyglossus aculeatus* (Shaw and Nodder), Echidna
*Aboriginal Names:* tjirilya—Pitjantjatjara; tjilkamaṭa—Nga:nyatjara.

*Field Notes.* We made no serious effort to locate the moderately plentiful echidna. Aboriginals at four settlements (Fregon, Ernabella, Musgrave Park and Warburton), reported that it was common in nearby rocky hills. Residents of two stations east and west of Lake Eyre reported seeing indisputable signs of *Tachyglossus* recently. We observed tracks and faeces at Mt. Lindsay, 129°54′E, 27°02′S.
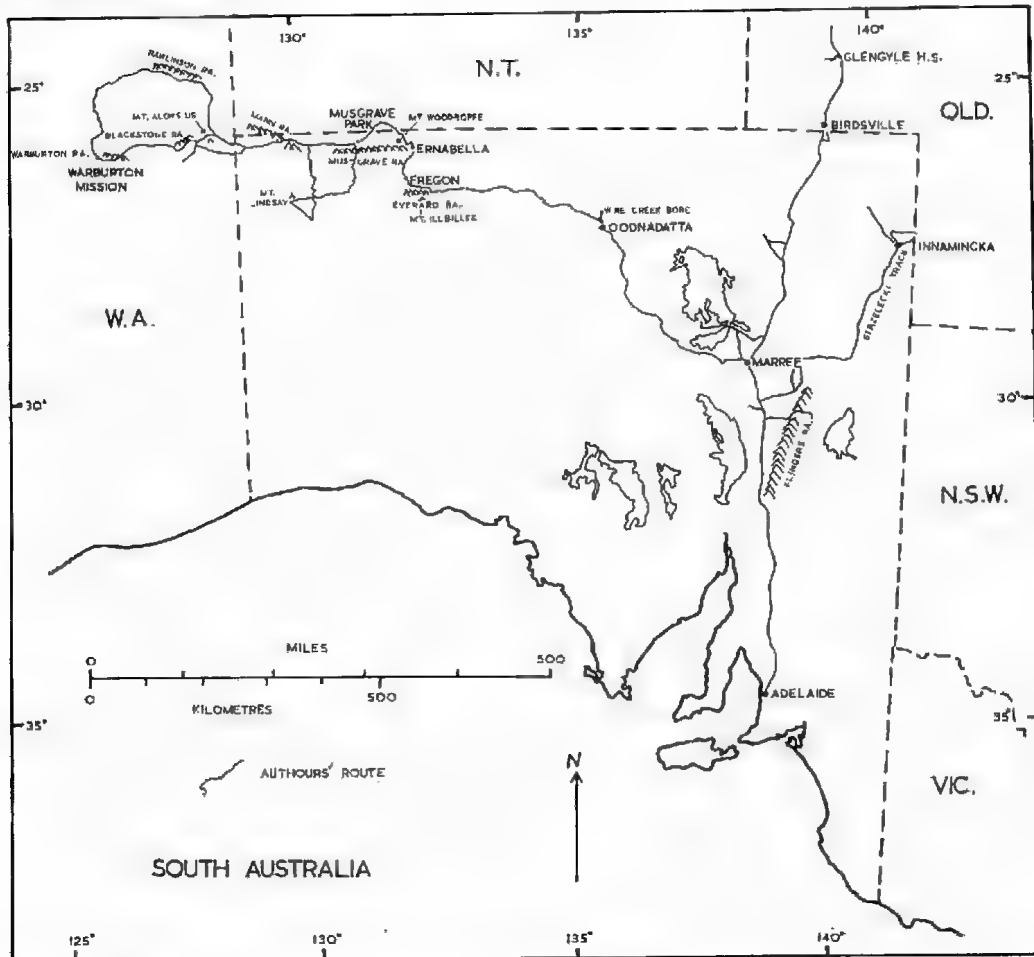


Fig. 1. Map of South Australia and adjoining areas, showing the survey route followed by the authors, and the principal place names mentioned in the text.

Order DIDELPHIA

Family DASYURIDAE

*Sminthopsis crassicaudata* (Gould), fat-tailed marsupial mouse
(Plate 1, Figure 1)

*Aboriginal Name*: Papalakuntalkuntalpa—Pitjantjatjara (probably a compound name).

*Localities.* (i) Within 15 miles (24 km) of Birdsville, SW. Queensland; 139°21′E, 25°54′S; June 6-23, 1966; 7 females ( ♀ ) and 12 males ( ♂ ); 1 ♀ now South Australian Museum registered number M 6398. (ii) Within 5 miles (8

km) of Glengyle Homestead, SW. Queensland; 139°36'E, 24°47'S; June 11-19, 1966; 3 ♀ and 4 ♂.  (iii) Wire Creek Bore, 20 miles (32 km) N. of Oodnadatta, N. South Australia; 135°28'E, 27°16'S; July 9-August 16; 8 ♀ and 4 ♂; 1 ♂ now M 6399.

*Field Notes.*  Most of the marsupial mice were caught at night using a spotlight.  At Birdsville and Glengyle, they were found on open gibber plains and on sand-ridges and the flats between these ridges.  A sand ridge where many individuals were caught is shown in Plate 1, Fig. 2.  At Oodnadatta, we caught them on a gibber-strewn and deeply cracked flat shown in Plate 3, Fig. 2.  Occasionally a marsupial mouse, seen in the spotlight, would seek refuge in a well-used burrow less than 12 inches (30 cm) long and 4 inches (10 cm) deep.

We obtained some indication of the most active period of *S. crassicaudata.* Fig. 2 is a histogram showing the number of marsupial mice caught per hour of searching, against the number of hours elapsed since sunset.  To draw this graph, we considered only those nights when one or more mice were caught. The accurate time of sunset in astronomical tables for all these dates was determined, and all times were converted to local time.  We did not search earlier than one hour after sunset or later than nine hours.
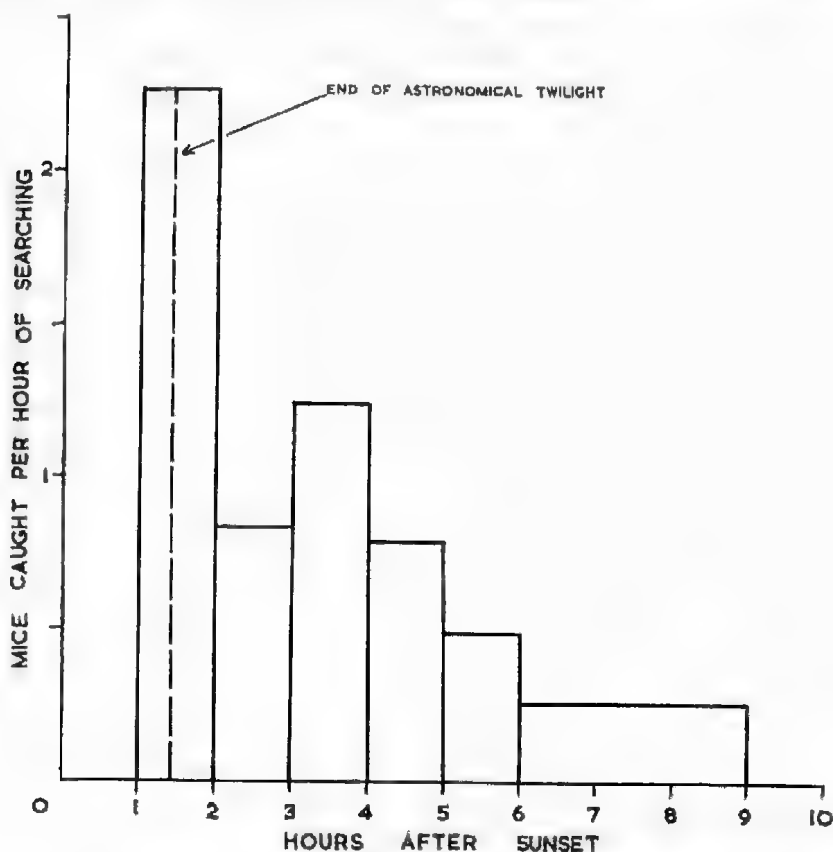


Fig. 2.  Histogram of the number of fat-tailed marsupial mice (*Sminthopsis crassicaudata*) caught per hour of searching with a spotlight, against the number of hours elapsed since sunset.  No searches were made earlier than one hour after sunset and later than nine hours.  Each interval includes at least three and a half hours of searching.

Fig. 2 shows a trend of decreasing numbers of mice being caught per hour of searching with increasing hours after sunset. This suggests that marsupial mice were most active in the early evening. The end of astronomical twilight, and the beginning of complete darkness was about 1 hour 25 minutes after sunset. Although we searched on several occasions before this time, we saw no active marsupial mice.

We caught S. *crassicaudata* on calm and on windy nights, and on clear and on cloudy nights. Some association of success in locating mice and the presence of moonlight is suggested by the following figures. Only twenty-two per cent of our successful searching time was carried out under moonlight (7 out of 32½ hours). Also, during these moonlight searches, we only caught eleven per cent of the total mice secured by this method (4 out of 37).

All mice were weighed alive within 24 hours of capture. There were no significant weight differences between localities. The mean weight of 19 males was $13 \cdot 2 \pm 0 \cdot 18$ gm, with a range of 10½ to 17 gm. For 18 females, the mean was $13 \cdot 9 \pm 0 \cdot 34$ gm, and the range from 10¾ to 19 gm. There was no significant difference between the weights of the sexes ($t_{35} = 1 \cdot 02$, 30% < P < 40%). None of the females had pouch-young.

A photograph of the tracks left by a live captive is given on Plate 1, Fig. 3. The mouse was running quickly for cover. The prints left by the two front feet are the last two in each series in the photograph. The left and right front feet do not regularly alternate as the leading foot, although this does occur in Fig. 3.

### *Sminthopsis larapinta* Spencer, stripe head marsupial mouse

*Locality.* Wire Creek Bore, 20 miles (32 km) N. of Oodnadatta, N. South Australia; 135°28′E, 27°16′S; July 7, 1966; 1 ♀.

*Field Notes.* This marsupial mouse was caught under similar circumstances to the S. *crassicaudata* individuals from locality (iii) shown on Plate 3, Fig. 2, and considered above. It lived sympatrically with them, and a male and female S. *crassicaudata* were caught close by within 35 minutes of the time of capture of this specimen. Its weight on capture was 21 gm.

### *Sminthopsis* species, unidentified

*Locality.* Fregon, NW. South Australia; 132°02′E, 26°47′S; July 16, 1966; 1 ♂; M 6366.

*Field Notes.* We dug this animal from a shallow burrow on a sand-ridge. The burrow resembled those of *Pseudomys* (*Leggadina*) *hermannsburgensis* Waite, a small rodent which was common in the area. Aboriginals from the settlement at Fregon did not have a specific name for this species. They gave us only the word "mingkiri", a word used generally for all small mice. This suggested that the animal was rare or particularly cryptic.

*Taxonomy.* This marsupial mouse was smaller and more delicately built than S. *crassicaudata* and S. *larapinta*. The flesh dimensions (given in mm) were: Head and body 70, tail 85, hind-foot 13, and ear 16. Its weight on capture was 10½ gm. The skull dimensions (given in mm) were: greatest length $20 \cdot 9$, basal length $20 \cdot 4$, zygomatic breadth $11 \cdot 5$, interorbital $4 \cdot 2$, braincase breadth $8 \cdot 9$, palate $11 \cdot 0$, nasals $7 \cdot 4$ x $2 \cdot 0$, bulla $5 \cdot 7$, anterior palatal foramina $1 \cdot 5$, P4 approx. $2$ x $P_1$ and $P_3$.

Careful examination of the pes and manus showed that the sole-pads had an obvious longitudinal row of enlarged granules at their apex. Troughton (1964) claimed that this was a diagnostic feature of the *murina* "complex". He

stated, however, "The fact remains that because of the acknowledged lack of differential cranial characters it is impossible to provide objective diagnoses of the typical and allied forms of *murina* at present." Positive identification of this interesting specimen will have to await further collections and comparisons.

*Antechinomys spenceri* Thomas, western hopping marsupial mouse

*Locality.* 16 miles (26 km) W. of Glengyle Homestead, SW. Queensland; 139°22′E, 24°48′S; June 14, 1966; 1 ♀; M 6387.

*Field Notes.* We caught this marsupial mouse while spotlighting at night on an undulating gibber plain. It did not have pouch-young, and weighed 19·5 gm on capture. The native rodent *Notomys cervinus* (Gould) was caught close by using the same method and it is probable that these two superficially similar species are sympatric.

## Family NOTORYCTIDAE

### *Notoryctes typhlops* Stirling, marsupial mole

*Aboriginal Names*: itjaritjari—Pitjantjatjara; yiṭarutju—Nga:nyatjara.

*Field Notes.* We were told that specimens of this distinctive species have been obtained within the last five years in sand-ridge areas on Everard Park Station, Musgrave Park Station (No. 16 bore), Curtain Springs Station (where it may be more common) and west of Warburton Mission. Aboriginals from Fregon and Warburton said that it is not seen in winter. However, others disputed this claim. Most suggested that this burrowing species comes to the surface after rain. It is not eaten by aboriginals. It seems likely that the marsupial mole, by reason of its small size and cryptic behaviour, is more common than is indicated by a general survey.

## Family PERAMELIDAE

### *Macrotis lagotis* Reid, rabbit bandicoot
#### (Plate 2, Figure 1)

*Aboriginal Names*: talku, niṇu—Pitjantjatjara; ṇiṇu, matura—Nga:nyatjara.

*Localities.* (i) 12 miles (19 km) SW. of Mt. Aloysius, Blackstone Range, Central Western Australia; 128°27′E, 26°06′S; November 9 and 14, 1966; 2 ♀; 1 ♀ now M 6340. (ii) 7 miles (11 km) N. of Warburton Mission, Warburton Range, Central Western Australia; 126°34′E, 26°02′S; December 7 and 8, 1966; 2 ♀; 1 ♀ now M 6397.

*Field Notes.* The results of a field study of a population from locality (ii) will be reported elsewhere.

This species was collected near Birdsville during 1957-59 (Mack, 1961). We were told that it had not been seen there for about five years. However, we obtained reports of sightings of a mammal which was probably *M. lagotis* within the last two years from localities west of Glengyle Homestead. The only area we visited where it seemed to be moderately plentiful was near Warburton Mission. None of the females had pouch-young.

*Taxonomy.* The measurements made on live specimens as soon as practicable after capture are given in Table 1. General appearance and the above measurements suggest that these specimens belong to the type subspecies *M. lagotis lagotis* Reid.

TABLE 1
Flesh measurements of four female rabbit bandicoots, *Macrotis lagotis*,
from Central Western Australia

|  | Juvenile ♀,<br>Blackstone Ra. | Adult ♀*,<br>Blackstone Ra. | Adult ♀,<br>Warburton Ra. | Adult ♀†<br>Warburton Ra. |
|---|---|---|---|---|
| Date of capture. | 9.XI.66 | 14.XI.66 | 7.XII.66 | 8.XII.66 |
| Wt. on capture (gm) | 400 | 700 | 960 | 850 |
| Head and body (mm) | 310 | 320 | 330 | 320 |
| Tail (mm) | 180 | 190 | 230 | 220 |
| Ear (mm) | 70 | 85 | 90 | 85 |
| Hind-foot (mm) | 78 | 88 | 96 | 92 |

* M 6340
† M 6397

## Family MACROPODIDAE
### *Petrogale lateralis* Gould, black-flanked rock wallaby
(Plate 2, Figure 2)

*Aboriginal Name*: waru—Pitjantjatjara, Nga:nyatjara.

*Locality.* Alkara, 90 miles (145 km) SW. of Mt. Woodroffe, Musgrave Ranges, NW. South Australia; 130°30'E, 27°04'S; July 27, 1966; 1 ♂ M 6388 (skull only).

*Field Notes.* We observed two or more rock wallabies on a rocky hill of tumbled, granite-like boulders shown on Plate 2, Fig. 3. They emerged from their lairs at about mid-afternoon. The testimony of aboriginals that this wallaby does not drink regularly was borne out by the absence of permanent water nearby. Herbs and shrubs growing on the slopes, and which were possible food species, included buckbush (*Salsola kali*), wild geranium (*Erodium cygnorum*), several perennial grasses, and the shrubs *Sida virgata* and *Ptilotus obovatus*.

Occasionally, aboriginals living on settlements from Fregon to Warburton Mission catch and eat rock wallabies, and suggest that it is one of the more plentiful mammals of the area.

The wallaby weighed 4·590 kg on capture, and its body dimensions (in mm) were: head and body 525, tail 540, hind-foot 142 and ear 66.

### *Petrogale xanthopus* Gray, yellow-footed rock wallaby

*Field Notes.* We observed these wallabies on April 10 to 16, 1966, at three localities in the Northern Flinders Ranges between 138°40' and 139°20'E longitude, and 30°20'S and 30°40'S latitude. In two areas, we watched them feeding on the green herbs in creek beds at dusk and at dawn. One female had a large joey.

## Order MONODELPHIA
## Family MURIDAE
### *Pseudomys* (*Pseudomys*) species, unidentified native rodent
(Plate 3, Figure 1)

*Locality.* Wire Creek Bore, 20 miles (32 km) N. of Oodnadatta, N. South Australia; 135°28'E, 27°16'S; July 9 and August 16, 1966; 4 ♀, 3 ♂ and 3 juveniles (J); 1 ♀ now M 6341.

*Field Notes.* These native rodents were living on an open gibber flat, with silver saltbush (*Atriplex rhagodioides*) being the only perennial plant. The habitat is shown on Plate 3, Fig. 2. We dug eight of them from burrows built under or near the saltbushes. These burrows were less than 2 feet (60 cm) long, and one is shown on Plate 3, Fig. 3. A male, a female and three juveniles were dug from one burrow; another contained a male and a female, whilst a third contained a solitary female. A male and a female were caught with a spotlight about 4½ hours after sunset on different nights. One of the females captured on July 9 produced a litter of 3 on about July 12. She was paired on October 21, and produced another litter of 3 on December 2. On January 3, 1967, she again produced young; this time there were 4 offspring.

*Taxonomy.* Tables 2 and 3 present flesh and skull dimensions of three of these native rodents, and of types of *Ps. minnie* Troughton and *Ps. rawlinnae* Troughton taken from Troughton (1932).

TABLE 2

Flesh dimensions of three adult females of an unidentified *Pseudomys* (*Pseudomys*) species from near Oodnadatta, N. South Australia, and of type specimens of *Ps. minnie* and *Ps. rawlinnae*.

|  | ♀, M6341 | ♀, M6342* | ♀, M6343* | ♀, allotype Ps. minnie | ♂, holotype Ps. rawlinnae |
|---|---|---|---|---|---|
| Wt. on capture (gm) | 33 | — | 35 | — | — |
| Head and body (mm) | 99 | 98 | 101 | 117 | 113 |
| Tail (mm) | 94 | 85 | 93 | 111 | 99 |
| Ear (mm) | 23 | 21 | 22 | 23 | 21½ |
| Hind-foot (mm) | 26 | 24 | 27 | 27 | 27½ |

* Born in captivity, and measured when 6 months old.

TABLE 3

Skull dimensions (in mm × 10) of three adult females of an unidentified *Pseudomys* (*Pseudomys*) species from near Oodnadatta, N. South Australia, and of type specimens of *Ps. minnie* and *Ps. rawlinnae*.

|  | ♀, M6341 | ♀, M6342* | ♀, M6343* | ♀ allotype Ps. minnie | ♂ holotype Ps. rawlinnae |
|---|---|---|---|---|---|
| Greatest length | 29·5 | 28·4 | 29·4 | 30·7 | 30·8 |
| Basal length | 26·6 | 25·1 | 25·8 | 25·0 | — |
| Zygomatic breadth | 15·4 | 14·6 | 14·5 | 16·3 | 16·1 |
| Braincase breadth | 14·1 | 12·9 | 13·7 | 14·3 | 13·7 |
| Interorbital breadth | 4·6 | 3·8 | 4·3 | 4·0 | 3·9 |
| Nasals length | 11·9 | 10·8 | 11·2 | 11·1 | 12·0 |
| Nasals breadth | 3·3 | 3·0 | 3·5 | 3·0 | 2·9 |
| Palatal length | 16·6 | 15·4 | 15·8 | 15·0 | 14·5 |
| Anterior palatal foramina | 6·8 | 6·7 | 6·7 | 7·3 | 7·0 |
| Bulla | 5·2 | 4·3 | 5·0 | — | — |
| Upper molar series | 5·3 | 5·3 | 5·3 | 5·8 | 5·3 |
| Breadth M1 | 1·8 | 1·9 | 1·8 | — | 1·8 |

* Born in captivity, and measured when 6 months old.

We have used Tate (1951) to assist in the following deductions.

The absence of accessory cusps anterior to the first loph of m1, and the large size of the species indicate that it may be assigned to the sub-genus *Pseudomys* Gray.

The above tables show that the dimensions of our series are similar to those given by Troughton (1932) for *Ps. minnie* and *Ps. rawlinnae*. The coat also appears to be similar. Finlayson (1939b) noted that these species were similar in some features, but that the upper molar row, anterior palatal foramina, and palatal length were shorter in *Ps. rawlinnae*. These differences are slight in Table 3, but they may indicate that our series are closer to *Ps. rawlinnae*. Troughton (1932), in his description of *Ps. rawlinnae*, made no mention of a black calcaneal patch which is well marked on our specimens. However, Finlayson (1939b) reported that the patch was present in the specimens he called *Ps. rawlinnae*.

J. A. Mahoney of Sydney has examined these specimens, and has indicated that he considered the sum total of characters to be closer to descriptions of *Ps. minnie*. However, he also noted that recorded descriptions of the two species are little different, and that they may perhaps be shown after further study to be conspecific.

### *Pseudomys* (*Leggadina*) species (group 1), unidentified native rodent
(Plate 4, Figure 1)

*Localities.* (i) 30 miles (48 km) N. of Birdsville, SW. Queensland; 139°28′E, 25°23′S; June 12, 1966, 2 ♂ ; M 6350-1. (ii) Wire Creek Bore, 20 miles (32 km) N. of Oodnadatta, N. South Australia; 135°28′E, 27°16′S; July 9, 1966. 1 ♂ ; M 6352.

*Field Notes.* The two specimens from locality (i) were obtained by spot-lighting about 7 hours after sunset. The single specimen from locality (ii) was taken from a shallow burrow, which was without a nest, and which had been freshly dug after rain. The habitat at locality (ii) is shown on Plate 3, Fig. 2. A series of tracks of a live captive from Birdsville are shown on Plate 4, Fig. 2. The mouse was running for cover.

*Taxonomy.* Tables 4 and 5 contain skull dimensions of these three native rodents, and also of types of *Ps. forresti* Thomas, *Ps. waitei* Troughton and *Ps. messoria* Thomas taken from the original descriptions.

TABLE 4

Flesh dimensions of three adult males of an unidentified *Pseudomys* (*Leggadina*) species (group 1), and of type specimens of *Ps. forresti*, *Ps. waitei* and *Ps. messoria*.

|  | ♂, M6350* | ♂, M6351* | ♂, M6352‡ | ♀, type *Ps. forresti* | ♂, holotype *Ps. waitei* | ♂, type *Ps. messoria* |
|---|---|---|---|---|---|---|
| Head and body (mm) | 80 | 75 | 80 | 104 | 83 | 67 |
| Tail (mm) | 56 | 60 | 61 | 72 | 59 | 53 |
| Ear (mm) | 12 | 11 | 14 | 15 | 12 | 13 |
| Hind-foot (mm) | 18 | 17 | 18 | 19 | 16½ | 17 |

\* From 30 miles N. Birdsville, S.W. Queensland.

‡ From near Oodnadatta, N. South Australia; weighed 18·5 gm on capture.

The general characteristics of the skulls of these specimens fit Thomas' (1910) definition of the subgenus *Leggadina*. The specimens readily fit into the *forresti-waitei-messoria* group of Tate (1951), who provides a key to the groups of *Leggadina*. The measurements above indicate that our specimens are considerably smaller than *Ps. forresti*, but larger than *Ps. messoria*. Flesh dimensions match those of *Ps. waitei*, but there are a number of differences, notably the palatal and nasal lengths of the skulls. Coat colours of all three species in

TABLE 5

Skull dimensions of three adult males of an unidentified *Pseudomys* (*Leggadina*) species (group 1), and of type specimens of *Ps. forresti*, *Ps. waitei*, and *Ps. messoria*.

| | ♂, M6350* | ♂, M6351* | ♂, M6352‡ | ♀, type Ps. forresti | ♂, holotype Ps. waitei | ♂, type Ps. messoria |
|---|---|---|---|---|---|---|
| Greatest length | 23·1 | 24·3 | 25·1 | 25·0 | 22·6 | 23·5 |
| Basal length | 20·6 | 21·7 | 21·5 | — | — | — |
| Zygomatic breadth | — | 13·3 | 13·1 | 13·5 | 12·0 | 13·0 |
| Braincase breadth | 11·3 | 11·7 | 11·6 | — | 11·1 | 11·2 |
| Interorbital breadth | 3·6 | 3·6 | 3·7 | 3·6 | 3·5 | 3·6 |
| Nasals length | 8·3 | 8·2 | 8·4 | 8·5 | 7·6 | 8·0 |
| Nasals breadth | 2·5 | 2·8 | 2·6 | — | 2·3 | — |
| Palatal length | 12·9 | 13·4 | 13·1 | 13·0 | 11·2 | 11·5 |
| Anterior palatal foramina | 5·1 | 5·3 | 4·9 | 5·5 | 5·3 | 6·0 |
| Bulla | — | 4·2 | 4·2 | — | — | 4·1 |
| Upper molar series | 4·5 | 4·5 | 4·4 | 4·4 | 4·1 | 4·5 |
| Breadth M1 | 1·5 | 1·5 | 1·4 | — | — | — |

* From 30 miles N. Birdsville, S.W. Queensland.
‡ From near Oodnadatta, N. South Australia.

the group, and of our specimens are apparently similar. However, Thomas (1910) said that the hairs on the belly of *Ps. messoria* were slaty grey, whereas those of the above series are pure white to the base.

*Pseudomys* (*Leggadina*) species (group 2), unidentified native rodent.

*Aboriginal Name*: ilpalya—Pitpantjatjara.

*Localities.*—(i) 20 miles (32 km) SSE. of Mt. Aloysius, Blackstone Range, Central Western Australia; 128°44'E, 26°17'S; November 15, 1966; 1 ♀ and 3♂; M 6344. (ii) 26 miles (42 km) SE. of Mt. Aloysius, Blackstone Range, Central Western Australia; 128°52'E, 26°18'S; November 15, 1966; 4 ♀, 1 ♂ and 11♂; M 6345-9.

*Field Notes*. We dug these mice from burrows in two loamy plains near rocky hills shown on Plate 5, Figs. 3 and 4. There were many small saltbushes, grasses and ephemeral herbs on both plains, but no other perennial plants. The burrows were about 6 inches (15 cm) deep and 15 inches (37 cm) long. A nest of grass and flowers of an everlasting daisy was found in the deepest part. One or more blind tunnels led from the nest. Unlike the unidentified *Pseudomys* (*Pseudomys*) species, adult males and females were not found in the same burrow. Two burrows contained solitary mice; one a male, the other a pregnant female. Four burrows each contained a lactating female and her young. There were two litters of three and two of four mice.

Living sympatrically with these rodents was the house mouse, *Mus musculus* Linne. We dug out two pregnant house mice from burrows near to and closely resembling those of the native mouse.

Pitjantjatjara elders from Musgrave Park unhesitatingly called the native mice "ilpalya". Finlayson (1961) reported that this was a Pitjantjatjara name for a *Notomys* species "close to *alexis* but not specifically identified".

*Taxonomy*. Tables 6 and 7 give measurements of individuals in the flesh and of skulls of this series.

We have considered this group of specimens separately from the preceding group of *Pseudomys*. Closer study may show them to be conspecific. As with *Pseudomys* (*Leggadina*) species (group 1), they fall readily into Thomas' (1910) subgenus *Leggadina*, and Tate's (1951) *forresti-waitei-messoria* group.

TABLE 6

Flesh dimensions of six adult specimens of an unidentified *Pseudomys* (*Leggadina*) species (group 2), from SE. of the Blackstone Range, Central Western Australia. All females were lactating.

|  | ♀, M6344 | ♀, M6345 | ♂, M6346 | ♀, M6347 | ♀, M6348* | ♀, M6349 |
|---|---|---|---|---|---|---|
| Wt. on capture (gm) | 25 | 29 | 18 | 24 | 29 | 21½ |
| Head and body (mm) | 88 | 100 | 80 | 85 | 90 | 81 |
| Tail (mm) | 59 | 69 | 58 | 59 | 69 | 56 |
| Ear (mm) | 15 | 14 | 14 | 14 | 14 | 12 |
| Hind-foot (mm) | 17 | 17 | 16 | 16 | 18 | 16 |

\* Pregnant.

TABLE 7

Skull dimensions of five adult female specimens of an unidentified *Pseudomys* (*Leggadina*) species (group 2) from SE. of the Blackstone Ranges, Central Western Australia.

|  | ♀, M6344 | ♀, M6345 | ♀, M6347 | ♀, M6348 | ♀, M6349 |
|---|---|---|---|---|---|
| Greatest length | 23·3 | 24·3 | 23·1 | 23·8 | 22·4 |
| Basal length | 10·9 | 21·2 | 21·1 | 20·3 | 19·2 |
| Zygomatic breadth | 12·0 | 13·4 | 12·2 | 12·5 | 11·9 |
| Braincase breadth | 11·1 | 11·7 | 11·0 | 11·0 | 10·8 |
| Interorbital Breadth | 3·6 | 3·3 | 3·9 | 3·5 | 3·2 |
| Nasals length | 7·9 | 8·3 | 7·9 | 8·0 | 7·9 |
| Nasals breadth | 2·2 | 2·4 | 2·2 | 2·4 | 2·3 |
| Palatal length | 12·0 | 12·8 | 12·0 | 12·5 | 11·5 |
| Anterior palatal foramina | 5·1 | 5·4 | 5·1 | 5·1 | 4·7 |
| Bulla | 4·2 | 4·1 | 4·1 | 3·9 | 4·0 |
| Upper molar series | 4·7 | 4·8 | 4·5 | 4·6 | 4·4 |
| Breadth of M1 | 1·6 | 1·6 | 1·6 | 1·5 | 1·5 |

J. A. Mahoney has examined a sample of the two preceding unidentified groups. He placed both of them in the *forresti-waitei-messoria* group, and, believing that its members are conspecific, tentatively called all our specimens *Pseudomys* (*Leggadina*) *forresti* Thomas.

The relationships of what we have called *Pseudomys* (*Leggadina*) species (group 1) and (group 2), and other native rodents will have to await further collections, and study of new specimens and the types before any definite statement can be made.

*Pseudomys* (*Leggadina*) *hermannsburgensis* Waite, sandy inland mouse.
(Plate 4, Figure 4)

*Aboriginal Name*: mingkiri — Pitjantjatjara, Nga:nyatjara (now used for all small mice).

*Localities*. (i) 15 miles (24 km) E. of Mt. Illbillee, Everard Ranges, NW. South Australia; 132°43'E, 27°01'S; July 13, 1966; 3 ♀ and 3 ♂. (ii) Fregon, NW. South Australia; 132°02'E, 26°47'S; July 16, 1966; 7 ♀ and 7 ♂. (iii) Bowden Hill, 80 miles (129 km) SW. of Mt. Woodroffe, Musgrave Ranges, NW. South Australia; 130°41'E, 26°58'S; July 23, 1966; 1 ♀ and 1 ♂; 1 ♀ now M 6354. (iv) Alkara, 90 miles (145 km) SW. of Mt. Woodroffe, Musgrave Ranges, NW. South Australia; 130°30'E, 27°04'S; July 27, 1966; 3 ♀ and 3 ♂; 1 ♀ now M 6353. (v) 42 miles (68 km) SW. of Mt. Aloysius, Blackstone Ranges, Central Western Australia; 128°06'E, 26°28'S; November 12, 1966; 2 ♀; 1 ♀ now M 6355.

*Field Notes.* This species was one of the commonest mammals between 128° and 132°E longitude and 26° to 27°S latitude. All specimens were taken from burrows in sandy-loam soil, often in mulga (*Acacia aneura*) scrub. The burrows were characterised by the absence of a large mound of soil near the mouth, as illustrated by Plate 4, Fig. 3. From one to four mice, with sex ratios amongst them variable, were taken from single burrows. One female from Fregon and two from locality (v) were pregnant, and a litter of four juveniles was seen at Fregon.

The mean weight of 17 adult males which were weighed less than 24 hours after capture was 11·1 ± 0·4 gm with a range of 8 to 13 gm. For 9 adult, non-pregnant females, the mean weight was 10·3 ± 1·4 gm, with a range of 9 to 13½ gm.

*Taxonomy.* Flesh and skull dimensions of the three specimens in the South Australian Museum (M 6353-5) all fall within the limits given by Finlayson (1941) for a large series of *Ps. hermannsburgensis*. Habits and coat colour which he described for this species are closely similar to those of our series.

### *Notomys cervinus* (Gould), fawn hopping mouse.
(Plate 5, Figure 1)

*Localities.* (i) From 18 miles (29 km) S. to 70 miles (113 km) N. of Birdsville, SW. Queensland; 139°21′E, 25°54′S; June 11-23, 1966; 3 ♀ and 7 ♂. (ii) 5 miles (8 km) S. of Glengyle Homestead, SW. Queensland; 139°36′E, 24°48′S; 9 ♀ and 9 ♂; 10 specimens from both localities now M 6357-65 and M 6400.

*Field Notes.* This species was moderately plentiful, and all specimens were taken while spotlighting at night on bare claypans and flats illustrated on Plate 1, Fig. 2. It was seen on the same nights and in the same areas as *Sminthopsis crassicaudata* and *Antechinomys spenceri*. All specimens were taken between 3 and 8 hours after sunset.

*Taxonomy.* There was no gular pouch in any of the specimens but a marked groove was present on the anterior surface of the upper incisors of 9 skulls examined from individuals from both localities (M 6357-65). Finlayson (1959) stated that these are characteristics of *N. cervinus*, and that they distinguish it from *N. fuscus* (Wood-Jones).

### *Notomys fuscus* (Wood-Jones), Wood-Jones' hopping mouse.

*Locality.* Pandie Pandie Homestead, Diamantina R., NE. South Australia; 139°23′E, 26°07′S; summer of 1964-65; 1 ♀; M 6356.

*Field Notes.* This specimen was obtained by Mrs. L. Morton, who reported that similar hopping mice were often seen during the summer of 1964-65; we found no live specimens while in the area.

### *Notomys alexis* Thomas, northern hopping mouse.
(Plate 5, Figure 2)

*Aboriginal Name:* tarkawara—Pitjantjatjara, Nga:nyatjara.

*Localities.* (i) Turner's Well, 22 miles (35 km) NE. of Mt. Woodroffe, Musgrave Range, NW. South Australia; 132°00′E, 26°07′S; July 19, 29, 1966; 3 ♀, 4 ♂ and 6J; 1 ♀ and 4J now M 6367. (ii) 14 miles (23 km) WSW. of Mt. Aloysius, Blackstone Range, Central Western Australia; 128°21′E, 26°10′S; November 1, 1966; 2 ♀ and 15J (including 8 ♀ and 7 ♂ ); M 6369-85.

*Field Notes.* This species was common over much of the area where we found that *Pseudomys* (*Leggadina*) *hermannsburgensis* was plentiful. However, we obtained most *N. alexis* from more sandy areas, with less mulga scrub. All specimens were dug from burrows. From two to five juveniles were taken from six single burrows; in four of these burrows lactating females were also taken. The burrows had a vertical entrance shaft, about 6 to 18 inches (15 to 45 cm) deep, and with no soil at the mouth. Horizontal "drives", with occasional branches extended from the base of the shaft to a maximum of about 6 feet (1·8 m). At the end of the "drive", a vertical escape shaft was often dug stopping about an inch (2·5 cm) below the surface.

At locality (ii), empty shells of the quandong, *Santalum acuminatum*, were found near the entrance and along the "drive" of one *N. alexis* burrow. The shells had been opened by removal of a small circular segment of the hard outer coat.

## DISCUSSION

Of the seven rare marsupials searched for specifically, we located only *Macrotis lagotis*. Because of the large fluctuations in numbers which occur in many desert-living species, and because we searched only a small proportion of suitable habitats, it is by no means certain that any of the others are extinct. However, only elderly aboriginal men had any knowledge of some of the species, and this knowledge was obtained when they were young men. For example, *Myrmecobius fasciatus* is spoken of as having gone for many years from the Everard and Bedford Ranges. However, we should note that aboriginal people everywhere are much less mobile and dependent on native mammals for food now than they were in the past.

None of the 18 female *Sminthopsis crassicaudata* caught during June, July and August had pouch-young though some of them were too young for breeding. Conditions during this period were excellent, with recent rains having increased plant and insect life. Martin (1965) recorded breeding of this species from July to April under optimal conditions in the laboratory. It is therefore possible that breeding in the wild is to some extent regular and seasonal, unlike the fairly regular breeding noted under laboratory conditions.

Nearly all of the females of the unidentified *Pseudomys* (*Pseudomys*) species, *Pseudomys* (*Leggadina*) species (group 1), and of *Notomys alexis* were lactating, or were pregnant. Recent rains had resulted in good growth of herbs, which had matured and shed their seed.

This large-scale, synchronous breeding of native rodents and consequent population increase, can perhaps explain to some extent the taxonomic difficulty of this group. That there are large fluctuations in numbers of many native rodents has often been noted, especially in arid regions such as the Lake Eyre Basin (e.g. Finlayson, 1939a). A large increase in variability has been observed when a large increase in the numbers of several animals has occurred. Ford and Ford (1930), working with the butterfly *Melitaea aurinia*, were one of the first to draw attention to this large increase in variability. The presence of much variation in rapidly increasing populations of rodents would tend to decrease the number of differential characters which could be used to separate closely related species. Also, variability of the one species from different areas would probably be large. This is because populations from different localities would perhaps be derived from isolated small numbers of individuals present before the large increase.

Finlayson (1961) considered that pastoral exploitation, and the introduced rabbit, fox and domestic cat were important factors influencing the abundance and range of Central Australian species. In order to conserve at least some of these species, they must first be located. Then, the influence of the above factors should be analysed. Finally, suitable areas should be proclaimed as reserves, and some control of the environment attempted in order to minimise these deleterious factors. We hope our study has contributed to the first step in such a programme of urgent conservation.

## ACKNOWLEDGMENTS

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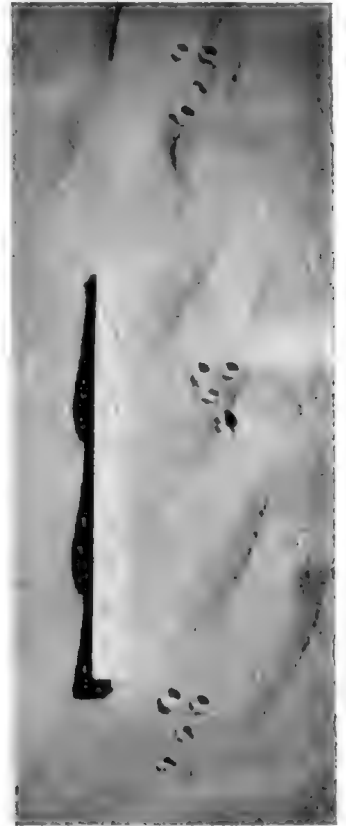
Fig. 1. Male *Sminthopsis crassicaudata* from near Birdsville, approx. life-size.

Fig. 2. Looking along a stabilized sand-ridge 3 miles east of Birdsville where we caught 6 *S. crassicaudata*. *Notomys cervinus* was also living nearby.

Fig. 3. Tracks of a captive male *S. crassicaudata* from Glengyle. Direction of travel is from bottom to top, and the scale is in inches and centimetres (see text).

Fig. 1. Immature female rabbit bandicoot (*Macrotis lagotis*) from south of the Blackstone Ranges, approx. ¼ life-size.

Fig. 2. A male black-flanked rock wallaby (*Petrogale lateralis*) taken in the wild at Alkara, south of the Musgrave Ranges.

Fig. 3. Alkara, 90 miles south-west of Mt. Woodroffe. We observed *P. lateralis* on the darker rock on the left of the hill. We caught *Pseudomys hermannsburgensis* on the sand ridge in the foreground.
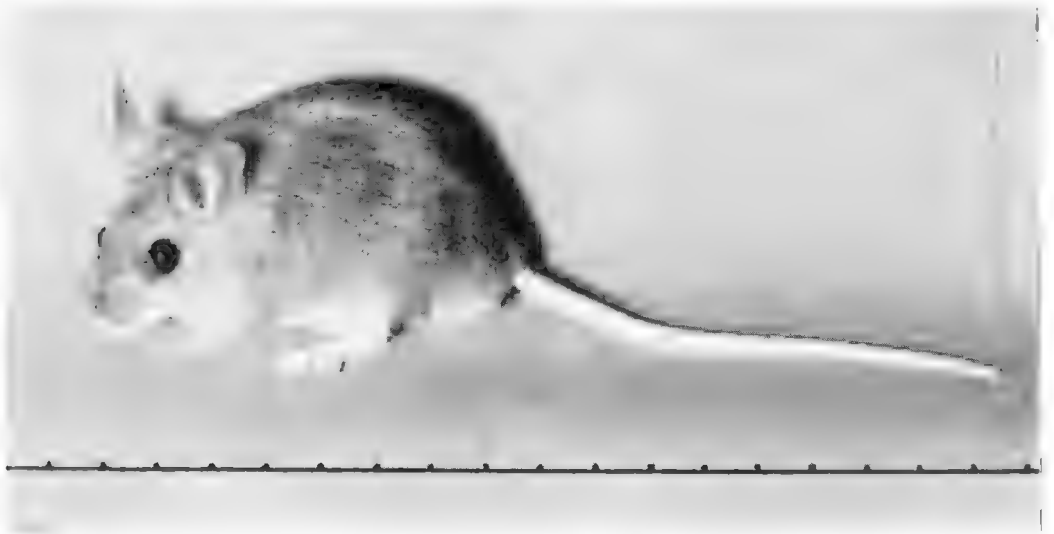
Fig. 1. An adult female *Pseudomys* (*Ps.*) *minnie* or *rawlinnae*, obtained as a juvenile from Wire Creek Bore, approx. 0·65 x life-size. Each division of the scale is 1 centimetre.

Fig. 2. Habitat at Wire Creek Bore 20 miles north of Oodnadatta. The shrub in the foreground is the silver saltbush, *Atriplex rhagodioides*. On this plain we caught *Sminthopsis crassicaudata*, *S. larapinta*, *Ps. minnie* or *rawlinnae*, and an unidentified species of *Ps.* (sub-genus *Leggadina*).

Fig. 3. A burrow of *Ps. minnie* or *rawlinnae* under a silver saltbush at Wire Creek Bore. The mound at the entrance is approx. 9 inches wide.
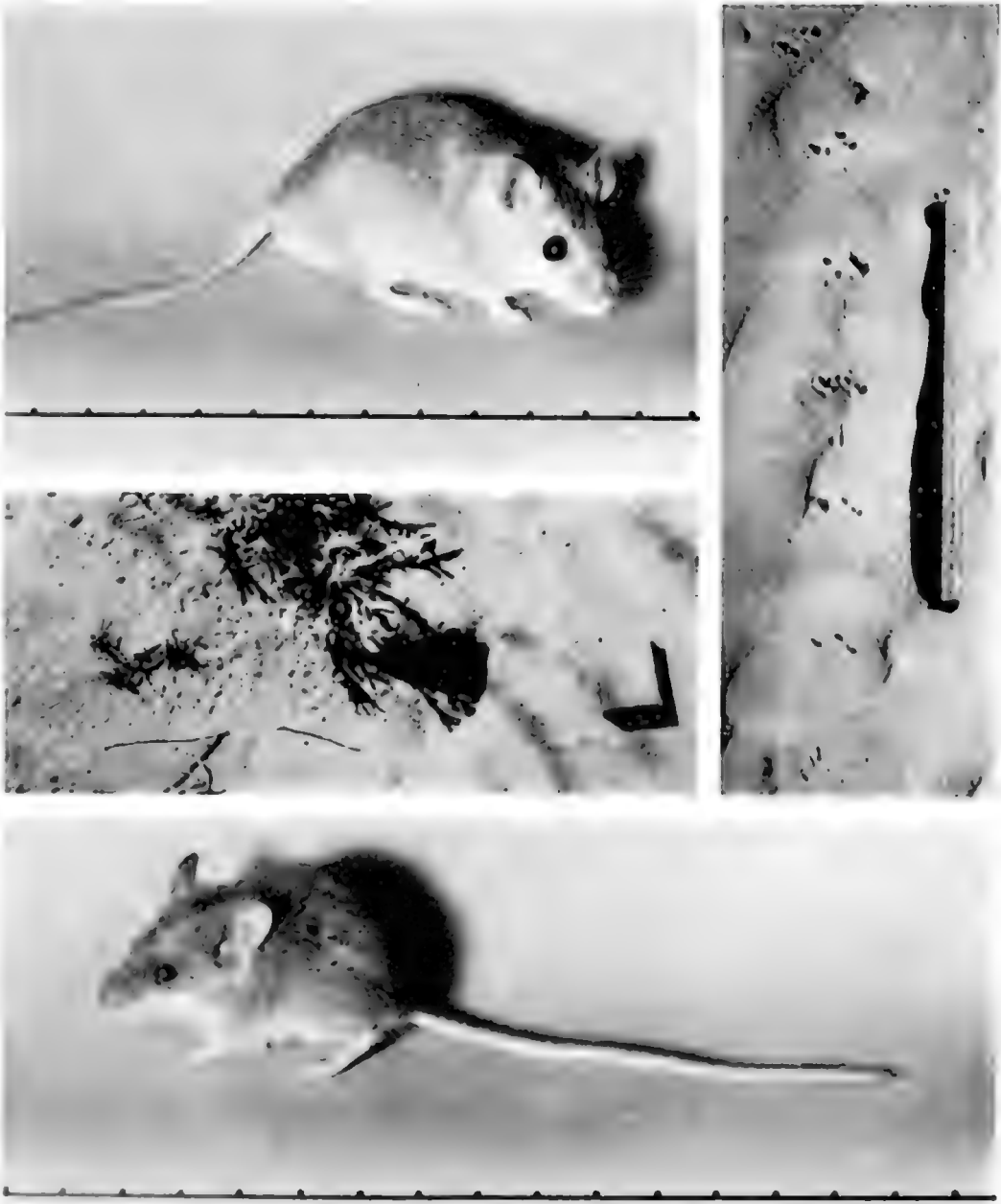
Fig. 1. An unidentified male *Pseudomys* (*Leggadina*) species from 30 miles north of Birds-
ville, approx. 0·6 x life-size.

Fig. 2. Tracks of the *Ps.* (*Leggadina*) species shown in Fig. 1. Direction of travel is from
bottom to top, and the scale is in inches and centimetres (see text).

Fig. 3. Entrance to a *Pseudomys hermannsburgensis* burrow near Fregon.

Fig. 4. A male *Pseudomys* (*Leggadina*) *hermannsburgensis* from Alkara, south of the
Musgrave Ranges.
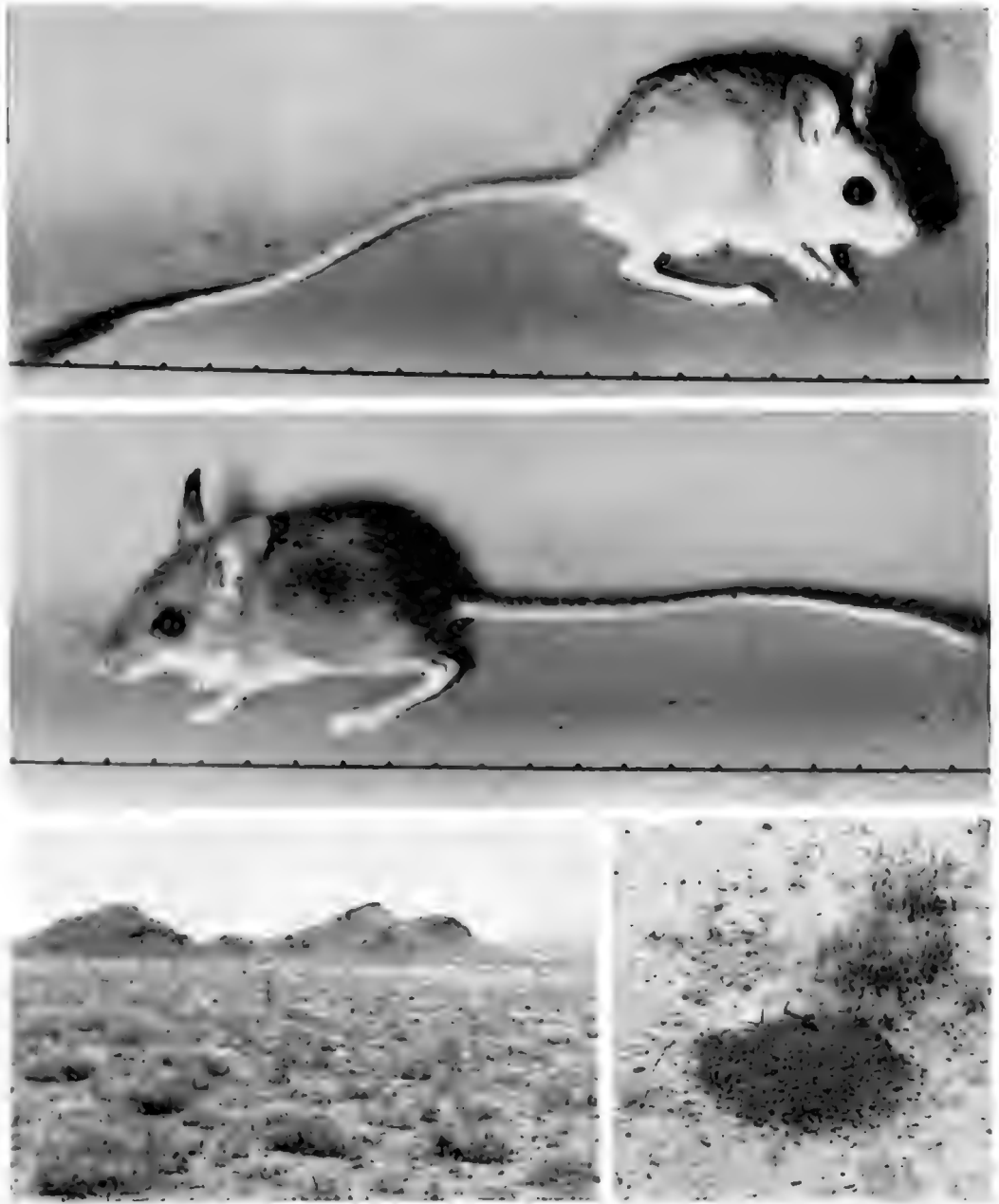
Fig. 1. A male *Notomys cervinus* from near Birdsville, approx. 0·6 x life-size.

Fig. 2. A male *Notomys alexis* from Turners Well, near Ernabella, approx. 0·6 x life-size.

Fig. 3. Habitat of an unidentified *Ps.* (*Leggadina*) species (group 2), 20 miles south-south-east of Mt. Aloysius.

Fig. 4. Entrance to a burrow of *Ps.* (*Leggadina*) species (group 2), at the locality shown in Fig. 6. The burrow contained an adult male.

# FOSSIL ELASMOBRANCH TEETH OF SOUTH AUSTRALIA AND THEIR STRATIGRAPHIC DISTRIBUTION

*BY N. S. PLEDGE**

## Summary

Several hundred fossil elasmobranch teeth, collected from Tertiary formations in South Australia, have been identified to species level in most cases. Twenty-five species have been recognized, including the new species *Carcharias maslinensis* Pledge, and three forms are identifiable only to genus level. The majority of species belong in the Infra-class Osteodonta, and some absentees are noted. Diagnoses for the various genera and species are given, and a guide to their salient features. When the occurrences are arranged stratigraphically, they fall into two main time spans, in Middle to Upper Eocene and Lower to Middle Miocene, when conditions were most suitable for preservation. It is concluded that the establishment of zones in Australia, based on assemblages of elasmobranch teeth, is not yet possible.

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Several hundred fossil elasmobranch teeth, collected from Tertiary formations in South Australia, have been identified to species level in most cases. Twenty-five species have been recognized, including the new species *Carcharias maslinensis* Pledge, and three forms are identifiable only to genus level. The majority of species belong in the Infra-class Osteodonta, and some absentees are noted. Diagnoses for the various genera and species are given, and a guide to their salient features. When the occurrences are arranged stratigraphically, they fall into two main time spans, in Middle to Upper Eocene and Lower to Middle Miocene, when conditions were most suitable for preservation. It is concluded that the establishment of zones in Australia, based on assemblages of elasmobranch teeth, is not yet possible.

## INTRODUCTION

The Elasmobranchii have a history reaching back to the Devonian Period, but many major groups became extinct before or during the Mesozoic. Although marine sequences of Cretaceous age are known in South Australia, no shark remains have been recorded from them yet. All the teeth described herein are from Tertiary deposits.

Apart from a brief note by McCoy (1875), Chapman (1913, 1914, 1917), Chapman and Pritchard (1904, 1907), and Chapman and Cudmore (1924) have been the only ones to write on the Tertiary fishes of Australia. Most of their material was from Victoria; only rarely were South Australian specimens mentioned.

The first work of any importance concerning fossil fishes was by Louis Agassiz, whose "Recherches sur les Poissons fossiles" was published at Neuchatel between 1834 and 1843. Other papers soon followed in Europe and America, and a few workers studied the fossil fishes of Indo-Pacific region. Very recently, L. S. Glikman (1964), of the Academy of Science of the U.S.S.R., published a volume wherein assemblages of sharks' teeth are used to define twelve zones in the Russian Paleogene. The present work was undertaken to determine whether similar zones could be established for the Australian Tertiaries.

## MATERIAL

The paleontological collection of the Department of Geology, University of Adelaide, includes several hundred fossil elasmobranch teeth, mostly from local Tertiary formations. A large number of teeth in the collection of the Geological Survey of South Australia, and several small private collections, were also studied.

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## DEPOSITORIES

Teeth held in the Department of Geology, University of Adelaide, are catalogued with the prefix "T".

Those in the collection of the Geological Survey are recorded in the Vertebrate Catalogue, and have numbers with the prefix "V", e.g. V35.

## NOMENCLATURE

Many elasmobranch genus names were established by naturalists of the early 19th century, such as Rafinesque (1810), de Blainville (1816) and Cuvier (1817). Cuvier is best known, but many of the genera he established were synonyms. Agassiz propagated these synonyms in the literature, and it is only in recent years that the original names have come into more general usage for the fossil species. Some authors, such as Glikman (1964), have split these "classical" genera, but it is difficult to see their reasons for so doing.

As genera and species of fossil sharks are established only on the character of the teeth, it is obvious that both "splitting" and "lumping" may occur. Comparison with the teeth of living sharks can reduce this risk somewhat, according to the particular genus of shark, but not remove it. Many species are therefore only morpho-species, and may represent several different biospecies, or conversely one biospecies may be represented by several morpho-species. As far as possible, the teeth described herein are compared with species originally described from Europe or America, on the grounds that most species of larger sharks have very wide distributions, and the number of parameters by which sharks' teeth are identified are not sufficient to establish geographic species for similar forms from different parts of the world.

## CLASSIFICATION

Several classifications of sharks have been proposed and these vary widely. Most have a strictly zoological approach, using characters, rarely, if ever, preserved in fossils. Nicholson and Lydekker (1889) used a major division based on the structure of the vertebrae, Tectospondyli and Asterospondyli, while Bertin and Arambourg (1958) had major divisions, Pleurotremata and Hypotremata, based on gill position, i.e. more or less on body form. Smaller divisions are based on morphological and physiological criteria in which tooth form is rarely included. Families and orders of fossil sharks' teeth are therefore based on living forms. However, the major division in fossil sharks is one of the basic tooth structure, and this has been utilised by Glikman (1964) in his classification of extinct and living elasmobranchs, which is marked by a distinction between orthodont and osteodont dentition.

Orthodont teeth (Text-fig. 1a) have a pulp cavity surrounded by orthodentine, and such teeth are found in the majority of living and fossil elasmobranchs, including one order of "true" sharks, the Carcharhinidae (whalers, topes, tigers and hammerhead sharks), also the dogfishes, rays and skates, and those primitive sharks: the hexanchids (notidanids) and heterodontids.

The Osteodonta have teeth (Text-fig. 1b) whose composition, including the root, is a vascular bone-like form of apatite called osteodentine. Only "true" sharks are included in the group: nurse and sand sharks, bulldog sharks, porbeagles, makos and blue pointers, threshers, and white pointers.

This division raises the question: which feature is of greater phylogenetic importance — a basic tooth structure, a basic vertebral structure, or overall body shape and anatomical layout?
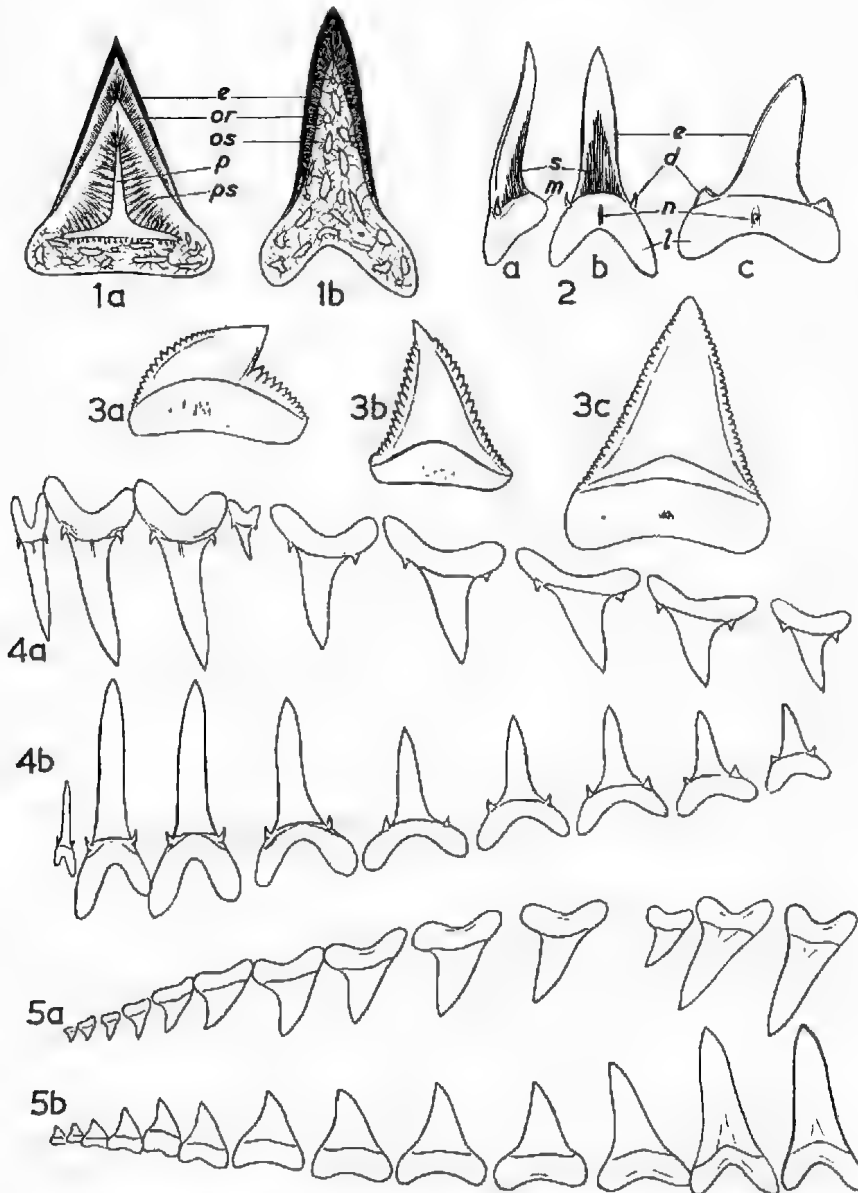
Fig. 1. a. Orthodont tooth (*Carcharhinus*). b. Osteodont tooth (*Carcharias*). *e*: Enamel (vitrodentine), *or*: orthodentine, *os*: osteodentine, *ps*: pseudodentine, *p*: pulp cavity (diagrammatic sections, after Bertin and Arambourg, 1958).

Fig. 2. a. Profile, *Carcharias macrotus*. b. Inner face, ditto. c. *Lamna apiculata*, inner face. *d*: lateral denticles, *e*: entire margin, *l*: root lobe, *m*: median boss, *n*: nutritive pit, *s*: striations.

Fig. 3. a. Serrated margins, e.g. *Galeocerdo*. b. Serrated margins, e.g. *Hemipristis*. c. Dentate margins, e.g. *Carcharodon*.

Fig. 4. *Carcharias arenarius* Ogilby. a. Upper jaw. b. Lower jaw. Anterior at left.

Fig. 5. *Isuropsis mako* (Whitley). a. Upper jaw. b. Lower jaw. Anterior at right.

However, the fossil record furnishes mainly the teeth, and the vertebrae found are difficult to ascribe to families. The use of the divisions Tectospondyli and Asterospondyli has been generally discontinued, and it is therefore felt that the use of basic tooth structure as a criterion for classification is defensible.

## TOOTH MORPHOLOGY AND VARIABILITY
### (Text-figs. 1-5)

Sharks' teeth consist of two main parts — the crown or biting surface, and the root. The crown may be solid (i.e. osteodont) or hollow (orthodont).

The crown consists of the main cusp or cutting blade, which may possess some accessory cusps. In osteodont sharks, these are paired lateral denticles or cusps; but in some orthodont sharks the teeth are asymmetrical, and accessory cusps occur only or mainly one the posterior side, e.g. "*Notidanus*" and *Galeocerdo*. The crown is often compressed into a blade, with the labial (outer) face being more planar than the lingual (inner) face.

The margins may be sharp cutting edges or quite blunt. Unless they are interrupted by dentes or serrae, they are termed "entire". Dentes are squarish "teeth" produced by invaginations of the edge, and serrae are saw-like points; intermediate shapes also occur.

Paired lateral denticles may take a variety of forms, even within the one species: sharp-pointed cones or barely discernible tubercles, straight or curved, broad sharp-edged compressed cones, or wedge-shaped blades. They may also bear serrae or dentes.

Ornamentation of the enamel is often present: plications of the enamel of the outer face, and longitudinal striations on the inner face.

The root is of bone-like material, and is usually bifurcated into two more or less distinct lobes which can take a variety of forms, according to position in the jaw. At the middle of the inner side of the root there is often a "median boss" which bears a vertical groove containing the "nutritive foramen". This is mainly seen in osteodont teeth, but some carcharhinids also have a nutritive pore. Within any one species of shark, variation in tooth form is seen; it may be slight, involving only an increasing obliquity in the more distal teeth, or radical, as in the hexanchids, where the difference between teeth of upper and lower jaws is extreme. Some generalisations may be made, although exceptions can be found.

1. Teeth from the upper jaw are broader than their lower jaw equivalents.
2. Upper teeth show more inclination than the equivalent lower teeth, which are normally erect.
3. There is a gradual decrease in the length-breadth ratio of the crowns as one proceeds backwards in the jaw.
4. In sharks having "eye" teeth (which are considerably smaller than their immediate neighbours), the anterior teeth are considerably more elongate than those lateral teeth immediately following the eye teeth.
5. There may be an increase in the number of lateral cusps on teeth in the distal parts of the jaws; the cusps also become broader and relatively coarser.
6. Small symphysial teeth may occur at the symphysis of either jaw.

The living sharks, *Carcharias arenarius* and *Isuropsis mako* (Text-figs. 4, 5), found in South Australian waters, show many of these features. Others, such as *Galeocerdo* and *Carcharodon*, show little variation within the jaw, save inclination and crown proportions.

Measurements are taken along three approximately perpendicular directions. Generally, crown height only can be measured due to damage to the root, and this is taken in the plane of the outer face, from apex to base, in a line perpendicular to the base. Width is measured at the base of the crown, where it naturally separates from the root. Thickness is often difficult to measure because of the configuration of the tooth; it is taken in a line normal to the outer face, as close to the base as possible.

## TAXONOMIC CHARACTERS

The characters that define genera of sharks' teeth are in some respects quite vague, yet in conjunction they serve to separate the groups fairly well.

Features used are:
1. Overall shape and proportions.
2. Presence or absence of serrated margins.
3. Presence or absence of lateral cusps.
4. Shape and number of lateral cusps, if present.
5. Shape of the roots.

Specific characters are the same as those listed above, with the addition of:
6. Presence or absence of striations on the lingual face.
7. Presence or absence of plicae in the enamel of the labial face.
8. Contortion or inclination of the crown.

In addition to just the presence or absence of these features, specific determinations also depend considerably on the degree to which a character is present. This can, and undoubtedly does, lead to some confusion in identification from inadequately illustrated descriptions.

## SYSTEMATICS

The classification used herein is given below, and is adapted from those of Glikman (1964) and Bertin and Arambourg (1958):

Superclass Pisces

  Class Chondrichthyes

  Subclass Elasmobranchii

   Infraclass Orthodonta

    Order Hexanchida

     Family "Notidanidae" (Hexanchidae)

    Order Heterodontida

     Family Heterodontidae

    Order Squatinida

     Suborder Rajoidei

      Families including Pristidae, Rajidae, Myliobatidae, Dasyatidae

     Suborder Squatinoidei

       Pristiophoroidei

       Orectoloboidei

       Squaloidei

    Order Carcharhinida

     Family Carcharhinidae

       Sphyrnidae

   Infraclass Osteodonta

    Order Carchariida

     Family Carchariidae (= Odontaspidae)

       Isuridae

## DESCRIPTION OF SPECIES

### Infraclass Orthodonta
### Family "Notidanidae"
### Genus "NOTIDANUS" Cuvier, 1817

*Diagnosis.* Teeth of upper jaw with prominent prime cusp and one or more small secondary cusps on distal side. Lower teeth very wide with numerous secondary cusps giving a saw-like form.

"*Notidanus*" Cuvier includes *Hexanchus* and *Heptranchias* Rafinesque, 1810, and *Notorhynchus* Ayres, 1855, as there is no apparent generic difference between the teeth of these living genera.

### "Notidanus" serratissimus Agassiz
#### (Plate 1, Figs. 1-3)

*Notidanus serratissimus* Agassiz, 1843, p. 222, pl. 36, figs. 4, 5.
  Woodward, 1886, p. 216, pl. 6, figs. 23-26.

*Diagnosis.* Teeth small, five to ten cones with blunt apices; principal cone only slightly larger than immediate neighbour, but more robust. Anterior edge produced downwards and denticulated on lower half.

*Observations.* Woodward's figures 24 and 25 (1886) most closely agree with two teeth at hand, although one of these has eleven cones—more than prescribed by the diagnosis. In all other respects, including geologic age, they agree with the figured material.

Another specimen, however, from the Naracoorte Bore, exhibits a somewhat different form. The principal cusp is very broad and less acute, and about twice as high as the following cusps which are about the same height. It also has eleven cusps.

Four fragments (Pl. 1, Fig. 3) found in close proximity at Blanche Point are tentatively assigned to this species, although they show some variation in the coarseness and style of serration.

*Occurrence.* Blanche Point Marl, at Port Noarlunga and Blanche Point. Knight Formation equivalents, Naracoorte Bore, 426 ft.

*Age.* Middle and Upper Eocene.

*Material Examined.* Three teeth and several fragments.

### Family PRISTIDAE
### Genus PRISTIS Latham, 1794

*Diagnosis.* Rostrum of skull long smooth blade with rounded end and parallel sides. Rostral teeth triangular, compressed dorsoventrally, faintly striated lengthwise, occur regularly along rostrum.

### Pristis cudmorei Chapman
#### (Plate 1, Fig. 6)

*Pristis cudmorei* Chapman, 1917, p. 139, pl. 9, fig. 7.

*Diagnosis.* Rostral teeth small, elongate, triangular, slightly inclined. Anterior margin sharp, finely denticulated to apex. Posterior edge thick and blunt. Both faces very finely and irregularly striated for half of height.

*Observations.* The three specimens at hand agree closely with Chapman's description of material of Upper Miocene age, but full equivalence of this neritic form is doubted because of the large time gap between the Victorian and South Australian occurrences.

*Occurrence.* Blanche Point Marl, Maslin Bay.

*Age.* Upper Eocene. Carter's Unit 2.

*Material Examined.* Three specimens.

## Family MYLIOBATIDAE
### Genus MYLIOBATIS Cuvier, 1817

*Diagnosis.* Dental pavement formed by regular interlocking of hexagonal tooth plates. Tooth plates with comb-like base—numerous transverse parallel blades on articulating surface. Median plates very broad, lateral plates regular hexagons.

### Myliobatis spp.
#### (Plate 1, Figs. 4, 5)

*Observations.* Two pieces from the Blanche Point Marl, and six pieces of different species from Naracoorte are the only South Australian specimens seen by the author. A fragment of caudal spine (Pl. 1, fig. 5) is also referred to this genus, but none of the material has been identified to species level.

*Occurrence.* Blanche Point Marl, Maslin Bay; Naracoorte E. & W.S. Bore No. 5, 426 ft., Knight Group equivalents.

*Age.* Middle and Upper Eocene.

*Material Examined.* Spine fragment from Blanche Point, 6 tooth plate fragments from Naracoorte bore, 2 from Blanche Point.

## Family CARCHARHINIDAE
### Genus CARCHARHINUS Blainville, 1816

*Diagnosis.* Teeth small, stout; lower teeth narrow, erect; upper teeth broader, inclined. No lateral denticles. Base widely expanded. Cutting margins often finely serrated. Root nearly straight, with central notch.

### Carcharhinus cf. collatus Eastman, 1904
#### (Plate 1, Fig. 7)

*Carcharias collata* Eastman, 1904, p. 85, pl. 32, fig. 3.
Chapman and Cudmore, 1924, p. 118, pl. 9, figs. 13-16,

*Diagnosis.* Robust *Carcharhinus* teeth with cutting edges finely serrated on basal prolongations, very finely on cusp, entire apex. Inner face strongly convex. Enamel of outer face extends much lower than on inner face. Root elongated, large, symmetrical.

*Observations.* The four specimens at hand agree with the figure of *C. collatus* given by Chapman and Cudmore (1924), and also with Eastman's figures of his types from the Miocene deposits in Chesapeake Bay, Maryland, although one specimen is more oblique, and another more robust.

*Occurrence.* The teeth all came from 255 ft. depth in the Marion No. 2 Bore, Sturt River Valley, Adelaide Plains. This depth is in or near the Munno Para Clay member of the Port Willunga Beds, as defined by Lindsay and Shepherd (1966).

*Age.* Lower to Middle Miocene: Batesfordian-Balcombian.

*Material Examined.* Four specimens.

## Carcharhinus (Prionodon) aculeatus (Davis)

(Plate 1, Fig. 8)

*Galeocerdo aculeatus* Davis, 1888, p. 8, pl. 1, figs. 1-3.
*Carcharias (Prionodon) aculeatus* Woodward, 1889, p. 440.
    Chapman and Cudmore, 1924, p. 119, pl. 9, figs. 19, 20.

*Diagnosis. Carcharhinus* teeth with whole cutting margin serrated, rather coarsely on lateral prolongations, finely on cusp, coarsest in notch; apex almost entire.

*Observations.* This species is represented by a solitary tooth from the River Murray Cliffs. It is similar to specimens of *C. collatus* at hand, but the serrations are considerably coarser and the tooth is slightly larger. The cusp shows a distinct inclination and the anterior notch is shallow. The tooth compares favourably with the figures of Chapman and Cudmore (1924).

*Occurrence.* River Murray Cliffs, locality uncertain, preservation suggests Cadell Marl Lens. Davis' material came from the Oamaru area (?L. Miocene) and from the L. Pliocene "Awatere Series".

*Age.* Lower Miocene.

*Material Examined.* One specimen.
With

## Genus HEMIPRISTIS Agassiz, 1843

*Diagnosis.* Principal teeth large, triangular, compressed; cutting edges coarsely serrated almost to apex. Lower anterior teeth slender, subulate, inwardly curved, only a few minute serrae at base.

## Hemipristis serra Agassiz

(Plate 1, Fig. 9)

*Hemipristis serra* Agassiz, 1843, p. 237, pl. 27, figs. 18-30.
    Woodward, 1889, p. 449.
    Chapman and Cudmore, 1924, p. 115, pl. 9, fig. 12.

*Diagnosis.* Marginal serrations in broad upper teeth large, extending almost to apex. Margins of anterior lower teeth very sharp distally. Inner face of root with deeply cleft median boss.

*Observations.* This species, while common in the Tertiaries of Europe, America and Indonesia, is quite rare in Australia, and only two specimens are known to the author, one found by Cudmore (Chapman and Cudmore, 1924) and the other very recently by Mr. R. J. F. Jenkins. The latter specimen is slightly smaller, but broader than that figured by Chapman and Cudmore. The marginal serrations are coarse, very sharp, and stop about 5 mm below the apex. The crown is inflated, but the external face is depressed at the base; the margins are twisted, convex outwards. Most of the root is missing.

*Occurrence.* Cliff, left bank of River Murray, one mile below Pelican Point, near Morgan, South Australia. Cadell Marl Lens in the Morgan Limestone.

*Age.* Lower Miocene-Batesfordian.

*Material Examined.* One specimen (F17288).

## Genus CARCHAROIDES Ameghino, 1901

*Diagnosis.* Teeth similar to *Lamna*, but with denticulated margin as in *Carcharodon*. Lateral denticles compressed, dentate. Orthodont.

## Carcharoides cf. totuserratus Ameghino

### (Plate 1, Fig. 11)

*Carcharoides totuserratus* Ameghino, 1906, p. 183 (footnote), fig. 50.
    Chapman and Cudmore, 1924, p. 121.

*Diagnosis.* Teeth large; inclined crowns. Large pointed lateral cusps, all margins denticulated.

*Description of Specimen.* Crown elongate triangular, acute, slightly oblique. Margin irregularly dentate, dentes wide and separated by shallow grooves. Outer face almost flat, smooth, inner face convex, smooth.

*Observations.* The sole specimen at hand consists only of the enamel shell of the crown, and no root or lateral denticles are present. It is somewhat smaller than Ameghino's type, and less oblique, and shows a flaring of the base that is difficult to visualize in *C. totuserratus.* It is also similar to *C. tenuidens* Chapman; Chapman records both forms from Janjukian deposits at Waurn Ponds, Victoria; Ameghino's material, from the Patagonian Series, is now regarded as being of Lower Miocene age.

*Occurrence.* Road cutting near Strathalbyn cemetery, Mannum Formation equivalents.

*Age.* Lower Miocene.

*Material Examined.* One specimen.

## Genus GALEOCERDO Müller and Henle, 1838

*Diagnosis.* Teeth serrated on both edges. Apex sharply inclined, deep notch posteriorly, coarse serrations below notch.

## Galeocerdo cf. aduncus Agassiz

### (Plate 1, Fig. 10)

*Galeocerdo aduncus* Agassiz, 1843, p. 231, pl. 26, figs. 24-28.
    Woodward, 1889, p. 444.
    Chapman and Cudmore, 1924, p. 117.
    Leriche, 1957, p. 38, pl. 45, figs. 18-21.

*Diagnosis.* Anterior margin arched; apex short, broad, sharply inclined, very similar to existing *Galeocerdo cuvieri* but smaller.

*Observations.* There is only one South Australian specimen of this species at hand. At first glance it seems referable to *G. latidens* because of its relatively great width and low crown. However, the anterior margin is distinctly arched, and finely denticulate. On reference to a jaw of the living *G. cuvieri,* it would appear that the tooth came from a posterior position, where the crown is relatively low.

Another tooth (Plate 1, Fig. 10b), of presumed Miocene age, and from an uncertain locality, is at hand. It differs from the above in having an elongated apex reaching almost to the posterior extremity of the tooth. The anterior edge shows a sharp bend about halfway along its length, and the two halves are straight. As such, it does not fit any species known to the author, but no attempt has been made to erect a new species on it at this stage.

*Occurrence.* Exact locality unknown, but from the River Murray cliffs, probably at Morgan.

*Age.* Lower Miocene.

*Material Examined.* Two teeth.

## Family TRIAKIDAE

### Genus MUSTELUS Linck, 1790

*Diagnosis.* Teeth small, similar, rhomboidal occlusal surface, arranged in oblique rows to form wide curved dental pavement on jaws; many in function at same time.



**Fig. 6**

Fig. 6. Comparison of *Mustelus antarcticus* and *?Mustelus* sp.
    a. *M. antarcticus*, occlusal surface, Recent.
    b. *?Mustelus* sp., ditto (F17287), U. Eocene.
    c. *M. antarcticus*, postero-occlusal aspect showing length.
    d. *?Mustelus* sp., ditto.   (x 5 approx.)

### cf. Mustelus sp.

(Text-fig. 6)

*Description.* A single, small, subrhomboidal tooth was found by Mr. R. J. F. Jenkins at Blanche Point. It is similar in form to a tooth from the living gummy shark *Mustelus antarcticus* Gunther, but differs in that the posterior corner of the rhomb is truncated, while the anterior truncation is wider.

The gently arched occlusal surface of the tooth is granulate, but there is a distinct smooth triangular area at the posterior corner (in the living *M. antarcticus* the whole surface is granulate, more coarsely on the posterior half). The tooth is not as deep as *M. antarcticus*, and its articulating process is obscured or missing.

*Observations.* This is the first report of any tooth of this form from Australian Tertiaries, although the Triakidae have a history reaching back to the Cretaceous, and *Mustelus* itself has been recorded from Oligocene deposits (Arambourg and Bertin, 1958, p. 2036).

If the present determination is correct, the genus will thus have its stratigraphic range extended back to the Upper Eocene.

*Occurrence.* Blanche Point Marl, Maslin Bay.

*Age.* Upper Eocene, Aldingan Stage, Carter's Unit 2.

*Material Examined.* One specimen, plus example from living gummy shark.

### Infraclass OSTEODONTA

### Family CARCHARIIDAE (= ODONTASPIDAE)

#### Genus CARCHARIAS Rafinesque, 1810

(syn. ODONTASPIS Agassiz, 1843)

*Diagnosis.* Teeth with high, narrow, compressed crown; with one or two pairs of lateral denticles, generally sharp pointed. Anterior teeth very high crowned, large and slender, with much produced bifurcated root. Similar to Cretaceous *Scapanorhynchus* and some forms of *Lamna*. Cutting edges entire, beginning several millimetres above base of crown.

## Carcharias macrotus (Agassiz)

(Plate 3, Figs. 1-8)

*Lamna elegans* Agassiz, 1843, p. 289, pl. 35, figs. 1-7, pl. 37a, figs. 58, 59.
*Otodus macrotus* Agassiz, 1843, p. 273, pl. 32, figs. 29-31
*Odontaspis elegans* Woodward, 1889, p. 361.
*O. macrota* Woodward, 1899, p. 9, pl. 1, figs. 19, 20.
*O. macrota striata* White, 1931, p. 58, figs. 45-74.

*Diagnosis.* High narrow crown, slightly curved; outer face smooth, slightly convex; inner face convex but medially flattened, longitudinally striated, striae rather irregular. Single pair of lateral denticles. Prominent median boss with nutritive pore. Root lobes long, generally pointed.

*Observations.* Teeth of this species show a variety of forms, depending on position in the jaw, and also, to some extent, on age. The denticles show a number of different forms, from fine curved cones to broad compressed cones, to chisel-like blades. Striations vary in continuity and degree, from strongly incised grooves to barely discernible narrow facets. Many specimens lack the root and/or lateral cusps, making identification rather uncertain. Several bio-species may be represented. According to White (1931, p. 62) the forms "*Odontapsis elegans*" (Ag) and *O. macrota* are the same species. "*O. elegans*" being juvenile to *O. macrota*.

Two other forms have been separated in the South Australian material. One is represented by six teeth (V49) from the Naracoorte bore assemblage (Plate 3, Fig. 7). They differ from most specimens in having a quite robust habit with short narrow crowns and strong, thick, widely bifurcated roots. All show the typical *C. macrotus* striations. Three of them are from the upper jaw, having shorter, inclined crowns. All bear short lateral cusps, and two of the lower teeth also have a second, minute, inner pair.

The other aberrant form (Plate 3, Fig. 8) is represented by three teeth (V53) from the Peel's Bore assemblage, which differ in size, preservation and root form from the numerous specimens of *C. macrotus* also present. All three bear strong striations, and lack lateral cusps. One is a compressed symphysial tooth, and the other two have roots with widely divergent, flattened, round-ended lobes.

Not enough is known of these two forms to put them in other species.

*Occurrence.* Basal member of the Tortachilla Limestone, upwards to the lower part of the Port Willunga Beds—Maslin and Aldinga Bays. Peel's Bore near Robe (390 ft.), and an aberrant form from the E. & W.S. Bore No. 5, at Naracoorte (426 ft.). Also from the Strathalbyn cemetery road cutting, Morgan type section, and Dry Creek Sands (Tennant's Bore, Salisbury).

*Age.* Common in Middle and Upper Eocene, and sporadically to Pliocene, in South Australia.

*Material Examined.* Approximately 50 specimens from Maslin and Aldinga Bays in A.U. catalogue; about 100 from Peel's Bore and other places, held in the Geological Survey collection, including the aberrant forms (V49 and V53).

## Carcharias contortidens (Agassiz)

(Plate 3, Fig. 11)

*Lamna (Odontaspis) contortidens* Agassiz, 1843, p. 294, pl. 37a, figs. 17-23.
*Odontaspis contortidens* Woodward, 1889, p. 366.
Chapman and Cudmore, 1924, p. 122.

*Diagnosis.* Teeth slender; delicate longitudinal striae on inner face. Sigmoidal curvature of anterior teeth and median boss of root more pronounced than in *C. macrotus.*

*Observations.* A large number of teeth from Peel's Bore were separated from *C. macrotus* by their greater slenderness and sinuosity. The striations are often finer and more numerous than in *C. macrotus* and extend nearer to the apex. Miocene specimens from the Marion No. 2 Bore are similar to, but considerably smaller than those from Peel's Bore.

*Occurrence.* Peel's Bore (390 ft.), near Robe; Marion No. 2 Bore (255 ft.), Sturt River Valley; Blanche Point Marl, Aldinga Bay; and Dry Creek Sands in the Abattoirs Bore.

*Age.* Middle to Upper Eocene, Miocene, Pliocene.

*Material Examined.* About 50 specimens, mainly from Peel's Bore (V14, V17).

## Carcharias maslinensis sp. nov.
### (Plate 2, Figs. 1-8)

*Diagnosis.* Teeth with very slender crown, circular cross-section at base. Anterior teeth with very sinuous elongate crowns, twisted. Anterior cutting edge more prominent. Regular, deeply-incised, longitudinal striations on inner face, almost to apex. Pair of minute, conical lateral denticles, well separated from crown. Root of anterior teeth with strong median boss. Lateral and distal teeth straighter, erect, having roots with widely divergent flattened lobes.

### Description of Types

*Holotype* (F17260) (Pl. 2, Figs. 1, 2). A typical anterior tooth of *Carcharias*, but distinguished by extreme slenderness, prominent sinuosity and axial twist. It is almost circular in section at the base, where the cutting edges are nonexistent, but becomes semicircular towards the apex, with the outer face being almost flat. Anterior cutting edge begins about two millimetres above base and is quite sharp; posterior cutting edge begins about 5 mm above base but is less prominent and rather blunt. The outer face is smooth except for a small sub-median plica, the inner face is strongly convex and longitudinally striated to within 3 mm of the apex. Striae are fine, regular, almost parallel, bifurcating towards the apex. A very small, curved-conical lateral cusp is preserved on the anterior side of the crown, some distance below the base.

The root is strongly bifid with narrow lobes at about 40°, separated by a prominent median boss with a deep nutritive pit at the apex.

*Dimensions.* Total height 20·8 mm; crown height (along outer face) 16·8 mm, inward displacement of apex c. 10 mm; base width 4·5 mm; base thickness 4·0 mm.

### Paratypes

(a) *Anterior teeth* (V35) (Pl. 2, fig.3). Similar to holotype, but most have lost the lateral cusps.

(b) *Lateral teeth* (V18) (Pl. 2, figs. 4a, 4b). A number of teeth found in the same Naracoorte bore assemblage are deemed to represent the lateral and posterior teeth of *C. maslinensis* sp. nov. because they are similar to the anterior teeth in slenderness, striation, and lateral cusps. They differ in being erect, with equal margins, a relatively short crown, and widely-bifurcating, flat-lobed roots. Two groups can be separated; one, having relatively wide main cusps, presumably represents teeth from the upper jaw, the other, lower jaw teeth. This conclusion is based on observations on the variation of teeth in the jaws of the living *Carcharias arenarius* Ogilby, which observations also explain the differences in root form and the shortness of the crown in the lateral teeth.

Judging by the gradation in size and form of both lateral and anterior teeth and the preservation, it is considered that they might represent one individual.

*Occurrence.* E. & W.S. Bore No. 5, Naracoorte (426 ft.).

*Depositories of Types.* Holotype: Dept. of Geology, University of Adelaide, F17260. Paratypes: Geological Survey of South Australia, V18, V35.

*Observations.* The teeth differ from *Lamna attenuata* Davis, which Chapman reported (1918) from the Lower Aldingan Beds, by possessing striations on the inner face, and a twisted sigmoidal shape of the crown. Chapman and Pritchard (1904) describe *Odontaspis attenuata* (Davis) as having a striated inner face, but none of the material seen in the Victorian National Museum agrees with the specimens of *C. maslinensis.* The lateral teeth of *C. maslinensis* are similar to very small specimens of *C. macrotus.*

TABLE I.

DIMENSIONS OF TYPES

| Anteriors | | | Upper Laterals | | | Lower Laterals | | |
|---|---|---|---|---|---|---|---|---|
| height | width | thickness | height | width | thickness | height | width | thickness |
| *holotype* | | | *paratypes* | | | *paratypes* | | |
| 16·8 | 4·5 | 4·0 | 8·3 | 4·8 | 2·4 | 7·7 | 3·9 | 2·3 |
| | | | 7·2 | 4·1 | 2·0 | 7·9 | 3·0 | 2·5 |
| *paratypes* | | | | | | | | |
| 16·1 | 4·9 | 4·1 | 6·1 | 3·5 | 2·0 | 7·0 | 2·4 | 2·2 |
| 12·1 | 3·5 | 2·5 | 6·8 | 3·4 | 2·0 | 5·8 | 3·0 | 1·7 |
| 12·1 | 3·6 | 2·9 | 7·0 | 3·7 | 2·2 | 7·3 | 2·8 | 2·1 |
| 13·0 | 3·4 | 2·5 | 6·5 | 2·8 | 2·1 | 5·8 | 2·1 | 1·7 |
| 9·9 | 3·1 | 2·3 | 5·0 | 2·7 | 1·8 | 7·5 | 3·0 | 2·3 |
| 12·6 | 3·0 | 2·5 | 5·1 | 2·9 | 1·7 | 7·2 | 3·0 | 2·0 |
| 8·4 | 2·8 | 2·4 | 5·4 | 3·3 | 1·5 | | | |
| | | | 6·0 | 2·9 | 1·6 | | | |
| | | | 3·6 | 2·2 | 1·7 | | | |
| | | | 7·6 | 4·5 | 2·3 | | | |

*C. maslinensis* is commonly found in the Eocene deposits of South Australia, and appears to have undergone some evolutionary change, as specimens from the Blanche Point Marl and Port Willunga Beds (lower part) are stouter than those from the older Tortachilla Limestone and Knight Formation. It is a common constituent of the assemblage of crowns in the basal grit member of the Tortachilla Limestone, but most identified specimens are of anterior teeth, for it is difficult to distinguish the lateral teeth on crowns alone. Three poorly preserved specimens from the Strathalbyn assemblage could conceivably be reworked from underlying Eocene strata during the Miocene transgression.

*Occurrence.* Peel's Bore, 390 ft., Co. Robe, Hd. Ross, Sec. 19; E. & W.S. Bore No. 5, Naracoorte, 426 ft.; a farm bore near Lucindale, 200 ft; a farm bore near Kingston, 715 ft.; basal grit of Tortachilla Limestone at Maslin Bay, basal part of Muloowurtie Formation, Yorke Peninsula, Blanche Point Marl; lower part of Port Willunga Beds; and Strathalbyn (cemetery road cutting) Mannum Formation equivalent.

*Age.* As recorded so far, *C. maslinensis* ranges from Middle to Upper Eocene, and possibly to Lower Miocene, unless reworked.

*Material Examined.* About 50 specimens from south-eastern bores, including the types F17260, V35, and V18. Another 50 crown enamels from the Tortachilla Limestone, and several teeth from other levels.

## Carcharias cf. cuspidatus (Agassiz)

(Plate 3, Figs. 9, 12, 13)

*Lamna cuspidata* Agassiz, 1843. p. 290, pl. 37a, figs. 43-50.
*Odontaspis cuspidata* Woodward, 1889, p. 125.
    White, 1931, p. 52, figs. 13-44.

*Diagnosis.* Teeth very similar to *C. macrotus* except for absence of striae on inner face. Sometimes more robust than corresponding teeth of *C. macrotus*, but smaller. One pair of small, pointed, lateral cusps. Nutritive foramen in deep cleft.

*Observations.* A large number of teeth, many from Peel's Bore, fit in this diagnosis, but most are wanting roots and/or lateral cusps. Those which are complete come within the range of variation for the species as illustrated in White's figures, but altogether they make up a rather heterogeneous collection which may represent several species. It has not been possible to separate them into more satisfactory groups.

*Occurrence.* Peel's Bore, 390 ft. (Knight Formation); basal part of Tortachilla Limestone, Blanche Point Marl, Port Willunga Beds in the Willunga Basin; and Strathalbyn (Mannum Formation equivalent).

*Age.* Middle Eocene to Lower Miocene, in South Australia.

*Material Examined.* Almost 100 specimens, including about 50 from Peel's Bore, and many crown enamels from the Tortachilla Limestone, and Strathalbyn.

## Carcharias cf. rutoti (Winkler)

(Plate 3, Fig. 14)

*Otodus rutoti* Winkler, 1876, p. 6, pl. 1, figs. 3, 4.
*Odontaspis rutoti* Woodward, 1889, p. 361.
    Chapman and Cudmore, 1924, p. 125, pl. 10, fig. 27.
    White, 1931, p. 49, figs. 4-12.

*Diagnosis.* Teeth small; robust but not very high, with faces smooth, but there may be vertical plications on outer face. At least two pairs of sharp lateral cusps—outer ones insignificant. Root with prominent median boss. Outer base-line of crown re-entrant.

*Observations.* Small specimens similar to *C. rutoti* have been recovered from the Blanche Point Marl, where the apparently easily detached lateral cusps are preserved. No specimens have been seen having three pairs of lateral cusps as in Winkler's description, but from White's figures, such occurrences are uncommon—only one of his nine figures shows three pairs of cusps. One specimen ascribable to the species was found in the Peel's Bore assemblage.

On the specimens available, the main cusp is more or less inclined, fairly broad, and relatively thin. The denticles are conical, sometimes compressed, and sometimes incurved towards the main cusp.

Chapman and Pritchard (1904) recorded similar teeth from Victoria as "*Lamna bronni*", which is a Cretaceous form, and it has been suggested that *C. rutoti* is the correct determination.

*Occurrence.* Blanche Point Marl, Blanche Point, Maslin Bay. Knight Formation, Peel's Bore (390 ft.).

*Age.* Middle and Upper Eocene.

*Material Examined.* Two teeth from Blanche Point, one from Peel's Bore.

## Carcharias dubius (Agassiz)
(Plate 3, Fig. 10)

*Lamna dubia* Agassiz, 1843, p. 295, pl. 37a, figs. 24-26.
*Odontaspis dubia* Glikman, 1964, pl. 25, figs. 12, 13, 16, 17, 19; pl. 27, figs. 18-23.

*Diagnosis.* Teeth very similar to *C. contortidens*, but lack striations on inner face. Crown rounded, subcylindrical at base, not flattened towards apex. Single pair of lateral cusps: cylindrical, elongate, very acute. Root and lateral cusps rarely preserved.

*Observations.* A number of teeth having similar characters to this form were found in the Peel's Bore Assemblage. The crowns are elongate and acuminate, with little or no cutting edge on the lower part. Width is only slightly greater than thickness. Root large, prominent median boss, lobes at about 90°. The teeth show signs of being polished, but not of excessive wear. They are similar to those figured by Glikman (1964) except that the root is not as broad.

*Occurrence.* Peel's Bore (390 ft.), County Robe, Hd. Ross, Sec. 19.

*Age.* Middle Eocene.

*Material Examined.* Five teeth from Peel's Bore.

## Carcharias sp. indet.

*Observations.* Five entirely unworn teeth, having some resemblance to *C. dubius* and *C. cuspidatus*, but differing in detail, were found in the Naracoorte Bore Assemblage.

The teeth are small, having narrow erect crowns and a pair of large conical lateral cusps. They differ from *C. dubius* in having sharp cutting edges, also on the denticles, and widely divergent root lobes. The median boss is prominent. One tooth is from an anterior central position, while another is posterior and is developing a second pair of denticles.

*Occurrence.* E. & W.S. Bore No. 5, Naracoorte (426 ft), Knight Formation equivalent.

*Age.* Middle Eocene.

*Material Examined.* Five teeth from the Naracoorte Bore.

## Carcharias cf. ensiculatus (Davis)
(Plate 3, Fig. 15)

*Lamna ensiculata* Davis, 1888, p. 18, pl. 3, figs. 6, 7.

*Diagnosis.* Teeth small, strong, erect. Crown enamel divides just above base, at point marked by constriction, and extends over upper part of root lobes. Faint indication of lateral cusps.

*Observations.* This form is represented here by a single specimen which well illustrates the peculiar flaring and bifurcation of the lower part of the enamel. No lateral cusps can be seen. The root is strong and deeply bifurcated at about 90°; the inner side is flattened and bears a prominent nutritive pit. However, the root is not as large as in the figures of Davis. His material came from the "Oamaru Formation" (Oligocene) of New Zealand, which is considerably younger than this specimen.

*Occurrence.* E. & W.S. Bore No. 5, Naracoorte (426 ft.).

*Age.* Middle Eocene.

*Material Examined*: One specimen.

## Genus CARCHARIOLAMNA Hora, 1939

*Diagnosis.* Teeth having form of *Lamna* and bearing close resemblance to *Carcharoides*, but being distinguished by osteodont structure, less developed lateral cusps, finely denticulated margin, and blunt apex.

## Carchariolamna cf. heroni Hora

(Plate 3, Fig. 16)

*Carchariolamna heroni* Hora, 1939, p. 203-205, pl. 13, figs. 1-4.

*Diagnosis.* Teeth similar to *Carcharias* or narrow specimens of *Lamna* sp., erect, broad base, apex blunt; margins finely denticulate, from apex almost to base. Lateral denticles small, blunt, incipient. Root broad.

*Observations.* The specimen at hand consists only of the crown of a tooth. It agrees with Hora's description and figures, except that the apex is more acuminate, and no flaring is seen at the base. The margin is well preserved, and differs from that of *Carcharoides* in the fineness of the dentes.

*Occurrence.* Marion No. 2 Bore, 225 ft., Sturt River Valley. Another tooth of this form was found by Howchin in a quarry at Mt. Gambier.

*Age.* Lower to Middle Miocene (Batesfordian-Balcombian).

*Material Examined.* Two specimens.

## Family ISURIDAE

## Genus LAMNA Cuvier, 1817

*Diagnosis.* Teeth as for *Carcharias* Rafinesque, but principal cusps broader, and lateral cusps larger and stouter. Cutting edges do not extend to base of crown.

## Lamna obliqua (Agassiz)

(Plate 4, Fig. 1)

*Otodus obliquus* Agassiz, 1843, p. 267, pl. 31, 36, figs. 22-27
*Lamna obliqua* Woodward, 1889, p. 404.
    White, 1931, p. 46, fig. 3.

*Diagnosis.* Teeth robust, large; crown moderately compressed, acuminate, one pair of broad lateral cusps, sometimes a second smaller pair in distal teeth. Both faces smooth. Rarely, cutting edges faintly denticulated. Prominent median boss, nutritive foramen not in groove.

*Observations.* This species is rare in Australian Tertiaries, and only two specimens have been available. The larger specimen is a distal tooth having a short crown and two pairs of stout lateral cusps. The root is stout and widely bifurcated with pointed lobes. The other specimen, from Peel's Bore, is small, more oblique, with one pair of small denticles.

*Occurrence.* The larger specimen is part of an old collection and is labelled "Miocene,? Deepwell, Murray Scrub". However, the preservation is similar to that of teeth from the Knight Formation of the Murray Basin. The smaller specimen is from Peel's Bore, near Robe.

*Age.* Middle or Upper Eocene.

*Material Examined.* Two specimens.

## Lamna cf. apiculata (Agassiz)
(Plate 4, Fig. 2)

*Otodus apiculatus* Agassiz, 1843, p. 275, pl. 37, figs. 32-35.
*Lamna apiculata* Chapman, 1918, p. 13, pl. 5, figs. 17-20, pl. 6, fig. 4.
Chapman and Cudmore, 1924, p. 126, pl. 10, figs. 28, 29.

*Diagnosis.* Moderate size, triangular, relatively thin, more or less oblique; outer face with some small vertical plicae at base; pair of short, blunt, biconvex lateral cusps. Root strong, widely divergent, pointed lobes. Detached crowns very similar to *Isurus hastalis*, but have greater median thickness.

*Observations.* Only a few of the specimens at hand still retain the lateral cusps; identification of others is uncertain. Many specimens are small, and may represent a different species, as they occur in only one horizon—the basal part of the Tortachilla Limestone. The form occurs sporadically through the Tertiary.

*Occurrence.* Basal member of Tortachilla Limestone, Maslin Bay; Blanche Point Marl at Aldinga Bay, Port Noarlunga and Moana; Strathalbyn; Morgan Limestone type section (Cadell Marl Lens); Morgan township; base of Loxton Sands, Waikerie.

*Age.* Upper Eocene to Pliocene.
*Material Examined.* Fourteen specimens.

## Lamna cf. crassidens Agassiz
(Plate 4, Fig. 4)

*Lamna crassidens* Agassiz, 1843, p. 292, pl. 35, figs. 8-21.
*Odontaspis* (?) *crassidens* Woodward, 1889, p. 373.
*Lamna crassidens* Chapman and Cudmore, 1924, p. 128.

*Diagnosis.* Teeth robust, large, rather spatulate outline; outer face gently convex; inner face strongly convex, medially depressed. Root strong, long widely divergent lobes. Crowns very similar to *Isurus desorii*.

*Observation.* A single tooth fits this description. The crown is erect, and spatulate, with the inner face strongly convex but medially depressed. It is placed in *Lamna* because the cutting edges do not extend to the base, and it is too robust to be put in *Carcharias*. There is no sign of lateral cusps. The root has widely divergent lobes.

*Occurrence.* River Murray cliffs, probably near Morgan.
*Age.* "Lower Murravian" i.e. Lower Miocene.
*Material Examined.* One specimen.

## Lamna vincenti (Winkler)
(Plate 4, Fig. 3)

*Lamna compressa* Agassiz (pars), Agassiz, 1843, p. 290, pl. 37a, figs. 41-42.
*Lamna vincenti* (Winkler), Woodward, 1899, p. 10, pl. 1, figs. 21, 22.
Leriche, 1905, p. 125-127, pl. 6, figs. 36-51.
Leriche, 1936, p. 390, pl. 26, figs. 14, 15.

*Diagnosis.* Teeth strongly compressed, crown expanded at base, inner face smooth; upper teeth oblique, lowers erect; one pair of lateral cusps, moderate size, well separated from crown, divergent; small outer pair of cusps in more distal teeth.

*Observations.* Two undoubted specimens of this species were found in the Blanche Point Marl by Mr. R. J. F. Jenkins, and several incomplete teeth may also be referable to the species. It is distinguished from the form C. cf. *rutoti*, which is also present, by the compressed crown and straight outer base-line.

*Occurrence.* Blanche Point Marl, Blanche Point.
*Age.* Upper Eocene, Carter's Unit 2.
*Material Examined.* Two complete teeth and several crowns.

## Genus Isurus Rafinesque, 1810

*Diagnosis.* Teeth generally large; crown compressed, triangular, acute, erect or slightly oblique; margins entire, extend right to base; no lateral cusps. Root thick; short, rounded lobes.

### Isurus cf. hastalis (Agassiz)
(Plate 4, Fig. 5)

*Oxyrhina hastalis* Agassiz, 1843, p. 227, pl. 34, figs. 3-13, 15-17.
    Woodward, 1889, p. 385.
*Isurus hastalis* Ishiwara, 1921, p. 62, pl. 10, figs. 1-32.
    Chapman and Cudmore, 1924, p. 129, pl. 10, fig. 30.
*Oxyrhina hastalis* Leriche, 1957, p. 27, pl. 2, figs. 1-8.

*Diagnosis.* Teeth large, broad, compressed; outer face flat or concave, sometimes with plicae; root short, almost straight, blunt-ended. Anterior teeth very large, triangular, thin erect; upper laterial teeth inclined. Lower teeth thicker, more erect.

*Observations.* This species has been the subject of much "splitting" and "lumping". Agassiz's species *Oxyrhina hastalis*, *O. trigonodon*, and *O. plicatilis* are now commonly included in the synonymy, and Ishiwara (1921), for instance, has included a number of Jordan's Californian species. As a result, *Isurus hastalis* consists of a number of forms, and allocation to the species is sometimes uncertain. Reference to the teeth of the living *Isuropsis mako* (Whitley) (= *Isurus glaucus* (Müller and Henle)) shows that such a wide range of forms is to be expected.

Few undoubted specimens of *I. hastalis* are at hand from South Australia, although they are abundant in the Victorian Miocene. The teeth show a similar range in form to those figured by Ishiwara (1921), but they are often considerably smaller. They also have a long time range, and may therefore represent several species. Some specimens assigned here may be incomplete teeth of *Lamna apiculata*.

*Occurrence.* Blanche Point Marl, and lower Port Willunga Beds in Aldinga Bay (uncertain identification); Strathalbyn cemetery road cutting; Cadell Marl Lens, Morgan type section; Morgan township; Mannum; Mt. Gambier.

*Age.* (?) Upper Eocene to Middle Miocene.

*Material Examined.* Eight good specimens and numerous enamel fragments from Strathalbyn.

### Isurus desorii (Agassiz)
(Plate 4, Fig. 7)

*Oxyrhina desorii* Agassiz, 1843, p. 202, pl. 37, figs. 8-13.
    Woodward, 1889, p. 382.
*Isurus desorii* Chapman and Cudmore, 1924, p. 132, pl. 10, fig. 32.
*Oxyrhina desori* Leriche, 1957, p. 26, pl. 44, figs. 18-23.

*Diagnosis.* Teeth with crowns narrower than *I. hastalis*, broader than *I. retroflexus*, sigmoidal curvature in upper anterior teeth. Outer face nearly flat, inner very convex, but medially depressed.

*Observations.* The few specimens available are generally in a poor state of preservation, consisting of detached crowns only. There are few really distinctive characters, but the teeth fit roughly between the limits set. However, there appears to be a tendency for the forms *hastalis*, *desorii* and *retriflexus* to intergrade, and these determinations must therefore be regarded cautiously.

*Occurrence.* The better preserved teeth are of uncertain origin, but appear to have been collected from the Murray Cliffs—possibly from the Cadell Marl Lens near Morgan. Others, consisting of enamel only, were collected from the road cutting near the Strathalbyn cemetery, i.e. Mannum Formation equivalent. A tooth ascribable to *I. desorii* was also found in the Peel's Bore Assemblage.

*Age.* Middle Eocene (?), Lower Miocene.

*Material Examined.* Eight specimens.

## Isurus retroflexus (Agassiz)
### (Plate 4, Figs. 8, 9)

*Oxyrhina retroflexa* Agassiz, 1843, p. 281, pl. 33, fig. 10.
    Woodward, 1889, p. 389.
*Isurus retroflexus* Chapman and Cudmore, 1924, p. 130, pl. 10, fig. 31.
*Oxyrhina retroflexa* Leriche, 1957, p. 30, pl. 45, figs. 9-11.

*Diagnosis.* *Isurus* teeth, rather short, robust, narrower than *I. desorii*. Anterior crowns strongly incurved. Inner face very convex, not depressed; outer face slightly convex in lower teeth, flat in upper teeth. Lateral teeth curved backwards to angle of jaws.

*Observations.* Teeth of this form are very similar to those of *I. desorii*, but are marked by greater incurvature, and by convex outer faces. One specimen of an upper anterior tooth is almost complete, and shows a basal expansion of the crown enamel onto the root.

*Occurrence.* One specimen, a lower anterior, was found in limestone at Myponga in a posthole at the Myponga cheese factory. The others are from less well defined localities: Aldinga Cliffs, Murray Cliffs, according to their labels.

*Age.* Upper Eocene (?)—Oligocene, Lower Miocene.

*Material Examined.* Seven specimens.

## ? Isurus sp.
### (Plate 4, Fig. 10)

*Description.* A number of similar teeth, represented only by the enamel of their crowns, have been found in two different formations.

The crowns are elongate, narrow, relatively thin, and slightly inclined. The apex is blunt. The margins are entire, reaching right to the base, but are blunt; although worn, they show little sign of having been sharp. The outer face is slightly convex, medially depressed at the base, and extends below the normal base-line in a wide "tongue". The inner face is more convex, smooth.

The slenderness and the character of the outer face make its allocation to *Isurus* rather uncertain.

*Occurrence.* Basal grit member of the Tortachilla Limestone, Maslin Bay; and Strathalbyn cemetery road cutting—Mannum Formation equivalent.

*Age.* Upper Eocene, and Lower Miocene.

*Material Examined.* Fifteen specimens.

Genus CARCHARODON A. Smith (in Müller and Henle, 1838)

*Diagnosis.* Teeth large to very large, triangular, serrate or dentate margin; outer face flat, inner face convex; sometimes with serrate lateral cusps.

## Carcharodon megalodon (Charlesworth)

(Plate 4, Fig. 12)

*Carcharias megalodon* Charlesworth, 1837, p. 225, fig. 24.
*Carcharodon megalodon* Agassiz, 1843, p. 247, pl. 29.
   McCoy, 1875. Dec. 2, pl. 11, fig. 4, p. 9.
   Woodward, 1889, p. 415.
   Ishiwara, 1921, p. 65, pl. 10, fig. 33, pl. 11, figs. 1-8, pl. 12, figs. 1, 2.
   Chapman and Cudmore, 1924, p. 133.
   Leriche, 1957, p. 32, pl. 3, figs. 1-18.

*Diagnosis.* Very large, broad triangular, robust; outer face flat; apex slightly everted; no distinct lateral cusps. Margin with rounded dentes.

*Observations.* This is one of the best known of fossil sharks' teeth, mainly because of its large size. The sharks growing these teeth have been estimated to have reached 30 metres in length, with a jaw gape of two metres. Although found in large numbers in some parts of the world, only relatively few teeth have been found in South Australia. An upper right lateral tooth, in the Department of Geology collection, has a crown about 45 mm high, and shows marked inclination towards the posterior. A fragment of enamel from the Strathalbyn locality may also belong to *C. megalodon*. The teeth are marked by a spatulate outline, the margins being convex towards the apex, and concave towards the base.

*Occurrence.* The specimens at hand come from Barber's Quarry, Mount Gambier, and also from Strathalbyn. Others have been found at Pt. MacDonnell, Lake Bonney (S.E.), Morgan, and Blanchetown, and elsewhere in the Murray Basin.

*Age.* Lower to Middle Miocene.

*Material Examined.* Seven specimens, including five in the South Australian Museum.

## Carcharodon auriculatus (Blainville)

(Plate 4, Fig. 11)

*Squalus auriculatus* de Blainville, 1818. p. 384.
*Carcharodon auriculatus* Agassiz, 1843, p. 254. pl. 28, figs. 17-19.
*C. angustidens* Agassiz, 1843, p. 255, pl. 28, figs. 20-25, pl. 30, figs. 2, 3.
   McCoy. 1875, Dec. 2, pl. 11, figs. 2, 3, p. 8.
*C. auriculatus* Woodward, 1889, p. 411.
   Chapman and Cudmore, 1924, p. 134.
*C. angustidens* Leriche, 1957, p. 32, pl. 3, fig. 14.

*Diagnosis.* Teeth robust, smaller and narrower than *C. megalodon*; single pair of serrated lateral cusps, especially large in lateral teeth, which have very narrow, rather oblique crowns.

*Observations.* The specimen at hand is almost complete, lacking only the apex of the crown. The crown is erect, and narrow in its upper part, but flares suddenly about 1 cm above the base. The inner face is convex but medially depressed. The lateral cusps are compound, i.e. their outer edges have two or more major points, all of which are serrated. The serrae are quite pointed, whereas the specimens of *C. megalodon* at hand have rounded dentes. The root is strong, with widely divergent, flattened lobes.

*Occurrence.* Port Willunga Beds, Aldinga Bay. Others have been found at Mount Gambier and Tailem Bend.

*Age.* Oligocene to Lower Miocene.

*Material Examined.* Seven specimens, including six in the South Australian Museum.

## Carcharodon carcharias (Linnaeus)

(Plate 4, Fig. 13)

Squalus carcharias Linnaeus, 1758, p. 235.
Carcharodon rondeletii Müller and Henle, 1841, p. 70.
　　Woodward, 1889, p. 420.
Carcharodon carcharias Ishiwara, 1921, p. 68, pl. 17, fig. 5.
　　Chapman and Cudmore, 1924, p. 135.

*Diagnosis.* Carcharodon teeth, but relatively small, reaching 40 mm height; broad triangular, thin, straight margins, no lateral cusps.

*Observations.* The specimen at hand consists of the main part of the crown. The margins flare only slightly at the base, and are irregularly denticulated with well-separated rounded dentes. The outer face is slightly convex, but medially depressed. This species is still found in South Australian waters, and has world-wide distribution.

*Occurrence.* Dry Creek Sands, Abattoirs Bore, Hd. Yatala.

*Age.* Upper Miocene, Recent.

*Material Examined.* One specimen, plus jaw of living shark.

## Carcharodon sp. indet.

(Plate 4, Fig. 14)

*Observations.* A small tooth, obviously belonging to *Carcharodon* sp., has been found in the Blanche Point Marl. The apex and much of the root are missing, and the total height of the remainder is about 15 mm. The crown is quite thick (6 mm), and almost complete, except for apex and extremities of the base, and is inclined to the posterior. Only one of the cutting edges is preserved intact, and shows moderate-sized round-ended dentes. The tooth evidently comes from the posterior part of the jaw. Of the root only the central portion remains, preserving a median boss with a shallow groove.

*Occurrence.* Blanche Point Marl, Blanche Point.

*Age.* Upper Eocene—Carter's Unit 2.

*Material Examined.* One tooth. Jenkins' collection.

## STRATIGRAPHIC DISTRIBUTION

It is seen that, although sediments covering most of the Tertiary are present in South Australia, the known distribution of fossil sharks' teeth within them is discontinuous. This is mainly a collecting bias, due to favourable lithology for preservation and subsequent discovery, although assemblages from bores come from discrete levels.

A number of assemblages from units in which fossil sharks' teeth are relatively plentiful are listed below. They are treated in stratigraphic order.

a. *Knight Formation* (lower part): Peel's Bore, Co. Robe, Hd. Ross, Sec. 19, 390 ft., E. & W.S. Bore No. 5, Naracoorte, 426 ft.

*Age.* Middle Eocene.

*Species.* "Notidanus" serratissimus, Myliobatis spp., Galeocerdo sp. indet., Carcharias macrotus, C. contortidens, C. maslinensis sp. nov., C. cuspidatus, C. rutoti, C. dubius, C. ensiculatus, Lamna obliqua, Isurus cf. desorii.

b. *Tortachilla Limestone* (basal grit), Maslin Bay.

*Age.* Aldingan (Upper Eocene), Carter's Unit 1.

*Species. Carcharias macrotus, C. cuspidatus, C. maslinensis* sp. nov., *Lamna* cf. *apiculata, Isurus* (?) *hastilis, Isurus* (?) sp.

These are all preserved as only the enamel shells of the crowns.

c.  *Blanche Point Marl.* Blanche Point and other places.

*Age.* Aldingan, Carter's Unit 2.

*Species.* "*Notidanus*" *serratissimus, Pristis* cf. *cudmorei, Myliobatis* sp., *Carcharias macrotus, C. contortidens, C.* cf. *cuspidatus, C.* cf. *rutoti, C. maslinensis, Lamna apiculata, L. vincenti, Isurus* cf. *hastalis, Carcharodon* sp. indet.

d.  *Strathalbyn,* cemetery road cutting (IId. Bremer, Sec. 2548).

*Formation.* Sublittoral equivalents of Mannum Formation.

*Age.* Lower Miocene.

*Species.* "*Notidanus*" sp. indet. (fragmental), *Carcharoides* cf. *totuserratus, Carcharias macrotus, C.* cf. *cuspidatus, C.* (?) *maslinensis, Lamna apiculata, Isurus hastalis, I. desorii, Isurus* (?) sp. (same as in Tortachilla Limestone), *Carcharodon megalodon.*

e.  *Marion No. 2 Bore,* Sturt River Valley, Hd. Adelaide (depth 255 ft.).

*Formation.* In or near Munno Para Clay member, Port Willunga Beds.

*Age.* Batesfordian-Balcombian (Lower Miocene), Carter's Units 9-10.

*Species.* "*Notidanus*" sp. indet. (fragment), *Carcharhinus* cf. *collatus, Carchariolamna* cf. *heroni, Carcharias contortidens, C. cuspidatus.*

f.  *Cadell Marl Lens,* Morgan Limestone (type section, 4 miles downstream from Morgan).

*Age.* Lower Middle Miocene. Carter's Unit 10.

*Species. Carcharhinus aculeatus, Galeocerdo aduncus, Hemipristis serra, Carcharias macrotus, C.* cf. *cuspidatus, Lamna apiculata, L. crassidens, Isurus hastalis, I. desrii, I. retroflexus, Carcharodon megalodon.*

g.  *Dry Creek Sands,* as in Abattoirs Bore, Tennant's Bore.

*Age.* Upper Pliocene (Yatalan).

*Species. Myliobatis moorabbinensis,*[*] *Carcharhinus* (*Prionodon*) *aculeatus,*[*] *Carcharias* cf. *macrotus, C. contortidens,*[*] *Lamna* sp., *Carcharodon carcharias.*

As the accompanying Table 2 shows, some species are restricted to relatively short-time ranges. This is partly an artificial zonation, caused by differential preservation and paucity of specimens. Some species have short time ranges on a world scale, and the specimens at hand fall into them; others have long time ranges and may be represented by only a few specimens. In several cases, teeth apparently fall outside the accepted time ranges for the species with which they are compared.

The following species are apparently restricted to the Middle Eocene in South Australia: *Carcharias dubius, C. ensiculatus, Lamna obliqua.*

Apparently restricted to Upper Eocene: *Pristis* cf. *cudmorei, Lamna vincenti.*

Found in both Middle and Upper Eocene: "*Notidanus*" *serratissimus, Carcharias maslinensis, C.* cf. *rutoti.*

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[*] These species were reported by Crespin and Cotton (in Miles, 1952) from the Abattoirs Bore, but the material has not been seen by the author.

| Isotopic Date M.yrs. B.P. | | 49 | 45 | | 37-38 | 31-32 | 26 | | 18-19 | | 12 | 7 | | 2-3 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

Series: M.Eocene, U.Eocene, L.Oligocene, U.Oligocene, L.Miocene, M.Miocene, U.Miocene, Pliocene, Pleistocene

Australian Stages: Johannian, Aldingan, Janjukian, Longfordian, Batesfordian, Balcombian, Bairnsdalian, Mitchellian, Cheltenhamian, Kalimnan, Yatalan

Carter's Faunal Units: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11

Correlation after Ludbrook(1967) - "Correlation of the Tertiary Rocks of the Australasian Region", in "Tertiary Correlations and Climatic Changes in the Pacific", Symposium 25, Sendai, Japan.

GAMBIER EMBAYMENT — Kingston Formation, Knight qsands, Gambier Limestone, dune limesands

MURRAY BASIN — lignite Moorlands Beds, Buccaleuch Beds, Renmark, Ettrick Fm., Mannum Fm., Morgan Lst., Cadell Ml., Finniss C., Pata Lst., Loxton Sands, Bookpurnong Beds, Norwest Bend Fm., Blanchetown Clay

ST. VINCENT BASIN — Nth.Maslin Sands, Sth.Maslin St., Tortachilla Lst., Blanche Point Marl, Chinaman Ely, type section, Willunga Beds, Port, Muloowurtie Clay, Hindmarsh Clay, Hallett Cove Sand, Dry Ck. Sand

| Species | |
|---|---|
| Notidanus serratissimus | |
| Notidanus spp. | |
| Pristis cf. cudmorei | |
| Myliobatis spp. | |
| Carcharhinus collatus | |
| C. aculeatus | |
| Carcharoides totuserratus | |
| Hemipristis serra | |
| Galeocerdo aduncus | |
| Carcharias macrotus | |
| C. contortidens | |
| C. maslinensis sp.nov. | |
| C. cuspidatus | |
| C. cf. rutoti | |
| C. dubius | |
| C. ensiculatus | |
| Carchariolamna cf. heroni | |
| Lamna obliqua | |
| L. cf. apiculata | |
| L. vincenti | |
| L. cf. crassidens | |
| Isurus hastalis | |
| I. desorii | |
| I. retroflexus | |
| Isurus (?) sp. | |
| Carcharodon megalodon | |
| C. auriculatus | |
| C. carcharias | |
| Carcharodon sp. indet. | |

x   stratigraphic position known
o   position uncertain
s   ditto - Strathalbyn locality
u   identification uncertain

Found only in Oligocene: *Carcharodon auriculatus.*

Apparently restricted to Lower and Middle Miocene: *Carcharhinus collatus, Carcharoides totuserratus, Hemipristis serra, Galeocerdo aduncus, Carchariolamna* cf. *heroni, Lamna* cf. *crassidens, Carcharodon megalodon.*

Apparently restricted to Pliocene (and later): *Carcharodon carcharias.*

Miocene to Pliocene: *Carcharhinus aculeatus.*

The other species occur during both Eocene and Miocene, and some range into the Pliocene. They raise the presently insoluble problem of whether such forms indeed represent single species.

In comparison with the list of species given by Chapman and Cudmore (1924), some notable absentees are seen for South Australia. *Heterodontus,* represented in Victoria by four species, has not been recorded, and there are fewer myliobatids. There are also fewer Carcharhinid sharks represented, and such species as *Galeocerdo latidens* and *Sphyrna prisca* have not been recognized. These omissions are apparently the result of unfavourable sedimentary environments combined with inadequate collecting in the requisite stratigraphic levels.

The time is not yet ripe to establish zones based on sharks' teeth assemblages as Glikman has done, although a large collection from any one locality would indicate the appropriate Cainozoic epoch. Although many sharks are pelagic, it is doubtful whether their teeth could be accurately used for wider than regional correlation.

## ACKNOWLEDGMENTS

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# EXPLANATION OF PLATES

*(All figures of inner faces except where stated)*

## PLATE 1

Infra Class Orthodonta (all 2 x natural size).

Fig. 1. *"Notidanus" serratissimus* Ag., Blanche Point Marl (F17262).
Fig. 2. *"N."* cf. *serratissimus* Ag., Naracoorte No. 5 Bore, 426 ft. (V34).
Fig. 3. *"Notidanus"*? *serratissimus* Ag., Blanche Point Marl (F17284 and Jenkins collection).
Fig. 4. *Myliobatis* spp., toothplates, articulating surfaces, Naracoorte No. 5 Bore (V41).
Fig. 5. *Myliobatis* sp., caudal spine. Blanche Point Marl (V56).
Fig. 6. *Pristis* cf. *cudmorei* Chap., rostral teeth, Blanche Point Marl (F17285, F17318).
Fig. 7. *Carcharhinus* cf. *collatus* (Eastman), Marion No. 2 Bore. Sturt River Valley (F17279. F17312-F17314).
Fig. 8. *C. aculeatus* (Davis), River Murray Cliffs, probably Morgan (F17270).
Fig. 9. *Hemipristis serra* Ag., Cadell Marl Lens, 4 miles S. of Morgan (F17288).
Fig. 10. a. *Galeocerdo aduncus* Ag., Morgan (F17275). b. *Galeocerdo* sp., locality unknown, possibly near Morgan (F17271).
Fig. 11. *Carcharoides* cf. *totuserratus* Ameghino, Strathalbyn (F17281).

## Plate 2

### *Carcharias maslinensis* sp. nov. (all 2 x natural size)

Figs. 1-4, E. & W.S. bore No. 5, Naracoorte (426 ft.), Knight formation.
Fig. 1. Holotype, inner face (F17260).
Fig. 2. Holotype, posterior profile.
Fig. 3. Paratypes—anteriors (V35).
Fig. 4. Paratypes (V18): a. upper laterals; b. lower laterals.
Fig. 5. Maslin Bay, basal Tortachilla Limestone—crown enamels only: a. upper laterals (F17295-F17300); b. lower laterals (F17301-F17307); c. anteriors (F17289-F17294).
Figs. 6, 7. Anterior teeth, Blanche Point Marl (Carter's Unit 2), Maslin Bay (Brooke and Jenkins collections).
Fig. 8. Anterior tooth, lower Port Willunga Beds (Carter's Unit 3), Aldinga Bay (F17267).

## Plate 3

### (Natural size except where stated)

Figs. 1, 2, 3. *Carcharias macrotus* (Ag.), large specimens, upper and lower anteriors, Blanche Point Marl, Maslin Bay (F17308-F17311, and Jenkins collection).
Figs. 4, 5, 6. *C. macrotus* (Ag.), Peel's Bore (390 ft.) near Robe; Knight Formation (V16, 19).
Fig. 7. *C.* cf. *macrotus* (Ag.), Naracoorte Bore No. 5 (426 ft.) (V49).
Fig. 8. *C.* cf. *macrotus* (Ag.), Peel's Bore (390 ft.) (V53).
Fig. 9. *Carcharias* sp. indet., Naracoorte Bore No. 5 (V32).
Fig. 10. *C. dubius* (Ag.), Peel's Bore, near Robe (V27).
Fig. 11. *C. contortidens* (Ag.), Peel's Bore (V14).
Fig. 12. *C.* cf. *cuspidatus* (Ag.), (?) Blanche Point Marl (F17264).
Fig. 13. *C.* cf. *cuspidatus* (Ag.), Blanche Point Marl, Maslin Bay (Jenkins collection).
Fig. 14. *C.* cf. *rutoti* (Winkler), Blanche Point Marl, Maslin Bay (F17263 and F17265).
Fig. 15. *C. ensiculatus* (Davis), Naracoorte Bore No. 5, x 2 (V36): a. inner face; b. outer face.
Fig. 16. *Carchariolamna* cf. *heroni* Hora, Marion No. 2 Bore, Sturt River Valley, x 2 (F17280).

## Plate 4

### Family Isuridae (all natural size).

Fig. 1. *Lamna obliqua* (Ag.), "Deep Well, Murray Scrub", probably from Eocene Knight Formation equivalents (F17269).
Fig. 2. *L. apiculata* (Ag.), Blanche Point Marl, Maslin Bay and Witton Bluff, Pt. Noarlunga F17261, F17266, and Jenkins collection).
Fig. 3. *L. vincenti* (Winkler), Blanche Point Marl, Maslin Bay (F17286 and Jenkins collection).
Fig. 4. *L.* cf. *crassidens* Ag., Murray Cliffs, probably near Morgan (F17272).
Fig. 5. *Isurus hastalis* (Ag.), Murray Cliffs, probably Cadell Marl Lens near Morgan (F17273).
Fig. 6. *I.* cf. *hastalis* (Ag.), basal Port Willunga Beds, Aldinga Bay (F17268).
Fig. 7. *I. desorii* (Ag.), Strathalbyn, crown enamels only (F17282, F17315).
Fig. 8. *I. retroflexus* (Ag.), upper right lateral tooth, Port Willunga Beds, Reddin's Bore, Gawler River (270 ft.). (Photo by courtesy of J. M. Reddin.)
Fig. 9. *I. retroflexus* (Ag.), anterior teeth, Murray Cliffs, ?near Morgan (F17274): a. inner face; b. profile.
Fig. 10. *Isurus* (?) sp., basal Tortachilla Limestone, Maslin Bay (F17283, F17316, F17317).
Fig. 11. *Carcharodon auriculatus* Ag., Port Willunga Beds, Aldinga Bay (F17276).
Fig. 12. *C. megalodon* Charlesworth, Barbers Quarry, Mt. Gambier (F17277).
Fig. 13. *C. carcharias* (Linn.), Dry Creek Sands, Abattoirs Bore, Pooraka (F17278).
Fig. 14. *Carcharodon* sp. indet., outer face, Blanche Point Marl, Witton Bluff, Port Noarlunga (Jenkins collection).

Plate 2
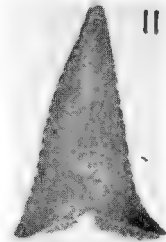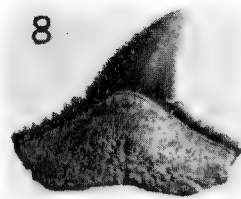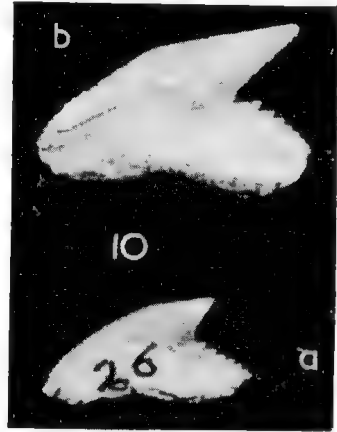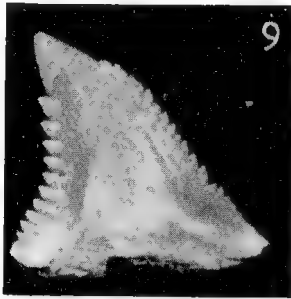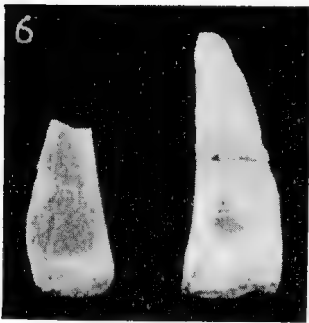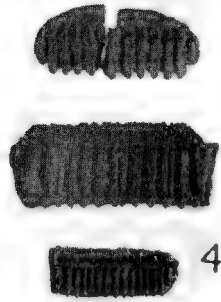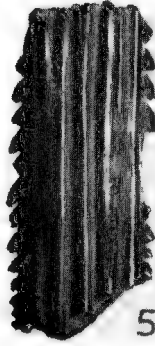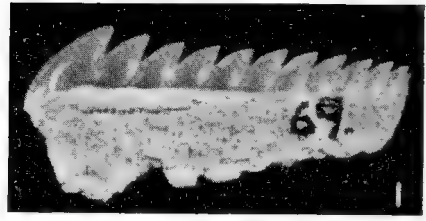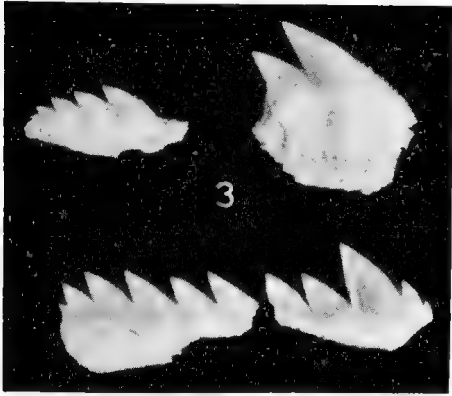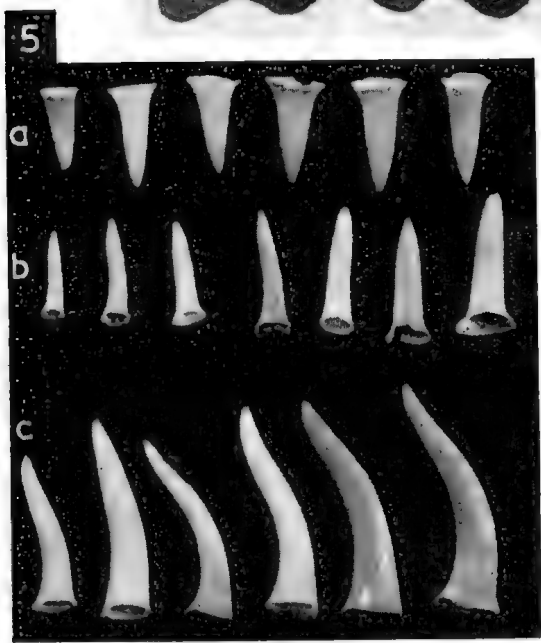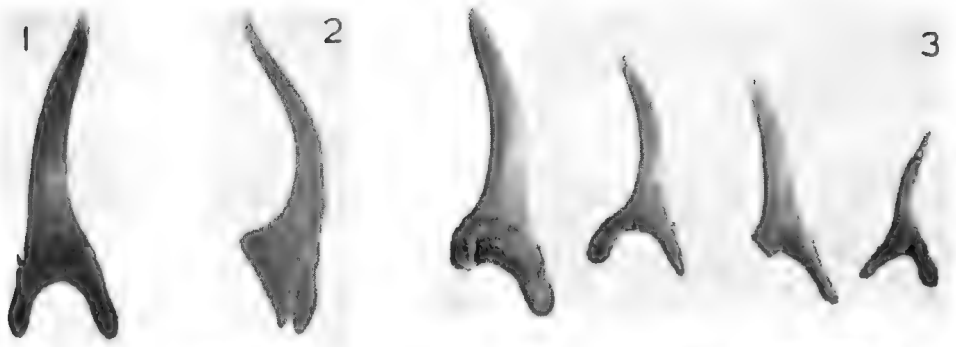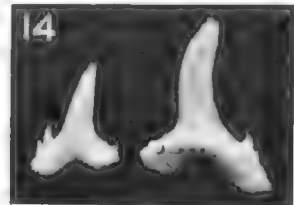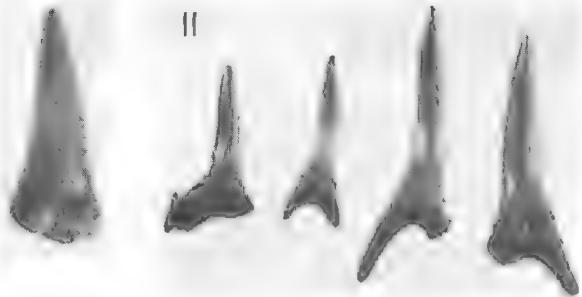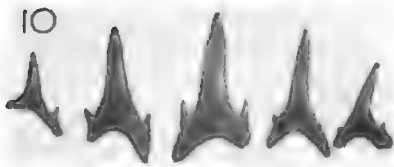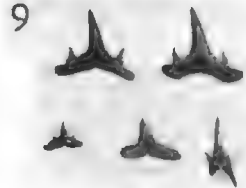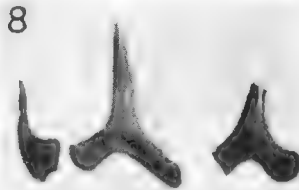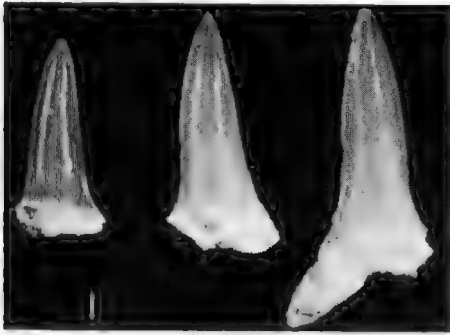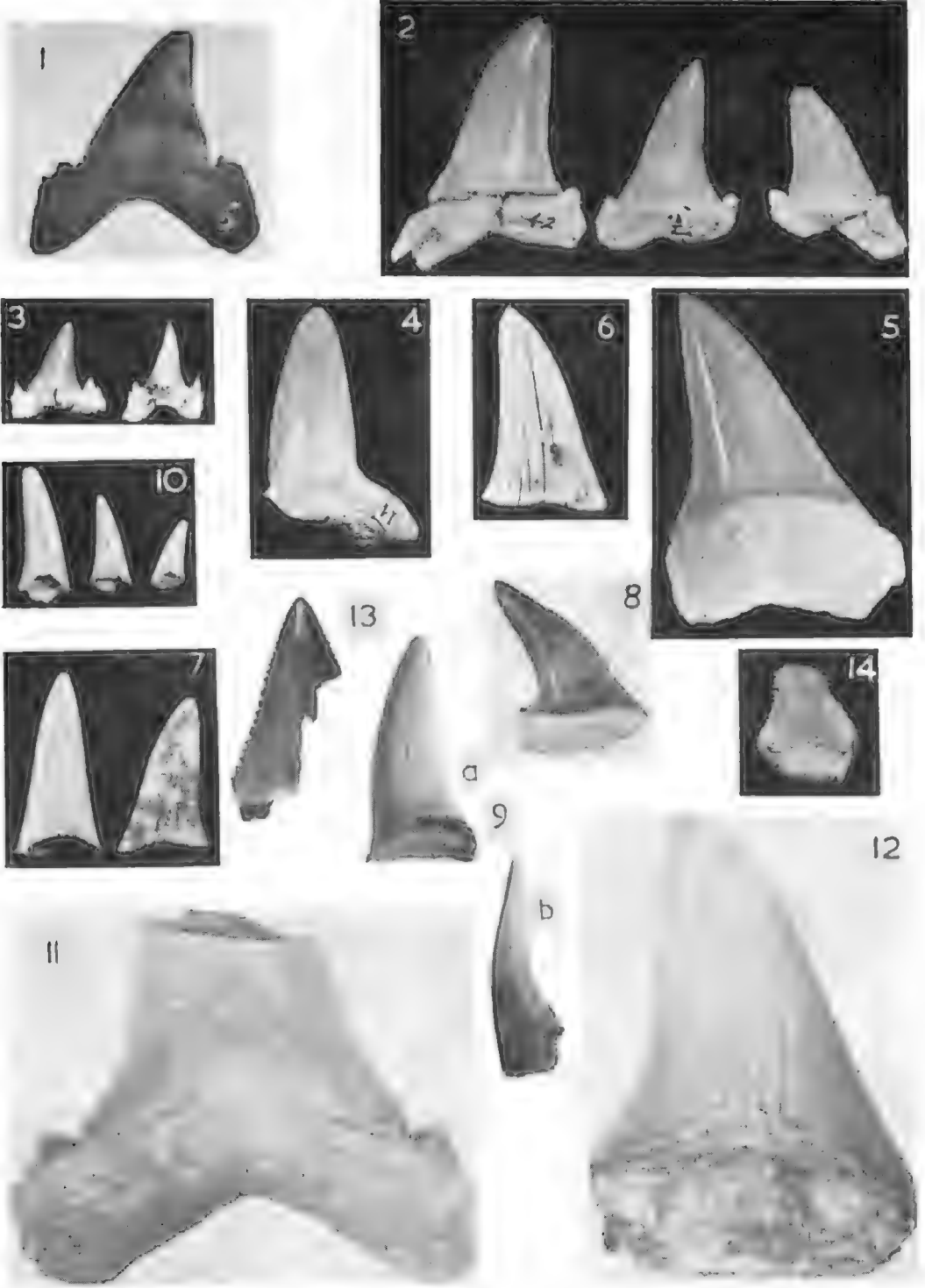
# STRATIGRAPHY OF LATE CAINOZOIC DEPOSITS IN SOUTH AUSTRALIA[1]

*BY J. B. FIRMAN[2]*

## Summary

The stratigraphy of late Cainozoic deposits in southern South Australia is set out for sedimentary basins and adjoining uplands in terms of environment and time.

Middle Tertiary tectonic movements initiated late Cainozoic sedimentation. Tectonic movements at the end of the Pliocene produced a pattern of lineaments, which set limits to the inland penetration of rising seas, and controlled trends of stream courses and lake and continental margins.

The Pliocene-Pleistocene boundary is well defined locally by faunal evidence, and regionally by an erosional break, which separates strongly ferruginized estuarine and fluvio-lacustrine sands from fluvio-lacustrine clays.

The sequence of Pleistocene shallow marine and littoral deposits on the continental margin is subdivided into lower, middle and upper beds. Correlation with inland continental deposits is facilitated by through going soil stratigraphic units containing silcrete, ferricrete and calcrete.

The shift from a cooler, wetter climate of the Pleistocene to a warmer and drier climate in the Recent is recorded inland by extensive dune sheets.

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## INTRODUCTION

This paper sets out the stratigraphy of late Cainozoic deposits in the southern part of South Australia. The study includes the Murray, St. Vincent and Spencer Gulf, West Coast and Eucla Basins and the adjoining uplands. Work has been concentrated on the southern margin of the continent where marine, transitional and continental deposits and related land surfaces occur together. The paper is essentially a study of physical sequences, and is a necessary preliminary to systematic radiometric dating and the study of changes in climate, flora and fauna during the late Cainozoic.

On the stratigraphic table, rock units are organised according to environment and time. The reader seeking detailed information on the identification and description of stratigraphic units and their relationships, is referred to the writers' papers quoted herein. Tabulations in these papers summarize much of the evidence used as a basis for correlation in this paper. Environments shown on the table depend upon different models; geomorphic, sedimentary, geological and palaeontological concepts have been employed at various places. A uniform treatment of environments must await a unified system of classification. Those deposits which show the influence of climatic zonality are emphasized on the table and in the text.

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[1] Published by permission of the Director of Mines, South Australia.
[2] Geological Survey of South Australia.

## LOCALITY MAP — MINOR LOCALITIES

Place names referred to in text and shown on Locality Map by numbers.

1. Avondale Homestead
2. Barossa Valley
3. Blanche Point
4. Blanchetown
5. Bookpurnong
6. Boston Bay
7. Bungunnia Homestead
8. Chowilla
10. Coomandook
11. Coorong Lagoon
12. Fulham
13. Etadunna
14. Dry Creek
15. Hall Bay
16. Hallett Cove
17. Hindmarsh
18. Karoonda
19. Kimba

20. Lake Torrens Graben
22. Loxton
23. Lipson Reach
24. Lyndhurst
25. Maree
26. Marmon Jabuk
27. Millewa
28. Parilla
29. Monoman Creek
30. Moorlands
31. Naracoorte
32. Nildottie
33. Nilpena
34. Maslin Bay
35. Noarlunga-Willunga Basin
36. Padthaway
37. Pinnaroo
38. Peebinga

39. Molineaux, Hundred of
40. Point Labatt
41. Port Augusta
43. Port Wakefield
44. Renmark
45. Ripon, Hundred of
46. Sir Joseph Banks Group
47. Spencer Gulf Graben
48. Swan Reach
49. Tartanga Island
50. Telford Railway Station
51. Yallunda
52. Callana
53. Coffin Bay
54. Luckleys
55. Marino
56. Smart Bluff
57. Coomunga

The study is based on examination of rock sequences revealed by drilling, regional stratigraphy and terrain analysis, and by investigations in support of mineral exploration, hydrology and soft-ground engineering. Although the paper has been prepared with the views of other workers in adjoining areas in mind, no attempt has been made to review their work in detail.

## STRATIGRAPHY AND GEOLOGICAL EVENTS

TERTIARY

*Tectonics and Sedimentation*

The nature and extent of late Cainozoic sediments in South Australia reflects earlier tectonic movements which caused the retreat of the Miocene seas and initiated dominantly clastic deposition throughout the remainder of the Cainozoic. For a summary of early Tertiary tectonic events the reader is referred to Webb (1958).

Sedimentary basins in South Australia contain about 1,000 feet of Tertiary sediments, overlying Permian and Cretaceous rocks resting on a Precambrian basement. Tertiary biostratigraphy has been described for the basins generally by Ludbrook (1958, 1959, 1961 and 1963). The basins, as they occur now, were shaped during the Cainozoic. Within each basin, a very strong trend from Miocene marine through transitional to continental sediments is apparent. Quaternary stratigraphic units are remarkably extensive, and the most important occur in basins on the seaward margin of the State where transitional sequences link the stratigraphic record of the ocean basins and the continents.

*Upland Ferricrete and Sedimentary Equivalents*

Although this paper deals mainly with late Cainozoic stratigraphy, the processes responsible for some of the silcrete and ferricrete so prominently displayed in the late Cainozoic landscape were in operation much earlier. One of the more important events during the Lower Tertiary was the formation of

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[3] Massive vesicular, cellular or concretionary ironstone overlying mottled and pallid zones is termed "laterite". Detailed stratigraphic studies reveal that this classic profile contains layers that have been formed in different ways at different times, the profile being as old as the first weathering of the parent rock. These considerations lead to the use of ferricrete as a non-genetic term for the ironstone in this and other profiles.

NORTHERN      TERRITORY

WESTERN AUSTRALIA

QUEENSLAND

NEW SOUTH WALES

VICTORIA

SOUTHERN    OCEAN

SPENCER GULF

G ST VINCENT

20

47

46

**SCALE**

Miles 0     100     200     300 Miles

Kilometres 0    100    200    300    400 Kilometres

67-387     Del. B.F      J.B.Firman      S.A Department of Mines

ironstone in "laterite"[3] profiles on old land surfaces in the upland areas marginal to the basins. Lower Tertiary ferricrete is recorded by Harris and Oliver (1965) above and below Lower Tertiary sediments in the Barossa Valley. Ferricretes associated with the remnants of a high-level "peneplain" surface in the Mt. Lofty area have been described by Rix and Hutton (1953), Thomson and Horwitz (1961), and by others quoted in Webb (*loc. cit.*) and Wells (1966). The Yallunda Ferricrete of the Lincoln Uplands (Johns, 1961; Firman, 1967) occurs in a similar geomorphic situation to the "peneplain" ferricrete of the Mt. Lofty-Olary and Flinders Ranges.

The sedimentary succession in the Murray Basin has been examined for equivalents of the ferricrete in upland areas: oolitic siderite and "laterite" have been recorded in the Lower Pliocene Bookpurnong Beds; ferruginous beds and cappings are found in the Upper Pliocene Loxton Sands; "ironstone" is recorded within the Upper Pliocene Parilla Sand and ortstein has been mapped at its surface; upper beds of Parilla Sand in the South Australia-Victoria border region are ferruginous and contrast with the non-ferruginous lower beds cropping out in River Murray cliffs. Ferruginisation in Lower Pliocene basin sediments may correlate with the massive ironstone described by Gill (1958) in the Black Rock Member of the Lower Pliocene Sandringham Sands in Victoria. Ferricrete (including ortstein) in Upper Pliocene basin sediments is correlated with ortstein on the eastern slopes of the Mt. Lofty Ranges. Geomorphic evidence shows that these deposits rest upon slopes incised through the "peneplain" ferricretes, and are therefore younger, and sedimentary evidence—notably similar lithology and close proximity to the Parilla Sand of the basin margin—suggests a correlation between ortstein-bearing beds on the eastern slopes of the ranges and the Parilla Sand of the type area in the Murray Basin.

Silcrete has been described mainly from inland areas of South Australia by Wopfner (1960, 1964), Wopfner and Twidale (1967), Stephens (1964), Stewart (1958), and others, but it has also been recorded on Yorke Peninsula

## NOTES ACCOMPANYING THE STRATIGRAPHIC TABLE

*Sedimentary Basins*

A, Murray Basin. B. Mt. Lofty-Olary and Flinders Ranges. C. St. Vincent and Spencer Basins. D. West Coast Basins. E. Eucla Basin.

*Notes*

1. For Pleistocene-Recent deposits, "Neritic" is applied to shallow-water marine environments identified from sedimentary and geomorphic evidence, and ranging from high-energy near-beach situations fronting the open ocean to low-energy near-beach situations within the Gulfs. For Pliocene deposits, "Neritic" includes epineritic shallow water Dry Creek Sands (Glaessner, M. F., and Wade, Mary, 1958) and marine shallow water Bookpurnong Beds (Ludbrook, N. H., 1958 and 1961).
2. Soils are superimposed on the units with which they are associated stratigraphically. Symbols in vertical bars show the time range, horizontal bars show the unit relationship.
3. Coorong lagoon area.
4. Coffin Bay area.
5. Deposits in the River Murray.
6. Port Wakefield.
7. Upper member contains several layers of moderately hard calcrete.
8. Sediments of the St. Vincent Graben.
9. Limestone at the top of Hallett Cove Sandstone at Marino, Hallett Cove, Blanche Point.
10. Sand below limestone (9) at Hallett Cove and Maslin Bay.
11. Sedimentary equivalents of the upland ferricretes on basin margins are shown below this line.
12. Deposits in the Barossa Valley (Example from Rowlands Flat in Harris, W. K., and Olliver, J. G., 1965).
13. Callana and Smart Bluff examples in Forbes, B. G. (1966).
14. Lincoln Uplands.

## LATE CAINOZOIC DEPOSITS IN SOUTH AUSTRALIA --- STRATIGRAPHIC TABLE



| | NERITIC [1] | LITTORAL, LAGOONAL, ESTUARINE | COASTAL AEOLIAN | LACUSTRINE, PALUDAL | FLUVIAL - COLLUVIAL | | INLAND AEOLIAN | SOILS [1] |
|---|---|---|---|---|---|---|---|---|
| | ENVIRONMENT | | | | | | | |
| RECENT | Shelly calcareous silts | Carbonate sediments [?] | SEMAPHORE SAND [c] Shell sand [b,i] | Peat A,B,C,D. Salt crusts | Recent alluvium | Recent colluvium | Recent aeolian sands | Leached sandy A horizons |
| | ? | ? | Volcanic ash at Mount Gambier | Clays and silts in intermontane basins | | Talus and slope deposits on surfaces post Loveday Soil | MOLINEAUX SAND [A] | Soft ropy and columnar masses of calcrete |
| | ST. KILDA FORMATION [c,D] | | | | TARTAN -GAN BEDS [?] | | FULHAM SAND BUNYIP SAND [A] | |
| | | LIPSON FORMATION [c] | | | | | | |
| UPPER | | | Sheets of aeolian shell sand (West Coast) | | POORAKA CLAY [c] TELFORD GRAVEL [B] Upper Member [v] | | WOORINEN FORMATION [A] and equivalents | LOVEDAY SOIL [A] B Horizons of soft nodular and platy calcrete Gypsiferous Soil [B] |
| | | | Sand and sandy clays in solution pipes [A,D] | | MONOMAN FORMATION [?] | | Red-brown sand sheet over calcrete [A,D] | TERRA ROSSA AND RENDZINA BLACK EARTHS RED BROWN EARTHS |
| | | GLANVILLE FORMATION [c] Beach Gravel [c,d] Calcreted shell sand [?] | BRIDGEWATER [?] Upper Member | | TELFORD GRAVEL [B] Lower "Member" [?] | | Loess and silt | Calcrete in BAKARA SOIL [A] |
| PLEISTOCENE | | | | | | | | RIPON CALCRETE [D] |
| MIDDLE | | | FORMATION [A,D] Lower Member | BUNGUNNIA LS. [A] | | | Terrestrial deposits [A,D] | Manganiferous staining |
| | | | | AVONDALE CLAY [B] | | | | Gypsum and gypsiferous clay |
| | | | | BLANCHETOWN CLAY [B] | COOMUNGA FM. | | | Soil horizons of nodular carbonate accumulation [B] |
| | Coquina and calcarenite at base of Bridgewater Formation [D] | | | | | ? | | |
| LOWER | | COOMANDOOK FORMATION [A] Sands at Lochleys [c] | | | HINDMARSH CLAY [c,B] | | | |
| | | Limestone [?] HALLETT COVE SANDSTONE Sand [?] | | CHOWILLA SAND [A] | | | | |
| | | NORWEST BEND FM. [A] Limestone at Fishery Bay [D] | | PARILLA SAND [A] | Talus and slope deposits flanking ranges and bedrock highs | | | Silicified rock surfaces [A] |
| | | DRY CREEK SANDS | | | ? | ? | | Ferricrete |
| PLIOCENE | | | | LOXTON SANDS (Upper bed) [A] | | | | BOSTON BAY SILCRETE |
| | | LOXTON SANDS (Lower bed) [A] | | | | | | |
| | | BOOKPURNONG BEDS | | LOWER PLIOCENE-MIOCENE | | | | |
| TERTIARY (DIFFERENTIATED) | LIMESTONE OF VARIOUS ENVIRONMENTS. Marine GAMBIER LIMESTONE; PATA and MORGAN MANNUM limestone [?] limestone at Myponga, and MELTON LIMESTONE, [?] PORT WILLUNGA BEDS, [b] and NULLARBOR LIMESTONE. [E] | | | Sands and clayey sands [B,12] | | | | Older silcretes |
| | | | | LOWER TERTIARY Shale with leaf impressions in MURNPEOWIE FORMATION [B,13] | Silty and sandy clays [B,12] | | | Older ferricretes (YALLUNDA FERRICRETE of Lincoln Uplands) |

(Crawford, 1965) and near Kapunda (Dickinson and Coates, 1957) and Adelaide (Stewart, *loc. cit.*). Recent investigations on islands of the Sir Joseph Banks Group by the Geological Survey of South Australia and on Eyre Peninsula from Kimba to Boston Bay (Firman, *loc. cit.*) have demonstrated its occurrence over a wide area in the southern part of the State. Fluvial processes have been more active on the southern margin of the continent, and this may account for the erosion of all but a few remnants of silcrete in upland areas and for burial of silcrete-bearing sediments on the basin margins. The occurrence of silcrete south of the arid zone demonstrates that silcrete formation is not restricted to that zone. Other considerations, notably geologic age, the need for a high water table favouring silica accumulation, and the presence of extensive ferruginous mottling in associated beds, favour a wetter climate than the present.

The approximate stratigraphic position of a ?Lower Tertiary silcrete has been shown at the base of the stratigraphic table following Forbes (1966). The stratigraphic position of the Boston Bay Silcrete is uncertain, but the unit is placed in the late Tertiary because of its position in the landscape and its relationship to younger deposits (Firman, *loc. cit.*).

The silicified cap on the eroded surface of Parilla Sand in the Murray Basin is placed in the Pliocene on the table, but it could equally well be a Pleistocene feature. The land surface at the time of silicification is termed the Karoonda Surface (Firman, 1966a).

In South Australia, clastic continental equivalents of late Tertiary marine sediments have a distinctive lithology and configuration. Their most characteristic features are ferruginisation and the presence of extensive developments of ferricrete. These features are not found in younger deposits of known Quaternary age.

## QUATERNARY
### *Late Pliocene-Pleistocene Tectonics*

Faulting occurred throughout the Tertiary and, by the close of the late Pliocene, a well-defined pattern of lineaments, including faults and major joints, had been developed. Some lineaments parallel older faults and have throws up to 200 feet, others are probably major joints. On photo-mozaics of the basin areas the fractures usually occur as lineaments trending roughly northwest and northeast. The fractures occur in several sets and their intersection forms rhomboid blocks. At this time, the inland side of the basins was upwarped and the seaward margin downwarped; the Mt. Lofty, Olary and Flinders Ranges were further uplifted and the extent of the sedimentary basins was reduced; limits were set to the inland penetration of rising seas and the trend of river courses and of lake and continental margins was established. The pattern thus controls the tectonic and geomorphic framework of Quaternary sedimentation.

### *Pleistocene*[1]

#### PLIOCENE-PLEISTOCENE BOUNDARY

A long period of erosion and sub-aerial weathering at the end of the Tertiary and the beginning of the Quaternary intervenes between a time of extensive quartz sand deposition in the Pliocene and a time of extensive clay deposition

[1] The South Australian sequence has been subdivided so that the Middle Pleistocene contains the Bridgewater Formation and associated calcretes. Sedimentary evidence suggests a short time-span for the Upper Pleistocene and a long time-span for the Lower Pleistocene when compared to the Middle Pleistocene.

in the Pleistocene. The period was interrupted locally by tectonic movements (see Twidale *et al.*, 1967).

The sands at Lockleys in the St. Vincents Basin that underlie the Hindmarsh Clay are placed in the Calabrian Stage at the base of the Pleistocene by Ludbrook (1963). The Pliocene-Pleistocene boundary has therefore been placed between the sands at Lockleys and the underlying Pliocene Dry Creek Sands. This same break in the sequence has been found in the Hallett Cove Sandstone, south of Adelaide, where Pleistocene fossiliferous limestone overlies a lower bed of sand which, according to Ludbrook (pers. comm.), contains a fauna equivalent to the Pliocene Yatalan fauna in the type section (see Twidale, Daily and Firman, 1967). In other sedimentary basins the Pliocene-Pleistocene boundary has been supposed to lie directly below the Pleistocene mottled clay sequence (Hindmarsh Clay and equivalents), but the evidence from Lockleys in St. Vincents Basin suggests that the boundary may lie deeper in the sequence in other basins also (Firman, 1965a).

On the south side of the Murray Basin on the Padthaway Archipelago, the Coomandook Formation overlies the Parilla Sand which is equivalent to the Dry Creek Sands, and is in turn overlain by the wedge of aeolian Bridgewater Formation. The seas in which this unit was deposited, penetrated inland as far as the Marmon-Jabuk scarp and the extension of a southeast trend to Naracoorte. No sedimentary evidence exists for greater inland penetration of any later Pleistocene high sea.

Although Tate (1877) refers to *debris* at Third Creek near Adelaide ". . . attributed to the action of glaciers", South Australia appears to lie outside the area of Pleistocene glaciation. Periglacial conditions may be indicated by late Pleistocene *Gilgai* soils, which resemble patterned ground and have shrink-and-swell structures that appear to be fossil, and by other structures in gravels near Peebinga and in cemented loess near Moorlands that may be due to frost-heave.

## CONTINENTAL AQUEOUS SEDIMENTATION

Fluvial and lacustrine deposition now occurred over a wide area in the southern Australian lowlands. In tectonic depressions flanking the Mt. Lofty-Olary and Flinders Ranges, such as the St. Vincents Graben, Spencers Gulf and Lake Torrens Graben, sequences up to 400 feet thick of irregularly bedded sandy clay with abundant sand and gravel lenses were laid down. The Hindmarsh Clay in the St. Vincents Graben is typical of the thick sequences and is comparable to the Shepparton Formation described by Lawrence (1966) in the Riverine Plains of Victoria. In shallow basins, sequences about 50 feet thick of regularly bedded sandy clay with a few thin beds of sand were deposited. The Blanchetown Clay in the Murray Basin, the Avondale Clay in basins adjoining the northern Flinders Ranges and the Ochre Cove Beds in the Noarlunga-Willunga Basin (Ward, 1965) are representative of the thin sequences. *Diprotodon* (Howchin, 1918) and *Macropus* have been recorded from these deposits.

The widespread occurrence of the units suggests the transportation of large amounts of fine clastics during a pluvial climate. Formation of gypsiferous evaporites and termination of clastic deposition marks a drier climate phase at the end of this time.

Thin dolomitic micrites (Bungunnia Limestone of the Murray Basin, Nilpena Limestone east of the Torrens Graben and on the west flank of the

Flinders Ranges) were laid down. The Bungunnia Limestone was mentioned
in Tate, Prof. Ralph (1885), who described "Travertine cover of thin-bedded
sandy limestone (over) red and blue clay" (Blanchetown Clay) as long ago as
1885. A "Cypridiferous limestone" was collected from the Victorian Mallee in
1912 and matched with other limestones, notably a *Diprotodon*-bearing lime-
stone from near Geelong, by Chapman (Chapman, Frederick, 1936). In the
Murray Basin, the extent of the Bungunnia Limestone marker defines the lake
system, called Lake Bungunnia in Firman (1965b), which contains the Blanche-
town Clay. The position of the limestone high in the Murray River cliffs 50
to 100 feet above a river graded to a modern higher sea-level, suggests a terrain
with less local relief and a lower seaward gradient than at present.

The position of the Bungunnia Limestone in the rock stratigraphic sequence
outlined on the table is reliably established. Other similar limestones have not
yet been placed in sequence. Reconnaissance traverses suggest that a sequential
arrangement of Pleistocene freshwater limestones exists; this would begin inland
with the Bungunnia Limestone and extend south through younger freshwater
limestones of the south-east (Blackburn, Bond, and Clarke, 1967) to modern
carbonate sediments described by Mawson (1929) and by Alderman (1964)
in the Coorong lagoon adjoining the Southern Ocean. The Bungunnia Lime-
stone-Blanchetown Clay sequence is correlated with a limestone[5]-clay sequence
(Forbes, *loc. cit.*) in the Maree-Lake Callabonna area which includes the
Avondale Clay of Firman (1967). The similarity of deposits suggests that the
climate during deposition of Bungunnia Limestone hundreds of miles inland
of the modern coast may have been similar, in some respects, to that prevailing
today in the lower south-east adjoining the Southern Ocean.

### AEOLIAN DEPOSITION IN THE COASTAL ZONE

After the withdrawal of the sea in which the Coomandook Formation was
laid down, the lower member of the Bridgewater Formation was deposited along
the southern coastal margin. Bridgewater Formation was defined in Victoria
and contains "Calcareous dunes and dune limestones" (Boutakoff, 1963). On
the southern edge of the Eucla Basin the lower aeolian member abuts directly
against a fossil cliff cut in Nullabor Limestone; on the west coast the lower
member lies on a steeply rising shoreline; in the south-east, the few known
occurrences of the lower member are scattered across the Padthaway Archi-
pelago; in the St. Vincent and Spencer Basins the formation lies across the
entrance to Spencer Gulf and Gulf St. Vincent. Within the Gulfs continental
aqueous sedimentation appears to dominate throughout the Pleistocene; Tindale
(1961)[6] refers to ". . . Late Pleistocene time, when St. Vincent Gulf was a great
alluvial plain, extending down towards Kangaroo Island". A similar situation
throughout the Pleistocene implies a delicate balance between tectonics and
sedimentation and sets a low limit to Pleistocene high sea-levels.

### PLEISTOCENE GRAVELS

Within the sedimentary basins a period of erosion is inferred from calcreted
deposits on fault-line scarps and erosion surfaces. In the Murray Basin, the
most prominent markers are pre-calcrete stream patterns in the Pinnaroo-

[5] Not to be confused with limestone of the Oligocene Etadunna Formation (Stirton,
R. A., Tedford, R. H., and Miller, A. H., 1961).
[6] Tindale, N. B. (1961): Advent of Man in Australia. Symposium on Geochronology
and Land Surfaces in relation to Soils in Australia. Organised by the Australian Academy
of Science.

Karoonda area (Firman, 1966b), and calcreted granule conglomerate derived from Bungunnia Limestone; in the St. Vincent-Spencer Gulfs area deep incision is indicated by pre-calcrete erosion surfaces cut into Pleistocene mottled clays (Firman, 1965a).

Extensive deposits of gravel occur in outwash fans flanking the Mt. Lofty-Olary and Flinders Ranges. The main unit within the deposits was named Telford Gravel in Firman (1967). The unit appears to form a significant part of the debris mantle described by Twidale (1967). Deposition of the gravel began prior to formation of calcrete. The unit overlies the Nilpena Limestone, which is probably the Bungunnia Limestone equivalent in the Beltana area (Leeson, 1966)[7]. The gravel is better preserved and better developed inland on the flanks of the Northern Flinders Ranges than it is on the flanks of the Mt. Lofty-Olary Ranges to the south. The increased thickness and extent may be explained by increased run-off due to greater tectonic uplift in the Northern Flinders Ranges in a wet phase of the climatic regime prevailing at the time.

The coarse grain of the clastics and their spatial relations suggest a change in base level as a cause of increased erosion: a major withdrawal of the Pleistocene sea is therefore postulated. Confirmatory evidence is found in younger deposits described later.

## Ripon Calcrete and the Ripon Surface

The Ripon Calcrete is an unusual deposit which is very well developed near Hall Bay on the West Coast. Its formation requires the following events: Movement by wind of calcareous silt released from weathering profiles, drying lakes and the exposed continental shelf to form a thin but extensive blanket of loess on the landscape; development of soil carbonate horizons followed by erosion, brecciation of the carbonate horizons and recementation; repitition of the process and formation of nodular carbonate accumulations interbedded with cemented clastic material. This mixed deposit of thoroughly cemented soil and sedimentary material has been named the Ripon Calcrete. It is up to thirty feet thick in places, and forms an extensive but thinner cuirass inland and on the southern continental margin. The surface below which carbonate accumulation occurred prior to renewal of aeolian sedimentation is termed the Ripon Surface.

## Bridgewater Formation — Upper Member

A return of the sea led to renewal of aeolian sedimentation in the zone where the lower member of the Bridgewater Formation had previously been deposited. As a consequence, the Ripon Calcrete separates the upper and lower members of the Bridgewater Formation and has some of the characteristics of an intraformational breccia.

The upper member contains horizons of moderately hard calcrete separated by lenses of weakly cemented aeolian calcarenite or non-cemented aeolian shell sand. The random arrangement of the carbonate layers suggests that conditions favourable for the formation of the layers prevailed throughout the time of formation of the upper member in the Bridgewater Formation, and that the process was interrupted near the coast by irregular aeolian sedimentation. Dune shapes in the upper member are well preserved.

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[7] Leeson, B. (1966). Explanatory Notes: The Geology of the Beltana 1-mile Military Sheet. Geol. Survey of S.A. Rept. Book.

## THE BAKARA SOIL

Inland, beyond the limits of marine ingressions, the Bridgewater Formation sediments are absent and the calcrete layers coalesce to form a vertically continuos zone of soil carbonate accumulation, in many places with Ripon Calcrete at the base. Soil profiles that include this calcrete zone are called the Bakara Soil (Firman, 1963a and 1964). The surface below which carbonate accumulation occurred in the Murray Basin is called the Nildottie Surface. This surface is re-named the Bakara Surface herein to cover both inland and coastal situations in southern Australia.

The original A horizons of the Bakara Soil were later stripped and the exposed calcrete was strongly indurated. Solution channels were then developed and these were infilled with sands and sandy clays. This sequence of events suggests that the sands and sandy clays in solution channels was formed much later than the calcrete. In some places a red-brown sand is found above the calcrete and in solution channels. This forms the upper part of a soil profile described as "terra rossa" in Stephens, *et al.* (1941) and is comparable with "fossil soils, mostly of the terra rossa type" in Fairbridge R. W. and Teichert, Carl, (1952). The red-brown sands are comparable to reddened fossil soils within the Bridgewater Formation. This and the proximity of the sand to the upper calcrete in Pleistocene Bakara Soil, suggests that the Pleistocene-Recent boundary could be placed above the sand. There are good reasons, howver, for placing the boundary even higher in the sequence.

## GLANVILLE FORMATION

A marine ingression during the last interglacial inundated the coastal zone (Firman, 1963b and 1966c). Marls with a fauna including *Anadara trapezia* (Sprigg, 1954) were deposited within the gulfs and in low areas between dunes of the Bridgewater Formation[8]. The sea penetrated as far up Spencer Gulf as Port Augusta—the first marine ingression recorded in the Tertiary-Quaternary sequence in that area (Firman, 1965a). Within Gulf St. Vincent, the high sea eroded the Ripon Calcrete near Port Wakefield to form a beach gravel that lies about 20 feet above modern sea-level.

A lime-cemented crust was formed on the Glanville Formation (Howchin, 1888). A similar lime-cemented crust occurs on the floor of Gulf St. Vincent, which suggests a major regression of the sea in which Glanville Formation was deposited. The lime-cemented crust is correlated with calcrete in Bakara Soil (Firman, 1963b and 1965a).

## LOVEDAY SOIL

The low sea at the end of Bakara Soil time led to accelerated erosion: Near the modern coast, aeolianite was re-worked. Inland, Bakara Soil profiles were eroded. Carbonate silt released from the loess was incorporated in dune sheets near the coast, in quartz sand of the Woorinen Formation[9] inland and in colluvial

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[8] By courtesy of G. van Andel of Scripps Institution of Oceanography, shell from the Glanville Formation at Port Adelaide has been C-14 dated at greater than 45,000 years. The absolute age is said to be within ten of thousands of years of the age given (Heath, G. R., pers. comm.).

[9] Woorinen Formation was defined in Victoria by Lawrence, C. R. (1966). Only the lower three of the five units recognised by Lawrence are mapped as Woorinen Formation in South Australia.

and alluvial formations such as the Pooraka Clay. The soil developed by accumulation of platy and nodular carbonate accretions in these deposits is termed Loveday Soil (Firman, 1966a). Reconnaissance traverses suggest that the Widgellie Parna of the Riverine Plains (Butler, 1956) may correlate with Loveday Soil. This accession of carbonate silt is the last in the record and is comparable to loess in earlier Pleistocene deposits. The extensive sheet of shell sand mixed with this carbonate silt on the West Coast most closely resembles earlier Pleistocene aeolian deposits. For these reasons the deposits containing Loveday Soil are placed in the late Pleistocene.

*Recent*

## THE FLANDRIAN TRANSGRESSION

The post-glacial Flandrian transgression is recorded in deposits below modern sea-level, such as the Lipson and St. Kilda formations (Firman, 1966c), in marine cliffs and beach deposits now stranded (Firman and Chugg, 1963), and in drowned topographic features marginal to the stable shield in the West Coast area.

Beach ridges of coarse shelly sand form the youngest member of the St. Kilda Formation[10]. These deposits are now stranded inland up to about ten feet above modern sea-level. Together with stranded marine cliffs, the position of the deposits marks a regression of the sea. The formation of deep off-shore channels marks a low stand of the sea, perhaps slightly below modern sea-level. These features are well developed at various places along the South Australian coast, near Lake Macdonnell for example, where they connect an older and higher littoral environment with the modern coast.

## DUNE FORMATION

Aeolian deposition began in the Pleistocene with the Woorinen Formation, and continued into the Recent when the Fulham Molineaux and Recent formations were deposited.

Each stage of dune formation has a characteristic colour; Woorinen Formation is pale red-brown, Bunyip Sand is red-brown, Molineaux Sand is yellow and Recent sand is pale grey. Except for Woorinen Formation, in which the paler colour reflects the admixture of carbonate silt with quartz sand, the shift in colour is due to successive removal of iron-oxide coatings on the quartz sand. This is paralleled by a decrease in the amount of carbonate in alluvial horizons within the dunes.

Although dune building was initiated at four separate times, minor re-working of older deposits is apparent; Two phases of development occur within the Molineaux Sand, and all the deposits are being actively re-worked at the present time in some places. Despite this minor re-working, the dune sands retain their colour. This leads to the conclusion that the initiation of each major stage of dune formation reflects an important change in environmental factors. The widespread distribution of each formation suggests that change in climate itself is involved.

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[10] Shell from the base of the beach ridges in the Port Wakefield area has been C-14 dated at 3,500 to 4,200 years B.P. by Scripps Oceanographic Institute (Heath, G. R., pers. comm.).

## RIVERINE DEPOSITS[1] AND OTHER RECENT SEDIMENTS

Recent sediments in the Murray River tract near Chowilla include deposits of an older meander belt, a younger meander belt and bed deposits of present river channels, which are now about 50 feet above modern sea-level. These together form a younger valley fill overlying the Monoman Formation. The Tartangan Beds of Hale and Tindale (1930) near Swan Reach are tentatively correlated with sediments of the older meander belt. The "Upper Beds" of Hale and Tindale (loc. cit.) are tentatively correlated with sediments of the younger meander belt in the Chowilla area.

During the time of dune building marked by Woorinen Formation, tributary streams were incised through thin surficial deposits into the gypsiferous beds at the top of the Blanchetown Clay. When the tributary streams dried, gypsum precipitated on the floors of valley lakes was blown by the wind to form lunettes and dune sands that interfinger with Woorinen Formation. Gypsiferous sediments were also deposited at the top of the upper valley fill.

Modern deposits are shelly calcareous silts of the neritic zone, carbonate sediments in the Coorong lagoon, quartz and shell sand of the coastal aeolian tract, peat of the swamps, saline crusts of the ephemeral lakes, sands and gravels of the present stream channels and thin light grey sand sheets on hill slopes and veneering inland dunes.

## ACKNOWLEDGMENTS

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# EXPLANATION OF PLATE

## PLATE 1

Fig. 1. Murray Basin. Boundary Point near Millewa: (1) Loveday Soil. (2) Bungunnia Limestone. (3) Blanchetown Clay, upper and lower members. (4) Silicified ferruginous sandstone at top of Parilla Sand. (5) Talus. (6) Parilla Sand.

Fig. 2. St. Vincent Basin. Blanche Point in the Willunga-Noarlunga sub-basin area: (1) Ochre Cove Beds equivalent to the Blanchetown Clay. (2) Hallett Cove Sandstone, upper bed of ?Pleistocene limestone overlying a lower bed of Pliocene sand. (3) Blanche Point Marls.

Fig. 3. West Coast Basins Area: (1) Ripon Calcrete. (2) Bridgewater Formation, lower member. (3) Reddened soil horizons. (4) Talus.

Fig. 4. Murray Basin. Renmark: (1) Recent soil. (2) Ball and sheet calcrete. (3) Bungunnia Limestone. Hammer marks top.
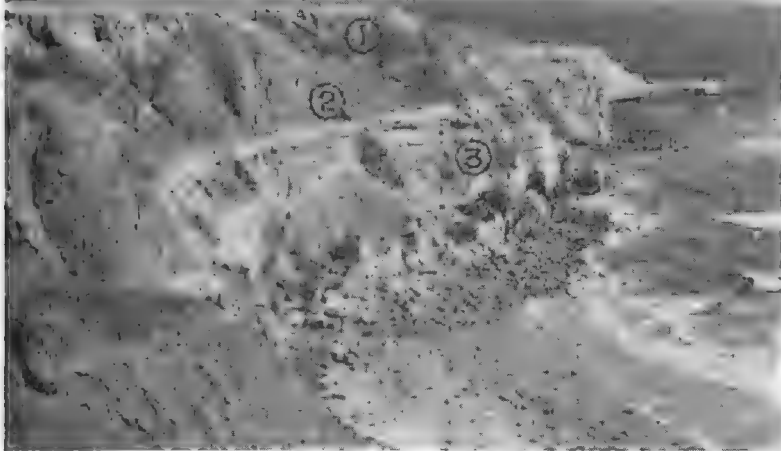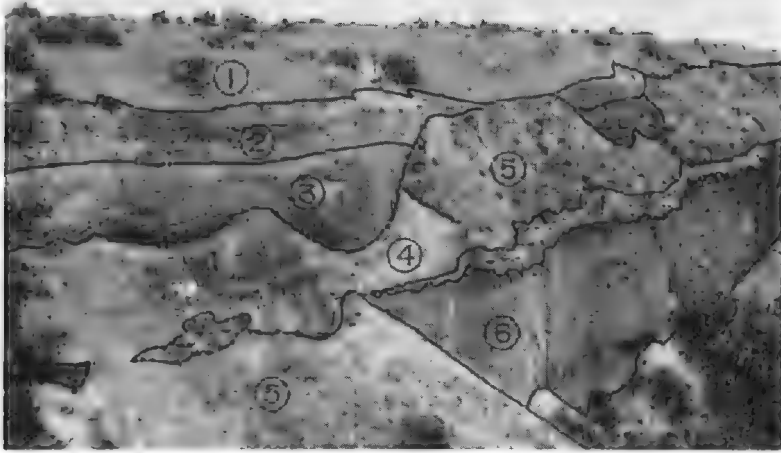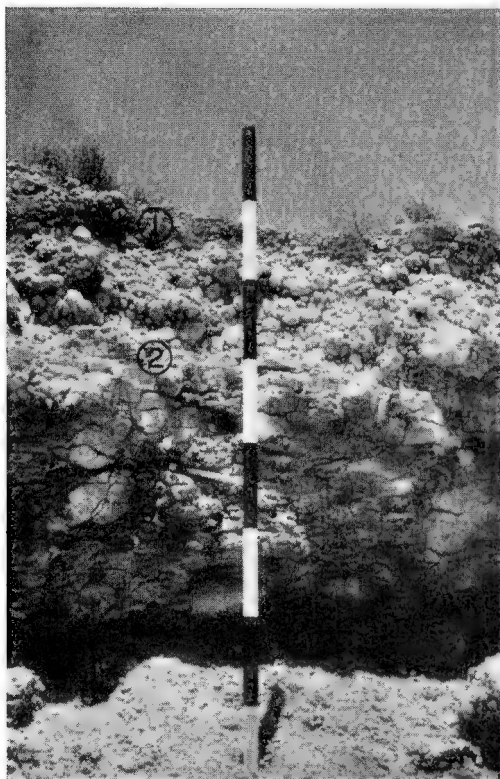
# THE INFLUENCE OF ENVIRONMENT ON TWO SPECIES OF LAND-SNAILS IN SOUTH AUSTRALIA

## BY D. E. POMEROY*

### Summary

*Helicella virgata* and *H. neglecta* are the most widespread of a number of species of exotic land-snails in South Australia. An analysis of their distribution and abundance by multiple linear regressions showed that the presence of organic matter in the soil was most important for *H. virgata* (it could not be tested for *H. neglecta*), and that there was a strong correlation between the availability of calcium and the numbers of both species. The availability of moisture was significant too, but the number of hot days in summer was markedly not so. The effects of land use, proximity to man, and type of vegetation were of relatively minor importance. The method gave satisfactory results, and might well be applied to other studies of distribution and abundance of animals.

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by D. E. Pomeroy[*]

[Read 12 October 1967]

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*Helicella virgata* and *H. neglecta* are the most widespread of a number of species of exotic land-snails in South Australia. An analysis of their distribution and abundance by multiple linear regressions showed that the presence of organic matter in the soil was most important for *H. virgata* (it could not be tested for *H. neglecta*), and that there was a strong correlation between the availability of calcium and the numbers of both species. The availability of moisture was significant too, but the number of hot days in summer was markedly not so. The effects of land use, proximity to man, and type of vegetation were of relatively minor importance. The method gave satisfactory results, and might well be applied to other studies of distribution and abundance of animals.

## INTRODUCTION AND METHODS

The family Helicidae includes several species of snails which have become established in Australia since the end of the nineteenth century. Of these, *Helicella virgata* (da Costa) is now widespread in South Australia, whilst *H. neglecta* (Draparnaud), *Cochlicella acuta* (Müller), *C. ventrosa* (Ferussac), *Helix aspersa* (Müller) and *Theba pisana* (Müller) are also abundant in some localities, and several other species are present in limited areas. Pomeroy and Laws (1967) described the distribution of these snails in South Australia, and pointed out that *H. virgata* and *H. neglecta* had ranges which were almost mutually exclusive, and that most of the localities where they occurred were inside the agricultural areas of the State. They were thus confined to places having an average annual rainfall of 250 mm or more.

During the summers of 1963-4 and 1964-5, a detailed survey was made of the distribution of these two species of *Helicella* on the Adelaide Plains, Mount Lofty Ranges, Lower and Mid North, Yorke Peninsula and Lower Murray. Some desert country of the Upper Murray was also included. Snails are easily seen in summer, when they aestivate conspicuously on fence-posts and similar places. The margins of paddocks are favourable areas for *Helicella*, because they are undisturbed there by cultivation. As most roads are bounded by paddocks on both sides, roadsides are convenient as well as representative places for finding snails. A route was planned which traversed the survey area in a series of parallel courses at intervals of about eight kilometres. When following this predetermined route, stops were made at places exactly eight kilometres apart by road. However, because the roads were not straight, the sampling-points could be considered as random with respect to roadside colonies of snails; the element of randomness is essential to the statistical analysis which follows.

Qualitative aspects of distribution were discussed by Pomeroy and Laws (1967), who publish maps of the distribution of the snails introduced into South

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Australia. The present paper is concerned with a quantitative analysis of the results, and their interpretation in terms of the snails' distribution and abundance. At each sampling-point, the density of the population of snails was recorded on an exponential scale, namely:

0 — if there were none
1 — if there were less than $2/m^2$
2 — if there were between 2 and $20/m^2$
3 — if there were between 20 and $200/m^2$
4 — if there were more than $200/m^2$

The decision as to which category was appropriate for a particular sampling-point was made by inspecting at least 20 m of roadside (the choice as to side of road being made randomly). Vegetation, aspect, and land-use were recorded at each of the 415 sampling-points, as well as the numbers of snails (however, snails were absent from more than half of the places examined).

## ASSESSMENT OF ENVIRONMENTAL INFLUENCES

Snails were mostly absent from places which had native vegetation alongside the road, but elsewhere there seemed to be little or no correlation between the numbers of snails and the type of vegetation or crop. However, six other components of the snails' environment were thought likely to be important, and each could be assessed quantitatively. These six components formed the six independent varieties in a regression analysis; they were as follows.

(A) *Calcium* — Many snails are known to be calciphobes to a greater or lesser degree, including *H. virgata* and *H. neglecta* in their native ranges (Taylor, 1894-1921). The available calcium-content of the soil was therefore one factor to consider. No direct measurements were made, but the results of detailed analyses made by the C.S.I.R.O. Division of Soils, and others, were available. These were studied with respect to measurements of the surface layers of the soil, the place from which calcium is most likely to be obtained by snails. Numerical data were not available for all districts, but the calcium-content of soils tends to be fairly uniform over the whole of the area covered by a particular type of soil.

Using the map of the soils of South Australia published by Northcote (1960) together with other analyses, it was possible to estimate the amounts of calcium in many of the forty or so soils which occur in the survey area. For the remainder, I was able to call upon Mr. Northcote's considerable experience, to estimate the probable calcium-content of those soils for which detailed information was not available. The result was that for each observation point a rating of 0, 1, 2, 3 or 4 could be given, indicating the probable level of exchangeable-calcium at that point. (The approximate range of values covered by the ratings is from 0·2 to 40 mille-equivalents of exchangeable-calcium, per 100g of soil; the ratings were intended to be linearly arranged within that range.)

(B) *Organic matter* — *H. virgata* is primarily a grazing animal, and is dependent on dead and decaying plant material as its major source of food (Pomeroy, 1966). So far as is known, the food requirements of *H. neglecta* are similar. The best measure relating to food, and available for the whole area surveyed, was the amount of organic matter in the soil. The estimated values for the surface layers of the soil (where snails feed) ranged from 0 to 4·5% as measured by the method of Walkley and Black (1934) for organic carbon. For purposes of analysis, these values were reduced to ratings of 0, 1, 2 or 3.

(C) *Temperature* — The native ranges of both species of *Helicella* include southern Europe, and it seems likely that this was where they originated; but there are parts of inland South Australia where the temperatures in summer exceed those of Europe. To test the hypothesis that long periods of high temperatures might limit the distribution and abundance of *Helicella*, a variable known as "temperature" was defined as the average number of days per year when the maximum shade temperature exceeded 35°C. Within the area covered by the survey described here, the range was from five to forty days.

(D) *Moisture* — Snails feed only when the surface of the soil is moist. Soil moisture is determined by a complex array of factors, but ecologists in Australia have often found that the ratio of precipitation to evaporation (P/E) is a useful guide. The number of months for which this ratio exceeds 0·5 is also a measure of the growing season for plants. Davidson (1935) published a series of maps, one for each month of the year, showing the places where this value was exceeded. From these, the number of months when (P/E) was greater than 0·5 could be calculated for each place visited. There was a range of from four to nine.

(E) *Land Use* — *Helicella* is rare in native scrub, and uncommon on permanent pasture. The highest densities seem to be in the well cultivated districts dominated by the growing of cereals. A hypothesis which would explain such observations is this: cultivation tends to increase the amounts of nutrients available at the surface, where they may be directly available to snails, or may promote conditions favourable to the production of food for snails. As many of the snails feed in the paddock rather than along the roadside, increasing cultivation should lead to an increase in the numbers of snails. To test this, the amount of cultivation was estimated as the probable number of times when the land would be cultivated in a ten-year period. For example, native scrub and unimproved pastures both rate as zero, cereal paddocks as three to six (depending on the area) and market gardens gained the highest rating, fifteen.

(F) *Proximity-to-man* — Pomeroy and Laws (1967) found that man's activities assisted the spread of *Helicella* in South Australia, in that the snails were carried along main roads and railways, presumably mostly by agricultural traffic. Therefore it seemed desirable to discover whether the abundance of snails at a particular place was related to its distance from the nearest township, railway siding, or main road. These distances were measured for each sampling-point; they varied from 0 to 130 km.

The names and most important properties of the varieties to be tested are summarised in Table 1.

## ANALYSIS OF DATA

Multiple linear regressions were chosen as suitable models for the analyses, each species being treated separately. Not all of the variates were normally distributed, and only variates C, E and F were continuous, but for *H. virgata* (where $n = 364$) both of these departures are covered, in part at least, by the central limit theorem. The same applies to *H. neglecta* (where $n = 51$) but to a lesser extent. The linearity of the independent variates is assumed in the hypotheses which were being tested. None of the independent variates was highly correlated with any of the others.

Analysis by multiple linear regression yields several useful statistics. Each independent variate has a corresponding coefficient, whose departure from zero provides a test of significance. The probability that the regression as a whole

TABLE 1

Summary of the components of the environments of the snails *Helicella virgata* and *H. neglecta*
which form the variates for the analysis shown in Table 2.

| Variate | | Units of Measurement |
|---|---|---|
| Dependent variate: No. of snails | | Arbitrary log-scale: 0, 1, 2, 3, 4 |
| Independent variates | A: Calcium | Arbitrary scale: 0, 1, 2, 3, 4 |
| | B: Organic matter | Arbitrary scale: 0, 1, 2, 3 |
| | C: Temperature | Estimated no. of days/year when shade temperature above 35°C. |
| | D: Moisture | Estimated no. of months/year when P/E exceeded 0·5 |
| | E: Land-use | Estimated no. of times/10 years when land cultivated |
| | F: Proximity to man | Distance from nearest township, railway-siding, or main road, in km. |

is significant—i.e. that the regression plane is not horizontal—can also be found.
The former test yields the statistic $t$, and the latter gives the variance ratio $F$.
The values of these statistics, and the likelihood of them having arisen by chance,
are given in Table 2. It will be noticed that not all of the variates were included
in the final analysis shown in the table. Inclusion of variate B (organic matter)
for *H. neglecta* was impossible because its rating was constant throughout the
range. Other variates (C for both species, and E for *H. virgata*) were excluded
because when tested they were clearly non-significant. Their omission increased
the value for the multiple correlation coefficient, $R$.

TABLE 2

The influence of several factors upon the distribution and abundance of *H. virgata* and *H. neglecta*:
results of two multiple linear regressions.

| Variate | H. virgata | | H. neglecta | |
|---|---|---|---|---|
| | Value of t | P* | Value of t | P* |
| A. Calcium | 2·61 | <0·01 | 2·99 | <0·01 |
| B. Organic matter | 4·71 | <<0·001 | — | |
| D. Moisture | 2·30 | <0·05 | 1·89 | 0·05<P<0·1 |
| E. Land-use | — | — | 1·56 | 0·1 <P<0·2 |
| F. Proximity-to-man | 1·88 | 0·05<P<0·1 | 0·93† | 0·3 <P<0·4 |
| Test of regression as a whole | $F_{(4, 259)} = 9·17$; P<<0·001 | | $F_{(4, 46)} = 3·46$; P<0·02 | |

*Probability of calculated value arising by chance alone.
†Negative coefficient.

## DISCUSSION

There was a close relationship between the numbers of *H. virgata* and the
amount of organic matter in the soil. This agrees with the observation that
snails feed upon organic detritus, and probably upon the micro-organisms which
are themselves feeding upon the detritus (Pomeroy, 1966). The degree of

statistical significance associated with this factor is high, and it was particularly disappointing to be unable to make a comparable test for *H. neglecta*.

For both species, density was highly correlated with the amount of calcium. This is almost certainly because of its importance in the shell, which accounts for about one quarter of the weight of a helicid snail; and about 98% of the weight of the shell is calcium carbonate (Pelseneer, 1935). Inability to obtain sufficient calcium affects the structure of the shell, which may become extremely fragile, thus reducing its efficiency as a skeletal structure.

Next in order of significance was soil moisture. It was emphasized previously that this is hard to measure, and the achievement of a significant result could be explained in several ways. The amount of rain, number of wet days, number of wet nights (including those with dew), and measures of the tendency of the soil to dry, all will be correlated to some extent with measurements of P/E; the exact extent of the correlation itself depending upon complex factors, some general and some local. It can only be concluded that some aspect or aspects of soil moisture are important, and are reflected in the measurement of P/E. However, it is known that availability of water limits the time when snails can be active, in addition to its necessity to the organisms which constitute their food.

Proximity-to-man seemed to be important in determining the abundance of *H. virgata*, thus supporting the hypothesis being tested. A more significant result would probably have been obtained if this factor had been tested only for the more remote parts of the survey area; closer to Adelaide, where the species has been established for several decades, it has had longer to reach all the suitable places. In any case, this variate could not exceed a value of two within 50 km of Adelaide, because of the relatively high density of human occupation. By contrast, the much less significant result for this variate for *H. neglecta* is rather interesting. Southern Yorke Peninsula, where it occurs, is rather sparsely inhabited, and the mean value for the variate was 7·8 km (as compared with 3·0 for *H. virgata*). There is some evidence that *H. neglecta* has been established on Yorke Peninsula for many years (Pomeroy and Laws, 1967), so that it may have reached its maximum distribution, at least for present conditions, throughout its range. Considered in this way, the variate "Proximity-to-man" becomes a measure of the present tendency to spread; a high score indicates rather recent arrival, and suggests that future enlargement of the range is likely.

Numbers appear to be weakly correlated with land-use in the case of *H. neglecta*. For *H. virgata* there is no support for the hypothesis that increasing land-use makes the environment more favourable. It is possible that further investigation would yield a different result, as this variate (if it is important) is the least likely to be linearly related to *y*: too much cultivation could be as unfavourable as too little, in that snails would be physically damaged, or become buried.

The absence of any correlation between the distribution and abundance of snails and the number of hot days is also interesting. It is consistent with the conclusion that *Helicella* is remarkably resistant to the effects of high temperatures. It was found that when the screen temperature is 35°C, even for a short time, the internal temperatures of snails often exceed 40°C (Pomeroy, 1966). And, within the survey area, there were many places where the screen temperature was estimated to exceed 35°C on more than thirty days a year; snails were present at many of these places.

In so far as comparisons between the two species are possible, the results for *H. virgata* and *H. neglecta* are closely similar, suggesting that their requirements are similar too. Perhaps this is to be expected for congeners, since closely related species usually have similar feeding preferences. It might offer a partial explanation of the observation that the distributions of the two species in South Australia are mutually exclusive, or nearly so.

Whilst it is useful to have obtained some objective support for several hypotheses about distribution and abundance, it must be stressed that the analyses only accounted for a small proportion (less than a quarter) of the total variance. This can mostly be explained by the poor quality of much of the data, but a possibility that cannot be excluded is that one or more important variates escaped notice altogether. The method seems to have been satisfactory in other respects, and could probably be applied to many other situations. The precision of the results obtained from such a survey would depend upon the correct choice of variables, and the accuracy of measurement.

## ACKNOWLEDGMENTS

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# MICROHYLID FROGS OF NEW BRITAIN

BY MICHAEL J. TYLER*

## Summary

The morphological characteristics of the two species of microhylid frogs occurring in New Britain are reported. *Oreophryne brachypus* was last collected seventy years ago, whilst *Sphenophryne mehelyi* represents an addition to the fauna of the island. The latter species was found in aggregations estimated to reach 300 specimens, and the females sit on clumps of up to six eggs in depressions beneath rotting vegetation.

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## INTRODUCTION

The only microhylid frogs reported from New Britain are the three syntypes of *Oreophryne brachypus* (Werner) collected in 1897. In the course of a visit to the island in January-February, 1966, the writer collected a series of specimens of this species. Later in the same year Mr. D. Morgan of Keravat on the Gazelle Peninsula collected further specimens and also large numbers of *Sphenophryne mehelyi* Parker, a species previously known from the two types collected in New Guinea.

The present contribution records morphological variation and field observations on the two species. The methods of measurement employed in the text conform to the techniques of Zweifel (1962).

### *Oreophryne brachypus* (Werner)

*Material Examined*: 22 specimens—South Australian Museum, R.6910, 6912. 6944. 6948. 6964. 6989, 7025, 7065, Pomugu near Kandrian, South New Britain; 6992, 6997, 7000. 7002, 7004-5, 7008, Aliwoh near Kandrian; 7749, 8123, 8440 (5 specimens), Keravat. Gazelle Peninsula.

*Variation*: The series consists of sixteen adult males, three adult females and three juveniles. The ranges and means of the snout to vent lengths of the adults are as follows: males $19 \cdot 2$-$22 \cdot 3$ mm (mean $19 \cdot 9$ mm), females $21 \cdot 5$-$22 \cdot 8$ mm (mean $22 \cdot 0$ mm). The syntypes are two adult males and a juvenile and each male has a snout to vent length of $21 \cdot 5$ mm.

These specimens conform closely to Tyler's (1965) redescription of the species; the only additional information relates to the colour of the species. In life *brachypus* has a dusky brown ground colouration with indistinct and slightly darker markings upon it. Of these markings the most common are a narrow trans-ocular bar and a W-shaped patch immediately behind the head. There has been no visible change after a period of fifteen months preservation.

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*Field Notes*: The males were located at each locality calling from vegetation at heights of from three to eight feet from the level of the ground. The call consisted of a single note, resembled a long squeak and had a duration of about four seconds.

## *Sphenophryne mehelyi* Parker

When Parker (1934) described this species the only specimens available to him were two on loan from the museum at Budapest which he designated type and paratype respectively. The specimens had been reported previously (as *Chaperina fusca*) by Méhely (1901). The herpetological collection at Budapest was destroyed in 1956 and there are no known topotypic specimens in existence.

The specimens referred here to *mehelyi* agree in almost all respects with Parker's description and there is perfect agreement with the reported colouration of the type which, to judge from comparisons with species in the South Australian Museum collection and descriptions in the literature, is quite unlike that of any other species of *Sphenophryne*.

It is pertinent to note that the type locality (Sattelberg) is located on the Huon Peninsula, the portion of New Guinea in closest proximity to New Britain.

*Material Examined*: 357 specimens—South Australian Museum R.7785-7839, 7955-8009, 8136 (232 specimens), 8438 (15 specimens), Keravat Corrective Institution, Keravat, Gazelle Peninsula.

*Variation and Comparison with Original Description*: Of the above specimens a series of 55 (R.7785-7839) have been examined in detail and measured. Nineteen proved to be adult males, 27 adult females (of which 21 were gravid) and 9 sexually immature specimens. The ranges and means of snout to vent lengths of the adults were as follows: males 15·5-17·2 mm (mean 16·3 mm), females 17·0-20·1 mm (mean 18·7 mm).

Parker's figure of 20 mm as the size of the holotype was not the snout to vent length. He states in an account of his descriptive methods (1934, p. 16), "The length of a frog is the maximum distance in a straight line between the tip of the snout and the hinder side of the thighs behind the vent." This "total length" would exceed the snout to vent length by about one millimetre, placing the size of the holotype very close to the mean snout to vent length of the females examined. As noted by Zweifel (1962), Méhely (1901) cites a figure of 24·5 mm for the same specimen and, since it is highly probable that his measurement is the "total length" in vogue at that time, this would indicate a snout to vent length of about 23 mm.

The specimens tally with Parker's original description in the following respects: the presence of a denticulated prepharyngeal ridge with an adjacent median swelling; the distance between the eye and the tip of the snout is approximately equal to the horizontal diameter of the eye; the loreal region is oblique; the nostrils are nearer the tip of the snout than the eye; the interorbital space is equivalent to twice the diameter of the upper eyelid; the fingers are short and equipped with small discs; the toe discs are larger than the finger discs; when the hindlimb is adpressed along the side of the body the knee reaches the eye. The colouration of the present specimens agrees in all respects with that of the holotype.

The canthus rostralis of *mehelyi* is said to be rounded but most of the Keravat specimens exhibit only the slightest curvature and in some it is definitely straight. A further point of divergence concerns the length of the fourth finger.

Parker reports that in the holotype it is equivalent to three-quarters of the internarial span, whereas its length exceeds the internarial span in the present material. The tympanum is said to be distinct and, "rather less than half the diameter of the eye". This is true of the majority of specimens, but in those in which the skin on the side of the head is at all loose, the site of the tympanum cannot be detected externally. The skin appears smooth when superficially examined, but minute tubercles are visible when it is examined beneath the microscope.

In Parker's key to *Sphenophryne* the tibia of *mehelyi* is said to equal about half the distance from snout to vent, and to reach the couplet containing *mehelyi* involves agreement with, "tibio-tarsal articulation reaching the eye". As indicated in a previous paragraph, the knee of the adpressed hind limb of the present material will reach the eye, but the tibia length is consistently less than half of the snout to vent length. A frog whose tibia length is exactly half the snout to vent length has a TL/S-V ratio of 0·500, whereas the range of the present material is ·354--·432.

The significance of these points of divergence from the original description cannot be determined until adequate topotypic material is available. At the present time it is considered that the interests of nomenclatural stability are best served by regarding the New Guinea and New Britain populations conspecific.

*Comparison with Other Species*: Of the thirteen species currently recognised five have snout to vent lengths exceeding 34 mm (*cornuta, macrorhyncha, palmipes, rhodadactyla* and *schlaginhaufeni*). The maximum recorded size of the present material (20·1 mm) therefore prevents any confusion with these species.

*Sphenophryne brevicrus, brevipes,* and *crassa* lack dilated discs on the fingers (present in *mehelyi*) whilst *polysticta* has a blunter snout, shorter hind-limbs and a different colouration.

Of the three Australian species reported by Zweifel (1962, 1965), S. *fryi* has shorter limbs (TL/S-V 0·31-0·38, mean 0·346, as opposed to 0·35-0·43, mean 0·390) and attains a larger size than *mehelyi* (of more than 25 specimens reported by Zweifel (1962), only one adult had a snout to vent length of less than 20 mm, whereas 20·1 mm is the maximum for *mehelyi*). *Sphenophryne pluvialis* is evidently also a larger species than *mehelyi* and the specimens reported by Zweifel were uniform in bearing, "ill-defined, and irregular dark brown spots", on the dorsal surface of the body. There is no trace of any dorsal markings on any of the 357 *mehelyi*.

The size and TL/S-V ranges of *robusta* are similar to those of *mehelyi* but the reported colouration of the former (although variable) is evidently quite distinct from that of *mehelyi*.

*Field Notes*: The specimens were found congregating beneath piles of decomposing vegetation, consisting of rotting grass and reeds laid upon ground covered with leaf mould. The piles covered areas of up to five square yards. As many as 250-300 *mehelyi* were estimated to occur together but, when the vegetation was removed the frogs rapidly dispersed in all directions and rarely were more than 50 or 60 captured at any one site.

Numerous females were found at the base of the piles sitting upon clumps of eggs at the foot of small depressions excavated to a depth of about two inches in the leaf mould. Each egg clump consisted of five or six eggs connected to one

another (in the form of a bead necklace) by a very fine cord. Subsequent measurements of the eggs revealed a mean diameter of 3·3 mm for those at a stage prior to gastrulation, and 4·8 mm for those containing well developed juvenile froglets apparently near to emergence. Six eggs is virtually the maximum number that a female of this diminutive species could cover with her body.

Three months prior to the collection of the frogs the area in which they were found was virgin rain forest, but subsequent deforestation had completely eliminated the natural environment of the species. It therefore remains uncertain whether the aggregation of large numbers of frogs in breeding condition is a natural phenomenon, or simply necessitated at Keravat by the reduction in the amount of rotting vegetation occurring in the area.

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# A NEW SPECIES OF FROG OF THE HYLID GENUS *NYCTIMYSTES* FROM THE HIGHLANDS OF NEW GUINEA

BY MICHAEL J. TYLER*

## Summary

A new species of *Nyctimystes* is described. The maximum recorded snout to vent length of males is more than 80 mm, and the species shows distinct affinities with *N. humeralis* (Boulenger). However, it lacks the characteristic humeral spine exhibited by males of that species, and is also distinguished by its undivided nuptial pad and by differences in colouration.

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## INTRODUCTION

In 1963 and 1964 Mr. Barry Craig donated to the South Australian Museum several large collections of frogs obtained in the vicinity of Telefomen in the Western Highlands of New Guinea. Amongst the specimens were eleven representatives of an undescribed species of the hylid genus *Nyctimystes*. In 1965 Mr. Craig was a member of the Australian Star Mountains Expedition and obtained 650 frogs in an area approximately 40 miles west of Telefomen. Included in the collection were four additional specimens of the same species.

The methods of measurement employed in the description of the new species conform to those used by Tyler (1963).

### *Nyctimystes zweifeli* new species

*Holotype*: South Australian Museum R.5426. An adult male collected at Telefomen, Western Highlands, New Guinea, on November 24th, 1963, by B. Craig.

*Definition*: A particularly large species of *Nyctimystes* in which males have a snout to vent length of up to 83 mm. The hindlegs are very long with a tibia length to snout to vent length ratio (TL/S-V) of ·588-·654. The veins of the palpebral venation are largely vertical in their orientation with a tendency to form a reticulum.

*Description of Holotype*: The vomerine teeth are in two roughly oval and prominently raised series between the oval choanae. The tongue is less than half as wide as the mouth, oval in shape and with a very slight posterior indentation. The head is broader than long (head length 26·8 mm, head width 29·4 mm). The snout is bluntly rounded when viewed from above and strongly rounded in profile. The canthus rostralis is slightly curved and the loreal region oblique. The nostrils are inconspicuous and separated from one another by a distance which is slightly less than the distance between the naris and the eye (eye to naris distance 7·2 mm, internarial span 7·0 mm). The eye is relatively small and not prominent, its diameter (7·8 mm) only slightly greater than

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[*] South Australian Museum, North Terrace, Adelaide, South Australia.

the eye to naris distance. The pupil is completely dilated. The palpebral venation forms a dense pattern of predominantly vertical lines. The tympanum is small (diameter 3·7 mm) with only the inferior portion of its annulus visible.

The distance from the snout to the vent is 75·9 mm.

The fingers are long with large terminal discs, broad lateral flanges and flattened subarticular tubercles (Fig. 1a). The webbing between the third and fourth fingers reaches the base of the subarticular tubercle beneath the penultimate phalanx on the third, and midway up this tubercle on the fourth. Fingers in decreasing order of length, 3, 4, 2, 1. The discs of the second, third and fourth fingers are larger than the tympanum.

The toes are almost fully webbed, the webbing reaching the discs of all toes except the fourth where it extends as far as the subarticular tubercle at the base of the penultimate phalanx, and continues to the disc as a broad lateral flange (Fig. 1b). The toe discs are only slightly smaller than the finger discs, and all are larger than the diameter of the tympanum. There is a small kidney-shaped inner but no outer metatarsal tubercle. The legs are extremely long; the tibia length is 47·4 mm and the tibia length to snout to vent length ratio (TL/S-V) is 0·625. When the hindleg is adpressed the heel reaches well beyond the tip of the snout; when the hindlegs are laid along the side of the body the knee and elbow overlap considerably; when the hindlegs are bent at right angles to the axis of the body the heels overlap slightly.

The skin covering the dorsal surfaces of the head, body and limbs is smooth. The lateral surfaces of the body are slightly granular, the throat and chest finely granular and the abdomen and undersurface of the thighs coarsely granular. There is an extremely prominent supratympanic fold, a sharp fold on the posterior surface of the forearm, and a less conspicuous tarsal fold.

The dorsal surfaces of the head, body, forearms and tibia are a very dark plum colour with a hint of a crimson suffusion on the dorso-lateral portion of the body. On the thighs the plum occupies the median portion whilst the anterior and posterior surfaces are white, heavily suffused with large, irregular spots of plum. The sides of the body, the tarsus and foot are similarly marked. The abdomen is cream and the remainder of the ventral surfaces grey with obscure brownish mottling.

There is a sub-gular vocal sac with paired openings in the floor of the mouth near the angles of the jaws, and an extremely large, black nuptial pad at the base of the first finger.

*Variation*: There are eight paratypes: South Australian Museum R.8812-8819 collected at the type locality during the period November 14th-18th, 1963, by B. Craig. All specimens are males (six adults and two juveniles). Six additional male specimens from other localities are clearly representatives of *N. zweifeli*: South Australian Museum R.5275, 8811, Okfekaman, approximately 10 miles west-north-west of Telefomen; R.6476, 6499, Kawolabib (141°05′ long., 5°08′ lat.), approximately 10 miles south-east of Capella, Star Mountains; R.6477, Begibajen near Kawolabib and R.6478, Tabek Creek, Kawolabib. The complete range of altitude of these localities is 4,700-5,500 ft.

The range of snout to vent length of the adult males is 60·8-83·4 mm, but the smallest specimen with a nuptial pad (R.8815) measures 73·6 mm.

There is very little variation in the proportions of the complete series. In one specimen the internarial span is equal to the eye to naris distance, and in the remainder slightly less than it, the eye to naris to internarial span ratio
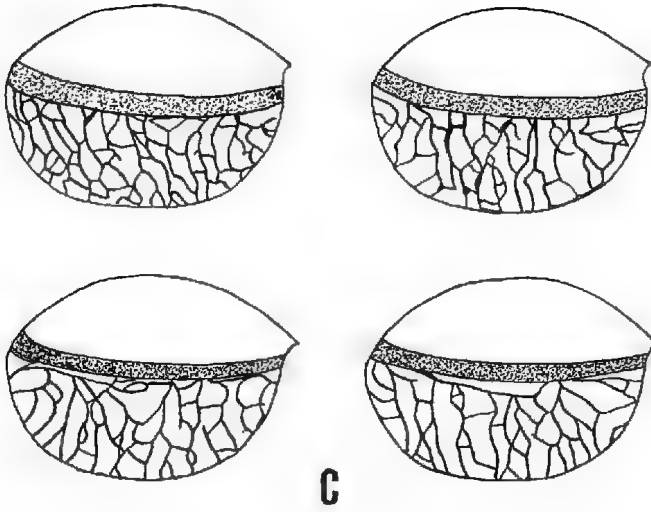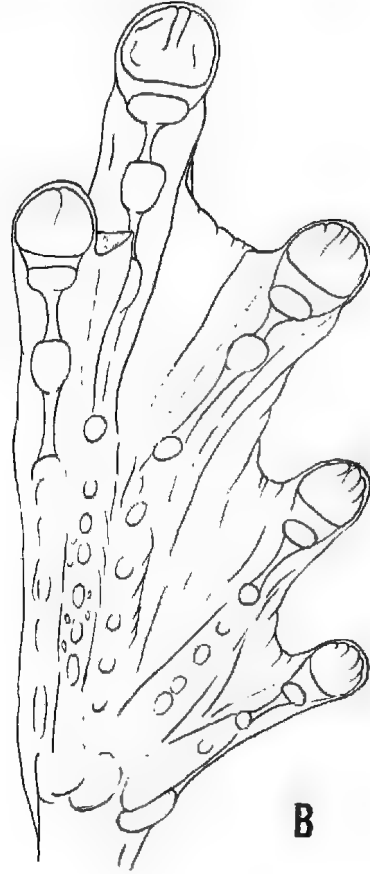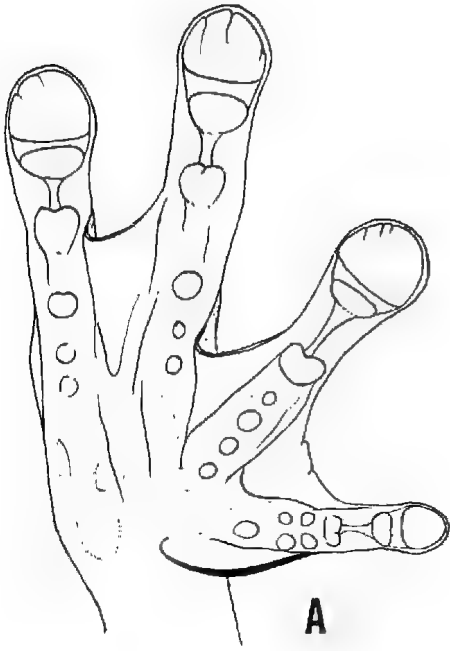
(E-N/IN) being 1·000-1·121 with a mean of 1·063. This is an exceptionally long-legged species, for the TL/S-V range is ·588-·654, with a mean of ·625.

The supratympanic fold is conspicuous in all specimens, whilst the fold of skin on the posterior surface of the forearm of two shows a tendency to form tubercles. In the remainder it is a continuous fold as found in the holotype. Finger webbing and the palpebral venation are features in which there is scant variation. (Four examples of the palpebral venation are depicted in Fig. 1c.)

The dorsal colouration varies from a very dark plum to pale violet. In the darkest specimens patches of dark slate are visible. In a few specimens there are a few tiny, brilliant white rings scattered on the dorsal surface. Markings on the thighs appear to increase in intensity with age. In the largest specimens the pale background of the anterior and posterior surfaces is almost completely obscured by irregular patches of plum and slate. There appears to be a similar correlation with markings on the ventral surface of the body, for in juveniles and small males it is an immaculate pale cream. In three specimens there are no islands of pigmentation on the lateral body surfaces or on the anterior and posterior surfaces of the thighs.

The size and number of the spines which make up the nuptial pad vary with the size of the individual. In the largest males the spines are larger and less numerous than in the smaller specimens.

*Comparison with Other Species*: The large size of *zweifeli* clearly distinguishes it from all species except *granti*, *humeralis*, *kubori*, *montana*, *narinosa*, *papua*, *perimetri* and *pulchra*. (The species referred to here as *N. montana* is *montana* (Peters and Doria) and not the species described by Parker, 1936, for which the substitute name *cheesmani* was proposed by Tyler, 1965.)

The only specimen of *granti* reported in the literature is the holotype female with a length of 100 mm. A female specimen from Antares (Rijksmuseum Van Natuurlijke Historie, Leiden, No. 12110) approximately 250 miles east of the type locality has been examined by the writer. It is a female with a snout to vent length of 70 mm; it agrees with the original description of Boulenger (1914) and perfectly reproduces the striking vermiculated pattern of the dorsal surface seen in the illustration accompanying it. From a comparison of this specimen with *zweifeli*, *granti* may be distinguished by its shorter legs (TL/S-V ·537), more widely spaced nares (E-N/IN ·790), less extensive finger webbing (not reaching the subarticular tubercle at the base of the penultimate phalanx of the fourth finger), and by its entirely different dorsal colouration.

The largest male *kubori* reported in the literature had a snout to vent length of 53 mm which is less than that of the smallest *zweifeli* (60·8 mm). Furthermore, the possession of a definitely reticulate and more heavily pigmented palpebral venation, and shorter limbs (TL/S-V 0·51-0·57, vide Zweifel, 1958) enable *kubori* to be readily distinguished from *zweifeli*.

In *montana* the eye to naris distance is considerably greater than the internarial span (only slightly less than the internarial span in *zweifeli*), the finger webbing is slightly more extensive and the palpebral venation is composed solely of vertical lines. *Nyctimystes narinosa* has an internarial span exceeding the eye to naris distance and only basally webbed fingers. In *papua* the legs are shorter than those of *zweifeli* (TL/S-V 0·51-0·58), the fingers are less extensively webbed and the palpebral venation is broken up into isolated segments.

*Nyctimystes perimetri* has a high E-N/IN ratio ($1 \cdot 20$-$1 \cdot 39$ compared with $1 \cdot 00$-$1 \cdot 12$ in *zweifeli*) and short legs (TL/S-V $0 \cdot 50$-$0 \cdot 56$), whilst *pulchra* possesses a slightly crenate ridge on the forearm and tarsus and a long heel lappet (*zweifeli* lacks these dermal appendages).

*Nyctimystes humeralis* has a similar size and similar proportions to those of *zweifeli* and shares in preservative a violet dorsal colouration. The former is distinguished in being immaculate and in the sexual characteristics of male specimens. Male *humeralis* possess the unique humeral spine and there are two separate nuptial pads at the base of the first finger. Male *zweifeli* lack a humeral spine and the nuptial pad is undivided.

*Colloquial Nomenclature*: All of the specimens from Telefomen and Okfekaman were referred to as "Itul".

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TYLER, M. J. (1963). A taxonomic study of amphibians and reptiles of the Central Highlands of New Guinea, with notes on their ecology and biology. II. ANURA: Ranidae and Hylidae. Trans. Roy. Soc. S. Aust., 86, pp. 105-130.

TYLER, M. J. (1965). An investigation of the systematic position and synonymy of *Hyla montana* Peters and Doria (ANURA, Hylidae). Zool. Abh. Dresden, 27 (10), pp. 265-270.

ZWEIFEL, R. G. (1958). Results of the Archbold Expeditions. No. 78 Frogs of the Papuan Hylid Genus *Nyctimystes*. Amer. Mus. Novit., No. 1896, pp. 1-51.

# OBITUARY:
# DR. P. S. HOSSFELD

**Summary**

# OBITUARY

## Dr. P. S. Hossfeld

Paul Samuel Hossfeld died in Adelaide on the 15th July, 1967, at the age of 71. His education commenced at Dutton, where he was born, and was continued at Prince Alfred College. He devoted some years to teaching before entering the University of Adelaide as a science student. He graduated as B.Sc. in geology and chemistry in 1924, and as M.Sc. in 1926. He was then appointed assistant to Dr. W. G. Woolnough, Geological Advisor to the Commonwealth Government. In New Guinea in 1929 he discovered, near Aitape, part of a human skull in beds of apparently late Pleistocene age. In 1935 he was appointed leader of a section of the Aerial, Geological and Geophysical Survey of Northern Australia and this gave him a wide knowledge of the geology of the Northern Territory. This work was disrupted by the war, during which Hossfeld worked as an industrial chemist. Later, he returned to the University and was awarded the degree of Ph.D. in 1953. He was appointed Lecturer in the Department of Geology and Mineralogy in 1954 and Senior Lecturer in 1959.

Among Hossfeld's varied contributions to geology, three are particularly notable. In his early detailed work in the northern Mount Lofty Ranges he advocated subdivision of the rocks of the Adelaide System into two series, the lower of which, the Para Series, corresponds closely with what, many years later, was named the Torrensian Series, the priority of Hossfeld's work and term apparently being overlooked. Probably his best known work is that on the stratigraphy of the Northern Territory. This is an immense compilation and the result of many years work. His contribution to the Cainozoic History of the South-east of South Australia overlapped two of his great interests, Quaternary geology and the study of aboriginal man, which, in later years, received much of his interest.

All Hossfeld's work was characterised by intensity of effort. It was typical of him that in 1962, at the age of 66, he walked great distances through New Guinea jungle to obtain materials which would give a radio-carbon dating of the skull fragments he had found at Aitape thirty-seven years earlier. Paul Hossfeld was a dedicated teacher and for this earned many tributes from both colleagues and students.

A.R.A.

## SELECTED BIBLIOGRAPHY

1925 The Tanunda Creek Granite and its Field Relations. Trans. R. Soc. S. Aust. 49, pp. 191-197.

1926 (With D. Mawson): Relics of Aboriginal Occupation of the Olary District, Trans R. Soc. S. Aust., 50, pp. 17-24.

1926 The Aborigines of South Australia: Native Occupation of the Eden Valley and Angaston Districts. Trans. R. Soc. S. Aust., 50, pp. 287-297.

1935 The Geology of Part of the North Mount Lofty Ranges. Trans. R. Soc. S. Aust. 59, pp. 16-67.

1936-1941 Twenty-two reports on the geology of the Northern Territory published by the Aerial Geol. & Geophys. Surv. N. Aust.

1946 (With T. D. Campbell and J. B. Cleland): Aborigines of the Lower South-east of South Australia. Rec. S. Aust. Mus., 8, No. 3, pp. 445-501.

1949 The Stratigraphy of the Aitape Skull and its Significance. Trans. R. Soc. S. Aust., 72(2), pp. 201-207.

1949 The Significance of the Occurrence of Fossil Fruits in the Barossa Senkungsfeld. South Australia. Trans. R. Soc. S. Aust., 72(2), pp. 252-258.

1950 The Late Cainozoic History of the South-east of South Australia. Trans. R. Soc. S. Aust., 73(2), pp. 232-279.

1954 Stratigraphy and Structure of the Northern Territory of Australia. Trans. R. Soc. S. Aust., 77, pp. 103-161.

1964 The Aitape Calvarium. Aust. J. Sci., 27(6), p. 179.

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1965 (With T. D. Campbell): Aboriginal Stone Circles. Mankind 6, No. 4, pp. 181-183.

1966 (With T. D. Campbell): Australian Aboriginal Stone Arrangements in North-west South Australia. Trans. R. Soc. S. Aust., 90, pp. 171-176.

1966 Antiquity of Man in Australia. Pub. in "Aboriginal Man in South and Central Australia". Government Printer, Adelaide. pp. 59-85.

1966 Materials Used in Australian Aboriginal Stone Implements. Pub. in "Aboriginal Man in South and Central Australia". Government Printer, Adelaide, pp. 163-168.

# BALANCE SHEETS:
# GENERAL ACCOUNT AND RESEARCH FUND


**Summary**

# THE ROYAL SOCIETY OF SOUTH AUSTRALIA INCORPORATED

## GENERAL ACCOUNT

### STATEMENT OF RECEIPTS AND PAYMENTS FOR THE YEAR ENDED 30th JUNE, 1967

| RECEIPTS | $ | PAYMENTS | $ |
|---|---|---|---|
| Opening Balance at 1st July, 1966 | 169.82 | Publishing Costs | 4,208.29 |
| Subscriptions | 1,058.53 | Cleaning Costs | 156.00 |
| Government Grant | 3,700.00 | Postage | 169.95 |
| Reprints | 426.00 | Petty Cash | 185.92 |
| Waite Institute Subsidy | 600.00 | Service Charges | 40.23 |
| Bank and Bond Interest | 71.73 | Rent of Rooms | 14.00 |
| Sundry Income | 48.74 | Printing of Notices | 111.72 |
| | | Key and Property Register | 40.50 |
| | | Transfer to Research Account | 349.38 |
| | | Sundries | 90.87 |
| | | Closing Balance as at 30th June, 1967 | 707.96 |
| | $6,074.82 | | $6,074.82 |

## LIBRARY ACCOUNT

### STATEMENT OF RECEIPTS AND PAYMENTS FOR THE YEAR ENDED 30th JUNE, 1967

| RECEIPTS | $ | PAYMENTS | $ |
|---|---|---|---|
| Opening Balance at 1st July, 1966 | 1,402.05 | Johnson Reprints | 317.20 |
| Sale of Transactions | 1,385.94 | Librarian's Wages | 413.74 |
| Bank Interest | 43.45 | Clerical Costs | 364.00 |
| | | Binding | 973.00 |
| | | Insurance | 119.02 |
| | | Sundries | 33.23 |
| | | Closing Balance at 30th June, 1967 | 611.25 |
| | $2,831.44 | | $2,831.44 |

# THE ROYAL SOCIETY OF SOUTH AUSTRALIA INCORPORATED

### ENDOWMENT AND SCIENTIFIC RESEARCH FUND

### STATEMENT OF RECEIPTS AND PAYMENTS FOR THE YEAR ENDED 30th JUNE, 1967

| RECEIPTS | $ | PAYMENTS | $ |
|---|---|---|---|
| Opening Balance at 1st July, 1966 | 474.67 | Purchase of Unsecured Notes | 1,000.00 |
| Interest and Dividends Received | 1,006.50 | Closing Balance as at 30th June, 1967 | 834.17 |
| Bank Interest | 13.62 | | |
| Transfer from General Account | 339.38 | | |
| | $1,834.17 | | $1,834.17 |

## SCHEDULE OF INVESTMENTS AS AT 30th JUNE, 1967

| | $ | |
|---|---|---|
| Fixed Deposits (at cost)— | | |
| Lensworth Finance—8% | $4,000.00 | |
| G.M.A.C.—7½% | 2,000.00 | |
| G.M.A.C.—6% | 1,000.00 | |
| F.C.A.—7¾% | 2,000.00 | |
| E.I.L.—8% | 900.00 | 9,900.00 |
| | | |
| Equity Stock (at cost)— | | |
| Woolworths—900 | 1,290.00 | |
| B.H.P.—300 | 1,472.00 | |
| A.C.I.—400 | 1,127.00 | |
| Adelaide Cement—800 | 1,275.00 | |
| C.S.R.—400 | 1,283.00 | |
| Herald and Weekly Times—300 | 1,367.00 | |
| Tooths Ltd.—250 | 1,330.00 | 9,144.00 |
| (Market Value, $10,301) | | |
| Inscribed Stock (at cost) | | 300.00 |
| Cash at Bank | | 834.00 |
| | | $20,178.00 |

### AUDITORS' REPORT

We report that we have examined the Books and Accounts of THE ROYAL SOCIETY OF SOUTH AUSTRALIA (INCORPORATED) for the year ended 30th June, 1967, and have obtained all the information and explanations we have required.

In our opinion, the attached Statements of Receipts and Payments for the General, Library and Endowment Fund are properly drawn up to record the cash transactions of the Society for the year ended 30th June, 1967, according to the best of our information and the explanations given to us and as shown by the Books of the Society submitted. We have also verified the schedule of Investments at 30th June, 1967.

Adelaide, South Australia,
5th of September, 1967.

MILNE, STEVENS, SEARCY & CO.,
Chartered Accountants

# REPORT ON ACTIVITIES OF THE COUNCIL, 1966-67

**Summary**

# REPORT ON ACTIVITIES OF THE COUNCIL, 1966-67

### Accommodation

The past year has seen several significant developments in both the accommodation and activities of the Society. Of particular importance has been the move to the new rooms. The old rooms were severely limited in both meeting space and library area and during the year several meetings were of necessity held in the S.A. Museum lecture room. The State Library has the responsibility to provide accommodation for the Society and fortunately it has been able to make available two large rooms at the southern end of the State Library building. This area should provide suitable and comfortable space adequate for the Society's library and meetings for at least some years ahead.

### Meetings

Eight meetings were held during the year with an average attendance of 42, a considerable increase on that of previous years. A total of 13 papers were read and 7 exhibits presented.

### Subcommittees of Council

During the past two years the Council has appointed several subcommittees to facilitate dealing with an increasing volume of business. The committees are elected annually. Rules governing their responsibilities and charter have been drawn up for incorporation in the By-laws.

### Research and Endowment Fund

A change in the Rules of the Society in 1965 permitted investment of the Endowment Fund in fixed interest and equity stock, so that both an adequate income would be available and its value would not depreciate. Council has decided that most of the income from the investments should be used for promotion of research. The sum available at present is $500 per year and this is to be awarded, at discretion of Council, as grants in support of research expeditions and field projects undertaken by members of the Society. The first awards will be made in 1968. The Executive Committee reports to Council on the fund and seeks approval for any transactions which need to be authorised by two-thirds of the full Council.

### Publications

The Society has been handicapped in publishing the Transactions by some lack of funds. It has been necessary, with the apparently regular annual rise in printing costs, to limit the volume size to 200 pp. approximately. The Publication Committee is responsible for decisions on acceptance, rejection or deferment of submitted papers, all of which are first refereed, and for deciding the size and composition of the volume. Unfortunately not all papers could be included this year. Attention is drawn to the instructions to authors at the back of the volume which have been largely re-written. The Committee dealt with 23 submitted papers during the year of which 17 were accepted for publication in the current volume. Vol. 90 was issued in December, 1966, and it is expected the present Transactions will also be issued by the end of the year.

*Library*

The Library, through the considerable effort of the Hon. Librarian, has been re-organized and is now in its new, more spacious quarters. The Council agreed that it should be confined to scientific periodicals and with this in view, the small stock of 300 books and a quantity of maps have been offered to and accepted by the State Library and The Flinders University. Ultimately, all books and duplicate periodical material will be similarly transferred. The transfer of the library to the new rooms took place in July under the direction of the Hon. Librarian and assistants with the help of State Library staff. This very consider-able undertaking was achieved smoothly and rapidly within two weeks. There is now room for at least five years' expansion. The exchange list now numbers 340 Societies and Institutions; 8 new exchanges of journals not held elsewhere in Adelaide were approved.

*Revision of Rules and By-laws*

It was decided last year that the Rules and By-laws should be thoroughly revised. Unfortunately, this has been delayed by the Secretary's illness, but it is hoped the revised set will be completed and placed before the Society during the coming year.

*Science Centre*

The Council, through its representative Dr. H. B. S. Womersley, took part in discussions with other bodies on the setting up of a Science Centre to serve all scientific societies in Adelaide. The necessity for such a centre, once rather acute, has diminished and as far as the Royal Society is concerned, could not now be strongly supported. The proposal has been shelved for the present.

*Verco Medal*

The Council recommended and the Society subsequently approved the award of the Verco Medal for 1967 to Professor L. D. Pryor.

*Membership*

The membership of the Society now stands at 257; 16 new members were elected during the year and one resigned. Four members of long-standing in the Society—Mr. A. G. Edquist, Mr. P. Ifould, Mr. F. M. Angel and Dr. P. S. Hossfeld—died during the year.

# OFFICERS FOR 1966-67

**Summary**

# ROYAL SOCIETY OF SOUTH AUSTRALIA

## INCORPORATED

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## OFFICERS FOR 1966-67

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# LIST OF NEW MEMBERS

**Summary**

# ROYAL SOCIETY OF SOUTH AUSTRALIA

## LIST OF NEW MEMBERS

1966. ALLCHURCH, P. D., B.Sc., Dept. of Mines, Box 38 Rundle Street P.O., Adelaide, S.A.
1967. CALLEN, R. A., B.Sc. (Hons.), Dept. of Mines, Box 38, Rundle Street P.O., Adelaide, S.A.
1966. CALLOW, J. C., B.Sc., c/o Delhi Australian Petroleum Ltd., 32 Grenfell Street, Adelaide, S.A.
1966. CEBASTIAN, SISTER MARY, B.A., B.Ed., Cabra Convent, 225 Cross Road, Cumberland Park, S.A.
1966. FLEMING, H. D., B.E., F.S.A.S.M., M.I.E., 104 Marion Road, Payneham, S.A.
1967. KENNEDY, G. R., B.Sc., Ph.D., The Flinders University, Sturt Road, Bedford Park, S.A.
1967. LEE, K. E., D.Sc., Division of Soils, C.S.I.R.O., Private Bag No. 1, Glen Osmond, S.A.
1966. RUTLAND, Prof. R. W. R., B.Sc., Ph.D., Dept. of Geology, University of Adelaide, Adelaide, S.A.
1966. SCOTT, I. F., B.Sc. (Hons.), Aust. Mineral Development Laboratories, Conyingham Street, Parkside, S.A.
1967. SMYTH, D. R., B.Sc. (Hons.), Dept. of Genetics, Australian National University, Canberra, A.C.T.
1967. SZENT-IVANY, J. J. H., Ph.D., F.I.C.E.S., 3 Addison Avenue, Athelstone, S.A.
1966. TURNER, A. R., B.Sc., Australian Mineral Development Laboratories, Conyingham Street, Parkside, S.A.
1966. WACE, N. M., M.A., Ph.D., Dept. of Geography, University of Adelaide, Adelaide, S.A.
1967. WALPOLE, J. R. B., Dept. of Genetics, University of Adelaide, Adelaide, S.A.
1967. WEBER, J. Z., Dipl.Biol. (Zagreb), State Herbarium, Botanic Garden, North Terrace, Adelaide, S.A.
1966. WELBOURNE, R. M. E., M.Sc., 15 Canterbury Crescent, Valley View, S.A.
1967. WHEELER, J. R., B.Sc. (Hons.), State Herbarium, Botanic Garden, North Terrace, Adelaide, S.A.
1967. WOOD, T. G., B.Sc., Ph.D., Division of Soils, C.S.I.R.O., Private Bag No. 1, Glen Osmond, S.A.
1967. WRIGHT, R. G., B.Sc. (Hons.), Dept. of Mines, Box 38, Rundle Street P.O., Adelaide, S.A.

## CHANGE OF ADDRESS

1965. MACONOCHIE, J. R., B.Sc. (Hons.), Herbarium of the Northern Territory, Animal Industry and Agricultural Branch, Alice Springs, N.T.
1962. BROWN, R. G., B.Sc., Ph.D., Geology Dept., University of Western Australia, Nedlands, W.A.
1962. DALGARNO, C. R., M.Sc., c/o Anaconda Aust. Inc., 127 Eagle Street, Brisbane, Queensland.
1964. FREEMAN, R. N., B.Sc., Ph.D., P.O. Box 7727, Johannesburg, Rep. of South Africa.
1965. SHAW, ELIZABETH A., Ph.D., Gray Herbarium, Harvard University, 22 Divinity Avenue, Cambridge, 38 Mass., U.S.A.
1963. TALBOT, Prof. J. L., M.A., Ph.D., Dept. of Geology, Lakehead University, Port Arthur, Ontario, Canada.

# LIST OF LECTURES, EXHIBITS AND
# AWARDS OF THE SIR JOSEPH VERCO MEDAL

**Summary**

# LIST OF LECTURES GIVEN AT MEETINGS DURING
# THE YEAR 1966-67

Sept., 1966    Mr. L. W. Parkin: "A Local Perspective on Energy from the Earth".

Oct., 1966    Dr. K. Lee: "Animal Life in the Soil".

Nov., 1966    Dr. R. F. Ewer, "The Innate and Learnt in the Behaviour of Mammals".

April, 1967    Dr. Daily delivered his 1966 Presidential Address entitled: "South Australia in the Cambrian World".

May, 1967    Dr. P. Miles: "Plant Bugs and Galls".

June, 1967    Dr. N. M. Wace: "The Southern Continents—Evolutionary Cul-de sacs or a Fragmented Biotic Realm".

July, 1967    Prof. R. J. Weimer: "Some Applications of Space Photography".

Aug., 1967    Dr. R. Carrick: "The Wildlife of Macquarie Island".

## Exhibits

Mr. B. P. Thomson: Some Recent Maps Issued by the Geological Survey of S.A.

Dr. J. V. Possingham: Effects of Nutrient Deficiencies on Chloroplast Structure.

Dr. R. T. Lange and Mr. W. K. Harris: Eocene Leaf Cuticles and Spores and Pollen from Maslin Bay, S.A.

Mr. H. Mincham: A Juvenile Echidna.

Mr. C. Boomsma: Eucalypts from the Victoria Desert.

Mr. I. M. Thomas: Barnacles from Whales.

Dr. H. M. Laws: The Sea Urchin *Centrostephanus*, Newly Recorded from S.A.

# AWARDS OF THE SIR JOSEPH VERCO MEDAL

1929    Prof. Walter Howchin, F.G.S.
1930    John McC. Black, A.L.S.
1931    Prof. Sir Douglas Mawson, O.B.E., D.Sc., B.E., F.R.S.
1933    Prof. J. Burton Cleland, M.D.
1935    Prof. T. Harvey Johnston, M.A., D.Sc.
1938    Prof. J. A. Prescott, D.Sc., F.A.C.I.
1943    Herbert Womersley, A.L.S., F.R.E.S.
1944    Prof. J. G. Wood, D.Sc., Ph.D.
1945    Cecil T. Madigan, M.A., B.E., D.Sc., F.G.S.
1946    Herbert M. Hale, O.B.E.
1955    L. Keith Ward, I.S.O., B.A., B.E., D.Sc.
1956    N. B. Tindale, B.Sc.
1957    C. S. Piper, D.Sc.
1959    C. G. Stephens, D.Sc.
1960    H. H. Finlayson
1961    R. L. Specht, Ph.D.
1962    H. G. Andrewartha, M.Ag.Sc., D.Sc., F.A.A.
1963    N. H. Ludbrook, M.A., Ph.D., D.I.C., F.G.S.
1965    R. V. Southcott, D.Sc., M.D., B.S., D.T.M. & H.
1966    Prof. A. R. Alderman, D.Sc., Ph.D., F.G.S.
1967    L. D. Pryor, M.Sc., Dip.For.
     For distinguished studies on the genus *Eucalyptus*, including hybridisation, controlled pollination and breeding, vegetative propagation and taxonomy, and the relation of Eucalypts to mycorrhiza. Other studies have dealt with poplar growing in Australia.

# C O N T E N T S