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*BY D. R. SMYTH*† AND C. M. PHILPOTT**

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[Read 2 October, 1967]

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## SUMMARY

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At least two bandicoots were living in one square mile of scrub containing mulga, spinifex and tussock grasses, near the Warburton Range, Western Australia. Their burrows, scratchings, tracks and faeces are described. Fifty-eight burrows were mapped and 55 of them found to be distributed at random within two areas delineated by presence of bandicoot scratchings. The main food species of the bandicoot were the termites *Hamitermes* (*Drepanotermes*) *rubriceps* (Froggat) and *Eutermes tumuli* Froggat. On each of 8 consecutive nights from 2% to 27% of the burrows were used. Out of 35 representative burrows, 14 were not used on any of the 8 nights, and none were used on more than 4 nights.

## INTRODUCTION

Since the coming of European man to Australia, the range and population size of many marsupials have been greatly reduced. In some species it is probable that this reduction has reached its limit, and that the species are extinct. Calaby (1963) suggests that there are six such species. If so, then further study of them is restricted to museum specimens and fossils. Calaby also lists other marsupials close to extinction. The biology of most of these is little-known, and opportunities to record it uncommon. Calaby includes the rabbit bandicoot, *Macrotis lagotis* Reid, shown in Pl. 1, Fig. 1, amongst these species.

Recently, we studied some of the natural history of a small population of rabbit bandicoots near the Warburton Range, Western Australia. Previous work of this nature in the genus *Macrotis* has mostly been in the form of brief observations made during collecting trips. Wood-Jones (1924) made many such observations. He discusses notes recorded by other authors, and also describes aspects of behaviour of captive rabbit bandicoots.

Our aim in recording and discussing our results is to provide a background on which other studies on rabbit bandicoots may be based, or with which they may be compared. If these bandicoots were to become extinct, we hope our study will give future workers some idea of how they lived.

## METHODS

During 1966, we surveyed the present range of rare marsupials in parts of arid Australia, the results of which have been reported (Philpott and Smyth, 1967). During this survey, we located an area near the Warburton Range where rabbit bandicoots were living, and used it as our study area. We carried out the work recorded here during November and December, 1966.

We were taken to the area by semi-nomadic aboriginal people of the Nga-:nyatjara and Pitjantjatjara tribes. These people have an intimate knowledge of the signs and habits of the rabbit bandicoot, because they still hunt it occasionally for food. They were happy to communicate this knowledge to us. This communication was facilitated by use of the aboriginal names of the rabbit bandicoot. Near the study area, they call it the "niṇu". East, in the Musgrave and Everard Ranges, it is called the "talku", while south-west towards Laverton it is called "matura". All aboriginal names are spelt phonetically following Douglas (1964).

We mapped the burrows in the study area by triangulation using a prismatic compass.

To record if burrows had been used overnight, we inspected them daily, swept away fresh tracks from the mouth, and placed a twig in the single entrance such that it would be dislodged by a bandicoot entering or leaving. We took care to minimize our scent on the twig and around the entrance of the burrow. We scored a burrow as being used by a rabbit bandicoot if the twig was knocked down and characteristic tracks and tail marks left near the entrance.

Faecal contents were examined microscopically after crushing in water containing a drop of detergent.

We identified plant species in the field, and checked several in the State Herbarium of South Australia. Ants were identified at the C.S.I.R.O. Division of Entomology, Canberra, and termites and insect larvae by staff at the South Australian Museum.

## RESULTS

(a) *General description of the study area*

The study area is about 7 miles (11 km) north of Warburton Mission, and its latitude and longitude are 26°02′ S. and 126°34′ E. respectively. Its position is shown in Fig. 1. It is an irregular shape, with a maximum length of 1·4 miles (2·3 km) and is 1·0 mile (1·6 km) across at its widest point. Fig. 2 is a sketch map of the study area, which has a total area of 1·0 square mile (2·6 sq. km).

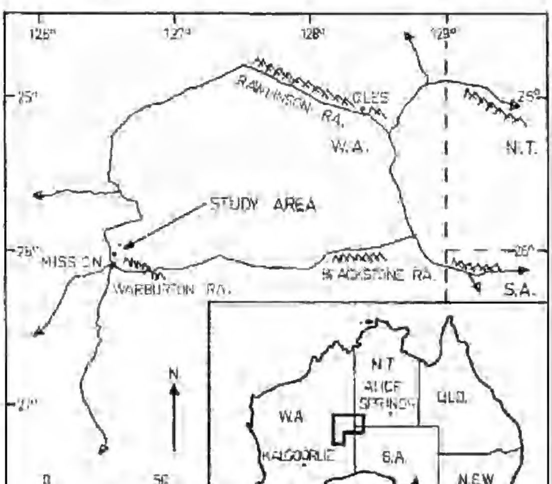


Fig. 1. Location of the study area near Warburton Mission, Central Australia, with the general area shown on an indented map of Australia.

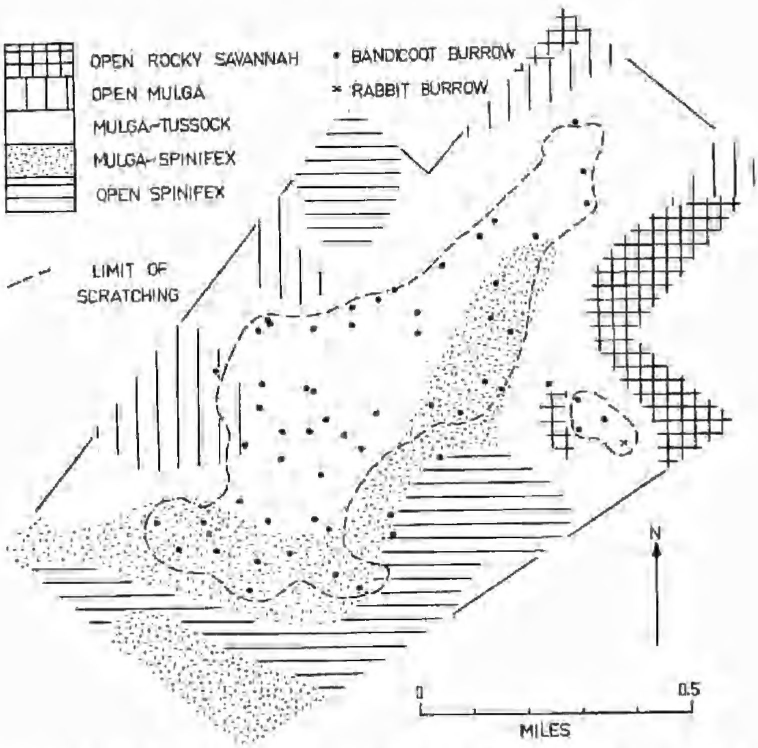


Fig. 2. Sketch map of the study area, showing approximately the positions of 58 bandicoot burrows, the limits of bandicoot scratchings, and the areas covered by the 5 vegetation groups.

The following general description is based on observations and on information from the Atlas of Australian Resources (1959).

The area has a dry continental climate, with irregular rainfall, but with the maximum amount falling in summer. The average annual rainfall is 5-8 inches (13-20 cm). The average daily maximum temperature in January (summer) is 95-100° F (35-39° C). In July (winter), the average daily minimum is in the range 40-45° F (4-7° C).

The study area is bounded by low rocky ridges on the north and north-west. From the low pass between them, the land slopes gradually to the south-west. Skeletal soils cover the hills, while the flats and plains are of deep, desert loams, with small rocks and pebbles distributed through all levels. Permanent surface water is absent from the study area, and uncommon nearby.

For the purpose of description, the vegetation of the area has been divided into five classes. These are not discontinuous, and are based on subjective observations.

(i) Open rocky savannah. This type occurs on the skeletal soils of the ridges and hills. Perennial hard-leafed grasses and occasional shrubs such as *Cassia* and *Ptilotus obovatus* provide a sparse cover. Mulga (*Acacia aneura*) also occurs at very low density.

(ii) Open mulga scrub, Pl. 3, Fig. 1—Mulga occurs in stands of low to medium density in certain areas. There are no shrubs or perennial herbs under the open mulga canopy. Ephemeral crucifers, grasses, composites and other herbs spring up on the bare ground after rain. The soil is often shallow.

(iii) Mulga-tussock scrub, Pl. 3, Fig. 2—This is similar to the second type, except that the mulga is usually more dense, and the ground has a moderate cover of perennial tussock grasses. The soil is probably deeper than in the previous class.

(iv) Mulga-spinifex scrub, Pl. 3, Fig. 3—On the deep desert loams, mulga and spinifex (*Triodia basedowii*) often occur together at medium densities. Many other species of trees and shrubs grow as scattered solitary individuals. Such trees as the bloodwood (*Eucalyptus terminalis*) and the corkwood (*Hakea suberea*) occur. The shrubs present include the dead finish (*Acacia tetragonophylla*), the witchetty bush (*Acacia kempeana*), and various *Cassia* and *Eremophila* species. Some herbs and grasses also occur.

(v) Open spinifex glade, Pl. 3, Fig. 4—In some areas, the major plant cover is spinifex. Occasional individuals of mulga and witchetty bush occur. Ephemerals grow in the spaces between spinifex clumps after rain.

The approximate limits of these classes in the study area are shown in Fig. 2.

(b) *Signs*

We did not see any rabbit bandicoots above the surface of the ground during daylight hours. They are probably strictly nocturnal. Their presence in an area searched during the day can only be proved by capturing a specimen. However, various characteristic signs of their presence can be readily seen.

(i) Burrows—The most obvious sign is the burrow. We located 58 bandicoot burrows in the study area, and completely dug out six. A sketch diagram of two representative burrows is shown in Fig. 3.

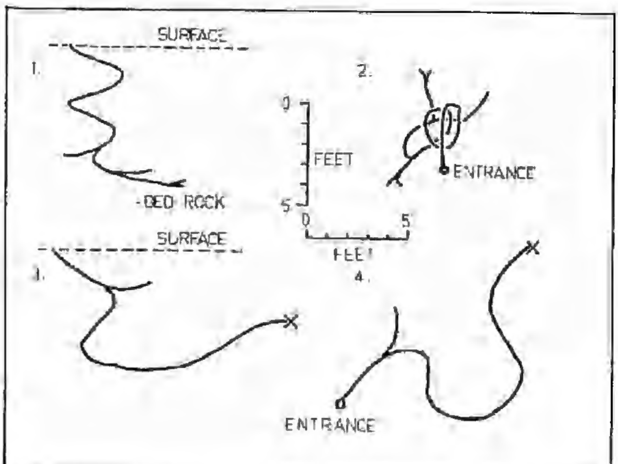


Fig. 3. Sketch diagrams of two burrows which were dug out completely. (1) and (2) are the side elevation and plan respectively of a burrow near the north-east corner, (3) and (4) are the side elevation and plan of a burrow on the central western edge. X indicates the position from which a female rabbit bandicoot was taken.

A small circular mound of soil was present outside the entrance of all burrows. The tunnel cross-section was usually circular or slightly oval, and about 6 inches (15 cm) in diameter. Burrow entrances were often partially hidden by dense spinifex, tussock grass or juvenile mulga plants. Occasional burrows were underneath or near fallen logs. Eight of the burrows were conspicuous by being dug into the large mounds of loose soil frequent in the area. Two representative burrows are shown in Pl. 2, Figs. 2 and 3.

In two burrows which contained a solitary rabbit bandicoot, the tunnels were blocked in from one to three places along their length by loose, frequently dug soil. There were no faeces in, or close to the burrows. In one of the burrows containing a bandicoot, an area of the floor near the end was damp, possibly from recently voided urine. The two bandicoots were at the extreme ends of their respective burrows, and were rapidly lengthening them when captured.

Rabbit bandicoot burrows were different from other types of burrows present in the area. Rabbit (*Oryctolagus cuniculus* Linne) burrows are often built in warrens, are of a different plan, and are often marked by faeces. We located two burrows which were probably used by rabbits in the study area. Goanna (*Varanus* sp.) burrows which were also present, were smaller, semi-circular in cross-section, and much shallower.

(ii) Scratchings—Diggings and scratchings covered the soil over much of the study area. They were of distinct types. (1) The most frequent type was a shallow, cylindrical pit, 2-8 inches (5-20 cm) deep, and 2-6 inches (5-15 cm) wide, an example of which is shown in Pl. 1, Fig. 2. The soil from them was piled up in all directions around their mouths. (2) There were also smaller scratchings of irregular shape, and areas of loosened topsoil, often near mulga roots. (3) A further type was a conical pit under certain tussock grasses, as illustrated by Pl. 1, Fig. 3. Out of a sample of 107, 62% were under *Eragrostis eriopoda* and *E. laniflora*, 18% under *Danthonia bipartita*, and the rest under *Aristida contorta* and *Eriachne mucronata*. These pits were mostly in mulga-tussock scrub. They were about 4-8 inches (10-20 cm) deep, and descended at an angle.

We believe that all these diggings were made by rabbit bandicoots. The evidence which suggest this is: (1) the diggings were distributed in close association with the bandicoot burrows, as shown in Fig. 2, and were never more than 600 feet (180 m) from one; (2) the density of scratchings was frequently higher in the vicinity of a burrow; (3) faeces, later shown to be closely similar to those of recently captured bandicoots, were occasionally found on or near the freshly dug soil; and (4) insect species, fragments of which were found in newly captured bandicoot's faeces, (see Results, Part [d]), were often found in the scratchings.

(iii) Tracks—Characteristic tracks were often left in burrow entrances and on fresh scratchings. They were also left on the pebbly surface between some burrows in the area. A sketch diagram of a set of tracks entering the mouth of a rabbit bandicoot burrow is shown in Fig. 4. Although we have only aboriginal opinion and circumstantial evidence, we believe these characteristic tracks were those of a rabbit bandicoot.

We observed characteristic grooves on loose soil near scratchings and also near burrow entrances, as shown in Pl. 2, Fig. 3. Captive bandicoots left similar

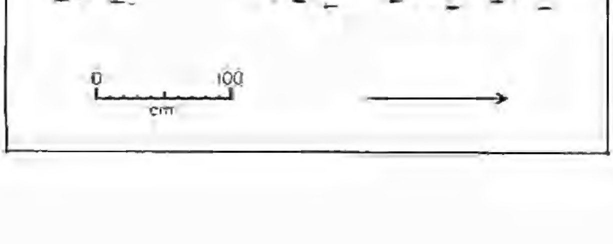


Fig. 4. Sketch diagram of a series of presumed rabbit bandicoot tracks leading to the entrance of a burrow. The probable direction of travel is shown with an arrow.

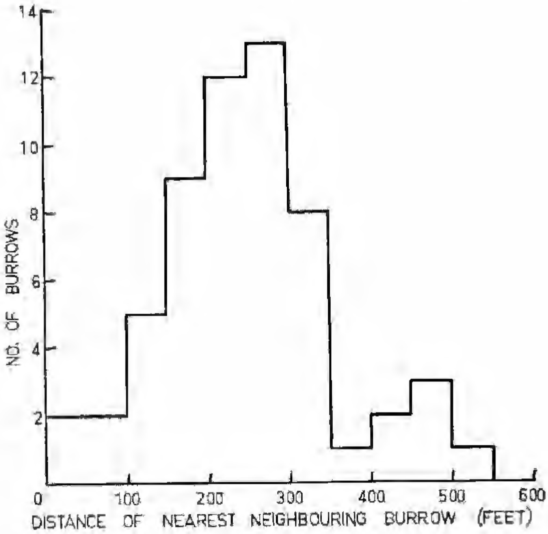


Fig. 5. Frequency distribution of 58 burrows, showing the distance of the nearest neighbouring burrow to each of these burrows. The mean distance is 249 feet with a standard error of 14·1 feet.

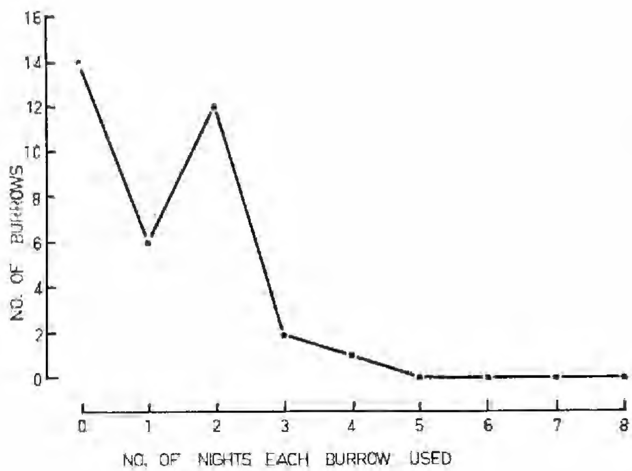


Fig. 6. Frequency distribution of 35 burrows, showing the number of nights each of these burrows was used over a period of 8 consecutive nights. The mean number of nights is 1·14, and its standard error is 0·036 nights.

marks while digging in loose soil on the cage floor. The marks were left by the tail, which was used as a strut while the hind legs were in use.

(iv) Faeces—Faeces of captive bandicoots were similar in shape and size to those found occasionally on or near scratchings. Four representative groups of pellets are shown in Pl. 2, Fig. 1.

## (c) *Distribution of burrows*

The distribution of the 58 burrows over the study area is shown in Fig. 2. Most burrows were in mulga-tussock scrub and mulga-spinifex scrub. Two were in each of open mulga scrub and open spinifex glade. There were none in open rocky savannah.

The burrows were distributed in two clusters bounded approximately by the limit of bandicoot scratchings. In order to test if the burrows were distributed at random within the scratched areas, a grid of quadrats with sides equivalent to 340 feet (105 m) was laid over a map of the area. We considered only those quadrats within the scratched areas, and those intersected by the limit of scratchings. The distribution of burrows within these quadrats was tested for goodness of fit with a Poisson distribution, as shown in Table 1.

TABLE 1

Distribution of burrows in quadrats covering all of the scratched area, showing goodness of fit test to a Poisson distribution.

| No. of burrows per quadrat | Observed No. of quadrats (O) | Expected No. of quadrats (E) | $\frac{(O-E)^2}{E}$ | |
|---|---|---|---|---|
| 0 | 60 | 61·28 | 0·027 | Mean = 0·529 |
| 1 | 34 | 32·41 | 0·078 | V'ce = 0·458 |
| 2 | 9 | 8·57 | | $\chi^2_1$ = 0·114 |
| 3 | 1 | 1·51 | 0·009 | 70% < p < 80% |
| 4 or more | 0 | 0·23 | | |
| Total | 104 | 104·00 | 0·114 | |

The result ($\chi^2_1 = 0{\cdot}114$, $70\% < p < 80\%$) strongly suggests that the burrows were randomly distributed over the area. This indicates that the position in which a bandicoot dug a burrow was independent of the position of other burrows in the area.

It is probable that a rabbit bandicoot uses a burrow as a refuge into which to flee when danger threatens. If so, then some description of distances between burrows is useful. Fig. 5 shows a histogram of the number of burrows and the distance of the nearest neighbouring burrow to each of these 58 burrows taken in turn. The spread of the nearest neighbour distance is small, with no burrow more than 550 feet (170 m) from any other one.

There is a small peak in the histogram composed of burrows with nearest neighbour distance greater than 350 feet (105 m). These burrows were distributed over the whole study area, and the presence of this peak is therefore perhaps fortuitous.

## (d) *Food*

We collected all the faeces voided by two bandicoots during their first night in captivity. One pellet from each was examined microscopically after crushing. They both contained more than 50% by volume of soil and grit. They also contained a small number of rabbit bandicoot hairs. However, the most striking contents were the hard, keratinised mandibles and whole heads of certain insects. We collected insects from the study area which were possible food species, dissected their mandibles, and compared these mandibles and heads with those found in the faecal pellets. By this method we were able to identify remains of both soldier and worker castes of two termite species, *Hamitermes* (*Drepanotermes*) *rubriceps* (Froggat) and *Eutermes tumuli* Froggat, and workers of one species of ant, *Camponotus* sp.

Counts of the numbers of mandibles, and in two instances twice the number of heads (for comparative purposes), of these species are given in the first two rows of Table 2.

TABLE 2

Frequency of mandibles of various insect species in faecal pellets from recently captured rabbit bandicoots and from near scratchings made by bandicoots in the study area.

| Origin of pellets | No. of pellets examined/ Total No. | Termites | | | | Ant *Iridomyrmex* species* | Various unknown species |
|---|---|---|---|---|---|---|---|
| | | *Hamitermes rubriceps* | | *Eutermes tumuli* | | | |
| | | Worker | Soldier | Worker | Soldier* | | |
| Bandicoot 1 | 1/5 | 8 | 1 | 76 | 34 | 0 | 0† |
| Bandicoot 2 | 1/12 | 3 | 0 | 60 | 14 | 0 | 0‡ |
| Extreme E edge | 5/5 | 76 | 1 | 2 | 4 | 0 | 0 |
| | | 57 | 1 | 1 | 0 | 0 | 0 |
| | | 72 | 2 | 1 | 2 | 0 | 6 |
| | | 18 | 4 | 0 | 2 | 0 | 0 |
| | | 120 | 6 | 6 | 2 | 0 | 4 |
| SW Centre | 2/2 | 70 | 4 | 0 | 6 | 2 | 1 |
| | | 59 | 0 | 3 | 12 | 0 | 0 |
| Extreme E edge | 2/2 | 87 | 1 | 0 | 2 | 174 | 0 |
| | | 85 | 0 | 0 | 2 | 140 | 0§ |
| E centre | 1/4 | 221 | 6 | 0 | 2 | 0 | 0 |
| Central E edge | 0·5/4 | 34 | 0 | 2 | 14 | 4 | 0 |
| Centre | 0·5/2 | 26 | 0 | 0 | 0 | 8 | 2 |

* No. of heads × 2.
† +1 mandible of *Camponotus* species.
‡ +2 mandibles of *Camponotus* species.
§ +2 mandibles of larval Lepidoptera.

The counts may not represent the relative numbers of individuals eaten. Captive bandicoots masticated their food very thoroughly, and it is possible that a different proportion of mandibles and heads from different food species were crushed beyond recognition. However, most mandibles from pellets were whole, and little changed in shape or colour. There is probably some simple relationship between numbers eaten and fragments in faeces.

After working with faeces known to be bandicoots', we analyzed contents from presumed bandicoot faeces collected near scratchings. These results are given in the remainder of Table 2. They closely resemble those from known bandicoot faeces. In these other pellets, we identified remains of a small black ant, *Iridomyrmex* sp., and a white Lepidopteran larva, as well as species found in the earlier analyses.

The two species of termites were abundant over much of the study area. They were found in vast underground colonies, with domes and mounds raised above the soil surface in places. Bandicoot scratchings often intersected the underground passages, but there was no sign of interference with the mounds. From the numbers of mandibles in the pellets, and from the numbers of scratchings intersecting colonies, it is likely that these termite species were a primary source of food for bandicoots in the study area.

The species of *Iridomyrmex* identified from faeces was also extremely abundant over the area. Being highly active and pugnacious, they readily attacked and carried off termites when given access to their colonies. Because of this, and their ubiquitousness (therefore being readily available where a bandicot was feeding on termites), as well as the fact that their remains only occurred in large numbers in one group of pellets, it is possible that they are only a subsidiary food source, or perhaps even a "contaminant" of the usual diet.

The larger ant, *Camponotus* sp., was less abundant than *Iridomyrmex*. Its sporadic appearance in faeces suggests that this is also a secondary food species.

We found the large white grub (larval Lepidoptera) under two species of tussock grass, *Eragrostis eriopoda* and *E. laniflora*. Of the five grasses scratched under in the study area, these two were the most frequent. Although mandibles of this particular larva were found only twice in a sample of 14 pellets, the large size of the grub (up to 20 mm long), and the large number of tussocks scratched under, suggests that larvae of this species and perhaps other unidentified ones are an important food.

Faeces occasionally contained other materials. Small amounts of plant tissue such as undigested seeds and plant hairs were sometimes present. Unidentified thickened tissue also occurred in moderate amounts. These objects were not consistently present.

### (v) *Activity*

For eight consecutive days we kept a record of the burrows that had been used during the previous night. Thirty five burrows were scored on all eight nights, and more were added to the list as we found them. For the last two days we scored 52 burrows, and considered that we had located at least 90% of all the burrows present. Our method of scoring did not differentiate between a single entry or exit by a bandicoot, nor did it differentiate either of these from multiple entries and exits during one night.

We must assume firstly that our working in the area did not have any effect on the behaviour of the bandicoots present. Although we have no concrete evidence to suggest that this is a valid assumption, we noted that recently captured bandicoots showed little fear of humans or human scent. Secondly, we will assume that the burrows we observed for the longest period were a representative sample of all burrows with respect to use by a bandicoot. We could not detect any visible difference between these burrows and the remaining ones.

For each night we calculated the percentage of burrows which were used out of all those we scored. The mean percentage and its standard error were $15 \cdot 5 \pm 2 \cdot 6\%$, with a range of from $2 \cdot 0\%$ to $26 \cdot 5\%$. The fact that only one burrow was used on one night ($2 \cdot 0\%$), indicates that all the bandicoots present did not forage every night, but spent at least one underground. We recorded overnight minimum temperature during the period, but could not deduce any relationship between it and percentage of burrows used.

When considering the number of times each *individual* burrow was used, it is convenient to take only those burrows scored for all eight nights. The frequency distribution of these 35 burrows showing the number of nights each of them was used is shown in Fig. 6.

Fourteen burrows (40%) were not used on any night. These burrows did not appear to be distributed at random over the area, but a statistical test is inpractical because of the small numbers involved. They tended to be on or near the eastern edge, where habitats with spinifex predominated. From Fig. 6, we can also note that more burrows were used on two occasions than on one. This can be explained when we consider that a bandicoot spending a day in a burrow would use it on entering one night and leaving on a subsequent night. It would be scored both times.

We know that there were at least two female bandicoots in the study area, because we captured two from burrows about 1,400 feet (425 m) apart on the western edge of the area. This was within two days of completing the observations on activity. Outside the study area, the nearest locality we found where rabbit bandicoots were living was about 3 miles (5 km) away. Even assuming no migration to or from the study area, it is impossible to estimate the total number of bandicoots present.

Because there were no signs of activity beyond 600 feet (180 m) from the nearest burrow, we may assume that for both female bandicoots captured, their home range was completely covered by the study area.

(f) *Notes on captive specimens*

The two adult females we caught in the study area did not have pouch young when taken in mid-December, nor when examined a month later.

When kept unavoidably at an air temperature of 100° F (39° C) for a short period, they lapped the water which was supplied. There was no permanent water available in or near the study area, and it is unlikely that bandicoots experience such high air temperatures in the wild. At these temperatures, they slept on their sides, with tail, hind-feet, and head all extended. However, at lower temperatures they slept crouched on all four feet, with the nose tucked under the chest, the tail curled around the body, and the ears folded forward over the eyes.

The captives started to eat chopped, tinned beef and to drink milk about a week after being taken into captivity. Later, they ate minced fresh meat and live mealworms.

## DISCUSSION

Where our study overlaps with those of other recent authors, the general results agree.

Marlow (personal communication) caught two rabbit bandicoots in an area of similar habitat on April 5 and 6, 1965. At latitude 20°49′ S. and longitude 130°15′ E., (about 25 miles (40 km) NW. of The Granites, N.T.), the bandicoots were living in an area of spinifex-*Melaleuca* scrub, with sandy soil and numerous termite mounds. One of the bandicoots, a female, is preserved in the Australian Museum, registered number M8620.

A brief survey of the distribution of rabbit bandicoots near Warburton Mission indicated that they lived in small isolated groups over a large area. Newsome (1962) says he found that rabbit bandicoots were living in at least four and perhaps six localities in a rectangular area 50 miles long by 30 miles wide (80 km by 50 km) in Central Australia. It is probable that rabbit bandicoots utilize only a small percentage of the large homogeneous areas which could support them.

Insect larvae and small vertebrates have both been the most frequently noted types of food of the rabbit bandicoot, e.g. Marlow (1962). Finlayson (1935) found rodent fur in the gut of a closely related species, *Macrotis minor* (Spencer). Although house mice, *Mus musculus* Linne, were present in the study area, their fur did not appear in any of 50 pellets cursorily examined. Aboriginal reports clearly indicated that the rabbit bandicoot eats the large witchetty grubs, (larvae of buprestid beetles), when they are present in the roots of the witchetty bush, *Acacia kempeana*. Gould (1845) made a similar observation in South-Western Australia. At the time of our study, witchetty grubs were absent from the study area, although aboriginals claim that they had been plentiful in former times.

The food of the rabbit bandicoot reported here is remarkably similar to that of the marsupial, *Myrmecobius fasciatus* Waterhouse, (banded ant-eater), which Calaby (1960) studied in South-Western Australia. He found that termites of many species, all different from those recorded above, were the principal food, and that remains of ants were also often found in faeces. Likewise, he argued that ants were ingested incidentally while termites were being eaten. However, he found no traces of Lepidopteran or other insect larvae.

There is little concrete data on the breeding of the rabbit bandicoot. Wood-Jones (1924) comments that breeding of *Macrotis* in Central Australia is regulated by rains and abundance of food, an observation made on many species which live in a climate without regular seasonal variation. Two other species of bandicoots have been shown to breed throughout the year. Lyne (1964) working with *Perameles nasuta* Geoffroy, and Mackerras and Smith (1960) with *Isoodon macrourus* (Gould), have both recorded breeding during all seasons.

Observations of activity of the rabbit bandicoot are limited, but Wood-Jones (1924) has noted that captives usually emerged about an hour after dusk. Stodart (1966) observed the long-nosed bandicoot, *Perameles nasuta* Geoffroy in a ½-acre enclosure. She found that they usually emerged from their nests at dusk, and most of their activity was completed after about two hours. They spent nearly all of this time searching for food.

Although we found that a group of rabbit bandicoots lived in a small proportion of an area with the potential to support them, we have no evidence concerning territorial behaviour within this small area. Two male and four female long-nosed bandicoots in an enclosure did not have territories (Stodart, 1966) and were solitary feeders, with intentional contact between individuals restricted to actual mating.

The rabbit bandicoot was moderately plentiful and widespread in temperate and arid Australia during the last century. However, a rapid decrease in range and numbers has been the pattern in recent years, especially in the more temperate regions. It has not been recorded from New South Wales since 1912 (Marlow, 1958), and from Victoria since at least 1866 (Brazenor, 1950). In 1934, it was said to be widely distributed in Western Australia south of the Kimberley region (Glauert, 1934), but twenty years later he reported that there were "no reports of its presence anywhere (in Western Australia) within recent years", (Glauert, 1954). In arid South and Central Australia, Finlayson (1961) claimed that it was rapidly being reduced to a rare form, but Newsome (1962) indicated that it had recently been recorded from 36 localities in the Northern Territory. Rabbit bandicoots were taken near Birdsville in South-Western Queensland during 1957 to 1959 (Mack, 1961), but while in the area recently, we obtained good evidence that the bandicoots disappeared there about five years later. Thus, a steady reduction in range towards parts of arid Central Australia seems to be taking place, with no evidence that this reduction is slowing down or stopping.

An attempt to conserve some natural populations of rabbit bandicoots is probably necessary now if they are to continue as one of Australia's naturally occurring species. Successful conservation of a species depends largely on a knowledge of its distribution and ecology. We hope our study will be useful to those who plan to conserve the rabbit bandicoot in its natural habitat.

## ACKNOWLEDGEMENTS

This work was supported by a Nuffield Foundation Research Grant to the Royal Zoological Society of South Australia, and was administered by the Society's President, Dr. P. S. Watts.

We wish to thank Professor H. G. Andrewartha of the Department of Zoology, University of Adelaide, for encouragement, guidance and for many useful discussions. The Council and Staff of the Royal Zoological Society of S.A. gave us unlimited help. We received excellent co-operation from the Western Australian Fisheries Department, and Mr. A. J. Fraser, Chief Warden of Fauna. Finally, we wish to thank the Western Australian Department of Native Welfare; and the superintendent, staff and people at the Warburton Ranges Mission for generous help.

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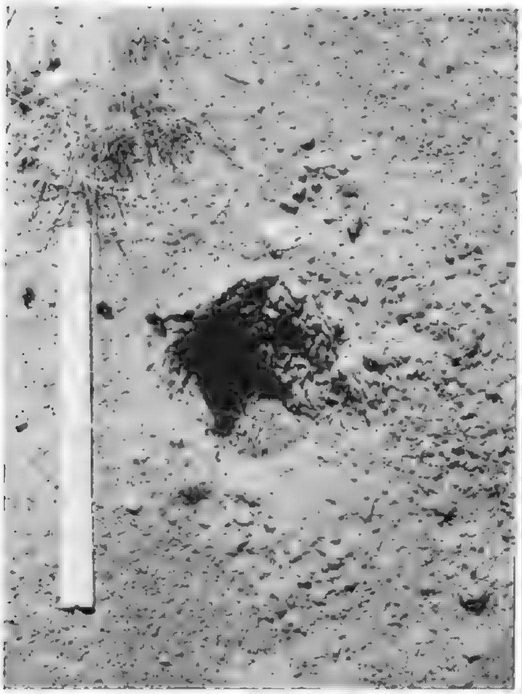

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PLATE 1

Fig. 1. An immature female rabbit bandicoot from 120 miles east of the study area. Approx. 0·28 x natural size.

Fig. 2. Cylindrical bandicoot scratching, with faecal pellets on the top edge. The measure is 1 foot (30 cm) long.

Fig. 3. Conical bandicoot scratching under *Eragrostis laniflora*. The measure is 2 in. x 1½ in., (5·0 cm x 3·5 cm).

1

2

3

PLATE 2

Fig. 1. Rabbit bandicoot faeces, showing groups of pellets voided together. The scale is in inches and centimetres.

Fig. 2. Bandicoot burrow near a fallen mulga log.

Fig. 3. Bandicoot burrow with tailmarks on the mound of soil at the entrance. The measure is 1 foot (30 cm) long.

1

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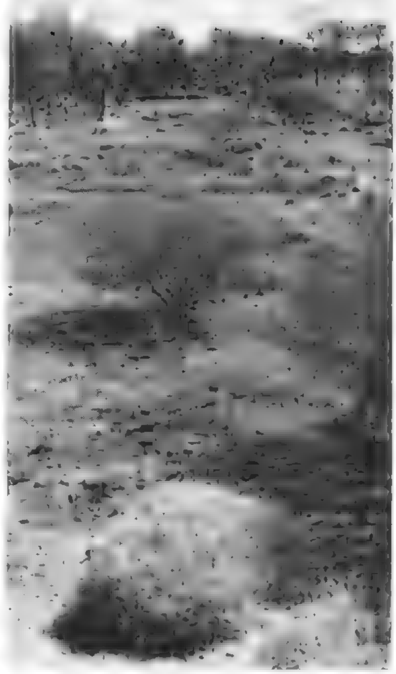

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PLATE 3

Fig. 1. Open mulga scrub, with a burrow at the base of a mulga in the foreground. This vegetation type contained only 2 burrows.

Fig. 2. Mulga-tussock scrub, with a burrow partially hidden by tussock grass in the foreground.

Fig. 3. Mulga-spinifex scrub, with bandicoot scratchings in the foreground.

Fig. 4. Open spinifex glade, showing low rocky hills in the background. There were only 2 burrows in this vegetation type.

# AN ANALYSIS OF VEGETATION ON STRANDED COASTAL DUNE RANGES BETWEEN ROBE AND NARACOORTE, SOUTH AUSTRALIA

*BY R. M. E. WELBOURN AND R. T. LANGE*

**Summary**

The presence or absence of 80 species has been scored in 330 samples of sclerophyll forest on nine dune ranges, and the data classified by association analysis.

The vegetation is a mosaic of groups, within which four main groups may be distinguished. These roughly correspond to orthodox vegetation societies, lint key species are determined solely by measured association with other species, without reference to physical prominence. For example, the species with the highest degree of association in this study, *Phyllota pleurandroides,* is a small shrub.

The potential value of the groups in vegetation mapping is indicated.

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The presence or absence of 80 species has been scored in 330 samples of sclerophyll forest on nine dune ranges, and the data classified by association-analysis.

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## INTRODUCTION

The purpose of this study was to show by measurement, the floristic composition of the dune range vegetation and to discuss factors controlling its disposition. A discussion of analytical methods used has been published elsewhere (Welbourn and Lange, 1967). The study was an M.Sc. project with the University of Adelaide, to whom, with the State Herbarium of South Australia, grateful acknowledgment is made.

The habitats are distinct ranges considered to be successively younger toward the present coast. In the area studied there are at least twelve ranges subparallel to the coast, about 2 km wide by 30 m high above the otherwise flat countryside (Pl. 1). Each range consists of two portions. The core is more or less consolidated calcareous beach sand, a relic of coastal dunes formed at various stages of the Pleistocene from about 600 to 200 thousand years B.P. (Sprigg, 1952). This material outcrops westward as aeolianite limestone, parent material of the terra rossa soil carrying open woodland. Overlying this core are siliceous sands, of uncertain origin but considered to be windsorted, leached and of Recent age (Blackburn *et al.*, 1965). These sands form the bulk of each range, and are the parent material of the podsol which supports the predominant vegetation. This is largely the *Eucalyptus baxteri* association within the dry sclerophyll forest formation (Crocker, 1944).

Pattern, the degree of non-randomness in the spatial distribution of individuals, was the vegetation feature investigated. Since pattern reflects habitat variation, the patterns of ecologically similar species tend to coincide, or associate, thus indicating a vegetation group. The variable commonly measured to reveal such groups is species frequency, the proportion of sample quadrats occupied. Associations were determined with such data in this study.

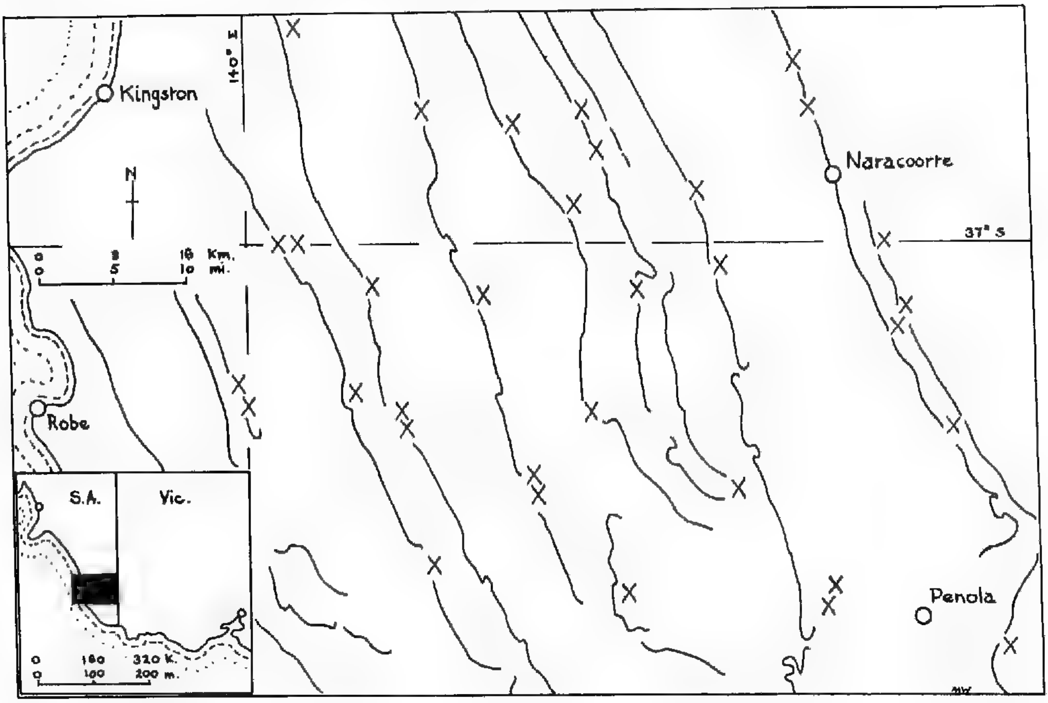
Kingston
140° E
N
Km.
mi.
Naracoorte
37° S
Robe
S.A.
Vic.
Penola

Fig. 1.

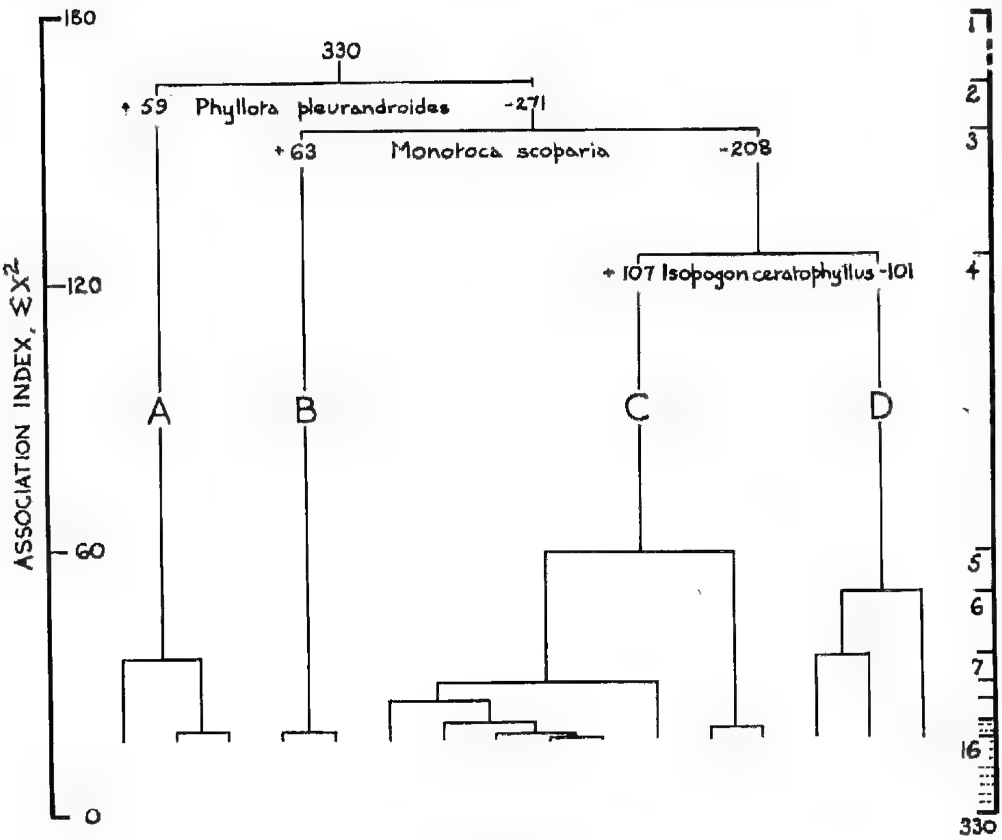
ASSOCIATION INDEX, $\Sigma X^2$
180
120
60
0
330
+ 59 Phyllota pleurandroides -271
+ 63 Monotoca scoparia -208
+ 107 Isopogon ceratophyllus -101
A
B
C
D
NUMBER OF GROUPS
1
2
3
4
5
6
7
16
330

Fig. 2.

## METHODS

The area bounded by Kingston, Naracoorte, Penola and Robe was selected for study because the dune ranges are most distinct here (Fig. 1). Sampling areas were located within the remaining estimated 750 sq. km of vegetation so that the variation of mean annual rainfall, about 200 mm, would be represented on each range. Most of the vegetation was unnatural in some way, so that, having excluded areas obviously disturbed, or burnt less than four years before, or dominated by bracken, 33 areas remained. At each of these, ten 20 sq. m circular samples were located randomly where feasible, otherwise systematically. All species likely to occur in upland sites in the area studied were scored; also *Banksia marginata* and *Calytrix tetragona* were divided into *ad hoc* forms to render the data more sensitive to habitat variation. A reference collection of relevant species was used throughout.

The method selected to reveal vegetation groups was association-analysis as proposed by Williams and Lambert (1959). Their recommended association index is for each species the sum of all the *chi-squared* values obtained from contingency testing with each other species in turn. The procedure is to subdivide the 330 samples firstly into two groups, respectively with and without the appropriate key species. The key species is that with the highest association index at any stage of subdivision. Within each of the groups thus formed, the process is repeated, fractionating the original single group of 330 samples into progressively more subdivisions. In this study, only species with a frequency greater than 1% were considered; data were computed electronically, and subdivision was stopped at 16 groups.

## THE VEGETATION

The analysis in these terms reveals a series of groups of decreasing importance, conveniently represented as a hierarchy (Fig. 2). The validity of any group as a recognizable vegetation community is indicated by the range of association index over which it persists undivided; this is supported by its containing relatively few minor groups. For example, Group B subdivided on *Monotoca* is such a community, since it persists from Index 155 to Index 20, and embraces only two minor groups as far as the data were analysed.

On this basis four such groups may be distinguished from the complex mosaic of groups of varying validity which comprise the samples studied. These groups, A to D, exist simultaneously over a larger range, 125 to 60, than any other number of groups. Thus within the limitations of the analysis, they are communities approximating societies within the *Eucalyptus baxteri* association. They are identified by 16 indicator species which vary in frequency between groups (Table 1). For example, vegetation containing *Monotoca*, *Persoonia* and *Acacia spinescens*, but not *Pultenaea*, would be either Group A or B. If furthermore it contained *Phyllota*, *Xanthorrhoea* and *Boronia*, but not *Ac. oxycedrus* or *Styphelia*, it would be Group A.

On the other hand, the remaining 64 species analysed are relatively insensitive to the discontinuities that affect the key species. Of these, 22 have a frequency greater than 30% (Table 2), their similar group frequencies indicating their unbiased distribution throughout the area studied. The appearance of the vegetation is dominated by the five species of frequency greater than 75%, *viz.* the tree *E. baxteri*, the small shrubs *L. myrsinoides* and *X. australis*, and the undershrubs *H. sericea* and *L. virgatus*. Superimposed upon this picture of four groups

TABLE 1

INDICATOR SPECIES

Species used to identify the groups; relatively high frequencies are in bold faced type.

| Species | Overall | Frequency % A | B | C | D |
|---|---|---|---|---|---|
| *Monotoca scoparia* (Sm.) R.Br. | 22 | **17** | **100** | 0 | 0 |
| *Persoonia juniperina* Labill. | 8 | **17** | **21** | 5 | 0 |
| *Acacia spinescens* Benth. | 2 | **10** | **2** | 0 | 0 |
| *Pultenaea prostrata* Benth. *ex* Hook. f. | 9 | 3 | 0 | **13** | **8** |
| *Phyllota pleurandroides* F. v. M. | 18 | **100** | 0 | 0 | 0 |
| *Xanthorrhoea quadrangulata* F. v. M. | 6 | **32** | 0 | 0 | 0 |
| *Boronia coerulescens* F. v. M. | 3 | **14** | 0 | 1 | 0 |
| *Hibbertia virgata* R. Br. *ex* DC. var. *crassifolia* (Benth.) Black | 5 | **27** | 3 | 0 | 0 |
| *Lhotskya alpestris* (Lindl.) Druce | 7 | **25** | 0 | 2 | 6 |
| *Acacia oxycedrus* Sieb. *ex* DC. | 2 | 0 | **11** | 0 | 0 |
| *Thomasia petalocalyx* F. v. M. | 15 | 29 | 2 | 15 | 14 |
| *Styphelia adscendens* R. Br. | 5 | 0 | **16** | 2 | 5 |
| *Eucalyptus obliqua* L'Herit. | 12 | 8 | 3 | **28** | 4 |
| *Isopogon ceratophyllus* R.Br. | 57 | 77 | 68 | **100** | 0 |
| *Dodonaea viscosa* Jacq. | 4 | 3 | 0 | 0 | 11 |
| *Leucopogon collinus* (Labill.) R.Br. | 23 | 49 | 30 | 22 | 5 |

TABLE 2

COMMON SPECIES

Species of overall frequency greater than 30%; frequencies greater than 75% are in bold faced type.

| Species | Overall | Frequency % A | B | C | D |
|---|---|---|---|---|---|
| MYRTACEAE | | | | | |
| *Eucalyptus baxteri* (Benth.) Maiden *et* Blakely *ex* Black | **89** | 95 | 97 | 72 | 74 |
| *Leptospermum myrsinoides* Schldl. | **89** | 97 | 98 | 94 | 70 |
| *Calytrix tetragona* Labill. (glabrous form) | 30 | 15 | 56 | 28 | 24 |
| EPACRIDACEAE | | | | | |
| *Leucopogon virgatus* (Labill.) R.Br. | **80** | 61 | 86 | 82 | 84 |
| *Astroloma conostephioides* (Sond.) F. v. M. *ex* Benth. | 74 | 70 | 86 | 70 | 74 |
| *Brachyloma ciliatum* Benth. | 63 | 42 | 70 | 65 | 65 |
| *Leucopogon ericoides* (Sm.) R.Br. | 52 | 19 | 60 | 45 | 79 |
| *Epacris impressa* Labill. | 51 | 47 | 40 | 58 | 31 |
| *Acrotriche serrulata* (Labill.) R.Br. | 47 | 32 | 52 | 61 | 39 |
| *Astroloma humifusum* (Cav.) R.Br. | 34 | 19 | 13 | 38 | 51 |
| *A. humifusum* var. *denticulatum* (R.Br.) Black | 31 | 34 | 25 | 23 | 44 |
| PROTEACEAE | | | | | |
| *Banksia ornata* F. v. M. *ex* Meisn. | 61 | 86 | 65 | 64 | 39 |
| *Isopogon ceratophyllus* R.Br. (see Table 1) | 57 | x | x | x | x |
| *Banksia marginata* Cav. (shrub form) | 49 | 63 | 57 | 57 | 25 |
| *Banksia marginata* Cav. (tree form) | 34 | 12 | 32 | 35 | 47 |
| LEGUMINOSAE | | | | | |
| *Acacia myrtifolia* (Sm.) Willd. | 30 | 41 | 59 | 26 | 13 |
| *Kennedia prostrata* R.Br. *ex* Ait. | 30 | 20 | 35 | 36 | 23 |
| OTHER FAMILIES | | | | | |
| *Hibbertia sericea* (R.Br. *ex* DC.) Benth. | **84** | 80 | 86 | 82 | 85 |
| *Xanthorrhoea australis* R.Br. | **80** | 76 | 84 | 93 | 61 |
| *Hibbertia stricta* (DC.) F. v. M. | 62 | 83 | 54 | 70 | 40 |
| *Hypolaena fastigiata* R.Br. | 60 | 78 | 81 | 62 | 35 |
| *Tetratheca ciliata* Lindl. | 48 | 25 | 70 | 55 | 38 |
| *Correa reflexa* (Labill.) Vent. var. *reflexa* | 40 | 39 | 62 | 49 | 18 |

contrasted with common widespread species, are 42 species with similar frequency to that of the indicators, 2 to 29%, but occurring haphazardly in the groups and thus distributed unpredictably throughout the vegetation. Superficially, then, the dry sclerophyll forest studied appears to comprise an open tree canopy over a layer of small shrubs dominated by relatively few species. The overall impression is of uniformity. However measurement reveals that, of the numerous low frequency species, some consistently associate in societies or groups.

Since it is difficult to assess the validity of the groups other than by field experience, it is necessary to state at least some sources of error inherent in the methods used. Firstly, there are the basic errors due to a sampling intensity of about 0·001%, and to operator fallibility in naming and scoring species. Secondly, data based on frequency are liable to misrepresentation because quadrat size affects the results. For example, a large quadrat overemphasizes uncommon species, whilst a small quadrat underemphasizes the importance of species of patchy distribution. This defect can be overcome only with additional data on variables such as density. Thirdly, the analytical method was arbitrarily selected from several which might have been used (Welbourn and Lange, 1967). Its most serious fault is that in subdividing on a single association index, this method does not indicate the extent or nature of any subordinate association which may exist. That is, there is no indication of the overall confidence with which a particular subdivision is made. Furthermore the association index itself falls short of theoretical excellence. Finally, it should be recognized that any such method imposes definite cut-off points to groups between which there is some continuity. Nevertheless such groups provide at least an objective basis upon which to classify and map vegetation variation.

Fig. 3 is such a map which reveals that the groups themselves are more or less geographically restricted. For example, Group A tends to the north-central area, B to the south-east, C to the west and south, and D to the east and north. Since these appear not to be chance distributions, there are likely to be environmental factors correlated with them. Several factors will be discussed, to illustrate the sort of hypothesis which may arise from such vegetation mapping.

If time was the only factor involved, some groups could be expected to represent stages in a succession, and so to predominate on ranges of similar age. Such trends are apparent; for example, between Naracoorte and Robe, Group D is gradually replaced firstly by A and B, then by C on the younger ranges. However, this evidence rests on the assumption that all other environmental factors are held constant. This was not so in the case of soil and topography which were more variable than expected. Thus the correlation of vegetation with habitat age cannot be tested under the sampling conditions of this study. Similar remarks apply to a correlation with aspects of climate such as coastal influence and annual rainfall.

From field descriptions of the sampling areas, it is apparent that variations in soil and topography are correlated to some degree with vegetation variations. For example Group A occurs on sand ridges normal to the ranges, suggesting an immature profile; the *Eucalyptus baxteri* here is stunted, and *E. diversifolia* Bonpl. was observed nearby suggesting a gradation to the solodized solonetz soil common to the north. Group B occurs on deep sands in the higher rainfall area; the vegetation is profuse and undisturbed. Group C is a diversified group which tends to occur in flat, shallow areas, particularly to westward where the ranges appear to have less siliceous sand covering the limestone. The next subdivision of this group (Fig. 2) is on *E. obliqua*, a species known to occur on shallower soils. Group D occurs on the eastern sides of ranges well away from limestone, but with some seasonal watertable influence.

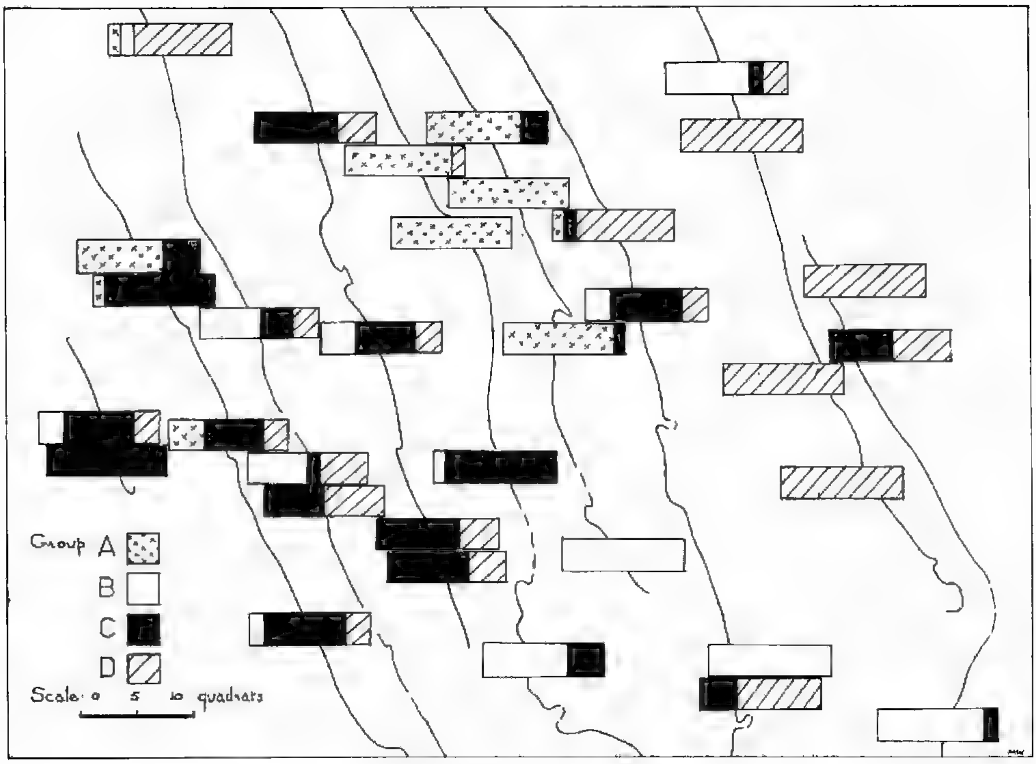


Fig. 3.

Clearly, profile measurements and more intensive sampling are required to substantiate any correlation of vegetation with soil and topography. Such correlation, once established, will be of value in habitat classification and mapping.

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Plate 1

General view of the area studied, looking eastward towards Naracoorte. Three ranges, each partly cleared of natural vegetation, are emphasized in the foreground and middle distance with a line along their crests.

# FURTHER TAXONOMIC NOTES ON THE SPECIES OF MILLOTIA CASSINI (ASTERACEAE)

*BY RICHARD SCHODDE**

**Summary**

One new species, *Millotia inopinata,* is described and chromosome numbers for it, *M. myosotidifolia* (Benth.) Steetz, and *M. tenuifolia* Cass. are reported. Attention is drawn to the reported tolerance to and accumulation of copper in *M. myosotidifolia.*

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[Read 9 November, 1967]

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Since the publication of my taxonomic account of the genus *Millotia* Cass. (Schodde, 1963), further material and information have become available. The abbreviations AD, CANB, K, MEL, PERTH used in the text refer respectively to the State Herbarium of South Australia, Adelaide, South Australia; the herbarium, C.S.I.R.O., Canberra, A.C.T.; the Herbarium, Royal Botanic Gardens, Kew, England; the National Herbarium, Royal Botanic Gardens, Melbourne, Australia; and the Western Australian Herbarium, Perth, Western Australia.

1. **Millotia inopinata** Schodde, sp. nov.—Fig. 1

*M. myosotidifolia* (Benth.) Steetz proxima, cujus involucrum, formam flosculorum, et cypselas plerumque strigulosas habet, sed habitu latiore, foliis ± anguste lineari-oblanceatis vel paene filiformibus, capitulis ± depressis globosis vel aliquantum turbinatis, bracteis involucralibus ad apices plerumque rotundatis, corollis aureo-flavis, cypselis aliquantum longioribus in rostris deflexis, papillis cypselarum ad apices integris et ± patentibus vix strigosis in rostris cypselarum, et pappi setis 5-8 grosse barbellatis vel sub-plumosis differt.

*Typus*: *B. L. Turner 5424*: CANB 156680 (*holotypus*), AD, K, PERTH: Western Australia, 82 mi. (miles) N. (north) Murchison River along North West Coastal Hwy. (Highway), 26 Aug. 1965.

Grey somewhat virescent *herb*, 2-11 cm tall, 2½-12 cm broad, with 4-10 *stems* branched and ascending broadly rarely rather erectly from the base, covered generally with a rather sparse white lanate *indumentum*, and bearing (2-)5-25 *flower heads*. *Leaves* relatively sparse and appearing confined towards stem bases due to the prominent peduncles, narrow linear or linear-oblanceate to almost filiform where attached towards bases and apices of stems, (½ –)¾ – 2(– 3) cm long × (¼ –)½ – 1(– 1½) mm broad at the widest part, obscurely mucronate at the apices, slightly or scarcely amplexicaul. *Peduncles* (½ –)¾ – 3 (– 4½) cm long, raising the flower heads ½ – 2½ (– 3½) cm above tops of cauline leaves, appearing hardly or, due often to denser woolliness, slightly expanded under involucres, and bearing occasional or frequent filiform *peduncular leaves* 3-10 (– 15) mm long.

*Flower heads* ± depressed globose or somewhat turbinate when mature, 6-9 mm long × (7 –) 8-11 or more mm broad, bearing ca (10 –) 25-80 + *florets*. *Involucres* (3 –) 3½-4½ mm long, of (7 –) 9-12 (– 13) ± biseriate and imbricate equilong oblong *bracts* (⅔ –) 1-1½ mm broad with rather lanate to glabrous carinate midribs narrower than the broad ± glabrous or sparingly lanate scarious margins and with apices broadly obtuse when mature (though rather acute to shortly caudate when young) and often finely or obscurely fimbriate or barbate.

* Division of Land Research, C.S.I.R.O., Canberra, A.C.T.

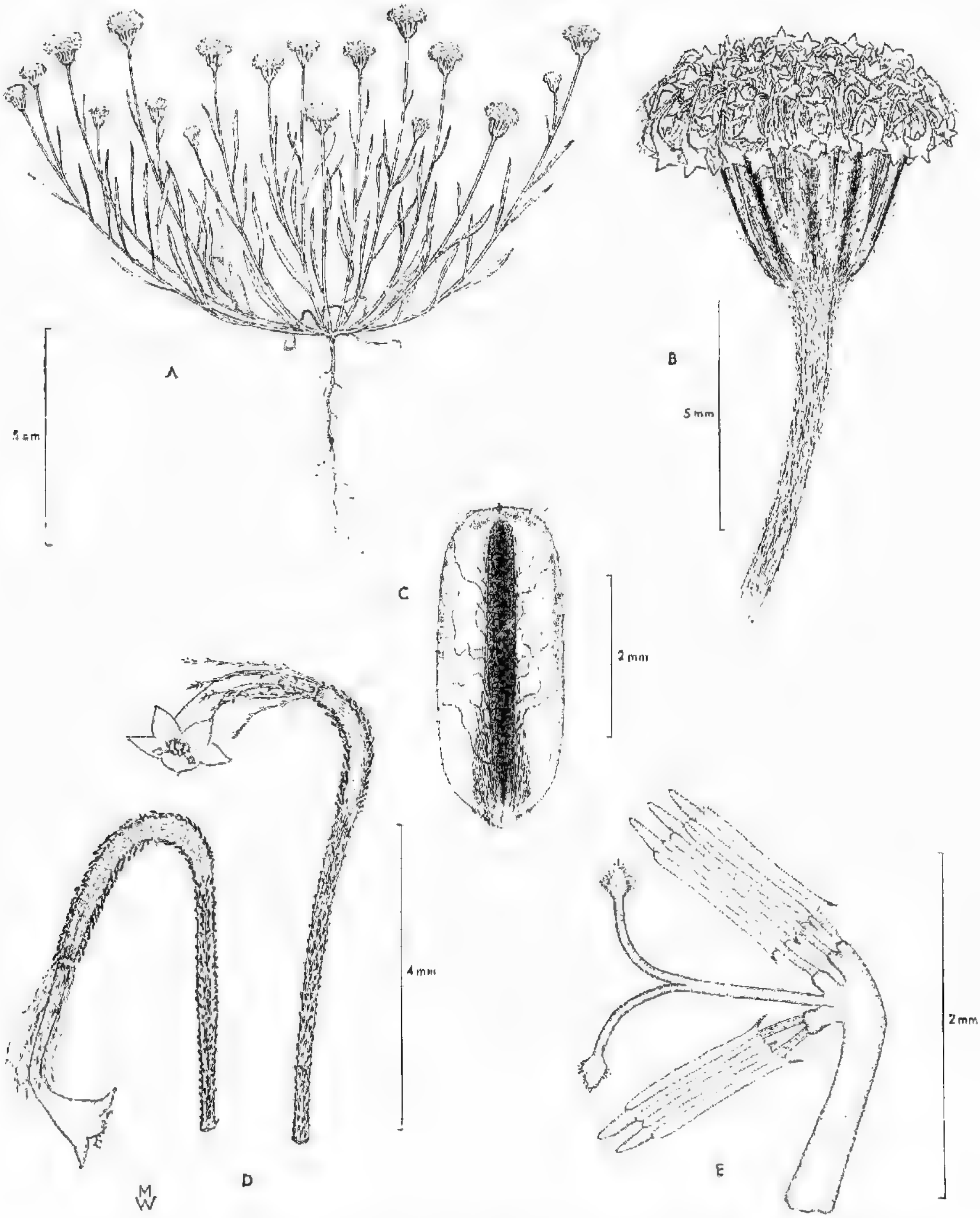


Fig. 1. A, whole plant; B, mature flower head; C, involucral bract; D, florets with maturing cypselae; and E, whole style and androecium.

*Corollas* rather narrow infundibuliform, 2½-3½ (−3¾) mm long, bent below the throat and deflexed over involucre when mature (central corollas as deflexed as or somewhat more erect than peripheral corollas), bright golden yellow with the tube becoming brownish after anthesis; *corolla* limbs of 5 (exceptionally 4) spreading acute lobes ⅓-⅔ mm long. *Stamens* 5, with apices becoming exserted to or a little beyond rims of corolla limb; *anthers* with oblong thecae ¾-1 mm long, the *connective tips* extended ⅓-⅔ mm beyond thecae. *Style branches* ⅔-1¼ mm long, dilated broadly at the apices with conoidal acute *appendages*. *Cypselae* linear, 6-9 (−10) mm long, sharply deflexed from near base of beaks over involucre and protruding 3-4 (−5) mm beyond at maturity, variously dark brown, sparsely hispidulous-strigillose; *cypsela beaks* (2½ −) 3-5 mm long at maturity, compressed and most broadly so on area of deflexion; *cypsela papillae* ± terete to narrow cylindrical clavate, ± ⅓ mm long, entire rather expanded obtuse at the apices, colourless more-or-less transparent, somewhat appressed and diffuse on body of cypsela, rather spreading, denser, and confined to margins of compressed faces on beak. *Pappi* of 5-8 twisting more-or-less erect *setae* ± ½-¾ as long as corollas, becoming sparsely coarse barbellate or semi-plumose towards the apices. *Chromosome number*: n = 8 (fide B. L. Turner).

## DISTRIBUTION AND ECOLOGY

Known presently from three collections: leg. A. S. *George 7978*: PERTH: 29 miles west of Mt. Magnet, comprising 12 plants, leg. C. H. Giffins 1540: PERTH: 7 miles south of Wannoo Roadhouse, comprising 7 plants, and the type collection, of 14 plants, from 82 miles north of Murchison river. All localities are in the central west region of Western Australia.

According to Turner (pers. comm.), the species was locally common in the type locality on coarse sandy soil in open areas with burned-over mulga (*Acacia* sp.); George records it in sandy loam at a granite outcrop. Flowering: August-September.

## CHARACTERS AND AFFINITIES

*M. inopinata* is closely related to and sympatric with *M. myosotidifolia*. The morphological similarities lie in the long compressed beaks and cylindrical mostly appressed papillae of the cypselae, the form of the corolla, androecium and style branches, the narrowly midribbed bracts, and the wholly lanate indumentum. The new species would be identified as *M. myosotidifolia* when my key to the species of *Millotia* (Schodde, 1963) is used but may be distinguished by the following characters against which the contrasting characters of *M. myosotidifolia* are bracketed: cypselae with beaks conspicuously deflexed and papillae obtuse at the apices (beaks erect and papillae minutely notched); corollas deep golden yellow (creamy white rarely creamy yellow); pappus bristles 5-8, ± ⅔ as long as corolla (bristles usually (15 −) 18-25 (− 30), ± as long as corolla, very rarely fewer and shorter); mature flower heads depressed globose (cylindrical-globose); apices of involucral bracts broad rounded obtuse, often finely or obscurely fimbriate, rarely attenuated (caudate more-or-less entire, rarely to acuminate or acute); leaves narrow linear-oblanceate to almost filiform (¾ −) 1-2 (− 3) cm long × (⅓ −) ½-1 (− 1½) mm broad (narrow to broad oblanceate or occasionally somewhat spathulate (½ −) 2-4 (− 6) cm long × (1 −) 2-5 (− 8) mm broad); habit broadly ascending (ascending to erect).

The chromosome numbers so far recorded, n = 8 in *M. inopinata* and n = 10 or 11 in *M. myosotidifolia* (see below), also appear to be consistent with differences between the two species. Additional counts from the localised populations of *M. inopinata* and from the eastern Australian populations of *M. myosotidifolia* are needed, however, to determine how far these numbers are characteristic of the species.

It is noteworthy that a number of the characters distinguishing *M. inopinata* from *M. myosotidifolia* resemble those of the eremaean *M. greevesii* F. Muell., in particular the habit, shape of leaf and flower head, depauperate pappus, and corolla colour. This may be a case of parallelism in so far as *M. inopinata* occurs towards the north-west and arid margins of the geographic range of *M. myosotidifolia*. There appear to be similar convergences in the characters distinguishing *M. macrocarpa* Schodde from its nearest relative, *M. tenuifolia* Cass.

There are also similarities between the new species and *M. depauperata* Stapf, which was reduced to *M. myosotidifolia* (Schodde, 1963), and to evaluate them Professor B. L. Turner (pers. comm.) has examined the type of *M. depauperata*. This specimen, though like *M. inopinata* rather than *M. myosotidifolia* in its few bristled pappus, apparently obtuse-tipped cypsela papillae, and broad-tipped involucral bracts, is apparently too young and depauperate in its various characters to permit certain identification. Turner considers that in general habit it resembles *M. myosotidifolia* and that its cypsela papillae and involucral bracts, though slightly different from much of the material of *M. myosotidifolia* he examined, do match certain determined collections of that species well enough, e.g. Pritzel 545. In the present circumstances, there seems to be little point in treating *M. depauperata* as anything else than a synonym of *M. myosotidifolia*.

2. **Millotia myosotidifolia** (Benth.) Steetz

*Chromosome number*: n = 10 or 11, reported by B. L. Turner. Vouchers: *Turner 5283*, 13 miles north of Norseman (n = ca 10): MEL; *Turner 5442*, 7 miles south of Three Springs (n = 10): MEL; *Turner 5482*, 30 miles south of Mandurah (n = 11): MEL. All localities are in southern Western Australia.

Blissett (1966) has recorded tolerance to and accumulation of copper in plants of this species found growing exclusively and abundantly on strips of open ground directly below old copper-bearing dumps from the Ukaparinga copper mine near Williamstown, South Australia. Spectrographic analysis of sample collections showed copper contents of approximately 40,000 p.p.m. in the ash of green plants and approximately 4% in the ash of dead plants. Voucher: *I. Moisseeff s.n.*, Ukaparinga Coppermine, 1½ miles east of Williamstown: AD96647108.

It is of interest to mention that the species has also been observed growing abundantly on the rocky dumps from the old Blinman copper mine, at Blinman, South Australia. Vouchers: *D. N. Kraehenbuehl 18*, rocky hillslopes of the old Blinman Copper Mine at the north end of Blinman: AD 95909049; *R. Schodde 997*, hillslopes of the old Blinman Mine at the north end of Blinman: AD95908084.

3. **Millotia macrocarpa** Schodde

The shape of the corolla is more accurately described as very narrow infundibuliform cf. the original description of the species in which the term "narrow cyathiform" was intended to apply to the throat only, not the whole corolla.

4. **Millotia tenuifolia** Cass.

*Chromosome number*: n = 13, reported by B. L. Turner. Vouchers: *Turner 5271*, 5 miles north of Norseman: MEL; *Turner 5315*, 14 miles west of Southern Cross: MEL; *Turner 5516*, 53 miles north of Albany: MEL. The counts are all from var. *tenuifolia* and the localities are all in southern Western Australia.

My attention has also been drawn to a recently collected specimen of this species from near Collie, in southern Western Australia (leg. *P. G. Wilson 3750*: CANB 161828) which is unusual in possessing predominantly 5-lobed corollas, and short laevigate cypselae 3-4 mm long at maturity, only $\frac{2}{3}$-$\frac{3}{4}$ as long as the involucre, and with short beaks $\frac{1}{2}$-1 mm long. It extends the known variation of the species in these characters.

## ACKNOWLEDGEMENTS

Thanks are due to Professor B. L. Turner, University of Texas, Austin, Texas, U.S.A., and Mr. P. G. Wilson for their collaboration, particularly to Professor Turner for making available the chromosome counts and checking details of *Millotia inopinata* against the type of *M. depauperata* at Kew. Professor Turner's investigations were assisted by a National Science Foundation Grant GB1216.

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# A NEW SPECIES OF *PTILOTUS* FROM SOUTH AUSTRALIA
## (*Amaranthaceae*)

By G. Benl, F.L.S.*
(Communicated by Hj. Eichler)

[Read 11 April, 1968]

## SUMMARY

A description and an illustration are given of a new species of *Ptilotus*, *Pt. symonii* from South Australia. The type specimens are cited and some critical notes are made on some characters of the new taxon which is compared with *Pt. seminudus* (J. M. Black) J. M. Black and other species.

A recent examination of specimens of Ptilotus sent us from both the State Herbarium of South Australia (AD) and Mr. D. E. Symon (Herbarium ADW) revealed the existence of a hitherto unknown species which is here described as follows:—

*Ptilotus symonii* Benl, sp, nov. (Fig. 1, a-c).

Planta perennis, pluricaulis, in statu iuvenili leviter tomentosa, demum subglabra. Rhizoma lignosum adscendens, plusminusve tortuosum, fusiforme, in speciminibus examinatis usque ad 25 cm longum, superne 16 mm crassum. Caules 50 cm et ultra longi, 1-3 mm diametro (in basi lignosa 3,5 mm crassi), virgati, saepius curvato-adscendentes, visu cinerei dein pallido-virides; iuveniles teretiusculi per totam longitudinem pilis crispis crassiusculis nodulosis, ad 1,5 mm longis dense, adulti sulcati sparse induti. Rami valde ramulosi, ramuli tenerrimi subdensi, adscendentes, divaricati vel patulo-erecti, ad 20 cm longi; basales 7-22 mm distantes, summi approximati, usque ad inflorescentiam dense foliati.

Folia permulta minora quin etiam minima, alterna interdum specie secunda (Fig. a), 2-6 mm, raro ad 13 mm distantia, primo modice puberula denique glabra et laete viridia, plusminusve coriacea, integerrima, siccitate marginibus raro subsinuatis, nervo medio subtus vix prominente; omnia inferne attenuata, breviter vel brevissime petiolata (petiolo indistincto ad 2 mm longo), in apice mucronata (mucrone 0,1-0,2 mm longo); maiora 1-2 cm longa et 2-3 mm lata oblongo-lanceolata, minora saepe acicularia.

Spicae haud amplae numerosae, hemisphaericae (1,5-2,5 cm diametro) vel subovoideae (2,5 cm longae et 1,8 cm latae), pedunculatae, solitariae ramulos terminantes, raro subsessiles laterales, rhachide breviusculo (0,7-1,3 cm longo) dense villoso, pilis plusminusve flexuosis nodosis, 1-1,5 mm longis. Flores (15-25, raro ultra) haud dense congesti, demum stramineo-flavescentes, albido-pilosi.

Bractea bracteolaeque acutae integerrimae, pilosae, extus pilis articulatis, apicem attingentibus quin etiam paullulo excedentibus obsessae, uninervae, post lapsum perianthii superstites, inaequales: Bractea inferior rigida, subcordato-lanceolata 2,5-3 mm longa et 1-1,2 mm lata, fuscescens, nervum medium versus obscura, in dorso omnino pilosa, pilis articulatis, circiter 1 mm longis densius vestita. Bracteolae 2 distincte maiores subcarinatae, membranaceae, tenues, ovato-lanceolatae 4-6 mm longae et 2 mm latae, tantum nervum medium fuscescentem versus pilos circiter 1,5 mm longos gerentes, lateribus glabris generaliter incoloratis, hyalinis, nitentibus, perianthio adpressae.

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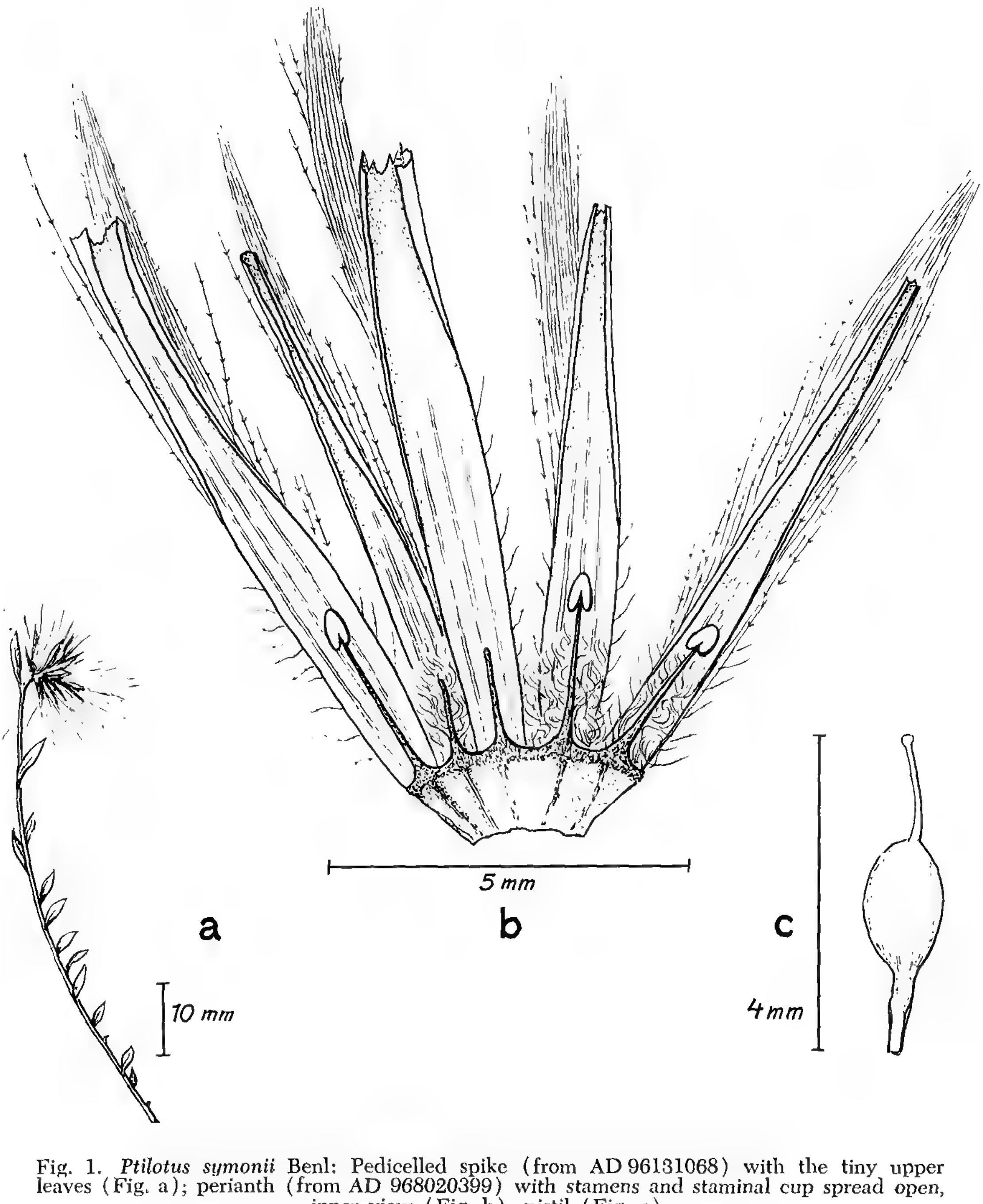


Fig. 1. *Ptilotus symonii* Benl: Pedicelled spike (from AD 96131068) with the tiny upper leaves (Fig. a); perianth (from AD 968020399) with stamens and staminal cup spread open, inner view (Fig. b); pistil (Fig. c).

Perianthium pentaphyllum elongato-erectum dein subcampanulato-patens, basim constrictam cartilagineam versus sensim indurescens, tubum angustum cylindraceum 0,8-1,2 mm longum, extus pubescentia plusminusve absconditum formans. Tepala elongato-linearia vel lineari-oblonga, anguste hyalino-marginata, trinervia—nervis lateralibus (superne saepius indistinctis) areolam medianam impellucidam, incrassatam, coloratam includentibus—, ecarinata, integerrima, truncata, apicibus inconspicuis, fere nudis 3-4 mm longis, rufescentia dein viridi-flavescentia, pilis dorsalibus strictis, rectis, articulatis, in articulis breviter verticillatis ad 9 mm (in ima basi circiter 1 mm) longis, imprimis dimidio inferiori areolae medianae tepalorum orientibus, sed apicem superantibus adpresse denseque obtecta, pilis marginalibus tenuioribus, brevioribus sparse ciliata, intus demum albido-laevigata, inaequalia: 2 exteriora 9-11 mm longa et 0,6-0,9 mm lata, marginibus (ca. 0,15 mm) in apicem paulo contractum, eroso-denticulatum, pilis dorsalibus longe (ad 2 mm) superatum transeuntibus (Fig. b); 3 interiora paullum breviora, sed angustiora (0,4-0,6 mm lata) et acutiora, marginibus superne involutis, inferne pilis crispis, nodulosis, uni sive duobus lateribus tepali, praecipue autem margini tubi perianthii orientibus et introflexis, plusminusve copiosis munita.

Stamina staminodiaque 5, in floribus examinatis semper 3 fertilia et 2 abortiva, basi modice (ad 0,2 mm) dilatata filamentorum applanatorum cupulam membranaceam, hyalinam, tubo perianthii adnatam formantia, anulo minimo (0,15-0,3 mm) libero integro, pseudostaminodiis nullis, filamentis ligulatis superne subulatis, interdum brunnescentibus, circiter 2 mm longis, abortivis rudimentis antherarum coronatis vel anantheris brevioribus (0,5-1,5 mm); antherae biloculares, flavae, lato-ellipsoideae 0,3-0,4 mm longae et 0,2-0,25 mm latae, dorso affixiae.

Ovarium subclavatum, conspicue stipitatum 2,5-3 mm longum (stipite circiter 1 mm longo incluso) et 0,7-1 mm latum; stylus sicut ovarium regulariter glaberrimum 1,3 mm longum et circiter 0,1 mm diametro, plusminusve excentricum; stigma inconspicuum haud distincte capitellatum, papillosum.

Holotype of species—5 miles south of Koonalda Homestead (east of Eucla), south-western region of South Australia; D. E. Symon, No. 4684, 21.II.1967, AD No. 968020399.

Isotypes—Idem, A, ADW, CANB, K, LE, M, TI, UC, W.

Further collection—Other material of this taxon had already been collected by P. G. Wilson (No. 1635) in North West Plains, ca. 40 km East of the Western Australian border, off Eyre Highway, 13.IX.1960 (AD 96131068). Our description is based on Wilson's specimens, too, which, therefore, may be regarded as Paratypes.

Habitat—Symon's plants were growing "in open Mallee scrub" and "mostly found in the twiggy remains of dead or dying plants of Westringia rigida". Wilson's material had been gathered in Acacia woodland.

Characteristics—The new taxon superficially approaches the South Australian *Pt. seminudus* (J. M. Black) J. M. Black as regards the general form and colour of the spikes. In this species, too, the outer perianth segments bear a truncate and denticulate apex, and the inner tepals are distinctly exceeded by dorsal hairs. The stems arising from a strong rhizome (see "Australian Plants" 4: 117, 1967) are pubescent in about the same way, when young.

In *Pt. seminudus*, however, the stems and branches are constantly shorter and thicker, the leaves (especially the radical ones) considerably larger, the spikes richer, the bract and bracteoles nearly equally long and more acute; the bract being usually less hairy. Moreover, the tepals are longer, the inner ones more narrowed towards the apex, and the points of the outer segments are not so markedly overtipped by the erect dorsal hairs.

In both species these hairs are articulate and of nearly the same length, but in *Pt. symonii* they primarily rise from the lower half of the tepals thus covering the perianth tube, while in *Pt. seminudus* the basal part of the segments looks naked, revealing the hirsute subglobular tube. In this plant we find inflexed hairs inside the perianth arising from the margins of the inner tepals above the tube, whereas in *Pt. symonii* a woolly pubescence of the inner segments takes its origin from the edge of the perianth tube, too.

In addition to these characters, numerous details of the reproductive organs diverge: e.g. two stamens only are fertile in *Pt. seminudus*, its staminal cup shows a comparatively higher free ring, and between two filaments much broadened at their base you may find a small lobe, at times; the ovary being pilose in summit. *Pt. seminudus*, therefore, differs markedly from our taxon.

As a striking particular feature of diagnostic importance are to be regarded the numerous and uncommonly small narrow leaves densely borne along the branches and branchlets of *Pt. symonii*. Except for the bushy and extremely branched *Pt. parvifolius* (F. v. Muell.) F. v. Muell., no other representative of the genus is characterised by such leaflets. But these two plants are quite unlike one another.

An additional trait of diagnostic interest is given by the relatively long and strict dorsal hairs of the intense pubescence in the perianth, distinctly exceeding and concealing the outer as well as the inner tepals, which look tapering because of this. To a lesser extent, we find a similar appearance in *Pt. arthrolasius* F. v. Muell., a subshrub with a yellowish pubescence, and still more in *Pt. eriotrichus* (W. V. Fitzg. ex Ewart & White) W. V. Fitzg., another frutescent species with a dense greyish tomentum. The shorter hairs in the small flowers of *Pt. forrestii* F. v. Muell. and the longer ones in *Pt. villosiflorus* F. v. Muell. are less distinctly articulate, and mostly lack the verticillate toothlets at the nodules, as is the case in *Pt. arthrolasius*, too. The tepals of the narrow-spiked *Pt. lanatus* Cunn. ex Moq. (including var. *glabrobracteatus* Benl) are surpassed by short bristly and thickish hairs, those of the long-spiked *Pt. leptotrichus* Benl by a tuft of relatively few articulate hairs. In *Pt. albidus* (C. A. Gardn.) Benl, *Pt. brachyanthus* (F. v. Muell. ex Benth.) F. v. Muell. and *Pt. petiolatus* L. Farmar the perianth is more or less completely hidden among dorsal hairs forming an intricate wool. Each of the cited species has a dissimilar appearance of its habit, of its leaves, spikes or floral organs, and there is no doubt left as to the specific nature of our well distinguishable taxon: *Pt. symonii* does not at all agree with any of the species hitherto described.

Name—The plant is named in honour of Mr. David E. Symon, B.Ag.Sc., Botanist at the Waite Agricultural Research Institute. Mr. Symon is one of the collectors of the new species, drew my attention to it, and supplied us with sufficient material.

# THE YELLOW-EYE MULLET
# AGE STRUCTURE, GROWTH RATE AND SPAWNING CYCLE OF A POPULATION OF YELLOW-EYE MULLET *ALDRICHETTA FORSTERI* (CUV. AND VAL.) FROM THE COORONG LAGOON, SOUTH AUSTRALIA

*BY J. A. HARRIS**

## Summary

The "Coorong mullet" spawns once per year, from January to early April. Males begin maturing a few months before the females are running ripe. Seven stages can be recognized in the gonads of the female and measurements of the diameter of the ova in each stage are given. The smallest fish with mature gonads were found to be 21 cm (males) and 23 cm (females), measuring from the tip of the snout to the caudal fork.

The ages of the fish were determined from a study of otoliths and this method was supported by the Petersen method of analysis of frequencies of lengths. The mean lengths attained by the "Coorong mullet" during their first four years are 14, 21, 26 and 31 cm respectively.

Characteristics of the "Coorong mullet" are compared with both the eastern and western races of the yellow-eye mullet (See Thomson, 1957a; 1957b). It is concluded that the "Coorong mullet" has the characteristics of the eastern race.

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## INTRODUCTION

The yellow-eye or fresh-water mullet *Aldrichetta forsteri* (Cuvier and Valenciennes) occurs in coastal waters of all Australian States except Queensland. Thomson (1957a) studied the yellow-eye mullet of Western Australia and compared it with those of Victoria and Tasmania. However, very little is known about the rate of growth and spawning cycle of the yellow-eye mullet of South Australia, especially from the Coorong lagoon (see Fig. 1).

The yellow-eye mullet is very common in South Australia, particularly in coastal brackish waters. It is the principal species of mullet sold commercially in this State. The only records of the commercial fishery available during this study were very rough estimates of the total weight of mullet sold in South Australian markets from 1951-62:

| | | | |
|---|---|---|---|
| 1951-52 | 770,000 lb | 1957-58 | 560,000 lb |
| 1952-53 | 500,000 lb | 1958-59 | 900,000 lb |
| 1953-54 | 500,000 lb | 1959-60 | 649,405 lb |
| 1954-55 | 431,220 lb | 1960-61 | 612,000 lb |
| 1955-56 | 550,000 lb | 1961-62 | 675,000 lb |
| 1956-57 | 650,000 lb | | |

The total weight of mullet handled by the South Australian Fisherman's Co-operative Limited (S.A.F.C.O.L.) from July 1st, 1961 to June 30th, 1962, was 584,984 lb. Approximately 75 per cent of this came from the Coorong lagoon, the other 25 per cent from the shallow coastal waters of South Australia. The fish

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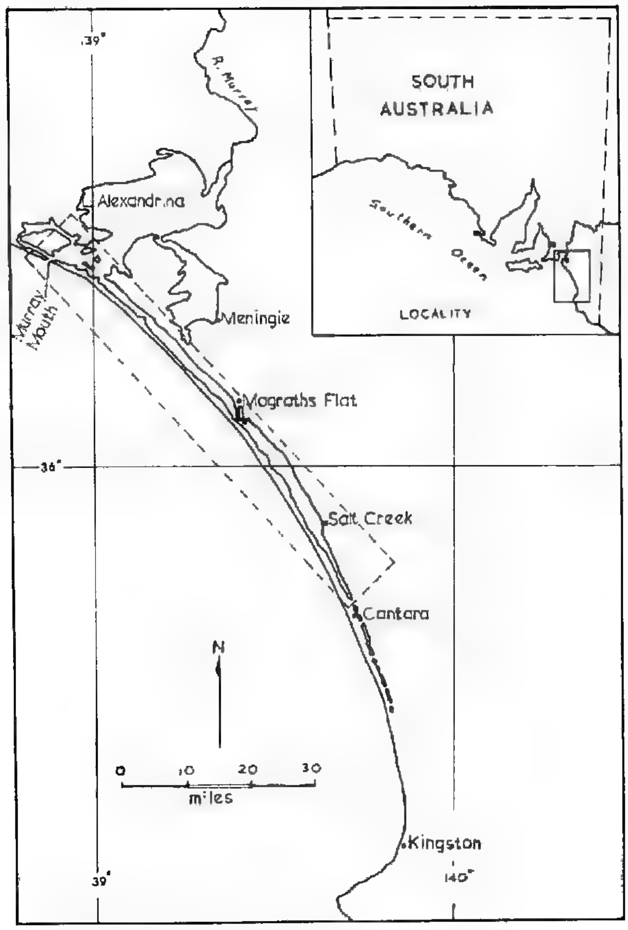


Fig. 1. Location map of the Coorong lagoon.

from the Coorong lagoon and those from the coastal waters are sold under different names at S.A.F.C.O.L. as "Coorong mullet" and "sea mullet" respectively. This investigation only deals with the "Coorong mullet".

The legal minimum length for yellow-eye mullet in South Australia is 7 inches (17·8 cm), total length. As so little is known about the commercial fishery in this state, the effectiveness of the present minimum legal length is open to question. The small amount of data pertaining to fish below 17·8 cm is a deficiency in the present investigation; however, the commercial catch (above 17·8 cm) has been covered as thoroughly as possible in the time available.

## THE "COORONG MULLET" FISHERY

The name "Coorong" applies to a long, narrow lagoon and associated shallow lakes, paralleling most of the upper south-east of South Australia. This area is divisible into two sections, the zone of permanent lagoonal water to the north and the shallow, non-perennial lake to the south. In Fig. 1 the lagoon is enclosed by the rectangle. The "Coorong mullet" fishery is only concerned with the lagoon.

The Coorong lagoon extends southwards from the mouth of the River Murray a distance of 68 miles and reaches a maximum width of 2½ miles. The maximum depth reached in winter near Salt Creek is about 14 feet, but the average depth is only 6 feet. The mouth of the Murray provides the only connection between the lagoon and the Southern Ocean. The mouth is about 300 yards in width and consists of a tidal channel through the unconsolidated dunes of Younghusband Peninsula.

Mesh and gill nets are the principal means of catching the "Coorong mullet" and regulations restrict the size of the mesh and the lengths of these nets. The influence that regulations on nets have on the yellow-eye mullet fishery in Western Australia has been discussed by Thomson (1957a). Regulations during the period of this investigation restricted the length of any net to 60 yards, the length of mesh nets to 35 yards and the size of the mesh used in all nets to not less than 2 inches.

The "set net" is by far the most common method used for catching mullet. Lengths of mesh or gill nets are anchored to stakes across the current. They are checked at regular intervals and the "gilled" fish collected. "Ring netting" is often used with great success on calm, still nights. The fisherman lays a net, one end of which is attached to a buoy, around a school of fish. A few fishermen use beach seine nets from sandy beaches or sand bars. Unfortunately, these beaches are rare due to the rocky nature of the bottom. During the summer months sand banks are exposed in the centre of the lagoon and from these banks beach seining is very successfully carried out. Most of the mullet from the lagoon is sent to Meningie to be packed in ice prior to transport to S.A.F.C.O.L.

## SAMPLING METHODS

Weekly samples of "Coorong mullet" were collected from S.A.F.C.O.L. Adelaide market for one year from February, 1962 to January, 1963. Over 100 fish were selected at random each week, and their lengths were measured by puncturing holes in a celluloid strip, mounted on a centimetre rule, with a bootmaker's awl (see Scott, 1954). From this random sample approximately 12 fish were chosen, representing the complete range of sizes of fish available, for further detailed examination in the laboratory.

This detailed examination consisted of: (a) collecting scales and otoliths and storing them in labelled envelopes, and (b) macroscopic examination of the gonads, after which they were fixed in 5 per cent formalin for microscopic examination.

On one occasion on October 7th, material was obtained from the Coorong lagoon by seine netting in shallow water with a net of 1 inch mesh. Only 31 fish ranging from 5·5 cm to 15·8 cm were caught.

During the year the lengths of 6,054 fish were measured and 631 otoliths were examined in order to determine their age and rate of growth. In addition, the macroscopic and microscopic conditions of about 600 gonads were noted. All measurements of lengths were taken from the tip of the snout to the caudal fork (L.C.F.) unless otherwise stated.

## DETERMINATION OF AGE BY MEANS OF OTOLITHS

Otoliths were found to be a good index of age and were easy to handle and examine. Both otoliths in any one fish were found to be identical. No preparation prior to the reading of them was required (see Dakin, 1939). Regular opaque bands and translucent bands are obvious even in the largest otoliths. The two otoliths collected from each fish were read together using a low power binocular microscope.

As the otolith bands are formed by regular concretions (Hickling, 1931), the alternate opaque and translucent zones must at some stage actually constitute the margin of the otolith. All the otoliths collected from each weekly sample of fish were placed into two groups, those in which an opaque band constituted the margin and those in which a translucent band constituted the margin. Transitional or doubtful ones were discarded and these accounted for about 20 per cent of the otoliths. The occurrence of opaque margins was plotted as a percentage of all otoliths examined during each month of the year from February, 1962 to January, 1963. The results are shown in Fig. 2.

Fig. 2 shows that the lowest percentage of otoliths with opaque margins occurs during August and September while the highest percentage occurs in January. Translucent bands occur during the winter months and opaque bands form during the summer months. A similar condition was observed for garfish in South Australia by Ling (1958), for plaice (Molander, 1947) and for the tiger flathead (Dakin, 1939; Fairbridge, 1951). Thomson (1957b), has shown that the annuli in the scales of the yellow-eye mullet from both Western and Eastern Australia are formed when growth recommences after the winter cessation.

The first translucent band is laid down during the first winter, approximately 6 months after spawning. The first opaque band is laid down during the first summer after spawning. Hence, the number of opaque bands represents the actual

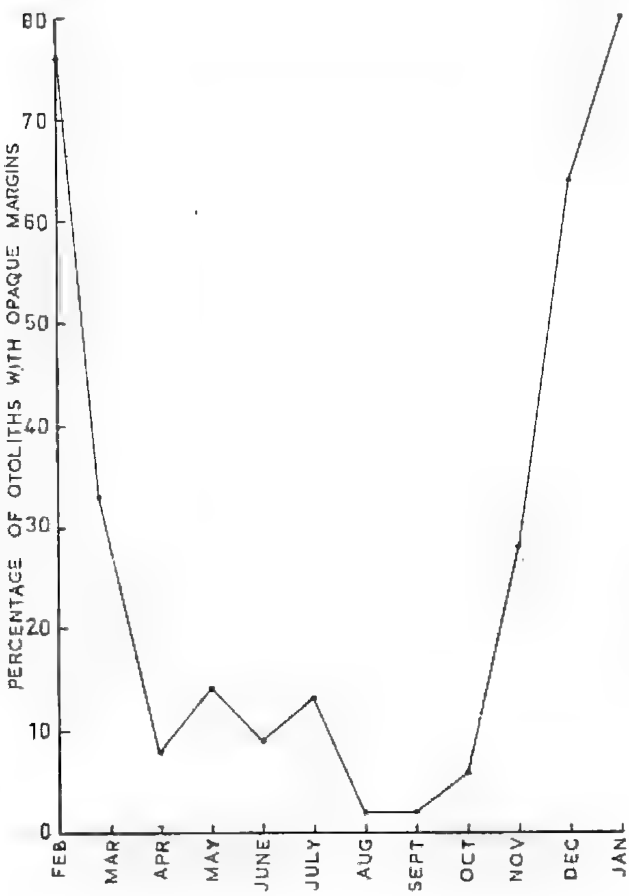


Fig. 2. Monthly percentage incidence of otoliths with opaque margins for the 12-month period February, 1962 to January, 1963.

age of the fish in years. For this reason the opaque zones were counted and the age groups denoted as 0+, 1+, 2+, etc., the numbers representing the age of the fish in years and the + — sign signifying an additional unknown number of months (but less than 12) above the preceding numbers. The results of the otolith readings are given in Table 1. The number of fish in each age group are arranged with their corresponding lengths.

Ling (1958) discusses in great detail the ways of confirming the otolith method as a means of determining the age of fish. He discusses Graham's original five tests to validate the scale method (Graham, 1929). In this investigation Petersen's method of interpreting the modes of a graph of length distribution as the model lengths of successive age groups is used to support the data obtained from otoliths.

Monthly histograms of the frequencies of lengths of fish measured each week by the celluloid strip method (see Scott, 1954) are shown in Fig. 3. In the majority of histograms a definite mode occurs about the lengths of 20-22 cm, a less

TABLE 1

Length frequencies of males and females with their ages, as determined from otoliths, for all fish examined in the laboratory from February, 1962 to January, 1963.

| Age groups | Male | | | | Female | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Length (cm) | 0+ | 1+ | 2+ | 3+ | 0+ | 1+ | 2+ | 3+ | 4+ | 5+ |
| 5 | 1 | | | | 1 | | | | | |
| 6 | | | | | | | | | | |
| 7 | 1 | | | | 2 | | | | | |
| 8 | | | | | 3 | | | | | |
| 9 | | | | | | | | | | |
| 10 | | | | | | | | | | |
| 11 | | 1 | | | | | | | | |
| 12 | | | | | | 1 | | | | |
| 13 | | 2 | | | | 2 | | | | |
| 14 | | 5 | | | | 6 | | | | |
| 15 | | 2 | | | | 4 | | | | |
| 16 | | | | | | | | | | |
| 17 | | | | | | 1 | | | | |
| 18 | | | | | | | 1 | | | |
| 19 | | | 7 | | | | 7 | | | |
| 20 | | | 30 | | | | 19 | | | |
| 21 | | | 46 | | | | 30 | | | |
| 22 | | | 30 | 3 | | | 38 | 1 | | |
| 23 | | | 9 | 3 | | | 40 | 3 | | |
| 24 | | | 2 | 14 | | | 8 | 10 | | |
| 25 | | | 1 | 10 | | | | 36 | | |
| 26 | | | | 5 | | | | 39 | | |
| 27 | | | | | | | | 27 | 1 | |
| 28 | | | | | | | | 17 | 3 | |
| 29 | | | | | | | | 6 | 3 | |
| 30 | | | | 1 | | | | 2 | 2 | |
| 31 | | | | | | | | | 11 | |
| 32 | | | | | | | | | 5 | |
| 33 | | | | | | | | | 7 | |
| 34 | | | | | | | | | | |
| 35 | | | | | | | | | | 2 |
| Total | 2 | 10 | 125 | 36 | 6 | 14 | 143 | 141 | 32 | 2 |

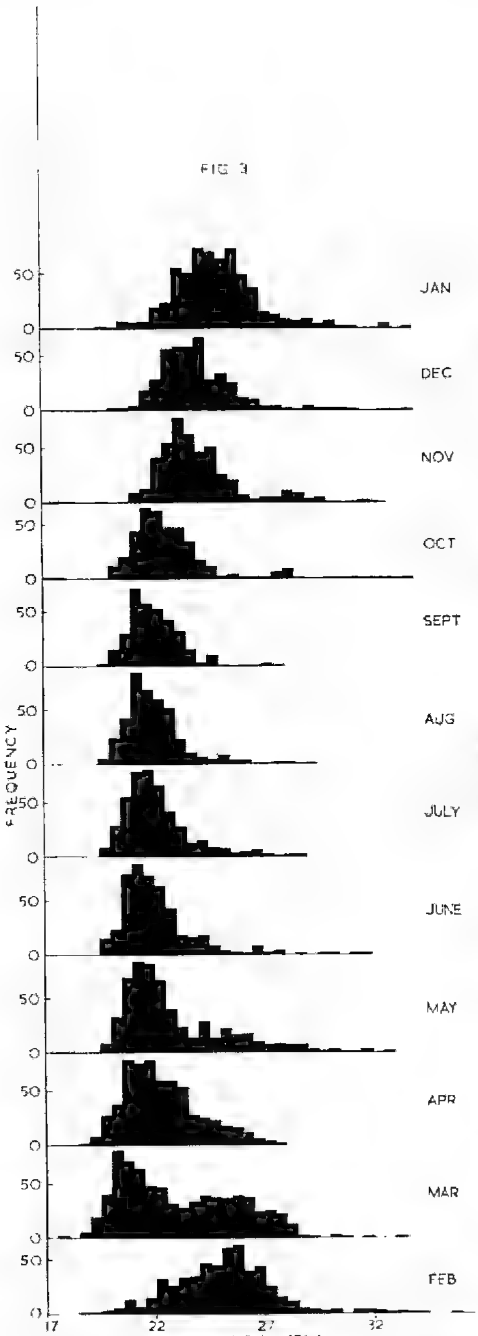


Fig. 3. Monthly frequency distribution of lengths of fish sampled each week for the 12-month period February, 1962 to January, 1963.

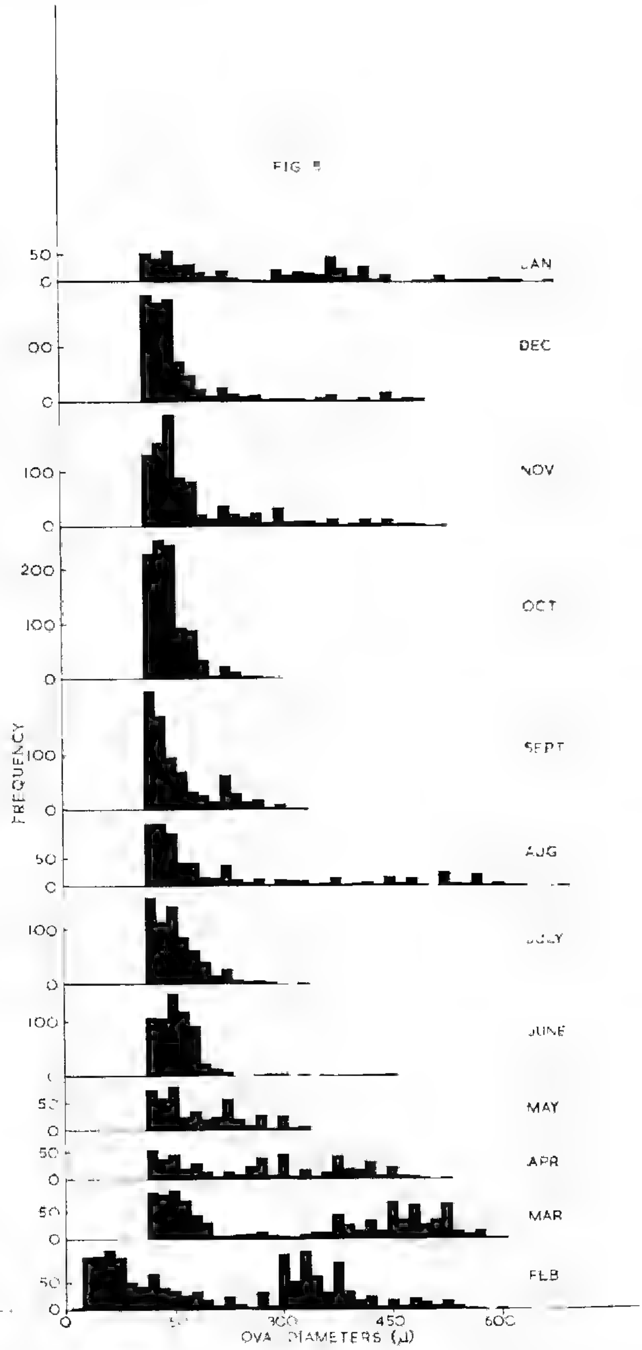


Fig. 5. Monthly frequency distribution of diameters of ova examined from fish selected at random over the 12-month period February, 1962 to January, 1963. (Note: Hickling's "reserve fund eggs" were only measured in February).

definite one about 24-26 cm, and the trace of a third mode about 30-32 cm. By comparison with the different age groups obtained using otoliths, these modes correspond to the age groups 2+, 3+ and 4+ respectively. Therefore, agreement between the Petersen method and the determination of age by means of otoliths is quite good. It can be seen that the majority of fish are in the age group 2+ with a smaller number in the age group 3+ and very few in the age group 4+.

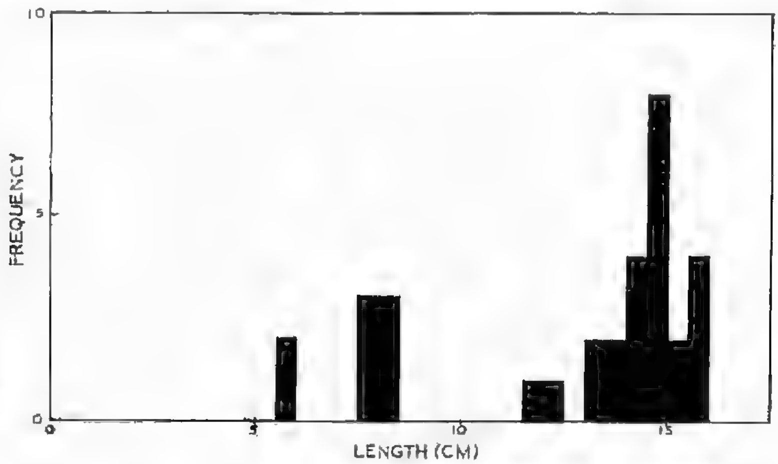


Fig. 4. Frequency distribution of lengths of fish caught October 7th with a net of 1 in. mesh.

Fig. 4 shows the length frequency histogram of 31 fish caught on October 7th with a net of 1 inch mesh. Only one mode at 15 cm is obvious, but probably there is one at 8 cm. These modes correspond to the age groups 0+ and 1+ respectively. In general, it may be stated that the determination of age by means of otoliths is supported by the results of the Petersen method.

## RATE OF GROWTH

(a) *Using otoliths and measurements of length*

Table 1 shows the frequencies of lengths of males and females with their ages, as determined from otoliths, for all fish examined in the laboratory from February, 1962 to January, 1963. An analysis of these results was carried out to test the two null hypotheses implicit in these results: (1) that there is no difference in the lengths of the fish in the age groups 0+ and 1+, 1+ and 2+, 2+ and 3+, 3+ and 4+, and (2) that there is no difference in the lengths of a male and female in the age groups 0+, 1+, 2+ and 3+. These null hypotheses were tested by the "t" test (Snedecor, 1956). The first null hypothesis was disproved for all cases, but the second null hypothesis was not disproved for all cases. The differences between the lengths of male and female fish in groups 0+ and 1+ were not significant, but those for groups 2+ and 3+ were highly significant.

The mean lengths attained by the female "Coorong mullet" during their first four years are 14·2, 21·7, 26·1 and 30·9 cm respectively. Rapid growth occurs during their first two years, but then falls off during their third and fourth years. The mean lengths attained by the males during their first three years are 13·7, 21·1 and 24·5 cm respectively. Growth is again rapid during their first two years, but during their third year the mean length attained is 1·6 cm less than that of the females. After the first two years, the rate of growth of males (using only length as the measure of growth) is much slower than that of females.

The two largest fish examined during this study were both females, approximately 35 cm long. Only one male fish examined was found to be longer than 26 cm and it was 30 cm in length. These data indicate that the females grow to a larger size than the males.

(b) *Using the Petersen method*

As mentioned earlier, the histograms of frequencies of lengths given in Fig. 3 show two definite modes occurring about the lengths of 20-22 cm and 24-26 cm with perhaps the trace of a third one about 30-32 cm. These modes are considered to correspond to the age groups 2+, 3+ and 4+ respectively. The evidence for modal progression when following the progress of one particular mode in the course of time is very good.

If March is taken as the time that spawning activity is at its peak, the histogram for March may be said to represent the frequencies of lengths at the beginning (or end) of one or more complete years in the life-cycle of the fish. Definite modes occur about the lengths 20·5, 24·5-26 and 30·5 cm respectively in the March histogram. It is easy to trace the mode about 20·5 cm throughout the year. In April and May, just prior to winter, a small amount of growth is apparent. In May the mode is obvious about 21·5 cm. Over the winter months June to September this mode about 21·5 cm is maintained, indicating no growth, or very little (as also indicated by the study of otoliths). From October to January the mode shifts rapidly from about 22 cm in October, to 23·5 cm in November, 24·5 cm in December and 24·5-26 cm in January. The histogram for February of the previous year shows a very good mode about 26 cm and supports the evidence for modal progression over one year being approximately 20·5 to 26 cm. This corresponds to a growth of 5·5 cm which is very close to the annual growth of a 2-year-old "Coorong mullet" as suggested by the study of their otoliths. Over the same time period possibly the mode about 24·5-26 cm gives way to modes about 28·5 cm in October and November, 29·5 cm in December and 30·5 cm in January. This corresponds to a growth of 4·5-6 cm which is roughly equivalent to the rate of growth of a 3-year-old fish as suggested by the study of otoliths.

## THE SPAWNING CYCLE

The methods by which the spawning cycle may be studied include a survey of the seasonal variations in the conditions of the gonads. This involves a macroscopic examination of the appearance of the gonads and a microscopic examination of the ova.

In most investigations (Clark, 1925; Fairbridge, 1951; Scott, 1954) the female cycle has been studied in more detail than the male cycle. In the present investigation the male cycle was examined in less detail because it was found hard to distinguish the stages of the testes and because the condition of the ovaries changed much more noticeably than that of the testes. A month by month comparison of the macroscopic conditions of the ovaries was noted and this was later correlated with a microscopic examination of the ova, including measurements of their size.

(a) *Macroscopic examination of gonads*

Hjort's classification of the gonads of herring (Hjort, 1910) has been adopted with certain modifications to suit this particular species. Seven stages in the ovaries of the "Coorong mullet" were distinguished while the testes were distinguished only as immature or mature. The classification of each of these seven stages of the ovaries is given in Table 2.

TABLE 2

Lengths and stage of maturity of 348 females sampled during January, 1963.

| Length (cm) | Stages of ovaries | | | | |
|---|---|---|---|---|---|
| | Immature | Adolescent | Maturing | Spent | Per cent maturing and spent |
| 19 | 2 | | | | 0 |
| 20 | 2 | 2 | | | 0 |
| 21 | 2 | 2 | | | 0 |
| 22 | 3 | 2 | | | 0 |
| 23 | 12 | 18 | 2 | | 16 |
| 24 | 15 | 55 | 25 | 1 | 27 |
| 25 | 13 | 43 | 50 | | 47 |
| 26 | 3 | 21 | 26 | 3 | 49 |
| 27 | | 2 | 17 | | 89 |
| 28 | | 3 | 4 | 3 | 70 |
| 29 | | | 9 | | 100 |
| 30 | | | 5 | | 100 |
| 31 | | | 3 | | 100 |
| Total | 52 | 148 | 141 | 7 | 43 |

Stage I. Immature virgins. Ovaries small, thread-like and translucent.

Stage II. Adolescent. Ovaries larger, walls taut, extending half-way into the body cavity.

Stage III. (a) Maturing virgins or (b) recovering or resting (spent) fish. Colour ranges from pink at early pigmentation to dark red at a later stage. In (a) walls of ovaries are taut but in (b) walls are flaccid. Ovaries extend further into body cavity.

Stage IV. Maturation continuing. Ovaries larger, red-yellow in colour. Walls taut and not quite transparent so that eggs can only be seen with difficulty after cutting the wall.

Stage V. Mature. Ovaries greatly enlarged from stage IV, occupying the whole of the body cavity. Yellow-orange in colour, walls taut and transparent with eggs clearly visible.

Stage VI. Running-ripe. Yellow-orange in colour with large eggs being extruded when slight pressure is applied to the abdomen.

Stage VII. Spent. Ovaries dark red and flaccid. This stage eventually passes into stage III from which it is hard to distinguish.

The seasonal changes in the gonads may be summarized as follows. The testes of the immature fish are white, thin bodies, triangular in section. During maturation they become thicker and rounder, protruding further into the body cavity and milt being exuded if the walls are ruptured. During the months of May, June and July no mature testes were noticed. For the rest of the year there were always a few mature testes present and during the spawning season January to March, over 50 per cent of all testes examined were mature. (See Table 3 for the percentage of maturing males during January).

When the investigation started in February, 80 per cent of the ovaries examined were mature (stages IV, V and VI) with 25 per cent of these being in the "ripe" condition (stage VI). During March a similar set of conditions continued with a few spent ovaries (stage VII) becoming apparent. However, during April and May spent ovaries became more evident and the last mature ovary (stage VI) was found on April 11th, except for one ovary at stage V found on May 2nd which appeared to be abnormal, only one branch having developed.

During the months of June and July, except for one fish on July 25th which was at stage IV, all ovaries were classified as belonging to stages II and III. Approximately 85 per cent of the ovaries examined during August, September and October were at stages II and III. Only 15 per cent were more advanced than stage III and it is possible that they were early spawners. During November and December, however, ovaries at stage IV became more evident with an occasional stage V until in January ovaries at stage V were common with several at stage VI. (See Table 2 for the percentage of maturing females during January.)

(b) *Microscopic examination of ovaries*

Several ovaries chosen at random, were set aside each week, preserved in 5 per cent formalin and stored in labelled vials. These ovaries were examined under the microscope at a later date.

To measure the diameter of the ova a small piece of ovary was teased out onto a microscope slide, mounted in 5 per cent formalin and covered with a cover slip. The diameters were measured using a micrometer eye-piece and a microscope.

All eggs were measured along whichever axis of the egg lay parallel to the cross-hair of the micrometer eye-piece. Clark (1925) has shown that this method gives a reliable estimate of the frequencies of diameters of the ova. Throughout the investigation group A eggs were not measured, except in February, as they were far too numerous in all of the ovarian stages.

Consistent with the classification of Hickling (1930) and other workers, the ova of the "Coorong mullet" were classified into four groups.

Group A — Immature ova. Very small, angular and colourless with nucleus clearly visible. They are Hickling's "reserve fund eggs" and measure up to 120 $\mu$.

Group B — Maturing ova. The smallest eggs in this group are becoming round and opaque due to accumulation of yolk granules, while the largest ova are quite round and opaque. Size varies from 120 $\mu$ to 255 $\mu$.

Group C — Mature ova. Large round opaque ova, pale yellow. Size varies from 255 $\mu$ to 380 $\mu$.

Group D — Ripe ova. Very large round opaque ova, yellow. Size varies from 380 $\mu$ to 600 $\mu$. This stage merges with group C, but is distinct from group C by size and coloration.

The microscopic characters of each ovarian stage were established as follows:

Stage I. The ova are all typically group A, with none larger than 60 $\mu$.

Stage II. As for stage I, but an occasional ova of group B may be present No ova larger than 135 $\mu$.

Stage III. Ova of groups A and B are very numerous with an occasional group C. Usually no eggs larger than 255 $\mu$.

Stage IV. Ova of groups A, B and C are numerous but group B is usually more numerous than group C.

Stage V. Ova of groups A, B and C are numerous with a few of group D. Group C is usually more numerous than groups B and D.

Stage VI. As for stage V, but the ovaries are much larger with ova of group D most numerous and lying free in the lumen. Groups A, B and C are confined to a layer inside the ovary wall.

Stage VII. Ova of groups A and B are both numerous. An occasional group D ovum is present undergoing breakdown.

The frequencies of diameters of the ova examined were plotted as monthly histograms and are shown in Fig. 5. Throughout the year there is a residue of Hickling's "reserve fund eggs" which were too numerous to measure every month and are shown only in the February histogram. From Fig. 5 it can be seen that numerous ova of group B also are present throughout the year. From May to October (except in August when the ovary examined may have been that of an early spawner) ova of groups A and B are by far the most numerous. During November, however, an increase in the diameter of the ova present is obvious. As maturation continues through December, the diameters of the ova continue to increase until "ripeness" (stage D) is obtained. Ripe eggs are present in greatest numbers during March, with large numbers also present in February and April. Spawning is thus at its greatest intensity during late summer. A sharp drop in the overall diameter of the ova marks the spent and recovering stages, during April and May. It is followed by a period of quiescence from June to October.

## SIZE AND AGE AT FIRST MATURITY

The gonads of 122 male and 348 female fish were examined; and their lengths taken, during visits to S.A.F.C.O.L. in January, 1963. The females were classified arbitrarily as immature (stages I and II), adolescent (stage III), maturing (stages IV, V and VI) and spent (stage VII). The males were classified under two divisions, immature and maturing. Tables 2 and 3 show the lengths and stages of maturity of these males and females.

Table 2 shows that 15 fish with lengths of less than 22 cm were examined and none showed signs of maturing. Sixteen per cent of the fish 23 cm in length were maturing and spent. The percentage rose to 100 per cent for all fish 29 cm and above. Females, therefore, do not reach maturity before 23 cm.

Table 3 illustrates that only 3 males 21 cm long were examined and that one of these was maturing. Because so few fish of this length were examined it cannot be proved that males mature at 21 cm. However, 19 fish of length 22 cm were examined and of these fish 42 per cent were maturing. Males, consequently, are definitely mature by 22 cm.

TABLE 3

Lengths and stage of maturity of 122 males sampled during January, 1963.

| Length (cm) | Stages of testes | | |
|---|---|---|---|
| | Immature | Maturing | Per cent maturing |
| 20 | 4 | | 0 |
| 21 | 2 | 1 | 33 |
| 22 | 11 | 8 | 42 |
| 23 | 22 | 29 | 57 |
| 24 | 11 | 24 | 69 |
| 25 | 1 | 7 | 87 |
| 26 | | 2 | 100 |
| Total | 51 | 71 | 61 |

Correlating the lengths at which the females and males first mature with the data obtained from the otoliths, it is concluded that the "Coorong mullet" attain maturity during their third year.

## DISCUSSION

The "Coorong mullet" grows to a relatively small size of 35 cm. At first the growth, using only length as a measure of growth, is rapid. The mean lengths attained during their first and second years are 14 and 21 cm respectively. After this period, however, there is a marked slowing down in growth reaching a mean length of 26 and 31 cm during their third and fourth years respectively. This slowing down is more pronounced in the males which do not grow as large as the females.

TABLE 4

Lengths (cm) attained each winter average by the Western and Eastern races of theYellow eye Mullet (Thomson, 1957b) and the mean lengths attained by the "Coorong mullet" over an equivalent time period.

| Year | | | | | | | |
|---|---|---|---|---|---|---|---|
| Western and Eastern races | I | II | III | IV | V | VI | VII |
| "Coorong mullet" | 0+ | 1+ | 2+ | 3+ | 4+ | | |
| Western fish | 11 | 18-19 | 24-25 | 29-32 | 32-35 | 38 | 39 |
| Eastern fish | 5 | 12-13 | 19-21 | 24-27 | 30 | | |
| "Coorong mullet" | 7(?) | 14 | 21 | 26 | 31 | | |

Table 4 compares the growth of the western and eastern races of the yellow-eye mullet with that of the "Coorong mullet". The data for the western and eastern races is taken from Thomson (1957b). The year-classes designated in Thomson's paper refer to the length attained each winter average (the western stock being winter spawners). Over an equivalent time interval the "Coorong mullet" grows to a mean length of 7(?), 14·2, 26 and 31 cm by their first, second, third, fourth and fifth winters respectively. It can be seen that their growth rate agrees closely with that of the Victorian and Tasmanian yellow-eye mullet which comprise the majority of fish referred to as "eastern" by Thomson (1957b). The "Coorong mullet" grow at a slower rate than the Western Australian yellow-eye mullet and do not become as large.

The spawning period lasts for 3-4 months from January to early April. This proves that the "Coorong mullet" have the characteristics of the eastern race rather than the western race of yellow-eye mullet (see Thomson 1957b, p. 12). Spawning probably takes place in the Coorong lagoon which would provide a very productive area in which the newly hatched fish can grow rapidly with little chance of a shortage of food occurring. The largest ova of the "ripe" fish were approximately 600 $\mu$ in diameter which is relatively small compared with whiting 980 $\mu$ (Scott, 1954) and garfish 3,500 $\mu$ (Ling, 1958).

The smallest fish recorded with mature gonads were 23 cm for females and 21 cm for males. They mature during their third year or by their third winter. The "Coorong mullet", therefore mature a little earlier and at a slightly smaller size than the Western Australian yellow-eye mullet studied by Thomson (1957a). In addition, due to the spawning periods of the two races of fish occurring at different times of the year, the summer spawning "Coorong mullet" reach maturity faster than the winter spawning western race.

Comparing the commercial catch of "Coorong mullet" with the catch of yellow-eye mullet in Victoria, some interesting facts emerge. In Victoria the fish reach the minimum legal length, 9½ inches total length (21·3 cm L.C.F.), from 2½ to 5½ months prior to spawning (Thomson, 1957a). In South Australia the minimum legal length is 7 inches total length (15 cm L.C.F.) and the fish attain this size approximately 12 months before they have spawned for the first time. South Australia's minimum legal length is obviously too small and at first glance the "Coorong mullet" fishery appears to be in jeopardy. However, Fig. 3 shows that no fish below 17 cm were sampled at S.A.F.C.O.L. The majority of fish, in fact, were well above 20 cm. This biased sample was due to the size of the mesh of the nets used by the commercial fishermen. In South Australia the minimum legal mesh size during the study was 2 inches, compared with 2¼ inches in Victoria. Thomson (1957a) showed that, as far as yellow-eye mullet are concerned, any mesh from 2 inches to 3¼ inches allows the majority of the catch to be above the length of 20 cm.

Thomson (1957a) discusses the management of the yellow-eye mullet fishery both in Eastern and Western Australia and concludes that the existing management policies are effective in maintaining stocks. Whether this is also true for the "Coorong mullet" fishery cannot be determined yet due to lack of information, both biological and statistical. A study of the length/weight relationships is required together with estimations of fecundity and observations of the survival of fry and small immature fish. Statistics of the catch and fishing effort are also required before a more complete management programme can be suggested.

## ACKNOWLEDGMENTS

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# THE DISTRIBUTION AND LIFE HISTORY OF THE SKINK HEMIERGIS PERONII (FITZINGER)

BY *MICHAEL SMYTH**

**Summary**

*Hemiergis peronii* occurs from south-western Western Australia to southeastern South Australia, but rarely inside the 12-inch isohyet and not in the Flinders or Mt. Lofty Ranges. Its northern limit is probably determined by aridity; its southern limit might be determined by the length of the winter.

*H. peronii* bears two to five living young in February. Females are inseminated in the autumn, when they are two years old. They ovulate in spring and do not bear their first young until they are three years old. Males first come into breeding condition when two years old.

*H. peronii* eats mostly arthropods and snails.

# THE DISTRIBUTION AND LIFE HISTORY OF THE SKINK

## *HEMIERGIS PERONII* (FITZINGER)

by MICHAEL SMYTH*

[Read 11 July, 1968]

## SUMMARY

*Hemiergis peronii* occurs from south-western Western Australia to south-eastern South Australia, but rarely inside the 12-inch isohyet and not in the Flinders or Mt. Lofty Ranges. Its northern limit is probably determined by aridity; its southern limit might be determined by the length of the winter.

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*H. peronii* eats mostly arthropods and snails.

## INTRODUCTION

*Hemiergis peronii* is a small, weak-limbed skink, very abundant in coastal dunes near Adelaide. Its reproductive cycle is unusual in that the females are inseminated in the autumn but do not ovulate until spring (Smyth and Smith, 1968). I now report some other details of its life history. They will provide a background against which the adaptive significance of the unusual reproductive cycle will perhaps become clearer, and they will slightly diminish our great ignorance about our native reptiles.

Some authors use *Hemiergis* as a sub-genus in the genus *Lygosoma*. *H. peronii* is called *L. (H.) quadridigitatum* Werner by Glauert (1961), probably for reasons which are explained and dismissed by Loveridge (1934). Worrell (1963) calls it *Lygosoma (Leiolopisma) peronii*.

## METHODS

The distribution of *H. peronii* was mapped from the records of the South Australian, Western Australian, and Australian Museums and the Department of Zoology, University of Melbourne, from the published records of Werner (1910), Waite (1929), Loveridge (1934) and Mitchell and Behrndt (1949), and from my own collections and those made for me by a group of students of Naracoorte High School directed by Mr. D. Von Behrens.

The natural history was described from samples of from four to 16 lizards taken at two to four-weekly intervals for a year at Port Gawler and Middle Beach, about 30 miles north of Adelaide. Most of them were taken from under dead clumps of the lily *Dianella revoluta* R. Br. on shell-grit dunes behind the beach. The lizards were brought back to the laboratory and kept at 10°C until they were

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dissected. They were then measured with dividers, their reproductive organs removed and examined, their guts removed, the food taken out and identified, and the guts examined for parasites. The bodies were then preserved in buffered neutral formalin. The gut parasites are described by Angel and Mawson (1968).

## DISTRIBUTION

*H. peronii* is confined to southern Australia, from south-western Western Australia to south-eastern South Australia (Fig. 1). It probably occurs in western Victoria as well, for according to Rawlinson (1966) there is a specimen in the National Museum, Melbourne, listed in the catalogue as from "Mallee district, Victoria". But it does not occur in southern Victoria, Tasmania, or the Bass Strait islands (Rawlinson, 1967). Lucas and Frost's (1894) claim that it has been taken in the Dandenong Ranges near Melbourne is probably mistaken, and Weekes's


Fig. 1

(1930) claim that she took *Lygosoma* (*H.*) *quadridigitatum* at Tanara and Jenolan, New South Wales, is probably based on a wrong identification.

In Western Australia, *H. peronii* is found into the 50-60 inch rainfall belt near Northcliffe, but as far as we know at present its range does not extend right to the west coast. Loveridge (1934) does record a specimen from Perth, but this might have been the address of the collector rather than of the lizard. It has been taken as far inland as Fraser Range, in the 11-12 inch rainfall belt.

In South Australia, *H. peronii* is very abundant around much of the coastline (Fig. 2). It also occurs on many of the offshore islands, including St. Francis, Franklin, Flinders, Pearson, Greenly, Price, Black Rock, the South Neptune, and Wedge Islands. It occurs inland on sandy or skeletal calcareous soils on Eyre and Yorke Peninsulas, Kangaroo Island, and in the south-east of the State. Its distribution extends slightly inside the 12 inch isohyet only on the West Coast and near the head of St. Vincent Gulf (Fig. 2). It seems not to occur in either the Flinders or Mt. Lofty Ranges.

Further collecting will no doubt extend the known range of *H. peronii*. For instance, it might be found all the way around the Bight, and further into the Murray Mallee of South Australia.

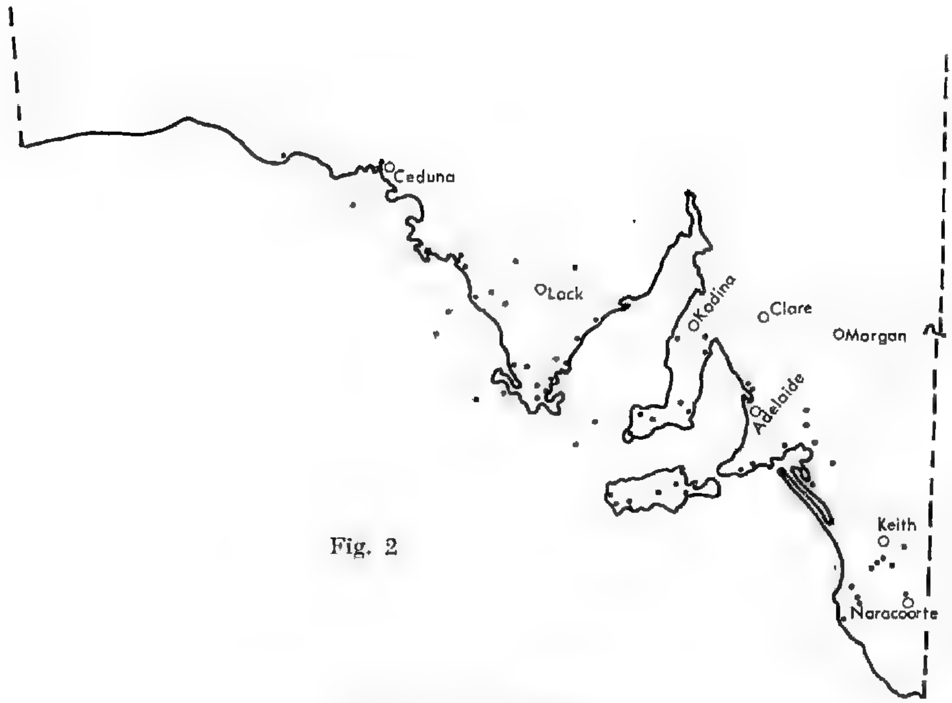


Fig. 2

## REPRODUCTION

Male *H. peronii* come into breeding condition and inseminate the females in the later summer and autumn (Smyth and Smith, 1968). The sperm is stored in the female genital tract over winter; the females ovulate and their eggs are fertilized in the spring, between late October and the end of November. Two, three or four young are born at the end of February, larger mothers bearing on the average large litters.

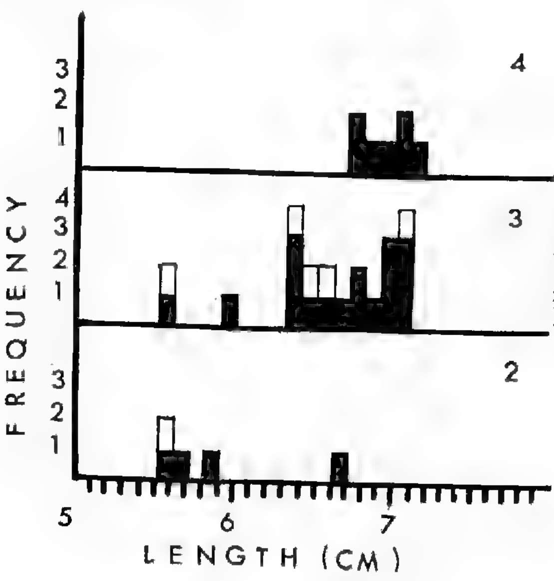


Fig. 3. The frequency distributions of snout-to-vent lengths of female *H. peronii* bearing two, three and four young. The number of young was counted from either large ovarian eggs (white) or eggs and embryos in the oviduct (black).

TABLE 1

Breeding condition of female *Hemiergis peronii.*

| Date | Number of females with* | | | | Total number |
|---|---|---|---|---|---|
| | developing follicles | ovarian eggs | oviducal eggs | no sign of reproductive activity | |
| 16 November 1966 | | | 1 | 1 | 2 |
| 29 November | | | 6 | 1 | 7 |
| 14 December | | | 6 | 2 | 8 |
| 5 January 1967 | | | 3 | | 3 |
| 25 January | | | 5 | 6 | 11 |
| 15 February | | | 4 | 3 | 7 |
| 1 March | | | | 5 | 5 |
| 14 March | | | | 2 | 2 |
| 28 March | | | | 9 | 9 |
| 12 April | | | | 2 | 2 |
| 25 April | | | | 8 | 8 |
| 10 May | 6 | | | 2 | 8 |
| 24 May | 4 | | | 1 | 5 |
| 13 June | 6 | | | 1 | 7 |
| 18 June | 4 | | | | 4 |
| 18 July | 1 | | | 1 | 2 |
| 18 August | 2 | | | 1 | 3 |
| 19 September | 2 | | | 1 | 3 |
| 3 October | 6 | | | | 6 |
| 17 October | | 5 | | | 5 |
| 31 October | | 2 | 2 | | 4 |
| 21 November | | 2 | 2 | | 4 |

* Females with no sign of reproductive activity included juveniles, one-year-olds, and, in March and April, older animals. Their ovarian follicles were small and transparent. Females were said to have developing follicles when the follicles became an opaque white, though they had enlarged very little if at all. Later, after the follicles had obviously begun to enlarge, the females were said to have ovarian eggs.

In *H. peronii* the right ovary is well anterior to the left in the body cavity, and the right oviduct is much longer than the left. About equal numbers of eggs are shed from each ovary but a high proportion migrates from the left ovary to the right oviduct. This is deduced from a comparison of the distribution of the corpora lutea between the two ovaries with the distribution of eggs and embryos between the two oviducts. Thus of 90 eggs shed from the ovaries of 29 females, 48 came from right ovaries, but 61 embryos developed in right oviducts and only 29 in the left. In only one of the 29 females was there more than one embryo in the left oviduct; in this case there were two in each. The most posterior egg was always in the left oviduct.

## GROWTH AND AGE STRUCTURE

Figs. 4 and 5 show the distribution of snout-vent lengths of all individuals taken during the year. It can be shown from these figures that males first come into breeding condition, and females are first inseminated, when they are two years old. Females therefore bear their first young when they are about three years old. Consider the snout-vent lengths of females (Fig. 4); in April and May there are clearly two year-classes in which there is no follicular development. These have been delineated in Fig. 4; the lower group is of young of the year, the

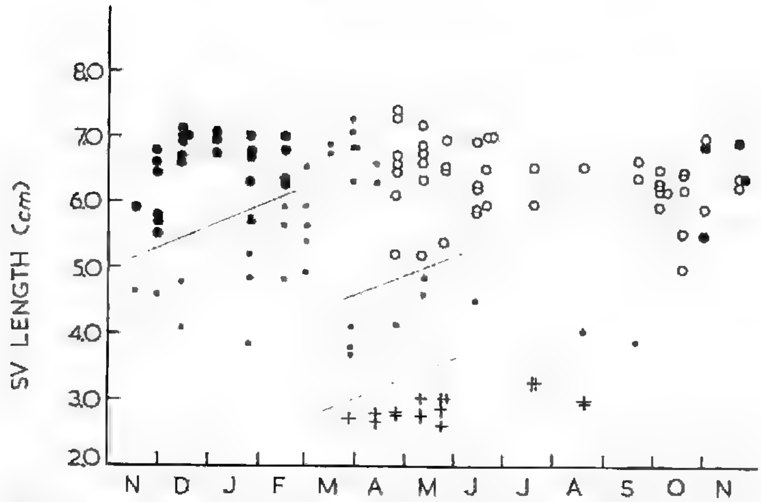


Fig. 4. The snout-to-vent lengths of all female *H. peronii* caught from November, 1965 to December, 1966. ● pregnant; • not pregnant, follicles undeveloped; ○ follicles visibly developing; + juvenile, sexes not distinguished.

upper group is of one-year-olds. Now consider the distributions for November, 1966 to February, 1967, when the females were pregnant. It is apparent that those females not pregnant must have belonged to these two youngest year classes. A somewhat similar argument can be applied to the males (Fig. 5). From February to May, when the testes of most males in the samples were enlarged, there were always some males with quite undeveloped testes; these were young of the year and, as well, larger animals which must have been one year old.

Neither the males nor the females, once they have reached sexual maturity, can be confidently separated into further year-classes, but it is likely that there are at least two year-classes of pregnant females in the summer, which by February will be three and four years old respectively. The larger females, probably approaching four years old, bear the largest litters (Fig. 3). Females grow to be longer than males.

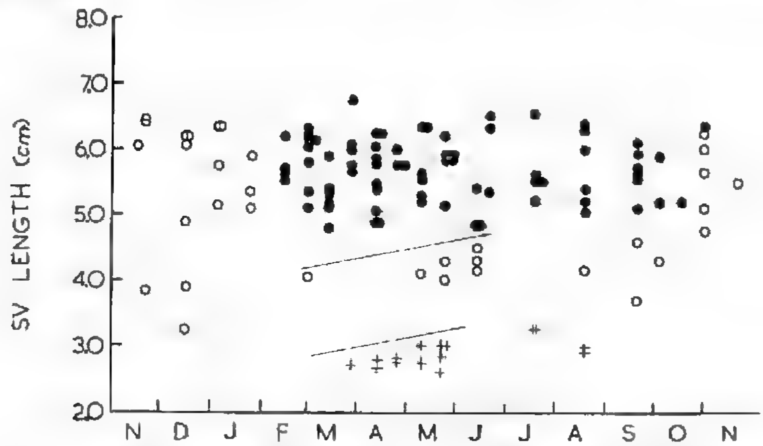


Fig. 5. The snout-to-vent lengths of all male *H. peronii* caught from November, 1965 to December, 1966. ● testis and/or epididymis contains sperm; ○ no sperm; + juvenile, sexes not distinguished.

## FOOD

It was fairly easy to classify most arthropod foods to Order because at least the heads and usually other parts as well passed through *H. peronii* intact. But some other foods were probably missed. Land snails, for instance, were sometimes found without shells or with only a few fragments of shell adhering, which made them hard to notice. Also, the shells of land snails were probably sometimes confused with the small marine shells, mostly of gastropods and foraminifera, which made up much of the ground on which the lizards were living, and which often appeared in the lizards' guts. So the proportion of land snails in the diet was probably under-estimated.

The abundance of various items of food taken by male, female and juvenile *H. peronii* is shown in Table 2. Obviously *H. peronii* is almost exclusively insectivorous. The only plant food found more than once was the seeds of the lily *D. revoluta* under which most of the lizards were caught. These seeds are small, black and shiny, and might have been mistaken for insects. They were largely undigested.

TABLE 2

The diet of *Hemiergis peronii*.

| Item | Numbers of each item | | | % of total | | |
|---|---|---|---|---|---|---|
| | Males | Females | Juveniles | Males | Females | Juveniles |
| Beetles | 100 | 133 | 6 | 28·3 | 29·9 | 7·1 |
| Ants and other Hymenoptera | 24 | 56 | 2 | 6·8 | 12·6 | 2·4 |
| Cockroaches | 30 | 23 | 3 | 8·5 | 5·2 | 3·6 |
| Cockroach oothecae | 15 | 25 | | 4·2 | 5·6 | |
| Moths | 25 | 22 | | 7·1 | 4·9 | |
| Bugs (Hemiptera) | 17 | 10 | | 4·8 | 2·2 | |
| Unidentified insect larvae | 11 | 13 | | 3·1 | 2·9 | |
| Collembola | 2 | 1 | | 0·6 | 0·2 | |
| Grasshoppers | 2 | | | 0·6 | | |
| Flies | 1 | | | 0·3 | | |
| Earwigs | 1 | | | 0·3 | | |
| Ant-lions | | 1 | | | 0·2 | |
| Mites | 41 | 121 | 69 | 11·6 | 27·2 | 82·1 |
| Spiders | 13 | 10 | | 3·7 | 2·2 | |
| Pseudoscorpions | 3 | | 2 | 0·8 | | 2·4 |
| Slaters (Isopoda) | 4 | 7 | | 1·1 | 1·6 | |
| Centipedes | | 1 | | | 0·2 | |
| Snails | 29 | 6 | 1 | 8·2 | 1·3 | 1·2 |
| Lizards | 2 | 1 | | 0·6 | 0·2 | |
| Seeds | 21 | 15 | | 5·9 | 3·4 | |
| Unidentified | 12 | | 1 | 3·4 | | 1·2 |
| Total number of individual items | 353 | 445 | 84 | | | |

The range of size of the foods taken was large, from small mites, mostly Oribatids, up to adult skinks *Ablepharus greyii* (Gray), which are about 4 cm long. Juveniles took only small items: there is very little difference between the foods of males and females. Most of the animals eaten were feeders in litter or on the surface.

## INJURIES TO LIMBS

Several *H. peronii* had lost digits or parts of limbs. This would be no great handicap to them, since their movement is mainly by lateral undulations. Some of these members would have been lost in accidents; I found one *H. peronii* with an ant's head still firmly clamped onto its foreleg, though the limb distal to the ant's mandibles had withered and would soon have dropped off. In other cases, the members might have been lost by disease or fights.

Males and females apparently lost large portions of front and hind limbs with about equal frequencies, but in both sexes toes were missing much more often than fingers (Table 3). This suggests that digits and large portions of limbs are lost from different causes.

TABLE 3

Limb injuries in *Hemiergis peronii*.

| | | Male | Female |
|---|---|---|---|
| No. feet from which one or more digits were lost | front | 5 | 5 |
| | hind | 24 | 20 |
| No. limbs wholly or partly lost | front | 6 | 4 |
| | hind | 4 | 0 |
| No. animals with all members intact | | 60 | 73 |
| No. animals examined | | 92 | 98 |

One *H. peronii* was found to have five fingers on each front foot, though the usual number is four. This anomaly is worth mentioning only because several species of *Hemiergis* are most easily distinguished on the basis of the number of their fingers and toes. Werner (1910) claimed that this was the only way he could separate them at all. Glauert (1961) mentions some other freak numbers of digits, and gives the impression that the number of digits is not a good specific character.

## DISCUSSION

It is likely that the northern limit to the distribution of *H. peronii* is determined by aridity, for its powers to resist desiccation are relatively poor. Warburg (1966) has shown that its rate of evaporative water loss increases rapidly with increasing temperature, and that it quickly dies in a dry atmosphere at temperatures as low as 35°C.

The southern limits to its distribution might be determined by winter temperatures. Where winters are cold, lizards usually become torpid, and will become active again only in warm, sunny weather. Even then, they probably do not feed, for torpid cold reptiles with food in their guts are in mortal danger because they cannot digest the food, which then putrefies (Regal, 1966). I found food in the gut of *H. peronii* throughout the winter, so, though it certainly becomes less active, it probably does not become torpid for long. Also, abdominal fat bodies, which in some lizards are known to be important in over-winter metabolism (Dessauer, 1955), are absent in *H. peronii*, though they are prominent in some other local skinks.

So *H. peronii* might need to feed over winter in order to survive. If this is so, its preferred body temperature should be low. There is no information available on this, but Licht, Dawson, Shoemaker and Main (1966) have shown that the preferred body temperature of *H. quadrilineatum* is relatively low, and

*H. quadrilineatum*, like *H. peronii*, has a very high rate of evaporative water loss (Licht, Dawson and Shoemaker, 1966).

Why *H. peronii* does not occur in the Flinders or Mt. Lofty Ranges is hard to say. Over much of its range it occurs on sand; in the south-east, for instance, its range seems to coincide with the relict coastal dunes there (Sprigg, 1952). On parts of Eyre Peninsula it occurs on soils which, though not very sandy, are underlain by kunkar derived from old sand dunes. Perhaps *H. peronii* avoids soils prone to water-logging. But obviously a full analysis of its distribution requires much more detailed study.


## ACKNOWLEDGMENTS

I wish to thank John Mitchell, Glen Storr, Harold Cogger, Peter Rawlinson, Dierk Von Behrens and students from Naracoorte High School, Michael Braysher, Meredith Smith, Vaal Nielsen, Beverley Jones, Stuart Harris and Lewis Chinner for help and advice.


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# HELMINTHS FROM SOME LIZARDS MOSTLY FROM SOUTH AUSTRALIA

*BY* L. MADELINE ANGEL *AND* PATRICIA M. MAWSON*

**Summary**

An account is given of helminths from lizards from an area near Port Gawler in South Australia, including a table of their incidence. Records are also given of trematodes from two Queensland lizards. Species recorded (all from the Pt. Gawler region unless otherwise stated) are: *Paradistomum crucifer* (Nicoll) (syns. *Eurytrema crucifer* Nicoll, *Paragonimus trachysauri* MacCallum, *Cephalogonimus trachysauri* MacCallum, *Paradistomum muccallumi* Johnston) from *Hemiergis peronii, Trachydosaurus rugosus* (Pt. Gawler area and from Murray Bridge S.A.), *Tiliqua scincoides* (Queensland) , and *Varanus varius* (Queensland) *Oochoristica trachysauri* (MacCallum) (syn. *Oochoristica australiensis* Spassky (from *Trachydosaurus rugosus; Thelandros kartana* Johns ton and Mawson from *H. peronii, Phyllodactylus marmoratus; T. trachysauri* Johnston and Mawson from *Trachydosaurus rugosus; Skrjabinodon smythi* n. sp. From *P. marmoratus.* Other helminths recorded are *Microphallus* sp. from *T. rugosus; Trematoda,* ? sp., from *Rhodona bougainvillii; Oochoristica sp.* and *Baerietta* sp. from *R. bougainvillii,* H. *peronii* and *P. marmoratus; Skrjabinelazia* sp. From *P. marmoratus;* acanthocephalan cysts from *H. peronii.*

# HELMINTHS FROM SOME LIZARDS MOSTLY FROM SOUTH AUSTRALIA

by L. Madeline Angel and Patricia M. Mawson*

[Read 8 August 1968]

## SUMMARY

An account is given of helminths from lizards from an area near Port Gawler in South Australia, including a table of their incidence. Records are also given of trematodes from two Queensland lizards. Species recorded (all from the Pt. Gawler region unless otherwise stated) are: *Paradistomum crucifer* (Nicoll) (syns: *Eurytrema crucifer* Nicoll, *Paragonimus trachysauri* MacCallum, *Cephalogonimus trachysauri* MacCallum, *Paradistomum maccallumi* Johnston) from *Hemiergis peronii*, *Trachydosaurus rugosus* (Pt. Gawler area and from Murray Bridge, S.A.), *Tiliqua scincoides* (Queensland), and *Varanus varius* (Queensland); *Oochoristica trachysauri* (MacCallum) (syn. *Oochoristica australiensis* Spassky (from *Trachydosaurus rugosus*; *Thelandros kartana* Johnston and Mawson from *H. peronii*, *Phyllodactylus marmoratus*; *T. trachysauri* Johnston and Mawson from *Trachydosaurus rugosus*; *Skrjabinodon smythi* n. sp. from *P. marmoratus*. Other helminths recorded are *Microphallus* sp. from *T. rugosus*; *Trematoda*, ? sp., from *Rhodona bougainvillii*; *Oochoristica* sp. and *Baerietta* sp. from *R. bougainvillii*, *H. peronii* and *P. marmoratus*; *Skrjabinelazia* sp. from *P. marmoratus*; acanthocephalan cysts from *H. peronii*.

## INTRODUCTION

During 1967, Dr. Michael Smyth, of this department, undertook an investigation of aspects of the ecology of lizards inhabiting a coastal strip north of Adelaide. The parasites of these lizards, and some from the same host species from different localities, are discussed in this paper. The occurrence of a trematode from two other species of lizards, both from Queensland, is also recorded.

We are very grateful to Dr. Smyth, not only for giving us the viscera for examination, but also for the regularity and precision of his collection and records. An account of his work is in press.

The study area is a short distance north of Adelaide and the two collecting centres are Port Gawler and Middle Beach. The two areas are separated by two permanent salt water channels. The lizards from each area are listed in Table 1, with records of parasitism. It will be noted that trematodes were found (except in one case) only at Middle Beach; cestodes and nematodes occurred in both areas. Juvenile lizards seem to be free from helminths. Records were kept of the sex of each lizard dissected, but this appeared to have no significance in relation to the infestation by helminths, and has not been indicated in the Table.

Differences in the incidence of parasitism, as well as of the different groups of helminths, in the different species of lizards, are quite marked, and are discussed below.

We are grateful to Dr. S. J. Edmonds, of this department, for examining the acanthocephalan cysts. Our thanks are also due to Mr. John Mitchell, of the South Australian Museum, for the correct names of the lizards concerned.

* Department of Zoology, University of Adelaide.

TABLE 1

*Incidence of helminths in the study area.*

The figures refer to the number of lizards dissected or found parasitised. An asterisk indicates that the alimentary canal only, not the gall bladder, of these specimens was examined

| Lizard | Locality | Number dissected | Number parasitised | Number yielding | | | |
|---|---|---|---|---|---|---|---|
| | | | | Trematoda | Cestoda | Nematoda | Acanthocephala |
| *Trachydosaurus rugosus* (Gray) | Pt. Gawler | 3 | 3 | | — | 3 | — |
| | Middle Beach | 6 | 6 | 1 | 2 | 5 | — |
| *Ablepharus greyii* (Gray) | Pt. Gawler | 8* | 0 | | | | |
| | | 1 | 0 | | | | |
| | Middle Beach | 2 | 0 | | | | |
| *Hemiergis peronii* (Fitzinger) | Pt. Gawler | 80* | 16 | — | 7 | 12 | |
| | | 99 | 26 | — | 7 | 20 | 2 |
| | | 10 juv. | 0 | | | | |
| | Middle Beach | 13* | 4 | | — | 4 | — |
| | | 71 | 37 | 15 | 2 | 34 | 3 |
| | | 9 juv. | 0 | | | | |
| *H. decresiensis* (Fitzinger) | Pt. Gawler | 1 | 0 | | | | |
| *Rhodona bougainvillii* (Gray) | Pt. Gawler | 20 | 14 | 1 | 11 | — | |
| *Phyllodactylus marmoratus* (Gray) | Pt. Gawler | 12 | 11 | — | 2 | 10 | |
| | | 1 juv. | 0 | | | | |
| | Middle Beach | 1 | 1 | . | — | 1 | — |

## PARASITES RECORDED, ARRANGED UNDER THEIR HOSTS

*Trachydosaurus rugosus* Gray. *Microphallus* sp.; *Paradistomum crucifer* (Nicoll); *Thelandros trachysauri* Johnston and Mawson.

*Hemiergis peronii* (Fitzinger). *Paradistomum crucifer* (Nicoll); *Oochoristica* sp.; *Baerietta* sp.; *Pharyngodon kartana* Johnston and Mawson.

*Tiliqua scincoides* (Shaw). *Paradistomum crucifer* (Nicoll).

*Rhodona bougainvillii* (Gray). *Trematoda*, ? sp.; *Oochoristica* sp.; *Baerietta* sp.

*Phyllodactylus marmoratus* (Gray). *Skrjabinodon smythi* n. sp., *Thelandros kartana* Johnston and Mawson; *Skrjabinelazia* sp.

*Varanus varius* (Shaw). *Paradistomum crucifer* (Nicoll).

## TREMATODA

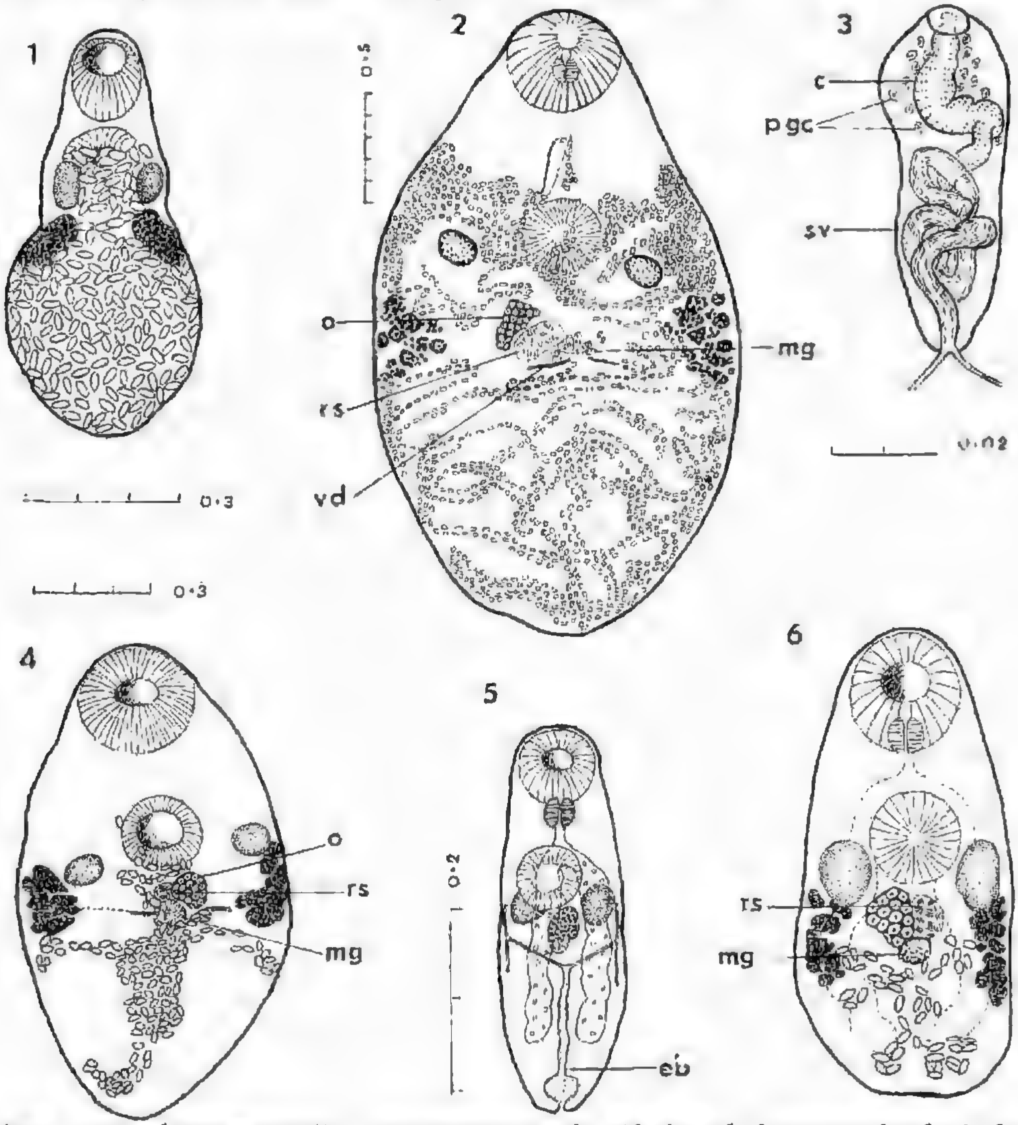
### Paradistomum crucifer (Nicoll)

(Figs. 1-6)

*Eurytrema crucifer* Nicoll, 1914, 338, in gall-bladder, *Delma fraseri*.
*Paradistomum crucifer* (Nicoll) Travassos, 1919, 12; 1944, 256.
*Paragonimus trachysauri* MacCallum, 1921, 173, in gall-bladder, *Trachydosaurus rugosus* (syn. *Trachysaurus rugosus*).
*Cephalogonimus trachysauri* MacCallum, 1921, 176, in gall-bladder, *Trachydosaurus rugosus*.
*Paradistoma trachysauri* (MacCallum) Dollfus, 1922, 329.
*Paradistoma trachysauri* (MacCallum) Dollfus; Johnston, 1932, 64.
*Paradistomum maccullumi* Johnston, 1932, 64 (nom. nov. for *Cephalogonimus trachysauri* (MacCallum).
*Paradistomum trachysauri* (MacCallum) Dollfus; (syns. *Paragonimus trachysauri* MacCallum and *Paradistomum maccallumi* Johnston), Malan 1939, 37.
*Paradistomum trachysauri* (MacCallum) Dollfus; Travassos, 1944, 262.

*Hosts and Localities*: *Hemiergis peronii*, Middle Beach, South Australia, from gall-bladder, occasionally in small intestine; *Trachydosaurus rugosus*, Murray Bridge district, South Australia, from gall-bladder and liver; *Tiliqua scincoides*, Facing Island, near Gladstone, Queensland, apparently collected by Professor T. Harvey Johnston, in 1918, from gall-bladder (ten specimens from one host); *Varanus varius*, Townsville, Queensland, collected by Dr. G. A. M. Heydon in 1927, from gall-bladder (two specimens from one host).

The description is based on 24 stained and mounted specimens from *Hemiergis peronii*, with details from living specimens. Notes on the trematode from *Trachydosaurus rugosus* are given in the discussion.




Figs. 1-6 *Paradistomum crucifer*. Drawings were made with the aid of a camera lucida. Scales in millimetres. Figs. 1 and 6 to same scale. Eggs not drawn exactly to scale.
Figs. 1-3, 5, 6, from *Hemiergis peronii*; 1, 2, 6, adults, showing variation in form, and in extent of uterus, (2, flattened); 3, cirrus sac; from specimen shown in fig. 2, enlarged; 5, young adult, excretory system from living specimen. Fig. 4, type specimen redrawn (from *Delma fraseri*). c, cirrus; eb, excretory bladder; mg, Mehlis' gland; o, ovary; pgc, prostate gland cells; rs, receptaculum seminis; sv, seminal vesicle; vd, vitelline duct.

The numbers of trematodes in the infected *H. peronii* ranged from 1-15, and generally included juveniles as well as adults. One gall-bladder contained 65 specimens, but all were very young. Nearly all specimens were found in the gall-bladder, but a few were in the liver, and four were taken from the intestine. Of these last, three were in two hosts whose gall-bladders were uninfected, and the fourth was in a lizard whose gall-bladder contained twelve trematodes. In one lizard only, the trematodes were found not only in the gall-bladder (thirteen), but also in ducts which appear to be pancreatic, running through the elongated pancreas from the gall-bladder to the intestine (fifteen).

Specimens were fixed, under a coverslip with only slight pressure, in formol acetic alcohol, stained in Van Cleave's combination haematoxylin stain, and mounted in Depex.

## DESCRIPTION

Shape: Elongated or leaf-like when living; fixed specimens with bluntly rounded posterior and often somewhat elongated anterior end. Colour pale pink, with caeca yellow.

Body 0·748-2·890 mm long by 0·306-1·496 mm wide. Cuticle not spined. Oral sucker rounded or slightly oval, 223-494 μ (average 342 μ) long by 129-423 μ (330 μ) wide. Acetabulum rather inconspicuous, rounded, 170-353 μ (235 μ) long by 141-306 μ (239 μ) wide; anterior border near anterior third of body. Ratio of width of oral to width of ventral sucker 1:0·7 to 1:0·9. Prepharynx short; pharynx 50 by 50 μ—110 by 100 μ, dorsal to oral sucker or partly posterior to it; oesophagus short; caeca wide, sinuous, extending nearly to posterior end of body.

Testes symmetrical, at sides of acetabulum, rounded in living, may be irregular in fixed specimens, equal or sub-equal, 71-165 μ (110 μ) long by 59-176 μ (106 μ) wide. Cirrus sac 92-184 μ long by 45-100 μ wide, between suckers, at an angle to left of mid-line. Seminal vesicle internal, much coiled. Cirrus inconspicuous, slightly coiled, surrounded by diffuse prostatic cells. Genital pore median, near posterior border of oral sucker.

Ovary post-acetabular, sinistral, irregular, 82-223 μ long by 71-188 μ wide. Receptaculum seminis mostly dorsal to ovary, may be posterior or to either side of it, 47-141 μ (96 μ) by 59-212 μ (107 μ). Mehlis' gland irregular, generally posterior to ovary and slightly to right. Laurer's canal not seen. Uterus varying in extent from condition shown by Nicoll, with relatively few eggs (Fig. 6), to one in which it fills all of hind-body and an area in front of acetabulum; passing to right of cirrus sac and opening by muscular metraterm at genital pore.

Eggs variable, largest 40 μ by 22 μ.

Vitellaria extracaecal, restricted to middle of body, reaching level of posterior third of acetabulum anteriorly; 270-764 μ (476 μ) in extent; lobules variable, some moderately large. Transverse yolk ducts widening at junction in mid-line, but forming no obvious yolk reservoir.

Excretory bladder elongate, main arms leaving anterior end. Excretory pore terminal.

## DISCUSSION

The mature trematodes found in *Hemiergis peronii* in this study show a considerable variation in size, ranging from 0·748 by 0·374 mm to 2·890 by 1·258 mm, and in appearance. The trematodes found in the pancreatic ducts were greatly elongated, while the worms from the gall-bladder tended to be foliate. As immature specimens are often present with the adults, some of the differences among egg-bearing adults are probably due to differences in age. For example, the testes and ovary may be as large in small worms as in much larger ones (Figs. 2, 6) giving a disproportimate emphasis to these organs in the small specimens. The specimen shown in Fig. 1 shows the acetabulum very near the oral sucker; a specimen of similar size from the same host showed a similar arrangement of eggs, but the body was more elongated and the acetabulum was in the more typical position. Even among specimens of the same size there is great variation in the number of eggs, and this leads to differences of form and general appearance. In the original description of *Paradistomum crucifer,* Nicoll stated that the uterus, especially in the less mature specimens, had a characteristic cruciform course, but that in more mature specimens this arrangement was, to some extent, obliterated. Among the small trematodes of my collection, some (Fig. 6) have a uterus showing the cruciform course, while in others (Fig. 1) the eggs form a more or less solid mass in the hind-body and sometimes anteriorly to the acetabulum, so that most of the organs are obscured. Even among the larger specimens there is also a good deal of variation in the number of eggs.

By courtesy of the Director of the School of Public Health and Tropical Medicine, Sydney, one of us (L.M.A.) has been able to examine the type of *P. crucifer.* Some of our smaller specimens are very similar to it in appearance, and one of them is almost identical with it, not only in overall size, but in the size and arrangement of the organs. The trematodes from *Hemiergis peronii* must be regarded as *Paradistomum crucifer.*

Although the range of measurements given by Nicoll shows that his specimens were uniformly smaller than the trematodes found in *H. peronii,* Nicoll's description was based only on "a few" worms. In addition, all measurements given by Nicoll are consistently smaller than those now made on the type (Table 2). It is possible that this is due to some flattening of the specimen over the years; it is also possible that Nicoll had made a mistake in his scale.

MacCallum (1921) found about twenty trematodes in the gall-bladder of a stump-tailed lizard, *Trachydosaurus rugosus,* which died in the New York Zoo. He stated: "there were three different sizes among them, which, with the decided differences in form, would almost make it necessary to divide them into three species, but as they are in many particulars alike, and for brevity's sake, we shall describe them as one species". This he named *Paragonimus trachysauri.* Later in the same paper MacCallum stated that he had found two different trematodes in the lizard, one being *P. trachysauri;* the second he described as *Cephalogonimus trachysauri.* Malan (1939) regarded the two as identical, and thus synonymous with *Paradistomum trachysauri,* and this has been accepted by later workers.

Although the largest specimens from *H. peronii* are smaller than the measurements given by MacCallum for *Paradistomum trachysauri,* the measurements of ovaries and testes are comparable, the ratios of the suckers appear similar, and the specimens resemble the one figured by MacCallum. Differences in fixation could account for some differences in body dimensions, as also could the relative sizes of the hosts*. There seems no reason to regard the specimens from *Hemiergis peronii* as distinct from those described by MacCallum from *Trachydosaurus rugosus,* so that *Paradistomum trachysauri* must become synonymous with *P. crucifer.* It should be noted, however, that *P. crucifer* as now interpreted

* It is of interest to note that *Delma fraseri* (the type host of *Paradistomum crucifer*), a pygopodid lizard, and *Hemiergis peronii* are much smaller than *Trachydosaurus rugosus.* I have not dissected *D. fraseri,* but it can be expected that its gall-bladder is very little larger than that of *H. peronii,* which is much smaller than that of *T. rugosus.*

TABLE 2

*Paradistomum crucifer* (Nicoll)

| Described as | *Eurytrema crucifer* (type specimen) | | *Paragonimus trachysauri* | *Cephalogonimus trachysauri* | *Paradistomum crucifer* | *Paradistomum crucifer* | *Paradistomum crucifer* | *Paradistomum crucifer* |
|---|---|---|---|---|---|---|---|---|
| Host | *Delma fraseri* | | *Trachydosaurus rugosus* | *Trachydosaurus rugosus* | *Hemiergis peronii* | *Trachydosaurus rugosus* | *Varanus varius* | *Tiliqua scincoides* |
| Locality | North Queensland | | New York Zoo | New York Zoo | Middle Beach | nr. Murray Bridge, S.A. | Townsville, N. Q'ld. | nr. Gladstone, Q'ld. |
| Date collected | — | — | 30/8/18 | 30/8/18 | 1967 | 2/1968 | 1927 | 1918 |
| Measurements given by | Nicoll, 1914 | Present study | MacCallum, 1921 | MacCallum, 1921 | Present study | Present study | Present study | Present study |
| Number examined | "a few" | 1 | ? 17 | 3 | 24 | 2[5] | 2 | 4 |
| Length | 0·7–0·8 | 1·224 | 5·00 | 3·00 | 0·748–2·890 | 1·088–3·774[6] | 2·720–3·162[7] | 2·142–2·516[7] |
| Width | 0·35–0·4 | 0·714 | 2·00 | 0·70 | 0·306–1·496 | 0·289–0·918 | 0·884–0·918 | 1·038–1·292 |
| Oral sucker[1] | 0·18 | 0·294 | — | 0·320 | 0·129–0·423[4] | 0·137–0·388 | 0·341–0·412 | 0·376–0·423 |
| Acetabulum[1] | 0·15 | 0·223 | — | 0·328 | 0·141–0·306[4] | 0·118–0·306 | 0·341–0·365 | 0·270–0·329 |
| Sucker ratio | 1:0·83 | 1:0·76 | [3] | 1:1 | 1:0·7–1:0·9 | 1:0·86;1:0·8 | 1:0·88;1:1 | 1:0·78 (av.) |
| Pharynx | 0·04 | — | — | — | 0·051–0·100 | 0·053–0·107 | 0·141 | — |
| Testes—length | 0·04 | 0·071–0·106 | 0·15 | 0·200 | 0·071–0·165 | –0·147 | — | — |
| —width | — | 0·082–0·094 | | — | 0·059–0·176 | –0·184 | — | — |
| Ovary—length | "About same size as testes" | 0·094 | 0·2 | 0·280 | 0·082–0·223 | –0·123 | — | — |
| —width | | 0·082 | — | — | 0·071–0·188 | –0·263 | — | — |
| Eggs | 30-33 x 21 | 36 x 22[2] | 50 x 20 | 40 x 20 | 40 x 22[2] | 39 x 24[2] | 31 x 20[2] | 35 x 20[2] |

All measurements are in millimetres, except for eggs, which are in microns.

[1] In measurements made in the present study, the width of suckers is given.

[2] Largest egg measured.

[3] Although MacCallum states in the text that "the acetabulum is as large as the mouth", his figure shows the acetabulum as smaller.

[4] The apparent discrepancy in the lower part of the two ranges is accounted for by the fact that, in the specimen with smallest suckers, the oral sucker was longer than broad, while the acetabulum was broader than long.

[5] The largest and smallest of 30 specimens.

[6] Specimens less flattened than those from *Hemiergis peronii* (see discussion).

[7] Spirit specimens; do not appear to have been flattened in any way.

shows considerable variation in size and general appearance. Variation has already been reported for another species of *Paradistomum* by Dollfus (1922, 328, footnote), who referred to the great morphological variations he had found in *P. mutabile* (Molin).

This is the first Australian record of a trematode from a lizard since MacCallum's report of *P. trachysauri*. In 1932, Harvey Johnston reported that "a number" of *T. rugosus* had been searched for parasites from time to time, but that no trematodes had been found. After *P. crucifer* was found in *H. peronii* in the present study, as many *T. rugosus* as possible were examined. It was not until this paper was completed that *P. crucifer* was found in this host, in two lizards from the Murray Bridge district. (Of the forty-five *T. rugosus* dissected only nine were from the study area north of Adelaide. The remainder came from a number of different localities.) In the first lizard there were 34 trematodes in the gall-bladder and 12 in the liver. In the second, there were 56 living and a number of disintegrating worms (which were mere collections of eggs) in the gall-bladder, and 13 living worms in the liver. The lizards had been in captivity for almost two months when they were dissected. All the trematodes were mature, but great differences in size were found. The specimens were fixed in formol acetic alcohol under a coverslip. Virtually no pressure was required to fix them flat, so that the measurements are not truly comparable with those of the specimens from *H. peronii* (which were fixed with slight pressure) but would probably have been greater (certainly in the width of the body) had the worms been fixed with the same pressure. Measurements of the largest and the smallest specimens from the first infected lizard are given in Table 2.

The following observations were made on the living trematodes from *T. rugosus*. The caeca appear bright yellow (due to bile), and contain many crystals, as recorded by MacCallum. These are tetragonal in shape, and vary in size from fine slender crystals to forms up to 223 $\mu$ by 35 $\mu$ by 35 $\mu$. (Crystals were not present in *P. crucifer* from *H. peronii;* this is presumably due to a difference in composition of the bile of the two lizards.) The part of the body which is not coloured by bile or obscured by eggs is pale pink in colour. Twenty mature eggs taken at random from the liver washings measured 34-39 $\mu$ (37 $\mu$) by 21-24 $\mu$ (22 $\mu$).

*P. crucifer* from both hosts was very sensitive to changes in the medium in which it was kept. In 0·65% saline it very quickly became swollen and died. It could be kept alive in bile at 6°C for several days.

## LIFE HISTORY

The only species of *Paradistomum* for which investigations on the life-history have been recorded is *P. mutabile* (Molin). Timon-David and Timon-David (1967) infected *Helicella arenosa* experimentally and obtained brevicercous xiphidiocercariae. (*H. arenosa* was not the normal host since it did not occur on the islands on which *Paradistomum mutabile* was commonly found in lizards). The cyst stage was not found, but the authors thought it probable that a second intermediate host is necessary, and suggested an isopod or an insect.

In the present study no information could be gathered on the life-history of *P. crucifer*. The only land snails found in the study area are *Austrosuccinea australis* Ferrusac, *Omegapilla australis* Angas, *Australbinula margaretae* Cox and *Paralaoma stabilis* Iredale. The last three of these are very small snails and quite difficult to find in the litter in which they occur. (*P. stabilis* was not, in fact, found in the open at all, but was recovered from the stomachs of lizards, in which it occurred quite often). It was therefore not possible to conduct any trematode life-history studies with these molluscs. Attempts were made to infect *Austrosuccinica autralis* (collected from another area) but it proved impossible to keep the snails alive long enough to obtain any results.

It will be seen from Table 1 that whereas fifteen of seventy-one *Hemiergis peronii* from Middle Beach were infected with *Paradistomum crucifer,* none of ninety-nine of these lizards from Port Gawler harboured the parasite. We can suggest no reason for this.

If, as seems likely, a second intermediate host is necessary, it is to be sought among the animals listed by Smyth (1968) as found in the stomachs of *H. peronii.* Of these, the most common are weevils, free-living mites (very small species), ants, cockroaches, moths and snails.

### **Microphallus** sp.

*Host and Locality.* *Trachydosaurus rugosus;* Middle Beach.
One specimen, in upper small intestine.

### **Trematoda**, ? sp.

*Host and Locality.* *Rhodona bougainvillii,* Port Gawler.
One specimen, in intestine.

## CESTODA

The authors, neither of whom is a cestodologist, are greatly indebted to Dr. John Hickman, of the Zoology Department, University of Tasmania, for identification of *Baerietta* sp. and verification of *Oochoristica* spp. Further identification of the material will be made by Dr. Hickman.

### **Oochoristica trachysauri** (MacCallum)
(Fig. 7)

*Taenia trachysauri* MacCallum, 1921, 229.
*Oochoristica trachysauri* (MacCallum), Johnston, 1932, 65.
*Oochoristica australiensis* Spassky, 1951, 547.

*Host and Locality.* *Trachydosaurus rugosus,* Middle Beach, South Australia.

This species was fully described by Johnston (1932). Spassky (1951) considered Johnston's specimens different from those of MacCallum and proposed for them a new species, *O. australiensis.* The material now examined, all from one host, shows similarity to all earlier collections—some specimens with an obvious rostellum, some with rounded anterior end; the mature segments vary (sometimes abruptly, fig. 7) from more or less square to elongate. It is considered that all belong to the same species.

### **Oochoristica** sp.

*Hosts and Locality.* *Rhodona bougainvillii, Hemiergis peronii, Phyllodactylus marmoratus,* Port Gawler.
More than one species may be present.

### **Baerietta** sp.

*Hosts and Locality.* *Rhodona bougainvillii, Hemiergis peronii,* Port Gawler.
The cestodes from these hosts are similar and probably belong to the same species.

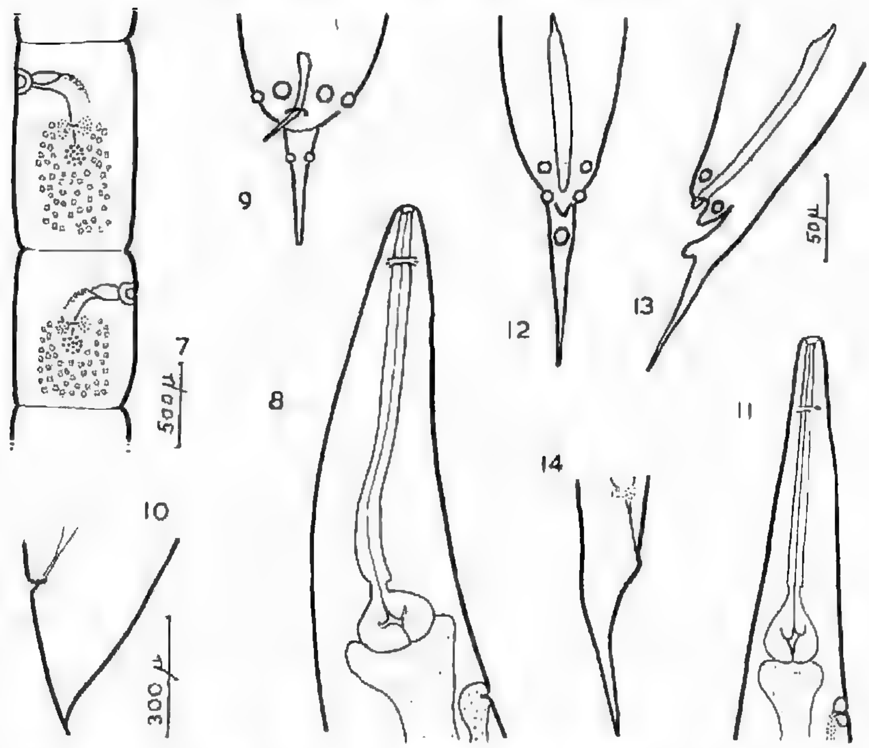



Fig. 7. *Oochoristica trachysauri*, part of strobila showing variation in shape of segments. Figs. 8-10, *Thelandros kartana*, 8, anterior end; 9, ventral view of male tail; 10, female tail. Figs. 11-14, *T. trachysauri*, 11, anterior end; 12 and 13, ventral and lateral views of male tail; 14, tail of female. Figs. 9, 12, 13, to scale beside 13, figs. 8, 10, 11 and 14 to scale beside 10.

## NEMATODA

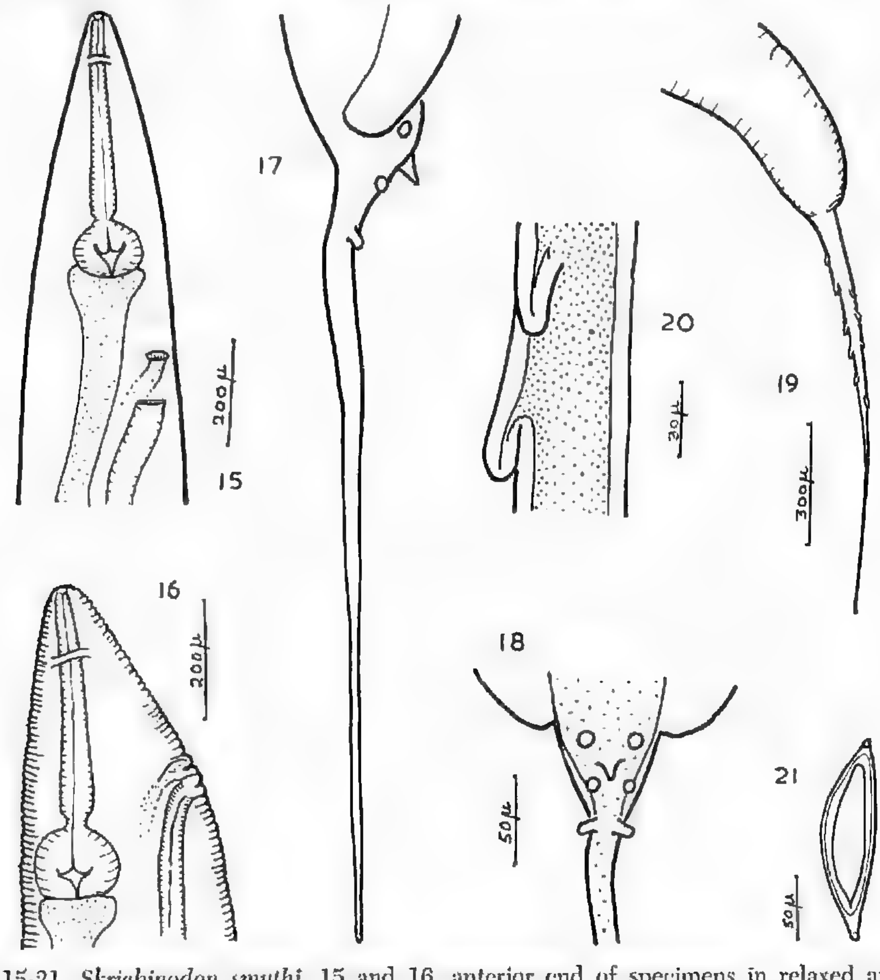
The nematodes taken from the lizards at Port Gawler show an interesting host distribution. None were found in *Ablepharus greyii* or *Rhodona bougainvillii*. Oxyurids were found in *Hemiergis peronii*, *Trachydosaurus rugosus* and *Phyllodactylus marmoratus*, and in almost all cases each of these hosts carried only its own species. The exceptions were two *P. marmoratus*, in which were *Thelandros kartana*, typically present in *H. peronii*. Although *H. bougainvillii* is apparently free of nematodes in this area, it carries the same cestode species as does *H. peronii* and these species are in turn different from that from *T. rugosus*. This difference in parasites may be due to a high degree of host specificity among the oxyurids, and perhaps of resistance among the lizards, or it may be explained in part by the different niches occupied by the lizards. Dr. Smyth has informed us that *R. bougainvillii* and *H. peronii* live mainly under certain bushes, *A. greyii* and *P. marmoratus* mainly under wood, stones, etc., and *T. rugosus* (a much larger lizard) may be found in either habitat. Most of the lizards are diurnal and insectivorous; *T. rugosus* is diurnal and predominantly vegetarian; *P. marmoratus* is nocturnal and insectivorous. Oxyurid eggs might be expected to be quite common over the surface in the area, especially those of *Thelandros trachysauri* which occurs in hundreds in each host animal.

## Thelandros kartana Johnston and Mawson
(Figs. 8-10)

*Thelandros kartana* Johnston and Mawson, 1941, 145; from *Hemiergis peronii*, Kangaroo Island.

*Hosts and Localities. Hemiergis peronii*, Port Gawler, Middle Beach. *Phyllodactylus marmoratus*, Port Gawler.

*Thelandros kartana* was taken from 22 specimens of *H. peronii* from Middle Beach and 27 from Port Gawler. Female worms with eggs were taken from two *P. marmoratus*. No more than four worms were present in any one lizard, and usually only one or two. They occurred almost always in the short caecum at the junction of small and large intestine. The new specimens have been compared with paratypes of *T. kartana* and found to agree closely. The original description can now be augmented by Figures 8-10 and measurements in Table 3. The measurements of the specimens from *P. marmoratus* are within the range of those from *H. peronii*.




Figs. 15-21, *Skrjabinodon smythi*, 15 and 16, anterior end of specimens in relaxed and contracted states respectively; 17, posterior end of male; 18, ventral view of cloacal region, male; 19, tail of female; 20, part of spike of female tail showing 'spines'; 21, egg. Figs. 17 and 18 to same scale.

### **Thelandros trachysauri** Johnston and Mawson
(Figs. 11-14)

*Thelandros trachysauri* Johnston and Mawson, 1947, 24, from *Trachydosaurus rugosus*, Adelaide.

*Host and Localities. Trachydosaurus rugosus*, Port Gawler, Middle Beach.

*Thelandros trachysauri* has been found in nearly all *T. rugosus* dissected in this Department—more than thirty-five from various places. It is present in very large numbers in the middle and posterior parts of the large intestine. The collections from the Port Gawler area agree with the original description, which can now be amplified by measurements of more specimens (Table 3) and by Figures 11-14.

The lateral alae, present in both sexes, are not very wide; in the male they extend from the posterior oesophageal region to near the cloaca; in the female they are restricted, commencing just posterior to the oesophagus and reaching to, not past, the vulva. The nerve ring is 190-210 $\mu$ from the head in females, rather more anterior than described earlier. The eggs are oval in shape, contain a bent larva, and measure 100 $\mu$ by 59-60 $\mu$.

### **Skrjabinodon smythi** n.sp.
(Figs. 15-21)

*Type Host and Locality. Phyllodactylus marmoratus*, Port Gawler. Other localities: Middle Beach, Chowilla, Loxton, Lock, all in South Australia.

Type ♂ and allotype ♀ will be deposited in the South Australian Museum.

This species appears to be common in *P. marmoratus* throughout southern Australia, although another species (unpublished) apparently takes its place in northern parts of the state. It has been taken from fourteen of seventeen host animals examined. In most cases there are about 6-8 worms in each host, but in some there are more, the greatest number being sixty-seven of which 38 were males, 7 females with eggs, and 22 females without eggs. All occur in a mass in the small caecum at the origin of the large intestine. Where few worms are present, the gravid females are stuffed with eggs, but where there are many worms, the eggs are few.

There is an apparent variation in the position of the vulva and excretory pore in the females. These appear to be oesophageal structures in some collections and well behind the oesophagus in others. This however is largely dependent on the degree of contraction of the body. It has been noted that those worms in which the excretory pore (and vulva) are oesophageal are stiff and barrel-like in appearance, with strongly marked ringed or ruched cuticle, whereas in flaccid specimens with smooth cuticle these two pores are further back. This is shown by the measurements, in Table 3, for *S. smythi* as, although the total length measurements show a great variation, the length of the oesophagus and the tail spike do not. In this Table, measurements are also given of some very flaccid specimens from Chowilla.

Lateral alae are present in both sexes, from about the midlength of the oesophageal region to the level of the anus. The amphids are large, more prominent, and slightly further back, than the four large cephalic papillae. The three lips are bilobed in the female and single in the male. At the anterior end of the oesophagus of the male are three small teeth, not present in the female. The position of the nerve ring is not clear in most specimens. The excretory pore is a transverse slit with cuticularised lips and it lies posterior to the oesophagus in relaxed specimens. It is more posterior in the male than in the female.

The male is without caudal alae; the male tail spike has a few very minute spines. There is no spicule, but cuticularised projection of the cloacal wall is

TABLE 3

Measurements of *Thelandros kartana*, *T. trachysauri* and *Skrjabinodon smythi*. All measurements are in μ unless otherwise indicated. The tail of the male *S. smythi* from Port Gawler is broken.

| Species | *T. kartana* | *T. trachysauri* | *S. smythi* | | |
|---|---|---|---|---|---|
| Locality | Port Gawler | Middle Beach | Port Gawler | Port Gawler | Chowilla |
| State of contraction | | | (contracted) | (relaxed) | (flaccid) |
| Males: | | | | | |
| length (mm) | 1·6–3·0 | 1·5–2·5 | 1·40–1·78 | 2·4–2·5 | 1·75–2·10 |
| oesophagus | 320–480 | 550–650 | 220–300 | 250–275 | 290–300 |
| antr. end-exer. pore | 560–1000 | 550–900 | 330–370 | 600–650 | 400–490 |
| tail spike | 50–70 | 100–120 | 360–410 | 400–420 | 450–550 |
| spicule | 65–75 | 100–150 | — | — | — |
| Females: | | | | | |
| length (mm) | 2·1–6·5 | 3·3–3·5 | 3·6–4·5 | 5·0–7·0 | 5·9–8·4 |
| oesophagus | 400–1200 | 820–980 | 500–560 | 470–500 | 450–500 |
| antr. end-exer. pore | 530–1400 | 900–1000 | 300–400 | 550–650 | 550–700 |
| -vulva | 3·0–4·8 | 1·9–2·0 | 350–450 | 650–760 | 600–780 |
| tail | 100–150 | (390)–450 | 1390–1500 | 1350–1800 | 1500–1600 |
| tail spike | — | — | 1000–1050 | 800–1050 | 900–1000 |

present. The preanal, adanal, and postcloacal papillae are almost evenly spaced on the ventral surface. Dorsolaterally to each adanal papilla is a papilla-like extension into, but not lifting, the cuticle, and terminating at a tiny pore. These are probably the phasmids.

The tail of the female bears about 7-9 irregularly spaced projections which are more digitiform than spinous (Fig. 20). The vulva is a transverse slit, without thickened lips. The eggs are 150-165 μ long, with a plug at each end and slightly flattened on one side. The most mature eggs contain a larva 120 μ long.

The genus *Skrjabinodon* was proposed by Inglis (1968, 179) for some species which had been placed in *Parathelandros* Baylis but which differed from the type species of this genus, and from other species which he described at that time. The species attributed to *Parathelandros* are all from Australian frogs, and those to *Skrjabinodon* are from lizards, mostly from places other than Australia, but one, *S. oedurae* (Johnston and Mawson) from an Australian lizard. The present specimens agree generally with other species of *Skrjabinodon* and with the generic diagnosis proposed by Inglis, except in the two characters which he marks as doubtful, namely the absence of onchia at the anterior end of the oesophagus (present in the male of *S. smythi*) and the lip shape, which does not appear to be bilobed in the male of *S. smythi*.

The species is differentiated from *S. anolis* (Chitwood), the only other species of the genus in which the spicule is absent and the female tail bears large "barbs", by the shape of the barbs, the larger size of the eggs, the longer oesophagus, the more anterior position of the anus in the female, and by the rather different spacing of the male caudal papillae.

## Skrjabinelazia sp.

*Host and Localities*: *Phyllodactylus marmoratus*, Port Gawler, Middle Beach.

The material available consists of several female worms from the intestine of five geckos. No males have been found.

The worms are large, up to 18·3 mm in length, and the cuticle at each end is markedly inflated. The anterior end bears four large papillae and two amphids. There are no lips. The mouth, more or less circular, leads into a short buccal cavity from the walls of which project a ring of tiny teeth, like an internal leaf crown. The oesophagus, 1·2 mm long, widens towards its posterior end, but is not obviously divided into muscular and glandular parts. The nerve ring is at about one third its length from the head, and the excretory pore at the same level. Cervical papillae were not seen. The posterior end narrows suddenly 300 $\mu$ behind the anus, and the body proper ends in a short spike about 110 $\mu$ long. The inflated cuticle extends behind this for about 50 $\mu$.

The vulva lies shortly behind the nerve ring, about 490 $\mu$ from the head. The eggs are large, sub-spherical, 90 $\mu$ in diameter, and contain a coiled embryo. The egg shell is thin and apparently not rigid, as some change their shape under pressure.

These worms are very similar in appearance to those of the genera *Skrjabinclazia* Sypliakova and *Salobrella* Freitas. The species of these genera differ, as far as the female is concerned, in the absence or presence, respectively, of lips, so the present specimens are identified as *Skrjabinclazia* sp. In the absence of males, no further identification is attempted. No species of *Skrjabinclazia*, or of *Salobrella*, has so far been recorded from Australian hosts.

## ACANTHOCEPHALA

*Host and Locality: Hemiergis peronii*, Port Gawler (2) and Middle Beach (3).

Five acanthocephalan cysts were taken from the mesenteries of these hosts. They have been examined by Dr. S. J. Edmonds, who has kindly given the following information.

All the cysts appear to belong to the same genus. In only one is the introvert extended enough to permit an estimate of its measurements. The ellipsoidal cyst is approximately 800 $\mu$ long by 300 $\mu$ wide. The introvert, which is cylindrical and bears numerous hooks, is about four-sevenths extended, and is estimated as 1100 $\mu$ long and 260 $\mu$ wide. The number of hooks is hard to estimate, possibly about 30 rings each of 26 hooks.

The only acanthocephalan so far recorded from Australian reptiles is *Sphaerechinorhynchus rotundocapitatus* (Johnston, 1912), from the black snake *Pseudechis porphyriacus* Shaw. The cysts from *H. peronii* do not belong to this species.

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# TWO SPECIES OF *SACCOGLOSSUS* (ENTEROPNEUSTA) FROM SOUTH AUSTRALIA

*BY I. M. THOMAS**

**Summary**

A new species of the Enteropneusta, *Saccoglossus aulakoeis* is described. It possesses a deep, dorsal, longitudinal groove on its proboscis. It is compared with three previously described members of the genus, which have similar grooves. One of these species, *Saccoglossus otagoensis* (Benham) has been found in the same vicinity. This is a new record for Australia. The two species however, occupy different habitats, S. *aulakoeis* being found in coarse sand and shellgrit in amongst the roots of *Zostera* while *S. otagoensis,* in this locality, has been found only under stones at or below the level of low water spring tides.

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by I. M. THOMAS*

[Read 8 August 1968]

A new species of the Enteropneusta, *Saccoglossus aulakoeis* is described. It possesses a deep, dorsal, longitudinal groove on its proboscis. It is compared with three previously described members of the genus which have similar grooves. One of these species, *Saccoglossus otagoensis* (Benham) has been found in the same vicinity. This is a new record for Australia. The two species however, occupy different habitats, *S. aulakoeis* being found in coarse sand and shellgrit in amongst the roots of *Zostera* while *S. otagoensis*, in this locality, has been found only under stones at or below the level of low water spring tides.

During an investigation to determine the distribution of *Saccoglossus apantesis* (Thomas, 1956) in South Australia, two other members of the genus have been found. One of these is a new species and the other a new record for Australia.

Material of both species was fixed in Bouin's-in-seawater and sectioned at 10 $\mu$. Sections were stained either with Ehrlich's haematoxylin and eosin or with Mallory's triple stain. The latter was very effective for showing the basement membrane and the skeletal parts derived from it. Proboscis skeletons were extracted by maceration of unfixed material in 4% borax for several days. After careful cleaning by brushing, they were stained in aniline blue and mounted in cedarwood oil.

## Saccoglossus aulakoeis n.sp.

The trivial name is descriptive of the deep, median groove on the dorsal side of the proboscis (αὖλαξ = a groove or furrow).

Specimens have been found at Port Willunga, South Australia (lat. 35° 16′ 50″ S, long. 138° 27′ 20″ E) in a shallow tidal pool about half an acre (0·2 hectares) in extent about a quarter of a mile (400 m) south of the ruins of the Port Willunga jetty. The pool is covered to a depth of five or six feet (about 1·6 m) at high spring tides and about half its floor is exposed at low spring tides.

*Zostera tasmanica* G. V. Martens grows sparsely in small patches at about the level of normal spring lows and in amongst the roots of some of these patches, the enteropneust has been found. It is by no means common. The soil over the underlying rock is not more than an inch or two deep and consists of sand and shell grit with little or no mud. The animal has not been found in sand without *Zostera* and many patches of *Zostera* do not contain it. One specimen has been found in amongst the roots of *Cymodocea antarctica* (Labill.) which grows abundantly in slightly deeper water in the pool. The pool is partly protected by a low, rocky elevation (covered at mid-tide) on its seawards side, but it is open to the sea at all states of the tide.

At Brighton, (lat. 35° 02′ S, long. 138° 31′ E), about thirty miles north of Port Willunga, after a heavy storm, some masses of *Zostera* roots were washed

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ashore on a sandy beach. In amongst the roots were found four fragments of enteropneusts similar in size to the Port Willunga specimens. One of these fragments included a portion of a proboscis with a deep dorsal groove. Sectioning of this material has confirmed that it is *S. aulakoeis.*

The species agrees with the diagnosis of the genus *Saccoglossus* Schimkewitsch, 1892 (syn. *Dolichoglossus* Spengel, 1893) in the possession of the following characters; (a) proboscis very long, (b) collar about as long as broad, (c) lateral genital folds present but dorsal gonads absent, (d) gill pores small but distinct, (e) perihaemal spaces present, (f) posterior oesophageal pores present, anterior ones absent.

## EXTERNAL FEATURES

*S. aulakoeis* (Fig. 1) is a species of small to moderate size. Full grown, intact specimens are difficult to obtain but a specimen of reasonable size which has been relaxed by the method recommended by Ledingham and Wells (1942) (isotonic magnesium chloride), had the following dimensions. Proboscis 16 mm; collar 2·5 mm; branchial region 5 mm; oesophageal region 2 mm; hepatic region 13 mm; intestinal region 24 mm; genital region (which overlaps from the branchial to the hepatic region) 10 mm. The gonads were not fully mature.

The proboscis is orange-red and its base, usually hidden by the collar, slightly darker. On this the preoral ciliary organ (Fig. 1) shows up as a U-shaped yellow line. The anterior three-fifths of the collar is similar in shade to the proboscis. The remaining two-fifths bears two broad, slightly elevated bands, paler and yellower and separated by a narrow groove, the posterior wall of which shows up as a still paler band. This latter band corresponds to zone four in the histological divisions of the collar epidermis (Fig. 6).

Dorsally and laterally, the branchial region is slightly browner than the proboscis and is beset with irregular flecks of yellow-orange. These are groups of gland cells (epidermal glandular eminences, Figs. 1, 7, 8 and 10). The ventral musculature of this region is again similar in shade to the proboscis but with narrow and slightly paler transverse striations (Fig. 1). The oesophageal region is similar in colour to the dorsal branchial region but the flecking, dorsally and laterally, is denser. In the hepatic region, the body wall is somewhat translucent and the surface flecks on the epidermis are smaller and sparser. In living specimens, the deep brown colour of the lateral saccules of the liver region of the alimentary canal show through clearly. The intestinal region, too, is translucent and the sandy gut contents show through. The flecks on the epidermis are still evident but are more widely spaced and are smaller than they are on the hepatic region.

In preserved specimens, the proboscis tapers slightly throughout its length but in living and fully relaxed material, it has the form of a very elongate pear, being appreciably thicker at its base. It has a deep mid-dorsal groove which, at its deepest, is a third to a half of the diameter of the organ and it extends almost to the anterior extremity (Figs. 1 and 4). Posteriorly, in the vicinity of the proboscis complex, it is shallower so that on the basal face of the proboscis, its depth is about one-fifth of the diameter. The preoral ciliary organ has a pattern similar to that in other members of the genus in which it has been described (Brambell and Cole, 1939b; Brambell and Goodhart, 1941; Thomas, 1956). It is U-shaped and lies on the base of the proboscis closer to the stalk than to the outer border of the base. The dorsal tips of its arms, however, are deflected inwards and herein it differs slightly from the organ as it is pictured by Brambell and Cole (1939b) in *S. ruber* (syn. *S. cambrensis* Burdon-Jones and Patil, 1960) in which the arms are

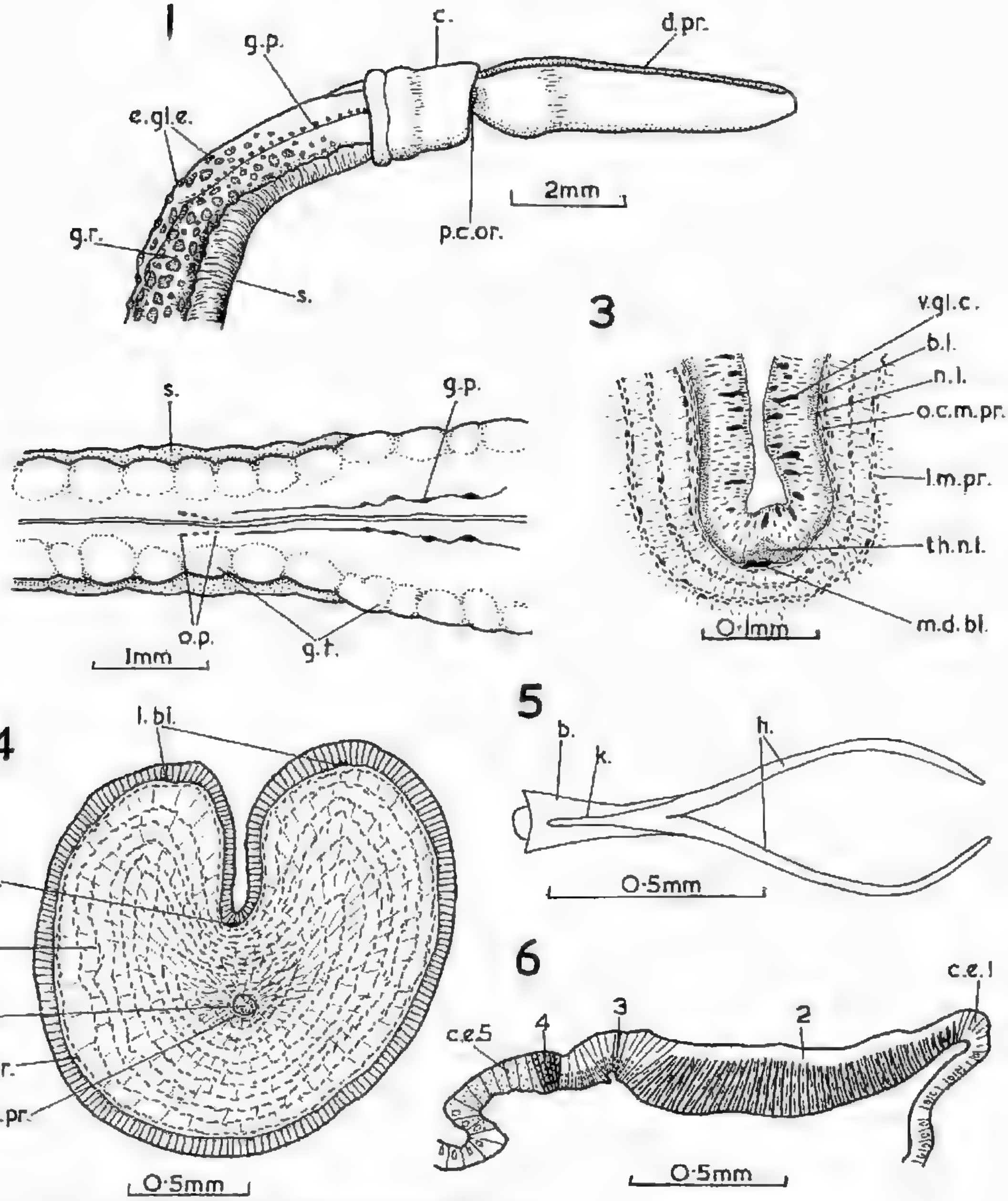


Fig. 1. *Saccoglossus aulakoeis*, anterior end, lateral view.
Fig. 2. Oesophageal region, dorsal view.
Fig. 3. Transverse section, dorsal proboscis groove.
Fig. 4. Transverse section, proboscis.
Fig. 5. Proboscis skeleton, ventral view.
Fig. 6. Zones of collar epidermis. b., body of proboscis skeleton; b.l., basement layer; c., collar; c.e. 1 to 5, zones of collar epidermis numbered from anterior end; d.pr., dorsal groove of proboscis; e.gl.e., epidermal glandular eminence; g.p., gill pore; g.r., genital ridge; h., horn of proboscis skeleton; i.c.m.pr., inner circular muscle layer of proboscis; k., keel; l.bl., lateral blood vessel; l.m.pr., longitudinal muscles of proboscis; m.d.bl., mid-dorsal blood vessel; n.l., nerve layer, o.c.m.pr., outer circular muscle layer of proboscis; o.p., oesophageal pore; p.c.or., preoral ciliary organ; pr., proboscis; pr.c., proboscis coelom; pr. sk., proboscis skeleton; s., sole, formed by ventral longitudinal muscles; th.n.l., dorsal thickening of nerve layer; v.gl.c., vacuole of epidermal gland cell.

straighter. There is a single, slit-like proboscis pore on the stalk, close to its junction with the collar and slightly to the left of the mid-line.

The collar is longer than its diameter in the proportion of about 1·0 to 0·77. It is also longer dorsally than it is ventrally in the proportion of about 1·0 to 0·85. This is due partly to a slight retraction of the ventral part of the anterior flange under the mouth and partly to the dorsal part of the posterior flange extending farther over the branchial region than does the ventral part (Fig. 1). The posterior two-fifths, approximately, of the collar bears two broad, slightly elevated bands of about equal width and separated by the narrow groove already mentioned.

Anteriorly, the branchial region is somewhat quadrangular in transverse section as most of the main musculature is ventral in position. The ventral surface of the body thus forms a broad sole on which the animal creeps (Fig. 1). Farther back in the branchial region, the sole has a shallow median ventral groove (Figs. 7 and 8).

There are from twelve to twenty-five pairs of small gill pores set in shallow dorso-lateral depressions. The anterior two or three pairs are covered by the posterior flange of the collar. The last five or six diminish in size and get successively closer to the mid-dorsal line (Fig. 2). In small (immature) specimens the first gonads are seen about half-way along the branchial region but in fully mature specimens, they begin closely behind the collar. Depending on the maturity of the specimen, the gonads form more or less conspicuous genital ridges (Fig. 7). In immature specimens (Fig. 8) the ridges are relatively inconspicuous. These extend to the beginning of the hepatic region in mature specimens and end rather abruptly. In immature specimens they do not extend as far back. In the branchial region, the gonads are rather lateral in position but behind the gill pores they become more dorso-lateral (Fig. 2).

About 1 mm behind the last gill pore lie the oesophageal pores (Fig. 2). These are arranged in two rows one on each side of the mid-dorsal line. The pores number from two to seven or eight pairs but the more anterior ones are not patent. The specimen shown in Fig. 10 had two patent (1 and 2) and three rudimentary (3, 4 and 5). The disposition of the rows is variable. Seven specimens were examined in this regard. In three of these the rows were almost parallel to each other and to the mid-dorsal line, in three they were slightly divergent, the more posterior being the farthest apart and in one they diverged at an angle of about 30°. This specimen is shown in Fig. 2. The larger and patent pores are the most posterior. In the anterior oesophageal region the sole (Figs. 7 and 8) is as broad as it is in the posterior branchial region but begins to narrow towards the posterior end of the oesophagus. The hepatic region can be recognized by the more or less regular lateral dilatations of the alimentary canal which can be seen through the somewhat transparent body wall. The sole here narrows further and becomes less in width than the dorsal part of the body though its lateral bulges are still apparent. In the intestinal region the body tapers slightly to the terminal anus and the ventral musculature diminishes in amount so that the sole disappears and the body is rounded in transverse section.

## INTERNAL ANATOMY

### *Proboscis*

The glandular and ciliated epidermis of the proboscis extends to the bottom of the dorsal groove and beneath it lies the nerve layer (Fig. 3 and 4). Over most of the proboscis, this is about 12 to 14 μ thick. At the bottom of the proboscis groove there is a marked ridge in the nerve layer so that at this point it is 30 to 32

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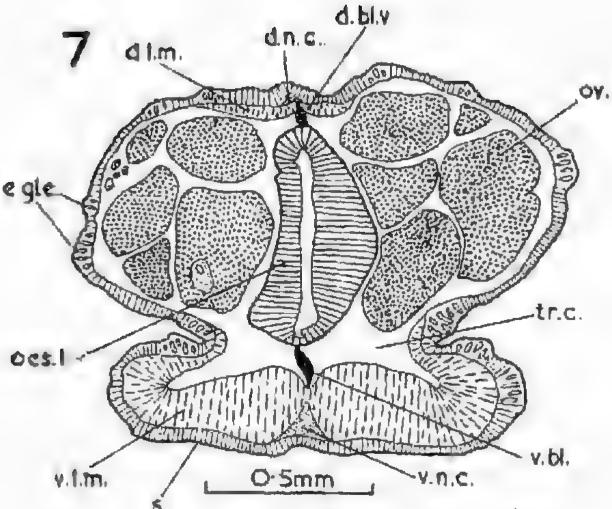


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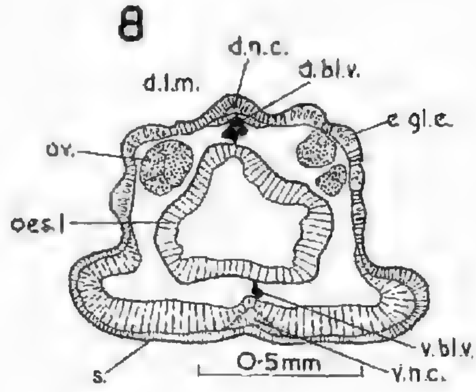


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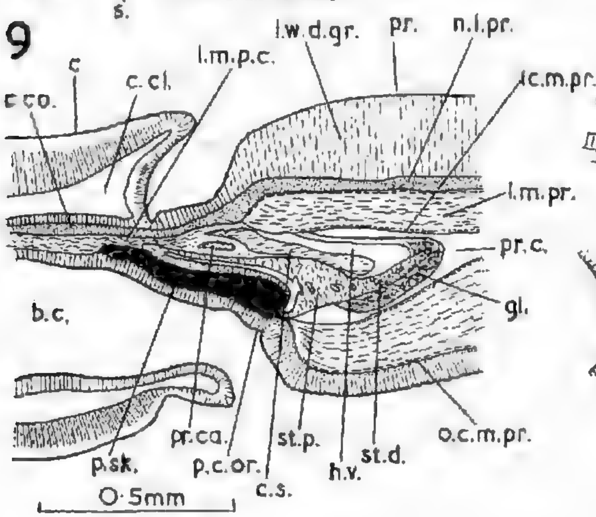


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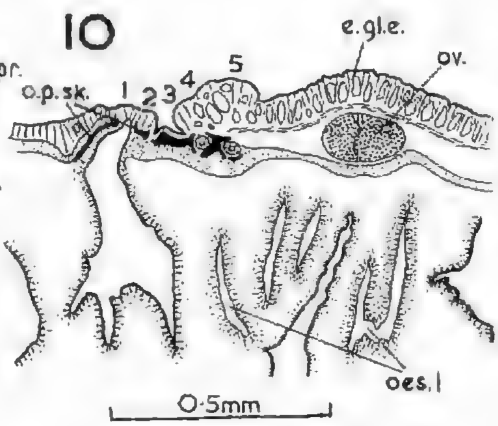


Fig. 7. *Saccoglossus aulakoeis*, transverse section of nearly mature female in first region of oesophagus.

Fig. 8. As Fig. 7 but of immature female.

Fig. 9. Longitudinal sagittal section of proboscis complex.

Fig. 10. Longitudinal section showing oesophageal pores. b.c., buccal cavity; c., collar; c.co., collar cord; c.cl., collar coelom; c.s. central sinus (blood sinus); d.bl.v., dorsal blood vessel; d.l.m. dorsal longitudinal muscle; d.n.c. dorsal nerve cord; e.gl.e., epidermal glandular eminence; gl., glomerulus; h.v., heart vesicle (pericardium); i.c.m.pr., inner layer of circular muscles of proboscis; l.m.pr., longitudinal muscles of proboscis; l.m.p.c., longitudinal muscles of perihaemal cavity; l.w.d.gr., vertical section through wall of dorsal groove; m., mouth; n.l.pr., nerve layer of proboscis; o.c.m.pr., outer layer of circular muscles of proboscis; oes. l, first region of oesophagus; o.p. 1 and 2, first and second oesophageal pores (patent); o.p. 3, 4, and 5, third, fourth and fifth oesophageal pores (rudimentary); o.p.sk., supporting skeleton of oesophageal pores; ov., ovary; pr., proboscis; pr.c., proboscis coelom; pr. ca., proboscis canal (endsac); p.sk., proboscis skeleton; st.d., distal portion of buccal diverticulum; st.p., proximal portion of buccal diverticulum; tr.c., trunk coelom; v.bl., ventral blood vessel; v.l.m., ventral longitudinal muscles; v.n.c., ventral nerve cord.

$\mu$ thick (Fig. 3). There is also a general thickening of the nerve layer at the base of the proboscis, particularly under the preoral ciliary organ where it may be three times its normal thickness (Fig. 9) The outer layer of circular muscles immediately under the basement membrane is a half to two-thirds of the thickness of the nerve layer. The longitudinal muscles form nine or ten concentric layers separated by loose connective tissue. These are compressed and barely distinguishable immediately under the dorsal groove (Fig. 4) and they are reduced to five or six in number posteriorly in the vicinity of the proboscis complex (Fig. 9). An inner, thin layer of circular muscles lines the coelomic cavity. The latter extends almost to the tip of the proboscis. Anteriorly it is narrow, being only about one tenth of the diameter of the proboscis, but it expands considerably posteriorly to accommodate the proboscis complex.

Two blood vessels are present immediately outside the outer circular muscle layer on the crests of the ridges formed as the result of the presence of the dorsal proboscis groove (Fig. 4). A small, subneural vessel (median dorsal vessel) has been seen in some specimens in the mid-dorsal line but a median ventral blood vessel has not been observed in specimens so far examined.

The buccal diverticulum (stomochord) (Fig. 9) has a wide, ventral pocket the posterior wall of which is indented by the blunt, anterior tip of the proboscis skeleton. The diverticulum is bent slightly backwards at its tip under the end of the skeleton. The lumen of the pocket is wide and broadly in contact with the main lumen of the buccal diverticulum within the neck of the proboscis but it is not confluent with the buccal cavity. It is occluded at the level of the point of origin of the horns of the proboscis skeleton. Anterior to the ventral pocket, the buccal diverticulum has no continuous lumen, but only a series of unconnected cavities which diminish in size anteriorly. This anterior part of the buccal diverticulum differs from the form usual in the genus in that it is sharply divided into two regions of more or less equal length. The proximal part is thick and conical, while the distal part is very thin being only about one sixth of the diameter of the proximal part at its widest. The distal part is attached antero-ventrally and curves dorsally to end near the anterior extremity of the glomerulus. Its cells are much smaller and less vacuolate than those of the proximal part but the separate portions of its lumen are apparent almost to its anterior end.

The glomerulus (Fig. 9) surrounds the distal part of the buccal diverticulum but at the level of the proximal part it is almost entirely lateral and ventral. It ceases posteriorly at the level of the ventral pocket of the buccal diverticulum. The cardiac vesicle (pericardium) and central sinus (Fig. 9) call for no special comment. The dorsal mesentery of the proboscis extends forwards nearly to the level of the constriction of the buccal diverticulum. The ventral mesentery is shorter, extending forwards only to the level of the ventral pocket of the buccal diverticulum. The left coelomic pouch so formed, communicates as is usual in the genus, through the proboscis canal (endsac) with the proboscis pore which is dorsolateral on the left side of the proboscis stalk.

The proboscis skeleton (Figs. 5 and 9) is slender, terminating anteriorly in a rounded tip which partly penetrates the posterior wall of the ventral pocket of the buccal diverticulum. The ventral keel is well formed and posteriorly it bifurcates to become continuous with the horns. These extend about half-way along the collar and embrace about half the circumference of the buccal cavity.

### *Collar*

The five transverse, epidermal zones of the collar distinguished by Spengel (1893) are present (Fig. 6). The first, which overlaps the anterior flange of the collar, contains cells which have large vacuoles distally. This zone merges into the second. This forms an epithelium, which, at its thickest, is more than three times as thick as the first zone, and occupies nearly three-fifths of the length of the collar. Its cells contain large numbers of small basophil granules in the inner three-quarters of their lengths. The third zone and the fourth and fifth zones combined, form two elevated bands which are readily visible externally. The third and fourth zones are little more than half as thick as the second. The third is histologically similar to the second except in that the basophil granules are concentrated in the inner half to two-thirds of its cells. The fourth zone is by far the narrowest and forms part of the posterior wall of the groove. Its granules are more densely packed and are fairly evenly distributed throughout the length of its cells. In the fifth zone the granules are more sparsely and evenly distributed and towards its posterior end there are peripheral vacuoles which are characteristic of the epithelium of the branchial region with which this zone merges.

The nerve cord of the collar is solid throughout its length. The dorsal mesentery is incomplete and ends anteriorly a little behind the point where the proboscis skeleton divides to form the two horns. The ventral mesentery is more variable in extent. In some specimens it extends as far forwards as the level of the posterior tips of the horns, i.e. about half-way along the collar while in others it is apparent only near the posterior end.

*Trunk*

The gill pores increase in size over the first two or three and decrease in size over the last four or six. The posterior gill pores are very small and may lack gill pouches. Behind these there may be two or more rudimentary gills. The tongues project farther into the pharynx than do the septa. The gills extend a little more than half-way around the circumference of the pharynx.

In the oesophagus there are three regions. In the first, the epithelium is similar to that of the ventral part of the pharynx but its walls are thicker and have a higher proportion of gland cells. Its lateral walls are irregularly sacculated (Fig. 10). In the second region the walls are much thicker and the lumen correspondingly narrower. At its antero-dorsal end there are deep grooves in the dorsolateral walls into which the oesophageal pores open. Of these, two to five are patent and two to four do not open to the surface but are represented by outpushings of the dorsolateral grooves. There may be corresponding indentations of the epidermis above them. All are supported by skeletal elements which usually fuse to form an almost continuous plate which is perforated in the positions of the patent and the non-patent pores. These elements are, like the other skeletal structures of the animal, thickenings of the basement layer which underlies the nerve layer over the whole of the body. In the third region of the oesophagus the walls are thinner and the lumen wider. Laterally there is an irregular sequence of shallow pouches. This region merges into the hepatic region which differs from it mainly in that the lateral pouches are larger and more regularly arranged. In the intestinal region, the alimentary canal is simple. Its wall is thin and the lumen wide. There are however, two ventral thickenings separated by a narrow, median, longitudinal groove which extend nearly to the posterior end.

## COMPARISON WITH OTHER SPECIES

Three other species of *Saccoglossus* have been described as possessing deep dorsal grooves on the proboscis. These are *S. mereschkowskii* (Nic. Wagner) 1885, *S. otagoensis* (Benham) 1899, and *S. sulcatus* (Spengel) 1893. While the first two have been adequately described (van der Horst, 1939), the third was described from three anterior ends only which became dried up so that detailed examination was impossible (Spengel, 1893).

The main differences between these three species and S. *aulakoeis* are listed in Table 1. The relevant data on S. *mereschkowskii*, S. *otagoensis* and S. *sulcatus*, have been taken, in the main, from van der Horst, 1930 and 1939.

S. *aulakoeis* is established on its possession of the following combination of characters.

1. A deep dorsal proboscis groove.
2. The ventral musculature forms a prominent "sole" in the posterior branchial and oesophageal regions.
3. The collar is slightly longer than broad.
4. The fourth epidermal zone of the collar epidermis is very narrow.
5. There are two to five pairs of patent oesophageal pores preceded by two to four rudimentary ones.
6. The longitudinal muscles of the proboscis are arranged in nine or ten concentric layers.
7. Epidermal gland cells extend to the bottom of the proboscis groove.
8. The glomerulus covers the anterior end of the buccal diverticulum.
9. The buccal diverticulum has a very narrow distal portion which is not conspicuously bent and in which the lumen is incomplete.
10. The proboscis skeleton is bluntly rounded anteriorly.
11. There are no cavities in the dorsal nerve cord of the collar.

## DISCUSSION

S. *aulakoeis* has been found only in the restricted regions indicated in the introduction. Even here it is not common. It is rare to find as many as two or three specimens in a spadeful of soil. It is interesting however, that frequently specimens varying in size from 1·5 cm to 5·5 cm may be found at the same time. This suggests that the breeding season for the species is an extended one or that there is a considerable variation in growth rate. However, animals with mature or maturing gonads are generally seen in late winter and early spring (Fig. 7), while in the summer months the gonads are invariably small (Fig. 8). Mature specimens do not coil markedly in the post-branchial and oesophageal regions as do those of S. *apantesis* (Thomas, 1956). This is, no doubt, to be associated with the lesser degree of development of the genital ridges.

In all specimens examined, with the exception of those fixed without adequate narcosis, the collar is slightly longer than it is broad. The definition of the genus states that the collar is "about as long as it is broad". The proportion of the length to breadth of 1·0 to 0·77 is considered to fall within the limits of the definition but the extent of the ratio is noteworthy.

Non-patent oesophageal pores have been described for S. *ruber* (syn. S. *cambrensis* Brambell and Cole, 1939) and they also occur in the present species. It will be necessary to determine their presence or absence in several other forms before reasons for their existence can be discussed.

There is a possible association between the dorsal thickening of the nerve layer and the dorsal groove of the proboscis. Both S. *otagoensis* and S. *aulakoeis* have deep dorsal grooves and a thickening of their nerve layers. Similar thickenings of the nerve layers have been described in S. *ruber* and in S. *horsti* (Brambell and Goodhart, 1941) and in these too there is a dorsal groove in the proboscis though it is not nearly as deep as it is in the first two species named. In *S. apantesis* however, the dorsal groove is only slightly developed and the thickening of the nerve layer is also slight.

While the description of this species was being prepared, some specimens which clearly belonged to the same genus were found under stones on Snapper Point. This lies about half a mile (about 800 m) south of the pool in which *S. aulakoeis* had been found. These specimens were at first thought to be the same species as they also had a deep dorsal groove on the proboscis. Closer examination and later, a study of longitudinal and transverse sections showed that this was not the case but that they were *Saccoglossus otagoensis* (Benham).

*Balanoglossus otagoensis*, Benham, 1899

*Dolichoglossus otagoensis*, (Benham) van der Horst, 1930

*Saccoglossus otagoensis*, (Benham) van der Horst, 1939 (p. 399)

This is the first record of the species outside New Zealand. Three fairly complete specimens and two fragments were found under stones in about one foot of water at low tide on the northern (more sheltered) side of Snapper Point Reef (lat. 35° 17′ S, long. 138° 26′ 30″ E). This is an extensive wave-cut platform of almost horizontally bedded sandy limestone of Pliocene age. It is relatively hard in parts but on its northern border and in some other regions, it is softer and somewhat friable. Thus, along its northern margin, a secondary, narrow reef flat has been formed about two feet below the general level of the main reef. This is covered by about a foot of water at normal spring lows. One specimen was found under a stone in a permanent rock pool about six inches deep on the main reef surface.

It is a crawling rather than a burrowing species, as is *S. aulakoeis* and it agrees closely with the description of *S. otagoensis* as given by Benham (1899), and van der Horst (1930 and 1939). The points of undeniable resemblance are asterisked in Table 1. In regard to the remaining points listed, the collar is rather shorter than it is broad in the proportion of about 1·0 to 0·70. This may be due to contraction in fixation. The specimens from Snapper Point are relatively immature so that the irregularity in the lateral genital bulges is not very apparent. In regard to the presence of gland cells in the proboscis groove, van der Horst (1930) states that they are absent from the base of the groove and his Fig. 2 (p. 137) shows them to be present in the lateral walls. This is the case in the Snapper Point specimens too. However in his diagnosis of the species (1939) he says "Keine Drüsenzellen in der Epidermis in der dorsalen Furche", which implies that they are absent from the groove altogether. This seems to be an oversight as they are present in the walls of the groove (though not at its base) in specimens in the author's possession which were collected at Portobello, New Zealand, which is close to the type locality of the species.

Van der Horst (1930 p. 139 and 1939 p. 661) describes the buccal diverticulum as having two marked flexures in front of the ventral diverticulum. This is figured in his 1930 description (Fig. 4, p. 139). The Snapper Point specimens do not have these marked flexures. It is felt that these may well be fixation artifacts in van der Horst's specimens.

In New Zealand, the species is found in amongst coralline algae at Wellington and amongst the holdfasts of *Macrocystis* at Portobello. This shows it to be a crawling rather than a burrowing species and indeed, Benham in his original account of the species writes of it as crawling on a stem of seaweed.

TABLE 1

Comparison of diagnostic features of *Saccoglossus otagoensis*, *S. mereschkowskii*, *S. sulcatus* and *S. aulakoeis*.

| *S. mereschkowskii* | *S. otagoensis* | *S. sulcatus* | *S. aulakoeis* |
|---|---|---|---|
| *External Features* | | | |
| Collar about as long as broad | Collar about as long as broad | Collar about as long as broad | Collar slightly longer than broad |
| Genital folds more or less regular appearing in female only | Genital folds in form of irregular bulges in female | - | Genital folds fairly regular in both male and female |
| — | No epidermal glands in base of dorsal proboscis groove | — | Epidermal glands present in base of dorsal proboscis groove |
| Longitudinal muscle in 7 to 10 concentric rings | *Longitudinal muscles in 3 or 4 concentric rings | | Longitudinal muscles in 9 or 10 concentric rings |
| *Proboscis* | | | |
| — | *Cavity of buccal diverticulum may open into mouth cavity | | Cavity of buccal diverticulum does not open into mouth cavity |
| Lumen of buccal diverticulum continuous | *Lumen of buccal diverticulum continuous | — | Lumen of buccal diverticulum not continuous anterior to ventral pocket |
| Buccal diverticulum relatively straight | Buccal diverticulum with marked ventral then anterior flexures; narrow anteriorly | — | Buccal diverticulum very narrow anteriorly but without marked flexures |
| Glomerulus covers nearly all of buccal diverticulum | *Two halves of the glomerulus not united in front of buccal diverticulum | — | Glomerulus extends anteriorly beyond tip of buccal diverticulum |
| Anterior tip of proboscis skeleton with long, sharp point | *Anterior tip of proboscis skeleton with long, sharp point | - | Anterior tip of proboscis skeleton bluntly rounded |

| *S. mereschkowskii* | *S. otagoensis* | *S. sulcatus* | *S. aulakoeis* |
|---|---|---|---|
| *Collar* | | | |
| — | *Horns of proboscis skeleton horizontal and reach hinder end of collar | — | Horns of proboscis skeleton extend about half-way along collar and embrace about half mouth cavity |
| Epidermis very thick (0.05 mm) | *Epidermis of normal thickness | — | Epidermis of normal thickness |
| — | *Three epidermal zones | — | Five epidermal zones |
| Dorsal and ventral mesenteries present but incomplete | *Dorsal and ventral mesenteries absent | — | Dorsal and ventral mesenteries present but incomplete |
| Cavities in dorsal nerve cord | *Cavities in dorsal nerve cord | — | No cavities in dorsal nerve cord |
| *Trunk* | | | |
| — | *Ventral longitudinal muscles of trunk do not form lateral ridges | — | Ventral longitudinal muscles form conspicuous lateral ridges |
| About 50 pairs of gills | *10 to 15 pairs of gills | 10 to 11 pairs of gills | 12 to 25 pairs of gills |
| Oesophagus with 3 sections | Oesophagus with 6 sections | — | Oesophagus with 3 sections |
| About 7 pairs of oesophageal pores | *One pair of oesophageal pores | — | 2 to 5 pairs of patent oesophageal pores and 2 to 4 pairs of rudimentary pores |
| | *Seldom more than 3 ripe ova in one ovary | — | 6 or more ripe ova in one ovary |
| *Location* | | | |
| Northern Russia to the Sea of Okhotsk | New Zealand and St. Vincent Gulf, South Australia | Japan | St. Vincent Gulf, South Aust. |

* Indicates points of similarity between South Australian and New Zealand specimens.

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# LUNETTES IN SOUTHERN SOUTH AUSTRALIA

*BY ELIZABETH M. CAMPBELL**

**Summary**

Lunettes are low crescentic ridges, which commonly occur on the eastern side of ephemeral lakes. They are of two types-those composed predominantly of sand, and those composed of sand, silt and clay. The mineral composition of lunettes varies, though lunettes rich in quartz or in gypsum are common.

The morphology, composition and distribution of lunettes in southern South Australia are examined in the light of suggested theories of origin. The deflation hypothesis of Stephens and Crocker and many other workers can account for most, though not all, of the field evidence. Lunettes develop as a result of wind action, but wave transport is an important factor in concentrating debris on the Ice sides of lakes.

The available evidence suggests that although some lunettes are apparently still forming, they are essentially relict features dating from the recent past.

# LUNETTES IN SOUTHERN SOUTH AUSTRALIA

by Elizabeth M. Campbell*

[Read 12 September 1968]

## SUMMARY

Lunettes are low crescentic ridges which commonly occur on the eastern side of ephemeral lakes. They are of two types—those composed predominantly of sand, and those composed of sand, silt and clay. The mineral composition of lunettes varies, though lunettes rich in quartz or in gypsum are common.

The morphology, composition and distribution of lunettes in southern South Australia are examined in the light of suggested theories of origin. The deflation hypothesis of Stephens and Crocker and many other workers can account for most, though not all, of the field evidence. Lunettes develop as a result of wind action, but wave transport is an important factor in concentrating debris on the lee sides of lakes.

The available evidence suggests that although some lunettes are apparently still forming, they are essentially relict features dating from the recent past.

## INTRODUCTION

The purpose of this paper is to describe the shape, composition and internal structures of lunettes in southern South Australia, and to discuss their possible age and origin. The term lunette as here used includes not only the crescentic dunes located on the lee side of lake and swamp depressions and composed variously of silt-clay, clay-loam and sand, but also the so-called gypsum dunes of Jack (1921) and others.

Features of similar morphology and situation have been described from several parts of the world, including North Africa (Tricart, 1954a; Boulaine, 1954) and North America (Coffey, 1909, Huffman and Price, 1949). They have also been recorded from several parts of the Australian continent. In general, they are best and most commonly developed in the semi-arid regions of Victoria, South Australia and Western Australia, though they occur also in humid zones, for example Tasmania, and in truly arid regions as, for example, the north of South Australia.

## DESCRIPTION

### *Morphology and Size*

The dune on the eastern side of Lake Bumbunga, Mid North,[1] 6·4 km long, 21 m high, and 1·2 km wide, is an example of the larger lunettes known in South Australia. At the other end of the scale are the small rises about 0·8 km long, 4·5-6·0 m high and 45 m wide, typical of the flat, swampy interdune areas of the Southeast. There is no consistent and direct relationship between the size of each lunette and the extent of its associated lake. Lake Greenly, Eyre Peninsula, which is about 23 km$^2$ in area, is bordered by a lunette which is only just distinguishable. Lake Baird, Eyre Peninsula, on the other hand, which covers only 1·3 km$^2$ is bordered by a lunette 2 km long, 21 m high and 0·8 km wide (Fig. 2). Nor is there any consistent distributional pattern; in a given district, some lakes have associated lunettes, others do not.

* Geography Department, University of Adelaide.

[1] For the location of all South Australian place names mentioned, see Fig. 1.

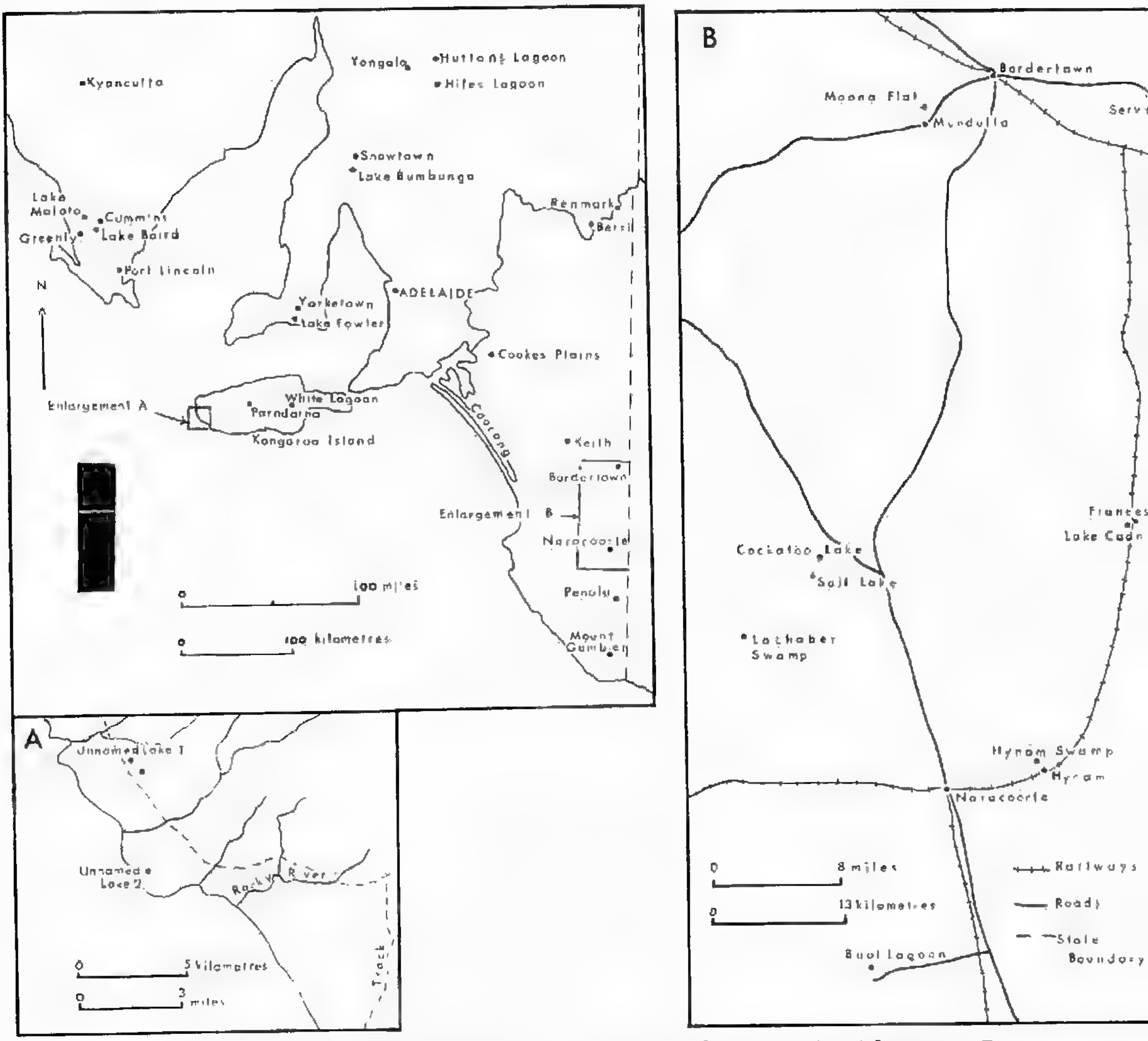


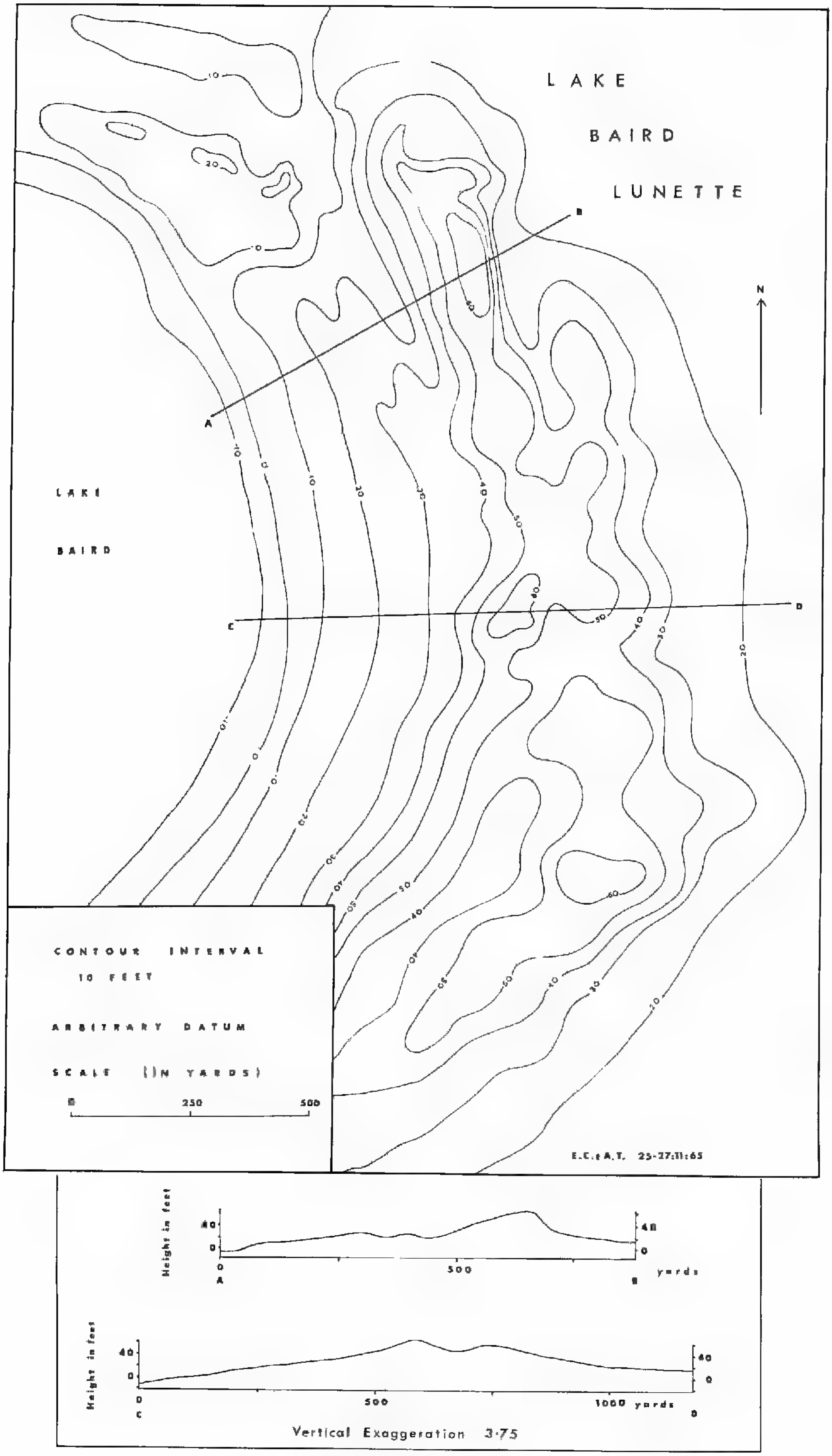

Fig. 1. Southern South Australia—Location. Enlargement A. Enlargement B.

Lunettes are crescent-shaped in plan and extend between one-quarter and one-half the way round the perimeter of the lake (Figs. 3, 4, Pl. 1).[2] They are most commonly found either on the eastern or southeastern side.

The smooth form of the lunette on its western or lake side contrasts with the irregular or sinuous shape of the eastern slope of many lunettes. The occurrence

[2] For reasons not yet clear, an unnamed lake on the laterite plateau of Kangaroo Island is completely surrounded by a dune, whilst several depressions south-east of Renmark are bordered on their western side by gypsum dunes. In the south-west of Western Australia between Kindinin and Corrigin where summer easterly winds are significant lunettes occur on the western side of depressions (C. R. Twidale—personal communication).

*See opposite page* Fig. 2. Contour plan of Lake Baird lunette. Plane table survey. Five feet = 3·3 metres, 500 yards = 500 metres.


LAKE BAIRD LUNETTE
LAKE BAIRD
N
A
B
C
D
CONTOUR INTERVAL 10 FEET
ARBITRARY DATUM
SCALE (IN YARDS)
0 250 500
E.C. & A.T. 25-27:11:65
Height in feet
40
0
500
yards
1000 yards
Vertical Exaggeration 3·75

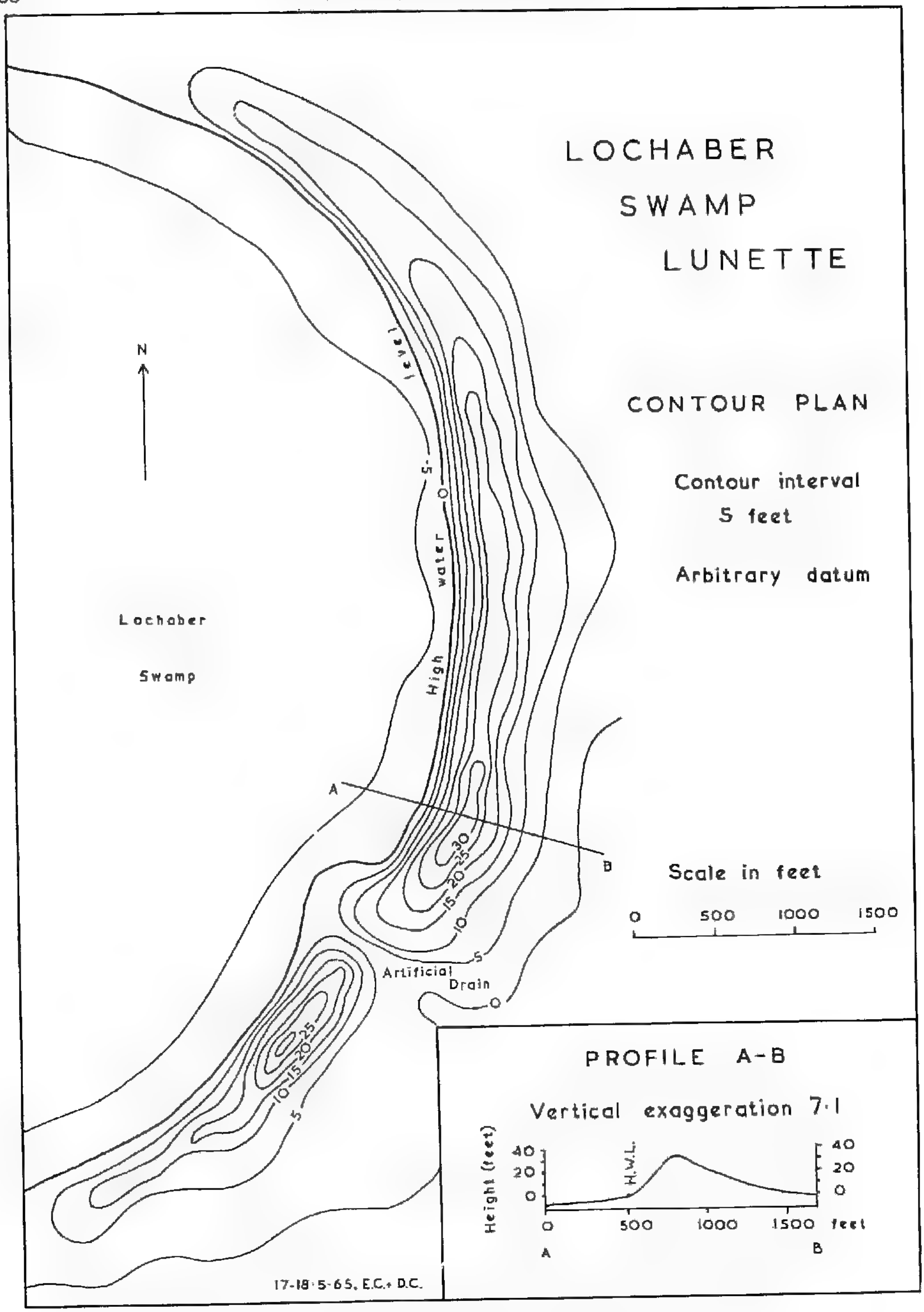



Fig. 3. Contour plan of Lochaber Swamp lunette. Plane table survey. Five feet = 1·7 metres, 1500 feet = 500 metres.

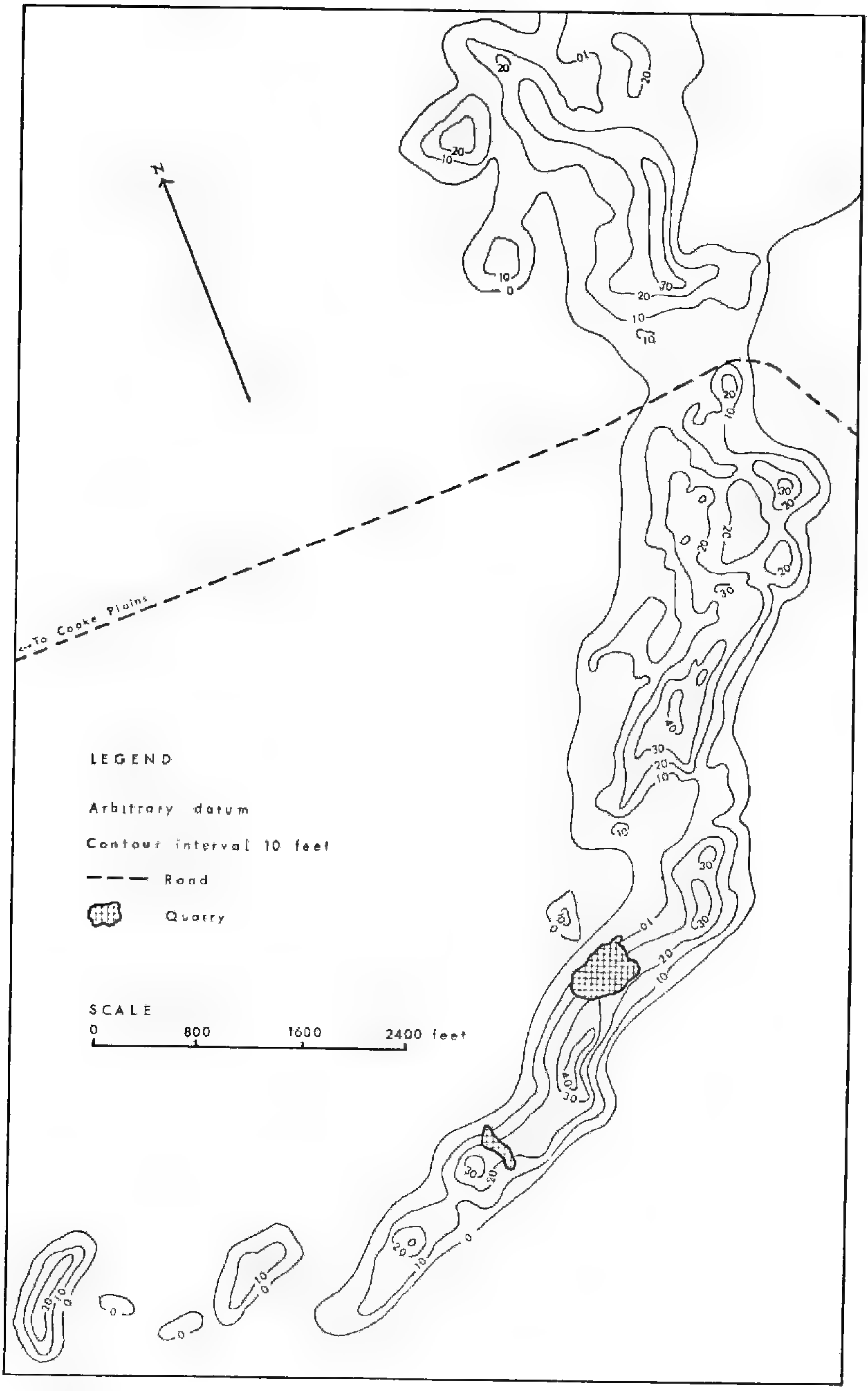



Fig. 4. Contour plan of Cooke Plains lunette. Redrawn from King 1949a. Ten feet = 3.3 metres, 2400 feet = 800 metres.

of consolidated rock outcrops at the lake edge, as for example at Lake Greenly, introduces complications and further irregularities in the plan.

Many lakes are bordered not by a single lunette, but by two or more lunettes arranged concentrically, or nearly so, around the eastern shore. At White Lagoon, Kangaroo Island (Pl. 2), for example, there are no fewer than three distinct and separate dune ridges bordering the lake on its eastern side. The pair of lunettes which borders Lake Fowler, Yorke Peninsula, and those close to the eastern shore of Hiles Lagoon, Mid North, are of similar composition, but at White Lagoon the outer or easterly dune is sandy, the westerly ridge immediately bordering the lake is composed predominantly of silt and clay, and the one between these is

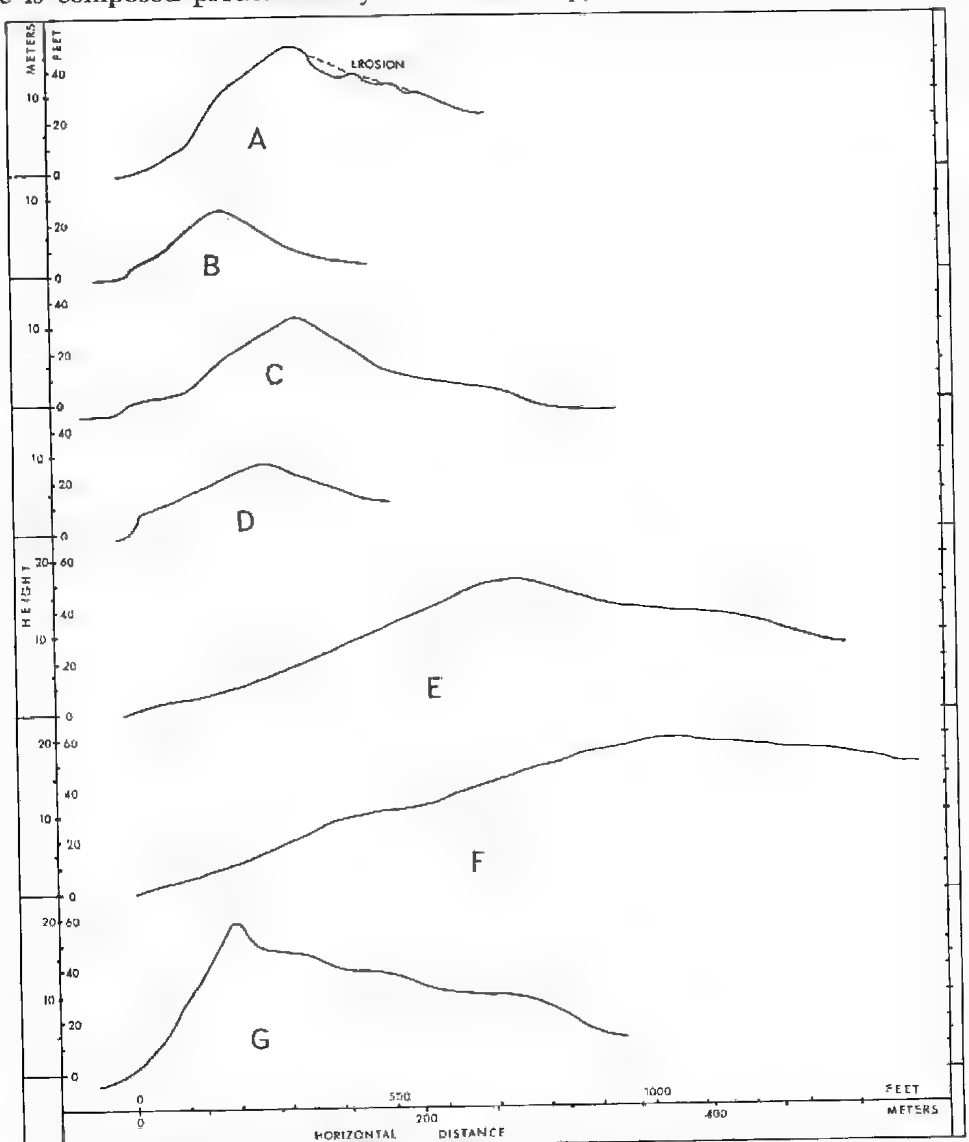



Fig. 5. Transverse profiles across selected lunettes from west to east (left to right). A—Moona Flat lunette, B—Lake Cadnite lunette, C—Lochaber Swamp lunette, D—Cockatoo Lake lunette, E—Hutton's Lagoon lunette, F—Hiles Lagoon lunette, G—Bool Lagoon lunette.

composed of sand, silt and clay. More complex patterns of lake and multiple lunettes are displayed at Bool Lagoon and Salt Lake near Naracoorte, Southeast (Pl. 3). Here complexes of small lakes each with their associated lunette or lunettes, occur within larger lake basins on the eastern margins of which are found individual lunettes.

Most lunettes in southern South Australia are asymmetrical in transverse section, the steeper slope being the western or lake slope (Fig. 5). The gradient of the western slope of Bool Lagoon lunette (Pl. 4) averages 1 in 3·3, whilst the eastern slope is 1 in 18·5. Some few, however, are roughly symmetrical and several examples have been noted in which the eastern slope is steeper than the western. This is so along part of the Lake Baird lunette (Fig. 2), part of the middle lunette on White Lagoon and along most of the inner lunette at the same site. The western slopes are for the most part smooth and rectilinear and, though varying from one lunette to another, are essentially uniform on any given feature. The inclination of the eastern slope, however, varies considerably, even on the same lunette.

In longitudinal section, the crests of lunettes typically rise gradually to a high point near the centre of the feature (Fig. 3) but many crests are undulating (Figs. 2, 4). On the innermost of the White Lagoon lunettes, there are no fewer than four distinct crest lines, all of them undulating, the high points of one crest invariably located opposite depressions in the adjacent ridge (Fig. 6).

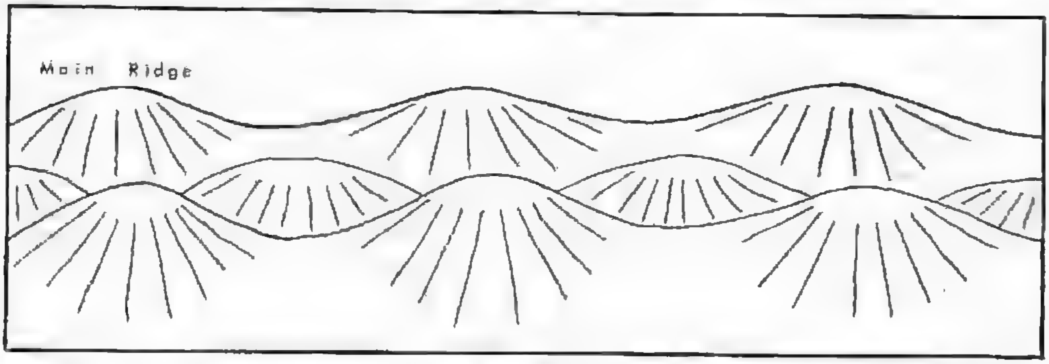



Fig 6. Diagram showing the multiple crestline of the lunette immediately adjacent to White Lagoon, viewed from the east.

*Composition*

Samples of lunette material were collected on the crest where it reached its maximum development, and from the lake bed adjacent to this position. Borings were made to below the level of soil development.

On the basis of particle size, lunettes are of two distinct types—those composed of almost pure sand and those composed of sand, silt and clay (Fig. 7). The predominantly gypseous and predominantly quartzose sandy lunettes are clearly differentiated. The sorting value developed by Trask (Krumbein and Sloss, 1963 p. 101) is a measure of the uniformity of the sample and is derived from the formula $S_0 = Q_1/Q_3$ where $S_0$ is the sorting value and $Q_1$ and $Q_3$ represent the grain size values corresponding to the 25% and 75% marks respectively of the sample. The sorting value of the sandy lunettes is 1·5 or less, that is they are well sorted, whilst the fine-grained lunettes are poorly sorted, with a value ranging from 5·6 to 7·6. Field determinations of samples collected at various depths and from various positions across the lunette indicate that the mechanical composition is generally uniform, although there are local and minor irregularities.

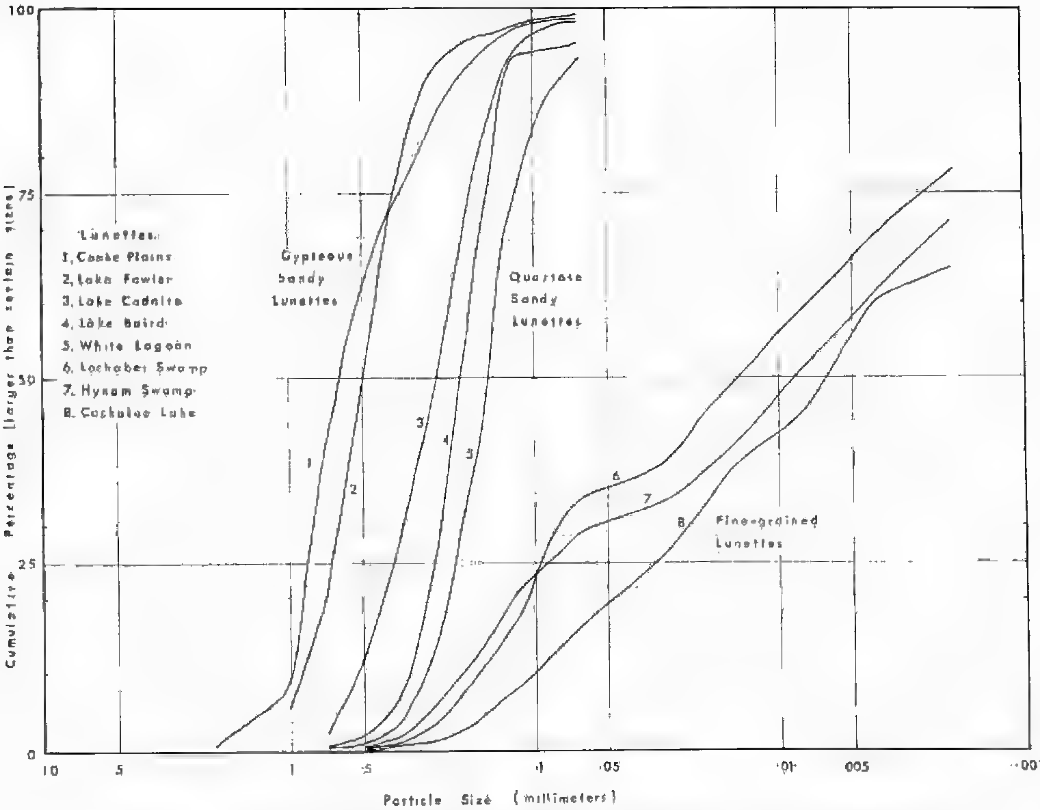



Fig. 7. Cumulative percentage curves of the size distribution of lunette samples.

The mineralogy of samples from six lunettes and their associated lake beds was analysed by Australian Mineral Development Laboratories (A.M.D.L.), Adelaide. The $< 0{\cdot}002$ mm fraction (Table 1) of the lunette samples is composed predominantly of "amorphous" material, which was not positively identified but which shows physical properties similar to illite and smectite, or "amorphous" material and illite. Quartz and kaolin are present in all cases, and illite-chlorite, illite, calcite and chlorite in some.

The $> 0{\cdot}002$ mm fraction was separated into a light and a heavy fraction (S.G. 2·96). The light minerals (Table 2) include quartz which is abundant in all and dominant in most, silt- and clay-sized particles too small to be identified by the methods used, and, in some samples, minor amounts of calcite, layer silicates, organic remains and opal.

The heavy minerals (Table 3) vary from 0·007%-0·31% of the total sample. They are numerous and vary from one lunette to the other. Hematite, magnetite, other opaques, tourmaline and zircon are the most common.

Gypseous lunettes were not included in the selection analysed by A.M.D.L. Apart from varying amounts of gypsum which is mainly the "seed" variety, calcite, halite and insoluble materials, including quartz, opaques and many other minerals are present in some samples (Table 4).

There is generally a close relationship between the mechanical and mineralogical composition of samples taken from the lunette and from the associated lake bed, though minor variations occur. The mineral composition (Table 4) is

TABLE 1

Semiquantitative analysis of clay minerals in samples from lunettes and associated lake beds.

| Sample | Weight % of total | Minerals Present: Amorphous Material | Illite-chlorite | Quartz | Kaolin | Illite | Calcite | Chlorite |
|---|---|---|---|---|---|---|---|---|
| Moona Flat | | | | | | | | |
| lunette | <10 | | | | | | | |
| bed | <10 | | | | | | | |
| Lake Cadnite | | | | | | | | |
| lunette | <10 | | | | | | | |
| bed | 17 | D | A | A | T | | | |
| bed (surface) | <10 | | | | | | | |
| Lochaber Swamp | | | | | | | | |
| lunette | 32 | D | A | A | T | | | |
| bed | 11 | D | | A | T | F | | |
| Cockatoo Lake | | | | | | | | |
| lunette | 31 | D | | A | T | A | | |
| bed | 63 | D | | F | T | A | A | |
| Hutton's Lagoon | | | | | | | | |
| lunette | 8 | S | | A | A | S | F | T |
| bed | 22 | S | | A | A | S | F | T |
| Bool Lagoon | | | | | | | | |
| lunette | 28 | D | A | F | T | | T | |
| bed | 76 | D | A | A | T | | T | |

D — Dominant >50%
S — Subdominant 20-50%
A — Accessory 10-20%
T = Trace <10%
F = Faint trace just detectable.

TABLE 2

Analysis of the light fraction mineralogy (S.G. <2·96 and diameter >0·002 mm) of samples from lunettes and associated lake beds.

| Sample | Weight % of total | Minerals present as percentage of light fraction: Quartz | Silt + clay | Opal | Layer silicates | Calcite | Organic Remains |
|---|---|---|---|---|---|---|---|
| Moona Flat lunette | >90 | 100 | | | | | |
| bed | >90 | 95 | | | | | 5 |
| Lake Cadnite lunette | >90 | 100 | | | | | |
| bed | 83 | 75 | 20 | | | | 5 |
| bed (surface) | >90 | 100 | | | | | <2 |
| Lochaber Swamp lunette | 68 | 30 | 65 | | | | 5 |
| bed | 89 | 85 | 15 | | | | |
| Cockatoo Lake lunette | 69 | 75 | | <5 | 20 | | <5 |
| bed | 37 | 30 | | | 50 | 20 | |
| Hutton's Lagoon lunette | 92 | 25 | 70 | | | 5 | |
| bed | 78 | 40 | 55 | | | 5 | |
| Bool Lagoon lunette | 72 | 20 | | | 50 | 25 | 5 |
| bed | 24 | 15 | | 5 | 60 | 10 | 10 |

TABLE 3

Semiquantitative analysis of heavy minerals (SG > 2·96 and diameter > 0·002 mm.) in samples from lunettes and associated lake beds.

| Sample | Weight % of >0·002 mm. fraction | Weight % of total | Minerals Present | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Hematite | Magnetite | Other Opaques | Tourmaline | Zircon | Garnet | Rutile | Anatase | Brookite | Corundum | Topaz | Sillimanite | Andalusite | Blue Spinel | Epidote | Brown Amphibole | Hypersthene | Malachite |
| Moona Flat lunette | 0·10 | 0·10 | — | — | A | C | A | P | C | — | — | — | — | P | P | — | P | P | — | — |
| bed | 0·16 | 0·16 | — | — | A | C | P | P | C | — | — | — | — | P | P | — | ? | P | — | — |
| Lake Cadnite lunette | 0·06 | 0·06 | P | — | P | C | P | — | — | — | — | — | — | P | P | — | — | — | — | — |
| bed | 0·12 | 0·12 | | — | C | C | C | | P | | — | P | P | P | P | — | — | P | — | — |
| bed (surface) | 0·31 | 0·31 | P | — | P | A | P | P | — | — | — | — | — | ? | P | — | — | P | — | — |
| Lochaber Swamp lunette | 0·07 | 0·05 | P | — | — | A | C | P | C | P | — | — | P | P | P | P | P | P | — | — |
| bed | 0·06 | 0·05 | C | — | — | P | A | P | P | — | P | — | P | P | — | — | P | P | ? | — |
| Cockatoo Lake lunette | 0·14 | 0·10 | P | C | A | P | P | P | P | — | — | — | P | P | P | — | — | P | — | — |
| bed | 0·14 | 0·05 | P | — | A | P | P | — | — | — | — | — | — | — | — | — | P | P | — | — |
| Hutton's Lagoon lunette | 0·10 | 0·09 | — | A | A | P | P | — | P | — | — | — | — | — | — | — | — | — | — | — |
| bed | 0·06 | 0·05 | — | P | A | P | C | — | P | ? | — | ? | — | — | | — | — | — | — | — |
| Bool Lagoon lunette | 0·01 | 0·007 | — | P | A | P | A | — | P | — | — | — | P | P | — | — | P | P | — | P |
| bed | 0·30 | 0·07 | — | P | C | P | A | P | P | — | — | — | P | P | P | — | — | P | — | — |

A = Abundant (>40% of heavy fraction)
C = Common (10-40% of heavy fraction)
P = Present (<10% of heavy fraction)
? = Non positive identification because of poor crystallinity and rarity.

TABLE 4

Mineral composition of two gypseous lunettes and their associated lake beds.

| Sample | Minerals present | | | | | |
|---|---|---|---|---|---|---|
| | Gypsum | Calcium Carbonate | Sodium Chloride | Ferric Oxide | Insolubles | Total |
| Cooke Plains lunette (average of 16 samples) (a) | 83·88 | 2·80 | n.a. | n.a. | 11·21 | 97·89 |
| Cooke Plains bed (trial hole S12:2′10″-3′2″) (a) | 47·77 | 21·70 | n.a. | n.a. | 18·43 | 87·90 |
| Lake Fowler lunette (average of 33 samples) (b) | 92·9 | 1·1 | 0·7 | 0·1 | 3·9 | 98·7 |
| Lake Fowler bed (sample C4:0-29½″) (c) | 75·70 | 1·11 | 1·95 | 0·34 | 18·3 | 97·4 |

*Source:*

(a) King (1949a p. 145)

(b) King (1949b p. 66)

(c) Hiern (1957 p. 40)

n.a. not available.

TABLE 5

Percentages by weight of sand, silt and clay.

(The silt and clay fraction was not separated in some samples; silt and clay—less than 0·066 mm. sieve size.)

| Sample | Sand | Silt & Clay | Silt | Clay |
|---|---|---|---|---|
| Cooke Plains lunette | 98·4 | 1·6 | | |
| Lake Fowler lunette | 98·7 | 1·3 | | |
| Lake Baird lunette | 99·4 | 0·6 | | |
| White Lagoon lunette | 93·2 | 6·8 | | |
| Moona Flat lunette | 96·1 | 3·9 | | |
| bed | 96·4 | 3·6 | | |
| Unnamed lake 2 lunette | 97·0 | 3·0 | | |
| bed | 97·2 | 2·8 | | |
| Unnamed lake 1 lunette | 94·2 | 5·8 | | |
| bed | 92·5 | 7·5 | | |
| Lake Cadnite lunette | 95·2 | 4·8 | | |
| bed | 74·4 | 25·6 | | |
| bed-surface 2″ | 98·3 | 1·7 | | |
| Hynam Swamp lunette | 37·5 | | 37·5 | 25·0 |
| Lochaber Swamp lunette | 45·0 | | 32·1 | 21·9 |
| bed | 85·0 | | 4·0 | 11·0 |
| Cockatoo Lake lunette | 33·0 | | 37·0 | 30·0 |
| bed | 7·9 | 92·1 | | |
| Hutton's Lagoon lunette | 34·2 | 65·8 | | |
| bed | 37·7 | 62·3 | | |
| Hiles Lagoon lunette | 29·7 | 70·3 | | |
| bed | 41·1 | 58·9 | | |

TABLE 6

Percentage size distribution (by weight) of samples from lunettes and lake beds
range of particle size in millimetres: each fraction expressed as a percentage of the total sample.

| Sample | Sieve Analysis | | | | | | | | | Pipette Analysis | | | | | Remainder |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | >1·003 | 0·711-1·003 | 0·500-0·711 | 0·353-0·500 | 0·252-0·353 | 0·178-0·252 | 0·124-0·178 | 0·089-0·124 | 0·066-0·089 | 0·031-0·066 | 0·016-0·031 | 0·008-0·016 | 0·004-0·008 | 0·002-0·004 | |
| Cooke Plains lunette | 18·9 | 22·3 | 20·0 | 13·3 | 10·8 | 7·3 | 4·5 | 0·9 | 0·4 | | | | | | 1·6 |
| Lake Fowler lunette | 5·3 | 15·5 | 30·9 | 27·1 | 13·1 | 3·6 | 2·4 | 0·4 | 0·4 | | | | | | 1·3 |
| Lake Baird lunette | | 0·4 | 1·5 | 4·8 | 19·7 | 38·1 | 28·8 | 4·7 | 1·4 | | | | | | 0·6 |
| White Lagoon lunette | | 0·2 | 0·6 | 2·9 | 11·0 | 23·4 | 35·7 | 13·9 | 5·5 | | | | | | 6·8 |
| Moona Flat lunette | | | 0·1 | 0·7 | 6·0 | 19·9 | 43·1 | 21·2 | 5·1 | | | | | | 3·9 |
| bed | | | 0·1 | 0·5 | 6·0 | 18·9 | 43·7 | 18·8 | 8·4 | | | | | | 3·6 |
| Unnamed lake 2 lunette | | 0·1 | 0·1 | 1·2 | 14·7 | 37·3 | 30·7 | 9·0 | 3·9 | | | | | | 3·0 |
| bed | 8·2 | 0·5 | 1·1 | 2·2 | 12·4 | 41·5 | 26·6 | 4·2 | 0·5 | | | | | | 2·8 |
| Unnamed lake 1 lunette | | 2·2 | 3·8 | 8·3 | 29·7 | 26·2 | 16·1 | 4·9 | 3·0 | | | | | | 5·8 |
| bed | | 9·3 | 1·9 | 3·6 | 18·0 | 21·5 | 21·6 | 9·3 | 7·3 | | | | | | 7·5 |
| Lake Cadnite lunette | | 2·1 | 10·2 | 16·1 | 22·2 | 24·4 | 18·7 | 0·2 | 1·3 | | | | | | 4·8 |
| bed | | 0·5 | 2·3 | 0·6 | 22·7 | 17·3 | 18·7 | 8·2 | 4·1 | | | | | | 25·6 |
| bed-surface 2" | | 0·4 | 0·7 | 3·7 | 17·9 | 29·9 | 33·4 | 10·6 | 1·7 | | | | | | 1·7 |
| Hynam Swamp lunette | | | 0·5 | 1·3 | 4·4 | 6·1 | 8·4 | 3·7 | 5·0 | 3·5 | 7·2 | 10·9 | 10·9 | | 38·1 |
| Lochaber Swamp lunette | | | 0·4 | 0·6 | 2·8 | 6·2 | 6·5 | 12·1 | 4·7 | 4·4 | 11·9 | 10·0 | 9·8 | 8·7 | 21·9 |
| bed | | | 1·3 | 2·0 | 6·6 | 11·9 | 12·3 | 22·5 | 8·9 | 17·8 | 3·2 | 1·0 | 0·0 | 1·0 | 11·5 |
| Cockatoo Lake lunette | | | 0·2 | 0·2 | 0·6 | 2·1 | 4·6 | 3·4 | 5·3 | 8·8 | 12·6 | 7·9 | 14·7 | | 39·6 |
| bed | | | 0·6 | 0·5 | 1·0 | 1·5 | 1·8 | 1·9 | 0·6 | | | | | | 92·1 |
| Hutton's Lagoon lunette | | | 1·5 | 2·1 | 4·8 | 6·0 | 7·6 | 6·8 | 5·4 | | | | | | 65·8 |
| bed | | | 4·6 | 1·9 | 3·4 | 5·9 | 8·5 | 8·4 | 5·0 | | | | | | 62·3 |
| Hiles Lagoon lunette | | | 0·9 | 2·8 | 7·7 | 6·3 | 5·9 | 4·1 | 2·0 | | | | | | 70·3 |
| bed | | | 4·2 | 0·7 | 1·7 | 3·9 | 9·1 | 10·3 | 11·2 | | | | | | 58·9 |

TABLE 7

Quartile measures (in mms) and sorting of samples from lunettes and associated lake beds.

| Sample | $Q_1$ | $M_d$ | $Q_3$ | $S_0$ |
|---|---|---|---|---|
| Cooke Plains lunette | 0·85 | 0·61 | 0·35 | 1·5 |
| Lake Fowler lunette | 0·68 | 0·51 | 0·37 | 1·3 |
| Lake Baird lunette | 0·26 | 0·20 | 0·16 | 1·3 |
| White Lagoon lunette | 0·21 | 0·16 | 0·12 | 1·3 |
| Mogna Flat lunette | 0·18 | 0·15 | 0·12 | 1·2 |
| bed | 0·18 | 0·15 | 0·11 | 1·3 |
| Sandy Lake lunette | 0·23 | 0·19 | 0·14 | 1·3 |
| bed | 0·25 | 0·20 | 0·16 | 1·3 |
| Northwest Lake lunette | 0·32 | 0·23 | 0·16 | 1·4 |
| bed | 0·30 | 0·20 | 0·13 | 1·5 |
| Lake Cadnite lunette | 0·38 | 0·26 | 0·18 | 1·4 |
| bed | 0·26 | 0·16 | 0·06 | 2·1 |
| bed—surface 2" | 0·25 | 0·18 | 0·14 | 1·3 |
| Hynam Swamp lunette | 0·086 | 0·0084 | 0·0015 | 7·6 |
| Lochaber Swamp lunette | 0·096 | 0·015 | 0·0026 | 6·1 |
| bed | 0·17 | 0·098 | 0·044 | 1·9 |
| Cockatoo Lake lunette | 0·031 | 0·0066 | 0·001 | 5·6 |
| bed | n.a. | n.a. | n.a. | n.a. |
| Hutton's Lagoon lunette | 0·107 | n.a. | n.a. | n.a. |
| bed | 0·125 | n.a. | n.a. | n.a. |
| Hiles Lagoon lunette | 0·110 | n.a. | n.a. | n.a. |
| bed | 0·105 | n.a. | n.a. | n.a. |

$S_0 = Q_1/Q_3$
n.a. — not available.

the only information available by which to compare the gypseous sandy lunettes with their associated lake beds. The same minerals are present in both cases and the percentages vary only slightly. The percentages by weight of sand, silt and clay (Table 5), the size distribution (Table 6, Fig. 8), the quartile measures and degrees of sorting (Table 7), and the mineralogy (Tables 2, 3) all indicate that the composition of the quartzose sandy lunettes is very similar to that of the associated lake bed. The size distribution of samples from the fine-grained lunettes varies slightly from that of the lake bed samples, especially in the small size grades (Table 6, Fig. 8), but the mineralogy of the two is similar (Tables 1, 2, 3). The sample from Lochaber Swamp lunette, Southeast, shows a lower percentage of light minerals than might be expected from the percentages observed in the same lake bed (Table 2). However, the composition of the lake bed may have been altered by the man-made drain entering the swamp (Fig. 3). Other dissimilarities, for example, at Cockatoo Lake, can be accounted for by the difficulties associated with the analysis of the samples.

*Structures*

Internal structures have not been observed in fine-grained lunettes, but there are several exposures in gypseous and quartzose sandy lunettes. The most extensive of these are in Cooke Plains and Lake Cadnite lunettes, Southeast.

Cooke Plains lunette is composed almost entirely of seed gypsum of sand-grain size. In the quarry on the southern end of the lunette, near the swamp edge, the dip of the beds is about 2° towards the lake; near the centre of the lunette the dip is in the same direction but varies over short distances from 20° to almost flat (Pl. 5); and on the side of the lunette away from the swamp, the dip is consistently about 30° away from the depression.

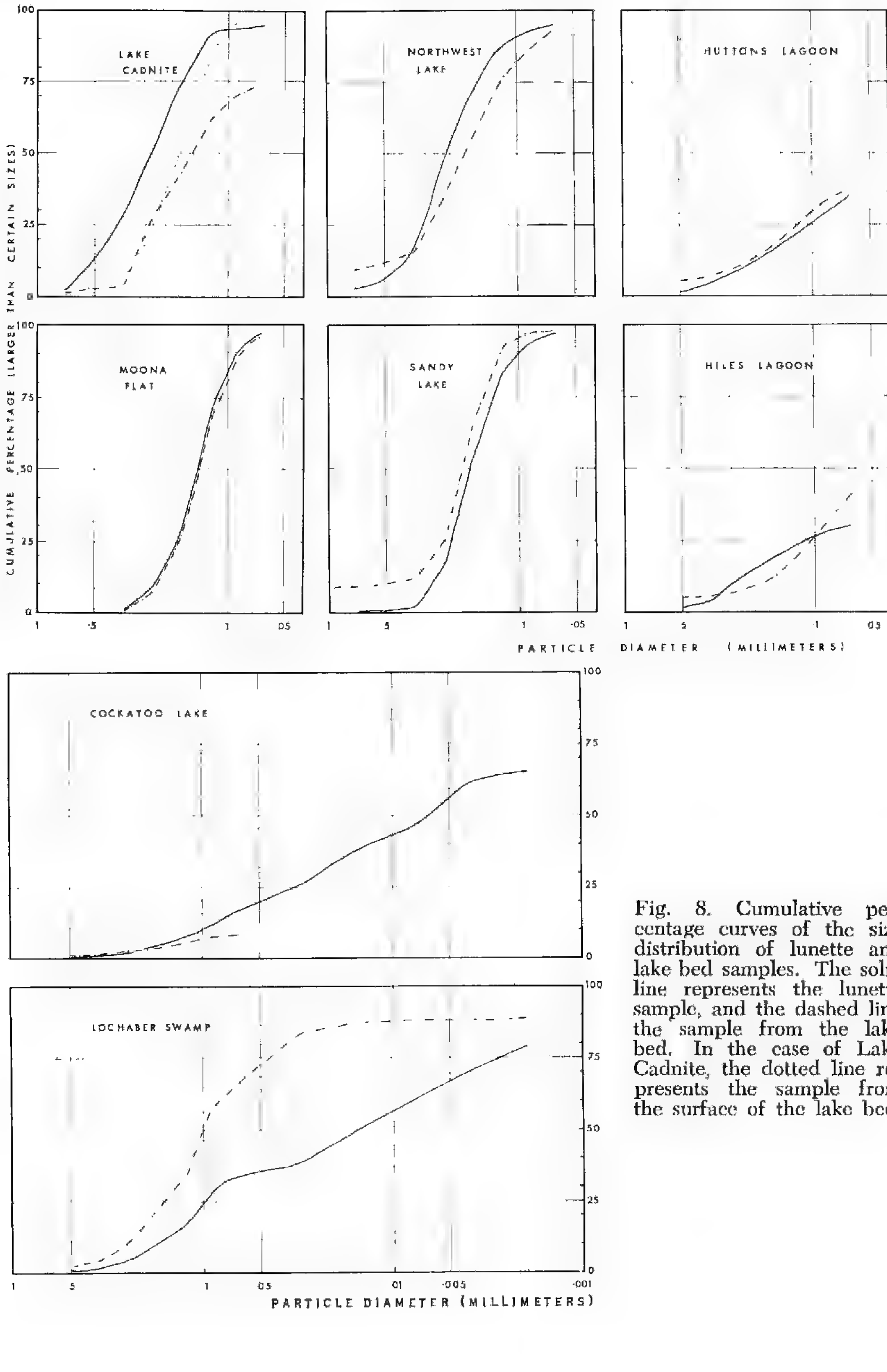



Fig. 8. Cumulative percentage curves of the size distribution of lunette and lake bed samples. The solid line represents the lunette sample, and the dashed line the sample from the lake bed. In the case of Lake Cadnite, the dotted line represents the sample from the surface of the lake bed.

The structures of Lake Cadnite lunette, composed almost entirely of quartz sand, are only visible in isolated places where the quarry face has been exposed to weathering. Typical measurements near the centre of the lunette are 2° to 12° to the east (Pl. 6), but whatever the value near the centre of the feature, the dips in all cases flatten to the east. A series of superimposed soil profiles is exposed in a quarry face to the east of the crest for a distance of a few metres. Each soil consists of a black humus-rich layer which grades to light brown with depth and overlies buff-coloured sand. This rests with sharp demarcation on the black horizon of the next lower soil.

*Vegetation Cover*

The surface of nearly all the lunettes in southern South Australia is protected by a dense cover of grasses. Trees are rare, but red gums about 6 m high are found on Lake Cadnite lunette, and the Cooke Plains lunette is covered by dense Mallee scrub. The grass cover has apparently been sufficient to protect the lunettes from erosion; the only occurrence where modifications to the original lunette form are evident are those in which wave action and slumping have resulted in a cliff on the lake edge, or where overgrazing by sheep and rabbits, or overcropping, have resulted in erosion of the surface.

## ORIGIN

*Previous Investigations*

The two principal hypotheses[3] advanced in explanation of lunettes are those of Hills (1939, 1940) on the one hand, and Stephens and Crocker (1946) on the other. It should be noted, however, that although Stephens and Crocker first gave prominence to the deflation theory, similar ideas are either implicit or explicit in the writings of Coffey (1909), Grayson and Mahoney (1910), Wybergh (1918), and Harris (1939).

Hills suggested that spray droplets whipped from the surface of the lake by wind and dew formed preferentially on the downwind side of the lake cause the deposition and retention of atmospheric dust on the lee shore of the lake. The presence of the water in the lake is thus an essential feature of this mechanism. Hills did not preclude the possibility of the addition of minor amounts of material by deflation from the dry lake bed but considered this of minor significance. Stephens and Crocker and many later workers (Huffman and Price, 1949; Gautier, 1953; Boulaine, 1954; Tricart, 1954a, b, 1955; Jennings, 1955) considered, however, that this latter process was of prime importance. They considered that wind scouring of the unconsolidated sediments exposed in the dry lake bed provides material which is trapped by vegetation growing on the lee shore of the lakes. Once the lunette has developed, it propagates itself by deflecting the wind over it whilst the material in transport is deposited on the lunette. The essential contrast between these two hypotheses is that Hills' requires water in the lake while the deflation hypothesis required a desiccated lake bed.

Thus it is that these two hypotheses have been construed by different authors as implying the association of the lunette either with wet (glacial) or dry (interglacial) phases of the Quaternary. In view of the marked seasonality of climate and lake conditions in southern South Australia at present, it seems unnecessary to invoke such definite and long term changes of climate. But the age or age range of lunettes is certainly significant, for, if the features developed under

[3] Various other hypotheses have been put forward to explain similar landforms in other parts of the world (Cooke, 1934, 1940, and Raisz, 1934; Grant, 1945; Melton and Schriever, 1933; Prouty, 1952), but none seems to have any relevance to the situation in southern South Australia.

conditions widely different from those which obtain at present, modern climatic parameters have little or no relevance to considerations of their evolution. Thus, before any assessment of the various lines of evidence, and a discussion of the possible genesis of these features, it is necessary to examine their likely age or age range.

*Age of Lunettes*

Soil profile development on lunettes varies considerably but most have been sufficiently stable to allow the development of mature soils on the surface. Similarly, a layer of "flour" gypsum, the weathering product of the "seed" variety, occurs at the surface of the gypseous lunettes. This is an indication that weathering has latterly outpaced accumulation, suggesting that lunette formation has ceased or has at least slowed down. However, it is not necessarily evidence of antiquity, as soils can develop in a relatively short time, as evidenced by horizon development on sediments no more than 100 years old at Beefacres, an Adelaide suburb (C. R. Twidale, personal communication).

There are isolated indications that lunettes are forming today; the bed of an unnamed depression 13 km. northwest of Naracoorte is bare, but flat-topped remnants standing ½ metre above the bed are vegetated. This is taken to mean that the mesa slopes and the bottom of the unsalted depression have been recently removed, apparently by deflation; movement of material across the lunette on Hutton's Lagoon has been observed; and there are reports of lunettes forming today in Western Australia (Bettenay, 1962), Victoria (Baldwin, Burvill and Freedman, 1939) and Texas (Coffey, 1909; Huffman and Price, 1949) under conditions similar to those in southern South Australia.

In any case, the evidence points to the lunettes being geologically youthful rather than to their antiquity. From a variety of evidence throughout southern Australia, Stephens and Crocker (1946) concluded that "it is apparent that the bulk of the lunettes belong to the late Pleistocene to Recent Period". King (1949a) concluded that the Cooke Plains gypsum dune postdated the emergence of land after the mid-Recent high sea-level when conditions permitted the evaporation of water and the precipitation of salts. In the Riverine Plains of south-eastern Australia, Pels (1966) noted that lunettes predate the most recent period of stream incision into the plain but postdate the last phase of deposition by the prior streams which occurred in the Pleistocene (Pels, 1964). Bowler and Harford (1966) in the same area, worked out a geomorphic sequence in which they recognized three phases of lunette formation: the first occurred about 7,000 B.P., indicated by a date from lacustrine silts in the bed of the lake on which the lunette formed; the second occurred following shrinking of the lake; and the third after a period of prior stream activity, deposits from which were dated by the carbon 14 method at 4,000 B.P. Bowler and Harford thus showed that lunette formation in this area began at least 7,000 years ago, and continued at least until 4,000 years ago, that is, through the middle Recent.[4]

Whilst lunettes in southern Australia may vary in age, it is likely that their age range is of the same general order, and it can be assumed that the lunettes in southern South Australia developed during the Recent. They are, therefore, a relatively youthful feature of the landscape. Since this time, the climate of southern Australia is thought to have changed only slightly so that conditions favourable to lunette formation are not very different from the range of those

[4] Carbon 14 determination of material at the base and at the surface of a lunette offer the most satisfactory answer to the range of time during which formation took place. Datable material has so far been found only near the surface of lunettes in South Australia and no age determinations have been carried out.

experienced at present. An examination of present climatic parameters is therefore relevant in a study of the origin of lunettes.

*Discussion of Origin*

The fine-grained lunettes in southern South Australia are composed of 76-90% material less than 0·1 mm diameter (Fig. 7), i.e. it can be transported in suspension. All the lunettes described by Hills (1939, 1940) in north-western Victoria are dominantly fine-grained. Most of these lunettes could have been formed by the deposition of atmospheric dust on the lee side of the lake. Deflation is not, however, excluded. Most of the particles in the sandy lunettes and some in the fine-grained lunettes are too large to be transported in suspension, and therefore cannot be explained by the mechanism suggested by Hills. Other lines of evidence from southern South Australia throw further doubt on this theory.

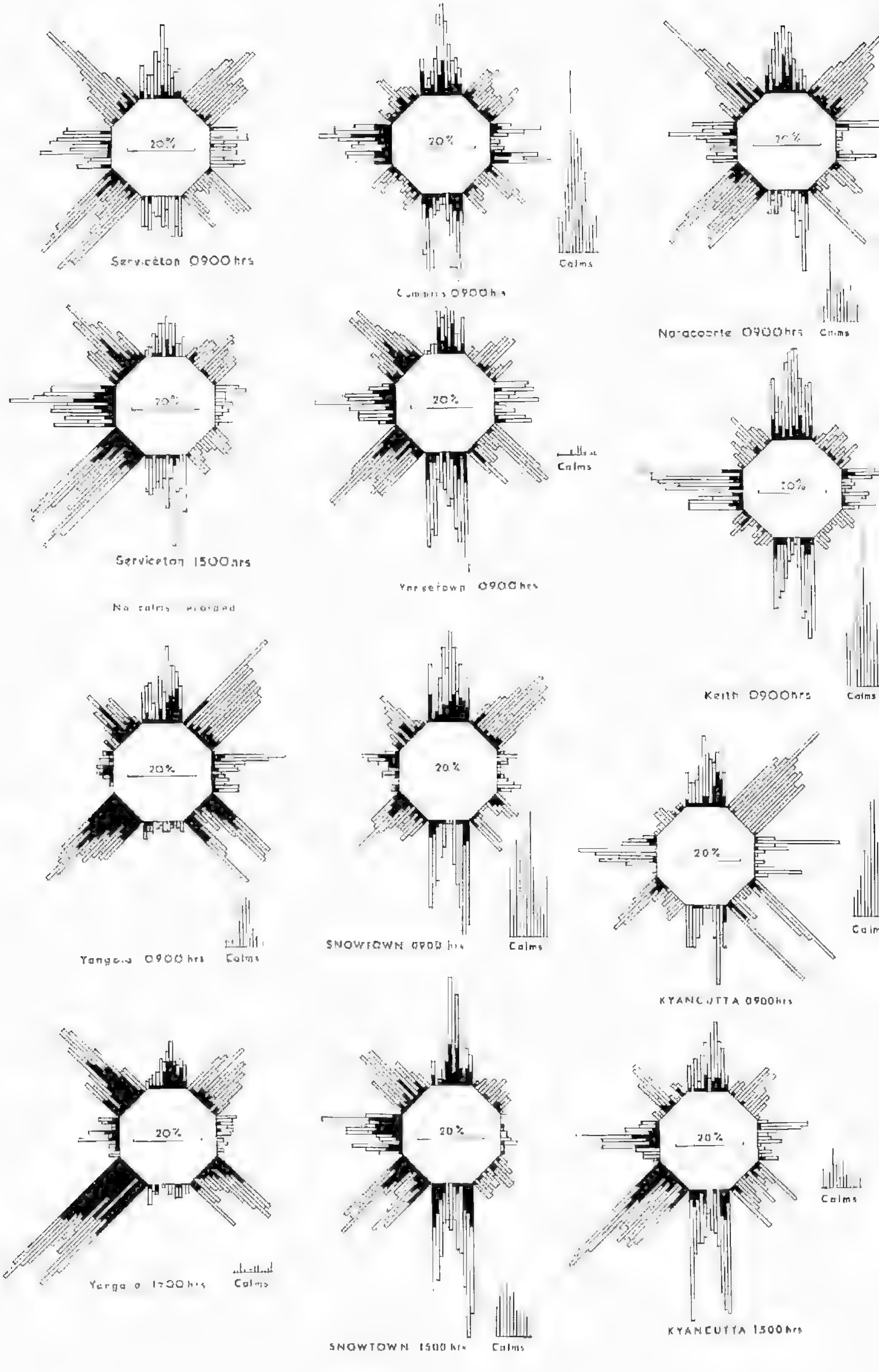
No measurements for the precipitation of dust over rural areas are available, but the amount precipitated in wetter months, as required by the atmospheric dust hypothesis, must be extremely small (R. Culver—personal communication). In view of the youthfulness of lunettes, it is considered that there has been insufficient time for the large amounts of material required to make up a lunette to have been deposited from material suspended in the atmosphere.

Variation in composition of lunettes in close proximity and in an area of uniform soil types is incompatible with the atmospheric dust hypothesis. Cockatoo Lake and Lochaber Swamp, no more than 10 km apart, are associated with lunettes of quite different composition (Tables 1, 2, 3), and the composition of the three lunettes associated with White Lagoon, as stated previously, varies considerably.

The position of the lunettes on the eastern side of lake depressions indicates formation by westerly winds, and, in general, winds in southern South Australia blow from this sector (Fig. 9). In most areas where lunettes are numerous, these winds are the least dust-bearing as they blow for only short distances across land (Stephens and Crocker, 1946).

Two morphological characteristics of lunettes which are atypical of dunes, their smooth and regular contours as opposed to a hummocky surface, and their asymmetry with the steeper slopes on the windward rather than the lee side, were interpreted by Hills (1940) as evidence against the deflation hypothesis of lunette formation. There are, however, several factors in the lunette environment different from that of dunes in general, which can account for these anomalies. The surface of lunettes is covered and protected by vegetation, thus preventing major reshaping of the material, and the development of a hummocky surface. A slow and steady (although not necessarily continuous) rate of accumulation which is indicated by the presence of low angle dips and the absence of marked disconformities in bedding,[3] would allow such a vegetation cover to develop and be maintained. This vegetation cover, together with the facts that lunettes are stationary, the rate of supply of material is limited, and most deposition takes place near the lake shore, can account for the steeper windward slope of lunettes. It is suggested that a large and continuous supply of material destroys the vegetation cover and permits the development of a hummocky surface and of steeper lee slopes. In fact, some lunettes, for example Cooke Plains lunette (Fig. 4) and some of those in northern South Australia (C. R. Twidale, personal communication) do have a hummocky surface due to wind and water erosion.

[3] The 30° dips of the beds in the Cooke Plains lunette on the side away from the lake presumably represent true foreset bedding, but the low angle beds in Cooke Plains and Lake Cadnite lunettes, although not characteristic of transverse dunes, are consistent with an aeolian origin.



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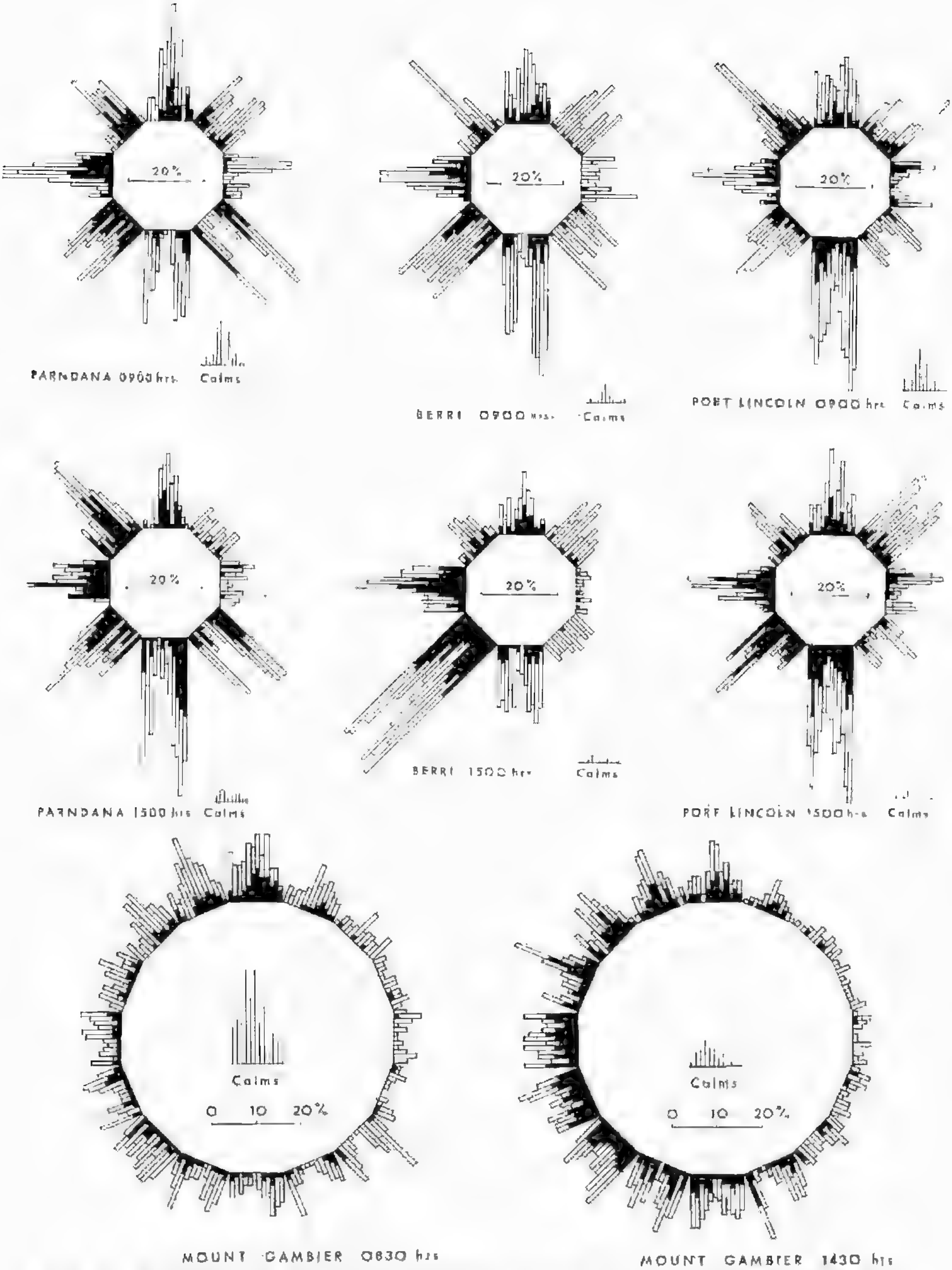


Fig. 9. Wind roses—all winds. The monthly percentage frequency distribution of wind directions from eight points of the compass. The sides of the octagons face towards the cardinal and semicardinal points—north is at the top. Projecting from each side are twelve columns representing the twelve months of the year and the lengths of the columns are proportional to the percentage frequency of winds from the given direction working round clockwise from January to December. The solid black part of the column represents the winds of speeds 13 m.p.h. (21 kilometres per hour) and greater, and the open part of the column represents the winds of speeds less than 13 m.p.h. The scale is shown in the centre of each wind rose. The percentage frequency of calms in the twelve months is shown to the right of the wind rose, working from left to right from January to December. The distribution of winds at 0900 hours is shown for each station and at 1500 hours for some stations. The wind roses for Mount Gambier show the distribution of winds from sixteen points of the compass, for 0830 and 1430 hours. The solid black part of the columns represents winds of speeds 15 m.p.h. (24 kilometres per hour) and greater, and the open part winds of speeds less than 15 m.p.h.

and some, for example parts of Lake Baird lunette (Fig. 2) are asymmetrical with a steeper lee side. These unusual morphological characteristics of lunettes represent conditions similar to those of normal dune formation, and can be expected in the lunette environment as a result of the seasonal and longer term variations in climatic conditions such as are experienced at present.

Similarly, normal variations in the climate of today can explain the multiple lunettes which developed at various stages in the recession of lake shorelines.[6]

There is little evidence in southern South Australia to support the atmospheric dust theory and much which contradicts it. On the other hand, there is ample evidence in support of the deflation hypothesis of lunette formation.

As stated previously, the particle size distribution, the mineralogy, the quartile measures and the sorting values of each lunette sample analysed are similar to those of the associated lake bed sample. Several components characteristic of, though not confined to lakes, have been found in lunettes; Hingston and Bettenay (1960) reported alunite in lunettes, and gypsum crystals make up a large proportion of many, such as those at Cooke Plains and Lake Fowler; specimens of *Coxiella* sp. have been found in Lochaber Swamp lunette and Characeae oospores in Hiles Lagoon lunette. The close similarity between the compositon of the lunette and of its associated lake bed suggests that the two are causally related, i.e. that the material in the lunette was derived from the lake bed, as required by the deflation hypothesis.

Although Hills discounted the likelihood of the formation of aggregates of particles in the lake beds of north-western Victoria, aggregates have been noted during analysis of samples from southern South Australia, and have been seen in transport across dry lake beds in Texas (Coffey, 1909). Although the process of aggregate formation is incompletely understood, aggregates are considered to explain the large proportion of particles in fine-grained lunettes (76-90%) which are too small to be transported by deflation as individual particles, but which, when bound together, behave as sand grains. The size composition of the sandy lunettes is also consistent with the deflation hypothesis.

If the lake depressions and their associated lunettes are not causally related, the lakes must be explained otherwise than by deflation. In southern South Australia examples can be cited where wave action, solution, blocking of surface drainage of fluviatile action have contributed at least in part to the origin of the lake, but these processes cannot satisfactorily explain all depressions. Owing to tectonic disturbances and the semi-arid climate of the area, conditions are favourable for the creation of basins of internal drainage. The periodic accumulation of water-transported debris in the centres of these basins under conditions of strong evaporation makes possible the removal of this material by wind. There are numerous examples in southern South Australia where depressions have been formed by this continuing process of deflation. The origin of the lakes is thus consistent with the deflation theory of lunette formation.

It is generally accepted (J. T. Hutton—personal communication) that dry conditions favour the generation of electric charges on particles, and these charges markedly assist in the deflation of material. In southern South Australia the following air temperature and relative humidity relationships usually apply (B. Mason—personal communication):

[6] Variations in composition of lunettes associated with the one lake result from variations in the material in the lake bed which has been transported by streams of varied rates of flow or from varied sources.

| *Air Temperature—° F.* | *Relative Humidity—%* |
|---|---|
| < 60 | > 50 |
| 60-80 | 35-55 |
| > 80 | < 35 |

The number of days on which the air temperature reaches these categories varies throughout the area, but statistics for Mount Gambier and Yongala represent values near the two extremes:

| | *No. of Days Temp. reached* | |
|---|---|---|
| *Air Temperature—° F.* | *Mt. Gambier* | *Yongala* |
| < 60 | 120 | 101 |
| 60-80 | 204 | 159 |
| > 80 | 41 | 105 |

For a considerable part of the year, dry conditions assist in the process of deflation.

However, the deflation hypothesis of lunette formation, though on broad terms consistent with the observed evidence, presents some difficulties.

First, lunettes are common on the edge of salt encrusted depressions from which deflation of the underlying material is impossible. However, the salt crust may be a more recent development.

Second, although the climate where lunettes are found varies from arid to subhumid, they are best developed in semi-arid areas, and not in truly air regions where deflation is most pronounced.

Third, an examination of the strong winds (greater than 13 miles per hour—about 21 km. per hour)[7] for selected stations in southern South Australia shows that in the wet season (May to October, based on the number of rainy days per month) westerly and northwesterly winds are predominant, whilst in the dry season (November to April) the strong winds most commonly blow from a southerly to westerly direction (Fig. 10). Lunettes occur most commonly on the eastern or south-eastern sides of lake depressions. That is, they face the wet season winds, those which blow when the lakes are occupied by water, when deflation from the lake bed is impossible. They are not primarily associated with the dry season winds which could achieve deflation from the dry lake bed.

These difficulties could be overcome by postulating a change in climate, for example, a change in temperature-humidity relationships resulting in different evaporation rates, a decrease in rainfall during the wet season, or a change in wind direction. However, there is no evidence that such drastic changes of climate have taken place during the recent past when lunettes have apparently developed. Other possibilities must therefore be considered.

Although all the lakes in southern South Australia are shallow, there is ample evidence of the effectiveness of wave transport and erosion. On the eastern shore of Lake Greenly, for example, a beach partly composed of well-rounded quartz pebbles, a shore platform, a cliff and rounded bays, all indicate the effect of waves (Pl. 7). Cliffs are common at other sites, for example Cockatoo Lake and Lake Fowler, and beaches are particularly well formed on the eastern shore of lakes on the laterite plateau of Kangaroo Island. In addition, a spit on the eastern shore of White Lagoon and of Lake Malata, and the characteristic rounding of the lakes (Pl. 1) (Campbell, 1967) are attributed to wave action.

[7] It is generally accepted (Bagnold, 1941, Chepil, 1945, 1958, 1959; Chepil and Milne, 1939; Condon and Stannard, 1957; Péwé, 1951) that winds of 13 m.p.h. and greater can initiate movement of some particles under certain optimum conditions, though stronger winds are more commonly required. 13 m.p.h. is also the lower limit of one of the classes on the Beaufort scale.

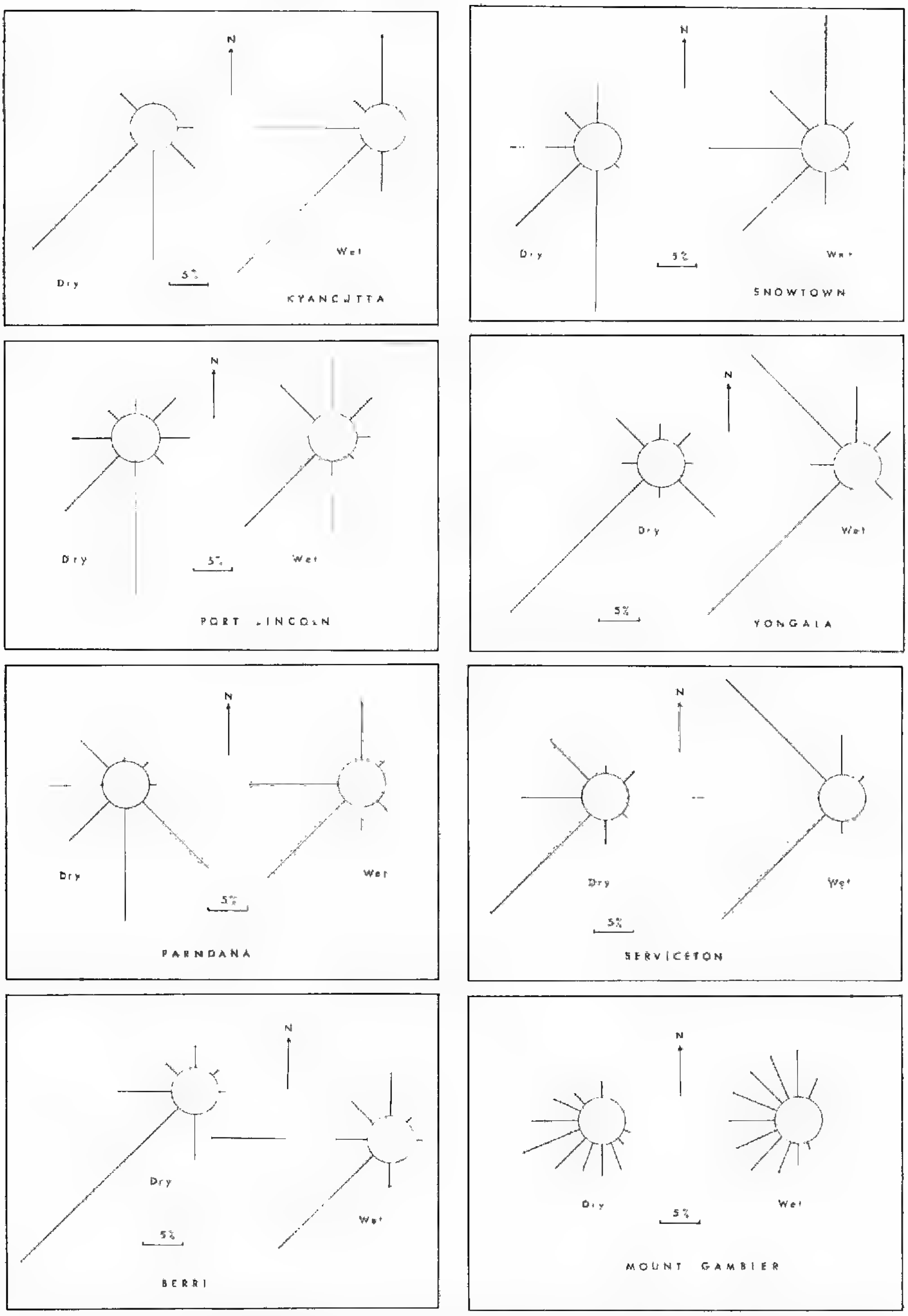


Fig. 10. Wind roses—strong winds in the wet and dry halves of the year. These wind roses show the distribution of strong winds from the cardinal and semicardinal points of the compass in the wet and dry halves of the year, differentiated on the basis of numbers of rainy days per month, and averaged over the selected stations. The monthly percentage frequency of the strong winds (13 m.p.h. (21 kilometres per hour) and greater) at 1500 hours for November to April and for May to October are expressed as a percentage of strong winds for the year.

Price and Kornicker (1961) noted the importance of waves and currents in transporting shell fragments on to the lower slopes of clay dunes similar to lunettes, in Texas. Bowler (1964) suggested that medium to coarse sand is concentrated in beaches before being blown by the wind on to the lunette, although finer particles, he considered, could not be concentrated in this way. However, although silt- and clay-sized particles are generally carried in suspension in water, some may be concentrated in a beach by one or more of the following methods. Clay particles may adhere to sand grains or themselves form aggregates. The salinity of the water in the lake will determine whether the clay particles are in true colloidal suspension, or are capable of transport by waves in the form of aggregates. As J. T. Hutton pointed out (personal communication) wave action sufficient to cause transport would probably also be capable of breaking up the aggregates; but many remained unseparated after mixing during the analysis of samples. Silt and clay in suspension may be filtered out by the sand and debris in a beach or by vegetation growing on the edge of a lake. It is suggested, therefore, that wave transport of sand, and possibly of silt- and clay-sized particles, is important in lunette formation.

As Stephens and Crocker (1946) pointed out, the vegetation growing on the edge of a lake provides the rough type of surface required to cause deposition of wind-transported material. The line of vegetable matter, floated on the surface of the lake and deposited as the water level recedes, has a similar result, as was recognized by Woods (1862, pp. 28-29).

The effect of waves and the presence of vegetation on the edge of the lake can overcome each of the difficulties encountered by the deflation hypothesis.

First, in the case of those lunettes occurring on the edge of the salt-encrusted lakes, the major part of deflation occurs from a beach built by wave action in the wet season, and not from the lake bed. Second, the reason for lunettes being best developed in semi-arid rather than arid regions, is that in arid areas there is insufficient vegetation on the lake edge to trap the material which has been scoured from the lake bed and to prevent later degradation, and the lakes in arid areas do not contain water long enough for significant wave transport[8] to occur.[9] The third difficulty concerns the distribution of the lunette in relation to the lake. The position of the lunette on the eastern or south-eastern side of the lake opposite the wet season winds is a result of wind generated waves. A beach is built on the eastern and south-eastern side of the lake, and the material in the beach is able to be transported by the wind. In the dry season, once the water level has fallen and with the winds blowing from the west and south-west, deflation from the lake bed takes place. In this way, a combination of wave and wind action results in the formation of the lunette on the eastern side, and where wave action and wind transport in winter are relatively more important on the south-eastern side. Thus, the analogy of lunettes with primary coastal foredunes is readily apparent.

## ACKNOWLEDGEMENTS

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[8] In sub-humid regions, the rainfall is sufficient to allow the development of co-ordinated drainage systems rather than dry basins of internal drainage, and the evaporation rate is lower. Therefore, deflation is limited.

[9] In several districts in southern South Australia, for example near Snowtown, some lakes have associated lunettes, whilst others do not. Such factors as the amount and nature of material carried into the lake, and the length of time the lake is occupied by water (enabling wave transport) or is dry (enabling deflation) must be considered in explaining this distribution.

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PLATE I

Hutton's Lagoon lunette—aerial view. The smoothly rounded eastern shore is typical of the lakes in southern South Australia. The dashed line indicates the position of the crest of the lunette. (Reproduced by courtesy of South Australian Department of Lands.)


Plate 2

White Lagoon multiple lunette—aerial view. White Lagoon is an example of the more or less concentric arrangement of a multiple lunette bordering one lake. The three ridges are marked by dashed lines. (Reproduced by courtesy of South Australian Department of Lands.)

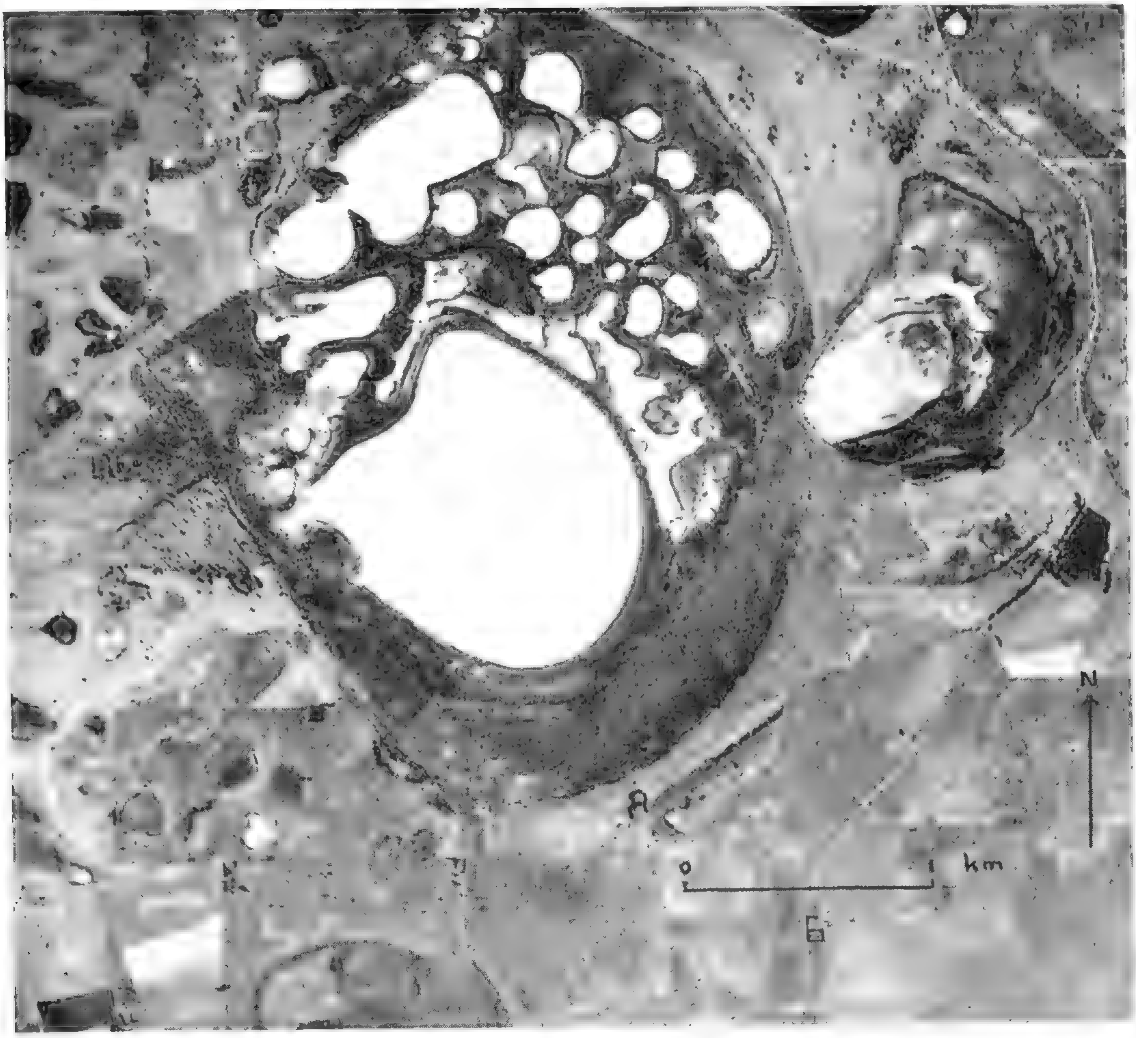



PLATE 3

Salt Lake multiple lunette—aerial view. A complex of small lakes, each with its associated lunette or lunettes, occurs within a larger lake basin on the edge of which is a large lunette. (Reproduced by courtesy of South Australian Department of Lands.)

PLATE 4

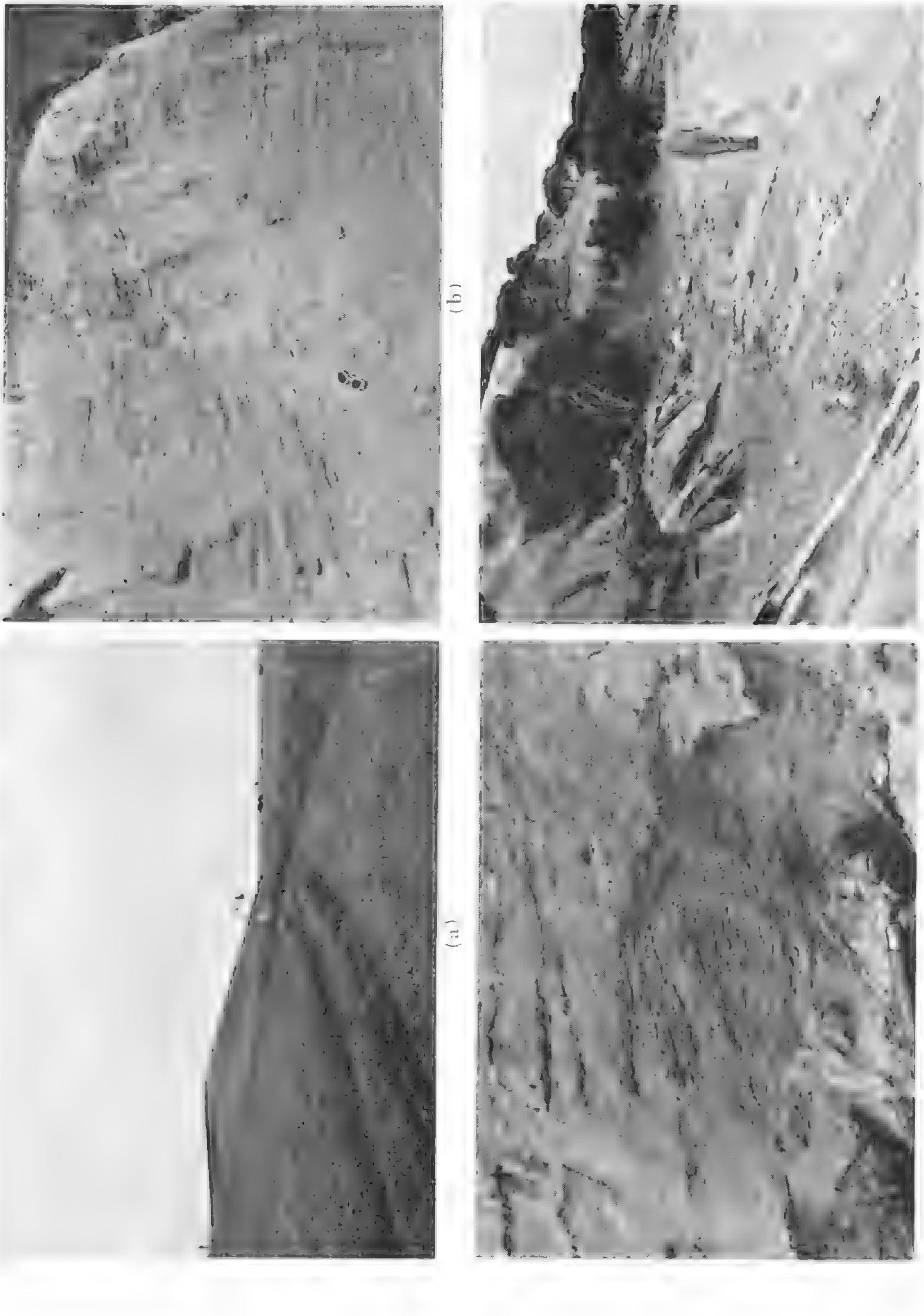
(*See next page*)

(a) Western slope of Bool Lagoon lunette. The smooth and rectilinear western slope of this lunette is typical.

(b) Bedding in Cooke Plains lunette near the crest. The dip of the beds is variable over short distances, but nowhere exceeds 20 degrees. View looking north-east.

(c) Bedding in Lake Cadnite lunette. The characteristic dip of the beds in this lunette near the crest is 2 to 12 degrees to the east. The example shown here indicates a rare cross-bedded sequence.

(d) Shoreline of Lake Greenly. Gneissic material outcrops on the south-eastern shoreline of Lake Greenly. A shore platform and a beach with rounded pebbles are evidence of the effectiveness of waves in transporting debris even in this shallow lake. The white material near the top of the photograph is "flour" gypsum on the surface of the lunette. (Photograph by C. R. Twidale.)


(b)
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# ORIGIN OF WAVE ROCK, HYDEN, WESTERN AUSTRALIA

*BY C. R. TWIDALE**

**Summary**

Wave Rock is a long high overhanging natural wall located on the northern side of Hyden Rock, in Western Australia's Wheat Belt. Though it displays some apparently unusual features, it has much in common with similar forms described from Eyre Peninsula and other areas both within Australia and overseas. The available evidence suggests that Wave Rock also evolved in similar fashion: by strong scarp foot weathering, and subsequent erosion of the weathered debris. This and other hypotheses advanced in explanation of Wave Rock are discussed in light of the field evidence.

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C. R. TWIDALE*

[Read October 10 1968]

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Wave Rock is a long high overhanging natural wall located on the northern side of Hyden Rock, in Western Australia's Wheat Belt. Though it displays some apparently unusual features, it has much in common with similar forms described from Eyre Peninsula and other areas both within Australia and overseas. The available evidence suggests that Wave Rock also evolved in similar fashion: by strong scarp foot weathering, and subsequent erosion of the weathered debris. This and other hypotheses advanced in explanation of Wave Rock are discussed in light of the field evidence.

## INTRODUCTION

Various opinions have been offered concerning the origin of Wave Rock, a well-known and spectacular feature located near Hyden, W.A. In *Land of the Southern Cross* (1956), for example, a popular picture book designed to attract immigrants and tourists, it is attributed to the work of "wind and rain" (p. 89). In Vincent Serventy's *Landforms of Australia* (1967, p. 25) it, and similar sharply sigmoidal or flared forms at Ayers Rock, are tentatively attributed to erosion by wind-driven sand. An alternative explanation has been offered by O'Riley (1967) who, citing professional opinion, suggests that Wave Rock is due fundamentally to selective erosion by running water. It is suggested that the upper, and earlier exposed, surface of Hyden Rock, on which Wave Rock occurs, has been indurated with silica to a greater extent than the more recently revealed flanks. Water coursing over the bare rock surface therefore erodes the weaker lower slopes more than the toughened upper surface; the lower slopes are "undercut by the continued flow of water"; and the stone wall erected around the flattish upper surface of the rock is intended to "arrest erosion".

Comparable, though less spectacular, flared forms on Eyre Peninsula (S.A.) and elsewhere (Twidale, 1962; 1964; 1968, pp. 145-147, 347-350) are evidently due to strong localised subsurface scarp foot weathering and subsequent erosion. Because this interpretation is at variance with the opinions cited above concerning the origin of similar forms, it may be both useful and interesting to describe the process of scarp foot weathering and its characteristic results; and to match the several hypotheses with the field evidence at Hyden Rock.

## SCARP FOOT WEATHERING AND EROSION

Flared forms developed on granitic rocks have been examined on Eyre Peninsula, in the Kosciusko region of southern N.S.W., in the western Mt. Lofty Ranges (S.A.), and in the Sierra Nevada of California. They occur on sandstone outcrops in the Flinders Ranges, and at Ayers Rock, as well as on the conglomerate of the

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Olgas massif, Northern Territory. Although flares are well developed on the north and west facing slopes, and although exceptions have been noted, they are best and most commonly developed on the southern and eastern, i.e. the shady, aspects of the residual hills or inselbergs on which they occur. Double and multiple flares or concavities are in places displayed. The flared slopes are not everywhere found in horizontally disposed zones of steepening or overhang. At several sites they are inclined or even irregularly distributed, though in all cases the disposition of the steepened zone varies in evident sympathy with that of the hill-plain or rock-soil junction. Flares are very well developed on the points of spurs.

Incipient flared slopes are developed beneath the land surface, beneath weathered country rock which is *in situ*. At the margin of the inselberg, the surface of the fresh rock, continued subsurface as the *weathering front* (Mabbutt, 1961) or limit of weathering, characteristically plunges steeply for a few feet beneath the land surface before gradually flattening out. Such concavities in the fresh bedrock surface, and formed beneath the natural land surface, have been observed in dry reservoirs located on the inselberg margins, and have also been detected by augering and excavation.

Finally, small flared slopes occur in clefts within the inselbergs, around boulders and on gentle slopes, in association with accumulations of soil or weathered debris.

Although several possible explanations of flared slopes have been entertained (Twidale, *loc. cit.* 1962; *op. cit.* pp. 347-350), all save one are found wanting when the field evidence is matched against the deducible consequences of the hypotheses. The interpretation which has survived rigorous testing and which accounts for the field evidence is that the flares evolve in two distinct stages involving first, strong localised scarp foot weathering, and, second, marked differential erosion of the scarp foot zone and exposure of the erstwhile weathering front (Fig. 1).

## HYDEN ROCK

### *General Setting*

Hyden Rock lies about 3 km. east of Hyden township, which is, in turn, 296 km. E.S.E. of Perth (Fig. 2). The Rock is about 2 km. long on an east-west axis and on a N.N.W.-S.S.E. line a little more than 0·8 km. wide (see Fig. 3). It is composed of granite, most of which is strongly porphyritic, though pegmatitic, even and medium grained, and fine grained, phases occur in patches and veins. No horizontal flat-lying zones of petrological differentiation have been detected in the granite.

The granite is jointed but most of the joints are tight and widely spaced. Avenues of weathering within the Rock are few, and its greater resistance to weathering and erosion, as evidenced by its remaining as an upstanding hill, is probably due to its being built of especially massive joint blocks. This is demonstrably the case in places on Eyre Peninsula and elsewhere.

Hyden Rock is a granitic inselberg which rises abruptly to a maximum elevation of some 55 m. above the surrounding plains, which, on the evidence of bores and dam excavations, are also underlain by granite. Here, however, the rock is deeply weathered: Berliat (1965) reports over 20 m. of weathered granite about 400 m. from the margin of a residual located 65 km. east of Hyden and well over 40 m. of disintegrated rock elsewhere beneath the plains.

The plains are not flat, for there is a pronounced slope down to the north; the few vaguely defined watercourses flow toward a complex of ephemeral lakes

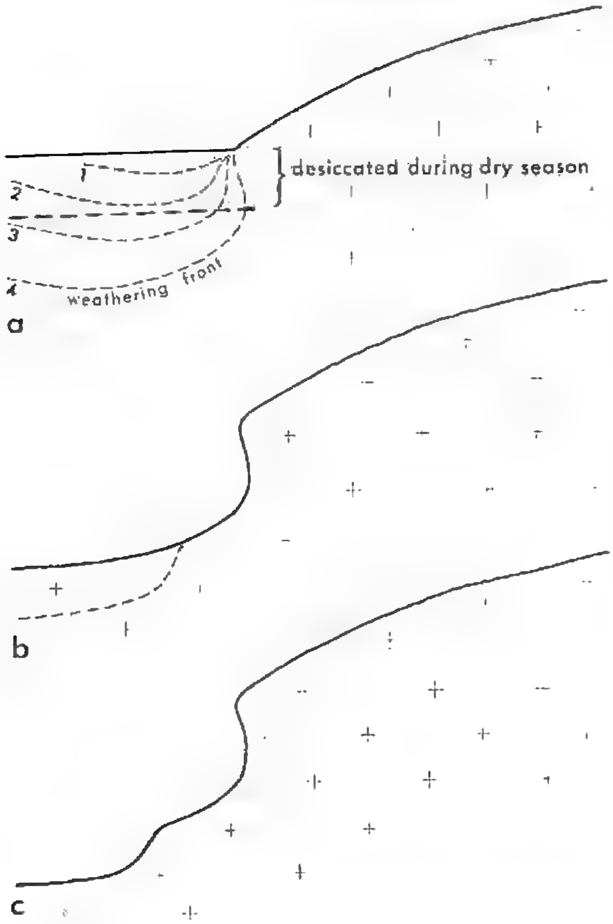


Fig. 1. Evolution of flared slope by scarp foot weathering and subsequent erosion. (a) Strong weathering by water (derived from run-off) at the lower margin of the residual hill. Numbered lines represent stages in advance of weathering front. (b) Lowering of base level, erosion of weathered debris, and exposure of weathering front as a flared slope, with further weathering beneath the new plain surface. (c) Development of double flare by repetition of the two-stage process.

located immediately to the north of the Rock. The plain to the south of the Rock is about 25 m. higher than the plain on its northern side.

The inselberg consists of three distinct hills, the central dome-shaped hill being both slightly higher and more extensive than its neighbours to east and west. All three hills are delineated by prominent vertical or near vertical joints, the more important of which run E.N.E.-W.S.W., N.W.-S.W., and N.W.-S.E. Many clefts within the hills follow along such joints. Flat lying or gently dipping joints are also important, for, although discontinuous, they subdivide the hill into massive slabs or sheets. The weathering and erosion of several of the latter gives the Rock its stepped appearance in broad view ( Fig. 4).

### *Flared Slopes*

Flared and basally steepened slopes are well developed on all three hills, not only around the margins but in clefts (Pl. I) and amphitheatres at higher levels also. The flared and steepened slopes are well formed on the long southern wall of the Rock, for instance, adjacent to the 13th fairway of Hyden Golf Club (A on Fig. 3) and they are well developed along much of the northern foot wall. In clefts and depressions the south-facing wall is commonly, though not in all cases, steeper than that opposite.

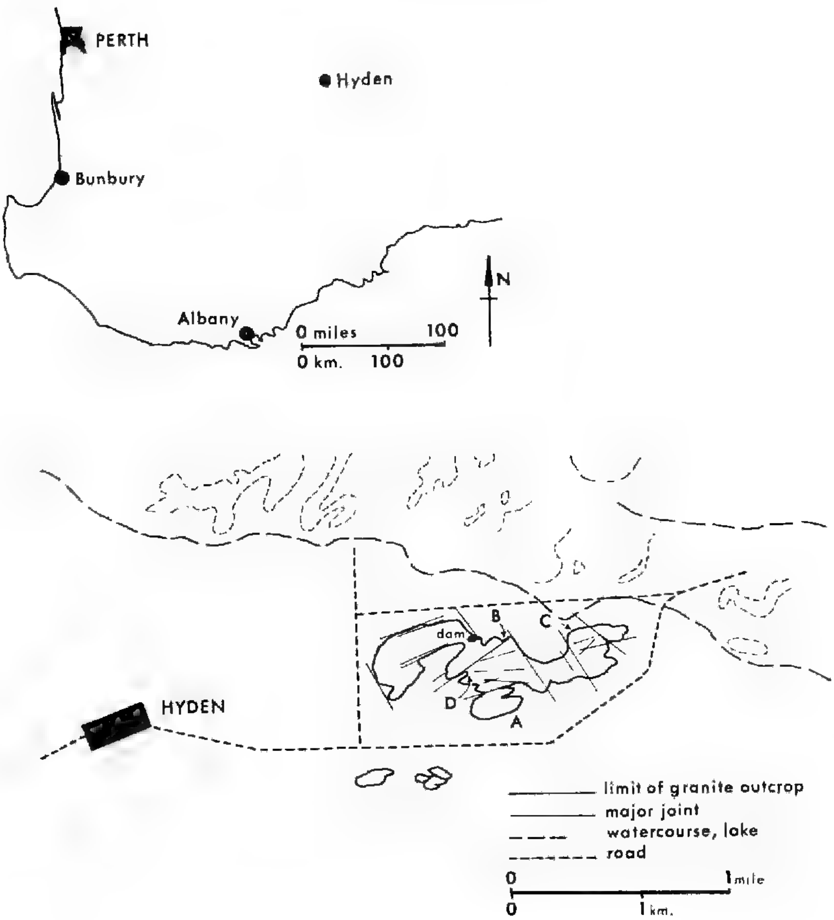


Fig. 2 and Fig. 3. Location map and map of Hyden Rock (drawn from W.A. Lands Dept. air photographs). Sites A-D are referred to in the text.

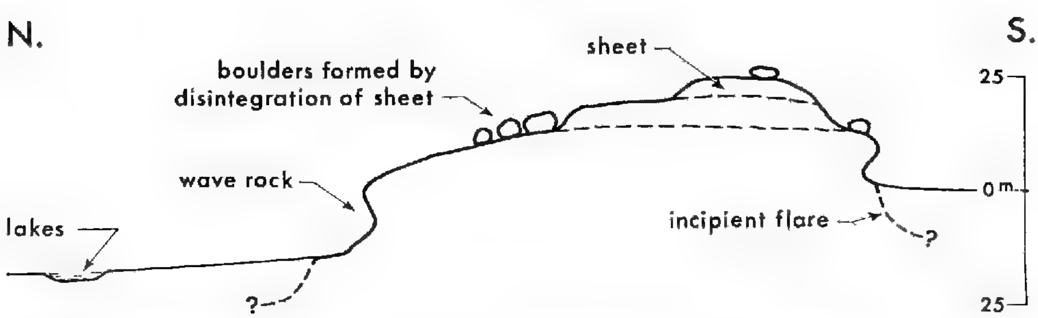


Fig. 4. Diagrammatic N.-S. section, not to scale, of Hyden Rock, showing stepped form, sheet structure, flared slopes, probable present weathering fronts, and the disparity in elevation between the plain north and south of the Rock.

But what is unquestionably the most majestic and impressive flared and overhanging slope is Wave Rock (Pl. II) which is a steepened and overhanging basal slope 10-12 m. high located on the north side of the central hill. Some flared slopes on Pildappa Hill, Eyre Peninsula, are as high or higher than Wave Rock, some at Ucontitchie Hill (also on Eyre Peninsula) overhang to a greater extent or are more complex, but as a high continuous overhanging wall, Wave Rock indubitably stands alone.

At the base of the flared slopes on the northern side is a continuous, virtually level platform up to 10 m. wide (Pl. II) and located at, or a little above, the present plain level. Similar platforms have been observed marginal to the inselbergs of northwestern Eyre Peninsula, but nowhere are they as extensive and level as at Hyden. Another notable feature is the angular junction between flared slope and platform. Double concavities or flares are fairly common, as, for instance, on Wave Rock itself (Pl. II). Some flared zones on Hyden Rock are inclined with respect to the horizontal, as, for instance, on the northern slope (Pl. III), in the enclave between the central and eastern hills. Finally, it is very typical that the weathering front—the surface between the fresh and the weathered bedrock—plunges steeply beneath the weathered granite which, with a veneer of colluvial debris, underlies the plain (Pl. III). Excavations reveal that this steeply inclined slope continues beneath the plain surface for rather more than one metre, at which depth it shows no sign of levelling out.

Thus, in many respects the flared slopes at Hyden Rock, and particularly Wave Rock, share characteristics with similar forms in other regions. The great contrast lies in Wave Rock itself, which is on the northern, and not the southern side of the inselberg, and which is located not on the point of a spur, but in a broad, probably joint-controlled, embayment (B on Fig. 3). These apparent anomalies are, however, susceptible of ready explanation in terms of the subsurface water weathering hypothesis.

Being in a broad embayment, to which drains run-off from a wide area of the central hill, the plains marginal to the inselberg in that area undoubtedly receive a more than average quantity of water, so that especially pronounced and deep scarp foot weathering is probably developed there. Furthermore, immediately to the north of the Rock and virtually at the same elevation as the plain on the northern side is a complex depression—probably an old drainage line—which receives water from a wide area and which in winter is full of water. Groundwaters from this drainage line may penetrate to the Rock itself.

The comparative degree of erosional exposure on the northern and southern aspects of Hyden Rock should also be considered. As already mentioned, the northern plain, close to the drainage depression, is about 25 m. lower than the plain to the south of the Rock (Fig. 4); indeed, the whole plain surrounding the inselberg slopes down to the north. Any lowering of the plain by streams must have been initiated from the old drainage line (Fig. 3) and therefore would have affected the northern slope of Hyden Rock before the southern. Thus, it may be argued that while greater erosion and lowering of plain level has already exposed the deep weathering front on the northern face, similar lowering of the surface has not yet extended to the southern side, where an incipient flared slope may be present beneath the surface (Fig. 4).

Thus, local circumstances may have combined to cause unusually deep and pronounced subsurface weathering of the granite on the northern side of Hyden Rock. The same northern slope may have been exposed by erosion to a greater extent than has the southern. These are the probable reasons for the unusual degree of steepening of the northern slopes, and for Wave Rock in particular.

The other suggested mechanisms for the development of Wave Rock either cannot explain the field evidence, or are inconsistent with it. For instance, aeolian sand blasting cannot account for the occurrence of incipient flares beneath the present land surface, below weathered granite *in situ*, and for the flares at high levels on the Rock (sand blasting is most effective within 1 m. or so of ground level). The areal distribution of the flares is also at odds with the expectable consequences of sand blasting. Lunettes due to deflation of exposed lake deposits are located on the western side of lakes in the Hyden-Corrigin area, indicating a prevalence of strong winds from the east, and in these terms the "undercut" slopes should be best developed on the eastern aspects of the hills. No such consistent and preferred orientation has been detected. Furthermore, the very fact of the inselbergs being there would disturb the air flow and divert winds (and sand) around the residuals; the abundant vegetation growing around the hills on the better watered scarp foot zone also serves to protect the lower rock walls against aeolian action.

The suggestion concerned with running water (O'Riley, *loc. cit.*) faces comparable difficulties:

(1) Induration of the surface of Hyden Rock has certainly occurred, partly as a result of climatic conditions, partly resulting from the work of the lichens which grow in profusion on the rock surface. Iron oxides have been concentrated at and near the surface, though much of this indurated layer appears to have been eroded, only small flat-topped nobs remaining in a few places. But the induration appears equally distributed over most of the surface. It is certainly not preferentially developed at upper levels of the Rock surface, so that selective erosion cannot be invoked. Furthermore, though the upper area must have been first exposed, there is a strong suggestion that far from being tougher than the lower slopes, the upper part of the rock has suffered considerable weathering, the upper sheets of granite having disintegrated into groups of blocks or rounded boulders.

(2) Some form of induration has undoubtedly affected many boulders, and preferential weathering has given rise to cavernous forms or tortoiseshell rocks. But in these forms the hardened crust forms thin projecting lips or visors, which do not occur in the flared slopes. At one site on the northern slope of eastern hill (C on Fig. 3) there is a concentration of cavernous and alveolar weathering which may be due to petrological factors, or may be a reflection of local concentrated weathering at or just below a former plain level (the site is some 6 m. above the present plain). In this area, quite deep hollows are developed beneath thin external crusts.

(3) Although running water, because of its downslope increase in velocity and volume, may appear capable of producing slopes of increasing downslope inclination (see for instance Fenneman, 1908; Cotton, 1952), particularly in an embayment such as those at Wave Rock and at D (Fig. 3) on the southern side of Hyden Rock, where flow is centripetal, there are sound hydrological reasons for suggesting that it does not do so (Twidale, *loc. cit.*, 1962). Moreover, once a certain critical inclination is attained, fast flowing water becomes detached from the rock surface to form a jet or waterfall. Only the slowest flowing thin films of water adhere to the steep rock face by surface tension—yet these are supposed to accomplish considerable erosion, and even pronounced undercutting. At Wave Rock in June 1968, some thin films of water were creeping down the overhanging slope, but there was a continuous drip of water from the upper lip to the foot wall. Also, on the upper part of Hyden Rock, pronounced overhanging flares are developed on spurs of very limited catchment, and in other places on boulders of similarly limited potential run-off.

(4) Selective erosion by running water cannot explain multiple flares, the development of flares in clefts and amphitheatres (nor, indeed, the amphitheatres themselves), the inclination of the flared zone, and their apparent occurrence subsurface marginal to the Hyden residual.

The scarp foot weathering hypothesis can readily account for these and other relevant details of the flared forms, and it is suggested that it is this process which is responsible for the development of Wave Rock and other similar features at Hyden Rock, as well as on other granite residuals in the southwest of Western Australia.

### *Angular Footwall*

The pronounced angularity of the junction between the flared slope and the basal platform, as displayed at Wave Rock, and other similar features at Hyden Rock and other inselbergs in the region, develops as a result of subaerial weathering. Rainwater and seepage waters trickle down the steepened lower slopes and cause the platform immediately adjacent to the hillslope to be wetted. The rock here disintegrates, and is subsequently washed out, leaving a miniature depression, one flake (1-2 cms) deep between the main platform level and the base of the flared slope. Such depressions, observed at the base of Wave Rock and on Gorge Rock, near Corrigin, W.A., carry water after rain, causing further weathering of the granite with which it comes into contact, including that exposed at the scarp foot. As the shallow depression is extended laterally by such weathering, the basal slope is undermined and steepened, and an angular junction is developed between hillslope and platform (Fig. 5).

### *Amphitheatres*

Another feature well displayed at Hyden Rock, but not so far described from the Eastern States, is the amphitheatre. Joint clefts with flared bounding slopes occur on Hyden Rock (Pl. I) and, for instance, on several of the inselbergs of northwestern Eyre Peninsula. These two areas have similar climates (both with hot summers, cool winters, 35-45 cm. average annual rainfall and a marked dry season), but at Hyden Rock the slopes of the clefts have suffered marked recession as a result of soil moisture weathering and as a result have been widened to form large amphitheatres (Fig. 6). It is not known whether this more advanced stage of development reflects a time factor or the less resistant character of the porphyritic granite exposed at Hyden Rock, but such developments clearly contribute to the breakdown of the sheets of granite and to the formation of an overall stepped morphology on the inselbergs.

## CONCLUSION

Though Wave Rock displays apparently unusual features, it has much in common with similar forms described from Eyre Peninsula and elsewhere. The available evidence suggests that Wave Rock evolved, as did the other flared slopes, by strong scarp foot weathering followed by erosional exposure. This interpretation accounts for the field evidence more readily than any of the other hypotheses so far advanced.

## ACKNOWLEDGEMENTS

The writer wishes to thank Professor M. J. Webb, Department of Geography, University of Western Australia, and the Director, Geological Survey of Western Australia, for facilitating in various ways the investigation of Hyden Rock and several other inselbergs in the region. Some travel expenses were met from a Research Grant from the University of Adelaide.

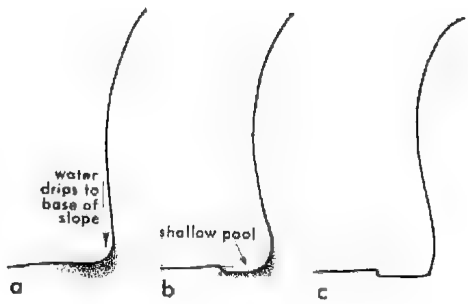


Fig. 5. Development of an angular junction between flared slope and platform by local subaerial water and pool weathering. (a) Water trickling down flared slope soaks the bedrock at the inner edge of the basal platform and weathers it. (b) The weathered debris is washed away, a shallow pool of water accumulates in the hollow so formed, and further weathering takes place. (c) The base of the flare is steepened and made angular as a result of weathering by pool water, and consequent lateral extension of the pool depression.

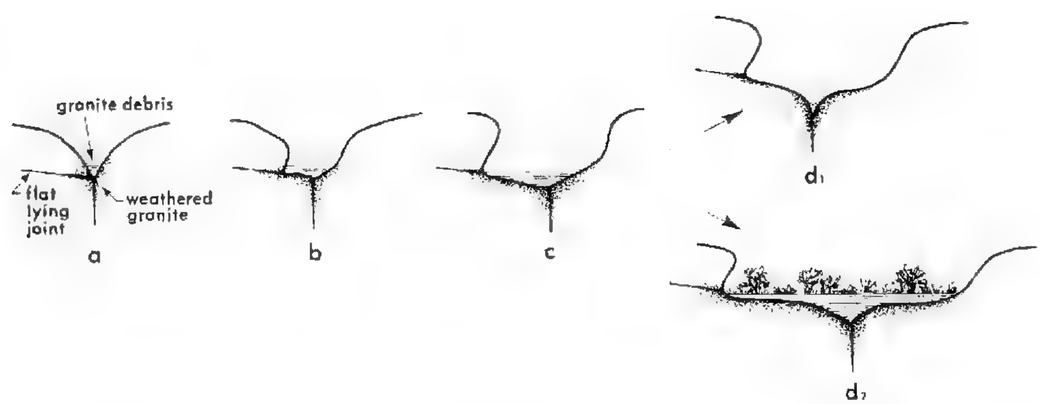


Fig. 6. Sequential development of an amphitheatre from a joint-controlled cleft by soil moisture, weathering, undermining of bounding slopes, and progressive widening. Several such phases of weathering, with intervening spells of debris evacuation, are evidently represented in these clefts and depressions with complex sides. The phases of weathering and erosion in the clefts, like those to which the flared slopes are attributed, are probably controlled by climatic changes or fluctuations or even seasonal and storm effects. a-d represents a sequence, representatives of which have been observed on Hyden Rock. d1 shows the result of baselevel lowering in a narrow cleft (cf. Pl. 1). The depth of fill must decrease as the area of the depression floor increases.

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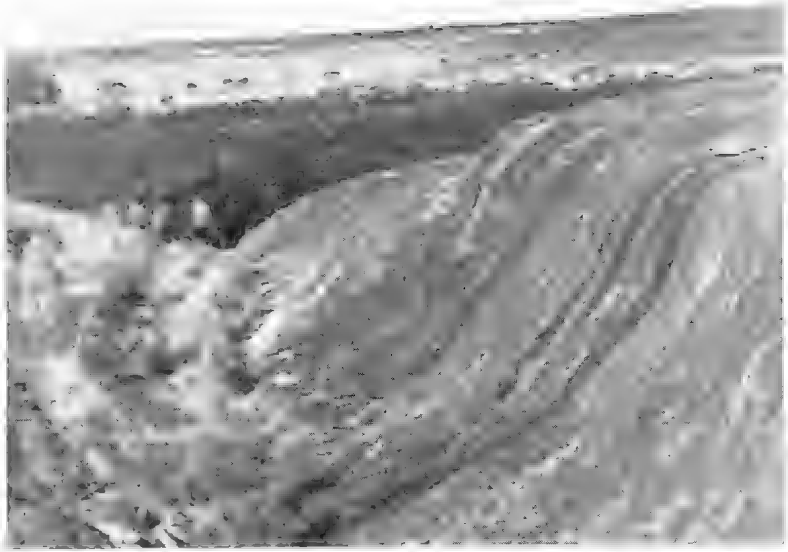

PLATE I.

PLATE II.

Plate I. Flared slopes in a joint-controlled cleft near the eastern extremity of Hyden Rock. (Photo C. R. Twidale.)

Plate II. Wave Rock from the eastern end of the embayment, showing the broad basal platform. The low wall above the Wave is intended to divert run-off into the reservoir from which Hyden draws its water supplies. (Photo C. R. Twidale.)

Plate III. Sloping flared zone, scarp foot platform, and plunge of weathering front beneath adjacent plain, on the north side of Hyden Rock some 200 m. east of Wave Rock embayment. (Photo C. R. Twidale.)

# OBITUARY: THOMAS DRAPER CAMPBELL 1894-1967

## Summary

# OBITUARY

## THOMAS DRAPER CAMPBELL (1894-1967)

Born at Millicent in the South-east of South Australia Campbell received his early education at Prince Alfred College and undertook tertiary study at the University of Adelaide where he graduated in dental surgery in 1921 continuing these studies to receive a doctorate in 1923. His doctoral thesis was published by the University in 1925 under the title "*Dentition and Palate of the Australian Aboriginal*" and has been widely acclaimed as a pioneer work in this field.

Soon after graduation Campbell entered the Dental Department of the Royal Adelaide Hospital as the first Dental House Surgeon, and in 1926 was appointed Superintendent. He was elected Dean of the Faculty of Dentistry in 1938, and appointed to the full-time University position of Director of Dental Studies in 1949. He became the first Professor of Dentistry in 1954 and upon retirement four years later was made Professor Emeritus.

During his professional career Prof. Campbell received high recognition for his work. In 1948 he was made F.D.S.R.C.S. (London); in 1950, F.D.S.R.C.S. (Edinburgh); in 1952 he was elected an Honorary Member of the Odontological Section of the Royal Society of Medicine, London, and in 1966 a Fellow of the Australian College of Dental Surgeons.

At all times Professor Campbell combined his dental studies with a keen interest in anthropology. In December 1926 he was associated with the formation of the Board for Anthropological Research, University of Adelaide, and has played a leading role in its research activities. As organiser and leader of many expeditions to Central Australia in the 1920's and 30's he was responsible for the collection of a large amount of important data and material on many aspects of the traditional life of the aboriginal. Stone technology fascinated him and he spent countless hours searching for and making a detailed study of aboriginal stone implements. He contributed important papers to the literature on this subject. Well known as an accomplished amateur film producer, Professor Campbell made a series of colour-sound movies on aspects of aboriginal technology for the Board. He was chairman of the Board at the time of his death.

He became a member of this Society in 1922 and spent ten years on the Council, holding the office of President in 1934-35. Following appointment to the Board of the Public Library, Museum and Art Gallery in 1932, he became a foundation member of the Museum Board in 1939, a position which he held until his death. In addition to being a Fellow of the Australian Research Council, Foundation Member of the Australian Institute of Aboriginal Studies and a Life Member of the Anthropological Society of South Australia, Professor Campbell was an honorary member of the Anthropology Staff of the South Australian Museum from 1923 until his death.

He was well known as a keen debater and will be remembered for his participation in many lively discussions at Royal Society meetings. A member of this Society with an outstanding international reputation, he died at his home at Tusmore on 8th December, 1967.

Robert Edwards.

# BALANCE SHEETS

## Summary

# THE ROYAL SOCIETY OF SOUTH AUSTRALIA INCORPORATED

## General Account

### STATEMENT OF RECEIPTS AND PAYMENTS FOR THE YEAR ENDED 30th JUNE, 1968

| RECEIPTS | $ | $ |
|---|---|---|
| *Opening Balance* 1st July, 1967 | | 707.96 |
| Subscriptions | 1,234.86 | |
| Government Grant | 3,700.00 | |
| Bank and Bond Interest | 65.27 | |
| Sundry Income (sale of shelves etc.) | 162.15 | 5,162.28 |
| | | 5,870.24 |

| PAYMENTS | $ | $ |
|---|---|---|
| *Deduct Payments* | | |
| Publishing Costs | 4,113.75 | |
| Cleaning Costs | 181.89 | |
| Postage | 126.88 | |
| Petty Cash | 230.00 | |
| Service Charges | 109.42 | |
| Sationery | 45.74 | |
| Insurance | 122.62 | |
| Sundries | 124.49 | 5,054.79 |
| *Closing Balance* 30th June, 1968 | | $815.45 |

## Library Account

### STATEMENT OF RECEIPTS AND PAYMENTS FOR THE YEAR ENDED 30th JUNE, 1968

| RECEIPTS | $ | $ |
|---|---|---|
| *Opening Balance* 1st July, 1967 | | 611.25 |
| Sale of Transactions | 2,176.19 | |
| Bank Interest | 16.21 | 2,192.40 |
| | | 2,803.65 |

| PAYMENTS | $ | $ |
|---|---|---|
| *Deduct Payments* | | |
| Postage | 20.00 | |
| Wages | 937.75 | |
| Printing | 24.75 | |
| Binding | 170.00 | |
| Insurance | 6.66 | |
| Sundries | 13.50 | 1,172.66 |
| *Closing Balance* 30th June, 1968 | | $1,630.99 |

# THE ROYAL SOCIETY OF SOUTH AUSTRALIA INCORPORATED

## Endowment and Scientific Research Fund

### STATEMENT OF RECEIPTS AND PAYMENTS FOR THE YEAR ENDED 30th JUNE, 1968

**RECEIPTS**

| | $ | $ |
|---|---|---|
| *Opening Balance* 1st July, 1967 | | 834.17 |
| *Add Receipts* | | |
| Interest and Dividends Received | 1,155.23 | |
| Bank Interest | 27.63 | |
| Redemption G.M.A.C. Debentures | 1,000.00 | |
| Sale of 300 B.H.P. Shares | 3,644.12 | |
| | | 5,826.98 |
| | | 6,661.15 |

**PAYMENTS**

| | $ | $ |
|---|---|---|
| *Deduct Payments* | | |
| Purchase of Investments:— | | |
| 583 Softwood Holdings Ords. | 1,151.85 | |
| 400 Softwood Holdings Prefs. | 800.00 | |
| 700 Lensworth Finance Ords. | 1,058.92 | |
| 500 I.C.I. Ords | 1,063.00 | |
| 2,000 F.N.C.B. Waltons Debs. | 2,000.00 | |
| | | 6,073.77 |
| *Closing Balance* 30th June, 1968 | | $587.38 |

### SCHEDULE OF INVESTMENTS AT 30th JUNE, 1968 (at(cost)

| | $ | $ |
|---|---|---|
| *Fixed Deposits* | | |
| Lensworth Finance—8% | 4,000.00 | |
| G.M.A.C.—7½% | 2,000.00 | |
| F.C.A.—7¾% | 2,000.00 | |
| E.I.L.—8% | 900.00 | |
| F.N.C.B. Waltons—7¾% | 2,000.00 | |
| | | 10,900.00 |
| *Equity Stock* | | |
| Woolworths—900 | 1,290.00 | |
| 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—250 | 1,330.00 | |
| I.C.I.—500 | 1,063.00 | |
| Lensworth—700 | 1,058.92 | |
| Softwood Holdings—Prefs.—400 | 800.00 | |
| Softwood Holdings—Ords.—583 | 1,151.85 | |
| | | 11,745.77 |
| Inscribed Stock | | 300.00 |
| Cash at Bank | | 587.38 |
| | | $23,533.15 |
| *Note:* Market Value of Equity Stock 30th June, 1968 | | $14,347.00 |

### 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, 1968 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, 1968 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, 1968.

Adelaide, South Australia,
6th of September, 1968.

MILNE, STEVENS, SEARCY & CO.,
Chartered Accountants

# REPORT ON ACTIVITIES OF THE COUNCIL, 1967-68

## Summary

# REPORT ON ACTIVITIES OF THE COUNCIL, 1967-68

*Meetings*

The usual eight ordinary meetings were held in the Society's rooms during the past year at which the attendance averaged 32. One special meeting was held on December 7th to ratify the new Rules and By-laws.

A total of 12 papers were read devoted to the following disciplines:— Zoology 8, Botany 3, Geology 1. Lectures were given at each meeting and two exhibits presented.

*Membership*

Twenty-two new members were elected during the year and nine resignations were received. The membership now stands at 266, the highest number in the history of the Society.

The Council records with great regret the death of Fellows: Emeritus Professor T. D. Campbell, a past president of the Society; Sir Tom Barr Smith and Mr. J. K. Powrie.

*Rules and By-laws*

During the year the new set of Rules and By-laws approved at the December 1967 meetings was issued to all members. One amendment has since been passed at the meeting of September 12th, 1968. Rule VI (2) now reads:—

> The nomination form shall be lodged with the secretary and shall be submitted to the Council at its next meeting. Upon approval by the Council the nomination shall be submitted to the next meeting of the Society and an election shall be held at the next meeting of the Society thereafter.

*Sub-Committees of Council*

The business of Council has been facilitated by the work of four sub-committees:—

- Library Committee—management of the Library
- Publications Committee—production and maintenance of standards in the Transactions and any other publications of the Society
- Awards Committee—nominations to the Council of names of members proposed for awards by the Society and other bodies
- Research and Endowment Fund Committee—management of investment funds.

*Library*

The library has operated efficiently and profitably during the year, the Library Account having a credit balance of $1630 as at June 30th 1968. The Council wishes to express their grateful thanks to the Assistants, Mrs. Dunlop and Mrs. Dougal for the services they have rendered to the Society both in the library and in assisting the Treasurer.

Rechecking of the bookstock has resulted in 200 new entries being forwarded to the C.S.I.R.O. Index.

Fifty volumes have been bound and another 160 prepared for binding.

The exchange list has been completely reviewed and adjustments made where necessary. Some 340 journals are now received on exchange from 46 countries, 10 new exchanges were negotiated during the year. In addition 37 continuing subscriptions are now in operation.

Altogether 245 volumes were borrowed during the year, mainly on inter-library loan within the state, interstate and with New Zealand.

Author and subject indexes for volumes 45 to 91 have been prepared for publication.

*Publications*

Vol. 91 of the Society's Transactions was published in December 1967. It contained 204 pages compared with 191 pages in Vol. 90. The cost of printing seems to rise steadily each year but it has been possible so far to include all papers received before the June Council meeting which is normally taken as the final date for acceptance of material for the current volume.

*Research and Endowment Fund*

As a result of moves which were initiated two years ago, to improve the management of the fund, its finances are now on a reasonably sound basis. Accordingly this year it was found possible to make available some of the income, in the form of grants, to aid scientific research. Two grants for the calendar year 1968 were made. Dr. C. R. Twidale was awarded a grant to study the geomorphology of the Arcoona Plateau, and Mr. I. M. Thomas and Mr. S. Shepherd on behalf of a group of workers will receive a sum of money to finance an expedition to Pearson Islands to study the flora and fauna of the islands and adjacent waters.

*Verco Medal*

The Council awarded the Verco Medal for the year 1968 to Mr. R. C. Sprigg.

# OFFICERS FOR 1967-68

## Summary

# ROYAL SOCIETY OF SOUTH AUSTRALIA

INCORPORATED

*Patron:*

HIS EXCELLENCY LIEUTENANT GENERAL SIR EDRIC M. BASTYAN, K.C.M.G., K.B.E., C.B.

## COUNCIL FOR 1967-68

*President:*

K. R. MILES, D.Sc., F.G.S.

*Vice-Presidents:*

H. B. S. WOMERSLEY, D.Sc.

F. J. MITCHELL

*Secretary:*

W. K. HARRIS, B.Sc.

*Treasurer:*

S. A. SHEPHERD, B.A., LL.B.

*Editor:*

J. K. TAYLOR, B.A., M.Sc., B.Sc.Agr.

*Assistant Editor:*

I. M. THOMAS, M.Sc., M.I.Biol.

*Librarian:*

N. H. LUDBROOK, M.A., Ph.D., D.I.C., F.G.S.

*Programme Secretary:*

D. E. SYMON, B.Ag.Sc.

*Members of Council:*

J. A. PRESCOTT, C.B.E., D.Sc., F.R.S., F.A.A., F.R.A.C.I.

J. T. HUTTON, B.Sc., A.S.A.S.M.

K. E. LEE, D.Sc.

M. J. TYLER

C. B. WELL, M.Ag.Sc.

H. E. WOPFNER, Ph.D.

*Auditors:*

Messrs. MILNE, STEVENS, SEARCY & CO.

# LIST OF MEMBERS

## Summary

# ROYAL SOCIETY OF SOUTH AUSTRALIA

## LIST OF NEW MEMBERS

1968. ADAM, J. R., B.E., A.M.Aust.I.M.M., Dept. of Mines, Box 38 P.O., Rundle Street, Adelaide, S.A.
1968. ANCOVE, P. C., R.D.A., M.A.I.A.S., Dept. of Agriculture, Gawler Place, Adelaide, S.A.
1968. VON BEHRENS, D., Naracoorte High School, Naracoorte, S.A.
1968. BLISSETT, A. H., M.Sc., A.M.Aust.I.M.M., F.G.S., Dept. of Mines, Box 38 P.O., Rundle Street, Adelaide, S.A.
1968. BOEHMER, Miss S., B.A. (Mus.), Dip. S.T., Bedford Park Teachers College, Bedford Park, S.A.
1968. CARRICK, R., Ph.D., Mawson Inst. for Antarctic Research, University of Adelaide.
1968. DAVY, R., B.Sc. (Hons.) Ph.D., L.R.I.C., F.G.S., C/o A.M.D.E.L., Conyngham Street, Frewville, S.A.
1968. DYKE, N. W., A.C.A.A., Mem. Inst. Inst. & Coni.. Aust., Seaton, S.A.
1968. ERNST, L. K., 50 Airdrie Avenue, Findon, S.A.
1968. FAIRBURN, W., B.Sc. (Hons.) A.M.I.M.M., F.G.S., Dept. of Mines, Box 38 P.O., Rundle Street, Adelaide, S.A.
1968. HENNINGSEN, M., B.E., F.S.A.S.M., A.M.I.E., Aust., A.M.Aust.I.M.M., Dept. of Mines, Box 38 P.O., Rundle Street, Adelaide, S.A.
1968. HIERN, M. N., B.Sc., Dept. of Mines, Box 38 P.O., Rundle Street, Adelaide, S.A.
1968. HUTCHISON, A. R., 218 Shepherds Hill Road, Bellevue Heights, S.A.
1968. JENKINS, R. J. F., B.Sc. (Hons.), Dept. of Geology, University of Adelaide.
1968. KENNEDY, Miss G. R., B.Sc., Ph.D., Flinders University, Sturt Road, Bedford Park, S.A.
1968. McGOWAN, B., B.Sc., (Hons.), Ph.D., Dept. of Mines, Box 38 P.O., Rundle Street, Adelaide, S.A.
1968. MILLER, P. G., B.Sc., (Hons.), A.M.Aust.I.M.M., Dept. of Mines, Box 38 P.O., Rundle Street, Adelaide, S.A.
1968. MOORCROFT, E., B.Sc., Dept. of Mines, Box 38 P.O., Rundle Street, Adelaide, S.A.
1968. MOULDS, M. S., F.R.E.S., 14 Chisholm Street, Greenwich, N.S.W. 2065.
1968. OLSEN, A. M., M.Sc., Dept. of Fisheries and Fauna Conservation, Adelaide, S.A.
1968. WILSON, R. B., B.Sc., (Hons.), 22 Chetwynd Street, West Beach, S.A.
1968. WOLLASTON, Miss E. M., Ph.D., Botany Dept., University of Adelaide.

# LIST OF LECTURES AND EXHIBITS, 1967-68 AND AWARDS OF THE SIR JOSEPH VERCO MEDAL

**Summary**

# LIST OF LECTURES GIVEN AT MEETINGS DURING THE YEAR 1967-68

| | | |
|---|---|---|
| Sept., | 1967 | Dr. H. B. S. Womersley: "Aspects of Coral Reef Biology". |
| Oct., | 1967 | Mr. C. A. Martin: "Moomba, a South Australian Gas Field". |
| Nov., | 1967 | Mr. T. R. N. Lothian: "The work of the National Parks Commission of South Australia". |
| April, | 1968 | Mr. D. R. Currie: "The Industrial future of South Australia". |
| May, | 1968 | Prof. C. M. Donald: "Rural development in the Northern Territory". |
| June, | 1968 | Prof. R. W. R. Rutland: "A structural view of Continental Drift". |
| July, | 1968 | Mr. R. C. Sprigg: "The Role of Research in Industry". |
| Aug., | 1968 | Prof. J. R. M. Radok: "Waves and tides of the South Australian Coast". |

### Exhibits

Dr. B. G. Forbes: Some recent maps issued by the Geological Survey of South Australia.

Mr. M. J. Tyler: Relationships between musculature and vocal sac structure in frogs.

# AWARD 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. |
| 1968 | R. C. Sprigg, M.Sc. |

For stimulating and versatile contributions to the geology of South Australia in the fields of sedimentation, stratigraphy, structural geology, and regional mapping. Significant in these are the discovery and description of the Ediacara medusoid fauna in the Pound Quartzite, formerly considered to be Early Cambrian but now regarded as of Precambrian age; initiation of a systematic study of the Adelaide System and sedimentation in the Adelaide Geosyncline; description of coastline migrations and geochronology of the Quaternary of the South-East Province and of submarine canyons off the South Australian coasts; direction of renewed interest in structures in the northeast of South Australia, thus encouraging petroleum exploration in the area in which gasfields were subsequently discovered. Mr. Sprigg is the author of some 62 scientific papers, 12 of which have been published in the Transactions.

## CONTENTS