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BY ELISE M. WOLLASTON

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by ELISE M. WOLLASTON*

Summary

WOLLASTON, E. M. (1978) Two new species of *Platythamnion* J. Agardh (Ceramiaceae, Rhodophyta) from eastern and southern Australia. *Trans. R. Soc. S. Aust.* **102**(1), 1-7, 28 February, 1978.

Two new species, *Platythamnion cuspidatum* and *P. francisianum*, are described from eastern and southern coasts of Australia. Both are small, uncorticated plants characteristic of the genus *Platythamnion* J. Agardh, with whorls of 4 (2 long and 2 short) adaxially branched whorl-branchlets on each axial cell of the thallus.

Introduction

J. Agardh (1892) first described the genus *Platythamnion* based mainly upon *Callithamnion heteromorphum* J.Ag. (type locality, Santa Cruz, California). Since that time further species have been recorded from the west coast of North America (Kylin 1925, Wollaston 1972), Japan (Inagaki 1935, Tokida & Inaba 1950), New Zealand (Adams *et al.* 1974) and one, *P. nodiferum* (J.Ag) Wollaston from southern Australia (Wollaston 1968). *P. nodiferum* which occurs commonly on coasts of southern Australia is a large plant (to 20 cm high) with axes densely corticated in the lower parts with rhizoidal filaments.

Platythamnion cuspidatum sp. nov. and *P. francisianum* sp. nov. represent the first records from Australia of uncorticated species of *Platythamnion* J.Ag. similar in habit to those occurring on the Pacific coast of North America and in Japan.

In all previously described species of *Platythamnion* the position, form and development of carpogonial branches and carposporophyte are markedly similar, and are typical of the tribe Antithamnieae. Hence segregation of taxa within the tribe is based primarily upon vegetative features and, on this basis, species of *Platythamnion* form a well-defined generic group (Wollaston 1972).

Recently liquid preserved material of the two species described below has become available for study and although stages of carposporophyte development are lacking, the plants are readily recognized as species of *Platythamnion* and described on the basis of vegetative and tetrasporangial features. All measurements quoted are taken within the gelatinous sheath which covers the thallus. Terminology follows Wollaston (1968). Type specimens have been deposited in the Herbarium of the Department of Botany, University of Adelaide (ADU).

Identification of the genus

Sexual reproduction in *Platythamnion* has been described in detail by Wollaston (1968, 1972). However, tetrasporangial features are less consistent, and position of tetrasporangia of inner cells of whorl-branchlets has been used with vegetative features to distinguish species of the genus (Wollaston 1972).

The genus is most readily recognized by the form and arrangement of whorl-branchlets which occur in whorls of 4 [2 opposite long (major) whorl-branchlets at right angles to 2 opposite shorter (minor) whorl-branchlets] from each axial cell, and the pattern of development at growing branch apices.

Major whorl-branchlets are typically oppositely or adaxially branched from a distinct rachis and are arranged distichously on branch axes so that thallus branches appear to be flattened laterally (Figs 15, 18). In some species, two branches occur side by side from inner cells of whorl-branchlet rachides (Fig.

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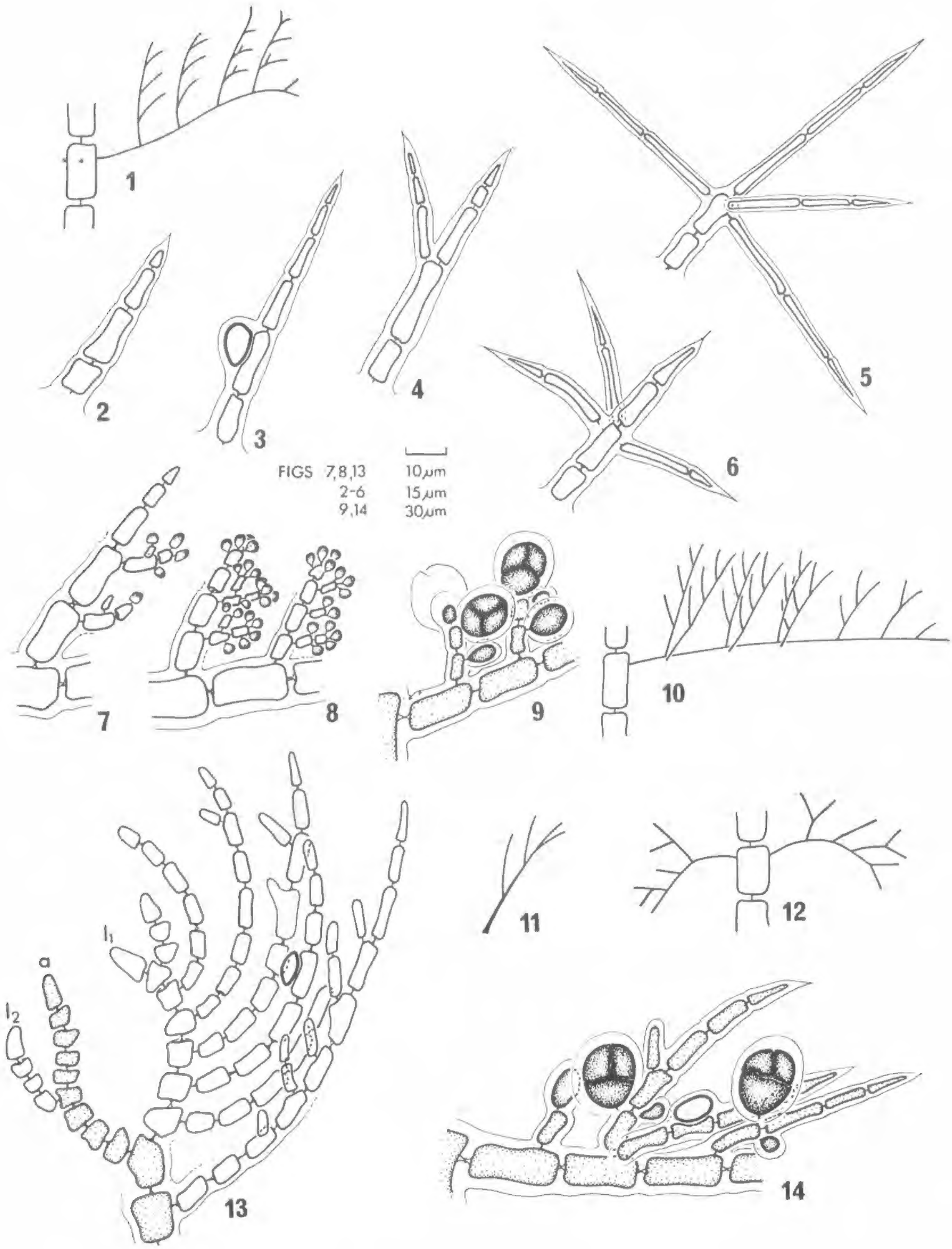
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FIGS 7,8,13 10 µm
2-6 15 µm
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10). The arrangement of these branches and of further branches developed from them, form the basis of species segregation.

Minor whorl-branchlets are never as conspicuous nor as regularly branched as major whorl-branchlets and in Australian species (including *P. nodiferum*) are unbranched or with 1–several short branches arising from a short rachis (Figs 2–6, 11). Wollaston (1972) described an enlarged rounded basal cell bearing usually three short branches for four of the five Pacific North American species. Towards the base of the plant, whorl-branchlets may become more densely branched or are sometimes reduced in length and branching. Thus the form of whorl-branchlets in the lower thallus may help in species identification.

Lateral thallus branches are formed in place of whorl-branchlets in distichous, alternate sequence at intervals of several (usually 4–10) axial cells, and near branch apices they contribute to the distinctive pattern of axial development. Young lateral branches develop rapidly and grow up to overtop the axial apex which is deflected away from the young lateral (Figs 13, 19). Whorl-branchlets elongate much more slowly and are often suppressed in development along the inner side of an axis lying closely adjacent to another branch (Fig. 13). Thus during early development whorl-branchlets are often small or completely lacking from the inner side of young lateral branches and from primary axes themselves. Deflection of branch axes away from lateral branches during development often produces a pseudodichotomous pattern of thallus branching throughout the plant (Fig. 15).

Gland cells are developed laterally on cells of the rachis or branches of whorl-branchlets (Figs 3, 14) and are scattered, sometimes abundantly, over the thallus.

Key to Australian species of *Platythamnion*

1. Plant large, to 20 cm high, lower axes densely corticated with rhizoidal filaments *P. nodiferum* (J.Ag.) Woll.
1. Plant small, to 2 cm high, completely lacking rhizoidal cortication 2
    2. Major whorl-branchlets adaxially branched with a single row of branches which are themselves branched from the outer side. Minor whorl-branchlets with spine-like branches. *P. cuspidatum* sp. nov.
    2. Major whorl-branchlets adaxially branched with branches which usually occur in pairs from inner rachis cells and are themselves branched from the inner side. Minor whorl-branchlets simple or with 1 to several short branches. *P. francisianum* sp. nov.

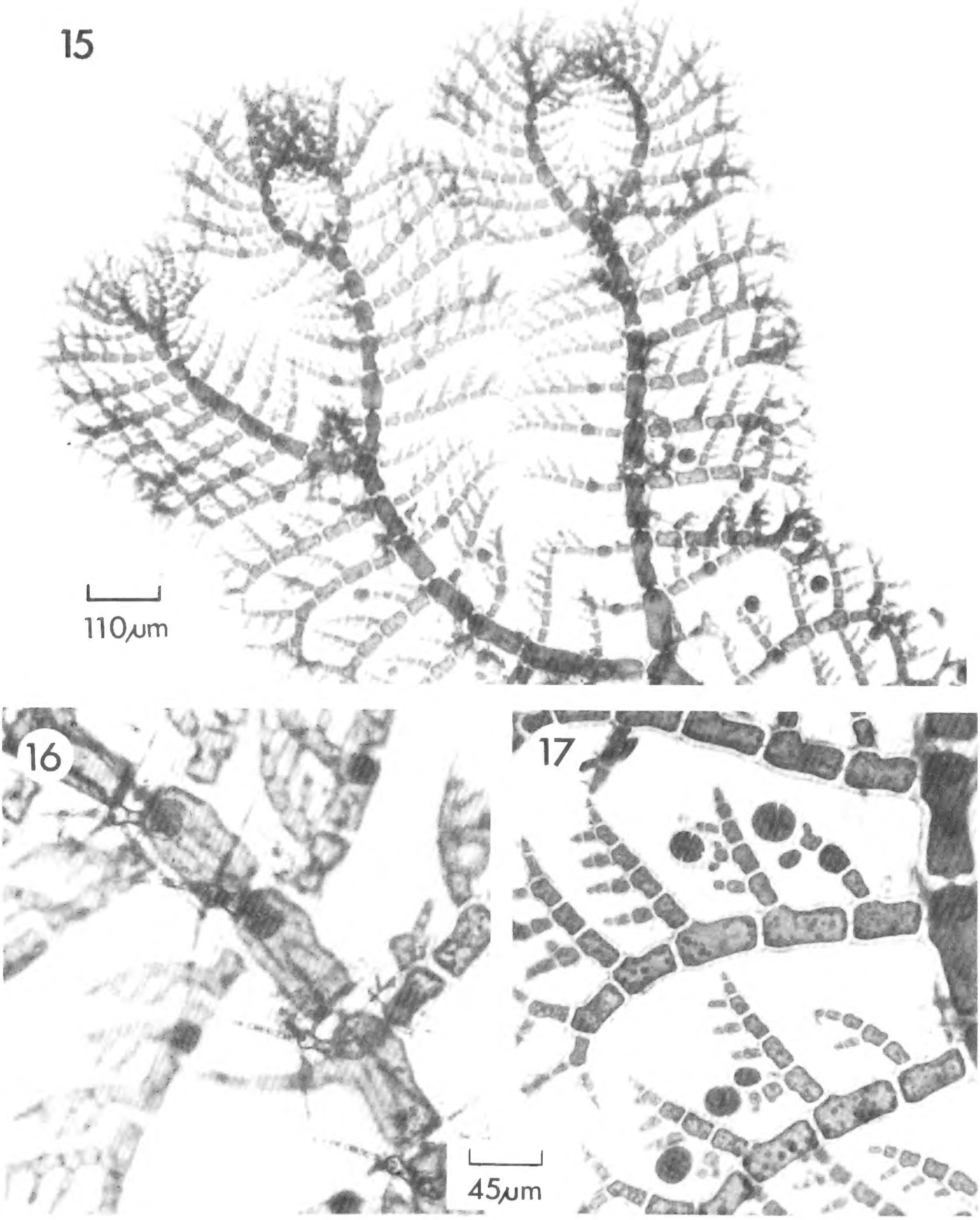
Platythamnion cuspidatum sp. nov.

(FIGS 1–9, 15–17)

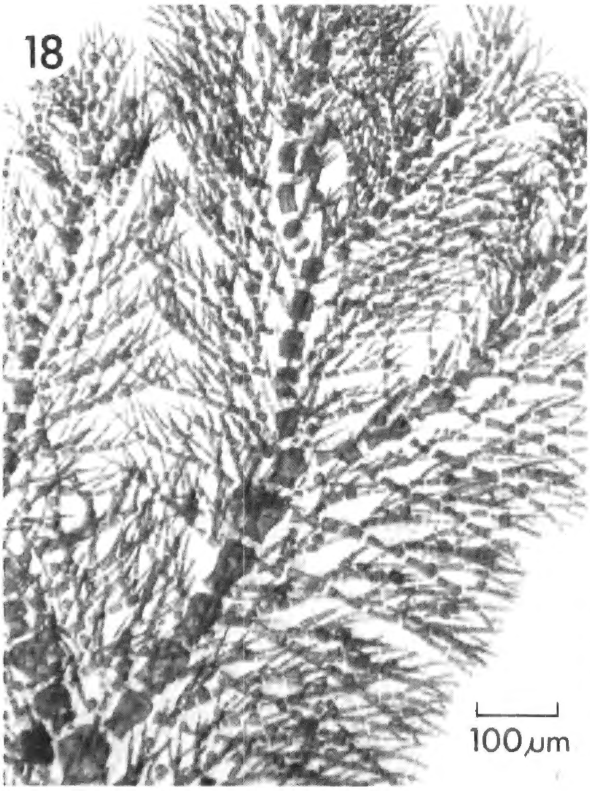
Thallus 1(–2) cm high consisting of branched axes without rhizoidal cortication; each axial cell bearing 2 opposite long (major) whorl-branchlets at right angles to 2 opposite short (minor) whorl-branchlets. Major whorl-branchlets to 250 μm long, branched from the adaxial side of rachis with abruptly tapered acute branches, to 100 μm long, which often bear further short branches from the outer side; minor whorl-branchlets simple or branched, to 130 μm long, often with 3(–4) tapering, acute spine-like branches. Gland cells lateral on cells of whorl-branchlets. Carposporophytes terminal on branches. Spermatangia forming dense clusters on cells of whorl-branchlet branches. Tetrasporangia on cells of whorl-branchlet branches, sessile, spherical, to 30 μm diameter, cruciately-divided but often appearing tetrahedral.

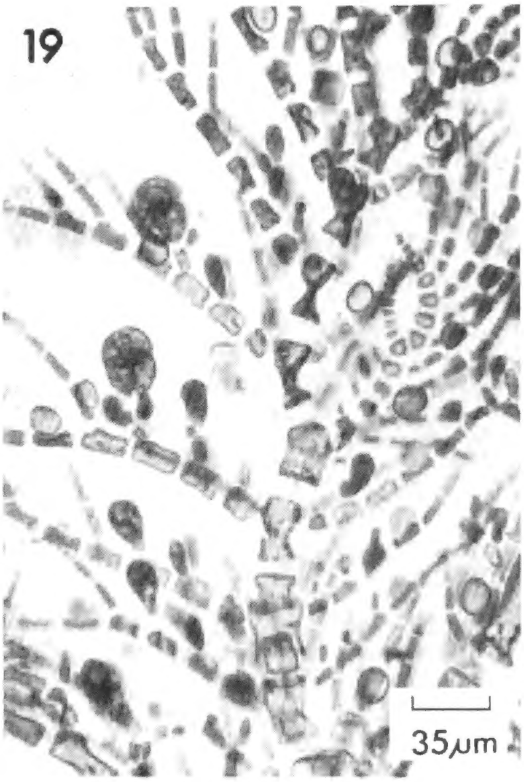
Thallus ad 2 cm altus; axes sine corticatione rhizoideorum. Omnis cellula axialis ferens 2 ramulos verticillorum maiores oppositos et 2 ramulos verticillorum minores oppositos ad angulum 90° patentes. Ramuli verticillorum maiores ad 250 μm longi, in latere adaxiali

Figs 1–9. *Platythamnion cuspidatum.*
Fig. 1. Form of major whorl-branchlet (diagrammatic).
Figs 2–6. Forms of minor whorl-branchlets, with spine-like processes shown in figures 5 and 6 and presence of a gland-cell in figure 3.
Fig. 7. Spermatangia developing on cells of whorl-branchlet branches.
Fig. 8. Spermatangial clusters on whorl-branchlet branches.
Fig. 9. Tetrasporangia on cells of whorl-branchlet branches.
Figs 10–14. *Playthamnion francisianum.*
Fig. 10. Form of major whorl-branchlet (diagrammatic).
Fig. 11. Form of minor whorl-branchlet bearing short branches (diagrammatic).
Fig. 12. Form of whorl-branchlets towards base of thallus (diagrammatic).
Fig. 13. Development of branch apex showing branch axis (a) with lateral branches l_1 and l_2, and whorl-branchlets developing only from abaxial side of l_1.
Fig. 14. Tetrasporangia developed on cells of whorl-branchlet branches; a pair of branches one of which bears a gland cell, is shown on the second cell of the rachis.



Figs 15-17. *Platythamnion cuspidatum.*
Fig. 15. Portion of laterally flattened thallus showing whorl-branchlet form and pseudodichotomous branching of axes.
Fig. 16. Spine-like branches of minor whorl-branchlets.
Fig. 17. Tetrasporangia on branches of major whorl-branchlets.





Figs 18–19. *Platythamnion francisianum.*
Fig. 18. Portion of a laterally flattened thallus showing whorl-branchlet form.
Fig. 19. Tetrasporangia on whorl-branchlet branches (left), and early stage in development of lateral branch (right).

rachidi, ramulis secundariis peracutis ramosi, ad 100 μm longi, gerentibus plures ramulos breves externe; minores ramuli verticillorum simplices vel ramosi ad 130 μm longi, saepe 3(–4) ramulos gradatim acutos spinulosis gerentes. Cellulae glandulosae in lateribus ramulorum verticillorum. Carposporophyti in ramulis terminalia. Spermatangia botryoidea in cellulis ramulorum verticillorum orta. Tetrasporangia sessilia, globosa, ad 30 μm diam., cruciatim sed in facie saepe tetraedrice in cellulis ramulorum verticillorum portata.

The species is named for the spine-like branches developed on minor whorl-branchlets.

Type locality: Port Kembla, N.S.W., about 20 m deep (*J. Watson*, 16.ix.1976).

Holotype: ADU, A47994.

Distribution: Known from the type locality and from Gabo I., Victoria (*Shepherd*, 19.ii.1973). Growing on the mussel *Trichoma hirsuta*, on hydrozoans and on other algae.

Platythamnion cuspidatum is distinguished by the branching pattern of the whorl-branchlets. Major whorl-branchlets are branched adaxially from cells of the rachis with branches which taper abruptly to an acute point and which bear further short branches from their outer side (Figs 1, 15). Major whorl-branchlets are widely spaced and seldom extend to adjacent whorl-branchlets above. Where a lateral branch is formed in place of a major whorl-branchlet, the opposite major whorl-branchlet often remains short and unbranched. Minor whorl-branchlets may be unbranched or with 1–several simple branches (Figs 2–4), but are frequently distinctive in bearing 3(–4) narrow, tapered, acute spine-like branches which develop from the upper end of a short 2-celled axis (Figs 5–6, 16); occasionally this branch axis is extended and may bear further "spines", or may itself become spine-like. Axial growth occurs as typical for the genus and mature axial cells have an average length to breadth proportion of 5:2, up to 150 μm long and 60 μm broad in central parts of thallus, but are usually shorter in proportion to length at the base of the plant.

Rounded groups of carposporangia occur near branch apices; however, stages of carposporophyte development have not been available for study.

Spermatangia are borne from the upper part of cells of whorl-branchlet branches which arise from inner and central cells of whorl-branchlet rachides. A single spermatangium develops first followed by further spermatangial cells (Fig. 7), so that up to four mature spermatangia may be present on a single cell at one time. Dense spermatangial clusters are thus formed (Fig. 8).

Tetrasporangia are also formed from the upper end of cells of whorl-branchlet branches, but are confined to inner branches which are sometimes only 2–several cells long (Figs 9, 17).

Platythamnion cuspidatum is apparently tolerant of polluted water and very low light conditions. At Port Kembla, N.S.W., it occurs on depauperate reefs subject to regular inundations of iron-rich floc $[Fe(OH)_3]$ with consequent low light intensity (J. Watson, pers. comm.).

Platythamnion francisianum sp. nov.

(FIGS 10–14, 18–19)

Thallus to 1 cm high consisting of branched axes without rhizoidal cortication; each axial cell bearing 2 opposite long (major) whorl-branchlets at right angles to 2 opposite short (minor) whorl-branchlets. Major whorl-branchlets to 500 μm long, branched from the adaxial side of the rachis with branches to 200 μm long which usually occur in pairs from inner cells of the rachis and often overlap the adjacent whorl-branchlet above. These branches themselves bear further narrow, tapering branches from the inner side. Minor whorl-branchlets to 175(–200) μm long, simple or branched with 1–several simple branches. Gland cells lateral on cells of whorl-branchlets. Procarp, carposporophyte and spermatangia unknown. Tetrasporangia on cells of whorl-branchlet branches, sessile, subspherical, to 36 μm in diameter, cruciately-divided but often appearing tetrahedral.

Thallus ad 1 cm altus; axes ramosi sine corticatione rhizoideorum; omnis cellula axialis ferens 2 ramulos verticillorum maiores oppositos et 2 ramulos verticillorum minores ad angulum 90° patentes. Ramuli verticillorum maiores ad 500 μm longi in latere adaxiali rachidi ramulos secundarios ferentes ad 200 μm longos saepe binatim ex interioribus cellulis rachidis et saepe super ramulum verticillorum contiguum superum superpositos. Ramuli secundarii plures ramulos gradatim decrescentes ferunt. Ramuli verticillorum minores ad 175(–200) μm longi simplices vel ramosi cum uno aliquotue simplicibus ramulis. Cellulae glandulosae in lateribus ramulorum verticillorum. Procarpium et carposporophytum et spermatangia ignota. Tetrasporangia sessilia, subglobosa, ad 36 μm diam., cruciatim sed in facie saepe tetraedrice in cellulis ramulorum verticillorum portata.

The species is named for the type locality.

Type locality: St Francis I., Isles of St Francis, S. Aust., S-W face, 55 m deep (*Shepherd*, 9.i.1971).

Holotype: ADU, A38087.

Distribution: Known only from the type locality, growing on *Ballia mariana* Harvey.

Platythamnion francisianum is distinguished by the form of its whorl-branchlets. Major whorl-branchlets are branched adaxially from cells of the rachides with branches which often occur in pairs on each inner rachis cell (Figs 10, 14); these branches are further branched from the inner side, but sometimes appear as if subdichotomously branched (Fig. 10). Mature whorl-branchlet branches are narrow and gradually tapered to an acute point (Fig. 18). Towards the base of the plant whorl-branchlets are shorter (–200 μm long) and more densely branched than those above (Fig. 12). Minor whorl-branchlets are simple or with 1–several short branches (Fig. 11).

Axial growth occurs as typical for the genus and axial apices are overtopped by developing lateral branches and whorl-branchlets (Figs 13, 19). Mature axial cells have an average length to breadth proportion of 3:2 (up to 200 μm long and 130 μm broad) in central parts of the thallus, but are often somewhat longer in proportion to breadth at the base of the plant.

Tetrasporangia are borne from lower cells of inner and central branches of whorl-branchlets, but are often lacking or less numerous on branches borne on the basal cells of rachides (Figs 14, 19).

Although this species is known only from a single collection it appears to be clearly distinct. Further details of reproduction and variation in form await future collections.

Acknowledgments

I am grateful to Mr S. A. Shepherd for Latin diagnoses and to others who have contributed to this study, and particularly for technical assistance provided through a grant from the Australian Research Grants Committee.

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NEMATODE PARASITES OF THE KANGAROO ISLAND WALLABY, MACROPUS EUGENII (DESMAREST)

1. SEASONAL AND GEOGRAPHICAL DISTRIBUTION

BY LESLEY R. SMALES & PATRICIA M. MAWSON

Summary

The helminths of Macropus eugenii in Kangaroo I. have been identified at least to genus. Comparison of genus collected in one four-day period from four areas, differing geographically and ecologically, show differences in their occurrence.

NEMATODE PARASITES OF THE KANGAROO ISLAND WALLABY, *MACROPUS EUGENII* (DESMAREST)

I. SEASONAL AND GEOGRAPHICAL DISTRIBUTION

by LESLEY R. SMALES* & PATRICIA M. MAWSON*

Summary

SMALES, L. R. & MAWSON, P. M. (1978) Nematode parasites of the Kangaroo Island Wallaby, *Macropus eugenii* (Desmarest), I. Seasonal and geographical distribution. *Trans. R. Soc. S. Aust.* **102**(1), 9-15, 28 February, 1978.

The helminths of *Macropus eugenii* in Kangaroo I. have been identified at least to genus. Comparison of species collected in one four-day period from four areas, differing geographically and ecologically, show differences in their occurrence.

The incidence of strongyle nematodes in the stomach and of their eggs in the faeces, checked at 2-monthly intervals over two years, shows seasonal variation both of total numbers and of the constituent species, and this is linked with climatic conditions suitable for reinfestation with the worms.

Introduction

A systematic survey of the helminths of the Kangaroo Island Wallaby *Macropus eugenii* (Desmarest) was undertaken preliminary to work (Smales 1976[1]) on the life history of the stomach strongyle, *Labiostrongylus eugenii* (Johnston & Mawson, 1940a).

The wallaby is one of the smallest macropods. Its distribution is now limited to small populations on the mainland of south-western Australia and to some off-shore islands, the largest of which is Kangaroo Island. The hosts for this study were taken from Kangaroo Island, where they are still present in large numbers.

The climate of Kangaroo Island is the Mediterranean type, with most rain falling in winter. The mean monthly maximum and minimum temperatures and monthly rainfall recorded at Kingscote (April 1972–August 1972) or at Parndana (September 1972–later) were obtained from the Adelaide Bureau of Meteorology (Fig. 1). There appears to have been little, if any, variation, in the temperature for each month over these four years, though there is some variation in rainfall—the September fall being low in 1972, the July fall high in 1974. The general pattern of winter rain and summer dryness was maintained throughout the four year period.

The vegetation of Kangaroo Island varies from wet sclerophyll forest to open grassland with scrub, the preferred habitat of the wallaby being dry sclerophyll forest with dense undershrubs. This species appears to be specialised for life under conditions of much less rainfall than would support the rainforest or wet sclerophyll forest where other wallaby species are found (Ride 1970).

The wallabies were collected from one or more of four farm properties, each in a different part of the island, and with different plant associations. At Brookland Park, on the central plateau, with a rainfall of 831 mm a year, a mallee form of *Eucalyptus remota* is dominant. Around Pioneer Bend, also on the central plateau, with 559-584 mm of rain a year, *E. obliqua* and *E. cosmophylla* are the dominants. At Cape Cassini on the northern marginal slopes of the plateau, 559-584 mm of rain, *E. cneorifolia* is the dominant, associated with *Melaleuca uncinata*. An association of *E. diversifolia* and *E. rugosa*, with *E. diversifolia* in different forms of mallee ranging from low

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[1] Smales, L. R. (1976) A study of the biology of a nematode *Labiostrongylus eugenii* (Johnston & Mawson) parasitic in the stomach of the tammar wallaby (*Macropus eugenii* (Desmarest)). Ph.D. Thesis, University of Adelaide (unpublished).

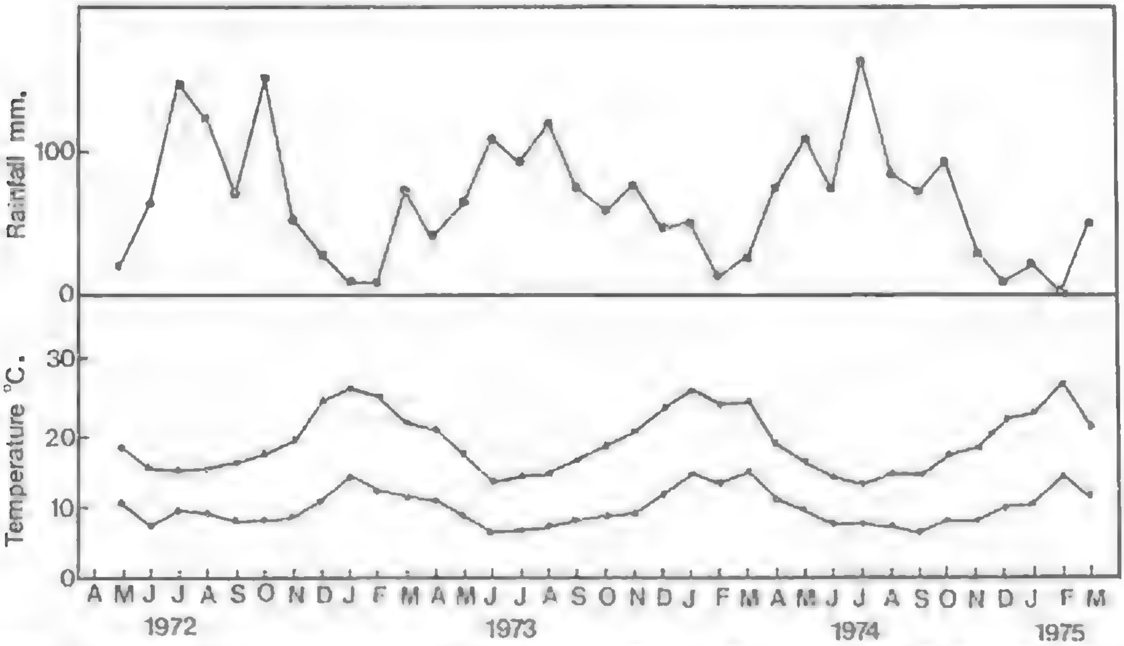

Fig. 1. Maximum and minimum average temperature and rainfall for 1972-1975, Kangaroo Island. From September 1972 taken at Parndana, previously at Kingscote.

tangled shrubs to trees 7.6 m high, is found at Nepean Bay in the Nepean Embayment lowland plain, where there is only 483-508 mm of rain. The species of undershrubs found with each plant association vary and are controlled for the most part by edaphic rather than climatic factors[2].

Stands of virgin bush have been left on each of the farms and these are often sufficiently large to provide shelter for the wallabies, which require the protection of dense undershrubs through the day, and come out into the farm paddocks at night to feed. Farming procedures were similar on all properties except that the clover fields at Brookland Park and Pioneer Bend were sprayed in August–October of 1973 and 1974 to control Black Spot disease, *Kabatiella* sp., with Thibenzole (Merck, Sharp & Dohme). Before this no spray had been used.

At autopsy of each wallaby the stomach wall was checked for lesions, and a low 10% (by volume) sample of the stomach contents taken. This sample as well as the intestinal tract, liver, and thorax, were examined for helminths, which were collected and fixed in hot 10% alcohol or 4% formalin, and later identified and counted.

Geographical variation

In view of the varying rainfall and vegetation in different parts of Kangaroo Island, we sampled and compared the helminth fauna of animals from different areas at more or less the same date.

Animals were collected from each of the four areas described above on four consecutive nights in April 1975. Autumn was chosen because the heaviest infestations had previously been observed during autumn and winter. Up to 10 wallabies were shot in each area. Each animal was weighed, sexed, and its age determined from the tooth eruption pattern.[1]

No helminths were found in the bile ducts or liver. The species identified were: from the thoracic cavity, the nematode *Dipetalonema* sp.; from the intestine, the nematodes *Globocephaloides trifidospicularis* Kung 1948 and *Austrostrongylus thylogale* Johnston & Mawson 1940, and the cestodes *Triplotaenia* sp., and *Progamotaenia* spp. A & B; from the stomach, the nematodes *Cloacina* spp., *Labiostrongylus eugenii* (Johnston & Mawson, 1940a), *L. longispicularis* Wood 1929, *Macropostrongylus pearsoni* (Johnston & Mawson, 1940b), *Oesophagonastes kartana* (Mawson,

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[2] Bauer, F. H. (1959) The regional geography of Kangaroo Island South Australia. Ph.D. Thesis. Australian National University (unpublished).

TABLE 1
Helminths collected from *M. eugenii* on Kangaroo Island during April 1975

Number of wallabies	Nepean Bay 10		Cape Cassini 10		Pioneer Bend 8		Brookland Park 10	
	No. infected	Mean No. worms	No. infected	Mean No. worms	No. infected	Mean No. worms	No. infected	Mean No. worms
Progamotaenia sp. A	3	2	0	0	0	0	0	0
Progamotaenia sp. B	1	1	0	0	4	3.5	5	0
Triplotaenia sp.	0	0	2	2	1	1	0	0
Cloacina spp.	8	1105	10	231	8	571.3	10	797
L. eugenii	5	966	9	874.4	1	nodule only	0	0
L. longispicularis	0	0	4	82.5	1	40	3	616.7
R. australis	7	552.9	7	457.1	8	587.5	10	2272
M. pearsoni	5	98	5	124	7	61.4	8	72.5
O. kartana	2	10	2	20	3	463.3	6	36.7
Filarinema sp.	2	5.5	0	0	1	1	3	39.3
G. trifidospicularis	5	6	5	9.8	3	2	3	2.3
A. thylogale	10	720	10	720	9	720	2	2
Dipetalonema sp.	4	1	2	1	6	1	10	2.2

1955), *Rugopharynx australis* (Mönnig 1926) and *Filarinema* sp. The species of *Cloacina* were not considered separately as not all of them have yet been described; they include *C. curta* Johnston & Mawson, 1938, *C. petrogale* Johnston & Mawson, 1938, *C. clarkae* Mawson, 1972, *C. smalesae* Mawson 1975, and *C. kartana* Mawson 1975. The numbers of each species or species group from each locality are shown in Table 1.

Filarinema sp. and *Labiostrongylus longispicularis* both appear to be accidental infections as they occur much more commonly in the Grey Kangaroo (*Macropus fuliginosus*) (Desmarest) which grazes on the same pastures as the Kangaroo Island Wallaby. Other species which have been found in the Grey Kangaroo as well as in the wallaby are *Macropostrongylus pearsoni* (rarely), *Globocephaloides trifidospicularis* (not common) and *Rugopharynx australis* (very common in both host species). *Oesophagonastes kartana* is typically found in the oesophagus of the host, and is collected from the stomach only when the infestation is heavy. The oesophagus was not examined regularly, and *O. kartana* may have been present in some of the wallabies though not recorded from the stomach.

Examination of the stomach wall showed that nodules caused by third stage *L. eugenii* larvae[1] were present in all hosts with adult *L. eugenii* in the stomach. It will be noted that the most striking variations in distribution were in the cases of *L. eugenii*, *Dipetalonema* sp., and *A. thylogale*. The incidence of infection with *Cloacina* spp. was high from all four localities, but possibly the actual species within the species group varied.

The territorial behaviour and movement patterns of these wallabies have not been studied although occasional individuals have been recorded moving up to 16 km (Andrewartha & Barker 1969). However, those collected in the present study were probably from different populations, so the observed differences in helminth distribution between the sites represent real differences in the infestations on Kangaroo Island.

Each of the sampling sites had different vegetation and soil types. Rykovskii (1972) suggested a close relationship between these factors and the viability of larval stages of trichostrongyles. Together with the differences in rainfall they may have been important in determining the distribution of the helminths.

The low incidence of *L. eugenii* in hosts from Pioneer Bend and Brookland Park (noted also in other collections from the same area in 1975) is noteworthy because in 1972 and 1973 this species was plentiful there. As mentioned above, the only difference noted in the collection areas between these periods was the use of sprays on the pasture.

Seasonal variation

A survey was made of the total numbers and incidence of the different species of strongyles in the stomach of the wallaby throughout the year. It was hoped to find how the wet winter and hot dry summer affected the different species.

Male wallabies were taken at two monthly intervals from April 1972 to January 1974 from Pioneer Bend and Brookland Park, and subsequently from these and other areas. Until September 1972 our sample comprised four

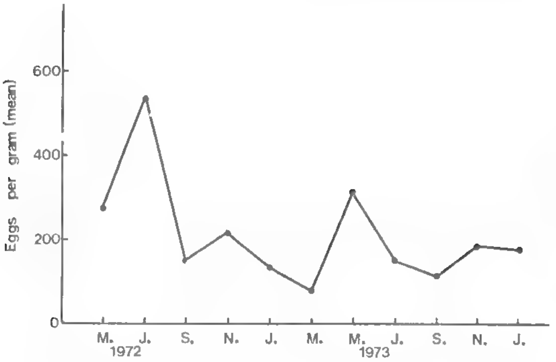

Fig. 2. Mean faecal egg counts: May 1972 to January 1974.

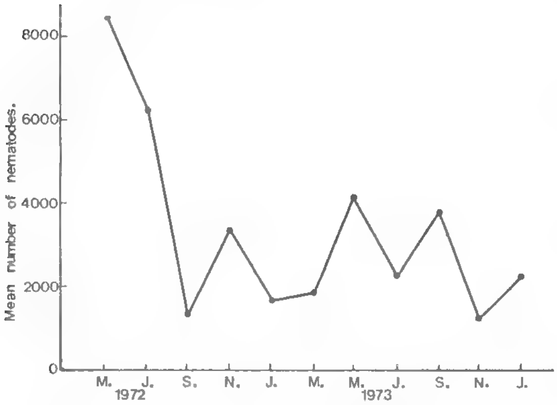

Fig. 3. Total worm burdens: May 1972-January 1974. The figure at each two monthly interval is mean obtained from 4-6 male wallabies.

TABLE 2

Occurrence (% of hosts infected) and relative abundance of nematode species collected from the stomach lumens of 99 wallabies between 1972 and 1975. Abundance expressed as % of largest total number—107527 *Cloacina* spp.

Species	Wallabies infected %	Relative abundance %
Cloacina spp.	98	100
L. eugenii	45	76.2
L. longispicularis	20	1.6
R. australis	84	31
M. pearsoni	34	6.5
O. kartana	43	2.5
Filarinema sp.	4	0.03

animals; subsequently 6 animals were taken. To compare seasonal differences, only the 64 animals from Pioneer Bend and Brookland Park were used. To compare relative abundance of the different spp., 99 hosts from all localities were used.

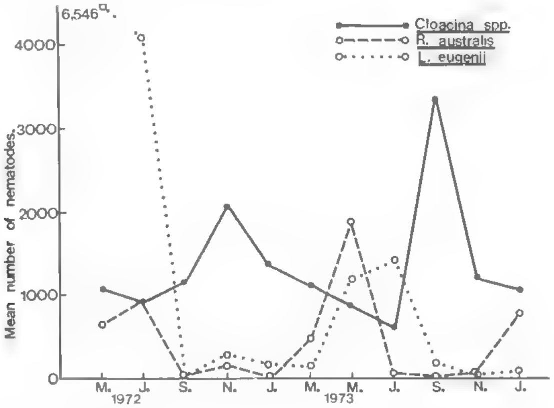

Fig. 4. Mean bi-monthly occurrence of three groups of nematodes, May 1972-January 1974.

At each autopsy a faecal sample was taken and the eggs per gram counted, using a modified Whitlock counting chamber. Faecal egg counts (Fig. 2) show peaks of egg production in May and November of 1972 and 1973, and in March and November 1974. These peaks indicate times when the potential number of infective larvae on the pasture was high.

The stomach of each wallaby was removed and the contents sieved through bolting silk ("64 mesh/inch"), diluting the retained solid material to an appropriate volume (200 or 400 ml), and sampling using Clark et al.'s (1971) method of enabling calculation of worm totals to a S.D. of ±5 worms. All the nematodes in each sample were fixed in hot alcohol, cleared in lactophenol, identified and counted.

Mean total worm burdens were determined for each bi-monthly sample of wallabies (Fig. 3). Highest figures occurred in May and November 1972 and May and September 1973, and lowest in September 1972, January and November 1973. The unseasonably dry weather (see Fig. 1) experienced earlier may have been responsible for the low worm burdens recorded in September 1972. The variation in worm burdens of individual wallabies sampled at the same time was often large. The oldest and youngest wallabies usually had the smallest number of nematodes. Only two young animals which had just left the pouch had no stomach nematodes. The relative abundance of each species was determined by expressing the total number (collected from 99 tammars), as a percentage of the largest total (Table 2). This is to distinguish between a nematode species present in large numbers in a few hosts, and a species present in small to moderate numbers

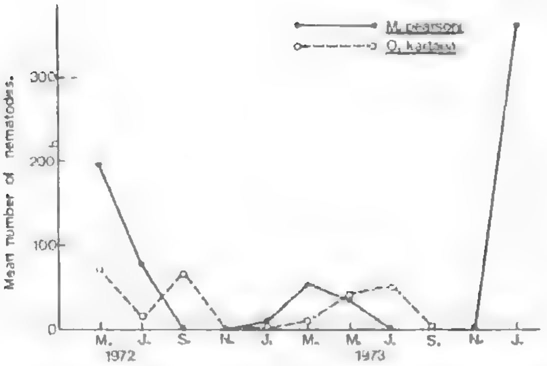

Fig. 5. Mean bi-monthly occurrences of two nematode speices, May 1972-January 1974.

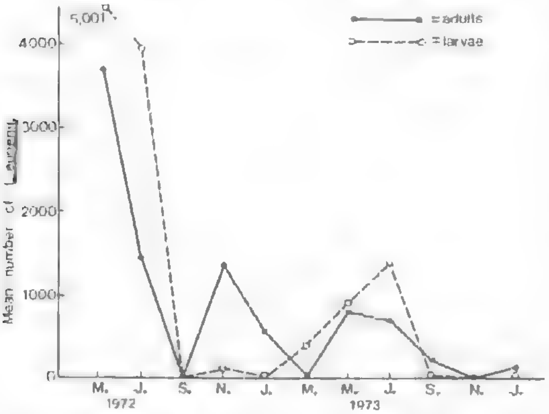

Fig. 6. Mean bi-monthly occurrence of adult and larval *Labiostrongylus eugenii*. Only infected animals were used to obtain the mean.

TABLE 3

Seasonal presence or absence of *L. eugenii* in the stomach lumens of 64 wallabies

	Present	Absent	Total
May 1972 and 1973	7	3	10
July 1972 and 73	7	3	10
Sept. 1972 and 73	3	7	10
Nov. 1972 and 73	2	8	10
Jan. 1973 and 74	3	9	12
March 1973 and 74	8	4	12
Total	30	34	64

$\chi^2 = 12.53$ where χ^2 (5%) = 11.07 and χ^2 (2.5%) = 12.83

in a large number of hosts. Only the more common species, *Rugopharynx australis*, *Macropostrongylus pearsoni*, *Oesophagonastes kartana*, *Labiostrongylus eugenii* and the group of *Cloacina* spp., were considered in greater detail.

The results of the analysis of seasonal difference in abundance of each of these species are shown in Figs 5 & 6. The 1972 figures for *Cloacina* spp. seem to have been influenced by the dry conditions in September of that year. The peak for *M. pearsoni* in January 1974 was due to one host with an extremely heavy infestation. In all, the periods of heaviest infestation occurred during the wet season (*Cloacina* spp. early spring, *R. australis* late autumn and winter, *M. pearsoni* early autumn, *O. kartana* autumn and winter months only, *L. eugenii* late autumn and winter).

Statistical analysis of the data for *L. eugenii* (Tables 3 and 4) gave χ^2 values statistically significant at the 5% level, thus indicating that *L. eugenii* has a cycle of incidence dependent on the seasons. For this analysis counts from March 1974 were included.

The populations of *L. eugenii* from each host were sorted into adults and larval stages (Fig. 6). No third stage larvae and minimum of fourth stage larvae were found in the stomach lumen between September and January. Observations on the life cycle of *L. eugenii* have shown that third stage larvae are most likely to be acquired between June and November of any year. These larvae enter the stomach wall and remain there for about eight weeks or longer if development is inhibited[1]. It is likely that 3rd stage larvae are being ingested during this period and invade the stomach wall. Increasing numbers of these larvae would be migrating into the stomach lumen as 4th stage larvae from February onwards. Comparisons between individual hosts within the same sample revealed heterogeneous age structures, therefore the number of hosts sampled was too small to allow statistical analysis.

TABLE 4

Seasonal abundance of infection with *L. eugenii* in 64 wallabies

	Number of *L. eugenii*				
	a	b	c	d	Total
May 1972 and 73	4	1	2	3	10
July 1972 and 73	4	1	0	5	10
Sept. 1972 and 73	9	1	0	0	10
Nov. 1972 and 73	9	0	1	0	10
Jan. 1973 and 74	10	0	2	0	12
March 1973 and 74	6	3	1	2	12
Total no. wallabies	42	6	6	10	64

$\chi^2 = 26.77$ where χ^2 (5%) = 25

a—0-500
b—500-1000
c—1000-2000
d—2000

Incidence of infestation of *L. eugenii* with respect to host age was also examined. Those wallabies collected before March 1974 were grouped according to age, with 36 1–3 years old in one group and 22 over three years old in the other. Wallabies less than one year old were not considered, as they were never found to harbour *L. eugenii* (though other species might be present). An analysis of the incidence of infection was scored in terms of presence or absence of the species partly because of the small host sample size, and partly because of the practical difficulties involved in estimating the number of 3rd stage larvae in the stomach wall. The results of this analysis indicated that incidence of infection was independent of host age. The host sample was too small to analyse in terms of the age structure of the *L. eugenii* populations. Therefore it was not possible to say whether older wallabies have smaller numbers of *L. eugenii* larvae.

It was found that the times of peak egg production as determined by faecal egg counts appeared to be synchronized with those seasons most advantageous to the nematodes. The peaks occurring in May were at the time when weather conditions for survival of infective larvae were good and, in fact, numbers of infective larvae present on the herbage at this time have been found to be high.[1] The November peak occurred when conditions might have been too dry for many larvae to survive. However, such larvae as did reach infectivity did so at a time when there would be a large number of susceptible hosts (joeys just out of the pouch) grazing the pastures. A build up of infective larvae, from those overwintering as well as from recent hatching, would be possible from late winter through to spring.

The total worm burdens fluctuated both seasonally and from year to year. However, there was a trend towards lowest worm burdens during the dryest periods of the year. A number of workers (Anderson 1972; Gordon 1958; Parnell 1963) have found that sheep living in areas with winter rainfall record highest worm burdens in the late winter and early spring. Thus it appears that the uptake of infective larvae of trichostrongyles by domestic stock as well as strongyles infesting macropods occurs during or just after wet periods. The success of these Australian nematode species is probably related to this synchronisation of their life cycles with the season. The present study showed that the majority of 3rd stage *L. eugenii* larvae are ingested during the winter (older wallabies) and spring (wallabies just leaving the pouch). These develop in the stomach wall and escape into the lumen from February on as fourth stage larvae. They develop to maturity in the stomach lumen, producing eggs from late autumn through the winter. This long prepatent period of about 7–9 months[1] is probably important in enabling the synchronisation of life cycle with changes in seasons.

Seasonal differences in species composition of worm burdens were also observed. However, a detailed analysis of the population structures of species other than *L. eugenii* was not undertaken.

Acknowledgments

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THE AUSTRALIAN FROG CHIROLEPTES DAHLII BOULENGER: ITS SYSTEMATIC POSITION, MORPHOLOGY, CHROMOSOMES AND DISTRIBUTION

BY M. J. TYLER, MARGARET DAVIES & MAX KING

Summary

The external morphology, osteology and karyotype of Chiroleptes dahlii demonstrate that this species is erroneously referred to the Leptodactylidae and is in reality a hylid related to the southeastern Australian species, Litoria raniformis.

THE AUSTRALIAN FROG *CHIROLEPTES DAHLII* BOULENGER: ITS SYSTEMATIC POSITION, MORPHOLOGY, CHROMOSOMES AND DISTRIBUTION

by M. J. Tyler,* Margaret Davies* & Max King†

Summary

Tyler, M. J., Davies, M. & King, M. (1978) The Australian frog *Chiroleptes dahlii* Boulenger: its systematic position, morphology, chromosomes and distribution. *Trans. R. Soc. S. Aust.* **102**(1), 17-23, 28 February, 1978.

The external morphology, osteology and karyotype of *Chiroleptes dahlii* demonstrate that this species is erroneously referred to the Leptodactylidae and is in reality a hylid related to the southeastern Australian species, *Litoria raniformis.*

Introduction

The Australian frog *Chiroleptes dahlii* Boulenger (1895) was based on two specimens taken at Daly River, Northern Territory by Dahl. Despite its comparatively large size (up to 85 mm snout to vent length) this species has been reported only rarely, so that little is known of its morphology, and nothing of its biology and close phylogenetic relationships. In referring it to the genus *Cyclorana* Steindachner, H. W. Parker (1940) had access to only one specimen: a syntype.

The second published report of the species appears to be that of Tyler (1969) who identified as *C. dahlii* frogs from Knuckey's Lagoon near Darwin, previously reported as *Hyla aurea* by Loveridge (1949). The only additional published record of *C. dahlii* is one of its collection at Edward River in Queensland by F. Parker & Tanner (1971).

Through the assistance of Mr G. Miles we have received and maintained in our laboratory a series of *C. dahlii* from localities near Darwin. The striking superficial resemblance of these frogs to *Litoria raniformis* (Keferstein), familiar to us from South Australia, caused us to examine the systematic position of *dahlii.*

Material and methods

Data on external morphology reported here are derived principally from specimens deposited in various museum collections abbreviated in the text as follows:

Museum of Comparative Zoology, Harvard University (MCZ)
Northern Territory Museum, Alice Springs (NTM)
South Australian Museum, Adelaide (SAM)
Western Australian Museum, Perth (WAM)

Osteological details of *dahlii* were obtained from a series taken at Beaufort Hill near Darwin. Those from *L. raniformis* were from the southeast of South Australia. These preparations are housed in the University of Adelaide, Department of Zoology.

Karyological data were obtained from specimens of *dahlii* from Beaufort Hill and Cannon Hill, and of *L. raniformis* from Mil Lel, S.A., Renmark, S.A. and Interlaken, Tasmania. Mitotic chromosomes were obtained from intestinal epithelial cells using an air dried technique described by King & Rofe (1976).

Methods of measurements of external features follow those described by Tyler (1968), whilst skull measurements and descriptive terminology follow the pattern adopted by Davies (1978).

Systematic position

Parker (1940) referred *dahlii* to the genus *Cyclorana* Steindachner, a genus that Tyler (1970) and Robinson & Tyler (1973) have shown to exhibit distinct morphological and

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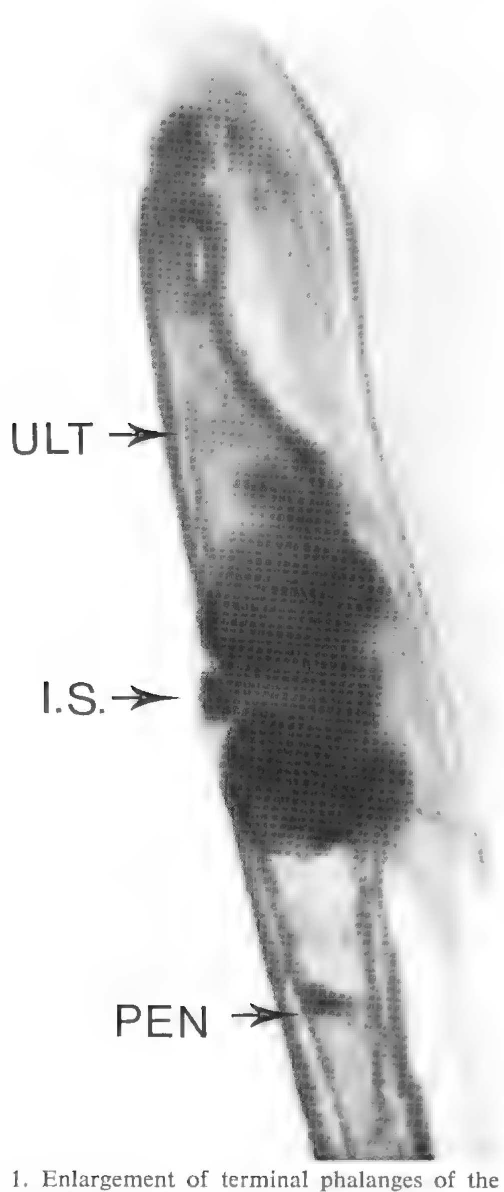

Fig. 1. Enlargement of terminal phalanges of the third toe of a cleared and alizarin stained preparation of *dahlii* showing biconcave, disc-like intercalary structure (x 12.5). Abbreviations: ULT = ultimate (terminal) phalanx; pen = penultimate phalanx; I.S. = intercalary structure.

biochemical affinities with Australopapuan frogs of the family Hylidae. More recently the concept of *Cyclorana* has changed, and with the sole exception of *dahlii*, is composed now exclusively of squat-bodied fossorial species (Tyler 1974; Tyler & Martin 1975, 1977).

Heyer & Liem (1976) omit *Cyclorana* from their study of Australopapuan leptodactylids (as myobatrachids), from which action it must be concluded that they regard it a member of the Hylidae.

The presence of intercalary structures is currently diagnostic of the Hylidae but not of the Leptodactylidae. Noting the presence of such structures in the species *inermis* (Peters) and *alboguttata* (Gunther), Straughan (1969) and Tyler (1974) referred these species from *Cyclorana* to the hylid genus *Litoria*. In the absence of other characters of significance at the family level we regard any deviation from this recognition likely to result in the Hylidae becoming a heterogeneous assemblage.

Examination of the phalanges of *C. dahlii* reveals ossified intercalary structures forming supernumerary bones (Fig. 1). From the hylid genus *Nyctimystes* this species is further distinguished by its horizontal pupil and absence of a palpebral reticulum. Accordingly we transfer the species to *Litoria* and examine its specific relationships there.

With the removal of *dahlii* from *Cyclorana* the latter genus comprises the following species:

Cyclorana australis (Gray)
Cyclorana brevipes (Peters)
Cyclorana cryptotis Tyler & Martin
Cyclorana cultripes Parker
Cyclorana longipes Tyler & Martin
Cyclorana maculosus Tyler & Martin
Cyclorana maini Tyler & Martin
Cyclorana novaehollandiae Steindachner
Cyclorana platycephalus (Gunther)
Cyclorana slevini Loveridge
Cyclorana verrucosus Tyler & Martin

Litoria dahlii (Boulenger)

Chiroleptes dahlii Boulenger, 1896, p. 867.
Phractops dahlii: Nieden, 1923, p. 522.
Cyclorana dahlii: Parker, 1940, p. 17.

Material examined: *Northern Territory*—SAM R6448, 15930–34, NTM 1836–64, Beatrice Hill (4); SAM R12338, E. Alligator River; MCZ 25994–5, Knuckey's Lagoon; *Queensland*—R9674–6. Strathgordon H.S.; *Western Australia*—WAM R34601. King River, 15 km S of Wyndham.

External Morphology

The head is moderately high and slightly longer than broad (HL/HW 1.01–1.12), its length equivalent to slightly more than one-third of the snout to vent length. The distance between the eye and the naris is greater than the internarial span (E–N/IN 1.22-1.39). The

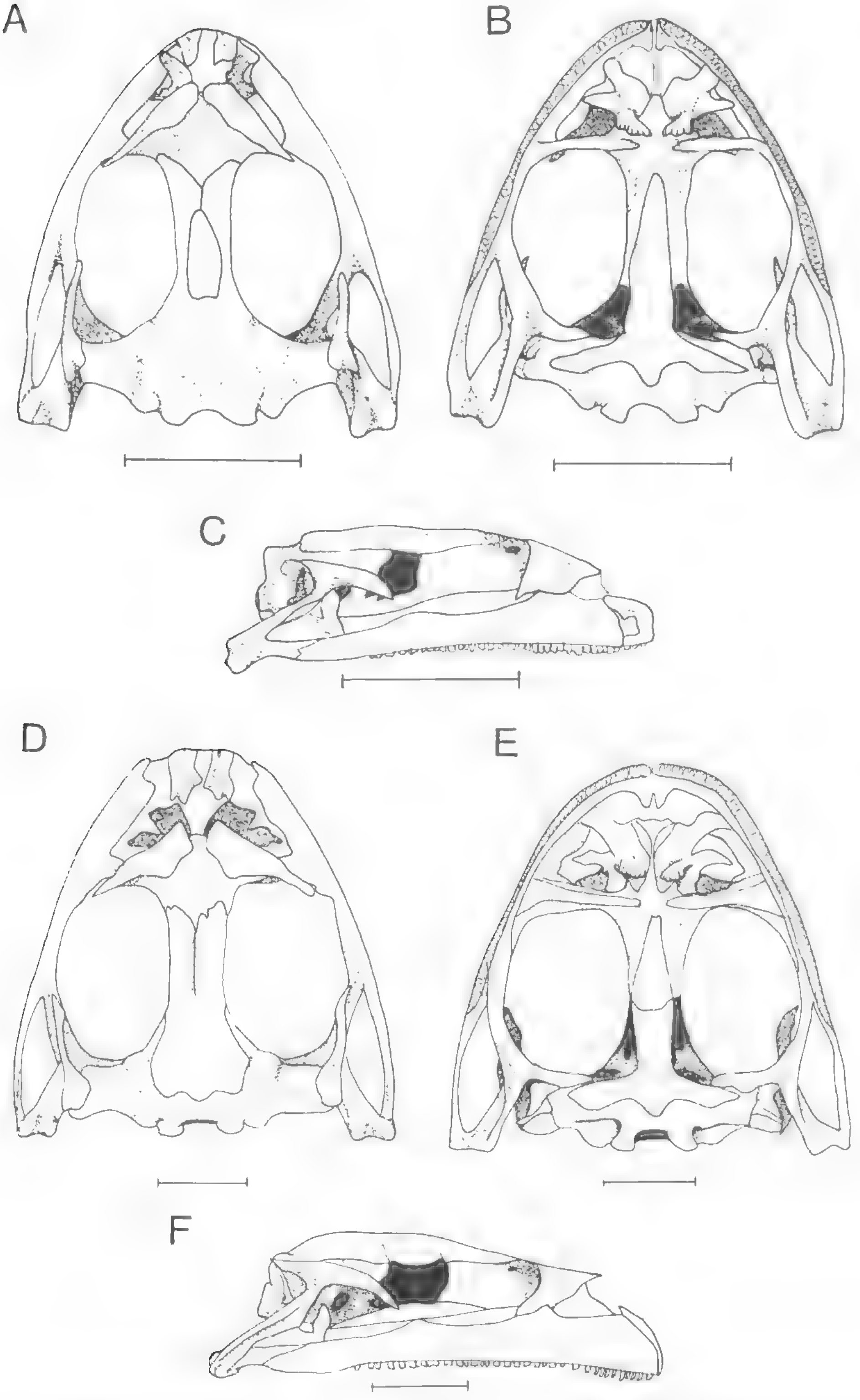

Fig. 2. Osteological preparations of: A-C, *L. dahlii* in dorsal, ventral and lateral view; D-F, *L. raniformis* in dorsal, ventral and lateral view. Scale — 5 mm.

canthus rostralis is straight and scarcely distinguishable. The eye is moderate, its diameter equivalent to approximately the eye to naris distance. The tympanum is large and conspicuous, its diameter almost equal to the eye diameter. The vomerine teeth are on two prominent elevations between and behind the internal choanae. The tongue is broadly oval. The fingers are elongate, lack lateral fringes and the tips are scarcely expanded; in decreasing order of length 3> 4 > 1 > 2. The fingers are unwebbed.

The hind limbs are relatively short (TL/S–V 0.45–0.51). Toes in decreasing order of length 4 > 5 = 3 > 2 > 1. Webbing is extremely extensive, reaching the tips of all digits and separating all of the metatarsals at least partly.

The skin on the dorsal surface is smooth. The throat and chest are smooth and the abdomen and lower thighs very weakly granular. There is no tarsal ridge.

In preservative, specimens are predominantly various shades of slate with irregular darker variegations. A mid-vertabral stripe is commonly present. The back of the thighs are dark slate with a broad, longitudinal creamish stripe or a series of large dots.

In life the animal is similarly a basic slate colour, but there are suffusions of pale green, particularly on the dorso-lateral surfaces.

Cranial Osteology

Material examined: two dried preparations (SAM R6448 and a specimen obtained live from Beaufort Hill); one alizarin preparation of an entire animal also obtained live from Beaufort Hill.

The skull is longer than broad, the slightly clongated snout having a rounded terminal tip in dorsal aspect (Fig. 2). The dorsal surfaces of the skull are smooth and unornamented, there is no coossification or exostosis present, and the skin overlying the skull is freely moveable. There is no evidence of prenasal or dermal sphenethmoid bones. Similarly there are no lateral flanges nor occipital crests present.

The nasals are moderately sized and are narrowly separated medially. The maxillary processes of the nasals are sharp and slender and make bony contact with the posterior processes of the pars facialis of the maxillary. They do not extend to the level of the maxillary.

The sphenethmoid is well ossified, with the nasals extending anteriorly beyond its anterior terminus. The frontoparietal fontanelle is large and ovoid.

The orbital margins of the frontoparietals are straight and postero-laterally the frontoparietals do not overlap the crista parotica.

The squamosals are well developed with the zygomatic ramus being long, extending 76% of the distance to the maxilla. The otic ramus is about half the length of the zygomatic ramus. It does not extend for the whole width of the crista parotica, but slightly overlaps the anterior half.

The pterygoid is moderately developed and the medial ramus is in bony contact with the otic capsule. The anterior ramus has an extensive articulation with the maxillary at approximately mid orbit, whilst the posterior ramus is poorly ossified and articulates with the ventral arm of the squamosal. The quadratojugal is well developed and articulates anteriorly with the maxilla and posteriorly with the ventral arm of the squamosal. The parasphenoid lacks odontoid structures and stretches anteriorly almost to the level of the palatines.

The premaxillaries are narrow, toothed structures and are narrowly separated medially. The alary processes are widely separated. Initially they rise perpendicularly to the dentigerous processes of the premaxillaries and then are inclined posteriorly in a hori-

TABLE 1

Cranial features of *Litoria aurea* group

skull shape:	broader than long
nasals:	articulate with and overlap the sphenethmoid which projects anteriorly between, separating them medially (exception: *alboguttata*)
alary processes of premaxillary:	well developed, inclined posteriorly at angle no less than 45°
pars facialis of maxillary:	moderately deep, posterior process articulates with maxillary process of nasal
quadratojugal:	robust and well developed
squamosal:	well developed, zygomatic ramus longer than otic ramus. Otic ramus overlaps crista parotica
palatine processes of premaxillary:	do not articulate with each other
dentigerous processes of prevomers:	short, inclined at an angle of 45° to midline.

Fig. 3. A—Chromosomes of *L. dahlii* ♂ from Cannon Hill, N.T. B—Chromosomes of *L. raniformis* ♂ from Mil Lel, S.A. Note the characteristic satellites on pair 13 in both species.

zontal plane. The height of the alary processes is almost 1.5 times the height of the dentigerous processes. The palatine processes of the premaxillaries do not articulate with each other. The premaxillaries articulate laterally with the pars palatina and pars dentalis of the maxillary.

The prevomers are narrowly separated medially. They are large, entire and toothed. Postero-laterally. the prevomers bear wings forming the anterior, medial and posterior margins of the choanae. The dentigerous processes are small and moderately separated. They lie perpendicular to the midline and bear 8-10 teeth.

The palatines are narrow slender bones forming the posterior margins of the choanae with the distal ends slightly expanded and lying adjacent to the maxillaries. The palatines do not appear to have postero-ventral shelves.

The maxillary bears a well developed pars facialis, the posterior process of which articulates with the maxillary process of the nasal. The pars palatina is very small, extending ventromedially to the pars dentalis; the maxillary articulates firmly with the quadratojugal at the level of the prootic foramen.

Karyotype Morphology

All specimens of *L. dahlii* and *L. raniformis* analysed had a chromosome number of 2n = 26. The karyotypes of these species grade from large to small and the chromosomes are metacentric or submetacentric. The centromeres were in the same position in corresponding chromosome pairs in both specimens. A characteristic pair of satellites is present on chromosome pair 13 in both forms (Fig. 3).

Phylogenetic Relationships

In its gross external morphology, resemblance to *Litoria raniformis* and other members of the *Litoria aurea* group (*sensu* Tyler & Davies in press) is quite striking. It shares with the members of that group, moderate to large size, elongate body form, muscular limbs of moderate length, unwebbed fingers and strongly webbed toes. The single external feature unique to *dahlii* is the degree of webbing of the hind foot, which is particularly extensive in that species.

Osteologically, the cranial features that support its association with the *Litoria aurea* group are listed in Table 1. See also Fig. 2A-F.

Karyotypically, *C. dahlii* and *L. raniformis* have many features in common. Firstly, *C. dahlii* has a chromosome number of $2n = 26$, which is the number most often encountered in the Australian and New Guinea hylids (Morescalchi & Ingram 1974; Menzies & Tippett 1976). In contrast, all known Australian leptodactylid species have $2n = 22$ or $2n = 24$. A number of $2n = 26$ was reported for *Cyclorana alboguttatus* by Morescalchi & Ingram (1974). This finding supports the recent systematic conclusions of Tyler (1974) who referred *C. alboguttatus* to the hylid genus *Litoria*.

Our unpublished data on the chromosomes of 35 species of Litoria indicate that many species may be grouped together by using characteristics of their chromosome morphology. *C. dahlii* and *L. raniformis* share the same karyotypic morphology in terms of centromere position in each chromosome pair. Moreover, *C. dahlii* possesses satellites on pair 13 which are a characteristic of *L. raniformis* and other members of the *L. aurea* group. The possession of this presumably derived condition suggests a close phylogenetic relationship between *C. dahlii* and the *L. aurea* group.

Geographic distribution of the *Litoria aurea* group

Tyler & Davies (in press) illustrated the distribution of the *L. aurea* group which has representatives in southwestern Australia and then in a continual arc from the southeast to the northeast. *Litoria dahlii* now represents the northern and northwestern species so completing a pattern of continuous distribution composed of largely contiguous populations.

Acknowledgments

We would like to thank Mr Greg Miles of the Northern Territory Fisheries and Wildlife Branch for the supply of live specimens of *L. dahlii*. Mr P. Kempster photographed the toes of *L. dahlii*. This study was supported by an Australian Research Grants Committee grant to M. J. Tyler.

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STRATIGRAPHY OF THE LOWER WILPENA GROUP (LATE PRECAMBRIAN), FLINDERS RANGES, SOUTH AUSTRALIA

BY P. S. PLUMMER

Summary

A revised nomenclature is proposed for the dominantly clastic sequence of sediments comprising the lower Wilpena Group (late Adelaidean) within the Adelaide fold belt. This sequence, herein termed the Brachina Subgroup, has sharp, locally disconformable lower and upper boundaries, between which formations are defined on the basis of mappable lithozones.

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PLUMMER, P. S. (1978) Stratigraphy of the lower Wilpena Group (late Precambrian), Flinders Ranges, South Australia. *Trans R. Soc. S. Aust.* **102**(1), 25-38, 28 February, 1978.

A revised nomenclature is proposed for the dominantly clastic sequence of sediments comprising the lower Wilpena Group (late Adelaidean) within the Adelaide fold belt. This sequence, herein termed the Brachina Subgroup, has sharp, locally disconformable lower and upper boundaries, between which formations are defined on the basis of mappable lithozones.

The Brachina Subgroup displays an upward coarsening sequence which represents a complete phase of regressive sedimentation, during which energy conditions became increasingly vigorous. As the regression progressed, depositional regimes changed from low energy settling (from suspension) in a subtidal environment to high energy traction deposition in deltaic plain, barrier-bar and intertidal mud-, and sand-flat environments. Toward the peak of regression at least two islands emerged in the central portion of the basin producing local high energy fluvial to marginal marine conditions.

Introduction

Stratigraphic and sedimentologic studies are usually undertaken with the ultimate aim of palaeogeographic reconstruction. In regions of great thicknesses of sedimentary rocks, especially where stratigraphic subdivisions are based solely upon lithologic criteria—such as within the Adelaide fold belt—the form of subdivision must complement this ultimate aim.

The present stratigraphic nomenclature defining the late Precambrian Wilpena Group (Dalgarno & Johnson 1964) was devised for in-the-field differentiation of major lithologic units to be applied to 1:250 000 scale mapping (Thomson 1964), and as such was based on dominant lithology using one type section as a reference -Brachina Creek in the central Flinders Ranges.

The Wilpena Group is, however, readily divisible into two coarsening-upward cycles, the lower cycle having a maximum thickness of approximately 2200 m whilst the upper cycle attains about 4000 m. Detailed stratigraphic mapping undertaken throughout the Flinders Ranges within the lower Wilpena Group has identified five separate and distinct mappable lithozones. Complex intertonguing between these lithozones, produced by sedimentary facies changes, renders the present nomenclature inadequate in differentiating between depositional environments and thus necessitates the formulation of a new and workable nomenclature to allow unambiguous application of such terminology throughout the basin of deposition. It is herein proposed that the lower Wilpena Group cycle be designated 'subgroup' status, whilst the individual lithozones be of 'formation' status, in accordance with the Australian Code of Stratigraphic Nomenclature (1973).

Present nomenclature

In its type section within Brachina Creek the lower Wilpena Group rests conformably upon the sediments of the Umberatana Group (Coats 1964), although local disconformity is recorded from parts of the northern Flinders Ranges. The lowermost unit, the Nuccaleena Formation, has at its base a laminated to well-bedded, pink to cream dolomite, which weathers a buff colour and has a maximum thickness of 10 m. Overlying this is up to 60 m of purple shale interbedded with occasional dolomite lenses, which forms a passage into the overlying Brachina Formation. In the Mount Lofty Ranges the dolomite unit becomes lenticular

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TABLE 1
Stratigraphic nomenclatures for lower Wilpena Group

<table>
<tr><th>Mawson
(1939)</th><th>Dalgarno and
Johnson (1964)</th><th colspan="2">Leeson
(1970)</th><th colspan="2">Proposed New
Nomenclature</th></tr>
<tr><td rowspan="2">ABC Range
Quartzite</td><td>ABC Range
Quartzite</td><td colspan="2">ABC Range
Quartzite</td><td rowspan="5">Brachina Subgroup</td><td>ABC Range
Quartzite</td></tr>
<tr><td rowspan="3">Brachina
Formation</td><td rowspan="3">Brachina
Formation</td><td>Bayley Range
Siltstone Member</td><td>Bayley Range
Formation</td></tr>
<tr><td rowspan="3">"chocolate
shales"</td><td>Moorillah
Siltstone Member</td><td>Moorillah
Formation</td></tr>
<tr><td>Moolooloo
Siltstone Member</td><td>Moolooloo
Formation</td></tr>
<tr><td>Nuccaleena
Formation</td><td colspan="2">Nuccaleena
Formation</td><td>Nuccaleena
Formation</td></tr>
</table>

and has been equated with a granule-bearing sandstone with siltstone and dolomite interbeds —the Seacliff Sandstone Member of the Brachina Formation (Thomson 1966).

The Brachina Formation comprises brown and drab olive green, thinly-bedded siltstones with shale and thin sandstone interbeds totalling approximately 1200 m in the type area. To the southwest of the type area greyish-red siltstones and purple shales replace these siltstones, whilst to the southeast the dominantly green Ulupa Siltstone (Mirams 1964) has been defined. Leeson (1970), when mapping the Beltana area of the northern Flinders Ranges, identified three major lithozones within the Brachina Formation and defined them as members (see Table 1). Directly overlying the Nuccaleena Formation are purple siltstones which pass upward into drab olive green micaceous siltstones—the Moolooloo Siltstone Member—these being overlain by the massive coarse-grained purple siltstones with minor quartzitic bands of the Moorillah Siltstone Member. The uppermost unit is the Bayley Range Siltstone Member which consists of drab olive green siltstones with grey fine-grained quartzitic interbeds.

Conformably overlying the Brachina Formation, and capping the lower Wilpena Group, is a white flaggy crossbedded quartzite—the ABC Range Quartzite—which is 120 m thick in the type section (Brachina Creek). This unit wedges out in an eastward direction where it is thought to be replaced by the uppermost siltstones and thin white fine-grained sandstones of the Ulupa Siltstone (Binks 1971). Although a disconformity marks the top of this sequence in the southwestern Flinders Ranges, elsewhere the dominantly purple shales of the overlying Bunyeroo Formation rest conformably upon the lower Wilpena Group.

Proposed new nomenclature

The lenticularity of the basal Nuccaleena dolomite along the basin margins and within the Mount Lofty Ranges, and the wedging out of the ABC Range Quartzite in an eastward direction has led to the wide usage within the literature of the term Brachina Formation in a context which spans nearly the entire lower Wilpena Group sequence. However, the three lithozones identified by Leeson (1970) within the Brachina Formation are readily recognizable and mappable, both within this formation and its lateral equivalent, the Ulupa Siltstone, throughout the basin of deposition. Also, the upper two of these lithozones are laterally equivalent to the ABC Range Quartzite (Fig. 2). It is therefore proposed that the term *Brachina Subgroup* be applied to the complete sequence of sediments lying above the Umberatana Group and below the Bunyeroo Formation, whilst each of the five lithozones has its status raised (where necessary) to formation level within this subgroup (Table 1). The term Ulupa Siltstone thus becomes redundant and should be abandoned.

Type section

Because of the regional intertonguing of the component lithozones of the Brachina Subgroup no single type section can be defined to characterize the full sequence. Also, the present

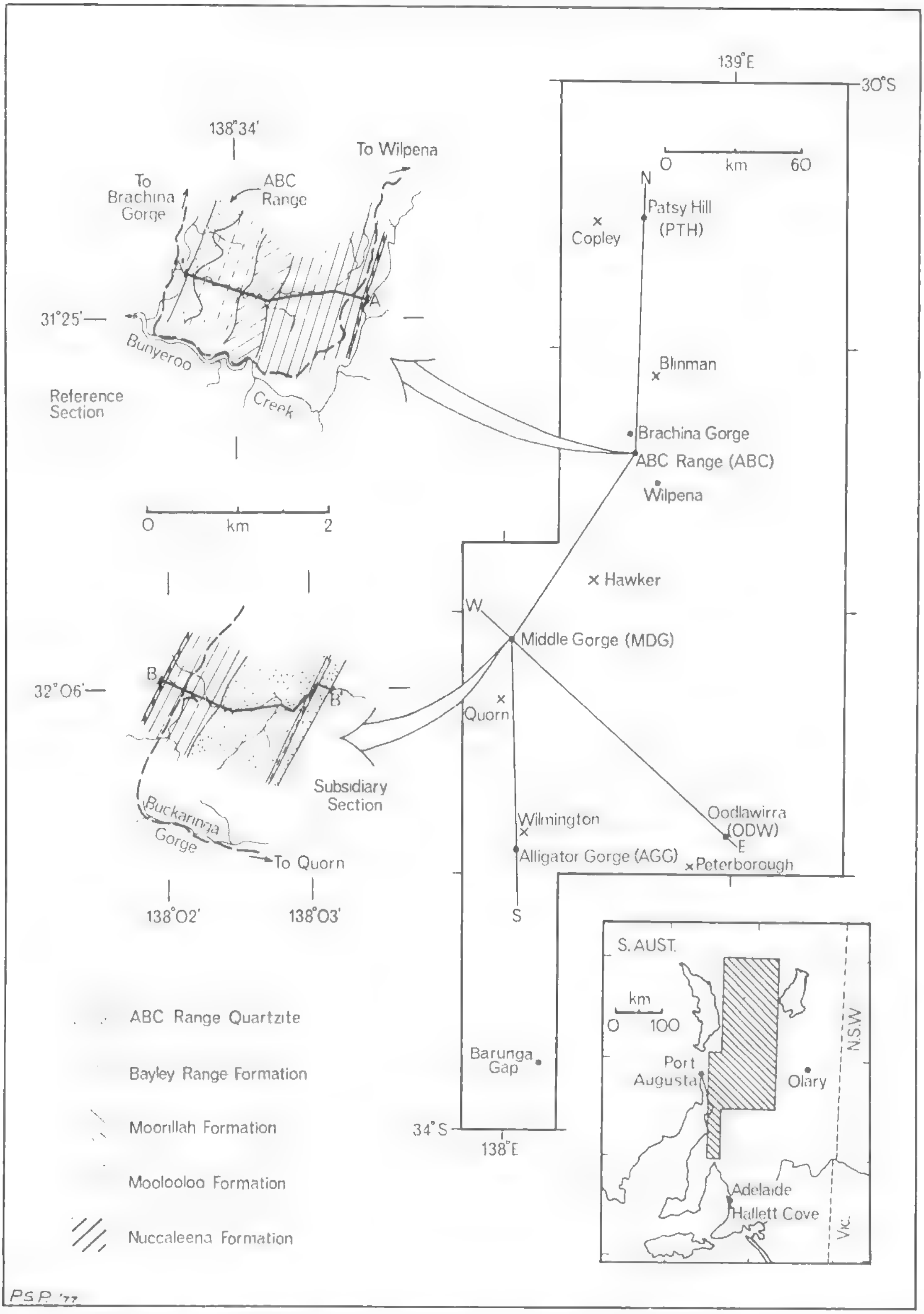


Fig. 1. Locality map, showing study area and locations of reference and subsidiary sections for Brachina Subgroup.

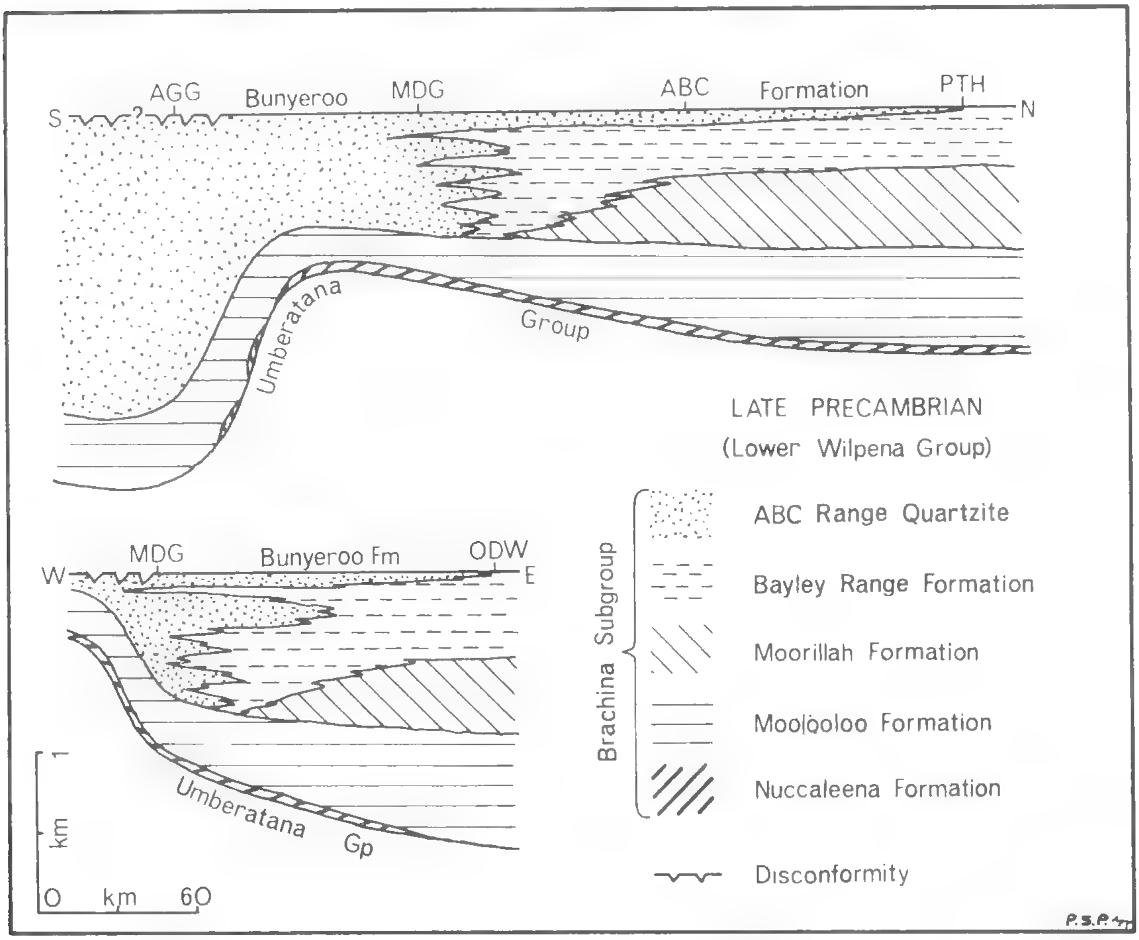


Fig. 2. Rock relation diagram for Brachina Subgroup. Lines of section and localities shown on Fig. 1.

type section (in Brachina Creek) suffers from structural complications and paucity of outcrop. These problems, therefore, necessitate the definition of a new reference section and a subsidiary section (see Fig. 1 for localities).

The new reference section for the Brachina Subgroup remains within the central Flinders Ranges, being defined 0.75 km north of Bunyeroo Gorge in the ABC Range at latitude 31°25′S and between longitudes 138°33′30″E and 138°35′E. This section, totalling 1500 m, defines the five component subgroup lithozones and lies within the western limb of an anticline with a dip of 50° toward the west. The subsidiary section is located in the southern Flinders Ranges 33 km north of Quorn in Middle Gorge, at latitude 32°06′S and between longitudes 138°02′E and 138°03′E, and lies within a synclinal western limb which averages a 75°E dip. This section totals 1150 m and defines the four component lithozones south of the region of intertonguing between the shale-siltstone-sandstone sequence and the ABC Range Quartzite. Both sections are readily accessible, and both display approximately 85% outcrop.

Umberatana Group—Wilpena Group Boundary

The boundary between the Umberatana Group and the Wilpena Group was originally proposed as occurring at the top of the Elatina Formation and its equivalents (Dalgarno & Johnson 1964, after Webb & Horwitz 1959). It therefore separated a series of pebbly, carbonate-bearing arenaceous sediments (upper Umberatana Group) from a series of fine-grained clastic deposits (the Brachina Formation) which has a massive to thinly-bedded dolomite at its base (the Nuccaleena Formation). Unfortunately, this dolomite becomes lenticular along the basin margins, in the Mount Lofty Ranges and the Olary area. Here, therefore, the boundary between the Umberatana Group and Wilpena Group is marked by

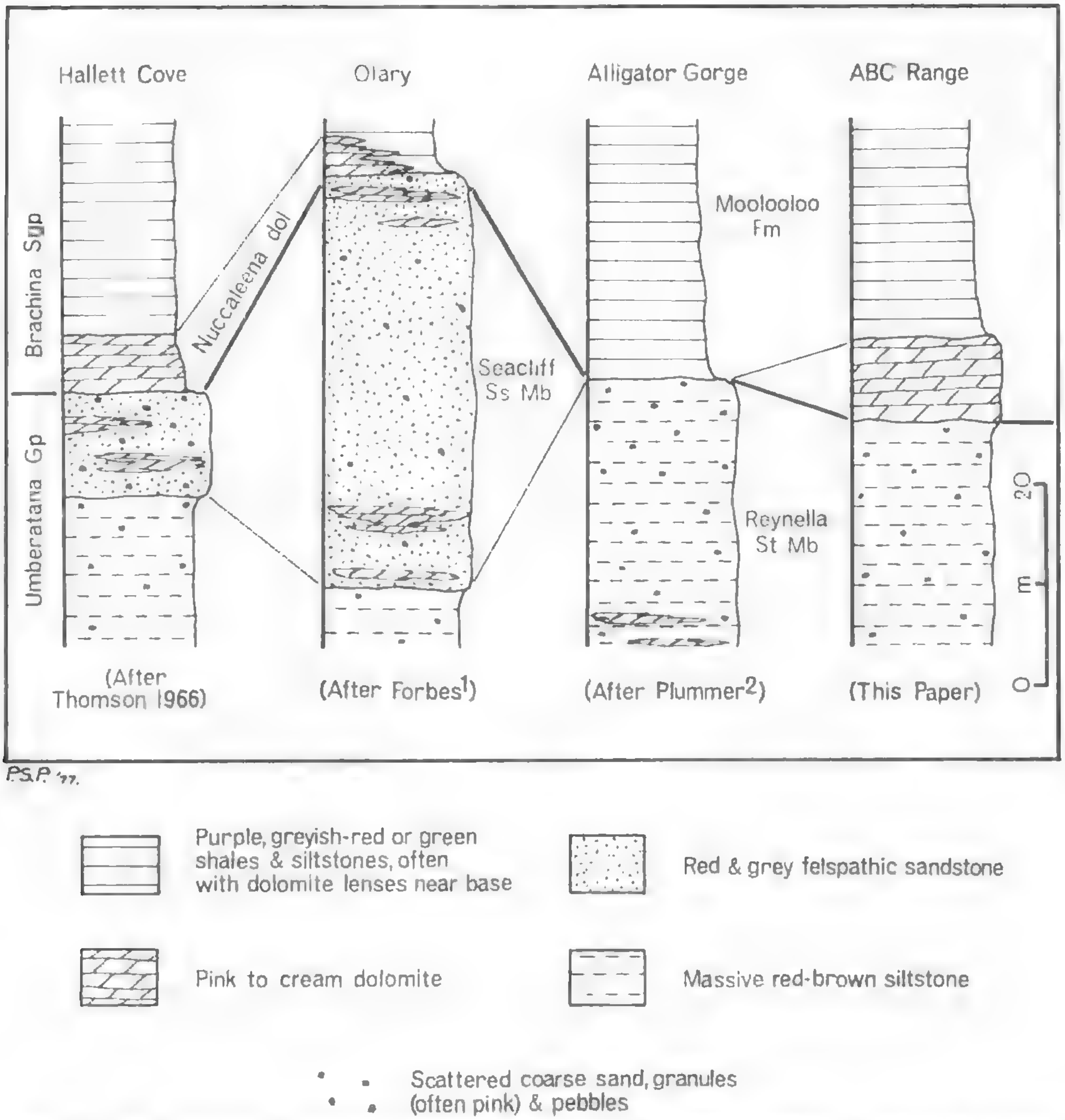


Fig. 3. The Umberatana Group-Brachina Subgroup boundary, separating massive siltstones and sandstones with scattered coarse sand, granules and pebbles from shales and siltstones, often displaying a massive basal dolomite. Section locations shown on Fig. 1.

[1] Forbes, B. G., from field notes.

[2] Plummer, P. S. (1974) The stratigraphy, sedimentology and palaeoenvironments of the late Precambrian Umberatana Group in the Mount Remarkable-Alligator Gorge area, South Australia. University of Adelaide, B.Sc. (Hons) thesis, unpublished.

the boundary separating pebbly arenaceous deposits typical of the Elatina facies from shaley and silty deposits typical of the Brachina facies. This lenticularity of the Nuccaleena dolomite has caused confusion in the Olary region and the Mount Lofty Ranges where a pebbly felspathic sandstone—the Seacliff Sandstone Member—is said to intertongue with, and replace the Nuccaleena dolomite, because of the presence of dolomitic interbeds within the sandstone. Where the Nuccaleena dolomite is developed in these regions, however, (e.g. Hallet Cove—Fig. 3) it distinctly overlies the carbonate-bearing Seacliff Sandstone Member.

Thus, by the original definition of the Wilpena Group, and on lithologic criteria, the lower boundary of the Wilpena Group (and hence of the Brachina Subgroup) lies at the top of the uppermost occurrence of pebbly carbonate-bearing arenaceous sediments. The Seacliff Sandstone Member, therefore is redefined herein as the uppermost member of the Elatina Formation and equivalents within the Umberatana Group (Fig. 3).

Nuccaleena Formation

The lowermost unit of the Brachina Supgroup is a thin to lenticular, though persistent bed of pink to cream dolomite overlain by purple shales with thin dolomitic interbeds. This unit was defined by Dalgarno & Johnson (1964) as the Nuccaleena Formation. Its basal contact is locally disconformable upon the underlying Umberatana Group, whilst its upper boundary is gradational with the overlying Moolooloo Formation. Outcrop of this unit occurs throughout the basin of deposition, although the basal massive dolomite becomes lenticular toward the margins of the basin, in the Mount Lofty Ranges and the Olary region.

Moolooloo Formation

Regional intertonguing of sedimentary facies occurs within the shale-siltstone-sandstone sequence which gradationally follows the Nuccaleena Formation. In the central Flinders Ranges three separate and distinct lithozones are readily recognizable, and these are overlain by the ABC Range Quartzite. In the southwestern Flinders Ranges, however, interdigitation between the upper two lithozones and the overlying quartzite, and their eventual replacement by the quartzite, leaves the basal lithozone as the major representative of the sequence (Fig. 2). This basal lithozone is defined as the *Moolooloo Formation.*

Purple to brown and greyish-red shales and siltstones with minor fine-grained sandstones dominate this formation in the type area where it is 630 m thick. Northward the sequence becomes finer grained, and in the northern Flinders Ranges is present as well-bedded shales and fine siltstones, red and purple at the base, but dominantly grey and green. South of the type area the sequence shows abundant graded bedding, from greyish-purple siltstone to purple shale in beds averaging 1–2 cm thick, between which thin (less than 1 cm) white fine-grained sandstones often occur as isolated lenses. In this region the colour change from purple to green is encountered as one moves toward the east (Fig. 5).

Moorillah Formation

In the central and northern Flinders Ranges the incoming of banded red and white medium-grained crossbedded quartzite and deep purple intraformational conglomeratic siltstone interbeds marks the boundary between the Moolooloo Formation and the overlying dominantly well-bedded dark-purple to red-purple shale-siltstone-sandstone sequence, the *Moorillah Formation.* Characteristic of this sequence, which is 460 m thick in the type area, is the presence of abundant soft-sediment deformation structures, generally found within massive, thickly-bedded purple siltstones (Fig. 6a). In the southeastern Flinders Ranges, however, this sequence is generally green, although the coarser grained sediments retain the purple hue and still display the soft-sediment deformational structures, thus allowing ready identification of the formation.

Bayley Range Formation

Gradationally overlying the Moorillah Formation throughout the Flinders Ranges, with the exception of the southwestern corner, is a sequence of drab olive-green, wavy-laminated to thinly-bedded shales and siltstones with abundant lenses to thin beds of off-white, fine-, to medium-grained rippled sandstones. In the type area this lithozone is 300 m thick and commonly displays small-scale soft-sediment deformation structures. The term *Bayley Range Formation* is used to define this unit. Toward the southwest this formation thickens to an estimated 650 m until it interdigitates with the ABC Range Quartzite (Fig. 2).

ABC Range Quartzite

Dalgarno & Johnson (1964) modified Mawson's (1939) original definition of the ABC Range Quartzite by restricting it to the massive quartzite forming the ABC Range. This definition is herein retained, although expanded to include the regional interdigitational relationship with the Moorillah and Bayley Range Formations for completeness. Throughout its distribution in the central and northern Flinders Ranges the ABC Range Quartzite overlies a sharp, though conformable contact with the Bayley Range Formation and consists of massive off-white, medium-grained crossbedded quartzite cyclically interbedded with green siltstones and fine-grained sandstones with thin to lenticular beds of rippled and crossbedded fine- to medium-grained sandstone. Generally

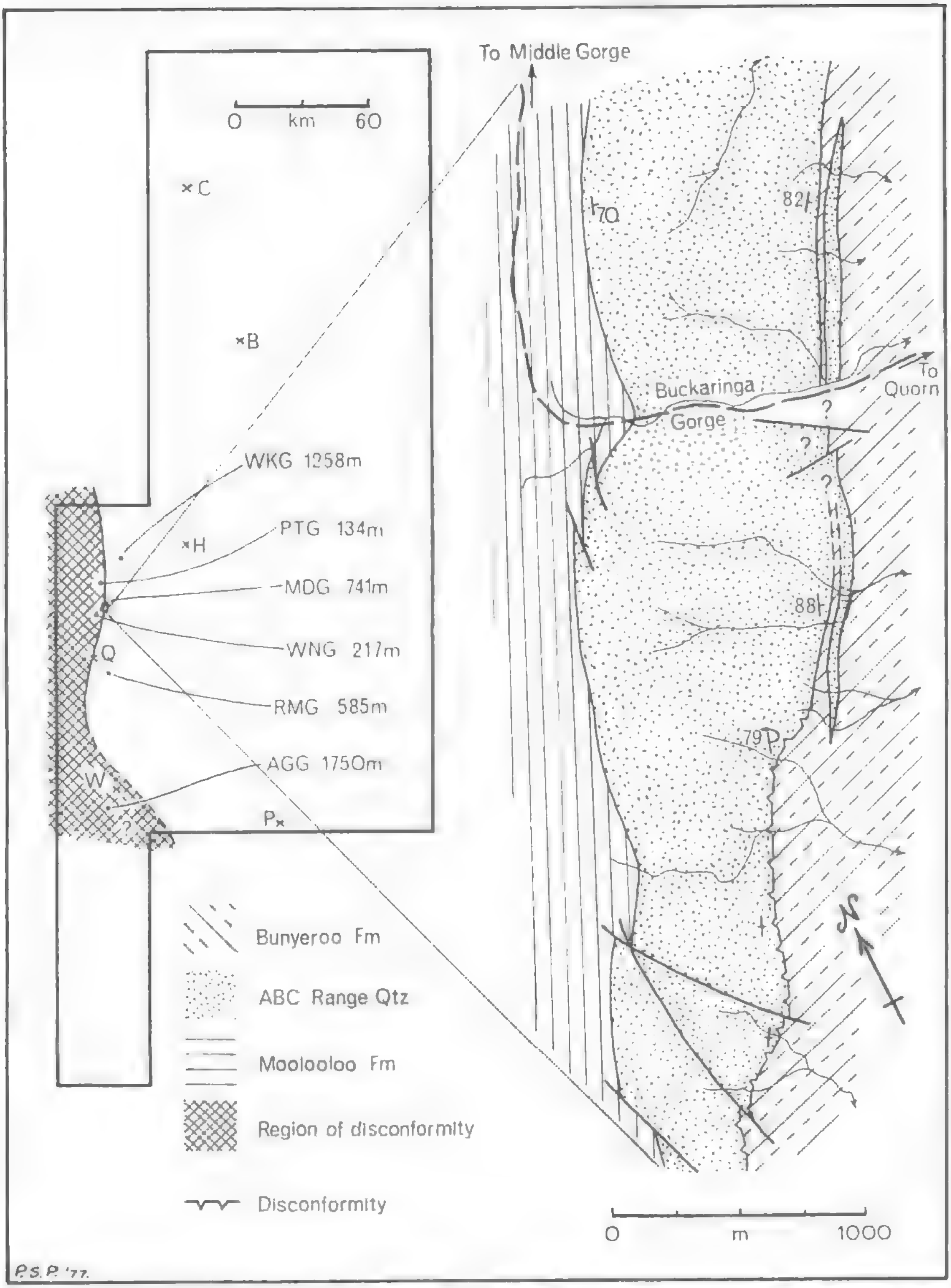


Fig. 4. Extent of the ABC Range Quartzite-Bunyeroo Formation disconformity, and detailed sketch map of its outcrop at Buckaringa Gorge. Thicknesses of ABC Range Quartzite are given for measured sections. Localities not given on figure 1 are: WKG—"Warrakimbo Gorge"; PTG—Pettana Gorge; WNG—Warren Gorge; and RMG—Richman Gap.

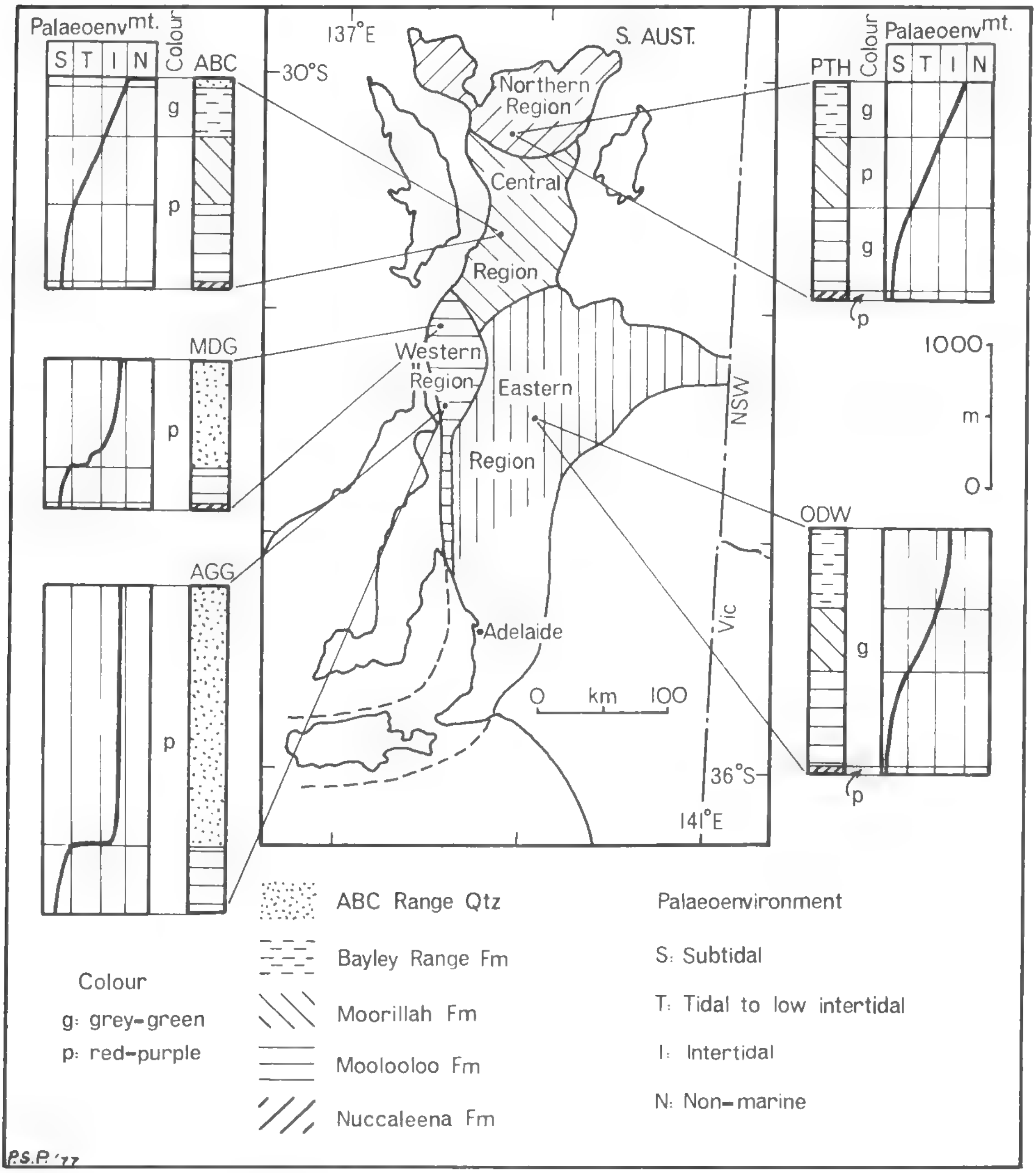


Fig. 5. Subdivision of Adelaide fold belt into major structural regions, and palaeoenvironmental variations of Brachina Subgroup within these regions.

this facies is overlain by a thin (less than 10 m) massive deep purple coarse-grained to pebbly crossbedded sandstone, with local interbeds of microconglomerates and purple shale and siltstone. This unit caps the Brachina Subgroup and underlies the purple shales of the Bunyeroo Formation with a sharp, yet conformable contact; isolated lenses of coarse sand are found within the basal 5 m of the latter shales. The thickness of the ABC Range Quartzite in this region ranges from a feather edge to 80 m.

In the southwestern Flinders Ranges, however, the ABC Range Quartzite directly overlies the Moolooloo Formation. The basal 5 to 100 m of the quartzite in this region comprises

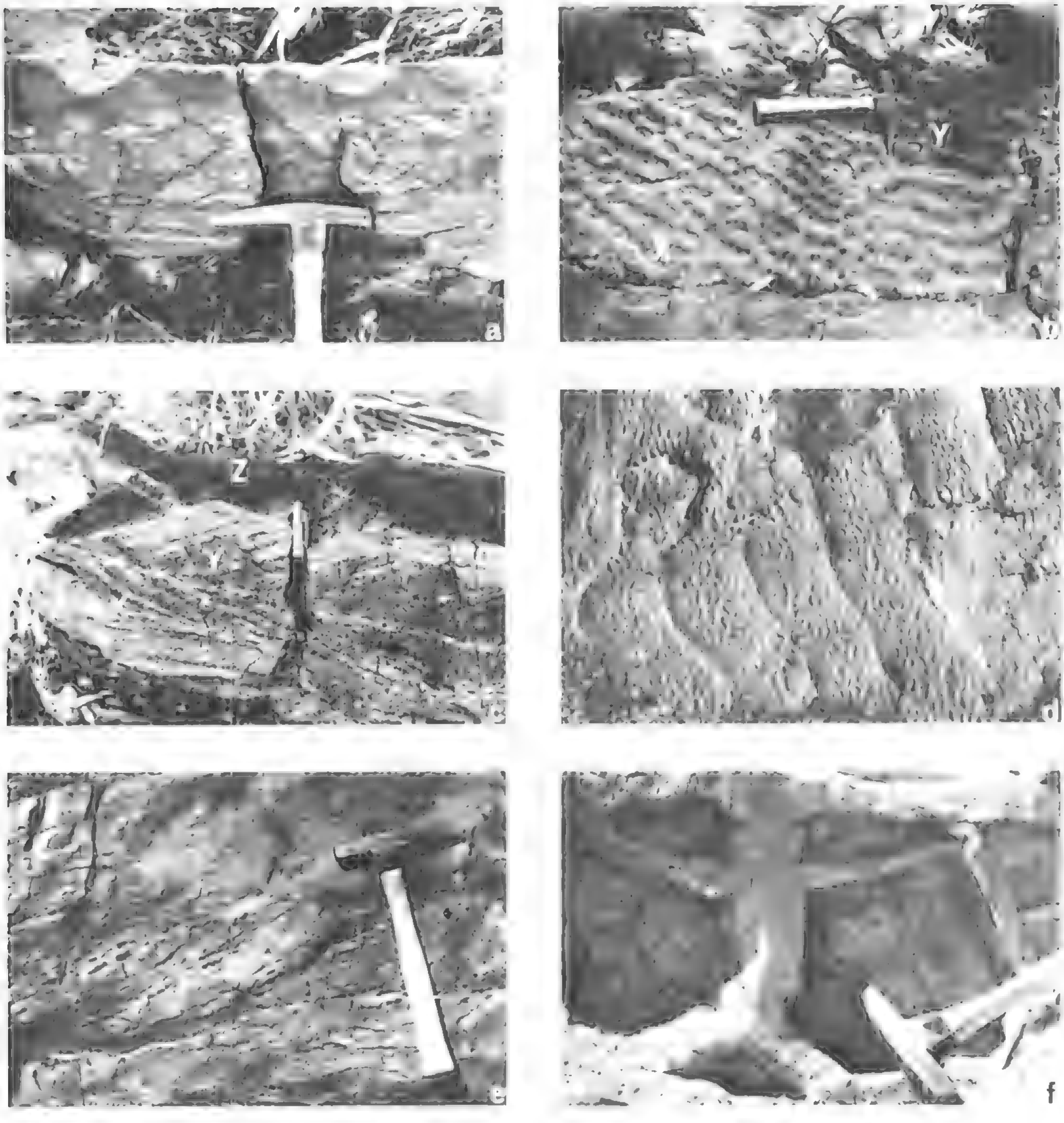


Fig. 6. (a) Soft-sediment deformation. Moorillah Formation, near "Warcowie" Homestead.
(b) Flood-oriented symmetric ripples; flat-topped during ebb tide with late-stage runoff producing secondary ripples in troughs (X). Ebb-oriented asymmetric ripples in shallow channel (Y). Moorillah Formation, ABC Range.
(c) Flood-oriented crossbedding (X); ebb-oriented crossbedding (Y); and ebb-oriented flat-topped ripples (Z). Bayley Range Formation, ABC Range.
(d) Sand waves with superimposed asymmetric ripples. Current from bottom left to top right. Deltaic plain facies, ABC Range Quartzite, "Warrakimbo Gorge".
(e) Crossbedding with shale pebbles on foreset faces, and reactivation surface (dashed). Deltaic plain facies, ABC Range Quartzite, Middle Gorge.
(f) Large polygonal desiccation crack. Deltaic plain facies, ABC Range Quartzite, Woolshed Flat.

massive purple, trough crossbedded, or massive white to pink, planar crossbedded medium-grained quartzites, and/or massive deep purple to grey-green siltstones, all generally interbedded with purple shales and siltstones. Following these is the dominant cyclical facies of the ABC Range Quartzite (now a purple crossbedded quartzite with purple shale and siltstone interbeds) which interdigitates with the Bayley Range Formation. Above this dominant cyclical facies are deep purple shale-pebble rich, flat-bedded to shallow crossbedded siltstones which grade into fine-, and medium-grained sandstones, overlain by brown to purple, crossbedded coarse-grained to pebbly sandstones, which are in turn overlain by massive white coarse-grained quartzites with granule beds and occasional microconglomerate lenses. In this region the ABC Range Quartzite reaches an estimated maximum thickness of 1800 m (741 m in the subsidiary section) and appears to conformably underlie, and intertongue with the Bunyeroo Formation—except in the westernmost segment of this region, west of longitude 138°02′E. Here pre-Bunyeroo erosion has scoured deep into the quartzite leaving a well-defined discontinuity between the Brachina Subgroup and the Bunyeroo Formation (Fig. 4).

South of this region, outcropping sporadically in the Hummock and Barunga Ranges, is a buff crossbedded sandstone—the Barunga Sandstone. This sandstone is correlated with the ABC Range Quartzite on the basis of outcrop pattern, petrologic and palaeocurrent characteristics.

Interpretation of depositional environments

The present configuration of the Adelaide fold belt appears to reflect the original basin morphology, at least during Brachina Subgroup time. Four readily recognizable regions are present (Fig. 5) displaying differences in their respective sequences related to variations in water depth and sediment influx. The temporal and spatial arrangement of facies within these sequences, along with their textural and sedimentological characteristics, suggest that the regional pattern of sedimentation was regressive, with conditions of deposition shallowing from low energy subtidal, through high energy tidally dominated deltaic plain, mudflat and sandflat, to locally high energy fluvial and non-marine environments.

The two lowermost formations of the subgroup (*viz.* the Nuccaleena and Moolooloo Formations) were deposited under low energy shallow subtidal conditions. Although initially clastic deficient, this period of sedimentation was dominated by the settling of clays from suspension. Within the central region beds of silt and fine sand displaying small-scale cross-lamination, ripple marks and flute casts testify to the interruption of this quiet environment by pulses of higher energy traction currents. The red and purple colouration of these sediments suggests that conditions of deposition were oxidizing. In comparison, the Moolooloo Formation in the northern and eastern regions lacks the coarser material and displays a green colouration, suggestive of greater water depth (Fig. 7a). The presence of graded beds, groove casts and rare flute casts—especially in the eastern region—attest to the existence of traction currents.

The end of Moolooloo Formation deposition in the central and northern regions is marked by pulses of coarser detritus (medium sand sized) and the shallowing to a low intertidal mudflat environment, as evidenced by the presence of tidally oriented ripple mark associations (Fig. 6b), many being flat-topped. Thick beds of massive silt displaying abundant soft-sediment deformation structures (Fig. 6a) attest to the rapid ingression of sediment into a saturated environment. The influx of coarser clastic material—the basal ABC Range Quartzite—occurred in the western region. Reactivation surfaces within sandwave crossbed sets (Fig. 6d and 6e), flat-topped ripple marks and large polygonal desiccation cracks (Fig. 6f) support an intertidal deltaic plain environment of deposition which is bordered by a barrier-bar system. Deeper water remained in the eastern region with green clays and silts still dominant (Fig. 7b). The Moorillah Formation is identified in this region by the presence of red and purple beds of coarse silt and fine sand which display soft-sediment deformation typical of the formation elsewhere.

As shallowing through the intertidal zone gradually progressed and the deltaic plain grew steadily seaward, the Moorillah Formation was replaced throughout the basin of deposition by the green shales and siltstones of the Bayley Range Formation. Sand interbeds exhibiting tidally oriented crossbedding and ripple marks, again often flat-topped (Fig. 6c), along with the intertonguing of these deposits with those of the deltaic plain, support the interpretation of an intertidal mudflat environment for this formation (Fig. 7c). The green hue of these

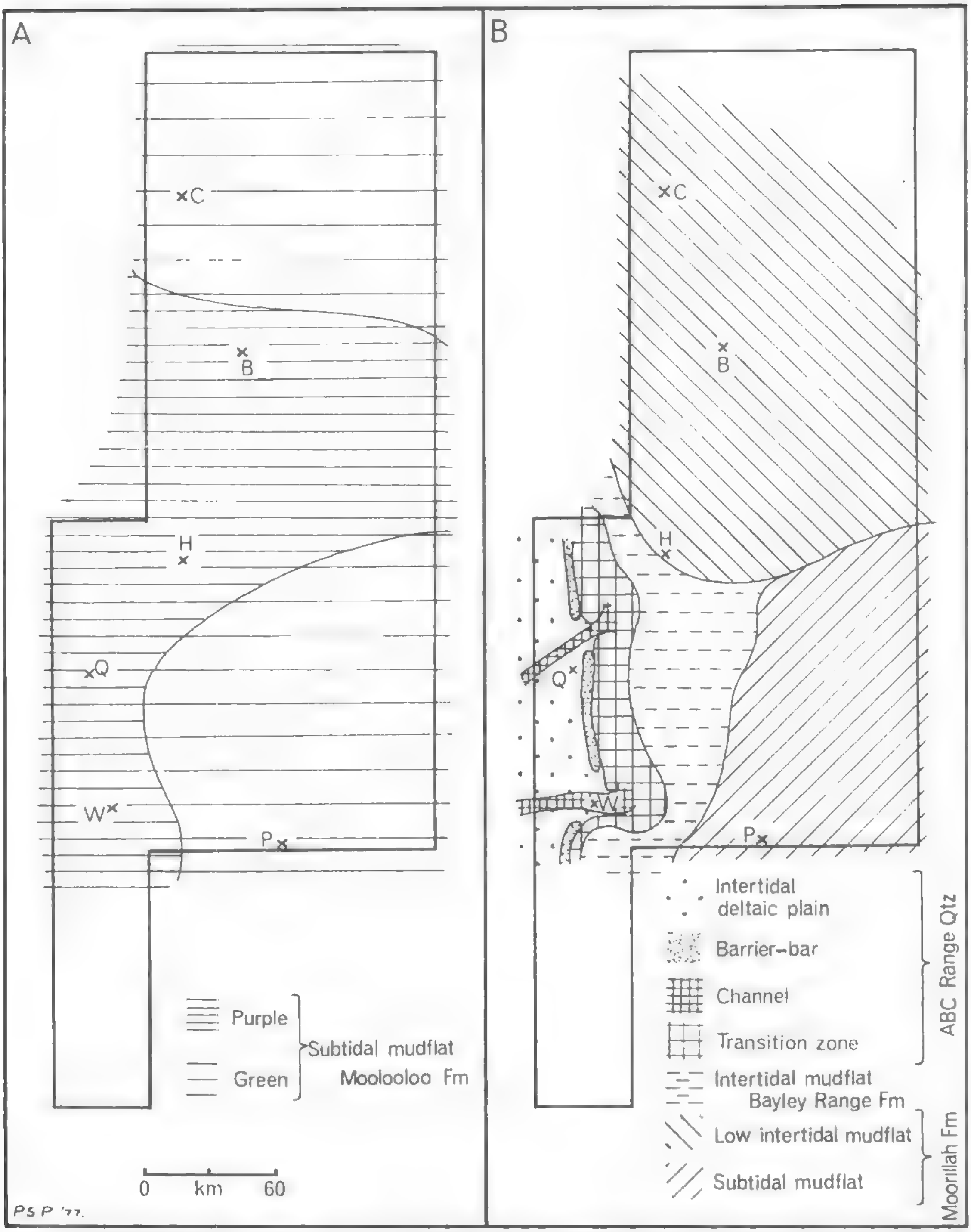
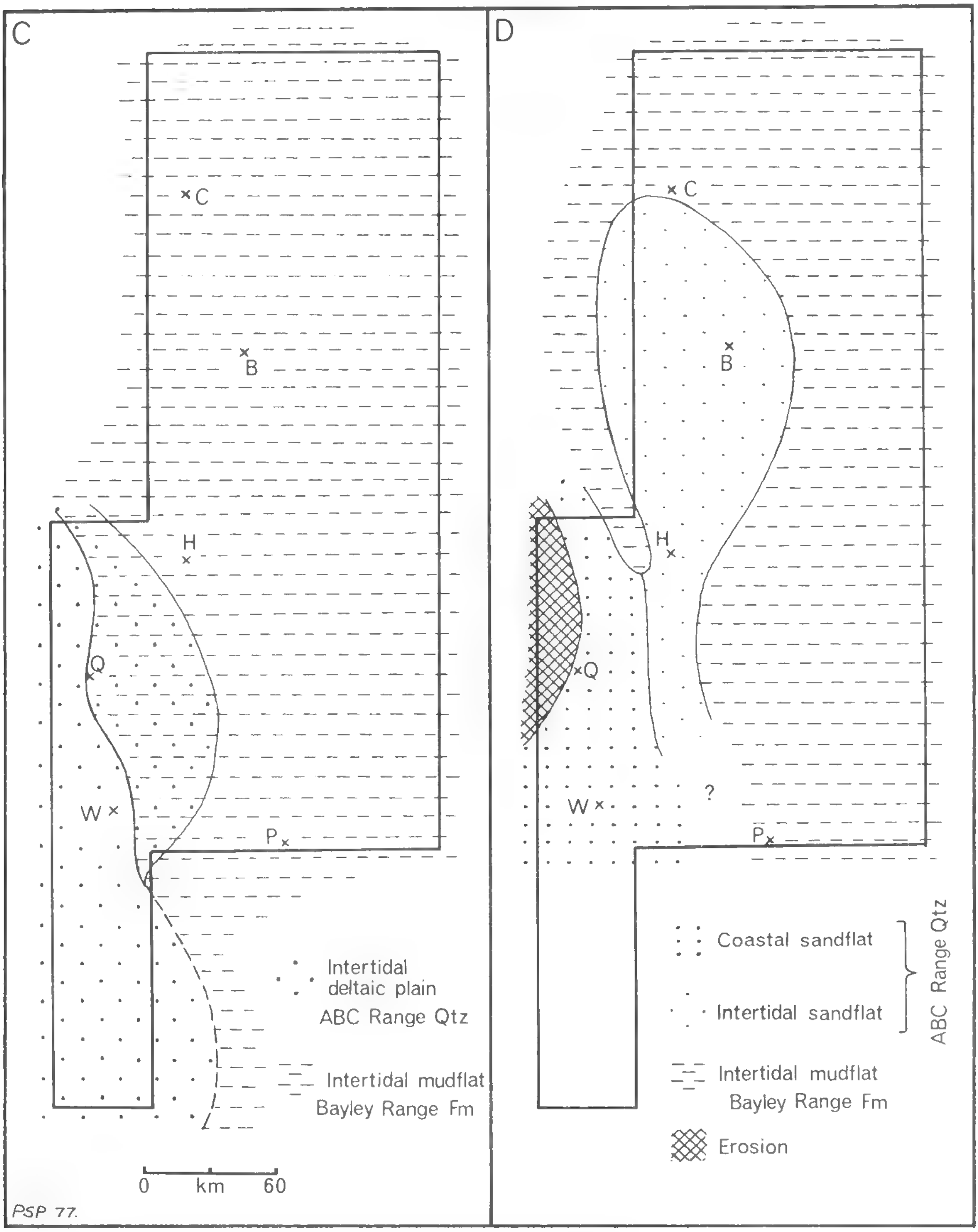
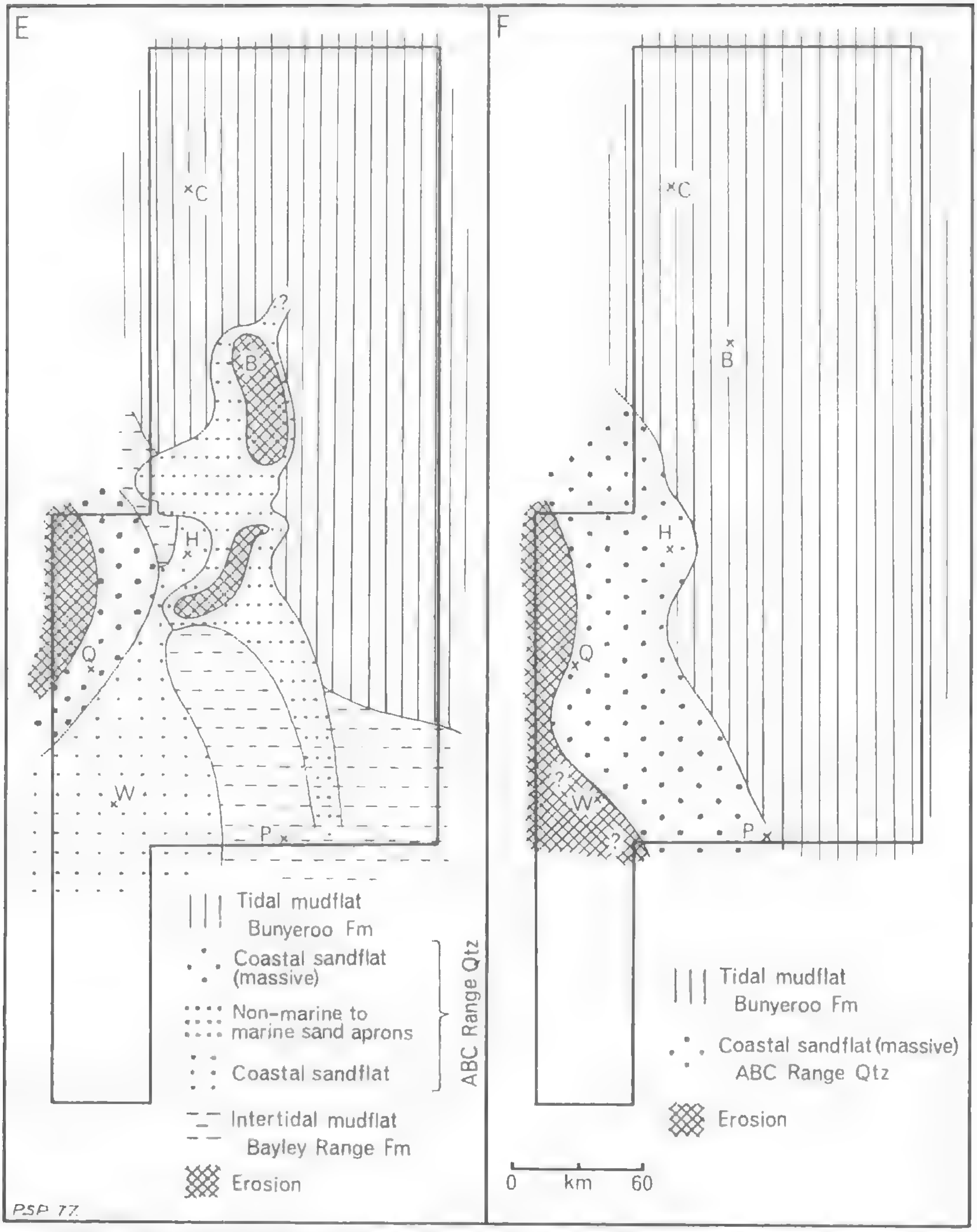


Fig. 7. Palaeogeographic reconstructions through Brachina Subgroup time: A subtidal mudflat; B. initial development of barred delta with adjacent mudflats.



Palaeogeographic reconstruction through Brachina Subgroup time: C. maximum deltaic progradation; D. erosion, and development of intertidal sandflat.



Palaeogeographic reconstruction through Brachina Subgroup time: E. emergence of islands and development of associated non-marine deposits; start of transgression; F. transgressive tidal mudflat and remnant coastal sandflat.

sediments, however, is suggested as being due to greater organic activity[3] in comparison to the greens of the underlying formations which appear to be the result of deposition under greater depths of water.

The rapid increase in sand content toward the top of the Bayley Range Formation reflects continued regression, along with uplift of the western margin of the basin and the subsequent erosion of the deltaic plain deposits, forming a well-defined disconformity in the western region. Eventually this formation is replaced by a massive quartzite—the ABC Range Quartzite—deposited in an intertidal sandflat environment in the central region with spillover into the northern and eastern regions (Fig. 7d). Also, this uplift of the western margin of the basin caused an influx of coarse- to very coarse-grained sand from the west which was probably dispersed along the coast by longshore currents.

Toward the peak of regression the intertidal sandflat received local injections of coarse sand of a different provenance. This sand, with intercalated microconglomerates, forms a longitudinally oriented cap to the Brachina Subgroup. The material appears to have been derived from the regions of the present day Blinman-Enorama-Oraparinna and Worumba 'diapir' complexes and their immediate surrounds in the central Flinders Ranges, and it is postulated that islands emerged within these regions shedding the material through high energy fluviatile and non-marine mid-fan environments into a marine-dominated distal fan (Fig. 7e).

Despite minor renewed uplift in the western region and the resultant reworking of sediment to form a coastal sandflat, a transgression, and subsequent decrease in sediment influx, produced very shallow, low energy conditions of sedimentation under which clays settling from suspension formed the overlying Bunyeroo Formation (Fig. 7f).

Conclusion

Regional stratigraphic mapping has revealed the presence of five separate and distinct lithozones within the lower Wilpena Group that are persistent and readily recognizable throughout the Flinders Ranges. Because lithologic criteria are the basis of subdivision in the late Precambrian Adelaidean succession the form of nomenclature is designed to reflect palaeogeographic significance. As such, the entire lower Wilpena Group is herein defined as the Brachina Subgroup, whilst each individual lithozone is designated with formation status. It is the intention behind this nomenclature that it be applicable to all occurrences of lower Wilpena Group sediments within the Adelaide fold belt.

Acknowledgments

For helpful discussion both in the field and during the preparation of the manuscript the author extends his thanks to Dr V. A. Gostin. Valuable criticism concerning the manuscript was also received from Mr B. Murrell, whilst Dr B. G. Forbes made available his field notes of the Olary region.

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[3] In present day intertidal mudflats where sedimentary structures are well preserved the sediment usually displays a black colouration due to the reduction activity of abundant microscopic organisms.

CHANGE IN GRAZED ARTIPLEX VESICARIA AND KOCHIA ASTROTRICHA (CHENOPODIACEAE) POPULATIONS, 1929-1974

BY T. J. FATCHEN

Summary

A vegetation transect laid in virgin Atriplex vesicaria – Kochia astrotricha arid shrubland in 1929 was relocated and sampled in 1974, after 45 years of grazing. The A. vesicaria population was almost eliminated within the period, and that of K. astrotricha was much reduced. Merits and difficulties in the re-examination of early data records are highlighted.

CHANGE IN GRAZED *ATRIPLEX VESICARIA* AND *KOCHIA ASTROTRICHA* (CHENOPODIACEAE) POPULATIONS, 1929-1974

by T. J. FATCHEN*

Summary

FATCHEN, T. J. (1978) Change in grazed *Atriplex vesicaria* and *Kochia astrotricha* (Chenopodiaceae) populations, 1929-1974. *Trans. R. Soc. S. Aust.* **102**(2), 39-41, 28 February, 1978.

A vegetation transect laid in virgin *Atriplex vesicaria* — *Kochia astrotricha* arid shrubland in 1929 was relocated and sampled in 1974, after 45 years of grazing. The *A. vesicaria* population was almost eliminated within the period, and that of *K. astrotricha* was much reduced. Merits and difficulties in the re-examination of early data records are highlighted.

Introduction

The importance of *Atriplex* and *Kochia*[1] species to pastoral interests prompted a number of early investigations into their ecology (e.g. Cannon, 1921; Murray, 1931). Although most of the researches were of a descriptive or anecdotal nature, those of Osborn, Wood & Paltridge (1932) relied heavily on quantitative data. The data records for the 1932 paper in particular were much more extensive than was reported, and are still in existence at the Department of Botany, University of Adelaide. They comprise field notes giving the location and a general description of the several study areas: the origin, direction and length of the transects used in sampling; the number and position of individuals of target species along the transects; and the height, widest diameter and condition of foliage for each individual. The basic survey technique was the use of belt

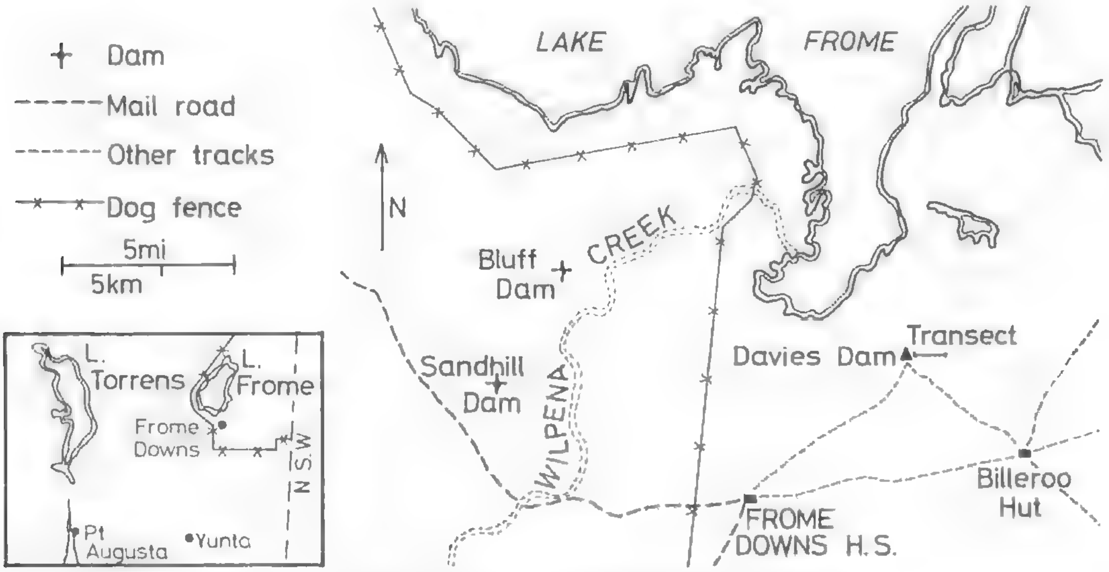

Fig. 1. Frome Downs area showing location of transect.

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[1] Nomenclature as in Black's Flora of South Australia.

* National Parks & Wildlife Division, Department for the Environment, Box 1782, G.P.O., Adelaide. S. Aust. 5001.

Table 1: Number of individual plants in transect.

Species	Individuals 1929	Individuals 1974
A. vesicaria	946	4
K. astrotricha	299	80
K. aphylla	–	26
K. pyramidata	–	9
Total *Kochia*	299	115
Total shrubs	1245	119

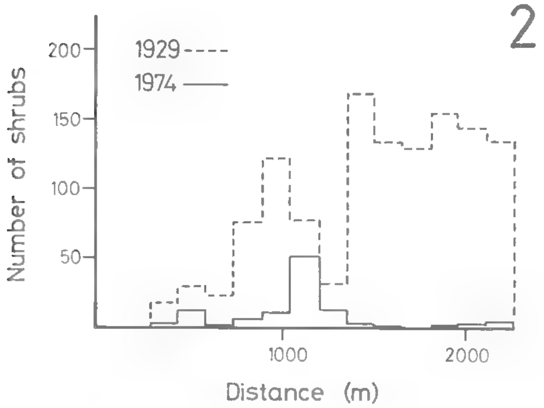

Fig. 2. Distribution of all shrubs in the transect, 1929 and 1974.

transects radiating from stock watering points. Three were laid in virgin pasture on Frome Downs station, S. Aust. (Fig. 1), in 1929, each having a newly sunk dam as its starting point.

These data have received no further attention since 1932, despite their potential as a baseline for accurately determining changes in specified plant populations in the long term. This communication describes the results of re-examining an early, documented traverse, demonstrates the standard of information obtainable and highlights the problems arising on re-examination.

Methods

Efforts were made to relocate the three traverses documented by Osborn *et al.*, but two of the three could not be found, dams having either changed their names beyond recognition or fallen into disuse. The third and longest was relocated and sampled in March 1974. The dam at the start of this transect was originally named Davis's, but time and changed ownership had corrupted this to Davie's.

The 1929 scoring methods were followed (see details in Osborn *et al.*, 1932) with two exceptions: distance was measured by rangefinder rather than paces, and foliation was not measured because of the disparity between the 1929 and 1974 seasons. The transect was sampled from the original starting point, but on a compass bearing allowing for the intervening magnetic variation. All perennial *Atriplex* and *Kochia* species were scored.

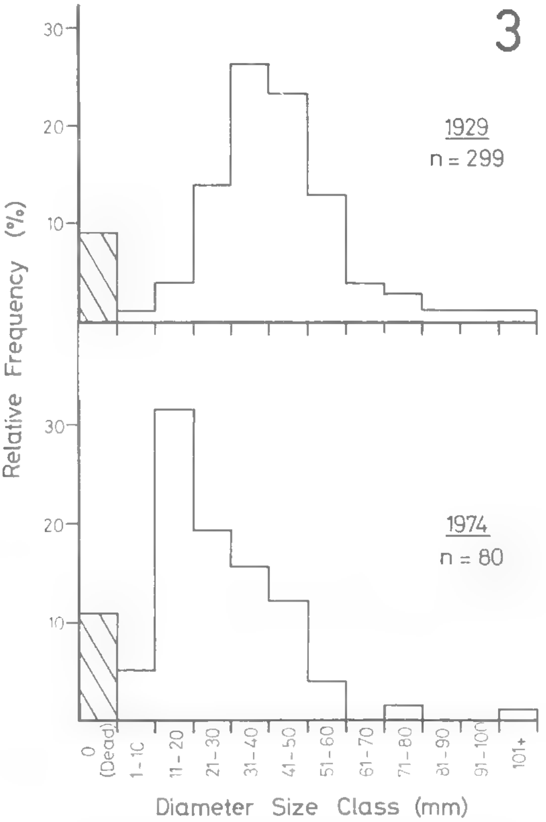

Fig. 3. Relative frequency distribution of largest diameters of *K. astrotricha* canopies, 1929 and 1974.

The stocking history was sought by reference to station books, past and present lessees and the South Australian Pastoral Board.

Results

Stocking history

Stock records for the area are almost non-existent. Davie's dam was sunk shortly before 1929, but not stocked because of drought. For the next ten to fifteen years, sheep may have watered from it. Cattle certainly watered from it after 1946, and may have been present from the start. There are no figures on stocking variation in the immediate area of the dam.

Rabbits had become established in the area well before 1929.

Vegetation change

Table 1 summarises the results. The clearest changes with time are (a) the almost total elimination of the *Atriplex vesicaria* population and (b) the decimation of the *Kochia astrotricha* population. These changes were found not only in the immediate vicinity of the dam, but extended throughout the whole transect (Fig. 2).

K. aphylla, not mentioned at all in 1929, was a significant component of the shrub vegetation in 1974. Similarly, some *K. pyramidata* was noted in 1974 but not in 1929.

K. astrotricha individuals were smaller in 1974 than in 1929, with the mode of diameter size class reduced from 31-40 cm to 11-20 cm (Fig. 3). A proportional change in height was also noted.

Discussion

Re-examination of the transect and evaluation of the resulting data has inherent difficulties, of which the worst is determination of past stocking rates. Although a dramatic change in the pasture vegetation is documented here, the cause cannot be indentified with certainty. Domestic stock grazing is the most probable, as rabbits were already present in 1929, and no evidence was found of other factors such as fire. Given this, the stocking levels which brought about such changes are not known. Nor is it certain whether the changes were gradual or sudden, nor even which of sheep or cattle initiated the process.

Present experience also indicates that documentation intended to allow future relocation of study sites must be more thorough than early investigators realized. No matter how comprehensive the original field notes, reference points such as fences or dams can go out of commission and memory, or at least change names with time.

Insufficiency in the original data may prevent their most efficient use. For instance, although Fig. 3 suggests a change in *K. astrotricha* age structures between times, the original data are not comprehensive enough to test this adequately: the size structure of a pasture shrub may be largely dependent on season or grazing pressure, and without supporting evidence independent of these factors cannot be taken as indicative of age structure. As a further example, both *K. aphylla* and *K. pyramidata* may well have increased since 1929; or alternatively may have been of no interest then and hence not scored.

Nonetheless, despite such limitations, the repeat of the 1929 observations has yielded two significant results. First, if stocking is the cause of changes as seems most likely, a population of *K. astrotricha*, albeit diminished, can survive while a much large population of *A. vesicaria* is eliminated. Second, irrespective of whether sheep or cattle were responsible for the initial changes, cattle grazing has at least maintained the effects of the original impact since 1946, and may have been the original agent. This in turn suggests that the impact of cattle grazing on these chenopods may not differ significantly from that of sheep grazing.

Such results far outweigh the attendant limitations and are relevant in their own right. Further examination of the rest of the Osborn *et al.* data is likely to yield far more extensive and significant information.

Acknowledgments

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DEFORMATION HISTORY OF THE OUTALPA AREA AND ITS APPLICATION TO THE OLARY PROVINCE, SOUTH AUSTRALIA

BY R. F. BERRY, R. B. FLINT AND A. E. GRADY

Summary

The structural and metaphoric history is outlined for a small area of Willyama Complex and its Adelaidean cover rocks in the central Olary Province. Five penetrative events (three major, two minor) affect basement rocks, while the final two phases also occur in the cover rocks. The clear distinction between basement and cover deformations of similar orientation (D_3 and D_5) coupled with a more complete deformation history allows concise interpretation of observable mesoscopic structures. Four metamorphic events are indicated: a mid amphibolite facies event associated with the earliest deformation; greenschist facies retrogression associated with the second and third basement deformations (in basement only), and a final greenschist facies metamorphism associated with the final two deformation phases. Six significant faults are recognised, three of which post-date cover deposition. Comparisons made between this area and four others suggest that the general relations are valid over a wide area of the Olary Province. The structural history determined at Outalpa is consistent with the history of Willyama Complex rocks at Broken Hill.

DEFORMATION HISTORY OF THE OUTALPA AREA AND ITS APPLICATION TO THE OLARY PROVINCE, SOUTH AUSTRALIA

by R. F. Berry,[1] R. B. Flint[2] and A. E. Grady[1]

Summary

Berry, R. F., Flint, R. B. & Grady, A. E. (1978) Deformation history of the Outalpa area and its application to the Olary Province, South Australia. *Trans. R. Soc. S. Aust.* 102(2), 43-53, 28 February, 1978.

The structural and metamorphic history is outlined for a small area of Willyama Complex and its Adelaidean cover rocks in the central Olary Province. Five penetrative events (three, major, two minor) affect basement rocks, while the final two phases also occur in the cover rocks. The clear distinction between basement and cover deformations of similar orientation (D_3 and D_4) coupled with a more complete deformation history allows concise interpretation of observable mesoscopic structures. Four metamorphic events are indicated: a mid amphibolite facies event associated with the earliest deformation; greenschist facies retrogression associated with the second and third basement deformations (in basement only), and a final greenschist facies metamorphism associated with the final two deformation phases. Six significant faults are recognised, three of which post-date cover deposition. Comparisons made between this area and four others suggest that the general relations are valid over a wide area of the Olary Province. The structural history determined at Outalpa is consistent with the history of Willyama Complex rocks at Broken Hill.

Introduction

Crystalline basement rocks of the Olary Province form part of the lower Proterozoic Willyama Complex which extends from the Olary region of South Australia to the Broken Hill area of New South Wales. At Outalpa Station, 140 km west of Broken Hill, these rocks are unconformably overlain by metamorphosed upper Precambrian (Adelaidean) sediments of the Burra and Umberatana Groups. The broad stratigraphic relationships have been established by Campana & King (1958).

The area studied (Figs 1, 4) has a central granodiorite body that is now fully albitised. On its eastern flank this is partially bounded by a migmatite zone which grades outwards into structurally overlying psammitic and pelitic schists with elongate pods containing corundum and beryl. Further to the east is a faulted block of massive, coarse-grained quartz-feldspar-biotite gneiss.

A high-angle unconformity separates the older rocks from the onlapping Adelaidean sediments. These consist of a lower sequence of shallow water marine sediments characterised by a discontinuous basal conglomerate, and an upper sequence of pebbly siltstones, shales, quartzites and tillitic units. The lower and upper sequences are correlated with the Burra and Umberatana Groups respectively.

Within the Olary area, the deformational history of the Willyama Complex and Adelaidean metasediments is only poorly known. Talbot (1967, 1969) has discussed the structural style at Weekeroo. This report on the Outalpa area gives a more detailed, phase related interpretation of the deformation history.

Structural interpretation of the Outalpa area

Structural analysis of the area is based on widespread mesoscopic and macroscopic overprinting criteria and the assumption of coherence of orientation of tectonic fabric elements. Fold style could not be used in this analysis as the different phases can have similar and overlapping styles which appear to be a function of rock type and deformation intensity. The history of deformation involves five

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[1] School of Earth Sciences, Flinders University of S.A., Bedford Park, S. Aust. 5042.

[2] Geological Survey of South Australia.

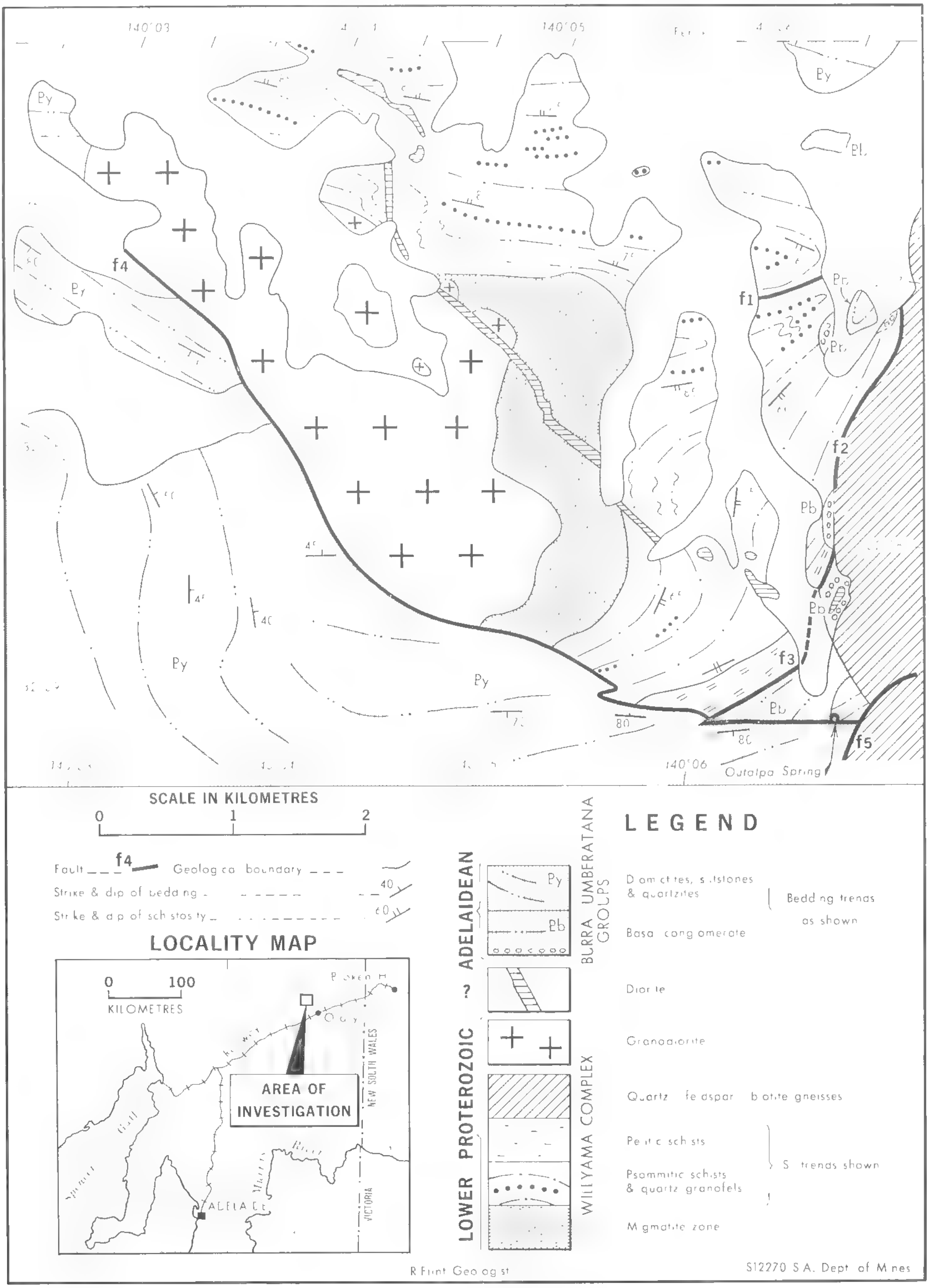


Fig. 1. Geological sketch map of the Outalpa Springs area.

TABLE 1

Summary of structural and metamorphic events recognised at Outalpa.

Event	Time	Structural Elements	Comments
D_1	Lower Proterozoic	S_1	Schistosity and gneissosity. Granodiorite intrusion. Mid-amphibolite facies metamorphism
D_2		S_2,F_2	Open folding and crenulations
D_3		S_3,F_3	Macroscopic tight folding, strong mesoscopic crenulation cleavage. Retrogressive green-schist facies metamorphism
		f_1	Late D_3 faulting
		f_2	Block faulting
		UNCONFORMITY	EROSION
		S_0-ADEL	Adelaidean sedimentation: deposition of basal Burra Group and overlying Umberatana Group sediments
D_4	Delamerian Orogeny 450-500 m.y.	S_4F_4,f_3	Schistosity in cover metasediments and crenulations in the basement. Basement-cover interactions giving tight synclines and broad anticlines in the unconformity. Barrovian type upper greenschist facies metamorphism
		f_4	Block faulting
D_5		S_5,F_5	Cleavage and schistosity in cover metasediments, crenulations in the basement. Open anticline over the granodiorite resulting in opposite plunging F_4 synclines in cover rocks. Continuing Barrovian type upper greenschist facies metamorphism
		f_5	Late block faulting, producing local horizontal crenulations.

penetrative deformational events and six faults of which three affect only the basement. This provides a framework in which to consider information available from other sections of the Olary Province. The deformational history is outlined below and summarised in Table 1.

Deformation 1 (D_1)

A strong, pervasive schistosity (S_1) defined by the basal planes of muscovite in the schist zone and biotite in the granodiorite and migmatite zones constitutes the first recognisable phase of deformation. This schistosity is normally parallel to remnants of bedding and compositional layering, however rare mesoscopic D_1 isoclinal folds were observed. The foliation in the granodiorite is parallel to the schistosity and gneissosity of nearby metasediments.

The granodiorite has an aureole consisting of an inner zone of intense migmatite development and an outer zone of feldspar blastesis. These textures are indicative of temperatures in the range 650–720°C at 2–4 kb (Mehnert 1968). The muscovite content of surrounding schists decreases (and biotite content increases) as the more gneissic and migmatitic terrains are approached. The gradual disappearance of muscovite is expected in the middle amphibolite facies due to the breakdown of its paragonite component (Thompson 1974) and a range of reactions with coexisting minerals (Thompson 1976). The earliest recognised period of deformation was associated with amphibolite facies metamorphism as has been recorded previously from other areas of the Willyama Complex (e.g. Talbot 1967).

Deformation 2 (D_2)

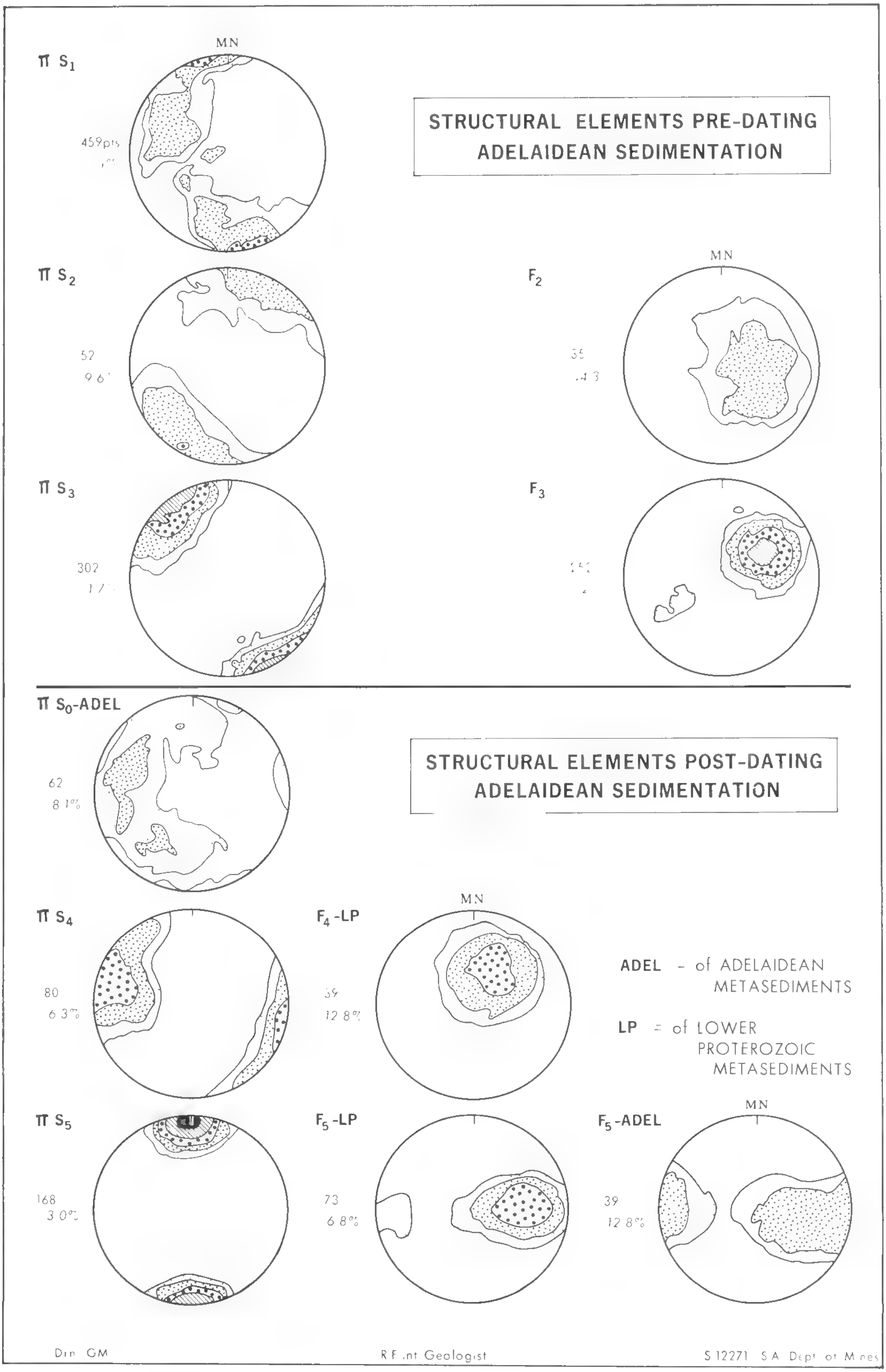
A weak crenulation (S_2) is recognised locally within the Willyama Complex metasediments. It is restricted to the pelitic units and has been obscured by later deformational phases.

Opposite plunging third phase fold axes in the north of the study area (Fig. 3) suggest that the second deformation had produced an open synform in S_1 prior to both D_3 and the fault f_1.

Recognition of D_2 folds is difficult where no overprinting criteria are available. However, axial planes of crenulations indicate a steep dip for S_2, with a strike varying from 090° to 180° but concentrating at 120°. The fold axes (F_2) have a diffuse orientation. Muscovite crystallised in the axial plane of this phase but the grade of metamorphism could not be determined. Retrogression of D_1 mineralogy probably began during this phase.

Deformation 3 (D_3)

The third phase of folding produced a tight eastward plunging macroscopic antiform (half wavelength of 3 km) over the granodiorite


STRUCTURAL ELEMENTS PRE-DATING ADELAIDEAN SEDIMENTATION
π S1
MN
459pts
π S2
52
9.6
F2
MN
35
14.3
π S3
302
1.7
F3
STRUCTURAL ELEMENTS POST-DATING ADELAIDEAN SEDIMENTATION
π S0-ADEL
62
8.1%
π S4
80
6.3%
F4-LP
MN
39
12.8%
ADEL - of ADELAIDEAN METASEDIMENTS
LP = of LOWER PROTEROZOIC METASEDIMENTS
π S5
168
3.0%
F5-LP
73
6.8%
F5-ADEL
MN
39
12.8%
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R Flint Geologist
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(Fig. 1). The mesoscopic fabric elements are a strong crenulation and a crenulation cleavage in more pelitic rocks. This phase has been most effective in redistributing S_1 and S_2.

Third phase axial plane structures (S_3) are constant in orientation (Fig. 2), except for slight variations in the southeastern sections where late generations are strongest (Fig. 3). Muscovite crystallised in the axial plane of D_3 mesoscopic folds which is compatible with continued retrogressive greenschist facies conditions.

Adelaidean sedimentation

A major unconformity truncates the macroscopic D_3 antiform providing a separation of fold generations into pre- and post-cover. Adelaidean sediments are fault-separated into an onlapping basal sequence (Burra Group), and an upper tillitic sequence (Umberatana Group). Further west, Talbot (1967) has shown that equivalents of the upper sequence unconformably overlie the basal sequence.

The Adelaidean rocks are strongly folded. The northern outcrops of the Burra Group (Fig. 1, northeast corner) occupy a tight northward plunging syncline. A central pocket of Burra Group conglomerates define a small elongate basin. Near Outalpa Springs the outcrop suggests a southerly plunging syncline but transposition and metamorphism has obscured bedding and an exact delineation of the structure was not possible. These three patches are not simply related as the northern tongue is associated with a hinge trace which strikes out across the basement west of the southern and central outcrops. The variation in plunge of the hinge line of these north south folds is ascribed to the fifth phase of folding.

In the Umberatana Group bedding is strongly folded about an east west hinge and the north trending folds can only be detected by perturbations in the cylindrical nature of these easterly trending folds. Note the diffuse nature of the great circle containing poles to bedding (S_0-ADEL).

Deformation 4 (D_4)

The fourth generation of folding in the Willyama Complex metasediments is equivalent to the first event recognised in the cover rocks. Within the older schists crenulations are produced with NNE striking axial surfaces.

In the basal sequence of the Adelaidean sediments this phase produced a tight syncline with an axial plane schistosity (S_4) defined by biotite, chlorite and actinolite indicating biotite zone greenschist facies conditions (Winkler 1967). No mesoscopic elements were observed within sediments of the Umberatana Group. However, open macroscopic folding of this upper sequence is inferred from the distribution of bedding and F_5-ADEL (Fig. 2).

The geometry of fourth generation folding is controlled by the basement cover interaction. The tight syncline in the Burra Group is associated with the more schistose members of the basement. It is similar in style to the synclines in the unconformity found at Weekeroo (Talbot 1967). D_4 mesoscopic structures at Outalpa predominate in the cover syncline and are common in the nearby basement rocks. They are rare in basement rocks further from this contact and were not found in sediments of the Umberatana Group.

The orientation of the axial plane of these mesoscopic structures (S_4) is constant over most of the area but refracts across the basement cover contact in the southeastern map area.

Deformation 5 (D_5)

The fifth penetrative deformation has produced easterly trending crenulations and gentle macroscopic folds within the Willyama Complex metasediments. In the cover rocks mesoscopic structural elements vary from a slaty cleavage in the pebbly siltstones and arenites, to a schistosity defined by biotite and chlorite in the pelites. Anticlinal folding of the basal unconformity has produced a variable plunging complex D_4 syncline (Fig. 3). Reactivation of basement structures was restricted to a tight fold in the southern fault (f_4) where S_1 and S_5 are subparallel, and to minor folds in the conglomerate in the northeastern map area where S_3 and S_5 are subparallel. No major tight synclines in the unconformity were observed, nor does S_5 refract across the basement-cover boundary (Figs 2, 3).

As S_4 and S_5 are steep and strike at 90° to each other the plunges of F_5 folds provide an indication of the geometry of the previously singly folded Adelaidean bedding. Fold axis plunges ($F_{5\text{-ADEL}}$) vary over 120° suggesting

Fig. 2. Lower hemisphere equal area projections of structural data from the Outalpa area. Contours at 1, 2, 4, 8, 16% per 1% area. Computer contouring using counting cell area shown in brackets. Planar elements plotted as poles.

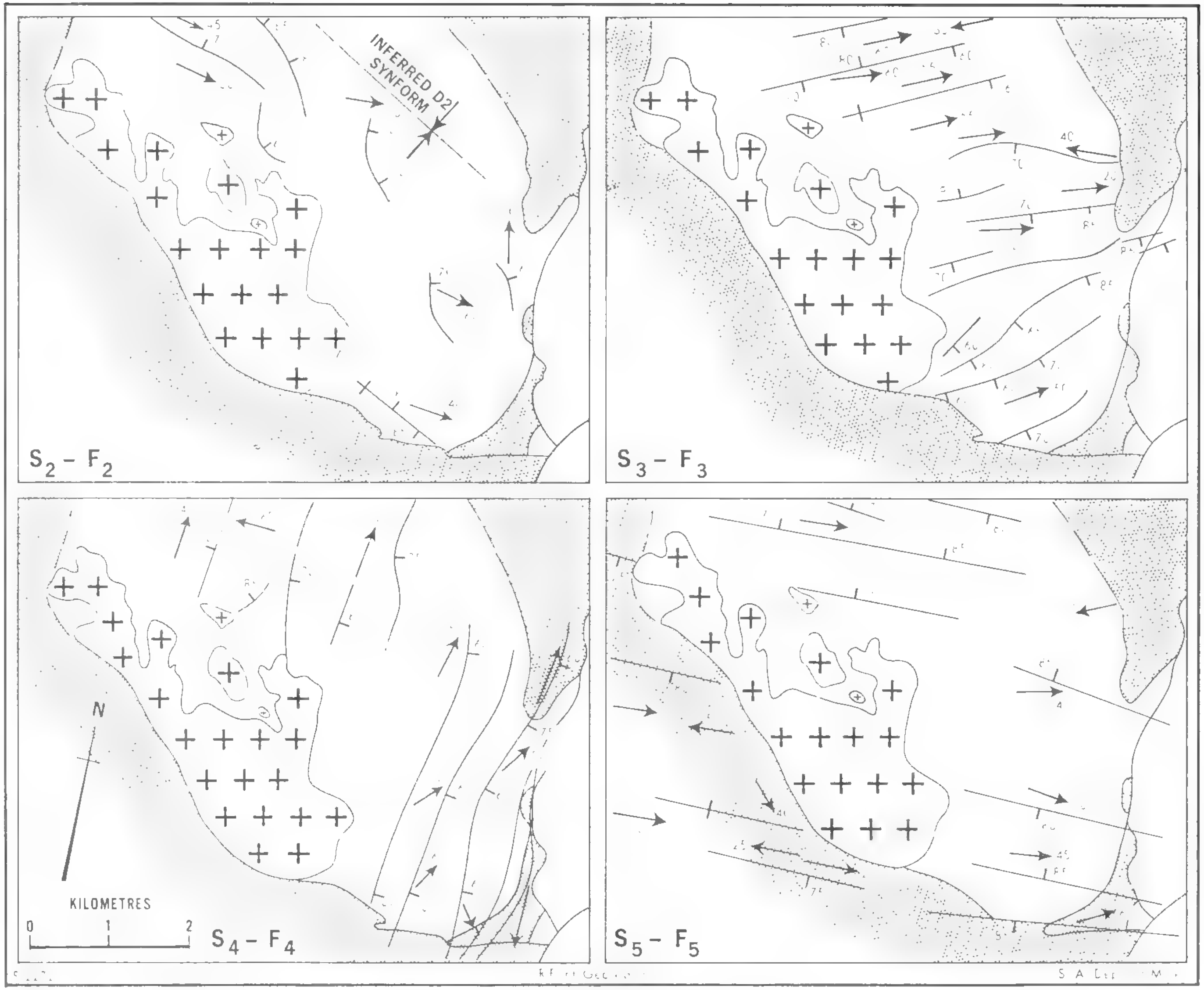

Fig. 3. Strike lines for axial planes produced during 2nd, 3rd, 4th, 5th deformations at Outalpa. Lines represent a composite result from measured mesoscopic data showing significant variations in the strike of these surfaces. Representative dips and fold axes are included.

open to close fourth generation folds. The concentrated maxima for basement fold axes indicates that little reorientation of S_1 took place during the fourth and fifth phases.

Both the cover deformations (D_4 and D_5) have associated schistosities. S_4 is restricted to within the tight syncline of the Burra Group. This was probably the result of an increased rate of recovery and recrystallisation due to higher strain and temperature conditions during the development of the tight D_4 syncline. The regionally more significant fifth deformation was associated with the peak of metamorphic conditions (upper greenschist facies) for the cover rocks. Generally, the fifth deformation had a more homogenous effect on both basement and cover rocks. This suggests that recrystallisation was more advanced and the viscosity difference between the two units reduced. This hypothesis is supported by the changing shear response of the cover. The fault f_3, which is syn-D_4 is a shear zone while faults postdating D_4 (e.g. f_4 and f_5) have a single shear plane.

Faults

Six faults, five of which are indicated in Fig. 1, can be given relative ages from their interactions with structural elements discussed previously. They are considered in two groups.

Faults Pre-dating Adelaidean Sedimentation

There are three near-vertical faults whose movement predates the beginning of Adelaidean sedimentation. The inferred D_2 synform (as indicated by the systematic change of F_3 plunge) is truncated by the small fault, f_1. The fault is in turn truncated by the unconformity at the base of the Adelaidean sediments. We conclude that motion on the fault occurred after D_2 but before Adelaidean sedimentation. As f_1 is subparallel to S_3 a genetic relationship is possible. The fault may have been effected by the pre-existing S_3 surface or may be an anticlinal reverse fault associated with the D_3 compression.

The diorite dyke, striking 135° across the area (Fig. 1), has been injected into a fault over the major part of its length. In the central map area this fault displaces the margin of the granodiorite by at least several tens of metres. The fault is locally folded by D_3 but the age relationship of diorite intrusion could not be determined.

A large fault, f_2 bounds the eastern gneiss block and is truncated by the unconformity. A large difference in rock types adjacent to f_2 indicates a large fault movement. The fault is unaffected by the third phase deformation and is the last recognised phase of tectonic activity prior to Adelaidean sedimentation.

Faults post-dating Adelaidean Sedimentation

Three faults involve displacement of the younger metasediments and postdate at least that part of the sedimentation involved in the units recognised in the study area.

A shear boundary, f_3, dipping 80° to the southeast, reflects the intense deformation in the younger metasediments during the fourth deformation. The intense deformation was primarily due to the large variation in competence between the Willyama Complex metasediments and the Adelaidean metasediments. Movement continued on f_3 over a long period of time and although it was initiated prior to the development of fault f_4, f_3 displaces f_4 slightly.

The fault f_4 is near vertical with a large vertical displacement. It is folded locally by D_5 and is truncated by f_5. Movement on f_4 was probably synchronous with the fifth deformation.

In the southeast a near vertical fault, f_5, truncates f_1 and the southern extension of f_2. Within pelitic rocks close to this fault, a new crenulation, dipping at 10° to 080°, has been produced. The area of intersection of f_2, f_1 and f_5, near Outalpa Springs, is a very complex crush zone. A simplified interpretation is shown in Figure 1.

Comparison with other studies

Other structural studies within the Olary Province have led to a confused structural history. This is partly due to the large variety of rock types studied and the varying details established. In an attempt to synthesise the available information the probable correlations of structures from various areas are highlighted (Table 2). Areas from which data are available are shown in Figure 4.

Wiperaminga Hill

Parker[1] and Robertson[2] discuss in detail a small area southeast of Kalabity Homestead. The early, pervasive, sillimanite-mica schistosity parallel to pegmatitic segregations observed

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[1] Parker, A. J. (1972) A petrological and structural study of a portion of the Olary Province west of Wiperaminga Hill, S.A. (Unpubl. B.Sc. Hons. Thesis, Univ. of Adel.)

[2] Robertson, R. S. (1972) Petrological and structural investigation of the Willyama Complex rocks Wiperaminga Hill area, S.A. (Unpubl. B.Sc. Hons. Thesis, Univ. of Adel.)

TABLE 2

Comparison of structural interpretations from various studies in the Willyama Block (see text for sources).

OUTALPA	WIPERAMINGA HILL	WEEKEROO		MOUNT HOWDEN	BILLEROO HUTS	BROKEN HILL
		after Talbot	from this paper			
D_1 Muscovite biotite schistosity	Muscovite, biotite sillimanite schistosity	Muscovite biotite schistosity gneissosity		Muscovite biotite schistosity. Mesoscopic isoclinal folds	Muscovite biotite schistosity	Sillimanite biotite schistosity/gneissosity Some mesoscopic folds.
D_2 Open macroscopic folds Rare crenulations and mesoscopic folds						Sillimanite schistosity in high grade rocks Weak open macroscopic folds in some medium grade rocks
D_3 Tight upright macroscopic folds Common mesoscopic folds and crenulations Fault f_1 may be related to this phase	Tight upright macroscopic folds	Tight upright macroscopic folds		Vertical crenulation cleavage	Subvertical crenulation cleavage (possibly a later phase)	Open upright macroscopic folds associated with some of the retrograde sheer zones
	Shear zone crenulation age unknown				Crenulation (cf orientation at Wiperaminga Hill)	
UNCONFORMITY						
D_4 Tight upright macroscopic folds in the unconformity Gentle folds in cover distant from unconformity Crenulations in the basement biotite muscovite chlorite schistosity in strongly deformed parts of cover	?	Basement kinks Cover schistosity and cleavage	Open crenulations in the basement Biotite muscovite chlorite actinolite schistosity in cover	Two later sets of crenulations	?	Late crenulations
D_5 Open folds in cover Gentle folds in the basement Crenulations in the basement and nearby cover A new biotite muscovite chlorite schistosity cleavage in the cover	?		Mesoscopic and macroscopic folds and crenulations in the cover A new biotite muscovite chlorite schistosity cleavage in parts of the cover			

R.B.F. R., S.A. Department of Mines and Energy

correlates well with the S_1 schistosity of this study. This schistosity was assumed to be the axial plane to isoclinal folds. Cross-cutting relationships of schistosity and bedding were rarely observed.

Tight macroscopic folds of the early schistosity were developed with an associated biotite-chlorite schistosity and relatively tight crenulations. These folds have a steeply dipping axial plane striking from 030° in the west to 105° in the east, with steeply but variably plunging fold axes. This phase is correlated with D_3 at Outalpa which is also responsible for macroscopic folds within the basement.

A weaker late phase is associated with macroscopic shear zones which dip 80° to 315°. No apparent correlation exists with the Outalpa area.

Weekeroo

Talbot (1967, 1969, 1962[3]) defined several deformations in the cover and basement north-west of Weekeroo Station (Fig. 4). Basement layering and schistosity, defined by muscovite and biotite, are parallel except in rare isoclinal hinges. The D_1 phase (at Outalpa) is correlated with this schistosity.

Within the basement, a crenulation cleavage with tight macroscopic folds has a subvertical axial plane striking 070°, with fold axes plunging 60° to 070°. The D_3 deformation of our study is correlated with this folding phase at Weekeroo.

A later set of kink bands in basement rocks has moderate to steep axial planes dipping towards 100°. They may correlate with the S_4 phase at Outalpa (dipping 75° towards 090°).

Adelaidean cover metasediments unconformably overlying basement as at Outalpa, are folded with poles to bedding forming a diffuse great circle about an axis plunging 40° towards 075°. Axial plane structures developed are a cleavage in psammites and a schistosity in

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[3] Talbot, J. L. (1962) A study of the structural and metamorphic relationships between older and younger Precambrian rocks in the Mt Lofty-Olary Arc, South Australia. (Unpubl. Ph.D. Thesis, Univ. of Adel.)

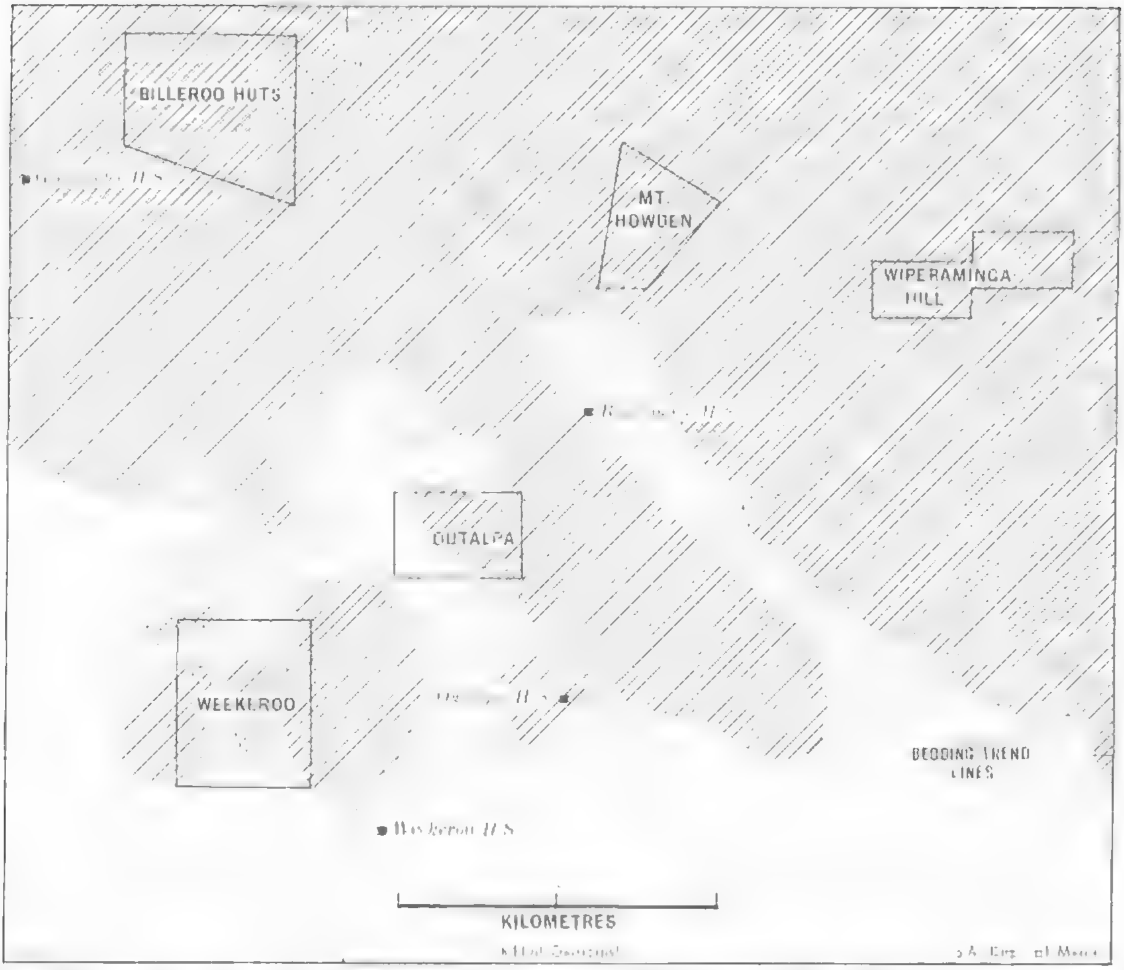

Fig. 4. Locality map for areas considered in comparison study. Bedding trend lines shown for cover metasediments. Diagram modified from Campana & King 1958; and Dickson (1975)[5].

pelites. The axial plane predominantly dips at 80° towards 160°, but the dip direction varies around to 120°. This has been interpreted as a single phase of deformation.

A brief study of the mesoscopic structures by the authors revealed that the basement crenulation cleavage (Weekeroo) correlated with S_3 (Outalpa) is overprinted by an open crenulation with an axial plane subvertical and striking 010°. In the cover the earliest schistosity strikes 020° and involves biotite, chlorite and actinolite as at Outalpa. It is correlated with S_4.

This early cover schistosity is folded and crenulated by a later fold phase which commonly has a subvertical axial plane schistosity striking 040° to 060° which we correlate with the fifth deformation at Outalpa. A new cleavage and schistosity is produced in some areas. This phase at Weekeroo produced tight short wavelength folds parallel to the third phase basement structures which Talbot (1969) has interpreted as basement reactivation features.

Mount Howden

Flint & Flint[4] summarised the structure in the vicinity of the Mt Howden mine. An early schistosity and gneissosity are associated with mesoscopic and macroscopic isoclinal folds. A later vertical crenulation cleavage, striking

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[4] Flint, R. B. & Flint, D. J. (1975) Preliminary geological investigations on the CURNAMONA 1:250 000 sheet. S.A. Dept. Mines unpubl. rept. 75/124.

[5] Dickson, I. W. (1975) Exploration Licence No. 130, Olary Province, S. Aust. S.A. Dept. Mines Open File, Env. 2441 (unpubl.).

020°, associated with tight mesoscopic folds is subparallel to the early schistosity. We correlate the schistosity and crenulation cleavage with the D_1 and D_3 phases at Outalpa.

At least two later crenulation cleavage phases were recognised but insufficient evidence was found to separate them in the area examined. The axial planes have a variable strike but always dip steeper than 45° and are probably equivalent to the later phases at Outalpa.

Billeroo Huts (Flint & Flint)[4]

An early schistosity and gneissosity found in the Billeroo Huts area is overprinted by a very strong crenulation cleavage, which is subvertical and striking 090°. The former surface correlates with S_1, but the crenulation cleavage can not be clearly correlated with Outalpa. It may be a result of D_3 or D_5.

A weak late crenulation cleavage with a steep axial plane striking 050° has no apparent correlation with any structures in our study but is similar to the shear zone crenulation observed at Wiperaminga Hill.

Broken Hill

A summary of the structural history of the Broken Hill area is presented in Glen *et al.* (1977) and a comparison made between structures of the Gawler and Willyama Domains. Similar sequence of events and deformational styles were shown for the two areas.

At Broken Hill in the highest grade rocks, the first recognised structure is a sillimanite-biotite schistosity and gneissosity parallel to layering. This varies to a muscovite schistosity, which is oblique to layering, in the low grade rocks. At Outalpa the first deformation has a schistosity which is subparallel to layering.

The second deformation of Glen *et al.* (1977) in the high grade rocks is associated with a sillimanite-biotite schistosity and tight, upright folds. However in medium and low grade areas no mesoscopic structures were observed and the only suggestion of this deformation is in variations of S_1 orientation. The latter case is very similar to D_2 at Outalpa where S_2 fabrics are rare and variations in S_1/S_3 intersections have been used to imply a D_2 synform.

The third deformation at Broken Hill developed upright open folds trending north-easterly in both high and low grade rocks. Metamorphism is of variable grade and the S_3 axial plane is defined by mica, chlorite and more rarely sillimanite. Retrograde shear zones parallel to S_3 are probably of the same age (Glen *et al.* 1977). At Outalpa, the third period of deformation produced the dominant macroscopic folds. D_3 folds correlate well in style and orientation to equivalent generation folds for the Broken Hill area. The fault f_1 (Fig. 2) is parallel to S_3 and has a similar time connotation to the retrograde shear zones noted at Broken Hill.

Late crenulations at Broken Hill still await more precise determinations before adequate correlations with the 4th and 5th deformations at Outalpa is possible. However the general history of weak crenulations and shear zones is similar for the two areas.

Conclusions

Detailed structural analysis for an area at Outalpa has established a concise interpretation of observable mesoscopic structures (Table 1). This has been possible because the basement-cover contact between the Wiliyama Complex and upper Precambrian (Adelaidean) cover rocks is exposed, allowing distinction between solely basement and cover deformation phases. This is particularly important as the final cover deformation (D_5) has a similar orientation to the much earlier third basement deformation (D_3).

Five penetrative deformations have been recognised of which three affect solely basement rocks. The first event (D_1) produced a layer-parallel foliation in the metasediments and a foliation in the syntectonic granodiorite. Metamorphism during this phase reached mid-amphibolite facies.

The second deformation (D_2) was only a minor folding phase producing macroscopic open folds and crenulations. Crystallisation of muscovite within S_2 indicates possible initial retrogressive metamorphism.

Macroscopic tight folding and the intense development of mesoscopic crenulations and crenulation cleavage resulted from the third penetrative event (D_3). Third phase axial plane structures (S_3) are relatively constant in orientation and strike at 065° across the map area. The crystallization of muscovite in the axial plane of D_3 mesoscopic folds is compatible with continued retrogressive greenschist facies conditions. Block faulting on f_1 and f_2 occurred prior to Adelaidean sedimentation.

Adelaidean sedimentation and deposition of the basal Burra Group and overlying Umberatana Group sediments postdate the third deformation. The first cover phase (D_4) resulted in north-south oriented tight synclines and broad anticlines in the unconformity. Crenulations were produced in nearby basement schists and shearing occurred on fault f_3. Metamorphism during D_4 reached upper greenschist facies with a biotite-chlorite-actinolite schistosity in cover rocks.

The final cover phase (D_5) has an east-west striking axial plane which is very constant in orientation. An open anticline produced in the unconformity over the granodiorite has resulted in the opposite plunging F_4 synclines in Burra Group sediments. Structural elements vary from a slaty cleavage in arenites to a schistosity defined by biotite and chlorite in the pelites. Continued upper greenschist facies metamorphism resulted in further retrogression of basement rocks. The fault f_4 was locally folded by this final folding phase.

Comparisons made between Outalpa, other areas of the Olary Province and Broken Hill suggest that the structural history outlined for Outalpa is valid over a wide area of the Willyama Complex and Adelaidean rocks.

The structural interpretation at Outalpa provides a framework to correlate structural elements over a large part of the Olary Province (Table 1). The S_1 schistosity and gneissosity are widespread over the entire Willyama Complex, while D_3 is responsible for most macroscopic basement folds. The first deformation in cover rocks (D_4), has resulted in N-S oriented tight synclines and a second deformation, D_5, has redistributed the plunges of those synclines and also regionally folded all cover meta-sediments.

Recent work from Broken Hill (Glen *et al.* 1977) has allowed a much improved correlation between the structural history at Outalpa and the more detailed studies within New South Wales. Structures predating the Adelaidean unconformity are very similar in the two areas.

Acknowledgments

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A NEW SPECIES OF THYSANOTUS R.BR. (LILIACAE) FROM EYRE PENINSULA, SOUTH AUSTRALIA

BY N. H. BRITTAN

Summary

A new species of Thysanotus R.Br. (Liliaceae), T. wangariensis N. H. Brittan from near Port Lincoln, Eyre Peninsula, South Australia is described and illustrated. It shows similarities with T. dichotomus (Labill.) R. Br. and T. virgatus N. H. Brittan.

A NEW SPECIES OF *THYSANOTUS* R.BR. (LILIACEAE) FROM EYRE PENINSULA, SOUTH AUSTRALIA

by N. H. Brittan*

Summary

Brittan, N. H. (1978) A new species of *Thysanotus* R.Br (Liliaceae) from Eyre Peninsula, South Australia. *Trans. R. Soc. S. Aust.*, **102**(2), 55-57, 28 February, 1978.

A new species of *Thysanotus* R.Br. (Liliaceae), *T. wangariensis* N. H. Brittan from near Port Lincoln, Eyre Peninsula, South Australia is described and illustrated. It shows similarities with *T. dichotomus* (Labill.) R.Br. and *T. virgatus* N. H. Brittan.

Thysanotus wangariensis N. H. Brittan
sp. nov.
(FIG. 1)

Holotypus: Alcock 815, Hundred of Lake Wangary, section 524, roadside near Wangary Hotel, 18.xi.1965 (AD 966031110), *Isotypus:* (K).

Herba perennis, ubi matura aphylla. Rhizoma parvum, 5–10 mm diametro, radicibus rigidis, fibrosis, haud tuberosis. Caules plures, recti, 20–40 (–50) cm alti, ramificatione monopodiali-pseudodichotoma, teretes, porcis basi numerosis, superne 4–5, pilis tuberculatis ferentibus. Folia 5–7 cm long basi caulium novorum prodientia ante florescentiam marcescentia. Umbellae terminales, floribus 1–3, bracteis 2–5, duobus exterioribus 1.5–2 mm longis, lato-deltoideis. Pedicelli 8–10 mm longi, erecti. Segmenta perianthii 11–12.5 mm longa, exteriora linearia, 3 mm lata, obscure 4–5–nervata, interiora elliptica, fimbriis 3–3.5 mm longis. Stamina 6, filamentis circa 2.5 mm longis, antheris poris terminalibus dehiscentibus, antheris tribus exterioribus 3 mm longis, rectis, contortis, antheris tribus interioribus 6–7 mm longis, curvatis, contortis. Ovarium sessile, loculis 3, biovulatis. Stylus terminalis, curvatus, declinatus, 10 mm longus. Capsula cylindrica, 5–6 x 3–4 mm. Semina nigra, 2 x 1.5 mm, arillo flavo.

Perennial with small (5–10 mm diam.) rhizome with stiff, fibrous, non-tuberous roots. Stems several per rhizome, erect-spreading, 20–40 (occasionally to 50) cm tall, monopodially-pseudodichotomously branched, terete, ridges multiple near base, 4–5 in upper parts, with tuberculate hairs on the ridges. Bracts 2–3 (occasionally 4) at each node, one subtending the branch, the other 1–2 (occasionally 3) very small, on inner side of axil enclosing buds leading to the production of 2–3 (occasionally 4) branches from some nodes. Umbels terminal, 1–3-flowered, bracts 2–5, outer two 1.5–2 mm long, broadly deltoid, inner bracts narrower, equal to or shorter than outer bracts. Pedicels 8–10 mm long, erect in flower and fruit, articulated just above the level of the apices of the outer bracts. Tepals 11–12.5 mm long; outer three linear, 3–4 mm wide, obscurely 4–5-nerved; inner three elliptic, 4 mm wide, fimbriae 3–3.5 mm long. Stamens 6, filaments ca 2.5 mm long, anthers dehiscing by terminal pore; outer three anthers straight, twisted, 3 mm long; inner three anthers curved, twisted, 6–7 mm long. The anthers are positioned in two groups of three, the longer three declinate in the same direction as the style. Ovary sessile, 3-locular, 2 ovules per loculus. Style terminal, curved, declinate, 10 mm long. Capsule cylindrical, 5–6 x 3–4 mm. Seeds black, 2 x 1.5 mm, with yellow aril.

Distribution: Eyre Peninsula—Wangary and a few other localities to the N., N.N.E. and N.W. of Port Lincoln.

Ecology: At the type locality it occurs in remnants of low heath vegetation on a sandy-loam soil.

Specimens examined: *Specht* 2544, Flora and Fauna Reserve, Hundred of Hincks, ca 85 km N.

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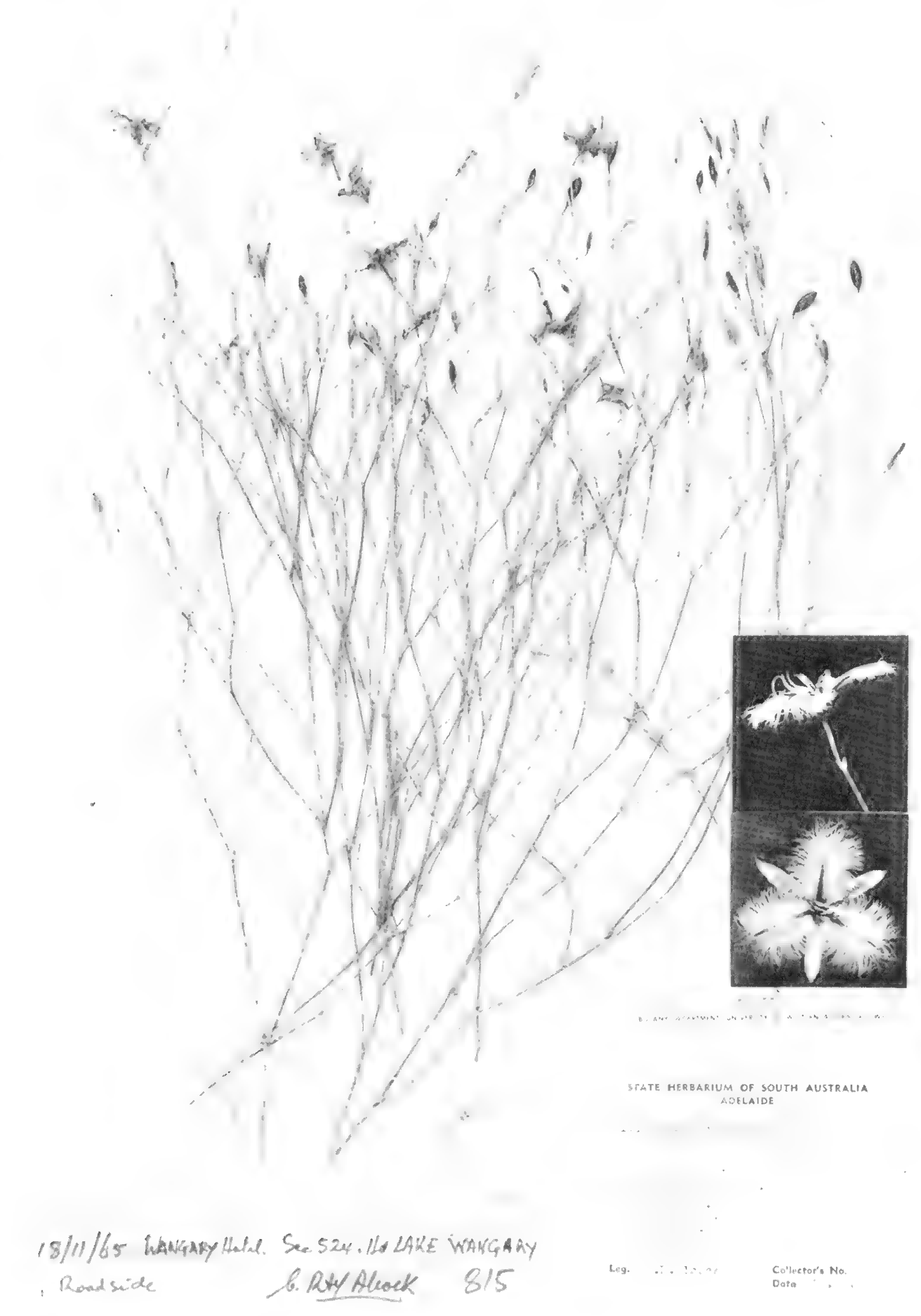

Fig. 1. Holotypus *Thysanotus wangariensis* N. H. Brittan sp. nov., *Alcock* 815 (AD 966031110) x 0.43; flower from *Brittan* 69/03 (cult.) x ca 0.8.

of Port Lincoln, 11.xi.1960 (AD 96107089); *Alcock* 1688, Hundred of Wangary, 40 km W.N.W. of Port Lincoln, 14.xi.1967 (AD 96807209); *Brittan* 69/03, near Wangary Hotel (type locality), 29.viii.1969 (UWA); *Cleland* s.n., reserve between Tooligie and Mt Verran, 100 km N.N.E. of Port Lincoln, 9.xi.1960 (AD 97226204).

Discussion

In South Australia this species may be confused with *T. juncifolius* (Salisb.) Willis & Court (1956), the latter however is usually erect in habit, from a linear, ± cylindrical rhizome, taller, up to 70–80 cm, the stem not ridged and with the possible exception of a region near the base, glabrous. The umbels are 3–5-flowered, the floral bracts whitish and membranous and usually longer than the membranous outer two bracts. *T. wangariensis* has a more spreading habit, ca 40 cm (occasionally up to 50 cm) tall, from a compact, ± spherical, rhizome, umbels 1–2 (occasionally 3)-flowered, the inner bracts shorter than, occasionally equal to, the two outer bracts.

T. wangariensis most closely resembles the two non-South Australian species *T. dichotomus* (Labill.) R.Br. (1810)—a Western Australian endemic—and *T. virgatus* N. H. Brittan—a New South Wales endemic. The former species both produce leaves in the juvenile state, those in *T. wangariensis* being shorter and usually more erect than those of *T. dichotomus*. The lower parts of the stems in *T. wangariensis* are frequently covered in long hairs, this condition is rarely found in *T. dichotomus*. The flowers differ in the outer tepals which are broader (3 mm) compared with 1.5–2 (rarely 3) mm of those of *T. dichotomus;* they are smooth and obscurely veined on the outer surface in *T. wangariensis*, whereas they are distinctly 3–5-veined and ridged in *T. dichotomus*. On the stems only a single bract, which subtends the branch, is found per node in *T. dichotomus;* in *T. wangariensis*, in addition to this bract, 1–2 (occasionally 3) others subtend buds, which leads to the production of 2–3 (occasionally 4) branches per node in this species.

This feature is also found in *T. virgatus*, to which *T. wangariensis* bears a close resemblance in general habit. *T. virgatus* can be separated on the basis of floral characters, especially the wide, 3–4 mm, 6–7-nerved, outer tepals, inner tepals broader, 5–6 mm wide, with longer fimbriae, 4–5 mm, compared with the 4 mm wide inner tepals and the 3–3.5 mm long fimbriae of *T. wangariensis*.

Acknowledgments

The author wishes to express his gratitude to Mr C. R. Alcock, formerly of Port Lincoln, for providing transport and hospitality during his visit to Eyre Peninsula to collect material of the species, to Dr Hj. Eichler, at that time Keeper of the Herbarium, Adelaide Botanic Garden, for permission to consult the collections, to Dr W. R. Barker for checking the Latin description and to the University of Western Australia for the provision of a grant to enable him to visit South Australia.

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NOTES ON RODENTS AND MARSUPIALS AND THEIR ECTOPARASITES COLLECTED IN AUSTRALIA IN 1974-75

BY J. F. ROBINSON, A. C. ROBINSON, C. H. S. WATTS & P. R. BAVERSTOCK

Summary

One monotreme species, twenty species of marsupials and twenty-seven species of rodents were taken during a collecting trip in eastern, western and northern Australia between October 1974 and July 1975. Information is provided on localities, dates, sexes and habitat-type of all species. Extensions of known ranges were recorded for Rattus villosissimus, Zyzomys argurus, Pseudomys delicatulus and P. gracilicaudatus. Data on the present location of specimens collected, observations on the reproductive condition of animals noted in the field and the ectoparasites collected are included. Comments are made on the low population densities of small mammals in Australia and the low number of species occurring sympatrically.

NOTES ON RODENTS AND MARSUPIALS AND THEIR ECTOPARASITES COLLECTED IN AUSTRALIA IN 1974–75

by J. F. Robinson*, A. C. Robinson†,
C. H. S. Watts‡ & P. R. Baverstock‡

Summary

Robinson, J. F., Robinson, A. C., Watts, C. H. S. & Baverstock, P. R. (1978) Notes on rodents and their ectoparasites collected in Australia in 1974–75. *Trans. R. Soc. S. Aust.* **102**(3), 59-70, 31 May, 1978.

One monotreme species, twenty species of marsupials and twenty-seven species of rodents were taken during a collecting trip in eastern, western and northern Australia between October 1974 and July 1975. Information is provided on localities, dates, sexes and habitat-type of all species. Extensions of known ranges were recorded for *Rattus villosissimus*, *Zyzomys argurus*, *Pseudomys delicatulus* and *P. gracilicaudatus*. Data on the present location of specimens collected, observations on the reproductive condition of animals noted in the field and the ectoparasites collected are included. Comments are made on the low population densities of small mammals in Australia and the low number of species occurring sympatrically.

Introduction

The distribution and habitat preferences of the small mammal fauna of Australia is still very poorly known. Important contributions in this field include—Harrison (1961) and Tate (1952) for Qld, Calaby (1966) and Marlow (1958) for N.S.W., Wood Jones (1923) and Finlayson (1961) for south and central Australia, Bannister (1969) and Glauert (1933) for W.A., and Calaby & Keith (1974). Johnson (1964) and Parker (1973) for the N.T. In addition Taylor & Horner (1973) provided information on all Australian species of the genus *Rattus*.

A. C. Robinson and J. F. Robinson made a collecting trip between October 1974 and July 1975 in eastern, western and northern Australia. The aim was to collect as many different rodent taxa as possible during the time available, primarily for studies of their karyotypes and blood proteins. Trapping localities were therefore chosen to maximise the chances of capturing specific species, and this generally involved visiting known occurrences rather than trapping in new areas. Overall sampling was therefore not systematic throughout the areas covered by the survey, but in any one locality efforts were made to sample the major recognisable habitats. This resulted in the capture of a number of small mammals other than rodents and details of these are included. In addition the ectoparasites collected from each species are recorded.

Companion papers record the results of an analysis of the karyotypes (Baverstock *et al.* 1975, 1976, 1977a,b,c), the blood proteins, the diet (Watts 1977), and the habitat, of most of the rodents collected. In addition some rare and little known ectoparasite taxa will be discussed in more detail in future papers by the relevant authorities listed in the Acknowledgments.

Methods

The route followed on the collecting trip started at Windorah, Queensland, to Cairns, then north up Cape York Peninsula as far as Portland Roads, south through coastal Queensland with a visit to Emerald, then through coastal N.S.W. (with a visit to Mt Kosciusko), through coastal Victoria (with a visit to the Grampians) and then to Adelaide.

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Fig. 1. Localities mentioned in the text.

Collecting on the second half of the trip began in the southwest of W.A., then north following the coast to Broome and Derby; a visit to the King Leopold Ranges then, via Wyndam, to Darwin, N.T. From Darwin trips were made east to Nourlangie Camp on the edge of Arnhem Land 205 km E, and south to the Reynolds River. Figure 1 gives the place names mentioned in the text. Most species were collected in live traps although some information is included on road kills. Forty Sherman folding aluminium traps, forty wire mesh cage traps 13 cm x 13 cm x 35 cm, and ten wire mesh cage traps 30 cm x 25 cm x 45 cm were used. As many of these traps as practicable were set at each locality. Traps were placed 20 m apart in lines of twenty traps, with Sherman and small cage traps alternating. The large cage traps were used only when attempts were made to capture large species, i.e. *Hydromys*, *Mesembriomys* etc. The bait used was a mixture of peanut paste and rolled oats. Normally traps were left down for two nights in any one location, although shorter and longer periods were employed, depending on the species of rodent we were attempting to catch. Altogether traps were set on 150 nights for a total of approximately 9,500 trap nights.

The nomenclature used follows Ride (1970) with the exception of the genus *Rattus* which is that of Taylor & Horner (1973), as modified by Baverstock *et al.* (1975).

Field identifications were checked in Adelaide, using karyotypic as well as morphological characters. This was particularly important in *Rattus* where several species are difficult to identify while alive, but readily separated on their karyotypes. In the case of Queensland *Melomys* we have followed the unsatisfactory convention that only two species are involved: that small animals caught in grassland are *M. littoralis*, and slightly larger ones caught in closed forest are *M. cervinipes*. However, some individuals could not be classified in this manner and these are simply listed as *Melomys* sp. The Northern Territory *Melomys* have been included in *M. littoralis* provisionally on karyotypic evidence.

The bulk of the paper contains a tabulation of localities where all the various small mammals were caught. Many of these animals were released subsequently at the points of capture. They are treated species by species and the following information is recorded: species name, common name, specific locality, latitude south and longitude east, number of individuals caught (males, females, unsexed), date, specimen registration numbers, notes on habitat, reproductive condition and ectoparasites. Localities are given as km on a compass bearing from a recognisable town. Latitudes and longitudes pinpoint the locality more precisely. Localities were regarded as separate when they differed by more than one minute of latitude or longitude. No year is given following the date of collection but all dates fall within the period October 1974 to July 1975. As many of the rodents are still alive at the Institute of Medical & Veterinary Science at the time of publication, a dual system of specimen numbers is introduced. All specimens have been assigned an I.M.V.S. publication number and a list of these will be lodged at the South Australian Museum, and periodically updated. Where specimens have already been placed in museums, the appropriate museum registration number is recorded. Museum abbreviations used are: NMV, National Museum of Victoria; QM, Queensland Museum; WAM, Western Australian Museum; AM, Australian Museum; SAM, South Australian Museum. I.M.V.S. publication numbers have no prefix. Habitat notes follow the vegetation classification of Specht (1970) and Specht *et al.* (1974), to the level of structural formation.

Results

MONOTREMATA

FAMILY TACHYGLOSSIDAE

1. *Tachyglossus aculeatus*, Echidna

Localities: *Qld* (i) Maslin Ck, Atherton, 17°15' 145°30' 1. 21 Nov, (ii) 26 km NW Townsville, 19°9' 146°36', 1. 9 Dec.

Notes: One specimen (i) was trapped near a creek bank in a cultivated paddock; the other (ii) on beach dunes covered by low open shrubland.

MARSUPIALIA

Family Macropodidae

2. *Thylogale stigmatica*, Red-legged Pademelon

Localities: *Qld* (i) 72 km S Mt Garnett, 18°14′ 144°46′, 1, 21 Oct., QM 712. (ii) 4 km S Atherton, 17°18′ 145°29′, 1, 21 Oct., QM 702.

Notes: Both road kill victims. Skulls only collected. Adjacent to open grassy woodland (i) and adjacent to closed forest (ii).

3. *Onychogalea unguifera*, Northern Nail-tailed Wallaby

Locality: *W.A.* (i) 19 km SW Wyndham, 16°35′ 128°14′, 1, 27 May.

Notes: A road kill specimen, skull only collected. Adjacent to open grassy woodland.

4. *Lagorchestes conspicillatus*, Spectacled Hare-wallaby

Localities: *Qld* (i) 74 km N Dajarra, 21°10′ 139°40′, 1, 8 October. (ii) 15 km S Mareeba, 17°3′ 145°26′, 1♀, 21 Oct., QM 710.

Notes: Both road kills. Parts of the skull of (i) and the complete skull of (ii) were collected. Adjacent to tall open shrubland (i) and open grassy woodland (ii).

5. *Lagorchestes hirsutus*, Western Hare-Wallaby

Locality: *W.A.* (i) Bernier Island, 24°56′. 113°9′ 4, 20 Apr.

Notes: Four specimens were seen while spotlighting on foot in hummock grassland. (Robinson *et al.* 1976.)

6. *Aepyprymnus rufescens*, Rufous Rat-kangaroo

Locality: *Qld* (i) 35 km S Proserpine, 20°40′ 148°35′, 1 ♂, 11 Dec., QM 708.

Notes: A road kill specimen. A complete specimen was collected. Adjacent to open grassy woodland.

7. *Bettongia lesueur*, Boodie

Locality: *W.A.* (i) Bernier Island, 24°55′ 113°9′ 1♀, 22 Apr.

Notes: Trapped on the edge of the island platform in low shrubland (Robinson *et al.* 1976).

Reproduction: (i) 1 pouch young C-R length 165 cm.

8. *Potorous tridactylus*, Potoroo

Locality: *Vic.* (i) 6 km SW Bemm River, 37°47′ 148°54′, 1, 20 Feb.

Notes: Trapped in low open forest/closed heath habitat.

Family Phalangeridae

9. *Trichosurus vulpecula*, Brush-tailed Possum

Localities: *Qld* (i) 28 km N Atherton, 17°2′ 145°26′, 3, 21–22 Nov. (ii) 6 km N Atherton, 17°5′ 145°29′, 1 ♀, 23 Nov., QM 714.

Notes: Locality (i) was a garden shed, surrounded by open grassy woodland. The road kill specimen (ii) was adjacent to a road-side strip of closed forest.

Family Peramelidae

10. *Isoodon obesulus*, Short-nosed Bandicoot

Locality: *Vic.* (i) 40 km SE Melbourne, 38°15′ 145°14′, 1, 27 Feb.

Notes: Trapped in low open forest.

11. *Isoodon macrourus*, Brindled Bandicoot

Localities: *Qld* (i) 112 km SW Mt Garnett, 18°36′ 144°44′, 1 ♂, 21 Nov. (ii) 7 km SW Portland Roads, 12°40′ 143°23′, 1 ♂, 2 Nov., QM 713. (iii) 25 km S Cooktown, 15°41′ 145°13′, 1 ♂, 7 Nov. (iv) 8 km SW Townsville, 19°20′ 146°4′, 2, 7 Dec. (v) 26 km NW Townsville, 19°9′ 146°36′, 3, 9 Dec. (vi) 58 km N Maryborough, 25°6′ 152°32′, 1♀, 14 Jan. *N.S.W.* (vii) 20 km SW Port Macquarie, 31°37′ 153°50′, 1 ♀, 1 Feb. *N.T.* (viii) 185 km E Darwin, 12°41′ 132°55′, 18, 15–17 June. (ix) Vicinity of Nourlangie Camp, 12°50′ 132°41′, 12°46′ 132°40′, 12°53′ 132°38′, 12°54′ 132°38′, 6, 18–19 June.

Notes: Trapped in a variety of habitats—closed sedgeland (vi), open grassy forest (i), low grassy woodland (iii, ix), low open grassy woodland (iv, viii, ix), closed scrub (vii) and low open shrubland on beach dunes (v). A road kill specimen was collected adjacent to open grassy forest (ii). Reproduction: (vi) (viii) 2 unfurred pouch young.

Ectoparasites: (i, iii) *Xenopsylla vexabilis.*

12. *Perameles nasuta*, Long-nosed Bandicoot

Locality: *Qld* (i) 98 km NW Bundaberg, 24°31′ 151°28′ 2, 10–11 Jan.

Notes; Trapped in closed forest.

Reproduction: (i) 2 independent juveniles trapped.

13. *P. bougainville*, Barred Bandicoot

Locality: *W.A.* (i) Bernier Island, 24°56′ 113°9′, 1 ♂, 2 ♀. 5, 21–22 Apr.

Notes: Five individuals were seen at night in low shrubland. Three individuals were captured in cage traps (Robinson *et al.* 1976).

Reproduction: (i) 2 pouch young C-R length 7 cm.

Family Dasyuridae

14. *Dasyurus hallucatus*, Little Northern Native-Cat

Localities: *Qld* (i) Coen, 13°56' 143°12', 1 ♀, 28 Oct. (ii) 23 km S Cooktown, 15°11' 145°12', 1 ♂, 10 Nov., QM 707. *N.T.* (iii) Nourlangie Rock, 230 km E Darwin, 12°52' 132°49', 1, 13 June. (iv) 185 km E Darwin, 12°41' 132°55', 5, 15–17 June. (v) 24 km NE Nourlangie Camp, 12°41' 132°37', 1 ♂, 15 June. (vi) 14 km S Nourlangie Camp, 12°54' 132°38', 1, 9 June.

Notes: Localities (iv) and (vi) were low grassy woodland. (ii) and (v) were road kill victims on roads through low grassy woodlands. Nourlangie Rock is an outlying formation of the Arnhem Land Escarpment and can best be described as a "rock-pile". The specimen from Coen was caught in a feed shed and donated by a local resident.

Reproduction: (i) Lactating female.

Ectoparasites: (i) *Xenopsylla vexabilis, Echidnophaga myrmecobii.*

15. *Dasyuroides byrnei*, Byrne's Pouched-mouse

Locality: *Qld* (i) 75 km SE Boulia, 15°32' 140°7', 1, 17 Oct.

Notes: One animal was seen at night on a flood plain covered with tussock grassland.

16. *Antechinus stuartii*, Brown Antechinus

Localities: *N.S.W.* (i) 20 km SW Port Macquarie, 31°37' 152°52', 1♂, 2 Feb. (ii) 56 km SE Canberra, 35°41' 149°32', 1 ♂ 2 ♀, 14 Feb., AM M10430. (iii) 20 km NE Mallacoota 37°37' 149°57', 1 ♀, 1, 17 Feb. *Vic.* (iv) 6 km SW Bemm River, 37°47' 148°54', 1 ♂, 20 Feb. (v) 40 km SE Melbourne, 38°15' 145°14', 9, 26–27 Feb. (vi) 38 km E Melbourne, 37°53' 145°22', 9, 1–2 Mar. (vii) 12 km SW Apollo Bay, 38°47' 143°32', 12, 3 Mar. (viii) 73 km NE Hamilton, 37°18' 142°36', 6, 7 March.

Notes: *A. stuartii* was captured in a variety of habitats: closed scrub (i), open forest (ii), woodland/closed heath (iii), low open forest/closed heath, (iv), low open forest (v), tall open forest (vi, vii), and closed heath (viii). It appears to be associated with a dense understorey regardless of canopy height.

Ectoparasites: (ii) *Pygiopsylla rainbowi* n.ssp., *Acanthopsylla rothchildi* ssp.

17. *Antechinus bellus*, Fawn Antechinus

Localities: *N.T.* (i) Nourlangie Rock, 230 km E Darwin, 12°52' 132°49', 1, 13 June. (ii) 185 km E Darwin, 12°41' 132°55', 6 ♂, 1 ♀, 15–17 June, 563, 564. (iii) 1 km S Nourlangie Camp, 12°46' 132°40', 1 ♂, 19 June. (iv) 10 km S Nourlangie Camp, 12°51' 132°41', 1 ♂, 20 June, 479. (v) 12 km S Nourlangie Camp, 12°53' 132°38', 1 ♂, 18 June, SAM M9896. (vi) 14 km S Nourlangie Camp, 12°54' 132°38', 1 ♂, 18 June.

Notes: With the exception of Nourlangie Rock all localities were woodland habitats. Nourlangie Rock is an outlying rock of the Arnhem Land escarpment surrounded by low grassy woodland.

18. *Antechinus godmani*, Godman's Antechinus

Locality: *Qld* (i) 39 km S Innisfail, 17°52' 146°4', 1 ♂, 5 Dec.

Notes: Caught in closed forest.

Reproduction: 1 independent subadult trapped.

Ectoparasites: *Acanthopsylla pavida.*

19. *Antechinus swainsonii*, Dusky Antechinus

Localities: *N.S.W.* (i) Kosciusko Natl Pk, 36°23' 148°28', 3 ♂, 4, 10–11 Feb. (ii) 54 km SE Canberra, 35°39' 149°32', 1 ♂, 14 Feb. (iii) 56 km SE Canberra, 35°41' 149°32', 1 ♂, 14 Feb. *Vic.* (iv) 6 km SW Bemm River, 37°47' 148°54', 1 ♀, 20 Feb. (v) 38 km E Melbourne, 37°53' 145°22', 5, 1–2 Mar. (vi) 12 km SW Apollo Bay, 38°47' 143°32', 1, 3 Mar. (vii) 73 km NE Hamilton, 37°18' 142°36', 1, 7 Mar.

Notes: Caught in a variety of habitats: closed grassland (i), open forest (iii), low open forest/closed heath (iv), tall open forest (v, vi) and closed heath (vii).

Ectoparasites: (ii) *Pygiopsylla hoplia, Acanthopsylla rothschildi* ssp., (iv) *A. rothschildi* ssp.

20. *Sminthopsis rufigenis*, Red-cheeked Dunnart

Locality: *Qld* (i) 23 km S Portland Roads 120°47' 143°18', 1 ♂, 2 Nov., QM 728.

Notes: Caught in low open forest/grassy woodland.

21. *Sminthopsis crassicaudata*, Fat-tailed Dunnart

Locality: *Qld* (i) 70 km SE Boulia, 15°28' 140°4' 1 ♂, 17 Oct., 520.

Notes: Caught on a flood plain in an area of tussock grassland.

RODENTIA

FAMILY MURIDAE

22. *Rattus fuscipes fuscipes*, Southern Bush-rat

Localities: *W.A.* (i) 30 km NW Augusta, 34°4' 115°2', 2 ♂, 1 ♀, 6 Apr., WAM M15265-M15267, (ii) 22 km NE Jurien, 30°8' 115°8', 3 ♂, 6 ♀, 12–13 Apr., WAM M15268-M15271 425, 426, 427, 429, 522.

Notes: Locality (i) was a low open woodland/closed heath formation and (ii) a closed heath formation.

Ectoparasites: (ii) *Mesolaelaps australiensis, Xenopsylla vexabilis.*

23. *Rattus f. assimilis*, Southern Bush-rat

Localities: *Qld* (i) 38 km E Kingaroy, 26°39' 152°13', 1 ♂ 4 ♀, 16 Jan., 236, 368. *N.S.W.* (ii) 11 km NE Nimbin, 28°32' 153°18', 1 ♂ 1 ♀, 1, 29 Jan., AM M10401-M10403, (iii) 50 km NE Newcastle, 32°39' 152°9', 1 ♂ 1 ♀, 3 Feb., AM M10404, M10414. (iv) Kosciusko Natl Pk, 36°23', 148°28', 6 ♂, 5 ♀, 10–11 Feb. (v) 54 km SE Canberra, 37°39' 149°32', 2 ♂, 4 ♀, 14 Feb., AM M10408-M10413, (vi) 56 km SE Canberra, 35°41' 149°32', 4 ♀, 14 Feb., AM M10405-M10407, 383. (vii) 20 km NE Mallacoota, 37°27' 149°57', 6 ♂, 9 ♀, 16–17 Feb, *Vic.* (viii) 1 km SW Bemm River, 37°46' 148°58', 1 ♀. 20 Feb. (ix) 3 km SW Bemm River, 37°47', 148°56', 1, 21 Feb. (x) 5 km SW Bemm River, 37°47' 148°5', 4 ♂, 3 ♀, 19–20 Feb., 281–285, 296, 388. (xi) 6 km SW Bemm River, 37°47' 148°54', 1 ♂, 1 ♀, 4, 20–21 Feb. (xii) 38 km E Melbourne, 37°53' 145°22', 5 ♂ 3 ♀, 28 Feb.–1 Mar., 292, 394–399. (xiii) 12 km SW Apollo Bay, 38°47' 143°32', 7 ♂, 6 ♀, 7, 3 Mar., 211, 293, 246, 400–404.

Notes: Caught in closed forest (i and ii), open forest (iii, v and vi), closed grassland (iv), woodland/closed heath (vi), low open forest/closed heath (vii), closed scrub (vii) and tall open forest (vii and ix).

Reproduction: (ii, iv, xii, xiii) Independent juveniles caught.

Ectoparasites: (i, vii, x) *Laelaps assimilis*, (i, iv, vi, vii) *Laelaps* sp., (vi, vii) *Mesolaelaps bandicoota*, (vii) *Guntheria taylorae*, (i, iv) *Macropsylla hercules*, (iv) *Pygiopsylla gravis* or n.sp., (iv, vi, vii) *P. hoplia*, (iv, v, vii) *P. rainbowii*, (i) *P.* sp., (ii) *Acanthopsylla incerta*, (v, vi) *A. rothschildi* ssp., (iv) *Stephanocircus concinnus*, (vii) *S. pectinipes*.

24. *Rattus f. coracius*, Southern Bush-rat

Localities: *Qld* (i) 14 km E Atherton, 17°15' 145°37', 1 ♂, 2 ♀, 28 Nov., QM 2103, 2121, 347. (ii) 41 km SE Cairns, 17°15' 145°46', 4 ♂, 6 ♀, 16 Nov., QM2100, 2106, 2108, 2124, 2126, 354–357.

Notes: Both localities were closed forest.

Reproduction: (ii) 3 young born.

Ectoparasites: (i) *Pygiopsylla sinuata*, *Acanthopsylla pavida*, *Stephanocircus dasyuri*, *Metastivalius rectus*, (ii) *Mesolaelaps australiensis*.

25. *Rattus lutreolus*, Swamp-rat

Localities: *Qld* (i) 29 km E Warwick, 28°16' 152°19', 1 ♀, 1, 24 Feb., 367. *N.S.W.* (ii) 20 km SW Port Macquarie, 31°37' 152°50', 6 ♂, 5 ♀, 1–2 Feb., AM M10422-M10428, 373-375, 376, 377, 387, 497, 523, 524. (iii) 20 km NE Mallacoota, 37°27' 149°57', 2 ♀, 17–18 Feb. AM M10429, 376, 377, 387, 497, 523, 524. *Vic.* (iv) 3 km SW Bemm River, 37°47' 148°56', 4 ♂, 1 ♀, 20-21 Feb., 286, 410, (v) 6 km SW Bemm River, 37°47', 148°54', 1♂, 4 ♀, 1, 20–21 Feb., 287, 389-391, (vi) 38 km E Sale, 38°6' 147°31', 1 ♀, 23 Feb., 393. (vii) 40 km SE Melbourne, 38°15' 145°14', 5 ♂, 26–27 Feb., NMV C15684-15688, 405. (viii) 37 km NE Hamilton, 37°35' 142°24', 1 ♂, 4 Mar. (ix) 42 km NE Hamilton, 37°32' 142°25', 2 ♀, 7 Mar., 407, 408. (x) 52 km NE Hamilton, 37°27' 142°28', 1 ♀, 7 Mar., NMV C15695. (xi) 53 km NE Hamilton, 37°26' 142°29', 1 ♀, 5 Mar., 409. (xii) 73 km NE Hamilton, 37°18' 142°36', 2 ♀, 6–7 Mar., NMV C15694, 294.

Notes: *R. lutreolus* was usually associated with damp soil. Habitats were woodland (i), closed scrub (ii and iv), woodland/closed heath (iii), closed heath (vi, vii, x, xi, xii), low open woodland/open heath (vi) and low open forest (vii). Reproduction: (v) 6 young born, independent juveniles trapped.

Ectoparasites: (ii) *Laelaps nuttalli*, *Mesolaelaps australiensis*, (v) *M. bandicoota*, (ii, v) *Pygiopsylla hoplia*, (v) *P.* sp., *Acanthopsylla rothschildi* ssp.

26. *Rattus sordidus*, Dusky Field-rat

Localities: *Qld* (i) 23 km S Portland Roads, 12°47' 143°18', 5 ♂, 4 ♀, 2–3 Nov., QM 2109, 2128, 327, 498-500, 525. (ii) 37 km S Cooktown, 15°48' 145°14', 3 ♂, 2 ♀, 9 Nov., 206, 334-337. (iii) 16 km S Cairns, 17°4' 145°47', 4♂, 2 ♀, 14 Nov., QM 720, 2110-2112, 258, 358. (iv) 17 km S Cairns, 17°5' 145°47', 2 ♂ 1 ♀, 14 Nov. (v) 22 km SE Atherton, 17°22' 145°33', 2 ♂, 3 ♀, 29 Nov., QM 2102, 253, 348-350. (vi) 11 km NE Atherton, 17°12' 145°33', 11 ♂ 3 ♀, 2, 22 Nov., QM 2105, 2107, 501-504. (vii) 29 km SE Innisfail, 17°46' 146°7', 1, 3 Dec.

Notes: In natural situations *R. sordidus* was caught in the following habitats: low open forest/grassy woodland (i), low grassy woodland (ii), closed sedgeland (v), low open grassy woodland (iv) and open forest (vii). Locality (vi) was a cane field/closed grassland and locality (iii) was a cultivated paddock/closed grassland.

Reproduction: (ii) Independent juvenile trapped.

Ectoparasites: (i, iii, vi) *Laelaps nuttalli*, (i) *L.* sp., (i, ii, iii, vi) *Mesolaelaps australiensis*, (i, iv, v, vi) *Pygiopsylla hoplia*, (i, v, vi) *P. rainbowii* n. ssp., (v, vi) *Stephanocirius dasyuri*, (vi) *Xenopsylla australiaca*, *X australiacus*, (i, ii, vi) *X. vexabilis*.

27. *Rattus colletti*, Northern Bush-rat

Localities: *N.T.* (i) 175 km E Darwin, 12°42' 132°32', 8 ♂, 7 ♀, 7–8 Jun., SAM M9900, M9902, 448–460, (ii) 15 km NE Darwin, 12°33' 130°56', 4♂, 5 ♀, 11 June, SAM M9901, 461–463, 465, 466.

Notes: Both localities were closed sedgeland.

Ectoparasites: (i, ii) *Laelaps nuttalli*.

28. *Rattus villosissimus*, Plague Rat

Localities: *Qld* (i) 56 km SE Boulia, 15°22' 140°0', 2 ♂, 3 ♀, 1, 18 Oct., 311–313. (ii) 72 km SE Boulia, 15°29' 140°6', 1, 17 Oct. (iii) 77 km SE Boulia, 15°35' 140°8', 1 ♂, 17 Oct., 310 (iv) 32 km W Windorah, 25°20' 142°18', 5 ♂, 15 Oct., 306-309. (v) 2 km NE Mt Isa, 20°38' 139°30', 1 ♂, 3 ♀, 19 Oct., 314-316. (vi) 33 km

SE Richmond, 2°49' 143°28', 1 ♂, 1 ♀, 20 Oct., 317, 318. *W.A.* (vii) 26 km SE Wyndham, 15°35' 128°6', 1 ♂, 25 May, 441.

Notes: Caught on gibber plain (i), flood plains covered with tussock grassland, (ii, iii, vi, iv), grassy woodland (v) and closed tussock grassland (vii)

Reproduction: (i) Independent juvenile trapped.

Ectoparasites: (i, iii, iv, v, vi) *Laelaps nuttalli*, (iv, v) *Mesolaelaps australiensis*, (i, iii, v, vi) *Xenopsylla vexabilis*.

29. *Rattus l. leucopus*, Mottle-tailed Cape York Rat

Localities: Qld (i) 19 km SW Portland Roads, 12°43' 143°17', 3 ♂, 3♀, 1–3 Nov., QM 2116, 323, 324, 326, 328. (ii) 20 km SW Portland Roads, 12°44' 143°16', 4 ♂, 4 ♀, 31 Oct.–1 Nov., QM 729, 2115, 2127, 236, 319–321. (iii) 24 km SW Portland Roads, 12°47' 143°18', 1 ♀, 31 Oct. (iv) 26 km SW Portland Roads, 12°44' 143°14', 1 ♂, 31 Oct. (v) 27 km Portland Roads, 12°49' 143°18', 1 ♂, 1 ♀, 2 Nov.

Notes: All localities were closed forest.

Reproduction: (ii) Female with 5 embryos in uterus, independent juvenile trapped.

Ectoparasites: (i, ii, iii, iv, v) *Laelaps* sp.

30. *Rattus leucopus cooktownensis*, Mottle-tailed Cape York Rat

Localities: *Qld* (i) 32 km S Cooktown, 15°45' 145°18', 2 ♂, 4 ♀, 6–7 Nov., QM 719, 329–332, 339. (ii) 17 km E Atherton, 17°15' 145°38', 2, 29 Nov.

Notes: Both localities were closed forest.

Ectoparasites: (i) *Laelaps* sp.

31. *Rattus t. tunneyi*, Tunney's Rat

Localities: *W.A.* (i) 165 km E Derby, 17°6' 125°10', 1 ♂, 2 ♀, 15–16 May, 431–433. (ii) 165 km E Derby, 17°7' 125°10', 1 ♂, 17 May, 436. (iii) 174 km E Derby, 17°10' 125°16', 1♂, 1 ♀, 18 May, WAM M15303, M15304. (iv) 246 km E Derby, 17°7', 125°43', 2 ♀, 20 May, 438, 527. (v) 26 km E Wyndham, 15°35' 128°6', 2 ♂, 1 ♀, 25 May, WAM M15308, 442, 526. *N.T.* (vi) Nourlangie Camp, 12°46' 132°40', 1 ♂, 1 ♀, 2, 18–19 June, SAM M9912, M9911. (vii) 1 km S Nourlangie Camp, 12°46' 132°40', 1 ♀, 1, 18–19 June, 471. (viii) 7 km SE Nourlangie Camp, 12°49' 132°42', 3 ♂, 13 June, SAM M9907, 467, 469. (ix) 8 km S Nourlangie Camp, 12°49' 132°40', 1, 19 June. (x) 9 km S Nourlangie Camp, 12°50' 132°41', 1 ♂, 26, 18–20 June, 529. (xi) 10 km S Nourlangie Camp, 12°51' 132°41', 10, 18–19 June. (xii) 14 km S Nourlangie Camp, 12°54' 132°39', 2 ♂, 3 ♀, 5, 18–19 June, 474–476.

Notes: Caught in closed tussock grassland (i, ii, iii, iv, v), low woodland/closed tussock grassland (iv), low closed forest (vi), low grassy woodland (vii, viii, ix, xi, xiii), and low open grassy woodland (xii).

Ectoparasites: (viii) *Laelaps nuttalli*, (xii) *Mesolaelaps australiensis*.

32. *Rattus tunneyi culmorum*, Tunney's Rat

Localities: *Qld* (i) 22 km SW Emerald, 23°41' 148°4', 1 ♂, 15 Dec., 363. (ii) 58 km N Rockhampton, 22°52' 150°41', 1 ♂, 5 Jan., QM 2101. (iii) 58 km N Maryborough, 25°6' 152°33', 14 Jan., QM 2098.

Notes: Caught in closed grassland (i), low open forest (ii) and grassy woodland (iii).

Ectoparasites: (ii) *Laelaps* sp., (iii) *Mesolaelaps australiensis*, (i) *Xenopsylla vexabilis*.

33. *Rattus rattus*, Black Rat

Localities: *Qld* (i) 13 km N Laura, 15°12' 144°25', 2 ♂, 28 Oct., QM 705. (ii) 17 km S Cairns, 17°5' 145°47', 1 ♀, 14 Nov., 360. (iii) 40 km SE Cairns, 17°15' 145°56', 2♂, 1 ♀, 16 Nov., 351-353. (iv) 11 km NE Atherton, 17°12' 145°33', 1 ♂, 1 ♀, 22 Nov., 340–341. (v) Maslin Creek, Atherton, 17°15' 145°29', 1 ♂, 1 ♀, 22–23 Nov., 339, 342. (vi) 3 km SE Atherton, 17°20' 145°30', 1 ♂, 1 ♀, 27 Nov., 345, 346. (vii) 58 km N Maryborough, 25°6' 152°32', 1 ♀, 14 Jan., QM 717. (viii) Mogill Creek, Brisbane, 27° 12' 152°56' 1 ♂, 1 ♀, 27 Jan., 369, 370. *N.S.W.* (ix) 50 km NE Newcastle, 32°39' 152°9', 4 ♂, 2 ♀, 3–4 Feb., AM M10415–M10418, 379. (x) 25 km NW Canberra, 35°9' 148°57', 1 ♂, 1 ♀, 9 Feb., AM M10419, M10420. *W.A.* (xi) 26 km NE Perth, 31°13' 116°9', 1 ♂, 1 ♀, 4 April, WAM M15262, 412. (xii) 30 km NW Augusta, 34°4' 115°2', 1 ♂, 6 May, 414. (xiii) 18 km N Roebourne, 20°36' 117°10', 2 ♀, 9 May, WAM M15263, M15264. *N.T.* (xiv) 114 km S Darwin, 13°20' 130°44', 1 ♂, 3 ♀, 24 June, SAM M9903–M9906.

Notes: Caught in grassy open forest (i), riverine closed forest (i), low open grassy woodland (ii), mangroves adjacent to closed forest (iii), closed grassland (iv), edge of closed forest (vi), open forest (ix), low open forest/closed heath (xii), rockpile and hummock grassland (xiii) and river banks (v, x, xi, xiv).

Ectoparasites: (ix) *Laelaps assimilis*, (iv) *L. nuttalli* (xi) *Echinonyssus butantanensis*, *Ornithonyssus bacoti*, (iv) *Pygiopsylla rainbowii* n. ssp., (xi) *P. tunneyi*, (iv, v) *Xenopsylla australiaca* (iv, vi) *X. vexabilis*, (v, xi) *Leptopsylla segnis*.

34. *Hydromys chrysogaster*, Water Rat

Localities: *Qld* (i) 63 km NW Coen, 13°26' 142°56', 1 ♂, 29 Oct., QM 698. (ii) 20 km SW Portland Roads, 12°44' 143°16', 2 ♀, 31 Oct.–2 Nov. (iii) 26 km S Portland Roads, 12°49' 143°18', 1 ♀, 2 Nov. (iv) 40 km SE Cairns, 17°15' 145°56', 2 ♀, 15 Nov., QM697. (v) Atherton, 17°15' 145°29', 4 ♂, 1 ♀, 24 Nov., 343, 344, QM 699. (vi) 29 km SE Innisfail, 17°46'

146°7′, 2 ♂, 2 ♀, 4 Dec., 192, 193, 362. (vii) 61 km N Rockhampton, 22°51′ 150°40′, 1 ♂, 5 Jan., 365. (viii) 9 km SE Dunwich, Stradbroke Island, 27°32′ 153°30′, 1 ♂, 19 Jan., 194. *W.A.* (ix) 26 km NE Perth, 31°13′ 116°91′, 2 ♂, 1 ♀, 4 Apr., 218, 219, 413. (x) 165 km E Derby, 1 ♂, 1 ♀, 16–17 May, 215, 220.

Notes: All localities were at the water's edge: flowing fresh water (ii, iii, iv, v, vii, viii, ix, x), stagnant (i) and saline (vi).

Ectoparasites: (iii, vi) *Laelaps wasselli*, (v) *Mesolaelaps australiensis, Pygiopsylla hoplia, Xenopsylla vexabilis.*

35. *Mesembriomys gouldii*, Black-footed Tree-rat

Localities: *Qld* (i) 28 km N Atherton, 17°2′ 145°26′, 1 ♀, 21 Nov., 87. (ii) 22 km N Atherton, 17°7′ 145°26′, 1 ♂, 22 Nov., QM 700. *N.T.* (iii) 7 km SE Nourlangie Camp, 12°49′ 132°42′, 1 ♀, 13 June, 64. (iv) 12 km S Nourlangie Camp, 1 ♂, 18 June, 85. (v) 185 km E Darwin, 12°41′ 132°55′, 1 ♀, 14 June, 86. (vi) 17 km E Darwin, 12°29′ 130°59′, 1, 17 June, 531.

Notes: Localities ii and vi were road kills. All localities were low open grassy woodland.

Reproduction: (iii) 2 young born.

36. *Conilurus penicillatus*, Brush-tailed Tree-rat

Localities: *N.T.* (i) 7 km SE Nourlangie Camp, 12°49′ 132°42′, 1♀, 13 June, 90. (ii) 9 km SE Nourlangie Camp, 12°50′ 132°41′, 1 ♂, 19 June, 88. (iii) 10 km S Nourlangie Camp, 12°51′, 132°41′, 1 ♀, 20 June, 89.

Notes: Both localities were low grassy woodland.

Reproduction: (i) 3 young born

37. *Notomys alexis*, Spinifex Hopping-mouse

Localities: *W.A.* (i) 14 km N Denham, 25°49′ 113°32′, 1 ♀, 19 Apr., WAM M15290. (ii) 14 km N Denham, 25°48′ 113°31′, 1 ♂, 1 ♀, 26–28 Apr., 166, 168. (iii) 160 km NE Carnarvon, 1 ♀, 13, 7 May, WAM M15291.

Notes: Caught in open scrub (i) and in tall open shrubland (ii). Both areas were on red sand. Judging from tracks in locality (i) and from spotlighting at locality (ii) *N. alexis* appeared to be common at both localities.

38. *Zyzomys argurus*, Common Rock-rat

Localities: *Qld* (i) 22 km S Cooktown, 15°39′ 145°13′, 3 ♂, 4 ♀, 7–9 Nov., QM 691, 2104, 95, 96, 534. *W.A.* (ii) Fortescue River, 21°18′ 116°11′, 1 ♂, 4 ♀, 8 June, WAM M15272, 107–110. (iii) 165 km E Derby 17°6′ 125°10′, 4 ♂, 5 ♀, 15–17 May, WAM M15273–M15286. (iv) 165 km E Derby, 17°7′ 125°10′, 3 ♂, 6 ♀, 15–17 May, 101, 104, 105, 543–548. (v) West Bastian above Wyndham, 5°27′ 128°21′, 1 ♂, 1 ♀, 27 May, WAM M15287, 100. *N.T.* (vi) 346 km S Darwin, 15°36′ 131°8′, 1 ♀, 31 May, 99. (vii) Nourlangie Rock, 230 km E Darwin, 12°51′ 132°47′, 1♂, 1 ♀, 13 June, 97, 98.

Notes: The habitat of *Z. argurus* cannot be described by Specht's classification. This animal occasionally occurs on rocky slopes covered with sparse vegetation as in locality (iv) but more often in rock piles devoid of vegetation (i, ii, iii and v).

Reproduction: (i) Copulation plug present, (vi) embryos in uterus.

Ectoparasites: (i, ii, iii, iv) *Laelaps pammorphus*, (i) *Echidnophaga myrmecobi.*

39. *Zyzomys woodwardi*, Large Rock-rat

Localities: *N.T.* (i) Nourlangie Rock, 230 km E Darwin, 12°51′ 132°47′, 3 ♂, 2 ♀, 2, 13 and 18 June, SAM M9899, 113–115. (ii) Cannon Hill 225 km E Darwin, 12°23′ 132°56′, 4 ♀, 21 June, 116–118, 549.

Notes: Both localities are outlying scarps of the Arnhem Land Escarpment.

Ectoparasites: (ii) *Laelaps pammorphus.*

40. *Mastacomys fuscus*, Broad-toothed rat

Locality: *N.S.W.* (i) Kosciusko Natl Pk, 36°23′ 148°28′, 4♀, 10–11 Feb., SAM M9897, AM M10431, M10432, 77.

Notes: This locality is a closed herbfield.

Reproduction: (i) 1 young born.

Ectoparasites: (i) *Laelaps cybiala, Macropsylla hercules, Pygiopsylla hoplia.*

41. *Pseudomys delicatulus*, Little Native-mouse

Localities: *Qld* (i) 22 km SW Emerald, 23°41′ 148°4′, 2 ♂, 15 Dec., QM 2133, 14. *W.A.* (ii) 189 km S Broome, 19°0′ 121°14′, 1 ♀, 11 May, 59. *N.T.* (iii) 185 km E Darwin, 12°41′ 132°55′, 1♀, 15 June, SAM M9898.

Notes: Caught in low woodland (i) tall open shrubland/hummock grassland (ii) and low open woodland.

Reproduction: (iii) 3 young born.

42. *Pseudomys novaehollandiae*, New Holland Mouse

Localities: *N.S.W.* (i) 30 km NE Newcastle, 32°39′ 152°9′, 2 ♂, 4–9 Feb., AM M10433. *Vic.* (ii) 38 km E Sale, 38°6′ 147°31′ 1 ♀, 23 Feb., 550.

Notes: Caught in closed scrub (i) and low open woodland/open heath (ii).

Reproduction: (ii) 5 embryos in uterus.

43. *Pseudomys albocinereus*, Ashy-grey Mouse

Localities: *W.A.* (i) 22 km NE Jurien, 30°8′ 115°9′, 2 ♂, 2 ♀, 12–13 Apr., WAM M15295, 25–27. (ii) Bernier Island, 24°56′ 113°9′, 2 ♀, 21–22 Apr., 28, 29.

Notes: Caught in closed heath (i) and low shrubland on coastal dunes (ii).

Reproduction: (ii) 4 young born.

Ectoparasites: (i) *Laelaps* sp.

44. *Pseudomys occidentalis*, Western Mouse

Localities: *W.A.* (i) 17 km NE Bendering, 32°22′ 118°28′, 3 ♀ 2 ♂ 3, 30–31 Mar., and 1 Apr., WAM, M15294, M15305, 551, 552. (ii) 17 km NE Bendering, 32°21′ 118°28′, 1 ♂, 1 Apr., 553.

Notes: Caught in areas of tall shrubland.

Ectoparasites: (i, ii) *Laelaps* sp., (ii) *Stephanocircus* n. sp.

45. *Pseudomys praeconis*, Shark Bay Mouse

Localities: *W.A.* (i) Bernier Id, 24°56′ 113°9′, 1 ♂, 21 Apr., WAM M15305, (ii) Bernier Id, 24°55′ 113°8′, 10♂, 1 ♀, 21–23 Apr., WAM M15306, 19, 554–556.

Notes: Caught in low shrubland (i) and tussock grassland (ii) (Robinson *et al.* 1976).

Ectoparasites: (ii) *Laelaps* sp., (i) *Xenopsylla vexabilis.*

46. *Pseudomys shortridgei*, Shortridge's Native-mouse

Localities: *Vic.* (i) 42 km NE Hamilton, 37°31′ 142°25′, 1 ♀, 4 Mar., 466, (ii) 52 km NE Hamilton, 37°27′ 142°28′, 1 ♀, 7 Mar., 18.

Notes: Caught in areas of closed heath.

47. *Pseudomys gracilicaudatus*, Eastern Chestnut Native-mouse

Localities: *Qld* (i) 8 km SW Townsville, 19°20′ 146°4′, 2 ♀, 8 Dec., QM 703. (ii) 26 km NE Rockhampton, 23°19′ 150°45′, 2 ♂, 17–21 Dec., QM 727. (iii) 9 km NE Rockhampton, 23°20′ 150°35′, 1 ♀, 8 Jan., QM 2120. (iv) 98 km NW Bundaberg, 24°31′ 151°28′, 1 ♀, 10 Jan., QM 2119.

Notes: Caught in open grassy woodland (i), low grassy woodland (ii and iii) and low open forest (iv).

Ectoparasites: (iv) *Laelaps aella*, *L. nuttalli*.

48. *Pseudomys nanus*, Western Chestnut Native-mouse

Localities: *W.A.* (i) 165 km E Derby, 17°6′ 125°10′, 4 ♂ 2 ♀, 1, 15–17 May, WAM M15297, M15300, M15301, 435, 557–559. (ii) 246 km E Derby, 17°7′ 125°43′, 2 ♂, 1 ♀, 21 May, WAM M15302, 439–440. (iii) 18 km NE Kimberley Research Station, 15°33′ 128°6′, 1 ♀, 28 May, 444. *N.T.* (iv) 346 km S Darwin, 15°36′ 131°7′, 1 ♀, 1 June, 445. (v) 7 km SE Nourlangie Camp, 12°49′ 132°42′, 1 ♀, 13 June, 255. (vi) 14 km S Nourlangie Camp, 12°54′ 132°38′, 1 ♀, 18 June, 473. (vii) 10 km S Nourlangie Camp, 12°51′ 132°41′, 1 ♀, 20 June, 478.

Notes: Caught in closed tussock grassland (i, iii and iv), open woodland/closed tussock grassland (ii and ii) and low grassy woodland (v, vi and vii).

Reproduction: (i, iii) Independent juveniles trapped, (iv, vi) 3 young born.

Ectoparasites: (i, ii, iii, iv, v, vi) *Laelaps aella.*

49. *Mus musculus*, House-mouse

Localities: *Qld* (i) 32 km W Windorah, 25°20′ 142°18′, 1, 16 Oct. (ii) 2 km NE Mt Isa, 1, 19 Oct. (iii) 25 km N Atherton, 17°3′ 145°26′, 10, 21 Nov. (iv) 11 km NE Atherton, 17°12′ 145°33′, 2, 21 Nov. (v) 22 km SW Emerald, 23°41′ 148°4′ ?, 14 Dec. (vi) Nogoa River, Emerald, 23°32′ 148°10′, 5, 15 Dec. (vii) 26 km NE Rockhampton, 23°19′ 150°45′, ?, 19 Dec. (viii) 58 km N Maryborough, 25°6′ 152°33′, ?, 14 Jan. *N.S.W.* (ix) 20 km SW Port Macquarie, 31°37′ 152°50′, ?, 2 Feb. (x) 50 km NE Newcastle, 32°39′ 152°9′, ?, 4 Feb., AM M10421. (xi) 20 km NE Mallacoota, 37°27′ 149°57′, 1, 17 Feb. *Vic.* (xii) 38 km E Sale, 38°6′ 147°31′, 15, 23–24 Feb. *W.A.* (xiii) 17 km NE Bendering, 32°22′ 118°28′, 22, 30 Mar.–1 Apr. (xiv) 32 km S Hyden, 32°49′ 119°, 7–10 Apr. (xv) 22 km NE Jurien, 30°8′ 115°9′, ?, 12 Apr. (xvi) 18 km N Roebourne, 20°37′ 117°11′, 2, 9 May.

Notes: *M. musculus* was both widespread and common. It was caught in tussock grassland (i), coastal dunes (xii), grassy woodland (ii and viii), closed grassland (iii, iv, v and vi), low grassy woodland (vii), closed scrub (ix), open forest (x), woodland/closed heath (xi), closed heath (xi) and tall scrubland (xii and xiii).

50. *Uromys caudimaculatus*, Giant White-tailed Rat

Localities: *Qld* (i) 23 km SW Portland Roads, 12°44′ 143°14′, 1 ♂, 31 Oct., 184. (ii) 19 km SW Portland Roads, 12°43′ 143°17′, 1 ♂, 1 ♀, 2 Nov., 182, 183. (iii) 32 km S Cooktown, 15°45′ 145°18′, 3 ♂, 1, 7–9 Nov. (iv) 22 km S Cooktown, 15°39′ 145°13′, 1 ♂, 3♀, 5, 7–9 Nov., QM 696. (v) 22 km S Cooktown, 15°39′ 145°14′, 1, 9 Nov. (vi) 40 km SE Cairns, 17°15′ 145°56′, 1 ♂, 1 ♀, 15–16 Nov., QM 2095, 191. (vii) 19 km SE Atherton, 17°25′ 145°31′, 6♂, 1 ♀, 25 Nov., QM 2096, 188, 190 (viii) 3 km SE Atherton, 17°20′ 145°30′, 1, 27 Nov. (ix) 14 km E Atherton, 17°15′ 145°37′, 1 ♀, 28 Nov.

Notes: All localities were in closed forest except locality (iv) where it was caught among boulder heaps close to patches of closed forest.

Reproduction: (ii) 1 young born.

Ectoparasites. (ii, vi, vii) *Laelaps southcotti*, (ii) *Odontacarus* sp., (vii) *Pygiopsylla hoplia.*

51. *Melomys cervinipes*, Fawn-footed Melomys

Localities: *Qld* (i) 26 km SW Portland Roads, 12°44′ 143°14′, 2, 30 Oct, (ii) 32 km S Cooktown, 15°45′ 145°15′, 3 ♂, 3 ♀, 7–9 Nov. (iii)

40 km SE Cairns, 17°15′ 145°56′, 3 ♀, 15–16 Nov. (iv) 41 km SE Cairns, 17°15′ 145°56′, 1 ♀, 15 Nov. (v) 19 km SE Atherton, 17°25′ 145°31′, 1 ♀, 25 Nov. (vi) 3 km SE Atherton, 17°20′ 145°30′, 1, 27 Nov. (vii) 22 km S Atherton, 16°28′ 145°59′, 1, 1 Dec. (viii) 61 km N Rockhampton, 22°51′ 150°40′, 1 ♀, 5 Jan. (ix) 98 km NW Bundberg, 24°32′ 151°28′, 1♀, 12 Jan. (x) 38 km E Kingaroy, 26°39′ 152°13′, 1, 16 Jan. Notes: All localities were closed forest.

Ectoparasites: (ii, iii) *Laelaps nuttalli*, (ii, iii, iv, v, viii, ix) *L. rothschildi*, (v) *Acanthopsylla incerta*, (ix) *A. pavida*.

52. *Melomys littoralis*, Grassland Melomys

Localities: *Qld* (i) 20 km SW Portland Roads, 12°44′ 143°16′, 1 ♂, 1 Nov. (ii) 19 km SW Portland Roads, 12°43′ 143°17′, 1 ♀, 1 Nov. (iii) 21 km SW Portland Roads, 12°44′ 143°16′, 2 ♀, 1 Nov. (iv) 23 km S Portland Roads, 12°47′ 143°18′, 3 ♂, 4 ♀, 2–3 Nov., QM 722. (v) 37 km S Cooktown, 15°48′ 145°15′, 1 ♂, 1♀, 2 Nov. (vi) 22 km S Cooktown, 15°39′ 145°13′, 3 ♂, 1 ♀, 7–8 Nov. (vii) 17 km S Cairns, 17°5′ 145°47′, 3 ♂, 3 ♀, 14 Nov. (viii) 25 km N Atherton, 17°3′ 145°26′, 1 ♂, 1 ♀, 21 Nov. (ix) 11 km NE Atherton, 17°12′ 145°33′ 1 ♂, 1♀, 22 Nov. (x) 22 km SE Atherton, 17°22′ 145°33′, 4 ♂, 4♀, 29 Nov. (xi) 29 km SE Innisfail, 17°46′ 146°7′, 1 ♂, 3 Dec. (xii) 61 km N Rockhampton, 22°52′ 150°41′, 2, 5 Jan. (xiii) 58 km N Rockhampton, 22°52′ 150°41′, 1 ♂, 1 ♀, 5 Jan. (xiv) 58 km N Maryborough, 25°6′ 152°32′, 1 ♀, 14 Jan. (xv) 9 km SE Dunwich, North Stradbroke Is., 27°32′ 153°30′, 3 ♂, 19–20 Jan. *N.T.* (xvi) Nourlangie Camp (205 km E Darwin), 12°46′ 132°40′, 1 ♂, 19 June. (xvii) 15 km NE Darwin, 12°22′ 130°56′, 1 ♂, 11 June.

Notes: Habitats were closed forest (xvi), open forest (xi, xii), low open forest/grassy woodland (i, ii, iii, iv, xiii, xiv), low grassy woodland (v, vi), low open grassy woodland (vii), closed grassland (viii, iv), closed sedgeland (x, xv, xvii).

Ectoparasites: (vi, xvii) *Laelaps nuttalli*, (i, iii, iv, v, vi, vii, viii, ix, xi, xiii, xiv, xv, xvii) *L. rothschildi*, (ix, xv) *Mesolaelaps australiensis*, (vii, ix, x, xiv, xv) *Pygiopsylla hoplia*, (x) *P.* sp., *Acanthopsylla incerta*, *A. pavida*, *Xenopsylla australiaca*, (iv, ix) *X. vexabilis*.

53. *Melomys* spp

Localities: *Qld* (i) 62 km NW Coen, 13°27′ 142°57′, 1 ♀, 29 Oct., QM 709. (ii) 19 km SE Atherton, 17°25′ 145°31′, 1, 25 Nov., QM 721.

Notes: Habitats were riverine closed forest (i) and closed forest (ii).

Ectoparasites: (i) *Laelaps rothschildi*, (ii) *Pygiopsylla sinuata*, *Acanthopsylla incerta*, *A. pavida*, *Xenopsylla australiaca*.

Discussion

The results contain some significant distribution records.

The Plague Rat *Rattus villosissimus* collected 26 km SE of Wyndham is the second and most northerly record from Western Australia (Calaby 1974).

The Common Rock-rat *Zyzomys argurus*, a relatively common species in suitable habitat in northern Australia, was collected 22 km S of Cooktown, which is the fourth and most northerly record from Queensland (Tate 1952; Gordon & Johnson 1973).

The Little Native-mouse, *Pseudomys delicatulus*, collected 189 km S of Broome, is one of the most southerly records for this species in Western Australia (Bannister 1969). The record from Emerald, Queensland is further inland than previous published records (Covacevich & Easton 1974).

The Eastern Chestnut Native-mouse, *Pseudomys gracilicaudatus*, has recently "reappeared" near Townsville (Horsboom 1975), Emerald (Taylor & Horner (1973) misidentified as *P. australis* c.f. Mahoney & Posamentier (1975)) and north coastal N.S.W. (Mahoney & Posamentier 1975). Our data add three more localities in coastal Queensland. This widely distributed species appears to occur at a uniformly low population density, and considerable trapping effort has usually been expended in its capture (Mahoney & Posamentier 1975). For comparison the trapping effort to capture this species in the present study was: locality (i) 60 trap nights, locality (ii) 330 trap nights, locality (iii) 60 trap nights and locality (iv) 219 trap nights. It is, however, necessary to take into account seasonal variations in population density and this is clearly not possible in a study such as this. As an example, Tunney's Rat *Rattus tunneyi culmorum* proved to be extremely difficult to capture, an experience also recorded by Taylor & Horner (1973). One specimen was trapped at each of three localities in coastal Queensland but many other localities were trapped in the hope of capturing this rodent. One of these was Archoocoora State Forest, a Hoop Pine plantation in southern Queensland where at certain times of the year *R.t. culmorum* is abundant and causes extensive damage to the Hoop Pine root systems (Taylor & Horner 1973). Although numerous signs of this species were seen in the area no rats were captured.

Two major generalisations regarding the Australian rodent fauna can be made as a

TABLE 1

Trapping success for all species, including introduced species, in the major habitat types sampled in eastern, western and northern Australia

Habitat	Number of localities	Total trap nights	Number of captures	Trapping success (%)
Closed forest	17	980	99	10.1
Tall open forest	2	138	55	39.9
Open forest	9	815	88	10.8
Woodland	17	2010	180	9.0
Shrubland	6	765	83	10.8
Heath	7	1070	112	10.5
Tussock grassland	10	718	64	8.9
Sedgeland	4	520	46	8.8
Rockpiles	9	850	65	7.6

result of this study covering a large proportion of the habitat types over a wide area of Australia:

(1) The trapping success in this study (8.3%) supports Watts' (1974) comment that population densities of Australian rodents are low in comparison with equivalent habitats in the Northern Hemisphere. The highest trapping success achieved was 55% in the Otway Ranges, Victoria. Table 1 provides a broad outline of the variation in trapping success in the major habitat types sampled. The two areas of tall open forest sampled proved to support a substantially higher density of small mammals than any of the other habitats. This trend is supported by trapping experience (A. C. Robinson unpublished data) in other areas of this habitat in Victoria.

(2) Australian small mammal faunas are characterised by the low number of species that occur sympatrically. In this study sympatric occurrence was defined as occurrence on the same 200 m trapline, bearing in mind that attempts were made to keep each trapline in a single major habitat.

Of thirty-nine instances of sympatry noted the largest number of species occurring together was four (Table 2). Most cases involve species occupying obviously different ecological niches by virtue of such factors as:

(a) size differences, e.g. *Rattus leucopus, Uromys caudimaculatus*. (b) above ground nests compared with burrows, e.g. *Melomys littoralis, R. sordidus*. (c) insectivorous marsupials compared with omnivorous rodents, i.e. *Antechinus stuartii, R. fuscipes*. (d) introduced species with native species, e.g. *Mus musculus, Pseudomys occidentalis*. Only three cases which may indicate some degree of competition between species were noted. (a) In locality 26(iv) 17 km S of Cairns, Qld, *R. rattus* and *R. sordidus* occurred together. This was an area of disturbed open woodland ad-

TABLE 2

Small mammal species occurring together in the same 200 m trapline. Most abundant species shown first; locality number refers to this species in the body of the paper

Locality	Sympatric species
28(v)	*Rattus villosissimus, Mus musculus*
29(i)	*R. leucopus, Uromys caudimaculatus*
26(i)	*R. sordidus, Melomys littoralis, Sminthopsis rufigenis*
38(i)	*Zyzomys argurus, U. caudimaculatus, M. cervinipes*
26(iv)	*R. sordidus, M. littoralis, R. rattus*
33(iii)	*M. cervinipes, U. caudimaculatus, R. rattus*
24(ii)	*R. fuscipes, M. cervinipes*
26(vi)	*R. sordidus, R. rattus, Mus musculus*
51(v)	*M. cervinipes, U. caudimaculatus*
24(i)	*R. fuscipes, U. caudimaculatus*
26(v)	*R. sordidus, M. littoralis*
11(iv)	*Isoodon macrourus, Pseudomys gracili caudatus*
32(i)	*R. tunneyi, Mus musculus*
32(i)	*Mus musculus, P. delicatulus*
32(ii)	*R. tunneyi, M. littoralis*
47(iii)	*P. gracilicaudatus, M. littoralis*
12(i)	*Perameles nasuta, M. cervinipes*
11(vi)	*I. macrourus, M. littoralis, R. rattus*
25(ii)	*R. lutreolus, Antechinus stuartii, I. macrourus*
33(ix)	*R. rattus, P. novaehollandiae*
33(ix)	*R. rattus, R. fuscipes*
23(iv)	*R. fuscipes, A. swainsonii, Mastacomys fuscus*
23(v)	*R. fuscipes, A. swainsonii, A. stuartii*
23(vii)	*R. fuscipes, A. stuartii, Mus musculus*
23(xi)	*R. fuscipes, A. stuartii, A. swainsonii, Potorous tridactylus*
49(xii)	*Mus musculus, P. novaehollandiae*
25(vii)	*R. lutreolus, A. stuartii, I. obesulus*
23(xii)	*R. fuscipes, A. stuartii, A. swainsonii*
23(xiii)	*R. fuscipes, A. stuartii, A. swainsonii*
16(viii)	*A. stuartii, R. lutreolus, A. swainsonii*
25(x)	*R. lutreolus, P. shortridgei*
49(xiii)	*Mus musculus, P. occidentalis*
45(i)	*P. praeconis, P. albocinereus, Perameles bougainville*
31(i)	*R. tunneyi, P. nanus*
31(iv)	*R. tunneyi, P. nanus*
31(v)	*R. tunneyi, R. villosissimus*
27(ii)	*R. colletti, M. littoralis*
31(xii)	*R. tunneyi, M. littoralis*
17(v)	*A. bellus, I. macrourus, Dasyurus hallucatus*

jacent to cane fields and may have represented an unstable situation. (b) In locality 33(ix) 50 km N of Newcastle, N.S.W., *R. rattus* and *R. fuscipes* occurred together. Again this was an area of open forest adjacent to heathlands regenerating from sand mining and may have been an unstable situation. (c) In locality 31(v) 26 km E of Wyndham, W.A., *R. tunneyi* and *R. villosissimus* occurred together. This was the edge of a flood plain supporting a closed tussock grassland adjacent to an open grassy woodland and may have been part of an ecotone.

Some previously unknown forms of ectoparasites were collected and some considerable range extensions were recorded. The fleas included a new *Stephanocircus* from *P. occidentalis*, a new *Pygiopsylla* from *R.f. assimilis* and a new subspecies of *Pygiopsylla rainbowi* from *R. rattus* and *R. sordidus*. The mites included a new *Laelaps* from *P. occidentalis*, a new *Laelaps* from *P. praeconis* and possibly also *P. albocinereus*.

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STRUCTURE OF THE WILLOCHRAN BASIN, SOUTHERN FLINDERS RANGES, SOUTH AUSTRALIA

BY B. E. MILTON & C. R. TWIDALE

Summary

Interpretation of seismic refraction data obtained on four east-west lines across the Willochra Basin suggests that the structure is bounded on its eastern and western margins by north-south trending faults which delineate a long narrow downfaulted zone. Thus as O'Driscoll (1956) suggested the Willochra Basin is occupied by a graben or rift valley, developed in the crest of a major anticline. Two types of Precambrian basement rock can be identified beneath the Cainozoic basin deposits which have a maximum thickness of some 250 m.

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Summary

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Introduction

The Willochra Basin (Fig. 1) is an intermontane basin eroded in folded Proterozoic Adelaide System strata and partially filled with Cainozoic lacustrine and alluvial sediments. Occupied by the Willochra plains and drained by the intermittently flowing Willochra Creek and its several tributaries, the basin surface stands about 335 m above sea level in the south and gently slopes down to about 200 m elevation at its northern extremity.

The flat aggradational plains are underlain by up to 170 m of unconsolidated flat-lying sediments in the northern half of the Basin and by up to 250 m in the south. They rest unconformably on a broad, gently sloping and only slightly irregular surface eroded in the Proterozoic sediments. In the south Quaternary alluvium rests directly on the Adelaidean rocks, but in the north up to 15 m of Eocene lake beds intervene. The latter are fine-grained in the basin proper and in marginal exposures near Simmonston (Miles 1956), but consist of quartzite and conglomerate in the lower Mount Arden Creek Valley and in the valleys of the Kanyaka and Wirreanda creeks (Shepherd & Thatcher 1959; Webb & Von der Borch 1962; Twidale 1966; Binks 1971).

These Cainozoic sediments are essentially restricted to an elongate, narrow, north-south depression extending from the vicinity of Melrose as far north as Gordon. There is considerable overlap of the Quaternary alluvia which extend up major valleys, but the thicker sequences are apparently confined to a long, narrow trough.

The nature of the deeper basin or trough has been the subject of mild controversy for some years. O'Driscoll (1956, p. 11) speculated that the Basin occupies a graben. He delineated a fault in the eastern side of the Basin but to the west the only faulting he could cite in support of his contention is located in the ranges well away from the area under discussion. More recent and conservative opinion has been that the topographic basin occupies a denuded anticline characterised by relief inversion (Shepherd & Thatcher 1959, p. 14; Twidale 1966, p. 8).

However, during the course of geophysical traverses undertaken in connection with pediment studies and designed to determine the shape of the pre-Cainozoic surface, that is, the surface cut in the folded Adelaide System strata where it plunges beneath the basin sediments, evidence has come to light which though it still does not incontrovertibly prove, nevertheless strongly suggests, that O'Driscoll's intuitive guess was correct and that the Willochra Basin indeed occupies a north-south trending graben.

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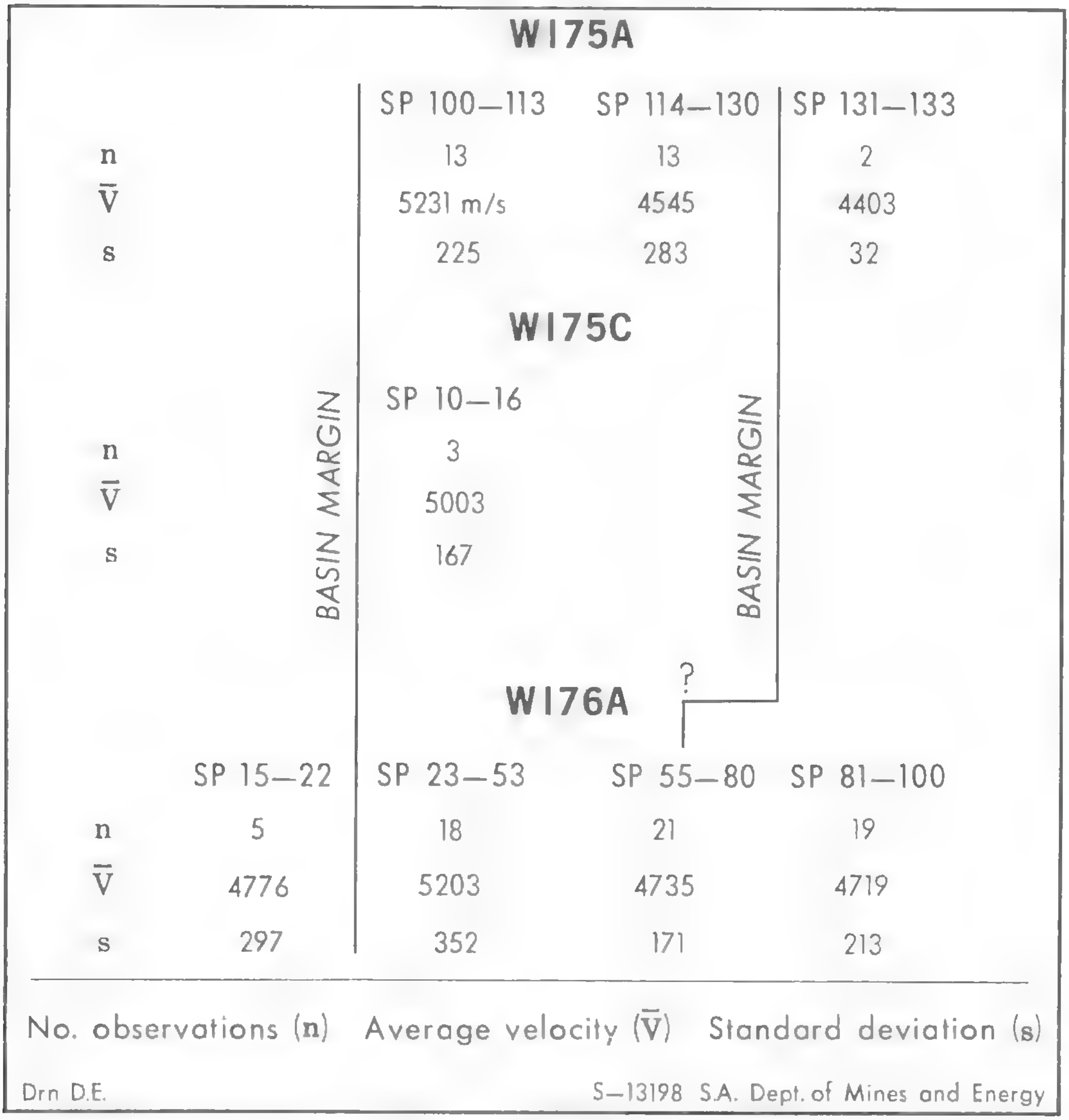
TABLE 1
Velocity analysis



W175A

	SP 100—113	SP 114—130	SP 131—133
n	13	13	2
$\bar{V}$	5231 m/s	4545	4403
s	225	283	32

W175C

	SP 10—16
n	3
$\bar{V}$	5003
s	167

W176A

	SP 15—22	SP 23—53	SP 55—80	SP 81—100
n	5	18	21	19
$\bar{V}$	4776	5203	4735	4719
s	297	352	171	213

No. observations (n) Average velocity ($\bar{V}$) Standard deviation (s)

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Geophysical Operations

Seismic Recording Procedures

The location of seismic traverses along which refraction data were obtained is shown in Fig. 1. Profiles WI75A, B and C were shot in 1975; WI76A in 1976. Detector intervals were 61 m or 30.5 m, with continuous coverage except on line WI75B. Detectors were laid in-line with the energy source, the location of which relative to the detector array was designed to record the basement refractor. Information on near surface material was obtained from refraction spreads with a detector interval of 9 m and shot every 1460 m.

Seismic Computing

Information extracted from the seismic data measures depth relative to mean sea level to a refracting horizon and velocity along the interface. "Time-distance" curves are constructed by plotting arrival times at individual

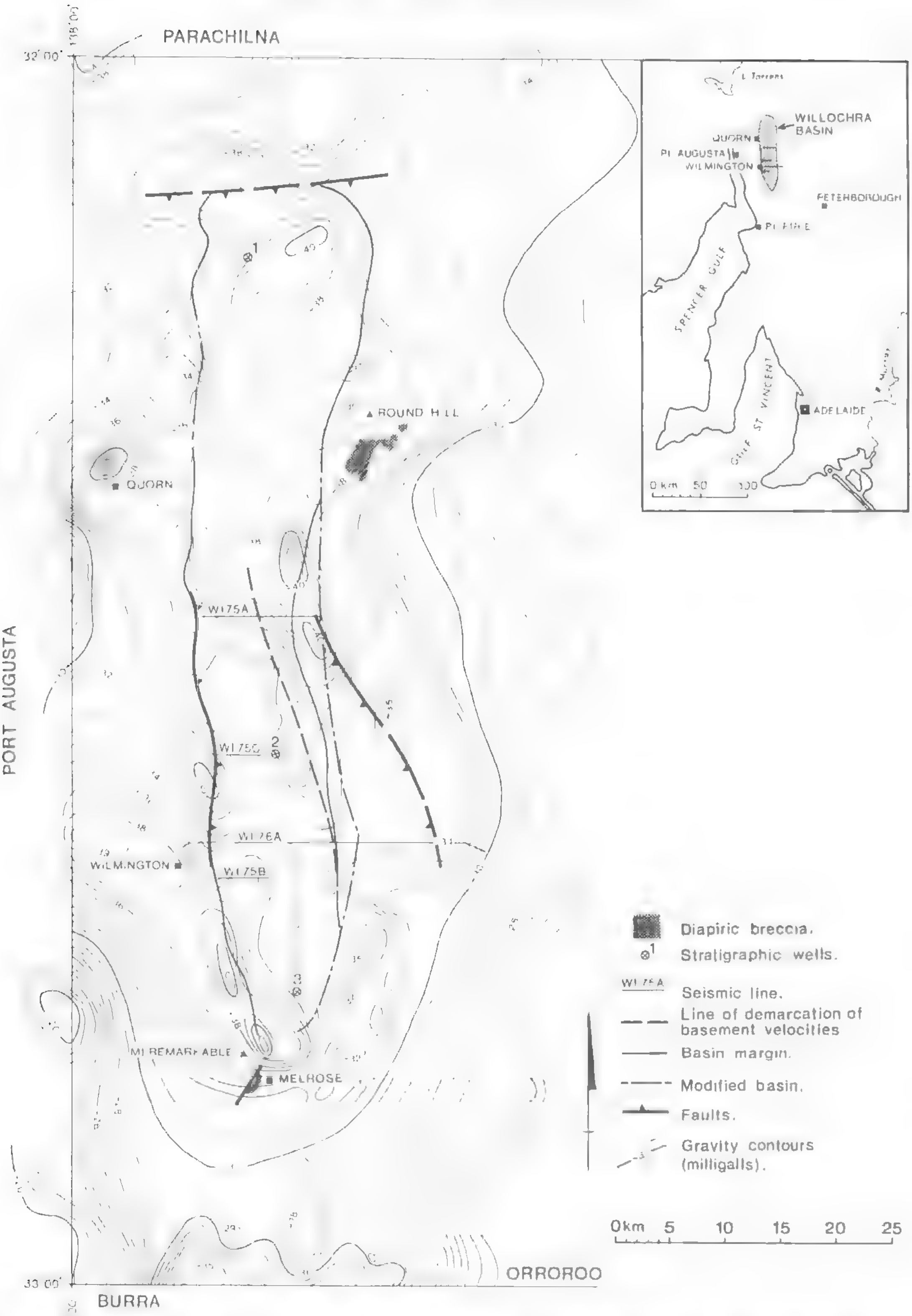

Fig. 1. Bouguer gravity anomalies and structure of the Willochra Basin, with locality map inset.

detectors against their distance from an energy source. If the assumption is valid that the velocities within seismic strata are constant, the plotted points fall on straight line segments.

Depths to refraction horizons below detector locations, other than the near surface seismic events, were computed using a method described by Hawkins (1961). Velocities were obtained by measuring the inverse of the slope of the straight line segments.

Velocities from observed data in this project have, except for shallow horizons for which reciprocal information is not available, been computed using the "method of differences". Provided the dip component of the refracting horizon along the seismic line does not change, the value so determined should contain a small error term only.

Depth calculations using Hawkins' method involve velocity and time terms, hence are subject to greater errors than velocities. For example, if basement velocity values have an error of ± 5% and refraction times ± .002 second, depth computations relative to datum could be in error by between 7% and 8%. It is considered that this error value applies approximately to depth calculations of the bedrock refractor in the Willochra Basin.

Velocity Analysis

Velocities computed for the bedrock horizon along the seismic traverses appear to fall into regular groupings, as shown in Table 1.

Bedrock velocities from spread WI75B are based on a very limited number of observations. They average about 5200 m/s and fit into the second column on Table 1.

The basin appears to be bounded by faulting on the eastern and western margins, but it is also apparent that a change in bedrock velocity occurs near the centre of the basin on line WI75A and near the eastern margin of the basin on WI76A. The significance of the change is discussed in a later section.

The near-surface material within the basin has a range of velocities from 300 to 800 m/s and a thickness of about 2 to 3 m. This layer has been omitted from the cross sections to avoid confusion. A possible water table velocity of around 1500 m/s has been recorded at some locations, e.g. near the western end of line WI75A. It also occurs erratically on line 76A, but has not been plotted because of its shallow depth of about 7 to 9 m below ground surface.

Below these events lies a refractor with the following velocity characteristics:

TABLE 2
Clay horizon velocities

		n	$\bar{V}$	s
WI75A:	SP 101-130	26	1913 m/s	151
WI75C:	10- 16	5	2186	352
WI76A:	23- 60	38	1890	75
WI75B:	103-114	2	1968	81
		71	1922 m/s	155

Captions as in Table 1.

This horizon has a depth ranging from about 6 to nearly 20 m and probably correlates with the upper surface of a mottled clay series, dated as Recent or late Pleistocene. The fairly wide variation of velocities could result from varying percentages of sand, calcite, etc., although lack of reciprocal refraction coverage in many instances reduces the precision of velocity measurements.

Intermediate velocities between the clay horizon and basement can be seen on the WI75B and WI76A sections. Average values of these and bedrock velocities, the latter divided into eastern and western groupings, are:

TABLE 3
Basement and intermediate horizon velocities

Basement, eastern	n = 34	$\bar{V}$ = 4681 m/s	s = 243	δ = 2.5 g/cm^3
Basement, western	n = 34	$\bar{V}$ = 5196	s = 296	δ = 2.6 g/cm^3
Intermediate I	n = 5	$\bar{V}$ = 3598	s = 222	
Intermediate II	n = 21	$\bar{V}$ = 2591	s = 268	

Abbreviations as in Table 1.

Equivalent specific gravity values have been computed from velocities using graphical relationship between density and velocity (Drake *in* Grant & West 1965, p. 200) for use in interpreting gravity patterns. The curve does not give reliable values of density for the Adelaide System rocks, but as density *contrasts* were used to calculate comparative gravity values, it was considered that these would be reasonable.

Gravity Data

Gravity expression of the basin can be seen on the western third of ORROROO 1:250 000 sheet, of which a Bouguer contour map was published by the South Australian Department of Mines in 1975. This map is based on data from a helicopter survey undertaken for the Bureau of Mineral Resources by Wongela Geophysical Pty Ltd in 1970 (Tucker & Brown 1973)[1] with stations on a grid spacing of about 7.2 km, and on ground data from South Australian Department of Mines surveys. Figure 1 is a contour map at 1 milligal intervals of Bouguer gravity, with station locations shown in the figure.

Contours of residual gravity were obtained by deducting a regional surface from the Bouguer contour map. Patterns do not vary significantly on the Bouguer and residual maps and the former only has been included here. Residual values reveal a total anomaly of between −6 and −10 milligals and the entire residual pattern is superimposed on a large gravity low extending from the southern part of BURRA, through ORROROO to the northern limit of PARACHILNA, a distance of about 350 km. This has a total residual anomaly of about −25 milligals and its origin is considered to be a deep, low density block in the pre-Adelaidean rocks (Tucker & Brown 1973).

Basin margins

At the western extremities of seismic lines WI75A, WI75C and WI76A (Fig. 2), faulting of the high speed (basement) refractor is in near coincidence with the western margin of the basin as mapped by O'Driscoll. The faults have a throw of between 100 m and 150 m, although the seismic data are not easily interpretable on the northernmost two lines. On the gravity maps, the location of the basin margin can be traced approximately to the north of line WI75A, but is less evident to the south of that line. This reflects the composite origins of the gravity patterns to which variations of density of the Adelaide System rocks contribute, as well as the contrast between low density basin sediments and basement rocks.

Although the basin shows as an area of low gravity values, its boundaries are not, in general, clearly defined. An exception is the gravity expression of the Simmonston Fault which forms the northern margin of the basin, over most of which there is a clearly defined gravity gradient to the south.

The eastern margin is more complex in its geophysical expression than the western or northern boundaries. On seismic line WI75A a basement fault with a throw of about 50 m represents the basin limits, and O'Driscoll's tentative margin has been adjusted on Fig. 1 to pass over the fault. On line 76A, however, a basement fault of about 75 m which appears to correlate with the fault on 75A, lies well to the east of the basin margin. The correlation of the two faults rests on the similarity in seismic velocities on either side of each fault and the (residual) gravity pattern, and is also indicated on Fig. 1. The margin interpreted by O'Driscoll coincides with a small basement fault on line 76A at shot point 54 (Fig. 2), but the consistency of the seismic section suggests that the limit of the basin sediments lies around shot points 60-61, i.e. about 2.2 km further east than indicated by the water well logs.

As at the western boundary, the eastern margin is reflected as a component of gravity patterns, but is difficult to extract from the total effect.

Basin fill

In the basin no seismic events were recorded between the Recent/Pleistocene clay horizon referred to in the section on velocity analysis, and the basement refractor. This clay layer persists completely across the basin on all traverses shot. It has an equivalent density value of about 1.8 g/cm^3, which has been used in gravity analysis in the section on "Basement rock types".

The near surface, "weathering" horizons and an intermittent water table event have been briefly described above.

Bedrock configuration

The physical contrasts between the sedimentary fill and bedrock, even where moderately weathered, are quite sharp. The seismic breaks are accordingly of good quality and mapping of the basement surface is considered to be of fair accuracy, subject to the error terms discussed above. Depth to bedrock below surface ranges from around 50 m on the eastern end of WI75A to about 250 m on WI75B. Although the data on this line are of poor quality, due to limited coverage, there is some confirmation of this maximum recorded thick-

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[1] Tucker, D. H. & Brown, F. W. (1973) Reconnaissance helicopter gravity survey in the Flinders Ranges, South Australia, 1970. *Rec. Bur. Miner. Resour. Geol. Geophys.* 1973/12 (unpublished).

Fig. 2. Seismic profiles across the Willochra Basin.

ness in the presence of a gravity low, which could result from a thicker section of low density material.

The basement surface over the seismic sections shows a slight increase in depth from east to west, with minor faulting and small scale structure being recorded as shown in Fig. 2. Some of the undulations could be the result of variations in thickness and degree of weathering of the bedrock. The overall change in depth to bedrock contributes significantly to gravity patterns within the basin, but the effect of minor faults and structure is unlikely to be of sufficient magnitude to detect on the gravity contours.

Basement rock types

The change in basement velocity shown in Table 1, could result from variations of weathering, or from changes in rock type. The latter is considered more likely because of the division into two discrete groups with a sharp discontinuity, with weathering effects having a minor influence on velocities. It is estimated that the observational error of the velocities is about 5%; the range of velocities recorded in each case is about 10%, the difference probably being accounted for by differential weathering of bedrock.

An examination of drillers' logs from water wells and geological logs from three stratigraphic wells drilled in the basin tentatively suggests that basement material associated with higher velocity, i.e. west of the line shown on Fig. 1, consists of slate, while that to the east of the line appears to consist of siltstones, quartzite and shales.

Gravity anomalies within the basin consist of lows in the north and central part and a west-northwest trending ridge in the south central area. It is considered that the source of the residual patterns has two major contributors, viz. the density contrast between Tertiary and younger sediments and bedrock, and changes in basement rock types, as discussed above. The degree of weathering of basement may also contribute in a minor fashion to the anomalous patterns.

Assuming density values of the two basement types of 2.5 and 2.6 g/cm^3, and of the sedimentary fill of 1.8 g/cm^3, an approximate effect on gravity patterns can be obtained. Along the northern seismic line, W175A, the variation in gravity values due to the change in basement density over a distance of 7.5 km is about 6 milligals, provided that this line segment is centred on the change in rock type. Over the same part of the seismic line, the contribution to gravity values due to changes in thickness of the sediments from less than 100 to 150 m, would amount to between 1½ and 3 milligals. The sum of these is sufficient to account for most of the gravity anomaly along W175A. If this explanation of the gravity patterns is valid, distribution of the two types of bedrock can be extrapolated north and south of the seismic line from a consideration of the residual gravity contours. The line of demarcation of the two bedrock velocities is shown on Fig. 1.

However, this simple analysis cannot be applied along line W176A due to a complex distribution of sediments of varying densities between the surface and basement over the eastern half of the line, as indicated in Table 3. The implications of these observations are discussed by Milton[2].

Discussion and Conclusions

The abrupt breaks of slope in the pre Cainozoic bedrock floor demonstrated by the geophysical traverses are best interpreted as fault scarps, though only drilling can really demonstrate their character. Alternative explanations of the steep scarps are not accepted for the following reasons. The lithology and disposition of the Proterozoic strata exposed at the edge of the Basin and probably giving rise to the strong refraction in the area of the subsurface scarps is not such as to promote the development of escarpments of either the steepness or elevation of those recorded by the survey. Nor are the strata and stratigraphy of a type or structure conducive to scarp retreat (see Tricart 1957; Twidale 1960, 1967): there is neither a really resistant formation, nor are the strata flat-lying. To interpret the scarps as river bluffs demands that all three traverses were quite fortuitously located over the points where the pre-Tertiary Willochra Creek impinged upon the valley sides to produce river cliffs; and this is asking much of coincidence.

On the other hand, if the scarps are interpreted as of fault origin their steepness is readily comprehensible. The readings to the

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[2] Milton, B. E. (1977) Geophysical exploration of the Willochra Basin. *S. Aust. Dept. Mines.* Unpubl. Rept. RB 77/79.

west of shot point 100 on line WI75A are confused, probably because the traverse was inadvertently located above a deep valley cut into the fault scarp—a feature commonplace on modern fault scarps such as those bounding Death Valley, California. If this interpretation is correct, the profiles of the floor eroded in Adelaidean sediments obtained on the three northern seismic lines (Fig. 2) indicate that the central part of the Willochra Basin, at least, is a graben structure, and that the Cainozoic sedimentation has been controlled by the marginal faulting.

It is not uncommon to find a graben developed in the crest of an anticline (see, e.g., Lafitte 1939; also Twidale 1971, pp. 120-131, esp. p. 129) and indeed one of the oldest and most widely favoured theories concerning the origin of grabens, that due to Gregory (1921), calls for the structure developing in such areas of tensional stress. The structure is essentially of pre-Tertiary age, for there is no evidence of significant dislocation of the Cainozoic strata along the lines of fault, though Eocene lake beds in the general region have been faulted (Webb & Von der Borch 1962). However, there is ample evidence of contemporary seismic activity at both margins of the postulated graben, but especially on the western side of the structure (Sutton & White 1968, pp. 27-29).

The Willochra Basin in thus essentially a graben. The structure is deeper in the west than in the east and may be more actively subsiding on the western than the eastern flank; again comparisons can be made with the modern grabens, like Death Valley, which are tilting as well as subsiding (Hunt & Mabey 1966).

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NEMATODE AND OTHER HELMINTH PARASITES OF THE KANGAROO ISLAND WALLABY, MACROPUS EUGENII (DESMAREST).

2. SITE SELECTION WITHIN THE STOMACH

BY LESLEY R. SMALES AND PATRICIA M. MAWSON

Summary

Stomachs of 99 Kangaroo Island Wallabies were divided into regions. The anterior 4/5 of the stomach appears to be analagous to the rumen while the posterior 1/5 corresponds to the abomasum of the sheep. Nematodes present were identified and site preferences determined.

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by LESLEY R. SMALES* and PATRICIA M. MAWSON*

Summary

SMALES, L. R. & MAWSON, P. M. (1977) Nematode and other helminth parasites of the Kangaroo Island Wallaby, *Macropus eugenii* (Desmarest). 2. Site selection within the stomach. *Trans. R. Soc. S. Aust.* **102**(3), 79-83, 31 May, 1978.

Stomachs of 99 Kangaroo Island Wallabies were divided into regions. The anterior 4/5 of the stomach appears to be analagous to the rumen while the posterior 1/5 corresponds to the abomasum of the sheep. Nematodes present were identified and site preferences determined.

Introduction

The stomach, caecum, and colon of many herbivorous hosts offer an environment capable of supporting a number of closely related nematode species. Such species flocks have been described for the rhinoceros and elephant (Chabaud 1956), tortoise (Schad 1963; Petter 1963) and kangaroo (Mycytowycz 1964). Holmes (1973) has shown that nematodes actively chose preferred sites within the host. Species flocks are able to exist in a host because each member species occupies a different ecological niche. These niches can be separated by spatial, behavioural or temporal characters.

The nematode *Labiostrongylus eugenii* occurs in the Kangaroo Island Wallaby (*Macropus eugenii*). A survey undertaken preliminary to a study of the life history of this nematode (Smales[1]) revealed the presence of such a species flock in the stomach. During a subsequent epidemiological survey of the nematodes (Smales & Mawson 1978), an opportunity was provided to study the ecology of the species comprising this flock. Spatial distribution in the stomach lumen was investigated, and some observations made on the feeding behaviour and seasonal occurrence of each species.

In addition the site preferences of the developmental stages of *L. eugenii* were defined.

Methods

The general gross and microscopical appearance of the wallaby stomach was examined and found to resemble that of the Red Kangaroo (*Megaleia rufa*) as described by Griffiths & Barton (1966) (Fig. 1).

Ninety-nine male wallabies were taken at two monthly intervals, between April 1973 and March 1975 from Kangaroo Island, South Australia. The collecting areas and methods of capture used have been described (Smales & Mawson 1978).

At post mortem the stomach of each wallaby was carefully removed and ligatured so that it was divided into the following four regions:

1. The cardiac end of the saccular stomach including the oesophageal opening.
2. The central section of the saccular stomach.
3. The pyloric end of the saccular stomach including the non-saccular region.
4. The gastric pouch and pylorus.

The contents of each section so formed were treated separately, by sieving through bolting

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[1] Smales, L. R. (1976) A study of the biology of a nematode *Labiostrongylus eugenii* (Johnson & Mawson) parasitic in the stomach of the tammar wallaby (*Macropus eugenii* Desmarest). Ph.D Thesis, University of Adelaide (unpublished).

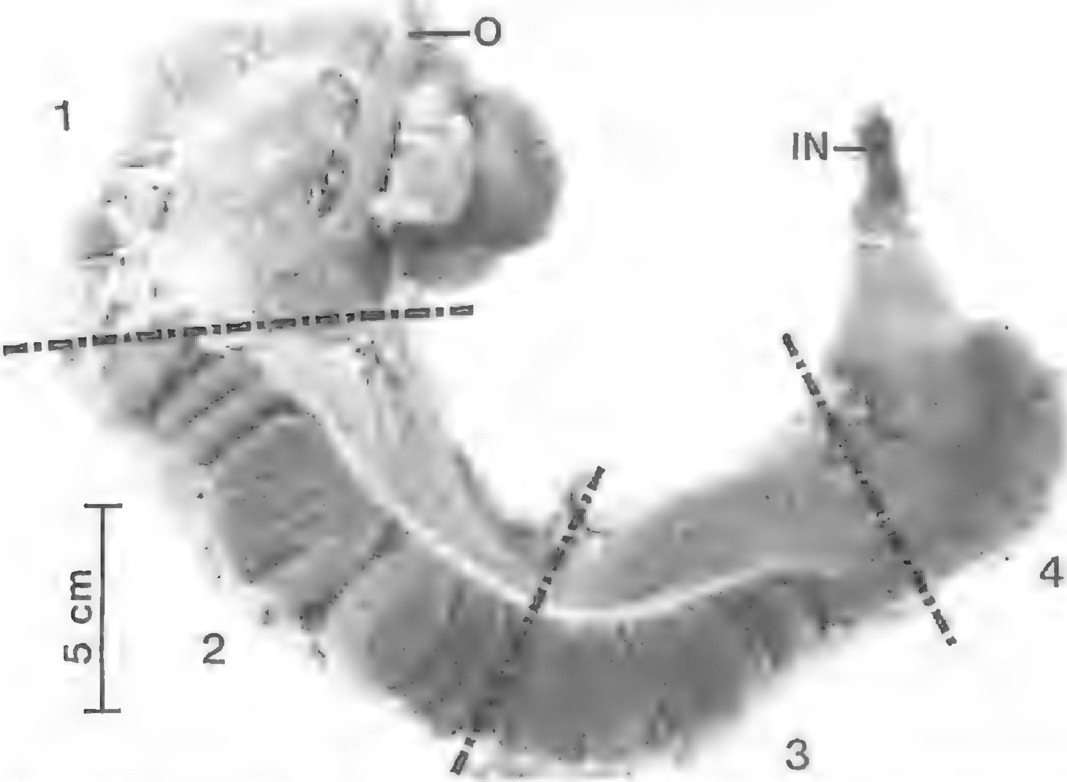

Fig. 1. Stomach of wallaby, showing positions (dotted lines) where ligatures were placed. Numbers indicate sections referred to in text. O, oesophagus; IN, anterior end of intestine.

TABLE 1
Mean measurements from 20 wallabies of the pH values in three parts of the stomach

	pH ± S.D.	Range
saccular stomach	6.99 ± 0.5	6.3 - 7.8
non-saccular stomach	6.7 ± 0.7	5.5 - 7.8
gastric pouch	3.27 ± 0.87	2.6 - 5.1

silk (64 mesh/inch), diluting the retained solid material to an appropriate volume (200 or 400 ml), and sampling using the method of Clark et al. (1971) enabling calculation of worm totals to a S.D. of ± 5 worms. All nematodes in each sample were fixed in hot alcohol, cleared in lactophenol, indentified and counted.

An indication of the environment in each region was obtained by measuring the pH of the stomach contents of the first 20 wallabies autopsied, using a glass electrode. The pH of the stomach contents ranged from 7.8 in the saccular region to 2.6 in the gastric pouch (Table 1). This agrees with the findings of Moir et al. (1956) in some other macropods, that the anterior 4/5 of the stomach appears to be analogous to the rumen of the sheep while the posterior 1/5 corresponds to the abomasum.

Results

The nematode species studied were *Cloacina* spp. (the genus considered as a whole because some of the species present have not been described), *Macropostrongylus pearsoni, Oesophagonastes kartana, Rugopharynx australis* and *Labiostrongylus eugenii. L. longispicularis* Wood, whose distribution in the stomach of the Red Kangaroo has been described by Dudzinski & Mykytowycz (1965), is present only in small numbers in the wallaby, so was not considered in this study. *Filarinema* sp., occasionally found in small numbers, was restricted to the fourth region of the stomach, and was the only species congregating in that region.

Of the other species found each showed a definite site preference along the length of the stomach (Fig. 2). *Cloacina* spp. and *M. pearsoni* were most common in the first section.

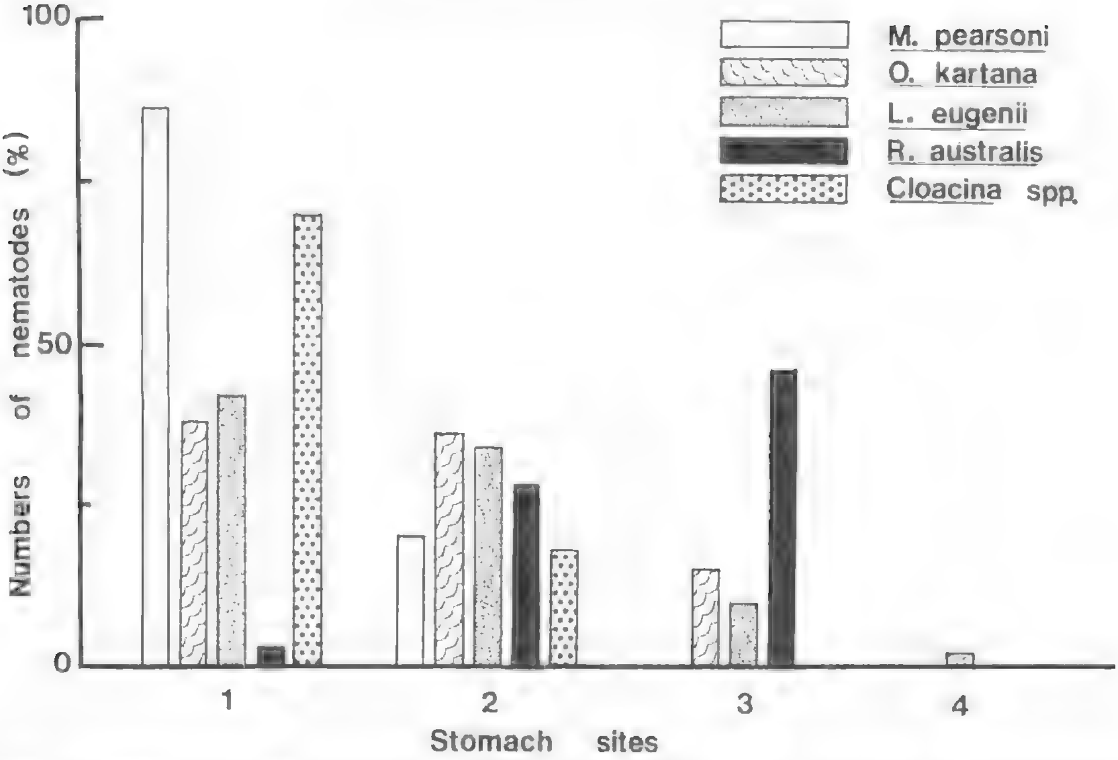

Fig. 2. Histogram showing occurrence of different nematode species in the four stomach sections referred to in text.

TABLE 2

Population structure of *L. eugenii* in four parts of the wallaby stomach. Results expressed as % of total number collected in each site. L = larva

	% *L. eugenii* *site 1*	*site 2*	*site 3*	*site 4*
♂	20.15	19.43	39.48	0
♀	22.13	21.49	43.68	0
L_4	53.51	45.82	16.50	0
L_3	4.21	13.26	0.35	0

O. kartana is normally found in the oesophagus and is present in the stomach only when there is a heavy infestation.. *R. australis* was most common in the third section of the stomach.

L. eugenii congregated in both first and second sections of the stomach but most were in the first. As with *L. longispicularis* (Dudzinski & Mykytowycz 1965) this may be related to the position of the oesophageal opening, worms being attracted to recently ingested food. In wallabies with heavy infestations, *L. eugenii* were seen protruding through the sphincter into the oesophagus.

In newly opened stomachs *L. eugenii* was found congregated in the paramucosal region of the stomach lumen. The *Cloacina* spp. were more often found in the central core whereas *O. kartana* was frequently associated with the crypts of the mucosal glands on the saccular stomach wall. This suggests that a radial distribution, across the 1st and 2nd sections separates these 3 species.

Seasonal observations on the occurrence of *M. pearsoni* (Smales & Mawson 1978) suggest that overlap with *Cloacina* spp. is minimal as the former seems to be present in large numbers at times when those of the latter are low.

Nearly all the third and some of the fourth stage larvae of *L. eugenii* were found in nodules on the stomach wall in the second section of the stomach. It was not practicable to assess the number of worms in these lesions. The site preference of *L. eugenii* was further analysed in terms of population structure (Table 2). No statistical difference was found in the numbers of adults and larvae free in sections 1 and 2. However, significantly more adults than larvae were found in section 3.

Discussion

The environment along the digestive tract is not stable, nor do changes occur abruptly, rather one region gradually merges with the next. Consequently nematodes are not restricted to a single anatomical region but move within limits to remain in the most favourable site (Crompton 1973). When sections of the wallaby stomach were ligatured no allowance could be made for any environmental changes in the stomach lumen which may have occurred in an individual wallaby. Some of the observed overlap between preferred sites may have been due to the necessarily arbitrary placing of the ligatures. Also when a large number of the same species infest a host the increased population density may cause some of the worms to move to less favourable sites (Crompton 1973). Examples of this appeared to be the presence of *O. kartana* in the stomach as well as the oesophagus and *M. pearsoni* and *Cloacina* spp. in the second sections of the stomach as well as the first.

Avoidance of the fourth section by those species congregating in any of the three sections comprising the saccular stomach was very marked. No doubt the differences in digestive function of the fourth section resulted in an unsuitable environment. Similarly the rumen-like conditions of the saccular stomach appeared to be unsuitable for *Filarinema* sp.

The nematode distribution described above, showing considerable spatial separation of niches both longitudinally and radially is similar to that found by Schad (1963) in analyses of *Tachygonetria* spp. in the colon of the tortoise *Testudo graeca*.

Where the site preferences of species overlap spatially there are usually differences in food habits, that is, behavioural separation of niches. Schad (1963) showed that while *T. robusta* (Drasche) and *T. stylosa* Thapar are found in the same site one species is an indiscriminate feeder while the other selects fine particulate matter, mainly bacteria. Observations of *L. eugenii* suggest that it is an indiscriminate feeder. Dudzinski & Mykytowycz (1965) suggest that *L. longispicularis* also feeds indiscriminately. The differences in oral morphology found amongst the *Cloacina* spp. and *M. pearsoni* may be associated with selection of different sized food particles. Some species may feed on material ingested by the host and others feed on the bacterial or ciliate populations present.

Petter (1966) suggested that the species flock may vary with age and sex of host as well as season. As only male wallabies were studied the question of sex was not considered. It was noted that *Cloacina* spp. were the earliest to infest joeys but this was not investigated further because of insufficient host numbers for each range. Seasonal differences appeared to provide niche diversification between *M. pearsoni* and *Cloacina* spp.

The species present in the *Cloacina* spp. flock have not been studied individually, but general observations suggest that the species composition of the flock does change with the season.

Acknowledgements

Our thanks are due to Mr P. Davis who collected the wallabies used in this study. The work was supported by a Grant from the Rural Credits Development Fund and a Commonwealth Postgraduate Research Award.

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BATHYMETRY OF LAKE EYRE

BY J. A. T. BYTE, P. J. DILLON, J. C. VANDENBERG AND G. D. WILL

Summary

The bathymetry of Lake Eyre has been contoured from depth soundings obtained on six expeditions, and one land tranverse of the dry lake. The lowest region of Lake Eyre North (the lowest land area of the Australian continent) appears to lie in Belt Bay, and to have the elevation of – 15.2 m A.H.D. The lowest region of Lake Eyre South (–13.2 m A.H.D.) occurs in the far southwest. From the bathymetry, the surface area and volume of Lake Eyre as a function of water level have also been calculated.

BATHYMETRY OF LAKE EYRE

by J. A. T. BYE*, P. J. DILLON†, J. C. VANDENBERG† and G. D. WILL†

Summary

BYE, J. A. T., DILLON, P. J., VANDENBERG, J. C. & WILL, G. D. (1978) Bathymetry of Lake Eyre. *Trans. R. Soc. S. Aust.* **102**(4), 85-89, 31 May, 1978.

The bathymetry of Lake Eyre has been contoured from depth soundings obtained on six expeditions, and one land traverse of the dry lake. The lowest region of Lake Eyre North (the lowest land area of the Australian continent) appears to lie in Belt Bay, and to have an elevation of 15.2 m A.H.D. The lowest region of Lake Eyre South (—13.2 m A.H.D.) occurs in the far southwest. From the bathymetry, the surface area and volume of Lake Eyre as a function of water level have also been calculated.

Introduction

The recent flooding of Lake Eyre has supported a considerable water traffic, much of which has been equipped for scientific study. Of basic importance in this work is, of course, navigation, which comprises position finding and depth sounding. As a result, approximately 387 soundings and some precision depth recorder traces have been obtained at various periods between June 1974 and September 1976. These data enable the bathymetry of Lake Eyre, which lies in the lowest land basin of the Australian continent, to be contoured, and the water storage of the lake to be determined. Land levelling surveys of the dry lake for Madigan Gulf (Bonython 1956) and Lake Eyre South (Bonython 1961) were also available for comparison with the surveys of the flooded lake. It was decided to omit the results of the Madigan Gulf survey, so that an estimation of any changes in bottom profile due to the flooding would be apparent. In Lake Eyre South, however, the number of data points was very small and this survey therefore has been included in the contouring.

Data sources

Data used in the construction of the bathymetry of Lake Eyre comprised soundings from five shipborne expeditions, one helicopter survey, and one land traverse (Table 1). Apart from the land traverse, all expeditions occurred after the filling of Lake Eyre in early 1974.

TABLE 1

Sources of bathymetric data.

Date	‡	Expedition	Method
Aug. 1960	—	Bonython (1961)	Levelling traverse
June 1974	— 9.2*	E & WS (1976)†	Leadline soundings from helicopter
Aug. 1974	— 9.3	E & WS (1976)†	Leadline soundings
Aug. 1974	— 9.3*	Bye (1976)	Soundings and precision depth recorder
Dec. 1974	— 9.8	E & WS (1976)†	Leadline soundings
Aug. 1975	—10.9	Clark (1976)**	Leadline soundings
Sept. 1976	—11.1	Clark (1976)**	Leadline soundings

* Data in Lake Eyre South have been corrected for differences in level between Lake Eyre North and Lake Eyre South.

† Lake Eyre data File, Water Resources Branch, Engineering and Water Supply Dept, S. Aust.

‡ Water level on E & WS north gauge board, Lake Eyre North (m A.H.D.).

** Lake Eyre logbook of IBIS (unpubl.).

The first expedition (led by G.D.W.), in which a helicopter chartered by the Engineering and Water Supply Department, South Australia (E. & W.S.), carried out nine leadline soundings at scattered points in both portions of the lake, occurred in June 1974. Two months later, a second E. & W.S. expedition (under the direction of the Chief Surveyor) reached the mouth of the Cooper Creek by boat. In the same month an expedition by the Flinders University of South Australia (led by J.A.T.B.), using a motor launch equipped with a precision depth recorder, made a trip between Curdimurka and the mouth of the

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† Engineering and Water Supply Department, S. Aust.

Fig. 1. Cruise tracks, and positions of individual soundings used as sources for bathymetric data in Lake Eyre.

Cooper Creek via Goyder Channel. In December 1974 the E. & W.S. party returned and surveyed a large area of Lake Eyre North as far as the Warburton River to the north, and Bandoo Hill to the west. Since 1974 the two most significant charting expeditions have been undertaken by Alvin and Max Atkinson and Bob Clark of the Port Vincent Sailing Club, in the "trailer-sailer" IBIS. The first expedition in August 1975, which was planned by J. A. Dulhunty of the University of Sydney, comprised a leg from Level Post Bay to the mouth of the Cooper Creek, followed by a detailed east-west section, and a return leg via Belt Bay. In September 1976 the same crew made soundings over the southern half of Lake Eyre North and obtained a good coverage of the lake bed in the vicinity of Bandoo Hill, Belt Bay and Jackboot Bay. All the cruise tracks (Fig. 1) were determined by triangulation on landmarks (which are few) and dead reckoning usually using a ships log.

In addition to the cruise programs, levelling traverses in the Level Post Bay area between Prescott Point and the eastern shore of Lake Eyre South, 6 km south of the Goyder Channel causeway, were undertaken by the E. & W.S in August 1974 and September 1976. The purpose of the levelling was to establish gauge boards in Level Post Bay and Goyder Channel for the conversion of data on water levels to Australian Height Datum (A.H.D.). The zero (.0 m) of the E. & W.S. north gauge board near the entrance of Goyder Channel in Lake Eyre North was determined to be a height of −20.6 m A.H.D. The water level on this gauge board at the time of each expedition (Table 1), was used to reduce the bathymetric data. In addition the zero of the level post in Level Post Bay was found to be at −13.2 m A.H.D. This post was erected by M. O. Hughes of Muloorina Station in June 1974, close to the site of the first level post in Level Post Bay erected by C. W. Bonython in 1951 (Bonython 1955) and subsequently uprooted by floodwater in April 1974. The zero of the first post (known as the 100' arbitrary reduced level) was assessed by Dulhunty in a levelling survey in 1972 to be −12.6 m A.H.D. (Will & Clark 1977)[1].

In September 1976 a detailed survey of the bathymetry of Goyder Channel was undertaken. In general the depths obtained by soundings are thought to represent the lake bottom occurring at the base of the salt crust which exists under dry lake conditions. The trace obtained from the precision depth recorder (Bye 1978) was a hard reflection showing no fine structure. The accuracy of an individual depth measurement appears to depend on three factors: (i) the measurement technique; (ii) the effect of oscillations in water level due to meteorological causes; (iii) the definition of the bottom. On estimating error bounds of ± 0.10 m for each of these factors an overall accuracy of about ± 0.3 m is obtained. The error bound (ii) is an estimate for the lake conditions under which most of the bathymetric data were obtained. Dulhunty (1976) has assumed the same bound for levels measured after a calm period of not less than six hours. In addition there are errors in position fixing, which in most cases are probably less than ± 0.5 km (root mean square absolute).

Bathymetry

The elevations of the lake bottom from each expedition were plotted together on a base map (1:250 000) from which the bathymetry was contoured in intervals of 0.5 m, except near the coastline (Fig. 2). In general the agreement between the various cruises and the traverses of the dry lake bottom was good, although the density of soundings (Fig 1) was not sufficient to define features on a scale less than 1 km. The Warburton and Kalaweerina Grooves and a new feature, known as the Cooper Depression (Dulhunty 1977), running from the mouth of the Cooper Creek to the north of Brooks Island, however, were apparent from the data.

The deepest region of Lake Eyre is apparently the eastern side of Belt Bay where bottom levels of −15.2 A.H.D. are found. In this region therefore lies the lowest point on the Australian continent. In Madigan Gulf also there is a large deep region with elevation less than −15.0 m A.H.D.[2] The bathy-

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[1] Establishing A.H.D. at Lake Eyre North and Lake Eyre South. Rept Surv. Br. Engineering & Water Supply Dept, S. Aust.

[2] We are very grateful to Dr Dulhunty for providing detailed additional sounding legs in November 1976 in central eastern Madigan Gulf. These results caused the authors to disallow some E. & W.S. soundings in Madigan Gulf which suggested that a deeper depression (−15.6 m A.H.D.) existed nearer the eastern shore of Madigan Gulf

Fig. 2. Bathymetry of Lake Eyre. Contours in m A.H.D.

TABLE 2

Surface area and volume, and elevation of Lake Eyre North and Lake Eyre South

Elevation m (A.H.D.)	Surface Area North km²	Surface Area South km²	Volume North 10^6m^3	Volume South 10^6m^3
−15.0	310	—	20	—
−14.5	960	—	340	—
−14.0	1 900	—	1 060	—
−13.5	2 810	—	2 210	—
13.0	3 780	25	3 870	3
−12.5	4 940	120	6 060	84
−12.0	6 080	290	8 800	135
−11.5	6 860	570	12 000	345
−11.0	7 520	890	15 600	710
−10.5	7 920	1 070	19 500	1 210
−10.0	8 240	1 170	23 500	1 770
− 9.0	8 430	1 260	27 700	2 380

metry of Madigan Gulf is very similar to that obtained in the land survey of Bonython in 1954 (Bonython 1956) indicating that there has been no significant moulding of the bottom by the floodwaters. The sill level between the two portions of Lake Eyre in Goyder Channel in September 1976 was −10.6 m A.H.D. This figure is close to −10.1 m A.H.D. obtained by Bonython in 1960 (Bonython 1961) indicating that in Goyder Channel also the scour produced by the floodwater was not large. The deepest points of Madigan Gulf and Jackboot Bay are respectively −15.1 m and −15.0 m A.H.D.

In Lake Eyre South there is the appearance of a long depression offshore of the southern coastline. The sill level (−10.6 m A.H.D.) in Goyder Channel occurs about 8 km from the entrance to Lake Eyre North.

Surface area and volume versus elevation

From bathymetry the surface area and volume of Lake Eyre North and Lake Eyre South, as a function of water level, can be determined by planimeter. The results (Table 2) indicate that the surface area of Lake Eyre North and Lake Eyre South at the times of the maximum levels in the recent flooding were respectively 8.4 and 1.3 10^3km². The maximum water depth anywhere in Lake Eyre was 6.1 m (in Belt Bay in May–June 1974) and the maximum volume of water was 32.5 Tl (in June–July 1974). The latter result is very close to that of 32.0 Tl obtained by Bonython (1975)[3].

Conclusion

The bathymetry derived from ships' observations has been found to be of sufficient quality to reproduce the known features of the dry lake basin, and to reveal some new features. In addition the storage of Lake Eyre North and Lake Eyre South have also been calculated.

There appeared to be no significant moulding of the lake bed by the floodwater by comparison with previous land levelling surveys.

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[3] Recording the event and spreading the information *in* Lake Eyre Newsletter, 2-3. Flinders University of South Australia.

WATER BALANCE OF LAKE EYRE FOR THE FLOODED PERIOD JANUARY 1974 – JUNE 1976

BY G. TETZLAFF AND J. A. T. BYE

Summary

After the filling of Lake Eyre in early 1974 the volume of the water decreased from a maximum of 32.5 Tl in June-July 1974 to 16.5 Tl in June 1976. Study of the water balance equation indicates that the major inflow of 38 Tl was from the Diamantina River system, and that local rainfalls and the Cooper River system contributed 8 Tl and 2 Tl respectively. Loss by evaporation during the period was 39.5 Tl.

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by G. TETZLAFF* and J. A. T. BYE†

Summary

TETZLAFF, G. & BYE, J. A. T. (1978) Water balance of Lake Eyre for the flooded period January 1974-June 1976. *Trans. R. Soc. S. Aust.* **102**(4), 91-96, 31 May, 1978.

After the filling of Lake Eyre in early 1974 the volume of water in the lake decreased from a maximum of 32.5 Tl in June-July 1974 to 16.5 Tl in June 1976. Study of the water balance equation indicates that the major inflow of 38 Tl was from the Diamantina River system, and that local rainfalls and the Cooper River system contributed 8 Tl and 2 Tl respectively. Loss by evaporation during the period was 39.5 Tl.

Introduction

From early 1974, when the dry area of the Lake Eyre basin was filled with water, a general decrease in the surface area and the water content of the lake has been observed. Some remarkable deviations from the general trend in water level have occurred, which may be interpreted in terms of the various inflows contributing to the existence of the lake. The water balance of any lake is dependent on only a few parameters, which are related by the water balance equation, $\Delta V = R - E + I$, in which ΔV is the change in volume of water (storage) in a lake, R the precipitation on its surface, E the water loss by evaporation, and I the net inflow including surface and groundwater exchanges. For Lake Eyre the net inflow may be replaced by the inflow itself, because negligible outflow (surface or groundwater) can be expected to occur as the lake lies in Australia's lowest basin, several metres below mean sea level.

The inflow may be classified into three parts. One: local inflow mainly supplied by small rivers and streams, but including the Neales and Frome rivers. Two: the Diamantina (including all northerly tributaries) and the Cooper river systems, both of which have large parts of their catchment areas situated in the humid zones of inner Queensland. Three: groundwater inflows into the lake basin caused by the rising of the groundwater table due to high rainfall rates. Thus, one can expect inflows from river systems after high rainfalls in Queensland, from local streams after local precipitation, and from groundwater flows after high widespread rainfalls producing seepage over a large area of the Great Artesian Basin surrounding the lake.

The ΔV-values for Lake Eyre are measured indirectly by taking a series of surface levels at a fixed position in each lake. A knowledge of the bathymetry of the lakes allows the conversion of the level recordings into water volumes (Bye *et al.* 1978, Table 2). The reading accuracy of an individual water level is about ±0.10 m, but fortunately most time periods are well covered with measurements, and hence the error on the adopted water level curves (Fig. 1) is significantly smaller. The cause of the scatter, apart from inaccuracies in reading, is the effect of wind stress. Strong wind conditions lasting for a long period are however exceptional, and it is probable that measurements not representative of mean lake levels can be recognised (e.g. the points with very high levels in June and July 1974). Errors in converting water level changes into changes in water volume are very small, because the error on ΔV is proportional to the error on the lake area at each depth. This is almost certainly less than 1%; thus the error on a typical ΔV of 1 Tl/month is only 0.01 Tl/month.

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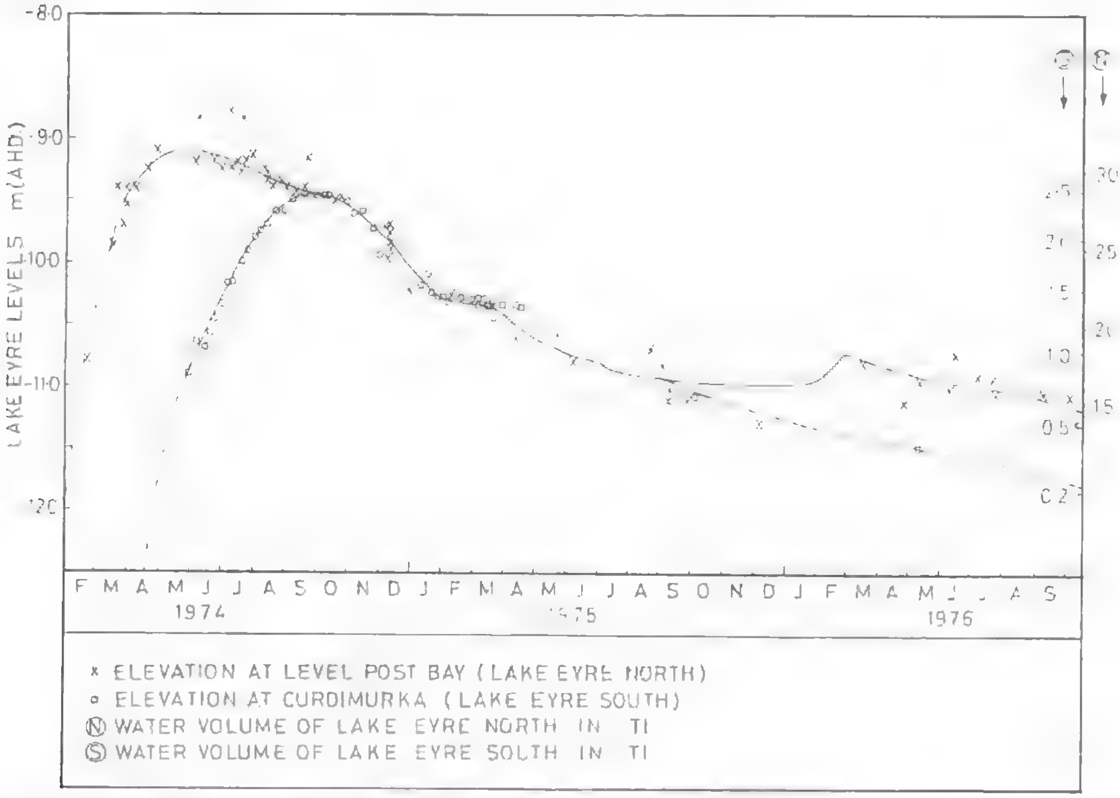

Fig. 1. Lake Eyre levels and volume of water February 1974-October 1976.

During early 1974 a large flooding filled Lake Eyre North and, from April onwards, Lake Eyre South. The maximum height of the water level of the northern basin occurred in May-June 1974, and that of the southern in September-October of the same year. The maximum combined water volume (32.5 Tl[1]) occurred in June-July. After the peak of the floodings had passed the losses exceeded the still continuing inflows (June-October 1974). Months of rapid decrease of the level followed until February 1975, when local rainfalls reduced the rate of loss, but with no subsequent rainfall or inflows the level then fell steadily until the late winter of 1975. The channel between the northern and southern basin closed about August 1975, and the levels of the two parts of the lake afterwards changed independently. In Lake Eyre South, the fall in level continued unabated until by September 1976 only a few patches of water remained. In Lake Eyre North however very high local rainfalls (cf. Fig. 2) caused the level to remain approximately constant between October 1975 and January 1976, and to rise temporarily in February and March 1976. After this interruption the level continued falling through to September 1976.

The maximum surface area of Lake Eyre North according to the bathymetric curve (Bye *et al.* 1978) was about 8.5 10^3km^2 which gives a mean water depth of 3.7 m (in June-July 1974) decreasing to about 2.0 m in September.

Monthly Precipitation Rates on the Surface of Lake Eyre

Monthly precipitation rates for Lake Eyre have been determined for the period January 1974-June 1976. The data which include all rainfall observation stations maintained by the Bureau of Meteorology in South Australia, and some additional data from stations in the Northern Territory, Queensland and New

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[1] 1 Tl = 10^9m^3

[2] Bureau of Meteorology, Aust. Rainfall Data. Monthly and Annual (unpublished).

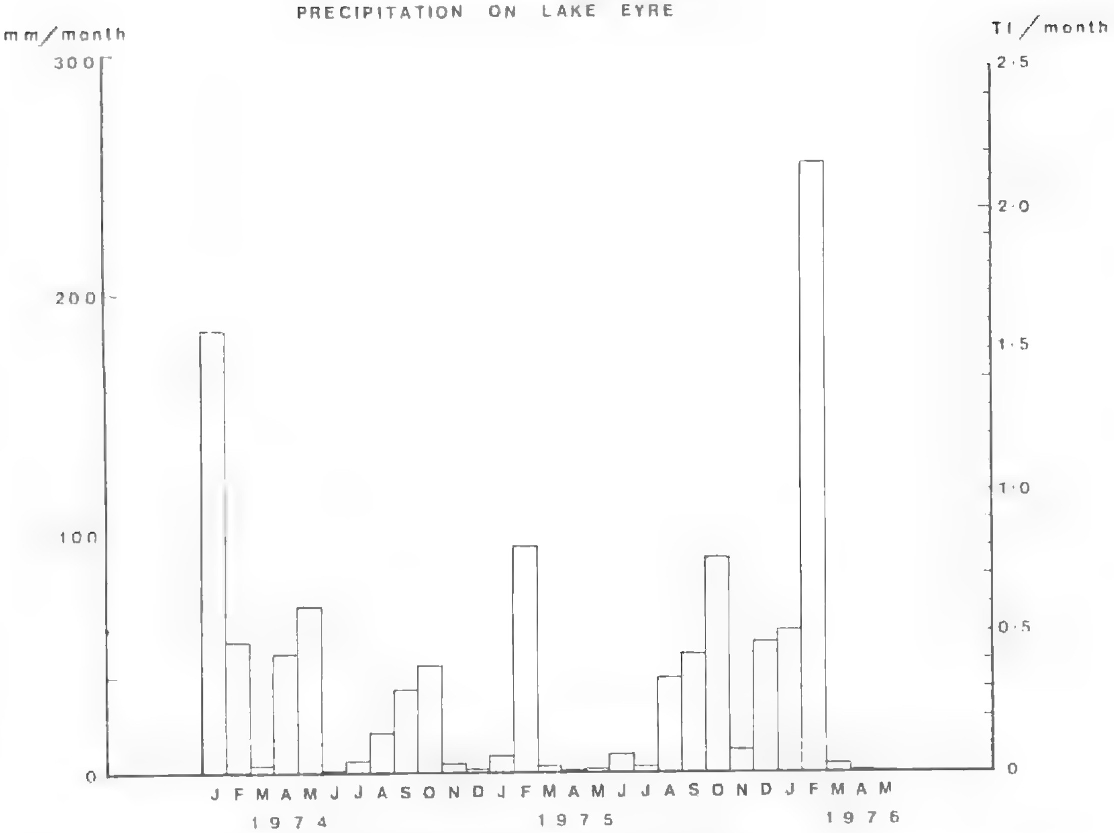

Fig. 2. Monthly precipitation on Lake Eyre January 1974-May 1976.

South Wales[2], were displayed on maps for each month from which the precipitation over Lake Eyre was found by interpolation with an estimated accuracy of ± 10%. In general the interpolated fields indicate a local maximum over the lake, although low precipitation rates sometimes exhibit a very irregular distribution (Tetzlaff unpublished data).

The long term average monthly precipitation in the Lake Eyre region has a well marked maximum in February, and a maximum in late winter (July-August); and the annual mean precipitation is 120 mm/year.

The rainfall during the times of the flooding followed the usual annual cycle, only the amplitude being enlarged (Fig. 2). In February 1976 alone, twice the amount of the long term annual mean value was found. In 1974 and 1975 annual rainfall exceeded all previous observed figures. These rainfall patterns during flooded years appear to be in part attributable to feedback mechanisms over the lake which precipitate on average about 100 mm/year (or 5%) of the evaporated water vapour (Tetzlaff unpublished data).

Evaporation from the Lake Surface

There are no direct measurements of evaporation from the lake surface. Hence, indirect methods must be applied to derive estimates of evaporation. Of these the well known micrometeorological methods (e.g. the Dalton and Penman methods) are precluded owing to a lack of systematic measurements of characteristic parameters such as water temperature, air temperature and relative humidity, and hence use must be made of the water balance equation itself. The difficulty is that of the four parameters in this equation only the precipitation rate R and the storage ΔV are known. The inflow in addition to the evaporation has to be regarded as unknown. It is possible however from the precipitation data for the catchment (mainly Queensland) and locally, to find some periods during which any inflow can be excluded. This occurred from November 1974 to January 1975 and again from April 1975 to July 1975, summer and winter periods respectively. In this case $E = -\Delta V$, and inferred evaporation can be compared with the measured pan evaporation

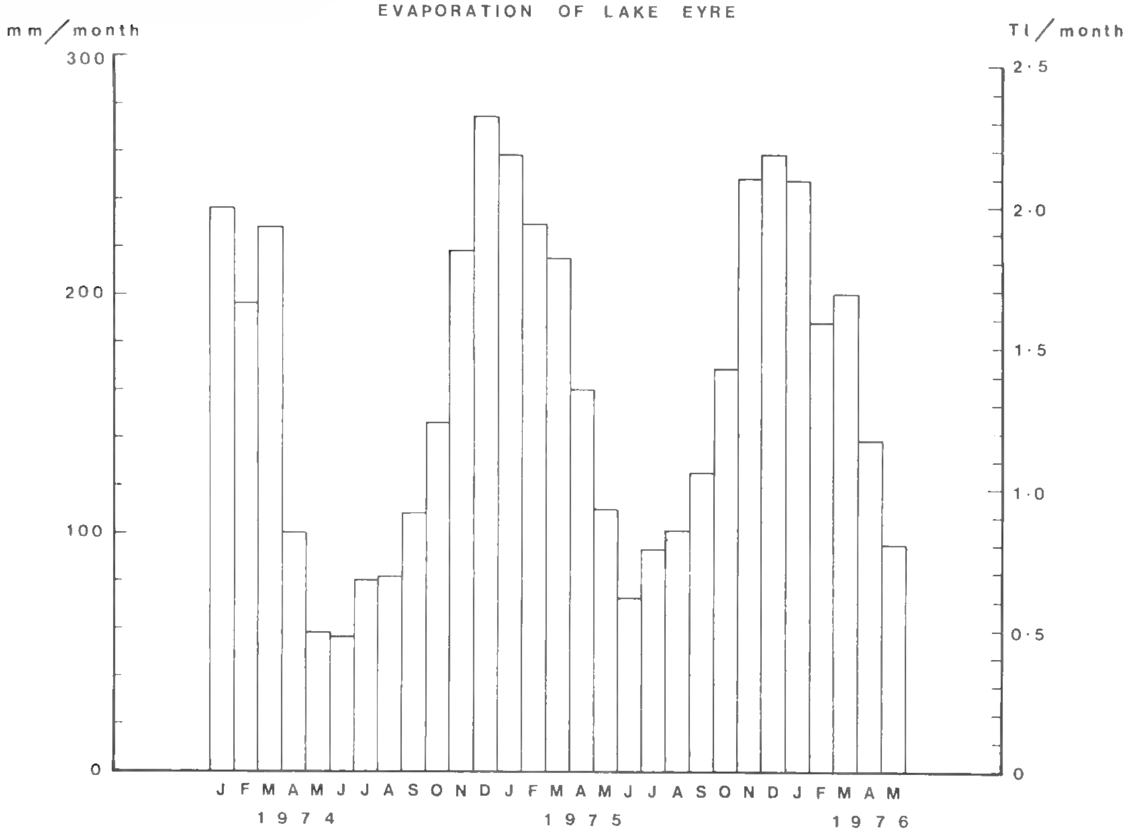

Fig. 3. Evaporation from Lake Eyre January 1974-May1976.

values at land stations. Oodnadatta, Woomera and Moomba all at about the same distance from the lake were chosen, and an average pan evaporation for the lake region was determined. The ratio between the inferred and the average pan evaporation during the above two periods was found to be a constant with the value of 0.67, and the month by month variation of the factor showed a low scatter, suggesting an error bound on the constant of ± 5%.

It is assumed therefore that this value may be applied also to determine evaporation for the remaining time intervals, and the resultant monthly lake evaporation values are shown in Fig. 3. The annual value is approximately 2000 mm. This figure is remarkably close to the original determination of 1950 mm for Lake Eyre for the year 1951 by Bonython (1955), and is comparable to that for lakes in similar climatic conditions such as Lake Chad where an annual evaporation rate of 2250 mm is observed.

Inflow into Lake Eyre

Detailed measurements of inflow into the lake are generally not available and inevitably strongly underestimated, as during the recent floodings the waters often proceeded on a broad front of several kilometres, of which only a small part could be measured at the gauging stations in the river beds of the Diamantina and the Cooper rivers. The amount of inflow of groundwaters is even more difficult to obtain. This flow is very slow and rather steady and can contribute noticeably only after periods of several months (Holmes pers. comm.). Therefore the total water supply to the lake (inflow and rainfall) was determined from the water balance by calculating $\Delta V + E$ (Fig. 4). The negative values give an insight into the accuracy of the deductions. The errors are approximately ± 0.15 Tl/month. This value corresponds to an error in the estimated water level of the lake of only ± 15 mm, which is significantly less than the error for an individual water level measurement.

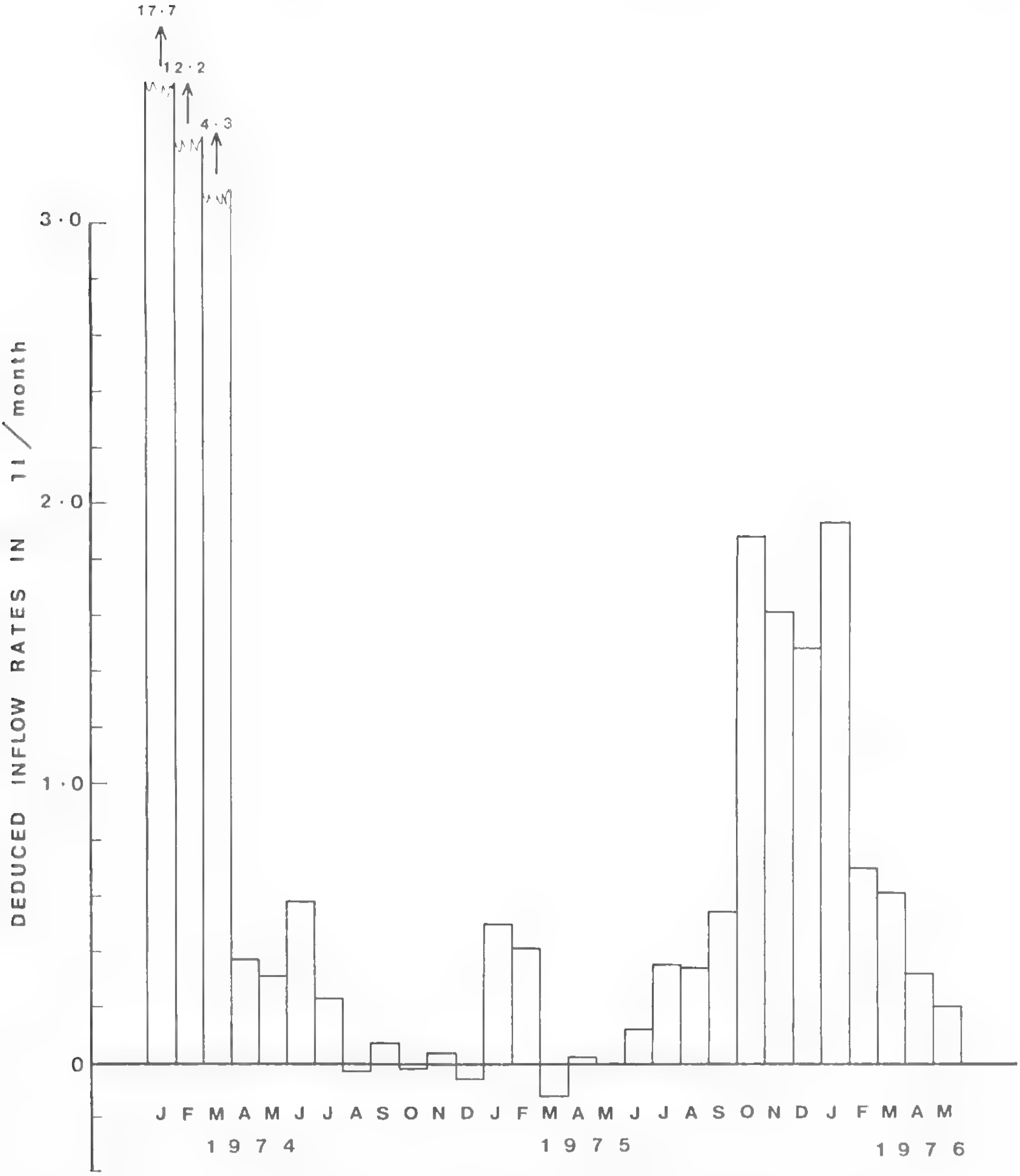

Fig. 4. Inflow into Lake Eyre deduced from the water balance equation January 1974-May 1976.

The partition of the inflows into the contributions from the Diamantina river system, the Cooper river system, the local floods, and the groundwater is an interesting problem, and it could not be solved rigorously, though the three surface components could be sufficiently separated using information on the velocity of advance of floods in the two river systems (Bonython 1963). As a result it can be stated that the Diamantina floods proceed generally four times as fast as the Cooper floods. The mean velocity for six floodings is 3.1 km/day for the Cooper, and 12.5 km/day for the Diamantina. In 1974 and 1976 the passage of the floodings of the Cooper was observed at Innamincka and Kopperamana. From these data using the velocity of advance it follows that the date of entrance of the Cooper flood waters into the lake was not before the end of April 1974, and not before July in 1976. By April 1974 however the bulk of the water had already entered the lake (Fig. 1). Hence, the major contribution can come only from the Diamantina river system, because groundwater inflows are excluded at that stage.

In comparison with the first inflow rates, all later inflow rates appear to be much smaller, reaching about one fifth of the 1974 values in 1976. The 1976 floods contain not only contributions from the river systems but also local inflow from local rainfalls and possible groundwater. During the period September 1974-August 1975 no surface inflows are observed except for those caused by local rainfalls. This situation served for the determination of the local inflows in relation to the local rainfalls. The inflows originate from sources such as the Neales and Frome rivers. The increase in volume of water at this time is that which falls directly on the lake surface plus inflow. Using the known precipitation rates it was found that the local inflow contributes about the same volume of water as does the rainfall. Adopting this factor for the other periods we find that the gain by local inflow is equal to the precipitation over the lake itself.

Total Water Budget

Applying the above conclusions for the whole period of the flooding from 1974 to June 1976 we obtain the total water budget (Table 1). It seems remarkable that the Cooper Creek inflow was not of importance at any stage in comparison with the northern floodings, or indeed with the local water from precipitation. The evaporation is of such a magnitude that with no more inflows from the Diamantina river systems the lake is expected to dry up in about one to two years (from 1976) mainly depending on the volume of local rainfall.

TABLE 1

Total water budget of Lake Eyre: January 1974-June 1976

Rainfall	8.0 Tl
Local Inflow	8.0 Tl
Inflow from Diamentina river system	38.0 Tl
Inflow from Cooper river system	2.0 Tl
	56.0 Tl
Evaporation	-39.5 Tl
BALANCE	16.5 Tl

Acknowledgements

The authors wish to express their appreciation to all observers. In particular Mr M. O. Hughes of Muloorina Station, The Engineering and Water Supply Department, S. Aust., and Australian National Railways Commission, who contributed the observations of water level in Lake Eyre North and Lake Eyre South shown in Figure 1. Many helpful comments by Mr C. W. Bonython on the interpretation of the data are also gratefully acknowledged.

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REDEFINITION OF THE AUSTRALIAN LEPTODACTYLID FROG NEOBATRACHUS PICTUS PETERS

BY J. D. ROBERTS

Summary

Neobatrachus pictus is redescribed using morphological and male call data. The redescription is based on topotypic material and an examination of syntypes. The geographic range is southern S.A. and Victoria. Most published information about N. pictus is based on congeneric species. N. sudelli (Lamb) is resurrected from the synonomy of N. pictus.

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Summary

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Neobatrachus pictus is redescribed using morphological and male call data. The redescription is based on topotypic material and an examination of syntypes. The geographic range is southern S.A. and Victoria. Most published information about *N. pictus* is based on congeneric species. *N. sudelli* (Lamb) is resurrected from the synonomy of *N. pictus*.

Introduction

Most authors acknowledge that two species of *Neobatrachus* (the type species *N. pictus* Peters and *N. centralis* (Parker)) occur in eastern Australia (Littlejohn 1971; Cogger 1975; Barker & Grigg 1977). However, there is considerable confusion about the identification of individuals to each of these species. For example Cogger (1975) figures the range of *N. pictus* as only just extending into northern Victoria. In contrast Brook (1975) indicates that it is found in almost all of Victoria. Similarly, Barker & Grigg (1977) figured the range of *N. pictus* as extending only peripherally into southeastern South Australia, so excluding the type locality near Adelaide.

Despite Moore's (1961) doubts about the validity of *N. centralis* Littlejohn (1965) provided clear evidence that at least two forms of *Neobatrachus* occur in northwestern Victoria. Littlejohn figured two audiospectrograms: one with a high pulse number, high pulse repetition rate and low dominant frequency was considered to represent *N. centralis*. The other had a low pulse number, low pulse repetition rate and high dominant frequency, and was referred to *N. pictus*. Here I refer to it as "type B". However, South Australian frogs that I refer to *N. pictus* did not make "type B" calls.

The identity of each of these species would be clarified by examination of various data, including male call, from type localities. The type locality of *N. pictus* is near Adelaide, and here I have attempted to redefine this species, and so permit its geographic range to be established.

The type locality

Parker (1940) and Moore (1961) state the type locality of *N. pictus* to be "near Adelaide". Peters' (1864) description was based on material collected by R. Schomburgk at Buchsfelde, "near Adelaide". Buchsfelde is 4.5 km west of Gawler and is now known as Loos (Praite & Tolley 1970).

Richard Schomburgk settled at Buchsfelde in 1849 and lived there or in the Gawler area until at least 1865 (Van Abbe 1960; Serle & Ward 1976). Although there is no direct evidence, it is reasonable to infer that his collection was made at Buchsfelde, and that this is the type locality of *N. pictus*.

Methods

(a) *Material examined:* Calls were analysed from recordings made at seven sites: 7.5 km N.W. of Gawler, i.e. 5.5 km N. of Loos (14 frogs); 15.5 km N.W. of Penola (2 frogs); Semaphore Park, 13 km N.W. of Adelaide (1 frog); Coffin Bay, 38 km W.N.W. of Port Lincoln (1 frog); 7.5 km S. of Kimba (1 frog); Roora Reservoir, Kimba (2 frogs); Pilepudla Reservoir, 17 km N. of Kimba (2 frogs) and Muratchina Dam, 33 km N. of Kimba (1 frog). All recording sites are in

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South Australia and all tape recordings are in my possession.

The following specimens were examined. All are in the S.A. Museum; registration numbers refer to that collection. Collection dates are provided only for topotypes from 7.5 km N.W. of Gawler, all collected by J. D. Roberts.

Topotypic material: R16384 ♀, R16385-R16387 all ♂, all 27.iii.73; R16388 ♂ 2.iv.73; R16389 ♀, R16390-R16394 all ♂, all 5.vi.73. Calls of eight of these males were recorded. Other material: R2590 1 ♂ 1 ♀, Lake Hamilton; R2776 4 ♀, Sellicks Beach; R2888 3 ♂ 1 ♀ 1J, between Nairne & Balhannah; R3007 1 ♀, Kangaroo Island; R3099 1 ♀, Muston, Kangaroo Island; R3474 1 ♀, Corny Point; R3482 2 ♀, Kangaroo Island; R3788 1 ♂ 1 ♀, Avenue Range; R4717 1 ♂, Reynella; R5093-5095 3J, West Beach; R5096 1 ♀, West Beach; R5149 52J, West Beach; R5175 1 ♂ 1 ♀, Naracoorte; R5176 1 ♀, Pt Lincoln; R5195 220J, Cummins; R5196 6J, Hampstead; R5197 1J, Hampstead Gdns; R5497 1 ♀, Mt Graham, nr Millicent; R8355 1J, Hardwicke Bay; R8356 1J, Box Flat, Lameroo; R8844 1 ♂, Edeowie Gorge; R8914 21 ♀ 1J, Naracoorte; R8960 1 ♀, 16 km W. of Vivonne Bay; R8963 1 ♂ 2 ♀, Lucindale; R8970 3 ♂ 2 ♀, Naracoorte; R8977 1J, 9.6 km N.N.E. of Frances; R8986 A-C 3 ♀, Naracoorte; R9974 1 ♂, Hincks Ntl Pk; R10857 1 ♂ 1 ♀, Narrung; R12251 1 ♀, Semaphore Pk; R13039 1 ♀, Nuriootpa; R13345 2 ♀ 1J, Mt Scott Ntl Pk; R13561 1 ♀, Mingbool, nr Mt Gambier; R13623 A-D 2 ♂ 2 ♀, 16-22.4 km S. of Naracoorte; R14256 1 ♀ nr Penola; R15382 3 ♂ 2 ♀ 1J, Bangham Conservation Pk; R15486 1 ♂, Laura; R16017 1 ♀, Innes Ntl Pk; R16129 1 ♀, Sandy Ck Conservation Pk; R16309 1 ♂, Jip Jip Conservation Pk; R16395 1 ♂, 7.5 km N.W. of Gawler; R16396 1 ♂, 9.1 km S. of Kimba; R16397-99 3 ♂, Roora Reservoir, Kimba; R16400 1 ♂, Pilepudla Reservoir, 17 km N. of Kimba; R16401-2 2 ♂, 15.5 km N.W. of Penola; R16403 7 ♂ 2 ♀, 49.1 km N. of Kingston; R16404 1 ♂, 5.3 km N. of Peake; R16405 1 ♂, 32.2 km S. of Mt Mary; R16406 1 ♂ 1 ♀, Yarna Stn, Eyre Peninsula; R16407 1 ♂, 41.6 km N. of Kingston; R16408 1 ♀, 7.0 km S.S.W. of Coolatoo; R16409 1 ♀, 3.5 km S.W. of Coolatoo; R16410 1 ♀, 4.8 km N.W. of Coolatoo; R16411 2 ♂ 1 ♀, 1.6 km S.E. of Mt Barker; R16412 1 ♀, 4.0 km N. of Strathalbyn; R16413 1J, 3.8 km N.N.W. of Littlehampton; R16414 1 ♀, 2.6 km W. of Mt Barker; R16415 7J, 16-32 km S. of Kingston; R16416 2 ♂ 1 ♀, Scorpion Springs Conservation Pk; R16417 1 ♀, 23.5 km N. of Meningie; R16418 2 ♂, Wharminda; R16419 3 ♂ 3 ♀, 24.5 km N. of Kingston; R16420 1 ♂ 1 ♀, Lake Gilles Ntl Pk; R16421 2J, Moody Tanks, W. of Ungarra; R16422 1 ♂, 2.7 km S.E. of Kingston; R16423 1 ♂, Banff; R16424 1 ♀, 4.6 km S.S.W. of Kybybolite; R16425 1 ♂, 0.6 km S.W. of Kybybolite; R16426 1 ♀, 0.3 km N. of Comaum School, Comaum; R16427 1 ♀, 2.5 km S.E. of Glen Roy Rwy Stn; R16428 1 ♂, 16.0 km N.W. of Penola; R16429 1 ♀, 2.5 km S. of Penola; R16430 1 ♀, 13.8 km S. of Penola; R16431 1 ♀, 8.7 km S. of Tarpeena; R16432 1 ♂, Allendale East, R16433 1 ♂ 2 ♀, 26 km N.N.W. of Naracoorte; R16434 7 ♂ 1 ♀, 28.9 km N.N.W. of Naracoorte; R16435 1 ♂ 1 ♀, 5.9 km N.E. of Beachport; R16436 1 ♀, 21.7 km S.E. of Robe; R16437 1 ♀, 5.2 km S.S.W. of Greenways; R16438 2 ♂ 1 ♀, 2.2 km N.E. of Greenways; R16439 1 ♂ 1 ♀, 12.8 km N.E. of Greenways; R16440 1 ♂, 7.5 km E.S.E. of Kingston.

(b) *Call recording and analysis:* Calls were recorded on a Nagra III N.P. tape recorder with Beyer M 100 microphone, a Uher 4400 Report stereo recorder with A.K.G. D 404 C microphone, or a Sony TC-510-2 recorder with A.K.G. D 190 microphone. In all cases tape speed was 19 cm/sec. Recording levels were set below −5dB to minimise overload distortion which could arise with signals of short duration. All recorded frogs were calling from still water. Water temperatures were recorded at the calling site, but may slightly overestimate cloacal temperatures. For fifteen frogs where both data are available the mean difference between water and cloacal temperatures was 0.16°C. This difference was significant (Wilcoxon T 6.5, $P < .05$). However, as only water temperature data were obtained in some cases this problem cannot be overcome.

Tape recordings were analysed by playback at half speed on the recorder used for field recording, with the output displayed on a Tektronix 502 double beam oscilloscope and photographed by a Grass C4 camera. A time marker (100 pulses/sec, derived from the 50 Hz mains frequency) was displayed on the second beam of the oscilloscope. With half speed playback the time marker effectively represents 5 m sec. rather than the expected 10 m sec. intervals.

Only the last clear recorded call was analysed for each frog. Successive calls of individual frogs were similar. Pulse repetition rate was measured from pulses 7 to 10 and pulse duration, dominant frequency and rise time (i.e. the time from start to peak pulse amplitude) were measured in pulses 7, 8 and 9 and the three values averaged. Pulses per call were counted in the last three recorded calls (either from oscillograms or by playback at reduced tape speed), and the three values averaged.

(c) *Geographic distribution and biology:* Distribution data were collated in three ways:

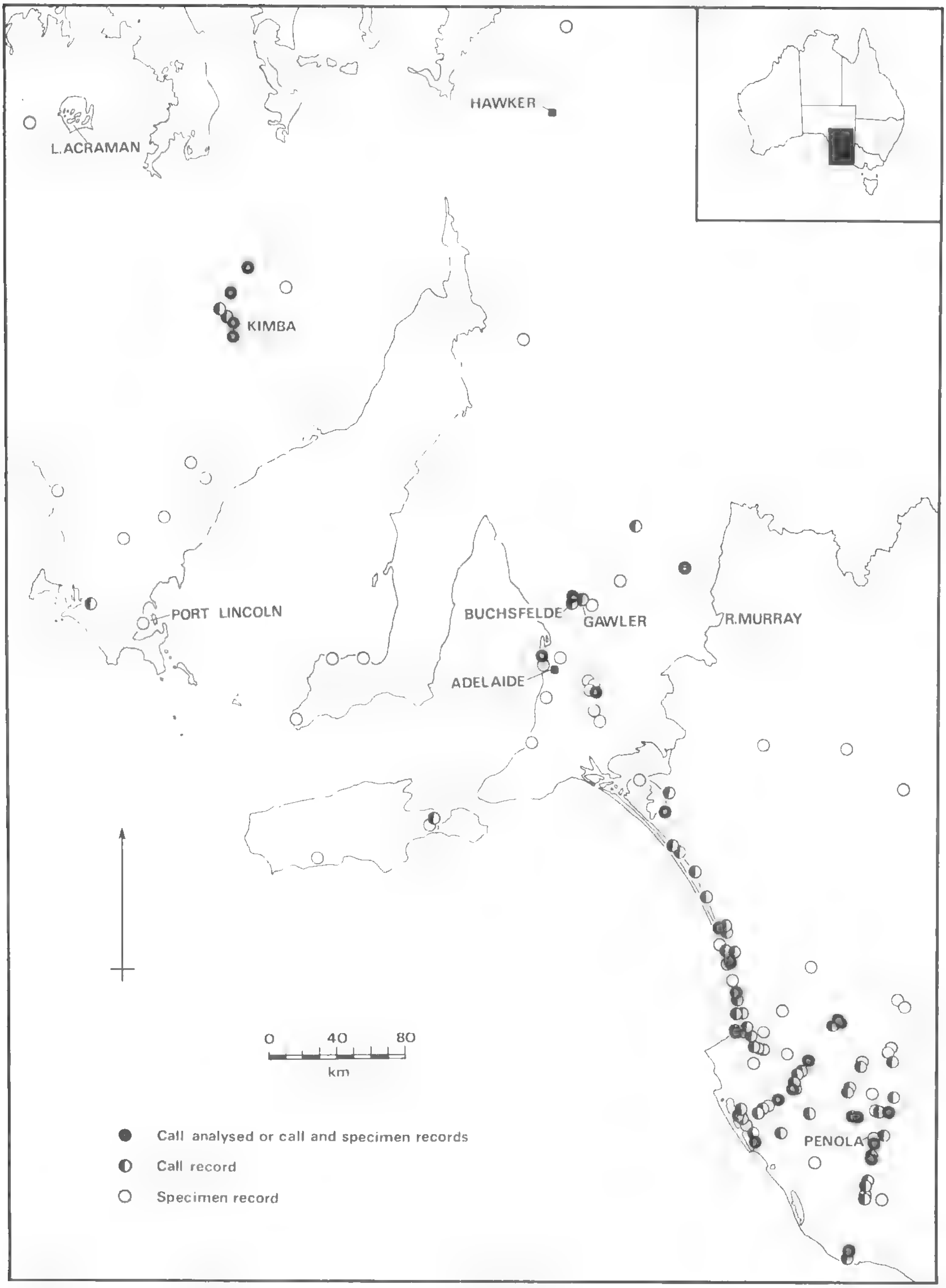

Fig. 1. Distribution of *Neobatrachus pictus* in S.A.

TABLE 1

Temperature effects on call component values. Temperature range 8.5–22.0°C; sample size 14. Significance of regression coefficients was compared with 0. (n.s. not significant, * p <.05, ** p <.01, *** p <.001).

Call Component	Slope	S.E.	Intercept
Pulses/Sec.	1.188**	.078	1.249
Pulse Rise Time	—0.136***	.026	5.635
Pulse Duration	—0.287*	.100	16.313
Dominant Frequency	0.011*	.004	1.139
Mean Pulses/Call	—0.473 n.s.	.370	40.098

TABLE 2

Call component values and standard errors at 15°C for temperature dependent components. Sample mean and standard error for pulses/call.

Call Component	Value	S.E.	Range
Pulses/Sec.	19.01	.397	–
Pulse Rise Time (msec.)	3.60	.117	–
Pulse Duration (msec.)	12.00	.444	–
Dominant Frequency (kHz)	1.30	.019	
Mean Pulses/Call	33.07	1.323	23.7–43.3

from detailed analyses of field recorded calls; by subjective evaluation of choruses heard in the field (call records, Fig. 1), and by examination of specimens collected without call data and held in the S.A. Museum (see p. —). Observations on general and particularly breeding biology were made during field recording trips.

(d) *Morphology:* I made a detailed examination of 11 specimens (9 ♂, 2 ♀, see Topotypic material listed above) collected 7.5 km N.W. of Gawler, and the syntypes of *N. pictus.* The following body dimensions were recorded: snout-vent length; head length (from tip of snout to posterior tip of jaw articulation); head width (measured behind eyes between tips of jaw articulation; eye length (horizontal distance from anterior corner of eye to anterior edge of naris); tibia length (measured with leg flexed so that bone fitted inside calipers).

Fig. 2. Upper, oscillogram of complete call of male (R16393) recorded 7.5 km N.W. of Gawler on 5.vi.1973. Lower, detail of pulse structure in pulses 7–8. In both cases the lower trace is a time marker representing 5 msec. intervals. Call starts on right.

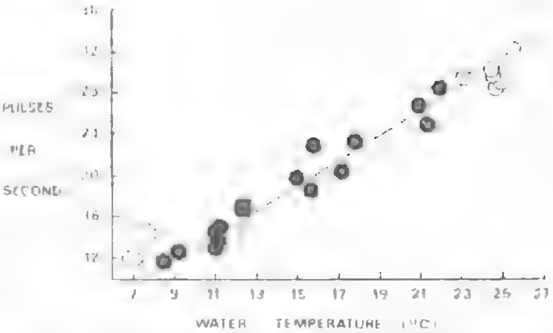

Fig. 3. Geographic variation in pulse repetition rate values. Solid circles: Gawler; open circles: Kimba area; open diamond: Penola; open square: Semaphore Pk; solid square: Coffin Bay. (See *Material Examined* for specific locality data.)

Less detailed examinations were also made of numerous frogs from localities throughout S.A.

Results

(a) *Calls:* For the Gawler sample all call component values were regressed on water temperature; the results of this analysis are given in Table 1. Only the average number of pulses/call is not influenced by temperature. Mean call component values (at 15°C, estimated from the regression lines for temperature dependent variables) are given in Table 2. A representative oscillogram is illustrated in Figure 2.

The call of *N. pictus* can be characterised by a high pulse number (33), low dominant frequency (1.3 kHz) and a high pulse repetition rate relative to other *Neobatrachus* calls known from South Australia (Roberts, unpublished observations). Pulses are short (12 msec.) and have a smooth rise and decay cycle (Fig. 2). Peak pulse amplitude rises slowly for the first few pulses then evens out (Fig. 2).

Calls analysed from other sites in South Australia closely resemble calls from Gawler, and there is no evidence of significant geographic variation in any call components (Fig. 3 illustrates this for pulse repetition rate).

The call Littlejohn (1965) considered to represent *N. centralis* is similar to calls from Gawler, and it is likely that in reality these individuals represent *N. pictus*. The identity of frogs he referred to *N. pictus* is therefore uncertain.

The calls described above are characteristic of males calling strongly. At the start of calling sequences males sometimes make calls with much lower pulse numbers. However, such calls have a pulse form, pulse repetition rate and dominant frequency as detailed above.

(b) *Geographic distribution:* The known range of this species in South Australia is given in Figure 1. The species occurs throughout the southern portion of the State, extending north to Edeowie Gorge (40 km N.N.E. of Hawker, S.A.M. R8844), west to Yarna Station near Lake Acraman, northern Eyre Peninsula (S.A.M. R16406) and east to the Victoria border.

Near Morgan and Blanchetown on the River Murray, and north from Kimba on Eyre Peninsula, *N. pictus* is replaced by another species (possibly *N. centralis*) differing in call and morphology. Near Naracoorte and Penola *N. pictus* occurs sympatrically with a congeneric species which can be distinguished by male call but less reliably by morphology. Calls of all these frogs are the "type B" of Littlejohn (1965).

I have no data on the distribution of *N. pictus* outside South Australia. However, Brook (1975) gave data on the distribution of *Neobatrachus* in Victoria, partly derived from field notebooks of Littlejohn and his co-workers. If Brook adopted Littlejohn's call nomenclature (see above), his records of "*N. centralis*" almost certainly refer to *N. pictus*. This species therefore extends into western Victoria, and in some sites is sympatric with a congeneric form.

The density of records on Figure 1 reflects the intensity of field investigation in various areas, and not necessarily the density of *N. pictus*. I have had little opportunity to work in mid-northern South Australia but have spent a considerable amount of time in the southeast of the State.

(c) *Biology: N. pictus* only breeds after heavy rain (usually more than 25 mm in 24 hr) and probably breeds at any time of year. I have observed breeding and calling activity in February, March and throughout winter and early spring. Breeding periods are short and rarely last more than a few days. Breeding aggregations are often dense. In July 1972, near Kingston, I observed more than 150 frogs in an area of about 225 m^2.

Males generally call while floating in water with the head above the surface but with the rest of the body submerged. Calling sites vary from exposed situations to sites where the male is completely concealed under flooded vegetation. Males often move when calling. Occasionally they call from very shallow water with only the ventral surface submerged.

Males are not discriminating in their choice of mates, and I have observed males trying to amplex other males, spent females and even moist rabbit dung on the pond margin. Amplectant pairs are quite often found on land apparently heading for breeding pools. Amplexus is inguinal.

Breeding sites are usually shallow, temporary pools, though breeding may occur in dams. I have never observed *N. pictus* calling or breeding in flowing water. The eggs are pigmented and deposited in large clumps or in long strands several eggs wide. Initially the eggs are stuck together with jelly, but egg masses soon break down and the clearly encapsulated eggs sink to the bottom of the pond.

I have no data on larval biology or morphology though Martin (1965), Tyler (1966) and Watson & Martin (1973) all give illustrations of the mouthparts and some other details. However, Martin's (1965) and Watson & Martin's (1973) data are from specimens outside the known range of *N. pictus*, and thus may refer to some other, related species.

Though *N. pictus* is encountered most commonly when breeding, individuals are often active on moist evenings, and I have found them on roads and around swamps, and other sites that may be used for breeding. This species burrows and I have found individuals buried hard against the underside of large stones. I have no data on other burying sites.

(d) *Morphology:* These data are presented as a redescription of *N. pictus*.

Neobatrachus pictus Peters

Neobatrachus pictus Peters 1864 *Monatsb. K. Preuss. Akad. Wiss. Berlin* 1864, 228.

Heleioporus pictus: Boulenger 1882 *Cat. Batr. Sal. Brit. Mus.* ed. 2, 272.

Definition: A moderate to large species of robust habitus. Limbs short, large inner metatarsal tubercle invariably with a black cutting edge. Dorsal skin, particularly on the anterior half of body, covered with numerous, fine,

TABLE 3
Proportions of 11 *N. pictus* from near Gawler.

Ratio	Mean	Range
Head width/Head length	1.22	1.16–1.35
Eye/Eye–naris	1.55	1.33–1.82
Eye–naris/Internarial span	1.00	0.83–1.14
Head length/Snout–vent length	0.35	0.33–0.39
Tibia length/Snout–vent length	0.34	0.25–0.38

Fig. 4. *Neobatrachus pictus*, Comaum, S.A.

small warts which are spinose in breeding males. Distinguished from related species either by its large size, distinctive call or, lack of a skin connection from the knee across the groin to the side of the body.

Description: Head high, wider than long and roughly one third of snout-vent length (Table 3). Snout rounded when viewed from above and angled slightly posteriorly in profile. Nares dorsal and, when viewed from above, closer to end of snout than to eye. Internarial span greater or less than eye to naris distance (Table 3). Canthus rostralis slightly rounded. Eye large and prominent, its diameter about one and one half times eye to naris length (Table 3). Pupil a vertical slit; iris covered with fine dark veins on, in life, a golden background (Fig. 4). Tympanum not visible externally but present and roughly circular. Vomerine teeth divided medially; their posterior margin in line with posterior margin of choanae. Vomerine teeth in close contact medially, or slightly divided and may be in a straight series or with lateral ends angled slightly towards snout. Tongue ovoid to circular; covers most of floor of the mouth. Attached closely anteriorly but posterior and lateral margins free.

Fingers short and cylindrical. No interdigital webbing; all fingers fringed, the fourth least (Fig. 5a). Dark brown to black nuptial pads well developed on first and second fingers of breeding males, extending from base of each finger to at least ultimate joint. Pads extend underneath base of first finger (Fig. 5a) but only occur on medial side, and medial upper half of second. In some specimens there is fine extension of pad past ultimate joint on both fingers. Dark, finely spinose material of nuptial pad may be lost in preserved specimens and underlying, calloused area is difficult to distinguish. Finger lengths usually 3 > 1 > 2 > 4; rarely 1 = 2. Subarticular tubercles well developed and irregular number of interdigital tubercles. Tubercles at base of second and third fingers often divided. Generally two large, flat palmar tubercles; that at base of first finger more prominent. Nuptial pad may over-

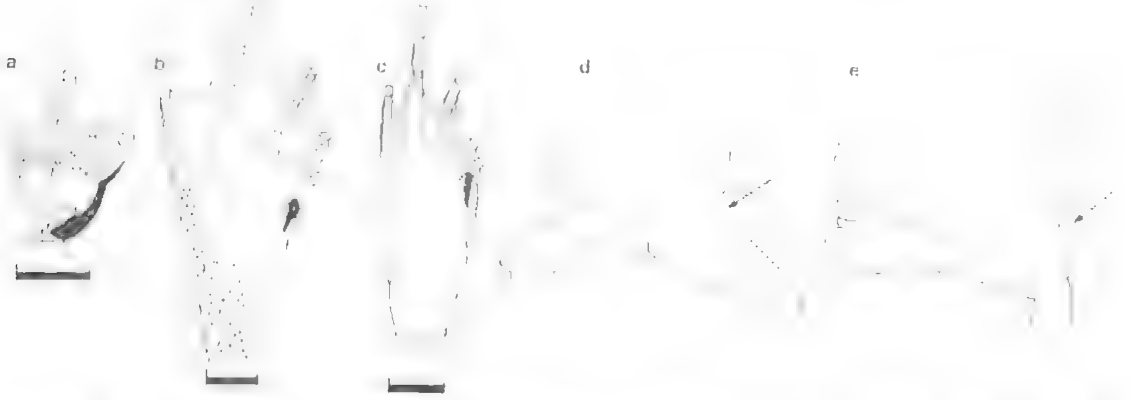

Fig. 5. a. Right hand of male (R16393); b. Right foot of male (R16391); c. Right foot of female (R16389); d. Groin of *N. pictus* (R16393); e. Groin of male making "type B" calls from 8 km W. of Blanchetown (R16449). In d. and e. arrow indicates area of difference. In a, b, and c, the bar represents 5 mm.

lap medial edge of inner palmar tubercle (Fig. 5a).

Hind limbs short with tibia averaging one third of snout-vent length (Table 3). Toes short and cylindrical with order of lengths 4 > 3 > 5 > 2 > 1. On one foot of R16399 toe 5 > 3. Subarticular tubercles poorly developed and may not be obvious on fifth toe. No outer metatarsal tubercle but large, shovel shaped, inner metatarsal tubercle, usually edged with black or rarely light brown. Blackened section always much longer than maximum width and symmetric about mid line (Fig. 5b, c). In males, webbing between toes extensive, extending to or beyond ultimate joint, with distinctive almost rectangular indentation between third and fourth, and fourth and fifth toes (Fig. 5b). At tip of fifth toe webbing may appear almost as fringe. In females webbing much less extensive, reaching only to second joint on fourth toe, and deeply indented between all toes (Fig. 5c).

Ventral surface, top of foot, femur and underside of arm smooth. Dorsal surface, head and eyelids, upper side of arms, tibia and underside of foot usually bear numerous, fine, smooth warts. On posterior half of dorsum warts may only occur in band down mid-line. In breeding males numerous small, short, sharp black spines. Cloacal region bears fine white granules. Just above jaw (extending back to above arm) there may be roughly linear series of large white granules, occasionally fusing to form fairly distinct stripe.

Ventral surface white; mandibular margins or whole chin may be lightly suffused with grey or light brown. In preservative dorsal surface varies from light to dark grey with numerous small to medium darker spots. Edges of spots usually diffuse. There may be a narrow, white to cream mid-dorsal stripe, often interrupted. Of the eleven specimens from near Gawler, three had no stripe, three a clear stripe and five an interrupted stripe. In life, background colour is generally a yellowish green with spots dark brown to black.

The eleven specimens from near Gawler had an average snout-vent length of 45.7 mm (40.5–52.0 mm).

Geographic variation: Frogs from all parts of the range in S.A. vary only in the following respects: in a series of males from and near Kimba the foot webbing is much less extensive, and closer to that in females from Gawler (Fig. 5c). In males from Penola the webbing is more extensive but through southeastern S.A. males have more extensive webbing than females. Some of this variation may be seasonal as reported for *N. pelobatoides* (Parker 1940).

In some specimens, particularly from the Mt Barker-Balhannah area of the Mt Lofty Ranges, as well as a mid-dorsal stripe there was an elongate V-shaped mark extending posteriorly from above the arm with the point of the V in line with the eye. In a few frogs from southeastern S.A. and the Mt Lofty Ranges the tip of the first toe bears a light brown to black spot.

The maximum snout-vent lengths recorded were 62.6 mm (♂ R16416, Scorpion Springs Conservation Pk) and 60.7 mm (♂ R10857, Narrung).

Call: Relatively long, averaging 33 pulses (19 pulses/sec. at water temperature of 15°C). Dominant frequency 1.3 kHz.

Comparison with other species: The call of *N. pictus* clearly distinguishes it from congeners known from S. Other *Neobatrachus* encountered all had similar calls with higher dominant frequencies (from 1.5–1.7 kHz), low pulse numbers (average about 15) and at any given temperature a much lower pulse repetition rate than *N. pictus*; my "type B" call of Littlejohn (1965).

Adults of these other call types are either much smaller (average S–V 36 mm) with large, clearly demarcated spots on the dorsal surface (southeastern S.A.) or are light brown or golden coloured with skin extending from the side of the body across the groin to the knee (Fig. 5e) (northern, northeastern and northwestern S.A.). In *N. pictus* skin only extends marginally along the upper leg from the side of the body (Fig. 5d). The skin enclosed groin also occurs in the small form in southeastern S.A., but is not a constant feature of these frogs.

Type specimens

There are five syntypes in the Zoologisches Museum, Humboldt University: 9507, a subadult (? female) of 31.3 mm, and a juvenile ? *Notaden melanoscaphus*; 4725 a partly decomposed adult female of 45.0 mm and a poorly preserved male of 41.8 mm; 4726 a well preserved gravid female of 55.1 mm S–V and 56.4 mm (total length measured to posterior extremity of body beyond the vent. It is clear from the size and other details that Peters based his description on No. 4726. It agrees with the original and this description in size and all other pertinent respects.

Discussion

The distribution data in Figure 1 combined with Brook's data for western Victoria probably represent the total range of this species. As *N. pictus* is replaced to the west, northwest, north and northeast in S.A. and to the east in Victoria (Brook 1975) by "call type B" frogs, the only possible extension is into southern and eastern N.S.W. Barker & Grigg[1] recorded "type B" calls 24 km S. of Condoblin, N.S.W., attributing them to *N. pictus*. If their use of the name *N. pictus* is consistent throughout the range they give for this species (central N.S.W. as far as Queensland and south into Victoria) then there is little chance that *N. pictus* (sensu stricto) occurs anywhere in N.S.W. or Queensland.

Previous redescriptions of *N. pictus* (Parker 1940; Moore 1961) differ from mine in several details. However, the character most profitably used in distinguishing *N. pictus* from *Neobatrachus* making "type B" calls (extent of skin in the groin: Fig. 5d, e), was not considered by either author. The differences between my description and those of these authors may reflect the fact that in all probability none of the specimens examined by them are conspecific with *N. pictus*. Parker examined material from Melbourne and Sandhurst (= Bendigo, Reed 1973) in Victoria, Urana and Ryalstone in N.S.W. and a skeleton from "Australia". Moore's description seems to be largely based on specimens collected at Mt Stromlo, A.C.T. If my interpretation of the range of *N. pictus* is correct, none of these sites fall within the range of this species.

The distribution data I have presented show clearly that *N. pictus* occurs on the Eyre Peninsula. Main, Lee & Littlejohn (1958), Cogger (1975) and Barker & Grigg (1977) have failed to recognise this fact. Furthermore this species is not yet known to occur in N.S.W., and published ranges extending across N.S.W. and into Queensland (Cogger 1975; Barker & Grigg 1977) are likely to be in error.

Heleioporus sudelli Lamb (1911) from Warwick, Queensland has been considered a synonym of *N. pictus* (Hosmer 1958; Moore 1961) though Parker (1940) expressed doubts. Because I have established that *N. pictus* does not occur in Queensland, this synonomy cannot be sustained. Thus I resurrect *N. sudelli* (Lamb) as a valid species, and possibly a senior synonym of *N. centralis* (Parker).

The relationships of *N. pictus* to congeners is unclear. Parker (1940) argued that *N. pelobatoides* is the western analogue of *N. pictus*, and that these two species are closely related: a sentiment reiterated by Main, Lee & Littlejohn (1958) and by Littlejohn (1967). However, as Parker's concept of *N. pictus* is now suspect the real relationships are more obscure. This problem will only be resolved following a thorough re-examination of material from all over Australia, variously referred to *centralis*, *pictus* and *sudelli*. The status of *Neobatrachus* populations making "type B" calls in S.A., N.S.W. and Victoria should be included in such a review.

Acknowledgments

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To the above and to the numerous persons who either sent specimens or recordings my sincere thanks.

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SALT TRANSFERS BETWEEN NORTH AND SOUTH LAKE EYRE

BY J. A. DULHUNTY

Summary

Investigations in 1977 indicated that approximately 30^6 tonnes, or 7.4% of the salt crusts in Lake Eyre North were transferred to Lake Eyre South by overflow of saline floodwater through the Goyder Channel during the major 1974 flooding. Absence of salt crust in the south lake prior to 1974 and evidence of three greater prehistoric floodings, indicate return of salt to the north lake, between high-level floodings, by a process believed to be solution in rain water and transport in underground water towards the lowest area of the salina.

SALT TRANSFERS BETWEEN NORTH AND SOUTH LAKE EYRE

by J. A. DULHUNTY*

(with a calculation of the rate of groundwater movement, by J. W. HOLMES)

Summary

DULHUNTY, J. A. (1978) Salt transfers between North and South Lake Eyre. *Trans. R. Soc S. Aust.* **102**(4), 107-112, 31 May, 1978.

Investigations in 1977 indicated that approximately 30^6 tonnes, or 7.4% of the salt crusts in Lake Eyre North were transferred to Lake Eyre South by overflow of saline floodwater through the Goyder Channel during the major 1974 flooding. Absence of salt crust in the south lake prior to 1974 and evidence of three greater prehistoric floodings, indicate return of salt to the north lake, between high-level floodings, by a process believed to be solution in rain water and transport in underground water towards the lowest area of the salina.

Introduction

Lake Eyre is a large normally dry salina, consisting of two parts—Lake Eyre North and Lake Eyre South, commonly referred to as the north and south lakes, connected by the Goyder Channel (see Fig. 1 and Bonython 1955). The lake forms the sump of a large internal drainage basin (Wopfner & Twidale 1967). When rivers rising in high rainfall areas reach Lake Eyre, they flow into the north lake to produce minor flooding of part of its bed, or less frequently major flooding over the whole of its bed (Dulhunty 1977; Bonython & Mason 1953). The south lake normally receives only small quantities of water from a relatively small arid drainage area on the southwestern side of the internal drainage basin, producing only minor flooding. On rare occasions, possibly once in several hundred years (Dulhunty, J. A. 1975) the north lake floods to a high level and overflows through the Goyder Channel into the south lake.

The purposes of this paper are (i) to record an estimate of the quantity of salt transferred to the south lake during the 1974 major flooding, and the nature and distribution of resulting new salt crusts in the south lake, and (ii) to consider transfers by prehistoric floodings and natural processes of return of salt to the north lake.

Salt crust distribution

The bed of the north lake slopes gently from north to south, and that of the south lake from northeast to southwest. Hard crystalline salt crusts up to 64 cm thick (Bonython 1956; Dulhunty 1974) occur in the southern bays of the north lake, which are the lowest areas of the lake as a whole, where final evaporation of floodwaters and brines takes place. Small quantities of local rain water accumulate in the south lake, and evaporate or soak into the bed, but no hard crystalline salt crusts had been reported or known to occur prior to the 1974 flooding of Lake Eyre. Bonython (1961) described the bed of the south lake in 1960 as encrusted with soft powdery salt forming a layer "never thicker than a fraction of an inch", but no solid salt crust like that found in Madigan Gulf. In 1939 the present author walked over part of the bed and found conditions similar to those described by Bonython.

Water levels in North and South Lake Eyre

The bed of the Goyder Channel rises to a sill which is about 2.0 m above the general level of the adjacent north lake shoreline, and the shoreline at the lower southwestern end of the south lake. The sill is also about 4.4 m above the deepest parts of the north lake, and 3.4 m above the deepest parts of the south lake (see Fig. 1).

The A.H.D. values of the spot heights shown in Figure 1 for the south lake, are based on original levelling by Bonython and Fenner in 1960 (Bonython 1961). Their heights were recalculated to A.H.D. values of bench marks

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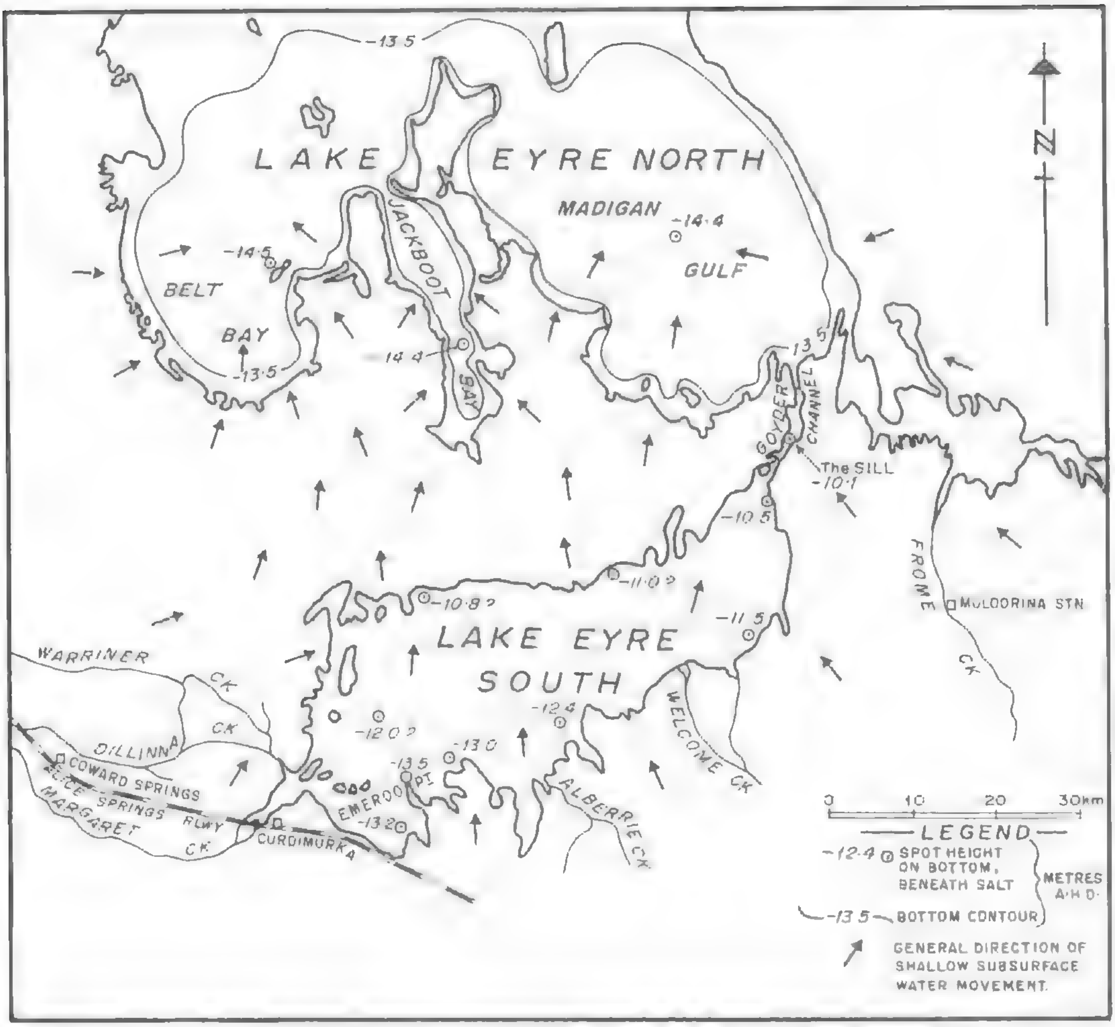

Fig. 1. Lake Eyre South and southern bays of Lake Eyre North showing relative bed levels and regional groundwater movement.

along the Alice Springs Railway near Curdimurka, recently amended by Mr R. T. Smith for Commonwealth Railways and adjusted to the A.H.D. value of Bench Mark L 40/6440 (Dept Lands, S. Aust.) at Prescott Point, adopted by the Engineering and Water Supply Department, Adelaide (Will & Clark[1]) as established A.H.D. value for the Lake Eyre area. A.H.D. values for Lake Eyre North, shown in Figure 1, are based on levelling by the author in 1972 as yet incomplete and unpublished.

The only occasion on which a definite overflow, from one lake to the other through the Goyder Channel, was authentically observed and recorded was during the 1974 flooding to the greatest depth ever recorded, and possibly for some 500 years (Dulhunty, J. A. 1975). The flooding commenced in February 1974. Water in the north lake rose to the level of the sill and commenced flowing through the Goyder Channel on about the 19th March 1974. Flow increased until May of that year when a maximum mean lake level of about

9.1 m A.H.D. was reached, approximately 1.0 m above the original sill level. It then decreased slowly as the north lake level fell and the south lake level rose, until an equilibrium level between the two obtained in October 1974. Small amounts of water then

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[1] Will, G. D. & Clark, J. (1977) Establishing A.H.D at Lake Eyre North and Lake Eyre South. Report. Sur. B., Engineering and Water Supply Dept, Adelaide

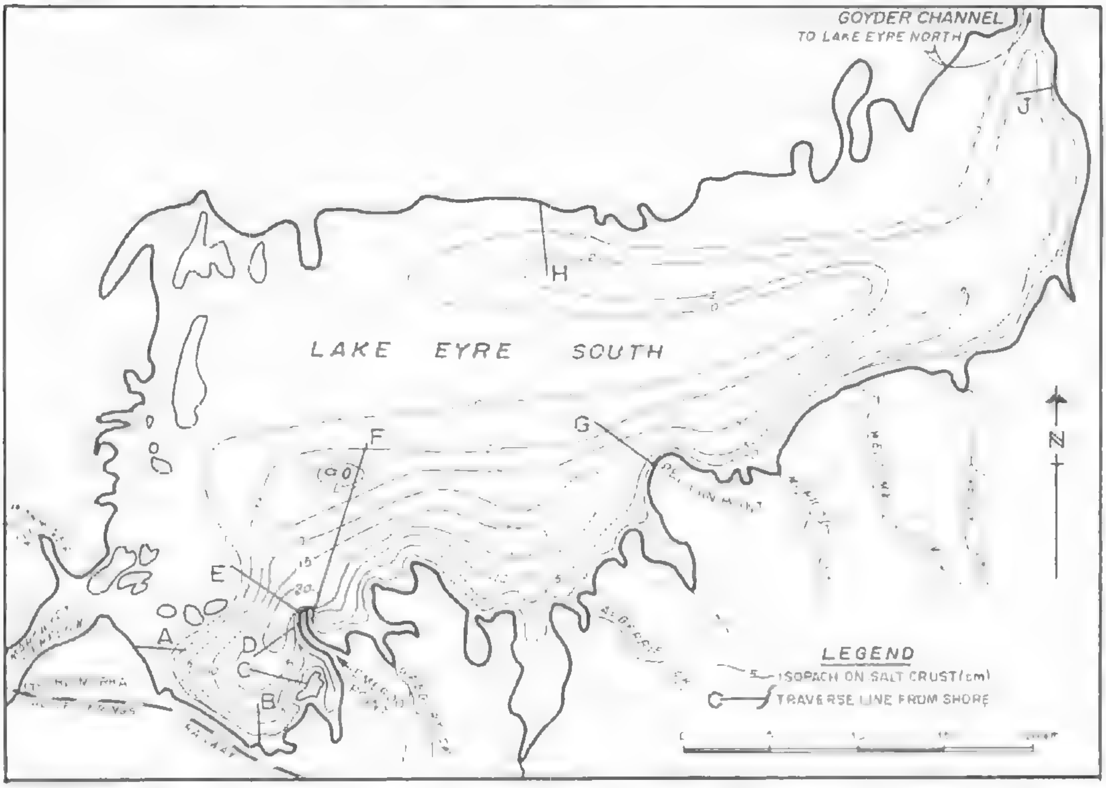

Fig. 2. Lake Eyre South showing salt crust distribution and thickness in October 1977.

moved back and forth through the channel with changes in wind direction, until water connection ceased during August 1975.

Transfer of salt during 1974 flooding

Water flowed freely through the Goyder Channel for seven months, during which time its salinity varied from 10 to 50 g/l. The volume of water which flowed through the channel cannot be calculated accurately as rate of flow varied widely, and the water required to fill the south lake came from local rain in its catchment area as well as from the north lake. However, it was evident that a great quantity of salt had been transferred from the north to the south lake in aqueous solution during the period of overflow.

After water ceased to flow into the south lake, and it dried up in 1977, large areas of its bed were covered with a hard white crystalline salt crust for the first time on record. The crust closely resembled that which had occurred over the southern bays of the north lake before the 1974 flooding. Practically all the salt formations and types of crust previously observed in the north lake (Bonython 1956; Dulhunty, R. 1975) were seen in the south lake in varying degrees of development in 1977. The only significant difference was greater porosity and lower bulk density in the south lake crust, due probably to immaturity and a somewhat more open texture in which additional salt had not yet crystallised. Also, in some places, lateral spaces or voids, from 0.5 to 3 cm wide, filled with water and occasional transverse salt crystals occurred on horizontal planes within the crust. All salt crust thicknesses recorded in this paper and in Figure 2, are nett figures excluding lateral spaces.

Quantity of salt transferred

A survey was carried out of salt crust thickness and distribution in Lake Eyre South in October 1977. Results are shown in Figure 2. Traverses were run out from the shore along 9 lines, A to H and J, across the lake bed (Fig. 2). Nett crust thicknesses were determined at intervals of 200–500 m depending on rate of change in thickness. Isopachs were then drawn through points on the traverse lines, and interpolated across intervening areas using all available information and indications obtained by aerial and surface reconnaissance.

The resulting isopach map (Fig. 2) is believed to be a good general overall picture of the occurrence of salt crust in the south lake in October 1977.

The area of thickest crust, occurring within the 20 cm isopach, varied up to 24 cm in the vicinity of the lowest place in the south lake discovered near Emeroo Point in 1960 by Bonython (1961). A maximum thickness of 29 cm was measured at one place near the shore off the northern tip of Emeroo Point, in a channel washed out by water flowing round the point.

Bonython (1956) recorded the mean bulk density for salt in Lake Eyre North as about 1.49 tonnes per m^3, and calculated the total salt content, above the surface of the true lake bed to be about 408^6 tonnes. Determinations of bulk density of the immature salt crust in the south lake, gave a mean value of about 1.0 tonne for m^3, representing about 67% of the bulk density of the older north lake crust.

The quantity of salt crust in Lake Eyre South, in October 1977, occurring above the surface of the true lake bed, calculated from isopach values, enclosed areas and a bulk density of 1.0 tonne per m^3, was about 30^6 tonnes. This indicates that approximately 7.4% of the salt crust in Lake Eyre North was transported to Lake Eyre South during the 1974 flooding.

Prehistoric floodings and salt transfers

The study of wave-built shingle terraces along the shores of the north lake (Dulhunty, J. A. 1975) established at least three prehistoric floodings to depths of 0.7, 1.6 and 2.8 m greater than in 1974, at intervals of the order of 500, 1500 and 3000 years before present. Quantities of salt equal to, if not greater than that carried through the Goyder Channel in 1974–75 must have been transferred to the south lake by each of the prehistoric floodings, yet no salt crust was known in the south lake, prior to the 1974 flooding, for at least 40 years. This means that in some way salt must be returned to the north lake between each of the major floodings which carry it into the south lake.

Return of salt to Lake Eyre North

There would seem to be only three ways in which salt could be returned to the north lake.

1. *Wind transport.* Transport of salt as an airborne powdery efflorescence, or absorbed on dust particles (Bonython 1956; Grabau 1920), by prevailing southwest to southeast winds from the crust in the south lake to the north lake or its catchment, is theoretically possible and probably has happened to some small extent. It would require solution of hard salt crust in partly saturated rising water, and rapid drying at the surface to form a powdery salt, or film absorbed on dust particles, which could become airborne. In both north and south lakes crusts salt solutions have been seen rising along cracks and drying at the surface to form soft cellular, or lace-like salt masses almost efflorescent but not powdery. The salt masses did not seem to be eroded by wind to become airborne, even in strong winds, but remained until dissolved in rain water, from which the salt was added to hard crust by recrystallization on evaporation. Nor was evidence seen of dust being wetted with salt solution and drying to become airborne.

Although no direct evidence of wind transport of salt was seen at Lake Eyre, it could have operated as a minor contributing factor in return of salt to the north lake.

2. *Solution in surface floodwater.* The most direct and simplest way in which salt could be returned to the north lake would be by solution in surface floodwater filling the south lake and overflowing into the north lake. However, no authentic report, record or observation exists of Lake Eyre South filling independently of the north lake, and overflowing to the north (Bonython 1969). Nor does it seem likely that this could have happened under present conditions of aridity (Bonython 1960), which must have existed for at least 3000 years in the relatively small drainage area of the south lake. The circumstances in which the north lake filled in both the 1949–50 and 1974 floodings, indicate that in rare high rainfall years when the south lake could have filled, the north lake would have filled first and overflowed into the south lake, preventing effective transfer of salt to the north. So return of salt to the north lake by north-flowing floodwaters would seem to have been so unlikely that it must be discounted.

The possibility of water, from minor fillings in the south lake, being blown by southwesterly wind up across its bed and through the Goyder Channel, must also be discounted. During the 1949–50 floodings mean lake level rose to within 24 cm of the sill level (Bonython 1961) but no water was known to be blown south through the channel. Also, after the 1974 flooding, when water receded in the south lake to a little south of the southern end of the channel, at some 40 cm below the sill, no water was known to have been blown north through the channel. Even if filled to the general level of its northern shore, at about 11.0 m A.H.D. (see Fig. 1) water would have to have been blown up through a vertical interval of 1.0 m to flow north through the Goyder Channel, which would seem impossible.

3. *Solution in subsurface groundwater.* Limited quantities of rain water, from an average annual rainfall over the south lake of less than 125 mm and brief flows of river water from its arid catchment area, accumulate at times, perhaps once every two or three years, in relatively small areas of its lake bed. After dissolving salt, some of the water could pass down through the bed and merge with shallow groundwater moving generally to the north beneath country separating the north and south lakes (Fig. 1). Such regional movement of groundwater could certainly be expected from the higher country south of the railway, north beneath the south lake towards the lower parts of Lake Eyre North (see Fig. 1).

The difference between lake bed levels in the south lake and the southern parts of the north lake is illustrated in Figure 1. It shows the bottom contour of 13.5 m A.H.D. equivalent to the lowest point in the south lake, close to the shorelines round Madigan Gulf and Jackboot and Belt Bays. Practically the whole of the lake bed in the three bays is up to 1.0 m below the lowest point in the south lake, and up to 3.5 m below other parts of its bed. This difference in elevation over the wide area of the three bays would promote a positive movement of groundwater to the north. It would be most active during and following years of higher rainfall. During years of very low rainfall it may well be interrupted by insufficient intake to maintain continuity of water and flow.

The groundwater carrying salt from Lake Eyre South would eventually surface in Madigan Gulf and Jackboot and Belt Bays, where the base of the salt crust is at, or slightly below the level of the "dry lake" watertable. It would then move up through the crust to evaporate and deposit its salt content at the surface. This is believed to be the principal factor contributing to the return to the north of salt periodically dissolved in floodwater and carried by overflow to the south lake.

Acknowledgments

It is wished to acknowledge (i) valuable assistance of Muloorina Station including the station aircraft in aerial reconnaissance over Lake Eyre South piloted in 1976 by Mr M. O. (Blue) Hughes and in 1977 by Mr Malcolm Mitchell who also helped in running ground control traverse line H (Fig. 1) in country of difficult access, (ii) helpful discussion with Mr Warren Bonython, and with Messrs G. D. Will and J. Clark of the Engineering and Water Supply Dept, Adelaide, and (iii) research facilities of the University of Sydney and funding by the Australian Research Grants Committee.

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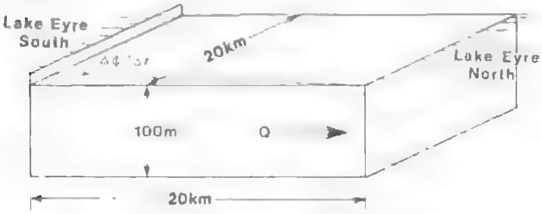
CALCULATION OF RATE OF GROUNDWATER MOVEMENT FROM LAKE EYRE SOUTH TO LAKE EYRE NORTH (by J. W. Holmes)

Suppose the geometry of the lakes can be simplified to the diagram in Figure 3.



The rate of groundwater flow is given by

$$Q = KA \frac{\Delta\phi}{\Delta l},$$

where K is the hydraulic conductivity that we will assume to be 1 m day^{-1}, A is the cross-sectional area through which the aquifer fluid flows ($= 2 \times 10^6$ m^2), and $\Delta\phi / \Delta l$ is the hydraulic head gradient ($= 5 \times 10^{-5}$).

Therefore

$$Q = 1 \times 365 \times 2 \times 10^6 \times 5 \times 10^{-5} \text{ m}^3 \text{ yr}^{-1}$$
$$= 4 \times 10^4 \text{ m}^3 \text{ yr}^{-1}.$$

The amount of salt to be transferred is 30×10^6 tonnes. Suppose it is transported in a solution of about 100 g l^{-1} concentration. That is, a solution volume flow would be required of about 3×10^8 m^3. The time required for this transfer would be about 7.5×10^3 years, consistent with Dr Dulhunty's statement that the filling of Lake Eyre South by overflow from Lake Eyre North may happen at a recurrence interval of ~1000's of years.

The physical transfer of the same salt as is infiltrated through the bed of Lake Eyre South to the bed of Lake Eyre North would take a longer time. The aquifer volume can be estimated to be 20 km × 20 km × 100 m, and if the aquifer porosity is approximately 0.3 then the volume of fluid is about 1.2×10^{10} m^3. One pore volume would be replaced by an annual flow of 4×10^4 m^3 yr^{-1} in 3×10^5 years on the average. The salt solution having its origin in Lake Eyre South would probably not emerge into Lake Eyre North earlier than about ½ million years after it was entrained into the bottom of the south lake.

If these order-of-magnitude calculations give a correct guide to the general picture of the hydrology of Lake Eyre South relative to Lake Eyre North, they suggest that there may well be zones of lesser and zones of greater salt concentrations in the aquifer fluid moving so slowly towards Lake Eyre North. Such zones would be expected to occur in response to variations in local climatic conditions. The gradients for flow are assumed to be relatively stable and appropriate to the present land levels. The mild tectonic activity of this region could entirely invalidate any time-scale predictions that go beyond about 10^5 years.

Dr Dulhunty states that the maximum depth of water in Lake Eyre South occurred in early 1975 and that water connection across the sill was severed in August 1975. The level of the sill appears to be 9.1 m. He states that Lake Eyre South dried up in 1977. That is, the maximum depth of $+13.5 - 9.1 = 4.4$ m, dried up in two years. This implies an evaporation rate of 2200 mm yr^{-1}, and is in good agreement with our understanding of net radiation into the interior of Australia and the energy available for evaporation of water from a large lake.

MACROPICOLA OCYDROMI N.G. N.S.P. (NEMATODA: STRONGYLIDAE) FROM A WESTERN AUSTRALIAN KANGAROO

BY PATRICIA M. MAWSON

Summary

The new genus is placed in the family Strongylidae, sub-family Globocephalinae, because of the large subglobular buccal capsule, without leaf crown, cutting plates, or anterior teeth, with regid mouth opening, and with three large oesophagal teeth. It differs from Globocephalus in the number of teeth, form of teeth, form of the dorsal ray, and position of the vulva.

MACROPICOLA OCYDROMI N.G. N.SP. (NEMATODA: STRONGYLIDAE) FROM A WESTERN AUSTRALIAN KANGAROO

by Patricia M. Mawson*

Summary

Mawson, P. M. (1978) *Macropicola ocydromi* n.g., n.sp. (Nematoda: Strongylidae) from a Western Australian kangaroo. *Trans R. Soc. S. Aust.* **102(4)**, 113-115, 31 May 1978.

The new genus is placed in the family Strongylidae, sub-family Globocephalinae, because of the large subglobular buccal capsule, without leaf crown, cutting plates, or anterior teeth, with regid mouth opening, and with three large oesophageal teeth. It differs from *Globocephalus* in the number of teeth, form of the dorsal ray, and position of the vulva.

Introduction

The new species and genus described in this paper is one of the only two strongylid nematodes to be found in Australian marsupials. The first, now under description, was also from a macropod.

The genus *Hypodontus* Mönnig 1929, previously considered a strongylid (s.f. Uncinariinae), was discussed by Inglis (1968) who referred it to the Amidostomatidae. This genus is at present under revision (Beveridge, in preparation).

Holotype male and allotype female of *Macropicola ocydromi* will be deposited in the South Australian Museum. Other material is in the Australian National Helminth Collection, in the South Australian Museum.

All worms were fixed in hot formalin, and cleared for light microscope examination in lactophenol. Specimens for use in the S.E.M. were brought through ethanol to xylol, and coated first with carbon, and then gold-palladium.

Macropicola n.g.

Strongylidae: Globocephalinae: Anterior end with flattened cuticular cap surrounding hexagonal mouth opening and bearing amphids and submedian papillae. Buccal capsule large, subglobular, with dorsal groove, and with three solid multi-tuberculate oesophageal teeth. Oesophagus clubshaped, Male: bursa entire, not deeply lobed, ventral rays together, ventrolaterals separate from postero and mediolaterals, externo-dorsal from dorsal ray, dorsal ray bifurcate each branch dividing again; spicules long, alate; gubernaculum present. Female: tail short, conical; vulva close to anus, ovejectors parallel, uteri pro-delphous. Parasites of the large intestine of macropod marsupials. Type species: *Macropicola ocydromi* n. sp.

This genus has been placed in the family Strongylidae rather than the Trichonematidae because of the subglobular shape of the well-developed buccal capsule. It has been referred to the subfamily Globocephalinae because of the absence of leaf crown, teeth or cutting plates around the mouth. Of genera in this group, *Macropicola* most closely resembles *Globocephalus* Molin (1861), differing from it in the number of final branches of the dorsal ray, the number of oesophageal teeth, and the more posterior position of the vulva. *Globocephalus marsupialis* Freitas & Lent (1936) was described from a South American marsupial, *Metachirops opossum*.

The only other strongylid from Australian marsupials is the new genus being described by Dr J. Beveridge. This differs markedly from *Macropicola* in the presence of two well developed leaf crowns.

Macropicola ocydromi n.g., n.sp.

FIGS 1–9

Host and localities: *Macropus fuliginosus ocydromus* Gould, from near Albany (5 ♀,

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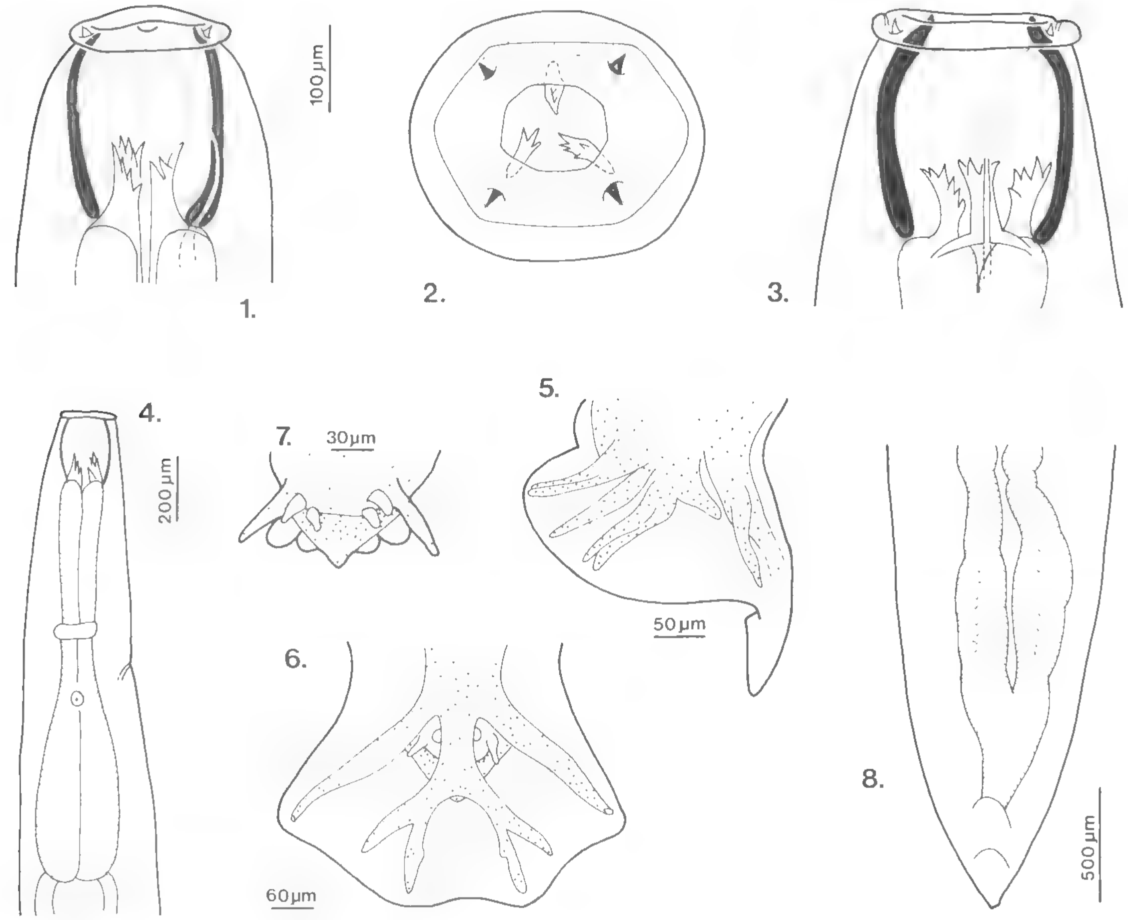
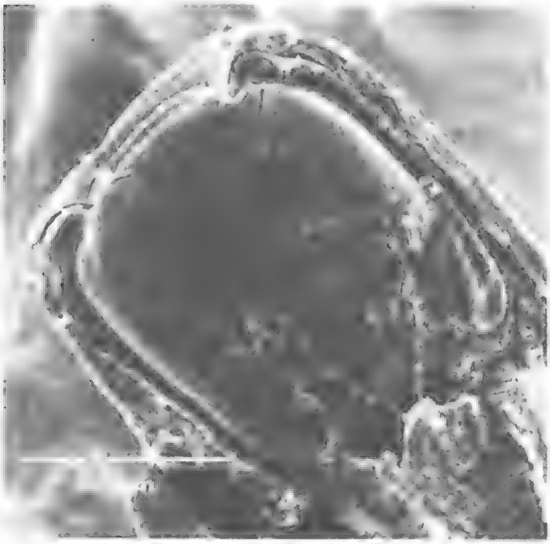
* Department of Zoology, University of Adelaide, North Tce, Adelaide, S. Aust. 5000.



Macropicola ocydromi: Figs 1–3: Head. In lateral, en face, and dorsal views, respectively, to same scale. Fig. 4: Oesophageal region. Figs 5–6: Bursa in lateral and dorsal views. Fig. 7: Genital cone, dorsal view. Fig. 8: Posterior end of female.

4 ♂, from 1 host), Jandacot Experimental Stn, W.A. (5 ♀ from one host), and near Perth (2♀, 1 ♂, from one host).

Males 12.8–13.6 mm long, females 18.3–20.4 mm, tapering only slightly anteriorly and posteriorly. Cephalic cuticle forms thick flattened plate, slightly wider than succeeding body, and bears four small conical submedian papillae, two amphids, and a central anteriorly directed octagonal mouth opening. Buccal capsule longer than wide and widest at its midlength (Figs 1, 2). Dorsal wall of capsule thicker in its basal quarter length, where it is penetrated by the duct of dorsal oesophageal gland; after its emergence through wall the duct connects with encircling groove, cut into capsule, following a course as shown in Figs. 1 and 2. From each of the three sections of oesophagus a stout tooth projects into buccal cavity, each tooth provided with a number of short pointed



Macropicola ocydromi: Fig. 9: Head cut longitudinally to show inside of buccal capsule.

projections (Figs 1, 2, 3, 9). Oesophagus 1400–1500 μm in male, 1600–1800 μm in female, cylindrical anteriorly widening posteriorly. Nerve ring 690–750 μm from head in male, 700–770 μm in female. Small conical cervical papillae and excretory pore shortly behind nerve ring (Fig. 4).

Male: Bursa entire, longer dorsally. Arrangement of rays shown in Figs 5 and 6. Posterolateral ray with branch from its base, passing dorsally. Genital cone (Fig. 7) large, posterior lip of cloaca with three pairs short projections. Spicules 990–1000 μm long, giving a ratio of spicule : body length of 12.8–13.6.

Female: Body tapers suddenly in region of vagina to short conical tail, 130–190 μm long. Vulva 220–300 μm from tip of tail, vagina short, ovejectors parallel, prodelphous. Egg in uterus (none in vagina) 150 x 70 μm.

The specimens described in this paper were collected by N. Allen, and were sent to me by Dr G. de Chaneet of the Animal Health Laboratory, Department of Agriculture, Western Australia. I am very grateful to have received this material. The photomicrographs were taken by E.T.E.C. Autoscan in the Central Electron Optical Laboratory of the University of Adelaide. I am indebted to Dr Karl Bartusek of this laboratory for help in taking the micrographs and to P. G. Kempster for developing and printing them.

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STRATIGRAPHY, PALYNOLOGY AND IMPLICATIONS OF ORGANIC BANDS IN A SMALL QUATERNARY BASIN, NEAR PALMER, SOUTH AUSTRALIA

BY ELIZABETH A. A. GRUBB

Summary

The strtigraphy and pollen content of dominantly sandy sediments in a creek bed near Palmer have been examined. Organic bands appear to reflect the presence of permanent standing water in a settling pond from about 8000 years B.P. to some time more recent than 6600 B.P. The generic content of the vegetation then was comparable to the present, but the presence of spores of Anthocerolates suggests that the climate was slightly wetter.

STRATIGRAPHY, PALYNOLOGY AND IMPLICATIONS OF ORGANIC BANDS IN A SMALL QUATERNARY BASIN, NEAR PALMER, SOUTH AUSTRALIA†

by ELIZABETH A. A. GRUBB*

Summary

GRUBB, E. A. A. (1978) Stratigraphy, palynology and implications of organic bands in a small quaternary basin, near Palmer, South Australia. *Trans. R. Soc. S. Aust.* **102**(5), 117-123, 30 August, 1978.

The stratigraphy and pollen content of dominantly sandy sediments in a creek bed near Palmer have been examined. Organic bands appear to reflect the presence of permanent standing water in a settling pond from about 8000 years B.P. to some time more recent than 6600 B.P. The generic content of the vegetation then was comparable to the present, but the presence of spores of Anthocerotales suggests that the climate was slightly wetter.

Introduction

An intermittently flowing stream 11 km south of Palmer, South Australia, has deeply incised earlier deposits, exposing organic layers in its steep banks. The site is interesting because it is the only known Holocene site containing organic sediments in the Mt Lofty Ranges. It is critically positioned near the eastern limits of the Ranges, in a boundary zone between the woodland and open forest vegetation characteristic of the higher and wetter ranges to the west and the scrub and mallee, common on the Murray Plains in the east.

This paper describes the stratigraphy and gives pollen counts from the organic sediments, and discusses the implications of these results in the light of work done on material of comparable age from other parts of southern Australia.

Gorge Creek, lat. 34°55'S, long. 139°10'E, flows in a shallow valley running east from Mt Beevor towards the Murray Plains (Fig. 1). Mt Beevor is 480 m high, and is a spur of the higher and wetter Mt Lofty Ranges. Above the site, which is at an altitude of 200 m, the creek drains an area approximately 8 km long and at the most 3 km wide. Below the site the valley is constricted by rocky outcrops and the creek runs to the Murray Plains 3 km away through a narrow pass between the hills, which form the eastern-most edge of the Mt Lofty Ranges.

The mean annual rainfall is estimated as about 400 mm. Daily mean maximum temperatures at nearby Murray Bridge range from 28.9°C in February to 15.8°C in July, and daily mean minima from 15.1°C (February) to 5.5°C (July). It is likely that similar temperatures are experienced at the site, modified a little by the constricted valley formation of the surrounding hills which probably tend to trap cold air. Prevailing winds are from the west and southwest.

Stratigraphy

A stratigraphic section (Fig. 2) was determined from natural exposures in the steep-banked gully of Gorge Creek. The deposit is about 100 m long; its breadth is uncertain but appears to be about 15 m. Alternating bands of sand and organic matter are about nine m thick (Fig. 3). The lower and more richly organic bands form discrete layers, but the upper bands are less rich and less distinct. Upstream and downstream there is a uniform brown sand which fills the bulk of the valley floor. Schist of the Kanmantoo group lies only a few centimetres below the present stream

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† This paper is based on: Grubb, E. A. A. (1967) Analysis of a semi-fossil organic deposit near Palmer, South Australia. M.Sc. thesis, Department of Botany, University of Adelaide (unpublished).

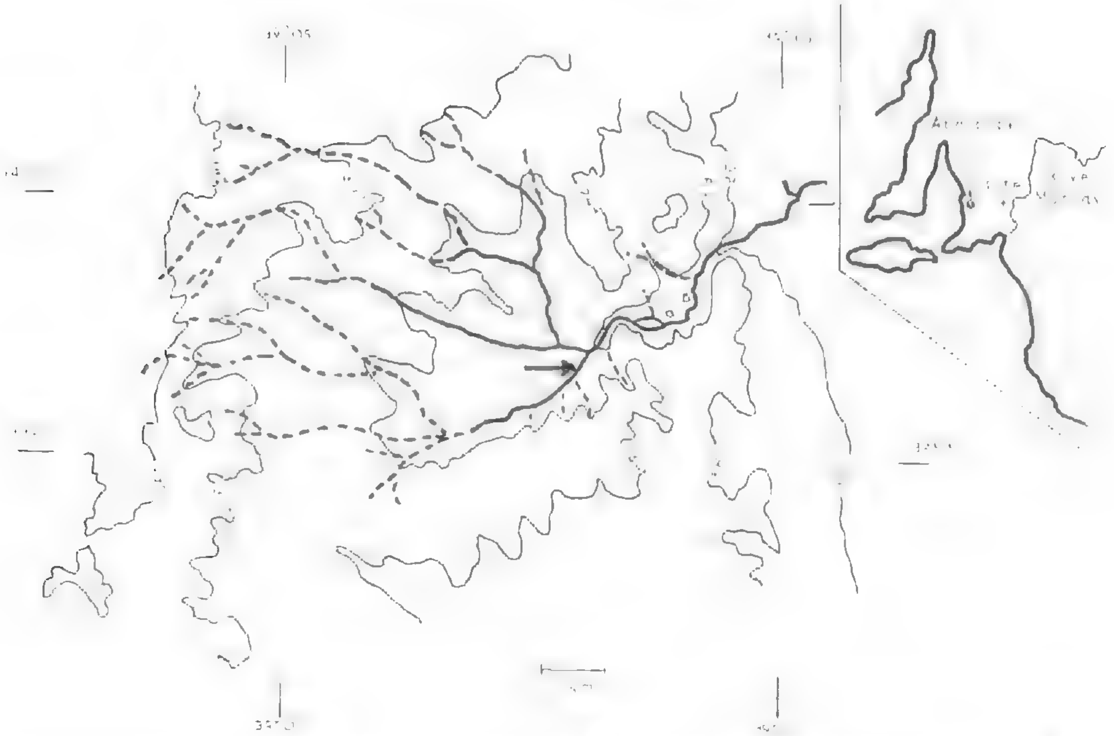

Fig. 1. Topography of upper reaches of Gorge Creek, showing position of deposit (arrowed). Palmer is 11 km to the north.

bed along the whole length of the deposit, and there is a particularly notable outcrop near the downstream end. It seems most likely that the deposit began to accumulate in a small waterhole or swamp retained behind a barrier formed by the schist. However, the deposit now extends over the schist barrier. Subsequent incision by Gorge Creek has formed a narrow, steep-banked gully, exposing the layers shown in Fig. 3.

The sands are of varying colour and texture, ranging from white through various shades of yellow, orange and brown to black organic sands and through fine and coarse sand to gravel (Fig. 2). Very little clay is present. The organic layers range from the black sand to a heavy moist peat-like material. There is no evidence of charcoal. The richest organic layers have been numbered one to seven (Fig. 2), and examined for the presence of pollen.

Two radio carbon dates were obtained. The oldest organic layer (7) was dated at 6600 ± 100 years B.P. A date of 8000 years was obtained for a more recent layer, and this makes it difficult to say with certainty when the earliest sedimentation occurred.

Methods

Samples were collected from each organic layer. As the layers were exposed sands were simply sampled using 2.5 x 5 cm glass vials. Slabs of the peat-like layers approximately 20 x 20 cm, were removed and transported in plastic bags; in the laboratory fresh surfaces were exposed and subsampled for analysis.

Subsamples of 1 g were processed using standard techniques given by Faegri & Iversen (1950). The most satisfactory means of preparation was treatment with 5% potassium hydroxide for 15 min., followed by acetolysis and vibration using a 'vibraflute' (Tshudy 1960). The dehydrated residues were mounted in glycerine jelly and stained with safranin.

A reference collection was made of the pollen grains of about 200 species commonly found in the Palmer area now. Spores proved to be common in the deposit and this necessitated a small collection of fern and bryophyte spores as there was at that time no suitable reference text for these species in Australia.

Vegetation of the study area

Specht (1972) has mapped the probable pre-settlement vegetation of the Palmer area as 'woodland to open-forest with herbaceous understorey' dominated by *Eucalyptus camaldulensis* (mainly in the valley bottoms), *E. odorata* and *Casuarina stricta*. The area was opened up for European settlement about 1850 and has been extensively cleared to leave an open grassland with occasional scattered trees. Within 2 km of the site can be found *Banksia marginata*, *Callitris collumellaris*, *C. preissii*, *Casuarina stricta*, *Eucalyptus anceps*, *E. camaldulensis*, *E. fasciculosa* and *E. porosa*. In most of the area the commonest trees are eucalypts, but on the rocky slopes surrounding the study site *Casuarina stricta* is relatively more prominent. The mallee eucalypts (*E. anceps* and *E. porosa*) occur in discrete outliers on sandy or rocky soils.

Native shrubs and sub-shrubs have been largely eaten out but some species may be found still: *Acacia* spp., *Billardiera sericophora*, *Bursaria spinosa*, *Correa schlechtandelii*, *Dodonaea viscosa*, *Haloragis heterophylla*, *Melaleuca neglecta*, *Olearia* sp., *Pimelea strictum*, *Rhagodia nutans*, and several small legumes. Three ferns found commonly are *Cheilanthes tenuifolia*, *Pleurosorus rutifolius* and *Pteridium esculentum*.

Within 1 km of the deposit are pools containing *Potamogeton crispus* and *Ruppia maritima*, and in the areas surrounding them grow *Carex tereticaulis*, *Juncus* sp., *Lepidosperma laterale*, *Leptocarpus brownii*, *Machaerina juncea*, *Scirpus americanus* and *S. nodosus*. In other areas probably seasonally waterlogged can be found *Cyperus gymnocaulos* and *Juncus* spp.

Nomenclature follows Black (1943–57) except where revised by Eichler (1965).

The pollen record and its evaluation

Layer 1, an organic sand, and layer 2, an organic layer whose stratigraphic origins are obscure, yielded no pollen. Layers 3, 5, 6 and 7 contained pollen in meagre quantities, the average slide having a count of about 100 pollen grains. Layer 4 appeared as richly organic as these four, but the average pollen count was only 1 or 2 grains per slide, and it was decided to ignore it. However, it was quite rich in diatom skeletons and a small circular scale, possibly also of diatom origin (?*Melosira*, David Thomas, pers. comm.).

The pollen counts obtained are given in Tables 1 and 2. Because of difficulties experienced in trying to concentrate the pollen, I have included in Table 1 total counts of all

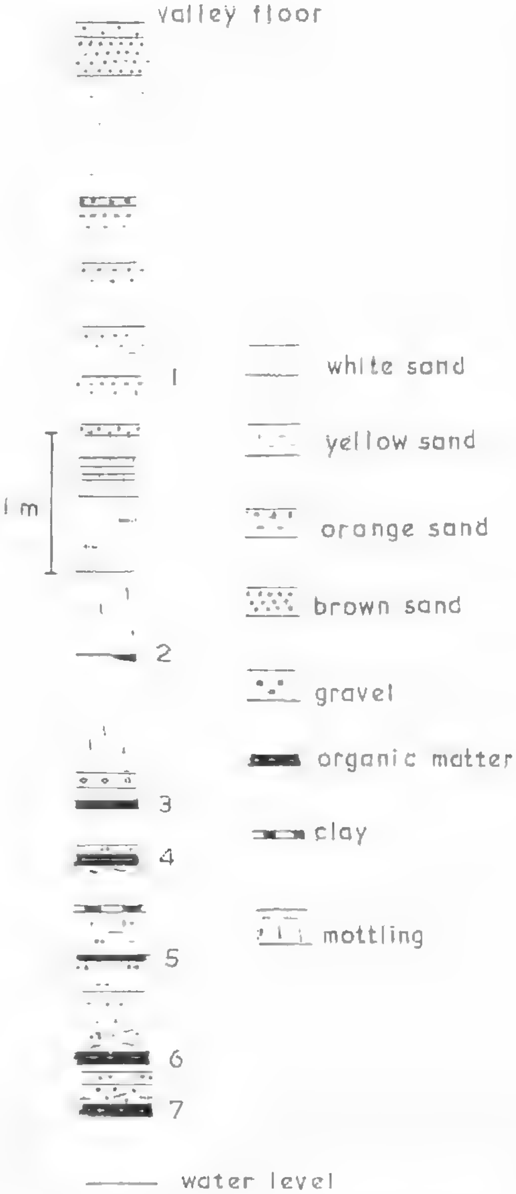

Fig. 2. Diagrammatic representation of sediments in deposit, showing organic coloured sands at top, mottled white sands in middle and organic bands containing pollen near base. Layers sampled for pollen analysis are numbered (and their thicknesses indicated below in parentheses): 1, very sandy, no pollen; 2, richly organic, but stratigraphically obscure, no pollen; 3, richly organic, pollen present (5 cm); 4, richly organic but very little pollen (7 cm); 5, (4 cm); 6, (7 cm) & 7, (5 cm), richly organic, pollen present. Depth of section about 8 m.

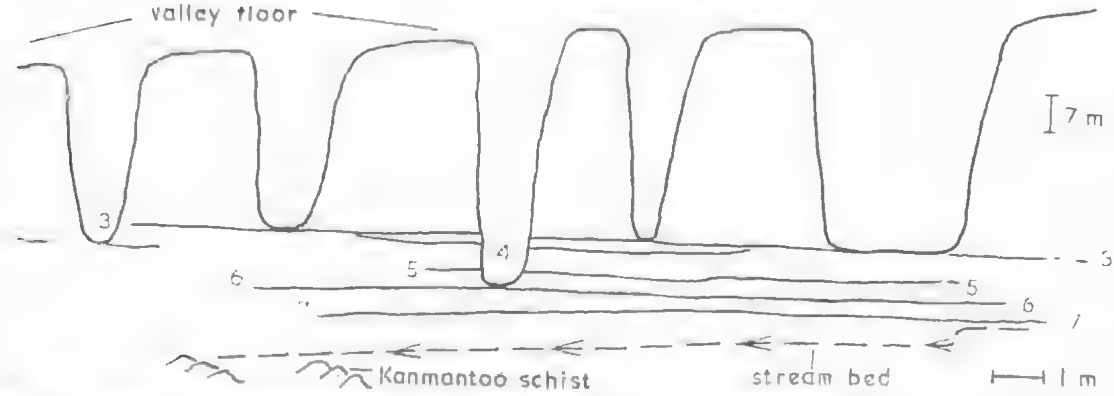

Fig. 3. Vertical section of east bank of Gorge Creek from valley floor to stream bed, showing extent of organic deposits. Organic sands are visible for further 26 m downstream. At the left is shown outcrop of Kanmantoo Schist which probably formed a barrier behind which deposit accumulated.

TABLE 1

Pollen counts from layers 3, 5, 6 and 7 (different forms in descending order of prevalence).

Abundant forms Layer	3	5	6	7
Number of slides counted	10	29	13	10
Casuarina	319	922	278	24
Compositae 1a†	89	96	30	10
1b	48	21	6	
2 (Liguliflorae)	21	6	1	3
Chenopodiaceae	44	45	44	8
Haloragaceae	58	45	13	6
Gramineae	22	35	29	9
Banksia	37	18	3	3
Myrtaceae	6	10	5	0
Spores	24	16	3	3
Unknowns	343	560	250	93
Rare forms				
Callitrichaceae	+	—	+	—
Caryophyllaceae	+	—	+	
Centrolepidaceae	+	—	—	
Convolvulaceae	+	—	—	—
Cruciferae	—	—	+	
Cyperaceae	?	?+	?	?
Droseraceae	+	—	—	
Geraniaceae	+	+	—	—
Hydrocharitaceae	—	+	+	
Labiatae	+	—	—	
Leguminosae—*Acacia*	+	—	—	+
—Papilionatae	+	+	+	-
Liliaceae	+	—	+	—
Potamogetonaceae	—		+	
Ranunculaceae—*Clematis*	—	—	+	—
Rutaceae	+	+	—	+
Thymelaeaceae—*Pimelea*	+	+	+	
Typhaceae—*Typha*-like	-	+	+*	
Umbelliferae	—	+	+	
Diatoms	+	+	+	

† 1a *Helipterum, Helichrysum, Olearia* type pollen. 1b Others.

* Very numerous.

slides examined from each layer and, to get some sort of comparison between the layers, I have listed in Table 2 percentage representation of pollen from 10 slides from each layer.

It is clear that the number of pollen present per slide varies markedly, but the commonest families are present in all layers. The unknowns, which made up 30–60% of the counts, appeared to be mostly Cyperaceae and Juncaceae. Both these families have thin-walled pollen grains with indistinct markings, and can easily suffer damage and distortion due to partial drying out.

The identification of the pollen to species level was not possible. Many of the genera represented are widespread and contain several species which have very similar pollen and distributions. Conversely, the pollen from the deposit was similar to, but not identical with locally abundant species. The possibility of species evolution as well as movement or migration needs to be borne in mind.

Casuarina-type pollen is by far the most abundant tree or shrub pollen in the deposit. There are three species of the genus currently found in the southern Mt Lofty Ranges: one tree (*C. stricta*) and two shrubs (*C. muelleriana* and *C. striata*). The shrub species are commonest in the wetter areas on infertile soils, while the tree species is characteristic of the drier facies of woodland and open-forest. With increasing moisture tall eucalypts become prominent. With decreasing moisture mallee eucalypts replace *C. stricta*. A further tree species, *C. cristata*, is very widespread in 'low woodland' on the dry side of the mallee formation in the Murray Plains. I tried to use pollen size to separate species, but found that this was of limited value because the range of size of the fossil pollen was considerably wider than that of the present-day species sampled. At the present time *C. stricta* is common on

TABLE 2

Pollen present on ten slides from layers 3, 5, 6 and 7 (commonest forms only listed and expressed as totals and %).

Layer	3		5		6		7	
	No.	%	No.	%	No.	%	No.	%
Casuarina	315	*42*	398	*51*	244	*50*	24	*15*
Compositae 1a	89	*9*	42	*5*	24	*5*	10	*6*
1b	48	*5*	4	*<1*	6	*<1*		
2	21	*2*	2	*<1*	1	*<1*	3	*2*
Chenopodiaceae	44	*4*	10	*1*	31	*6*	8	*5*
Haloragaceae	58	*6*	22	*3*	13	*3*	6	*4*
Gramineae	22	*2*	19	*2*	19	*4*	9	*6*
Banksia	37	*4*	8	*1*	2	*<1*	3	*2*
Myrtaceae	6	*<1*	2	*<1*	1	*<1*	—	—
Spores	24	*2*	14	*2*	—*	—*	3	*2*
Unknowns	343†	*35*	248	*33*	143	*30*	94‡	*60*
Totals:	1011		770		484		160	

[*] Spores were found in this layer but not on the slides counted.

[†] Probably included *Casuarina* and *Myriophyllum* grains too poorly preserved to identify accurately.

[‡] Probably largely Cyperaceae and Juncaceae

the rocky slopes around the study site, and the simplest interpretation of the pollen record is that a similar type of woodland persisted throughout the period represented by layers 7 to 3. However, the contribution of *Casuarina* to a pollen assemblage is usually out of all proportion to its importance in a mixed stand of trees, so that its apparent dominance of the local tree flora 8000 years ago should not be taken as proven.

Two *Banksia* species are found in South Australia. Both are largely restricted to areas with rainfall in excess of 400 mm per year. *B. marginata* is widespread in the Mt Lofty Ranges, and is known near the study site, whereas *B. ornata* is of more local occurrence in this part of the State, and is not known near the study site. The pollen size of the two species appears to be significantly different (Cookson & Erdtmann 1952), *B. marginata* averaging 34 μm and *B. ornata* 58 μm. My fossil material compared closely with *B. marginata*, an average of 38 μm was obtained for 12 grains. It seems likely that the pollen is largely from *B. marginata*-type plants. Unlike *Casuarina*, *Banksia* is a poor pollen-producer, and the relative abundance of *Banksia* pollen suggests that the genus was locally common.

The family Myrtaceae, an important family because of its dominance of much of the Australian tree flora, is represented by a remarkably low pollen count; eucalypts are now by far the most common trees in the area within a few kilometres of the site. The Myrtaceae pollen in the deposit seems to be mostly from eucalypts, and to represent a number of species. Eucalypts now locally dominant are known to have high pollen yields (Boomsma 1972) and, in view of the current close proximity of the trees to the site, one would have expected a more obvious record of their presence.

Chenopodiaceae, Compositae and Gramineae are all now found in 'woodland to open forest with an herbaceous understorey' (Specht 1972). The importance of the fluctuations in number of each group is obscure. Pollen from low shrubs such as *Acacia* and *Pimelea* are also present.

'Unknowns' play a prominent part on the pollen counts. The majority of these pollen were probably Cyperaceae and Juncaceae with possibly some Gramineae, which would be consistent with a valley-bottom sedge and rush community. *Typha*-type pollen were noted in very large numbers in layer 6 and, if this identification is correct, it seems likely that this species colonized the site for a relatively brief period, presumably because local conditions were suitable for its establishment. Whether this was a chance occurrence or dependent on certain specific ecological factors is uncertain.

It seems likely that the Haloragaceae pollen recorded consistently from each layer is *Myriophyllum*, a genus found locally with several aquatic or marginally aquatic representatives. This would be consistent with results found from other sites of similar age from southeastern South Australia. Dodson (1974a, 1974b, 1975) noted persistent high counts for *Myriophyllum* pollen in his material from Lake Leake, Marshes Swamp and Mt Gambier.

The precise identification of the different types of spores has yet to be realized, but there are probably at least 10 species in the deposit. A number of these are fern spores lacking a perispore with affinities to *Cheilanthes* and *Lindsaea*. Two other spore-types were identified as Anthocerotales, a group found occasionally in damp areas higher in the Mt Lofty Ranges but not now found in the Palmer area.

Two *Lycopodium* spores were also noted, although they could not be positively identified as being from one of the species now found in South Australia (*L. deuterodensum*, *L. laterale* and *L. serpentinum*). This genus now has a very restricted distribution in the state, and is found only at a few sites such as Square Water Hole, Mt Compass and the Mt Lofty Summit Swamps, all places with permanent standing water.

Discussion

It has been established by others that the climate in southern Australia has been relatively stable over the past 10 000 years; temperature and rainfall are thought to have been marginally higher between 8000 and 5000 years B.P. than now, and this spell was apparently followed by a drier period around 3000 years B.P. before it became wetter again (Bowler *et al.* 1976).

It appears that the generic content of the vegetation at Gorge Creek has remained largely unchanged over the last 8000 years. *Casuarina*, *Banksia* and *Eucalyptus* formed the most prominent pollen-contributing genera 8000–6600 years ago. An understorey of herbs and subshrubs (chenopods, composites and grasses) was present around a shallow lake or waterhole with Cyperaceae and *Juncus* species near the water's edge. In the pool grew *Myriophyllum*, *Potamogeton* and several other hydrophytes. On nearby slopes, possibly among rocks, were established a few ferns, Anthocerotales and possibly *Lycopodium* species. Only the Anthocerotales and *Lycopodium* species are no longer found locally.

The major plant families at this site are also the commonest families noted by Dodson (1974a, 1974b, 1975) and by Dodson & Wilson (1975) at five sites in southeastern South Australia and southwestern Victoria. All of the Victorian sites are in areas dominated by woodland or open-forest and, although the relative importance of the major floristic groups varies quite considerably, it is clear that the pattern of vegetation at this site is closely comparable with that at sites in the southeast. It is quite different from that found by Martin (1973) in material from Nullabor Caves where the present rainfall is about 200 mm per year; chenopods dominated her pollen counts, while Compositae, Gramineae and Myrtaceae accounted for most of the rest of the pollen.

Pollen analysis shows little change in the generic content of the four layers examined. The presence in quantity of the *Typha*-like pollen in layer 6 would appear to be a local phenomenon, a chance occurrence made possibly by some change in the local environment. Fluctuations in climate were apparently not great enough to cause significant changes in the vegetation, although pollen-containing sediments represent only a small part in the history of the sediments.

It appears that the onset of a slightly drier climate (perhaps about 5000 years B.P. as discussed by Churchill 1968, and Bowler *et al.* 1976), possibly coupled with a step in the vegetational succession of the waterhole whereby it was no longer permanently wet but only seasonally swampy, meant that anaerobic conditions were no longer maintained, and any organic matter formed was no longer preserved to form obvious organic bands.

More recently wetter conditions have prevailed again, and the organic content of the sediments has increased, as some sort of ground cover, presumably largely Cyperaceae and *Juncus*, has been established and maintained, but conditions suitable for the formation of permanent standing water or the preservation of pollen have not re-occurred. Sands with a marked dark colouration have accumulated, but no peat.

One of the most interesting features of the deposit is the occurrence of spores of the Anthocerotales, a group which appears to be absent from the area now. Dodson (1974b) found an abundance of '*Anthoceros*' spores in material from about 8000 B.P. at Lake Leake, and there were noticeable peaks in the abundance of the genus at Marches Swamp and Blue Tea Tree Swamp about 7500 years B.P. (Dodson & Wilson 1975), and at Lake Keilambete about 6500 years B.P. (Dodson 1974a). It is tempting to suggest that the increase in importance of the Anthocerotales about 8000–5000 years B.P. may have been correlated with slightly wetter conditions. However, one species of Anthocerotales has been recorded in the Wyperfield National Park in western Victoria where the rainfall is about 300 mm per year (G. A. M. Scott, pers. comm.), and some species are known to develop tubers, and appear to be able to withstand drought (Goebel 1905). Until the spores can be more positively identified, and more is known about the distributions of the genera and species and the factors controlling their growth, one cannot use them as unequivocal evidence of climatic change.

Acknowledgments

I am grateful to my supervisor, Dr R. T. Lange, and to Mr P. Lang (Department of Botany, University of Adelaide) for their encouragement and critical discussions in the preparation of this paper, and I am particularly indebted to my husband, Dr P. J. Grubb

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GEOLOGICAL HISTORY OF THE MOUNT GAMBIER VOLCANIC COMPLEX, SOUTHEAST SOUTH AUSTRALIA

BY M. J. SHEARD

Summary

The Mount Gambier Volcanic Complex comprises a close-knit series of composite maars with a complex history of eruption, the earlier date being 4720 ± 90 years B.P. Detailed field mapping has similarly revealed two main periods of eruption, each one comprising at least three phases of activity. Maars were the major volcanic structures produced; however, Strombolian and Icelandic eruptions are indicated by scoria cones and lava sheets.

GEOLOGICAL HISTORY OF THE MOUNT GAMBIER VOLCANIC COMPLEX, SOUTHEAST SOUTH AUSTRALIA

by M. J. SHEARD[*]

Summary

SHEARD, M. J. (1978) Geological history of the Mount Gambier Volcanic Complex, southeast South Australia. *Trans. R. Soc. S. Aust.* **102**(5), 125-139, 31 August 1978.

The Mount Gambier Volcanic Complex comprises a close-knit series of composite maars with a complex history of eruption. Carbon 14 dating indicates two periods of eruption, the earlier date being 4710 ± 70 years B.P., and the later date 1410 ± 90 years B.P. Detailed field mapping has similarly revealed two main periods of eruption, each one comprising at least three phases of activity. Maars were the major volcanic structures produced; however, Strombolian and Icelandic eruptions are indicated by scoria cones and lava sheets.

Each period of activity began with a highly gas charged magma eruption producing vitric tuffs. Ground water was the major hydrothermal fluid souce, the gas being mainly steam. Closing stages of these periods are marked by low volatile magma eruptions due to the deyhdration of the proximate country rocks.

There is no evidence for the caldera-collapse on which earlier writers had placed so much importance.

Recent seismic activity in the area, including two tremors in May and July 1976, may indicate that this volcanic province has not yet become entirely inactive.

Introduction

Mount Gambier forms part of a western extension to the Quaternary Newer Volcanics of central and western Victoria (Fig. 1). This volcanic centre and that of Mount Schank, 15 km south, are the youngest volcanoes in South Australia and possibly even southern Australia. A group of volcanoes 35 km northwest near Millicent (Fig. 1) comprise 16 eruptive centres and, according to Solomon (1951), Sprigg (1952), and Firman (1969), are much older. However, definite ages are unknown and they may range from 10^6 to 20 000 years B.P.

The aim of this paper is to present recent observations on the Mt Gambier Volcanic Complex in relation to current theories on volcanic structures and styles of eruption.

Previous investigations

Father Tenison Wood's journal, published in 1862, is the earliest surviving work which discusses the volcanics at Mt Gambier, his conclusions being that the volcanic structures there were produced by caldera-collapse and multiple eruptions.

H. Y. L. Brown, Government Geologist, in 1884 delivered a report to parliament dealing with the geological phenomenon at Mt Gambier. He added very little to Wood's observations but, supported the collapse theory as a mode of formation. Further work was carried out by Howchin (1901). He concluded that there had only been one period of eruption, and agreed that collapse had produced the large openings in the craters.

Stanley (1909, 1910) described in detail the petrology of the lava flows, and the ultramafic xenoliths contained within the volcanics. Numerous papers were written on the area between 1910 and the early 1950's but these failed to shed new light on modes of formation.

The first radiocarbon dating was carried out by Fergusson & Rafter (1957). They dated charred wood fragments found at the base of the tuff layers. Two samples taken from two sites 8 km apart gave different ages, the older of which was 4710 ± 70 years B.P. and the younger 1410 ± 90 years B.P. Blackburn (1966) considered that as the two samples were treated similarly and recent carbon con-

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[*] Flat 12, 15 Statenborough Street, Leabrook, S. Aust. 5068.

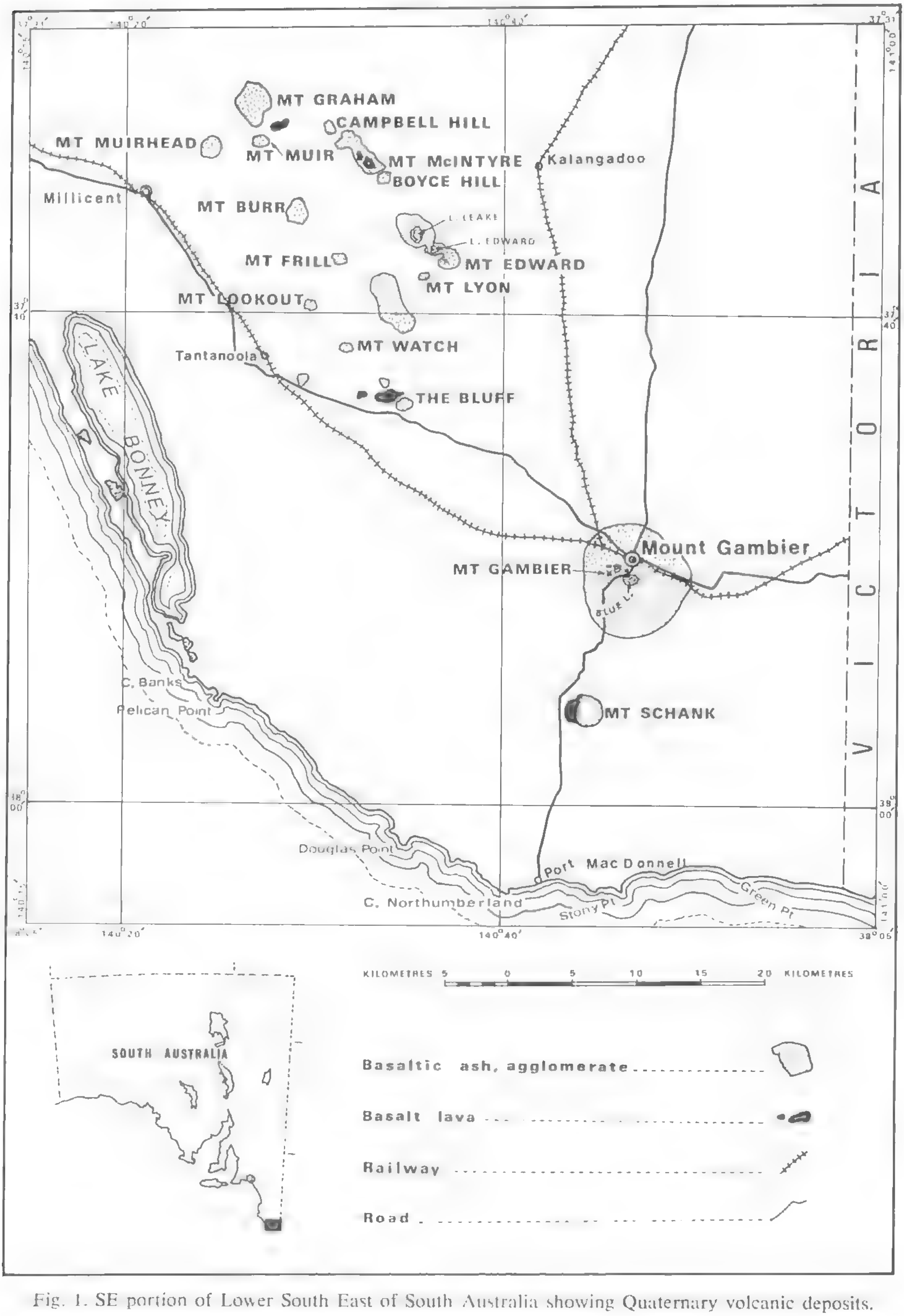

Fig. 1. SE portion of Lower South East of South Australia showing Quaternary volcanic deposits.

tamination could be ruled out, the two dates may record two main periods of eruption.

A major breakthrough in structural interpretation of volcanoes like those of Mt Gambier came with a paper by Ollier (1967). He demonstrated that volcanoes similar to Mt Gambier were not collapse structures but constructional features called maars. His proposed definition of a maar is as follows.

> 'Maars are landforms caused by volcanic explosion and consist of a crater, which reaches or extends below ground level and is considerably wider than it is deep, and a surrounding rim constructed of material ejected from the crater.'

In addition he further enlarged on this definition by explaining that calderas generally have diameters in excess of 5 km and are composed mainly of acid to intermediate volcanics where collapse plays a major role. Maars are smaller and dominantly constructional features where collapse plays a minor role. In maars the volcanics are generally basic but a few exceptions in South America are of intermediate composition.

Irving & Green (1976) classified the basalt lavas at Mt. Gambier as nepheline-hawaiites derived by partial melting from nepheline-basanite parent material.

A detailed description of the Mt Gambier volcanics and their eruptive history is set out in Sheard*. All sample numbers mentioned in this text refer to the collection in the School of Applied Geology, South Australian Institute of Technology, Adelaide.

General geology

The Mt Gambier area forms part of the Gambier Embayment of the Otway Basin, described by Wopfner & Douglas (1971). A relatively flat region exhibiting a semi-karstic surface, no surface drainage pattern, and broken by a series of low regular parallel aeolian sand dunes, surrounds the edifice of Mt Gambier. A sequence of sediments was deposited in the Gambier Embayment from Jurassic through to Recent times. Table 1 summarises ages, lithologies, and approximate thicknesses of the Cainozoic succession near Mt Gambier. Wangerrip Group and Knight Formation are, according to Harris (1971), equivalent names respectively for Knight Group and Tartwaup Formation, as used by Ludbrook (1969, 1971).

Recent volcanic activity is recorded locally by Mt Gambier and the smaller cone of Mt Schank to the south (Fig. 1)

Eruptive history and volcanic stratigraphy

The volcanic stratigraphy and structural disposition of the craters and rocks indicate that two main periods of volcanism took place. These two periods are characterised by three major phases of activity, each period beginning with gas charged magma eruption, and ending in gas poor magma eruption.

Second period eruptions were on a much larger scale and considerably more violent than those of the first period.

Fragments from the Bridgewater Formation, Gambier Limestone, and Wangerrip Group occur within the volcanics in quantities of 5 to 25%. These fragments were torn from the sides of the volcanic conduits during the eruption and ejected along with the volcanic material. Many of these fragments have been contact altered by the magma's heat making some of them harder or softer than their corresponding parent material.

A description of the three phases, in turn, within the two main periods of eruption follows.

First Period (4800 years B.P.)

First Phase

Prior to eruption the area consisted of a series of north-west trending parallel aeolian sand dunes 5–15 m high, a result of the Pleistocene marine regressions (Fig. 2a). The dune complex is collectively referred to as the Bridgewater Formation.

First phase eruptions took the form of small scale maar production. The initial magma had to pass through water saturated sediments and is thought to have become gas charged. Voluminous quantities of steam released caused maar construction rather than quiescent fissure eruption. These maars had vents 25–100 m across and ramparts 5–10 m high. Direct outcrop evidence for ash spread during the first phase is not available; however, sections in the Blue Lake crater provided data allowing extrapolations to be drawn for a minimum ash extent (Figs 2b, 3a).

Ejectamenta from this phase form a thin but distinct stratum at the type locality of the Nurses Landing (grid ref. 7967 E, 1175 N), where it overlies the Gambier Limestone and

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* Sheard, M. J. (1976) The Geological History of the Mount Gambier Volcanic Complex, South-East South Australia. B.App.Sc. Thesis, School of Applied Geology, S.A. Institute of Technology, Adelaide (unpublished).

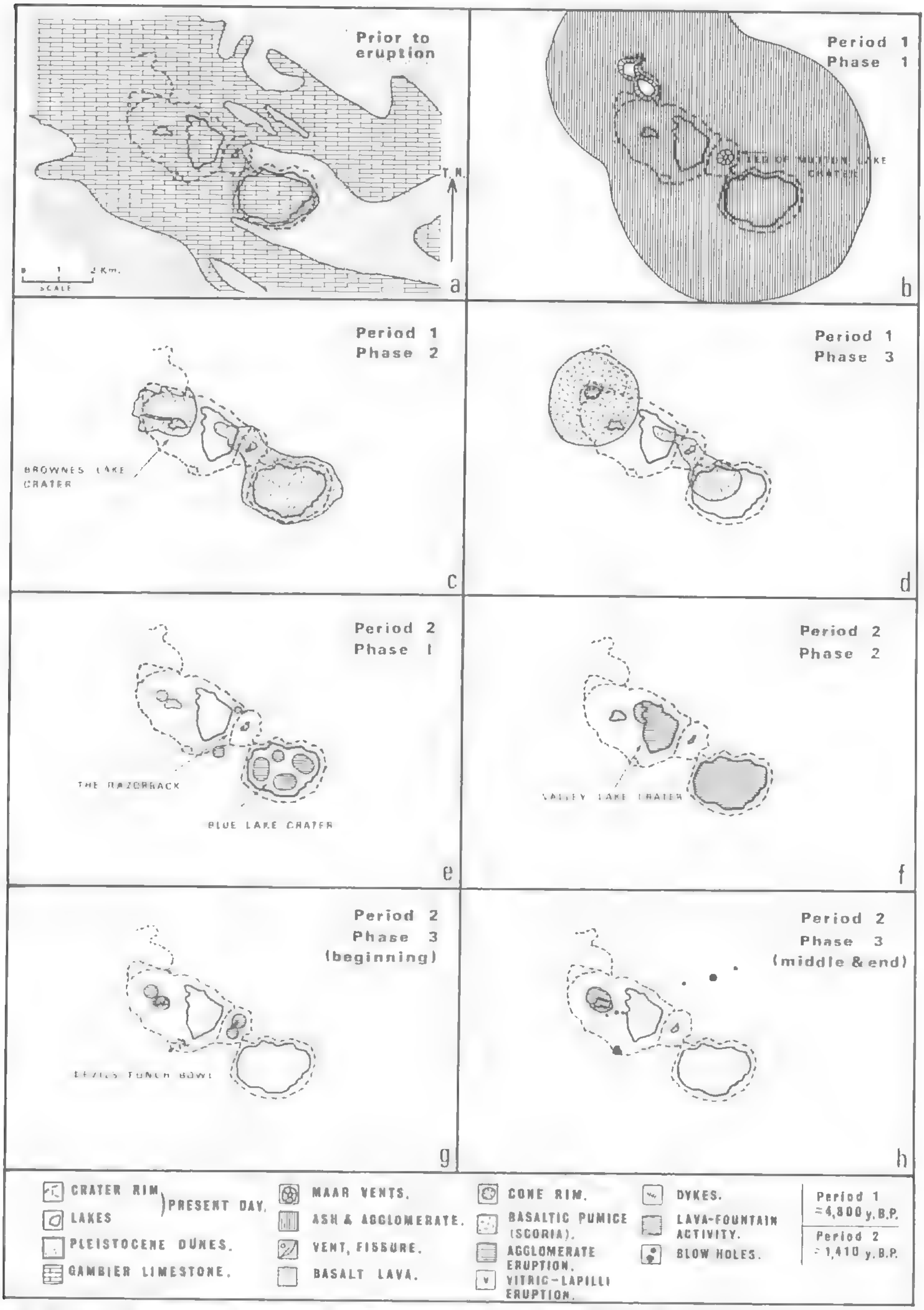

Fig. 2. a-h: the volcanic ejecta and eruptive centres for each phase of the two volcanic periods so far evident in relation to present day structure of Mt Gambier.

TABLE 1

Stratigraphic sequence in the vicinity of the Mount Gambier Volcanic Complex (modified after Ludbrook 1969, Harris 1971).

Age	Unit	Thickness	Lithology
Quaternary	Undifferentiated volcanics	0-160 m	Laminated ash, tuffs, agglomerates, and lava flows.
Quaternary (Pleistocene)	Bridgewater Formation	0-15 m	Largely aeolianite with some shelly beds. Often as well defined fossil dune systems marking old shore lines (Sprigg 1952).
Oligocene-Miocene	Gambier Limestone	120 m	Calcilutite-calcarenite, bryozoal and flinty. Well jointed and exhibits karstic solution features.
Late Oligocene (?)	Compton Conglomerate	0.5 m	Ferruginous, rubbly conglomerate—reworked Wangerrip Group sediments.
Middle to Late Eocene	Lacepede Formation	probably absent	Variable, glauconitic, silty limestone with polished brown ironstone grains grading to brown glauconitic silts.
Middle to Late Eocene	Kongorong Sand	probably absent	Poorly sorted ferruginous quartz arenite.
Middle Eocene	Knight Formation	20-35 m	Unconsolidated poorly sorted coarse sand, grit and interbedded conglomerates and carbonaceous clays (Harris 1971).
Paleocene	Wangerrip Group	in excess of 115 m	Laminated micaceous silts, quartz sands and lignitic clays (Harris, 1971).

underlies a later lava flow (Fig. 4). Thicknesses for this stratum range from 3.5 m at the Nurses Landing, 2.0 m at the western end of the Blue Lake, and 0.1 m at the eastern end of the Blue Lake. Three zones make up this stratum: the basal zone comprises a poorly bedded country rock-ash-conglomerate. Rock fragments range from silt sized to 5 cm across; 60% of this zone consists of pulverised Gambier Limestone. The middle zone contains more volcanic material than the basal zone and displays coarse bedding. Finely laminated ash and lapilli-ash form the upper zone. Boundaries between the three zones are gradational. The basal zone represents the initial break through to the surface of the volcanic material, hence the conspicuous quantity of country rock detritus.

Second Phase

Second phase activity consisted of passive Icelandic Type eruption of basaltic lava from both fissures and pre-existing vents. Field occurrences and apparent flow directions tend to suggest two lava sheets rather than the one large sheet as proposed by Fenner (1921). The dunes of the Bridgewater Formation prevented equidirectional spread of the lavas, confining them to the interdunal trough (Figs 2c, 3b). A second lava flow overlies the eastern lava sheet—indicating two pulses of activity there (Figs 2d, 3c). Heat from the lava baked the upper surface of the underlying ash layers over which it flowed. The result is a brick red zone of increased competency caused by the partial remelting of the ash particles (Fig. 4).

The basalt itself is grey-blue, fine grained with medium grained olivine phenocrysts. It is generally massive although vesicular and amygdaloidal patches do occur. Original lava flow surfaces exhibit rubbly 'aa' textures especially in close proximity to lava caves. Lava caves range from centimetres to metres across, and many metres deep. They crop out at the base of flows and form by the draining of liquid lava from a solidified jacket (Fig. 5). Within the caves drip structures, lava stalactites, wrinkles and drape structures, give clues to flow direction and likely source sites (Ollier & Brown 1965, Sheard*). Figure 6 shows a lava stalactite (3542) collected from a lava cave; its base was bent by the moving lava while the stalactite was still plastic. Thus flow movement was in the direction indicated by the point of the stalactite.

One strikingly different lava form, occurring as float only, is a tachylitic (glassy) basalt (Fig. 7), representing rapid chilling—possibly by water in the conduit at the commencement of lava outpouring.

Major element analyses of four basalt samples are given in Table 2.

Third Phase

Activity became more violent during the third phase with the construction of a small scoria cone at the western end of the area (Figs 2d, 3c, 13—section B-B'). This eruption was of the Strombolian type. It indicates that the geothermal gradient was lowered following the second phase basalt eruption, thus allowing some meteoric water back into the system prior to the cessation of activity.

The scoria (basalt pumice) when fresh exhibits iridescent glassy bubble linings. However, steam passing through the scoria during eruption has oxidised most of the material to a terra-cotta red colour, destroying the bubble linings. Outcrop of this ejectamenta forms a

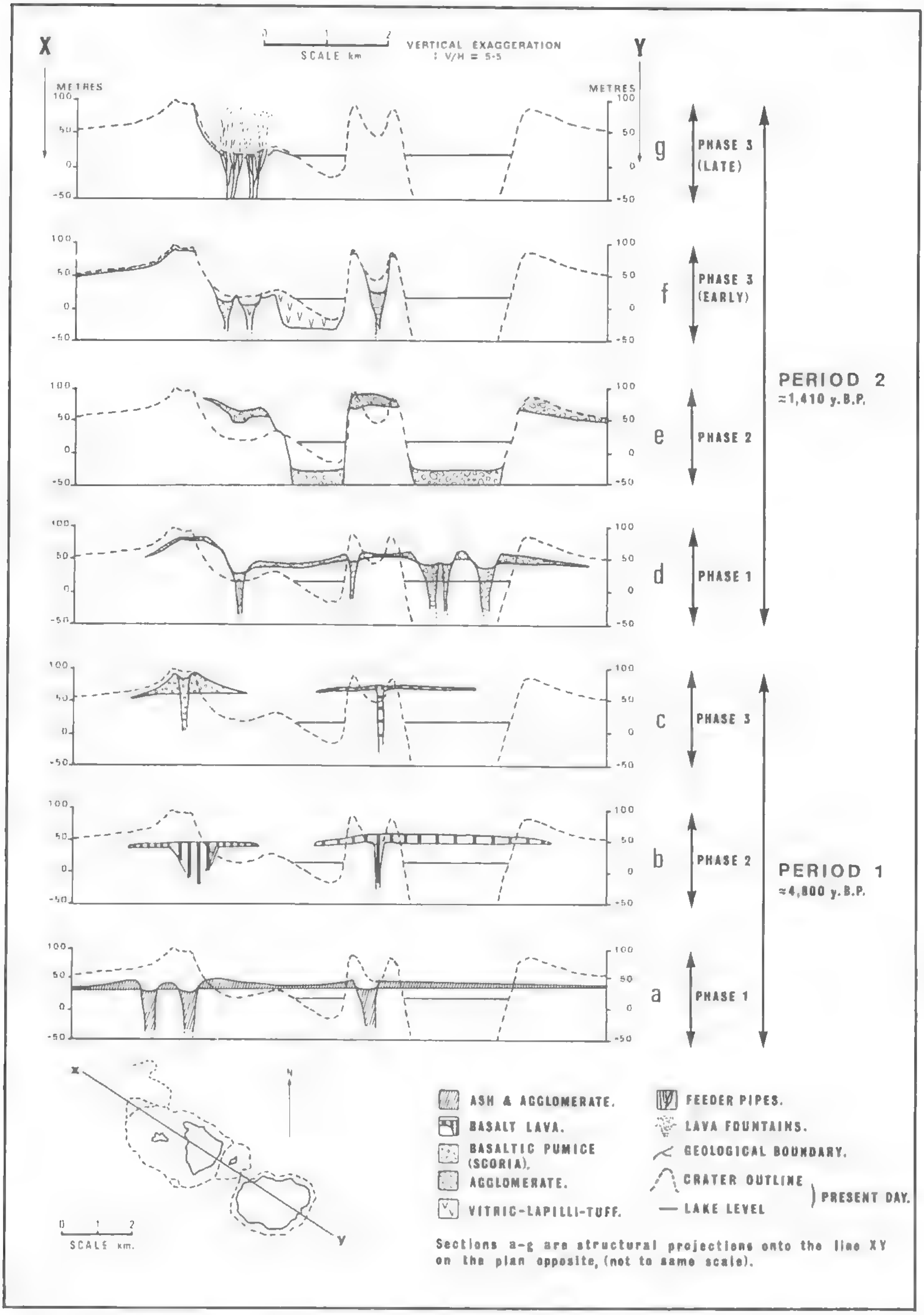

Fig. 3. Cross-sections indicating active conduits and spatial arrangement of the volcanic ejecta for each phase of the two eruptive periods so far evident in relation to the present day structure of Mt Gambier.

TABLE 2

Major-element chemical analyses by XRF (uncorrected) of four basalt samples taken from the two lava flows of period 1, phase 2. Samples housed in Applied Geology collection, School of Applied Geology, S.A.I.T., Adelaide.

ROCK TYPE—Alkali Olivine Basalts.
LOCALITY—Mount Gambier, S. Aust.

SAMPLES	3510	3513	3514	3540
SiO_2%	45.5	44.8	45.3	44.4
TiO_2%	2.5	2.5	2.5	2.4
Al_2O_3%	13.6	14.0	14.9	15.2
Fe_2O_3%	12.9	12.2	12.2	12.4
MnO%	0.16	0.18	0.17	0.15
MgO%	8.5	8.3	7.8	7.8
CaO%	10.1	9.0	9.0	10.2
Na_2O%	4.0	4.9	4.0	5.1
K_2O%	2.1	2.6	3.1	1.7
P_2O_5%	0.67	0.91	0.96	0.60
Cr_2O_3%	0.02	0.02	0.01	0.01
L.O.I.	—	0.63	—	0.16
G.O.I.	0.34	—	0.07	—
TOTAL	100.05	100.04	99.94	100.10

L.O.I.—Loss on ignition, equivalent to volatile loss.
G.O.I.—Gain on ignition, equivalent to mineral oxidation. Analysis by A.C.S. Laboratories Pty Ltd, Unley, S.A.
Preparation—crushed and pulverised rock

SAMPLE LOCALITIES (from Fig. 12)

Sample	Easting	Northing
3510	7953	1100
3513	7845	1200
3514	7967	1175
3540	7892	1210

steep cliff produced by later volcanic abrasion. Within the scoria exposures are caverns—one of which is known locally as Bootlace Cave.

Second Period (1500 years B.P.)

Second period volcanism was much more violent and gas charged than the first period, producing much more volcanic detritus. Ollier (1967) has classified this type of eruption as phreatic and it can be likened to the effervescence produced when soda water is uncorked.

During the 3300 years between the first and second periods, ground water in the country rocks percolated down earlier volcanic conduits. Apparently this meteoric water was converted to superheated steam when it reached the hot magma, possibly located in dykes as proposed by Gunn (1975). Remelting may have been induced by this influx of water into a high temperature system of partially solidified basic magma; certainly it would have made the magma less viscous and increased its drive to escape the confining rocks.

Gas drilling is the most likely mechanism by which the magma made its way to the surface. This process can be likened to sand blasting, producing a cylindrical conduit which becomes funnel shaped close to the surface.

New active vents were evolved which blasted their way through the basalt caps of the first period. Large blocks of basalt and limestone were thrown out, some weighing in excess of 20 tonnes. Such large blocks and smaller bombs create piercement structures in the ash layers when they land (Fig. 8). A second feature of the second period eruptions is crossbedded ash and dune structures within the ash (Fig. 9). According to Moore (1967) and Ollier (1974), crossbedding and dune like structures can be produced by base surge, a phenomenon associated with a vertically directed explosion column, and sweeping across the underlying surface at high velocity, radial to the explosive column. Evidence of rainwater affecting the tuffs is shown in Figure 10 where two fossil stream channels were exposed by road widening of the Crouch Street cutting (grid ref. 8085 E, 1205 N). Rain is often associated with volcanic eruption due to the large quantities of water vapour released from the vents.

First Phase

The first phase eruptions of the second period began at the sites of the present-day Blue Lake, and at two sites along the Razorback (ridge between the Valley and Leg of Mutton Lakes) (Figs 2e, 3d, 13—sections C-C' & D-D'). Tuff agglomerates were the major type of volcanics erupted; these are very poorly bedded near the craters but become finely laminated ash and lapilli-tuffs away from the rims. These volcanics are indistinguishable from later similar ejecta their existence has been inferred from structural evidence.

Second Phase

Volcanism of the second phase was on a larger scale than any previous eruptions and represents the stage where activity reached a maximum. Composite or grouped maars were produced at the present sites of the Blue and Valley Lakes (Figs 2f, 3e). These were formed by the coalescing of many small conduits as they were abraded wider. Although great volumes of gas were released by these vents, the magma seems to have been lower in volatiles as more lapilli and ash were ejected. A lowering of the volatile content in the magma suggests either that the boiling off of volatiles in the

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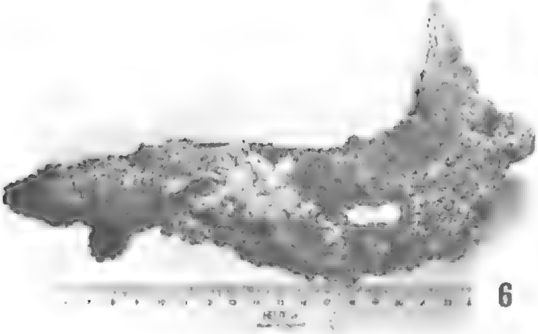

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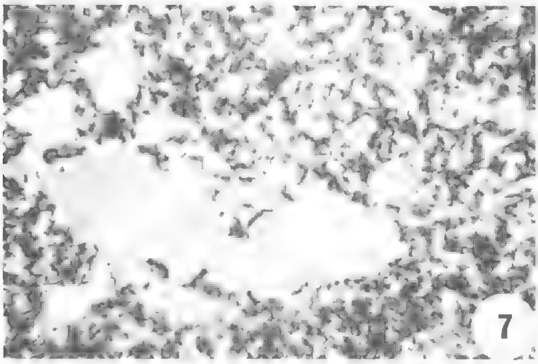

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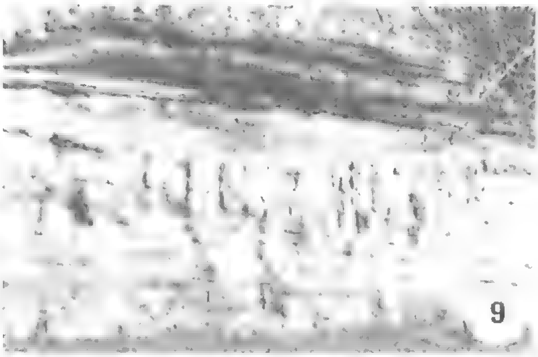

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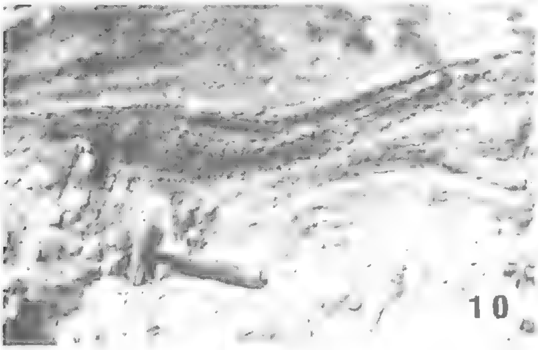

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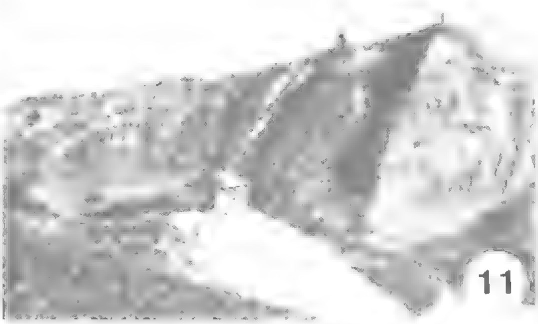

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magma was reducing the gase content or that the proximate country rocks were drying out because of the geothermal gradient set up near the conduits. Some combination of these mechanisms is also probable. The second process would have prevented additional steam from entering the system.

Tuff-agglomerates are by far the most voluminous of the volcanic detritus. Structurally there are many distinct tuff-agglomerates; however, texturally and compositionally they are all similar. Where two of these overlap or intertongue it is impossible to differentiate between them. Hence the descriptions will be generalised to cover these volcanics as a whole.

Bedding is so poor within the craters that dip and strike measurements are impossible to obtain, thus accurate eruptive sites cannot be plotted. The tuff-agglomerates are unsorted; particle sizes range from silt to boulders in excess of 2 m across.

The components of the tuff-agglomerate are:

(1) country rock fragments—Gambier Limestone, diagenetic flint and marcasite nodules (both from the Gambier Limestone), dolomitised Gambier Limestone, Wangerrip Group rocks (contact altered), and deep basement rocks—collectively 15% to 20%

(2) volcanic detritus—volcanic bombs (olivine and basalt) . . 5% to 10%
—lapilli, cinders, and ash 70% to 80%

Regression analyses applied to bore hole and exposure thicknesses indicate that the volcanics thin exponentially away from the craters.

Third Phase

Cessation of activity from the Blue and Valley Lake maars must have allowed the geothermal gradient to decrease, in turn allowing the meteoric water back into the surrounding rocks. Eruption from the site of the present day Leg of Mutton Lake crater occurred after this influx, water being so abundant that the ash and large ejecta were deposited in a damp condition. The cooling effect of this water on the ascending magma may account for the small size of this crater. That is, the magma was induced to set in the conduit after only a short eruptive cycle (Figs 2g, 3f). To the west continued activity from the Brownes Lake crater resulted in the creation of two different ash types. A double maar system is proposed as the generator of these pyroclastics which intermix along their south-western boundary (Figs 2g, 3f, 12, 14). The westernmost of the

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Fig. 4 Outcrop just above the Nurses Landing showing naked upper surface of first period—first phase ash layers in contact with eastern basalt lava sheet. To the left the basalt displays an auto-brecciated base, a result of movement after partial solidification. Length of hammer (centre) is 32 cm.

Fig. 5. One of large lava caves in eastern lava sheet, just south of the Nurses Landing, approximately 10 m deep and 2.5 m wide. A natural landslide during July 1977 has totally destroyed this feature since it was photographed in February 1976.

Fig. 6. A fine example of a lava stalactite (3152), lying on its side, collected from a large cave (grid ref. 7849 E, 8120 N). It was attached to the roof, the point of attachment being at the left of figure. As the lava drained out of its lava tube, fluid lava still clinging to the roof dripped off onto the flow. In this case the upper portion had set while the base remaining plastic for longer has been bent in the direction of the flow by the flow. Thus it shows one way of determining flow direction for lava flows. The ruler below the stalactite is 22 cm long.

Fig. 7. Photomicrograph (under plane polarised light) of a thin-section cut from the only sample (3516) of tachylitic basalt from the area displays one large bleb of glass. The glass exhibits perlitic cracking and, where it forms the matrix, it has devitrified to a magnetite bearing mesostasis. Field of view — 4.0 x 2.6 mm.

Fig. 8. One of the many sedimentary structures exposed in the Crouch Street cutting: this piercement or impact structure represents a block of tuff which was ejected from the craters and fell onto the ash surface, indenting the layering. Length of geological hammer 32 cm.

Fig. 9. Crossbedded ash and lapilli tuffs in the Crouch Street cutting; this figure represents an area 4 m x 2 m. Base surge turbulence is the most likely mechanism by which structures like this are produced. Overlying the truncated beds is an antidune, one of many exposed at this locality. The base surge passed from left to right in this section.

Fig. 10. Two small fossil stream channels exposed during road widening in Crouch St. late 1975/early 1976. Such channels were most likely created during a storm that took place while eruption was in progress. This structure has now been obscured by a retaining wall. The geological hammer is 32 cm long.

Fig. 11 Macroscopic bedding in the vitric-lapilli-tuffs below Centenary Tower, photograph ca 1900. To the left cavernous weathering is evident in several horizons near the top of the ridge. Directly below the Tower the volcanics reach a thickness of 160 m. The hut in the foreground is the R.S.L. lookout.

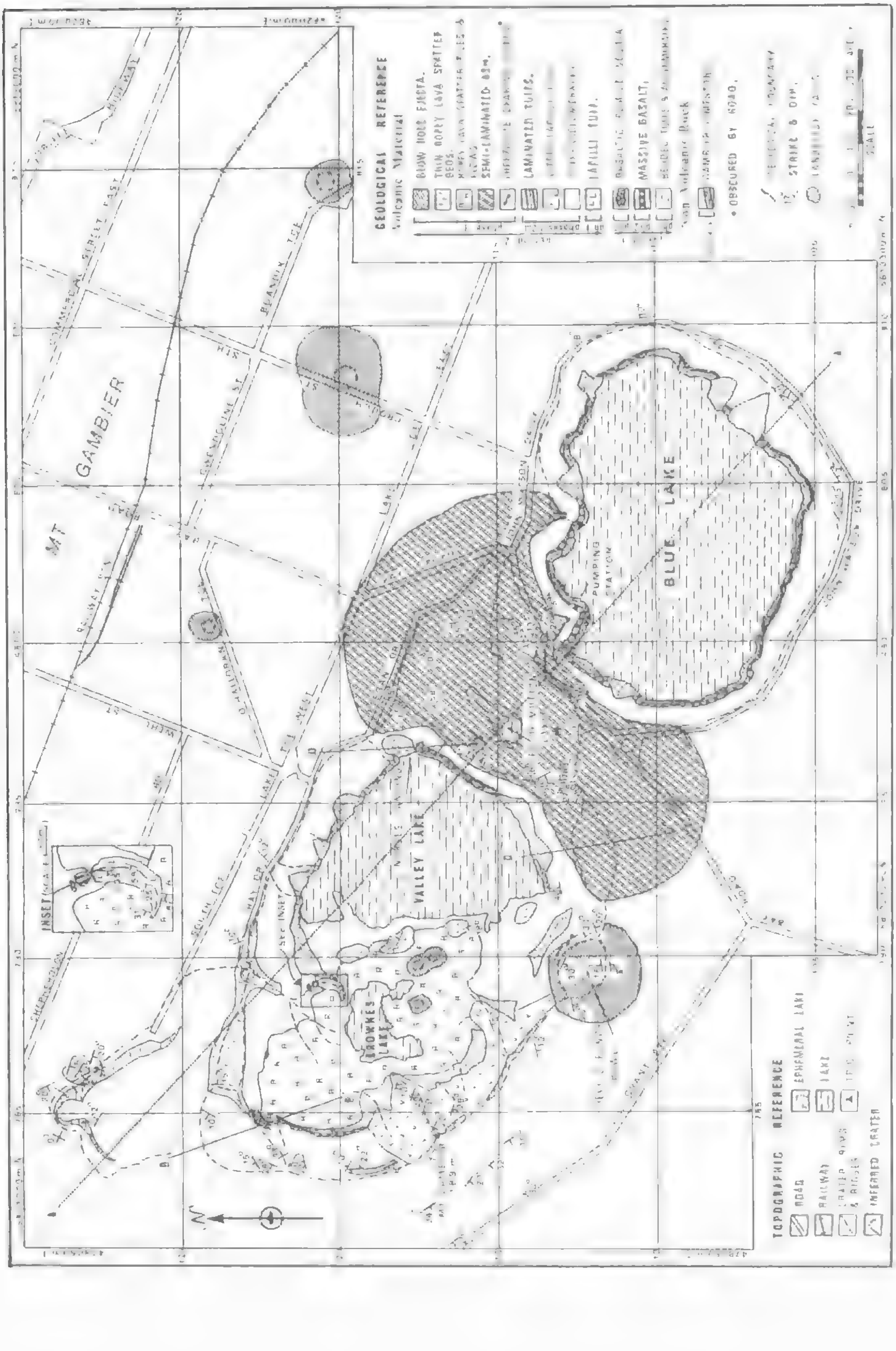

Fig. 12. Geological map of the Mt Gambier Volcanic Complex.

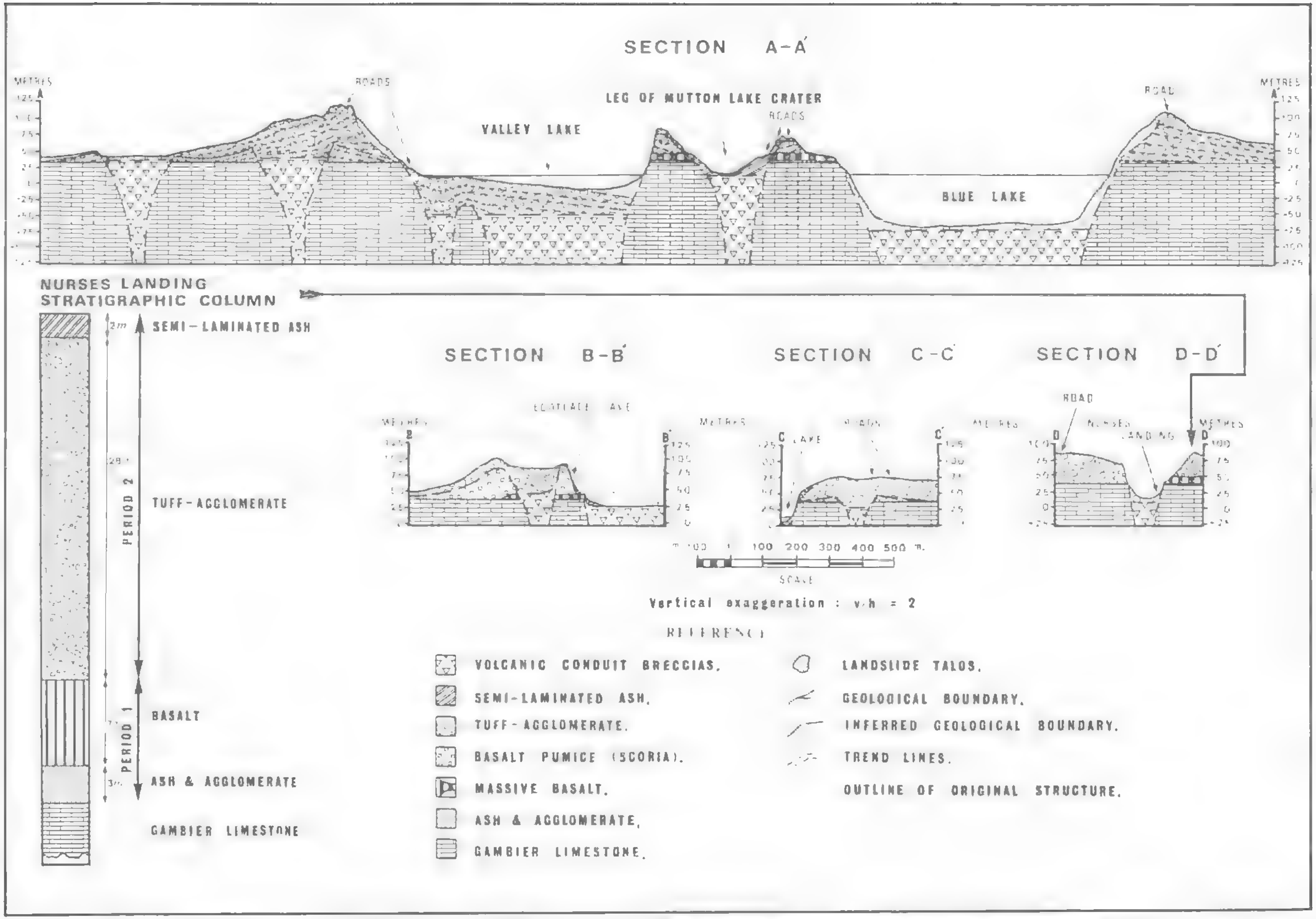

Fig. 13. Cross-sections to the geological map (Fig. 12), and the stratigraphic column for the Nurses Landing type locality.

two maars produced tuff-agglomerate, while the eastern maar ejected vitric lapilli-tuff. These latter tuffs were directed mainly to the south resulting in a high ridge which now forms the southern rim of the Brownes Lake crater. Centenary Tower was built at the apex of this rim. Erosion of the vitric-lapilli-tuffs appears slower than the remainder of the volcanics due to their more competent character, although cavernous weathering is a common feature of some horizons (Fig. 11).

A further feature of this eruption was the removal of most of the western crater rim of the Valley Lake composite maar. Only a few small remnants of this rim remain (Fig. 12 'lapilli-tuff'). Instead of a new wall being built up to bisect the now very large crater, most of this material back-filled the Valley Lake crater. Originally this crater must have been as deep as the Blue Lake crater to have accommodated the large quantity of pyroclastic material which seems to be missing. However, the Valley Lake does have a floor sloping away from the Brownes Lake crater, such that the western shore is shallow while near the eastern shore it is 30 m below water level (Fig. 13—section A-A′).

During the eruptions at the Brownes Lake crater, two dykes were emplaced within the ash layers of the southern Valley Lake crater rim, near what is now called the Devil's Punch Bowl (grid ref. 7905 E, 1130 N) (Fig. 2g). These dykes carry the only lherzolite (olivine + orthopyroxene and clinopyroxene) xenoliths known in basalt rock from this area. All other lherzolite occurs as bombs or float, thinly coated with lava or as free chunks within the volcanics. Over 25% by volume of material comprising the dykes consists of lherzolite blocks 5–50 cm in diameter. The dykes are approximately 20 m long and 50–120 cm wide. Jet-black basaltic pumice forms the bulk of these dykes. Dense material such as lherzolite would naturally settle out in a magma chamber—hence its late stage appearance, enclosed in basalt, may indicate a depleting magma reservoir. Road works in 1969 temporarily exposed the dykes but they are now obscured by a sealed road.

A short phase of lava fountain activity within the Brownes Lake crater brought major activity to a close. Activity of this type is really a continuation of the eruption from the Brownes Lake maars (Figs 2h, 3g). It indicates virtually complete degassing of the magma, allowing eruption of lava rather than lapilli or ash. Lava fountains built up small spatter piles of ropy lava and small ropy lava flows. Lava associated with this sort of event is very fluid and chills rapidly—preserving forms like twisted rope and fresh cow dung. Numerous spatter piles have resulted in a very irregular floor to the Brownes Lake crater. This floor is atypical of maars which generally have flat floors due to gas fluidisation (quicksand effect), as described by Ollier (1974).

Late stage fumarolic activity is indicated by the presence of blow holes, the largest of these being still observable in the Devil's Punch Bowl. Three others occur between the Brownes and Valley Lakes, while three more occur outside the main volcanic vents. The latter three occur within the city of Mt Gambier and represent the only activity outside the main volcanic vents (Figs 2h, 12). They form a linear trend which may indicate their close association with a near-surface dyke. Conical in shape, these depressions represent steam discharge accompanied by a small quantity of ash and country rock ejection. The largest blow hole in the city was used as a rubbish dump prior to 1939; now completely filled it serves as part of the City Council Depot in Crouch Street.

Present day

Ash extents are shown by Fig. 15. This mapping was carried out using natural exposures, hand augering and sewerage trench logs, and the boundary is based on the points where volcanic ash merge with the Pleistocene dune sands or recent soils—thus making visual separation of the two impossible. With the aid of microscopic and geochemical analysis Hutton et al. (1959) have shown that the distribution of fine volcanic ash in soils around Mt Gambier is much more extensive than is shown by Fig. 15.

The author found fossilised *Banksia* leaves within the ash layers near where they pinch out against the Pleistocene dune sands. These leaves are indistinguishable from modern day local *Banksia* leaves.

Weathering of the volcanics has produced very fertile soils which are dark brown in colour and loamy in texture. Soil profiles range from a few centimetres in thickness at the crater rims to 0.5 m on the plains.

The complete geological record is displayed in Figs 12–14. The crater wall profiles (Fig. 14) were compiled from strip photography and geological mapping; topographic control for Figures 13 and 14 was taken from Map 1 in Sheard*.

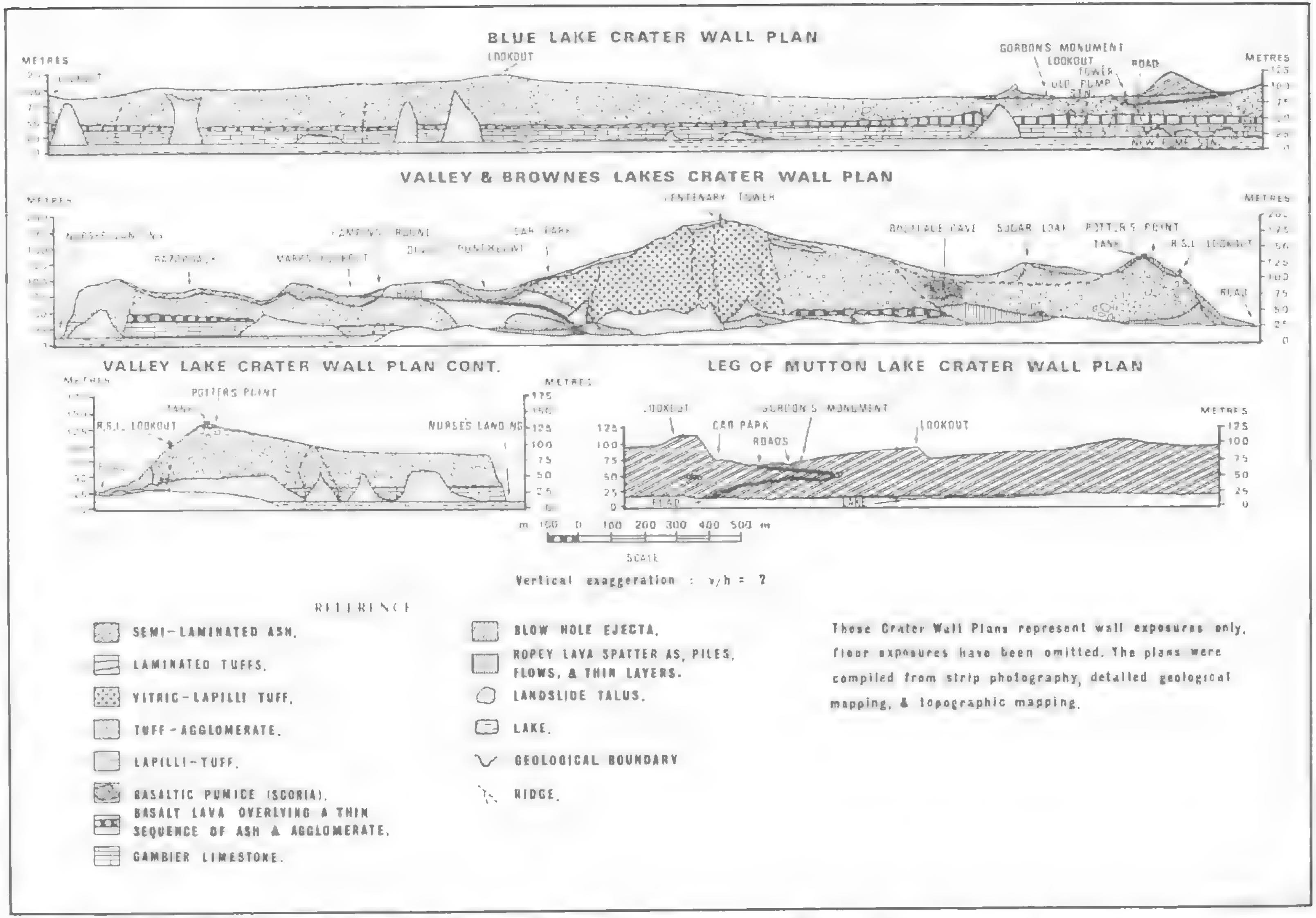

Fig. 14. Crater wall geological profiles for the main craters of the Mt Gambier Volcanic Complex. They represent the geology exposed in the crater walls and can be considered in the same way as cross-sections.

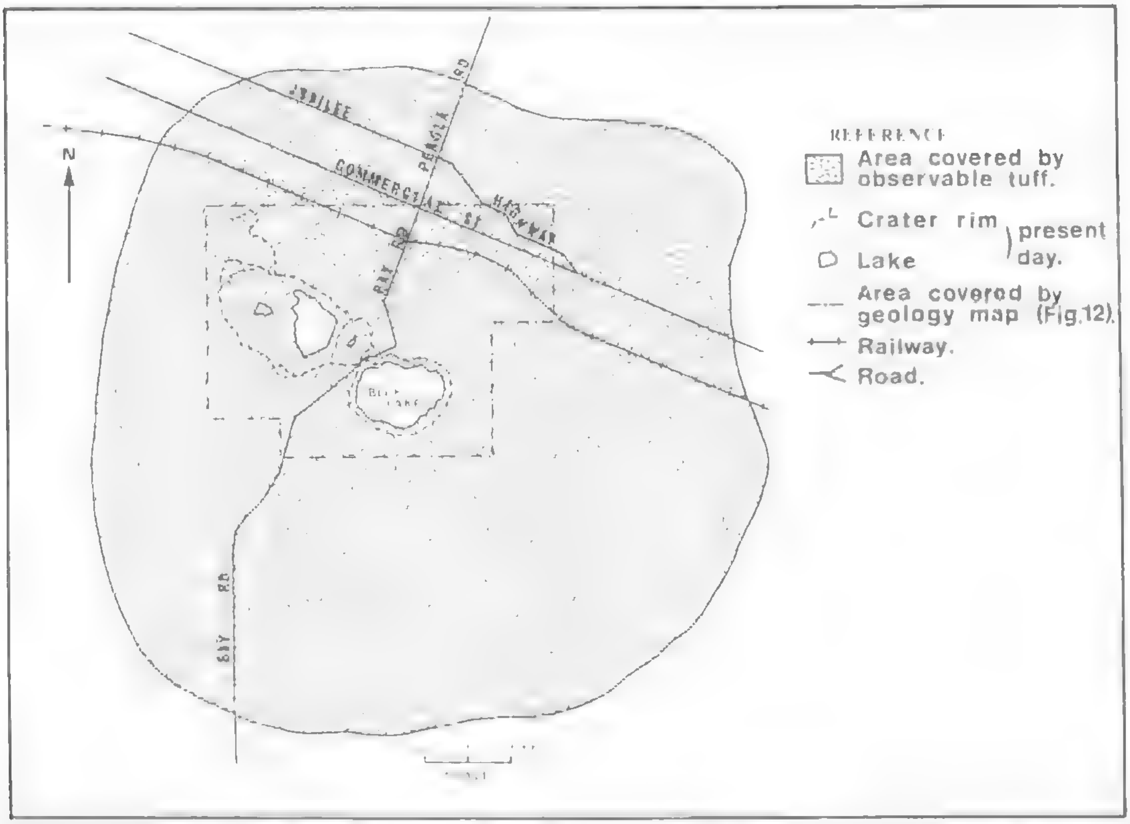

Fig. 15 Map showing extent of volcanic material that can be differentiated from soil and Pleistocene sands with the naked eye. Mapping was carried out using natural exposures, road cuttings, hand auger holes, bore logs and sewerage trench logs.

Fig. 13 portrays subsurface volcanic conduit breccias which do not crop out anywhere at Mt Gambier. One Mines Department bore log from a hole drilled in the Leg of Mutton Lake crater indicates the conduit contains poorly sorted material, called tuffisite—similar to that described by Ollier (1974). The other conduits are assumed to contain similar material. These breccias would, according to Ollier (1974), grade into massive basalt at depth. The Brownes Lake crater conduit breccia would be complicated by small feeder pipes to the late stage lava fountain eruptive centres.

The future

Recent seismicity in the region of Mt Gambier suggests that all the activity has not yet ceased. McCue (1975) has summarised the earthquakes that have occurred in the South-east of South Australia. The first recorded seismicity was centred at Kingston in May 1897, tremors being felt for five hours, causing water spouts and sand volcanoes on the beaches of Beachport, Kingston, and Robe. In 1948 Robe was again shaken by an earthquake of magnitude 5.6 on the Richter scale. More recently a series of tremors has shaken areas closer to Mt Gambier. In November 1975 a Richter magnitude 4.5 tremor occurred off-shore from Carpenter Rocks only 37 km from Mt Gambier. In 1976 two tremors were recorded; the first in May had a Richter magnitude of 2.0 and its epicentre was below the Mt Gambier Volcanic Complex. The second happened during the late evening of July 12th; it registered 3.6 on the Richter scale, and local people reported feeling it. An epicentre for this quake was tentatively put at 1 km northeast of Mt Schank and at a depth between 4 km and 30 km (McCue 1976, pers. comm.).

Some interesting facts are the time span of 3300 years between the two eruptive cycles so far evident, and the 1500 years since the last eruption. There is every possibility of a magma source at depth which may lead to the potential of geothermal energy exploitation or more eruptions. At present the Bureau of Mineral Resources (B.M.R.), Canberra, is conducting a geothermal study of the Mt Gambier region with two aims: firstly to obtain regional heat flow data from which crustal temperature profiles can be extrapolated; secondly to examine the geothermal energy prospects associated with the recent volcanism (B.M.R. 1977, pers. comm.).

Only close monitoring over a long period of time will provide factual data, upon which sound conclusions can be drawn as to whether the recent seismicity heralds further volcanicity, or is just regional settling.

Acknowledgments

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ARCHAEN TO EARLY PROTEROZOIC BANDED IRON FORMATIONS IN THE TARCOOLA REGION, SOUTH AUSTRALIA

BY S. DALY, A. W. WEBB & S. G. WHITEHEAD

Summary

A minimum metamorphic age of greater than 2400 Ma is inferred for two banded iron formations outcropping within the TARCOOLA 1:250 000 map sheet area. The age obtained is considerably greater than that of the mid Proterozoic Middleback Group with which both iron formations have previously been correlated. At least two periods of iron formation deposition therefore occurred in the Gawler Craton during the Precambrian.

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Summary

DALY, S., WEBB, A. W., & WHITEHEAD, S. G. (1978) Archaean to early Proterozoic banded iron formations in the Tarcoola region, South Australia. *Trans. R. Soc. S. Aust.* **102**(5), 141-149 31 August, 1978.

A minimum metamorphic age of greater than 2400 Ma is inferred for two banded iron formations outcropping within the TARCOOLA 1:250 000 map sheet area. The age obtained is considerably greater than that of the mid Proterozoic Middleback Group with which both iron formations have previously been correlated. At least two periods of iron formation deposition therefore occurred in the Gawler Craton during the Precambrian.

Introduction

The TARCOOLA 1:250 000 map sheet area lies within the northern part of the Gawler Craton (Thomson 1976), an area of crystalline basement stabilised in the Precambrian (ca 1500 Ma) and now partly covered by sediments of Permian to Recent age. The oldest rocks are quartzo-feldspathic gneisses with interlayered quartzites and thin discontinuous banded iron formations. Foliated granitic rocks also occur within the gneiss complex. Basic and ultrabasic rocks (Warne 1970[1], 1972[2]; Holcapek 1972[3]) containing anomalous base metal concentrations occur within the quartzo-feldspathic gneisses and may either be conformable or cross-cutting; complex structure and poor outcrop associated with extensive weathering obscure stratigraphic relationships. Overlying the quartzo-feldspathic gneisses and associated basic rocks is a gently folded sedimentary sequence, the Tarcoola Beds, which has subsequently been intruded by acid volcanics and 1480 Ma high level granites (Blissett 1975, 1977).

Geological mapping of the TARCOOLA 1:250 000 map sheet area began in July, 1974, as part of a systematic regional mapping programme of the Gawler Craton. Directly related to this mapping programme are current joint South Australian Geological Survey and Amdel geochronology projects, which are providing radiometric age limits for important stratigraphic units in the crystalline basement.

In 1975 an age of 2350 Ma was established for gneissic granites outcropping in the Glenloth Goldfield area, 25 km southwest of Kingoonya (Webb & Thomson 1977). A similar age was also determined for a small gneissic granite outcrop 17 km west of Tarcoola. These results prompted further sampling of gneissic rocks in the TARCOOLA sheet area; at Mt Christie and 6 km north of Kenella Rock Hole (Fig. 1). Both localities were chosen in an attempt to date the associated interlayered banded iron formations.

The term "iron formation" is used here in a lithological sense only and does not imply stratigraphic formality or specific genesis, i.e. the iron formation is simply an iron rich rock. Any formal name to be established in the future will refer to the enclosing gneisses; the iron rich horizon or horizons will be included in this unit.

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† Australian Mineral Development Laboratories.

[1] Warne, S. B. (1970) Mulgathing Examination, Mining Lease 333. Report by Kennecott Explorations (Aust.) Pty Ltd. S. Aust. Dept Mines env. 1375 (unpubl.).

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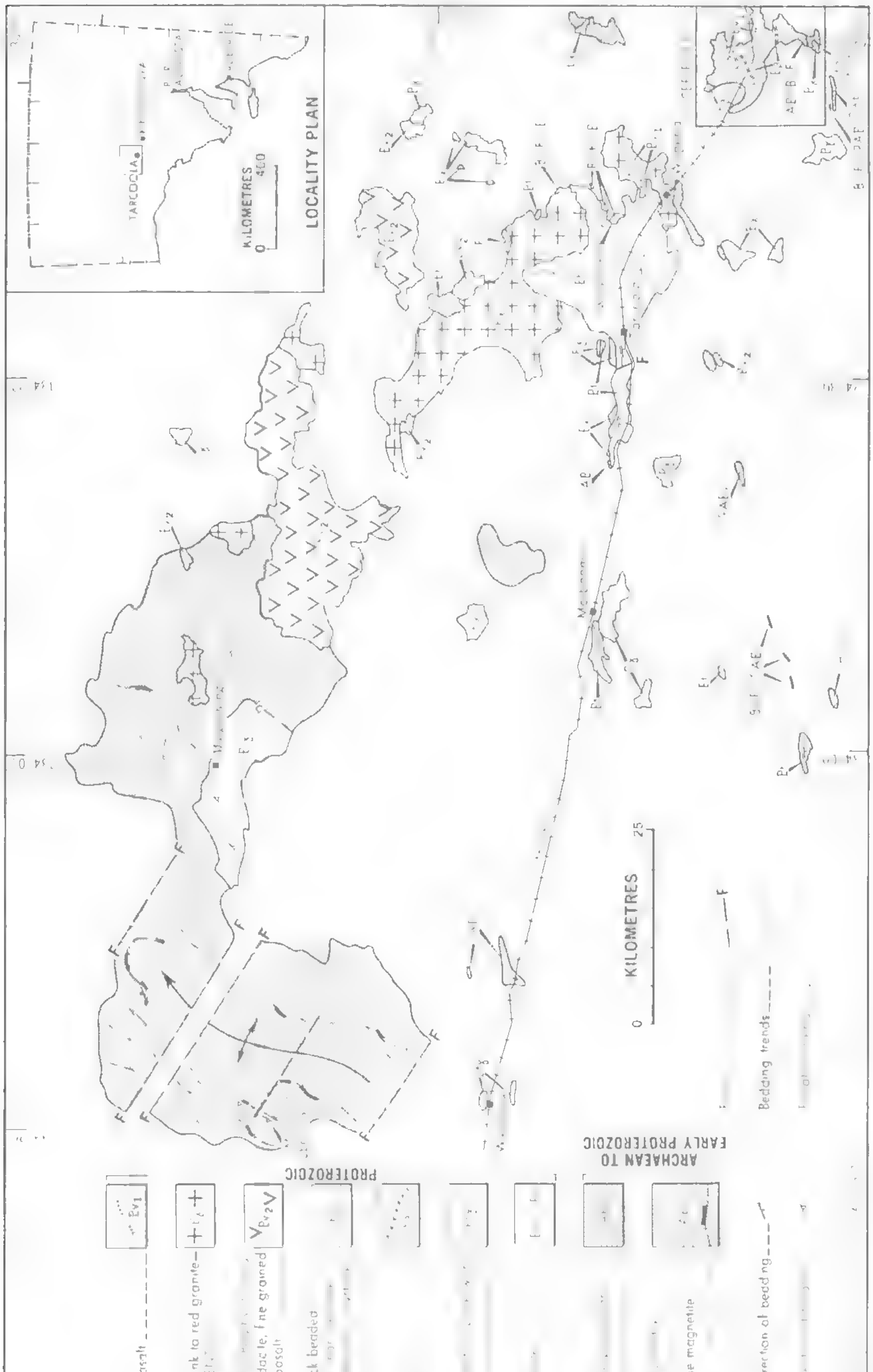

Fig. 1. Precambrian Geology of the Tarcoola region.

The iron formation at Mount Christie

Location

The iron formation outcrops at Lat. 30°18'33" and Long. 133°30'55" on the western edge of the TARCOOLA 1:250 000 map sheet area, 28 km north of the Transcontinental Railway (Fig. 1).

General geology

The iron formation outcrop is a layered quartz-hematite (martite)-goethite gneiss. It forms a prominent elongate hill surrounded by surficial scree, sand and mulga scrub. Nearby outcrop is poor, often very weathered and consists of low isolated hills of quartz-feldspar-biotite-garnet-gneiss and schist, and quartz-feldspar-biotite-garnet-cordierite gneiss with traces of sillimanite.

The iron formation was formally defined as the Mt Christie Metajaspilite by Whitten (1968). However, regionally the unit may be one of a number of iron formations.

Structural relationships

The iron formation, which outcrops over a distance of 0.5 km has a north-northeasterly trend, dips steeply west and contains numerous small folds with axes plunging gently northerly. A very weathered coarse-grained massive to poorly layered quartz-feldspar gneiss structurally underlies the iron formation. The structural top, however, is obscured by talus. Relationships with other iron formation outcrops, occurring to the north and southeast, are not known with any certainty because of surficial cover and complex structure.

A detailed aeromagnetic survey (Warne 1970[1], 1971[2]) shows that the iron formation outcropping at Mt Christie may be a portion of the western limb of a complex antiform (Gerdes 1975[4]) with a north-northeasterly trend and a northerly plunge (Fig. 1). Linear magnetic anomalies indicate three and possibly four magnetic horizons, probably all of which are banded iron formations. The proposed structure is intersected by the Mulgathing Trough, a major graben with a northwest trend (Nelson 1976).

Lithology (CD1, CD2)

In 1964, two fully cored holes (CD1, 2) were drilled through the iron formation (Whitten 1965[5]) perpendicular to strike, 100 m apart and depressed 40° easterly (Fig. 2). The purpose of the holes was to investigate the magnetite content of the iron formation at depth. Drill core from both holes has provided fresh material for geochronology.

The iron formation, approximately 50 m thick, is a quartz-magnetite-diopside-hypersthene-amphibole gneiss and is generally well layered with a characteristic greenish-black and white banded appearance. The magnetite layers are slightly discontinuous and of variable thickness, due to micro-folding. The layers average 6 mm in width and are interlayered with bands of quartz and pyroxene averaging 12 mm. As the magnetite content decreases, banding becomes less distinct. The iron formation retains a predominantly granoblastic texture even though there is evidence of a later phase of metamorphism accompanied by recrystallisation and replacement of some pyroxene by amphibole.

The iron formation contains laminae of feldspar, either microcline or plagioclase, and accessory apatite and iron sulphide. Interbeds up to 0.5 m thick of poorly layered foliated quartz-feldspar gneiss also occur and contain varying proportions of biotite and minor garnet. They are occasionally associated with very thin magnetite-pyroxene layers and rare, thin, massive calcite bands containing some pyroxene and pinkish garnet.

A coarse-grained pinkish-grey, poorly layered to massive quartz-plagioclase-microcline-cordierite-garnet gneiss structurally underlies the banded iron formation. This rock also contains minor ilmenite and traces of sulphide (pyrrhotite, chalcopyrite and a minute trace of pentlandite). These feldspathic gneisses also show evidence of later deformation and retrograde metamorphism. There has been extensive granulation and recrystallisation along grain boundaries and movement along small shear planes. Garnet has been replaced wholly or partly by fine grained biotite, and sillimanite has developed along grain boundaries in the cordierite-bearing rocks.

Age

Eleven samples of core from CD1 and CD2 were analysed by the Rb-Sr technique (see Appendix). Of these, four were quartz-microcline-plagioclase-biotite gneiss interlayered

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[4] Gerdes, R. A. (1975) Geophysical appraisal and interpretation of the detailed aeromagnetic data in parts of *[illegible], [illegible] Muckanippie, Mulgathing, [illegible]* 1:63 360 sheet areas in the northwestern corner of the TARCOOLA 1:250 000 sheet area. S. Aust. Dept Mines (unpubl.) rept 75/14.

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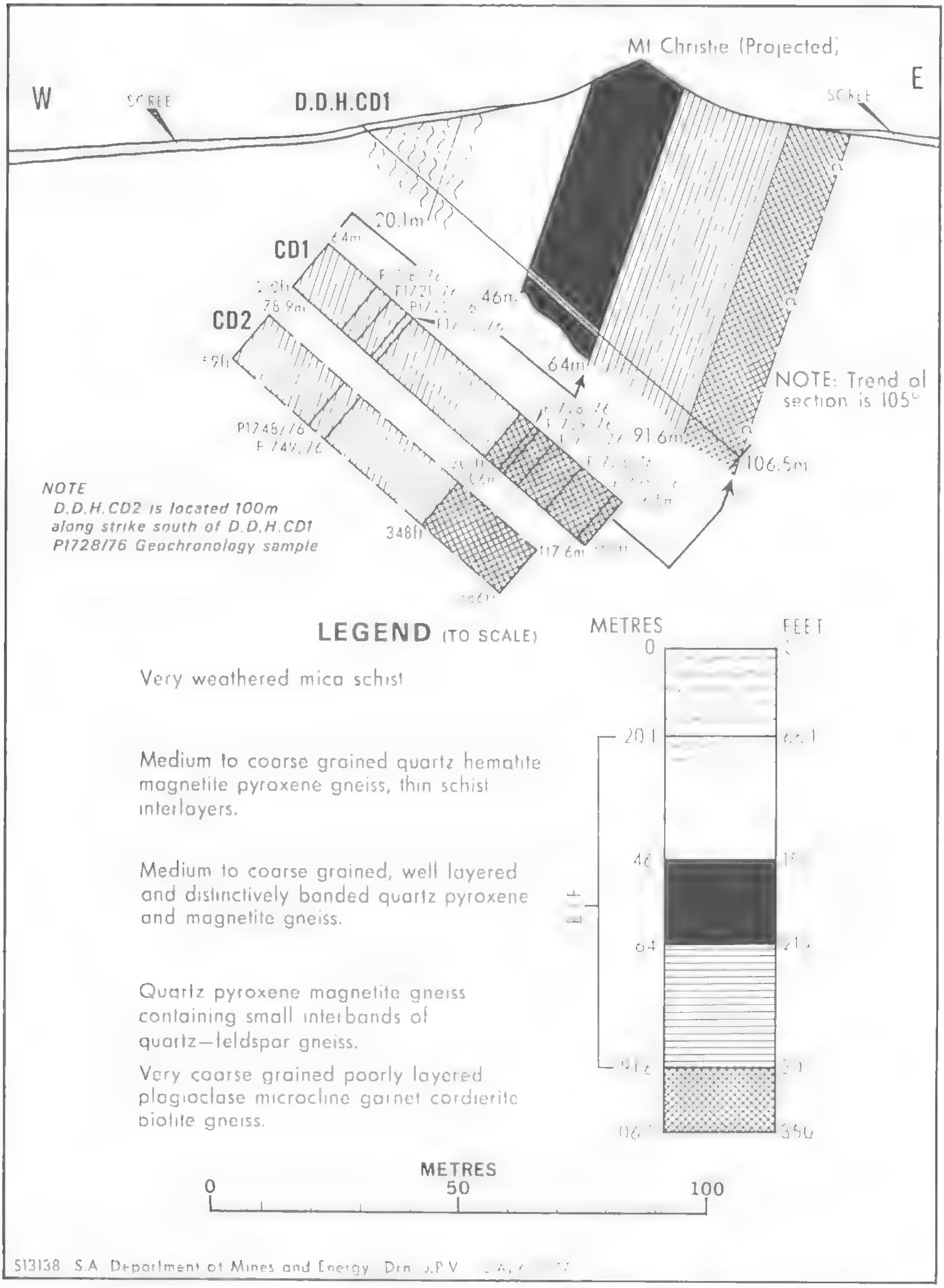

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Fig. 2. Cross section through the banded iron formation at Mt Christie.

TABLE 1

Rb-Sr data: Mount Christie

SAMPLE NUMBER		DEPTH (m)	LITHOLOGY	Rb/Sr	Rb^{87}/Sr^{86}	$^{*}Sr^{87}/Sr^{86}$
P1718/76	CD1	71.02-71.12	B	0.710	2.0638	0.7754
P1721/76	CD1	72.75-72.85	A	0.631	1.8329	0.7687
P1722/76	CD1	75.29-75.36	A	0.806	2.3449	0.7846
P1723/76	CD1	76.05-76.20	A	0.701	2.0376	0.7753
P1728/76	CD1	93.78-93.88	C	0.0701	0.2025	0.7114
P1729/76	CD1	94.49-94.59	C	0.573	1.6632	0.7612
P1731/76	CD1	96.49-96.67	A	0.500	1.4503	0.7535
P1733/76	CD1	100.61-100.71	D	0.413	1.1969	0.7444
P1735/76	CD1	105.54-105.66	D	0.367	1.0631	0.7405
P1748/76	CD2	89.71-89.81	A	0.906	2.6388	0.7962
P1749/76	CD2	91.69-91.80	A	0.663	1.9265	0.7718

with the quartz-magnetite-pyroxene gneiss and the remainder quartz-plagioclase-microcline-cordierite gneiss underlying the iron formation.

The Rb/Sr analyses (Table 1) were regressed and produced a Model 3 isochron of 2417 ± 59 Ma with an initial ratio of 0.7036 ± 0.0015. The MSWD of 3.35 indicates that there is little variance beyond that due to experimental error. The isotopic age represents a minimum metamorphic age for the interlayered iron formation. The low initial ratio indicates that the material had not resided in the crust for more than 100-150 Ma before metamorphism occurred (Moorbath 1976).

Recently the International Union of Geological Sciences Subcommission on Precambrian Stratigraphy (1977) assigned an age of 2500 Ma for the Archaean-Proterozoic boundary: "The particular time chosen is one which provides a reasonable and practical basis for the grouping of geologic events in most regions of the world and for continent to continent correlation". On this basis, the oldest recognisable metamorphic age of the banded iron formation is therefore assigned to the early Proterozoic. The depositional age of the iron formation, however, may be Archaean.

The iron formation near Kenella Rock Hole

Location

The iron formation outcrops at Lat. 30°55'23", Long. 134°57'57" on the eastern edge of the TARCOOLA 1:250 000 map sheet area, 7 km south of the Earea Dam Goldfield, and 1 km north of Kenella Rock Hole (Fig. 3).

General geology (Fig. 3)

The iron formation in outcrop is a poorly layered quartz-hematite-goethite rock. Nearby outcrop, both to the north and south, is pinkish-white to grey, well foliated, poorly banded quartz - microcline - plagioclase gneiss containing subordinate biotite, chlorite and garnet. The quartz-feldspar gneiss is intruded by non-foliated dykes and plugs of gabbro and dolerite and pinkish massive granite. Dykes of the Gawler Range Volcanics (Blissett 1975) ranging from acid to basic, intrude both the quartz-feldspar gneiss, the basic dykes and, rarely, the massive granite. The relationship between the metabasalt (in the N.W. of Fig. 3) and the quartz feldspar gneiss is uncertain.

Structural relationships (Fig. 3)

The iron formation (loc. 1) is locally tightly folded and has a moderate southerly dip. It is interbedded with well layered, very weathered gneiss, and is structurally underlain by a pinkish, well foliated quartz-feldspar gneiss. Approximately five hundred metres to the west (loc. 2) the banded iron formation outcrop is more linear and trends east-west with a steep southerly dip. No pink quartz feldspar gneiss outcrops at this locality.

The exact relationship between the structural top of the iron formation and the pinkish feldspar gneiss outcropping further to the south cannot be established because of paucity of outcrop. Local faulting and basic dyke intrusion have further complicated the relationship. Surface mapping, therefore, is unable to prove whether the iron formation is part of the well foliated gneiss sequence, or whether it is part of a younger sequence.

Drilling has now resolved the problem. In 1973, Abadon Holdings N.L. (Holcapek & Benbow 1974[6]) in search of base metals, regarded the quartz-hematite-goethite outcrop of the weathered iron formation as a gossan,

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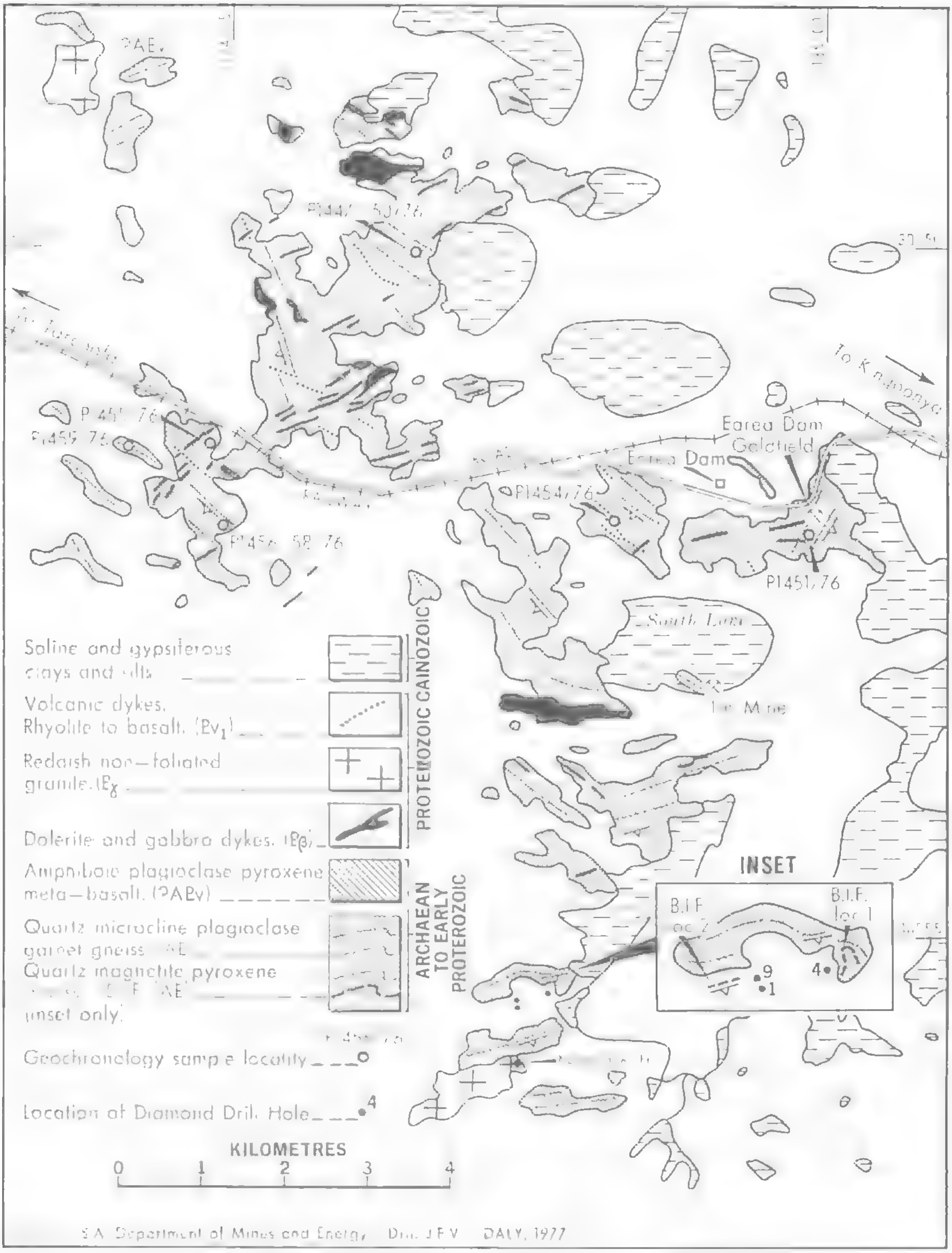
[6] Holcapek, F. & Benbow, M. C. (1974) Geology of the Kenella area. S. Aust. Dept Mines env. 2276 (unpubl.).



S.A. Department of Mines and Energy Drn. J.F.V. DALY, 1977

Fig. 3. Geological map of the Kenella Area.

Several soil geochemical anomalies and ground magnetic anomalies were recorded in the area. Nine holes were drilled in the immediate vicinity of the outcrop and drill holes 1, 4 and 9 penetrated unweathered iron formation (Fig. 3). Recent logging of this core indicates that the pinkish quartz-feldspar gneiss is interlayered with the iron formation. The iron formation is therefore part of a quartz-feldspar gneiss sequence which has a general east-west trend and a southerly dip.

Approximately 10 km west of Kenella Rock Hole is a small isolated outcrop of iron formation, trending easterly and dipping vertically, which may also be part of the quartz-feldspar gneiss sequence (Fig. 1).

Lithology (DDH1, 4, 9)

The iron formation, which has a maximum thickness of 25 m, ranges from a very poorly layered to a well layered greenish quartz-magnetite-pyroxene (diopside and hypersthene)-amphibole gneiss. The magnetite bands of the well layered gneiss are 2–6 mm wide and are interlayered with quartz-pyroxene bands which range up to 40 mm in thickness.

The iron formation contains laminae of feldspar intergrown with the magnetite and mafic minerals, and bands of well layered pinkish quartz-microcline-plagioclase gneiss containing varying proportions of biotite and subordinate garnet. This gneiss is associated with thin calcite layers containing minor amphibole, pyroxene, olivine and garnet. The iron formation also contains bands of generally very poorly layered greenish-grey quartz-feldspar (predominantly plagioclase) gneiss containing abundant relic garnet and some sillimanite. The greyish gneiss in DDH No. 1, from 143.1 m to 146.2 m, contains a small amount of sulphide with Cu 150 ppm, Pb 350 ppm, Zn 2.1% (Holcapek & Benbow 1974^{b}). Both the pinkish quartz-microcline-plagioclase gneiss and the greenish quartz-plagioclase-garnet-rich gneiss also occur above and below the banded iron formation. The greenish quartz-plagioclase gneiss is very readily weathered near surface, whilst the pinkish gneiss is far more resistant, which would explain the dominance of pinkish quartz-feldspar gneiss in outcrop.

The iron formation and associated felsic layers in part retain a granoblastic non-foliated texture; however, there is evidence of a later episode of retrograde metamorphism accompanied by tectonic stress. This event has resulted in the partial or complete replacement of pyroxene by amphibole, of garnet by chlorite and biotite, recrystallisation of much of the quartz and feldspar to a finer grain size and the development of a foliation.

Age

Fourteen samples of pinkish quartz-feldspar gneiss, from the more boldly outcropping area approximately 6 km north of the iron formation, were collected for isotopic dating (Fig. 3). Outcrop near the iron formation is poorer and more weathered. Material from the drill core was not used because of extensive fracturing. Nine samples were analysed by the Rb-Sr technique. Although of acid composition, all samples had a low Rb/Sr ratio which precluded the production of a precise isochron (Table 2). The analyses with the exception of sample P1458/76 produce a linear array. Regression of the eight samples comprising the array shows that there is still a sig-

TABLE 2
Rb-Sr data: Kenella Area

SAMPLE NUMBER	LITHOLOGY	Rb/Sr	Rb^{87}/Sr^{86}	*Sr^{87}/Sr^{86}
P1447/76	A	0.694	2.0173	0.7739
P1448/76	A	0.755	2.1941	0.7772
P1450/76	A	0.849	2.4706	0.7930
P1451/76	A	1.365	3.9949	0.8459
P1454/76	A	0.250	0.7245	0.7284
P1455/76	A	0.620	1.8019	0.7675
P1456/76	A	0.980	2.8549	0.8025
P1458/76	A	1.315	3.8386	0.8192
P1459/76	A	0.921	0.8416	0.7307

A Quartz-microcline-plagioclase-biotite gneiss
B Quartz-microcline-biotite gneiss.
C Quartz-plagioclase-cordierite biotite gneiss
D Quartz-microcline-plagioclase-garnet-biotite gneiss.
* Measured ratios normalised to $Sr^{88}/Sr^{86} = 8.3752$

nificant scatter of the data above that expected from experimental error (MSWD = 14.3). The isochron (Model 4) yields an age of 2488 ± 130 Ma with an initial Sr^{87}/Sr^{86} ratio of 0.7014 ± 0.0038 using the decay constant $Rb^{87} = 1.42 \times 10^{-11}y^{-1}$. The isotopic age represents a minimum metamorphic age for the pinkish quartz-feldspar gneiss sequence interlayered with the banded iron formation. A minimum metamorphic age of 2488 ± 130 Ma is therefore inferred for the banded iron formation. On the basis of the previous discussion the metamorphic age of the banded iron formation is assigned to the beginning of early Proterozoic

Conclusions

The banded iron formations near Kenella Rock Hole and at Mount Christie have a similar composition, age and metamorphic history and are possible stratigraphic equivalents. More significantly, both iron formations have a minimum metamorphic age greater than 2400 Ma. Previously, all banded iron formations within the Gawler Craton had been regarded as stratigraphic equivalents (Whitten 1966, Thomson 1976). However, initial Sr isotopic ratios for units of the Hutchinson Group, which includes the iron formations of the Middleback Ranges, suggest that deposition could not have occurred prior to ca 2000 Ma (Webb 1978[7]), considerably younger than the metamorphic age inferred for the iron formations near Kenella Rock Hole and at Mt Christie. Two periods of iron formation deposition therefore occurred in the Gawler Craton during the Precambrian: the older iron formations are now part of the gneissic sequence on which the younger iron formations were deposited

Iron formations of both ages outcrop within the TARCOOLA 1:250 000 sheet area. The Wilgena Hill Jaspilite (Whitten 1968), a fine-grained finely laminated quartz hematite rock, outcropping 14 km east of Tarcoola is considered to be Proterozoic in age. Although high grade gneisses (presumed older basement) outcrop only 6 km from Wilgena Hill, the metamorphic grade of the iron formation is probably only greenschist facies. It is thus strikingly different from the coarse grained, twice deformed banded iron formations outcropping at Mt Christie and near Kenella Rock Hole.

The Rb-Sr whole rock ages of 2400 Ma obtained for gneissic rocks from the Tarcoola region significantly extend the area of known Archaean to earliest Proterozoic basement from southern Eyre Peninsula, first described by Cooper *et al.* (1976) and Webb & Thomson (1977). In addition, gneissic rocks outcropping poorly to the north and west of the Tarcoola region have similar north-northeast structural and magnetic trends that are characteristic of the older basement near Mt Christie and hence a considerable part of the north-western Gawler Craton may be Archaean to earliest Proterozoic in age.

Acknowledgments

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Appendix

Analytical Methods

Rb/Sr ratios of the powdered total rock samples were determined in duplicate by X-ray fluorescence spectrography. Sr^{87}/Sr^{86} ratios were measured on unspiked samples with a 30 cm, 90° sector mass spectrometer and corrected for mass discrimination by normalising Sr^{88}/Sr^{86} to 8.3752. Measurements on Eimer and Amend $SrCO_3$, over the course of several years, give a value for Sr^{87}/Sr^{86} of 0.70802 ± 0.00006 (standard deviation of population). Constants used in the age calculations were:

$$Rb^{85}/Rb^{87} = 2.600$$

$$\lambda\ Rb^{87} = 1.42 \times 10^{-11}y^{-1}$$

Linear regression of the analytical data was made following the method of McIntyre *et al.* (1966) using estimates of analytical error of 0.6 (coefficient of variation based on 67 duplicate analyses of Rb/Sr in the concentration range of 20 to 600 ppm) for Rb^{87}/Sr^{86} and 0.05 (coefficient of variation) for Sr^{87}/Sr^{86}. The errors quoted are the 95% confidence limits.

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A NEW SPECIES OF HYLID FROG FROM THE NORTHERN TERRITORY

BY M. J. TYLER, M. DAVIES & A. A. MARTIN

Summary

A new species of hylid frog Litoria personata is described from the East Alligator Region of the Northern Territory, Australia. Eternal morphology and features of cranial and postcranial anatomy indicate a relationship to the Litoria latopalmata and L. nigrofrenata species groups. The species lives at the perimeter of the rock escarpment, and breeds in temporary rock pools. The tadpole is noteworthy for the spectacular gold stripes along its body and tail.

A NEW SPECIES OF HYLID FROG FROM THE NORTHERN TERRITORY

by M. J. TYLER*, M. DAVIES* & A. A. MARTIN†

Summary

TYLER, M. J., DAVIES, M. & MARTIN, A. A. (1978) A new species of hylid frog from the Northern Territory. *Trans. R. Soc. S. Aust.* **102**(6), 151-157, 31 August 1978.

A new species of hylid frog *Litoria personata* is described from the East Alligator Region of the Northern Territory, Australia. External morphology and features of cranial and post-cranial anatomy indicate a relationship to the *Litoria latopalmata* and *L. nigrofrenata* species groups. The species lives at the perimeter of the rock escarpment, and breeds in temporary rock pools. The tadpole is noteworthy for the spectacular gold stripes along its body and tail.

Introduction

Although frogs of the family Hylidae are popularly termed tree-frogs, numerous species are wholly or predominantly terrestrial, or else are scansorial in non-arboreal situations such as upon exposed rock faces. In Australia members of the *Litoria latopalmata*, *L. nasuta* and *L. nigrofrenata* species groups are good examples of terrestrial species. All have rather elongate bodies, unwebbed fingers, variably webbed toes and relatively long hindlimbs.

The terrestrial species occur only in eastern and northern Australia. One (*L. latopalmata* (Gunther)) extends into arids parts of western Queensland and New South Wales, and recently has been collected in the extreme northeast of South Australia (Tyler 1977).

There remains considerable uncertainty about the number of species in the *L. latopalmata* group as defined by Tyler & Davies (1978). The three named species differ only slightly in colouration and in the few morphological features recognised to be significant. Biological data are inadequate to permit clarification of the taxonomic status to be accorded to some populations. Similarly the phylogenetic relationship existing between this and other species groups has yet to be resolved

As a result of the collecting activities of Mr Greg Miles of the N.T. National Parks and Wildlife Commission, we were able to examine in 1977 specimens of an undescribed species of *Litoria* from the East Alligator River region of the N.T. It bears a resemblance to members of the *L. latopalmata* and *L. nigrofrenata* species groups. Subsequently Davies, Miles, and Tyler obtained a further adult specimen in November 1977, Miles and Tyler collected tadpoles and recently metamorphosed young frogs in April 1978, and Miles and I. Morris collected more adults and recently metamorphosed individuals in May 1978.

Here we describe the new species and discuss its phylogenetic relationships.

Material and methods

The specimens reported here are deposited in institutions abbreviated in the text as follows:

Northern Territory Museum, Alice Springs (NTM)

South Australian Museum, Adelaide (SAM)

Methods of measurement follow Tyler (1968a) and osteological comparisons are those adopted by Davies (1978). Tadpoles were fixed in Tyler's (1962) fixative and staged according to Gosner (1960).

Litoria personata sp. nov.

FIGS 1-6

Holotype: SAM R.16773. A gravid female collected at Birndu (12°32'S; 132°8'E), south-east of Cannon Hill Station, East Alligator

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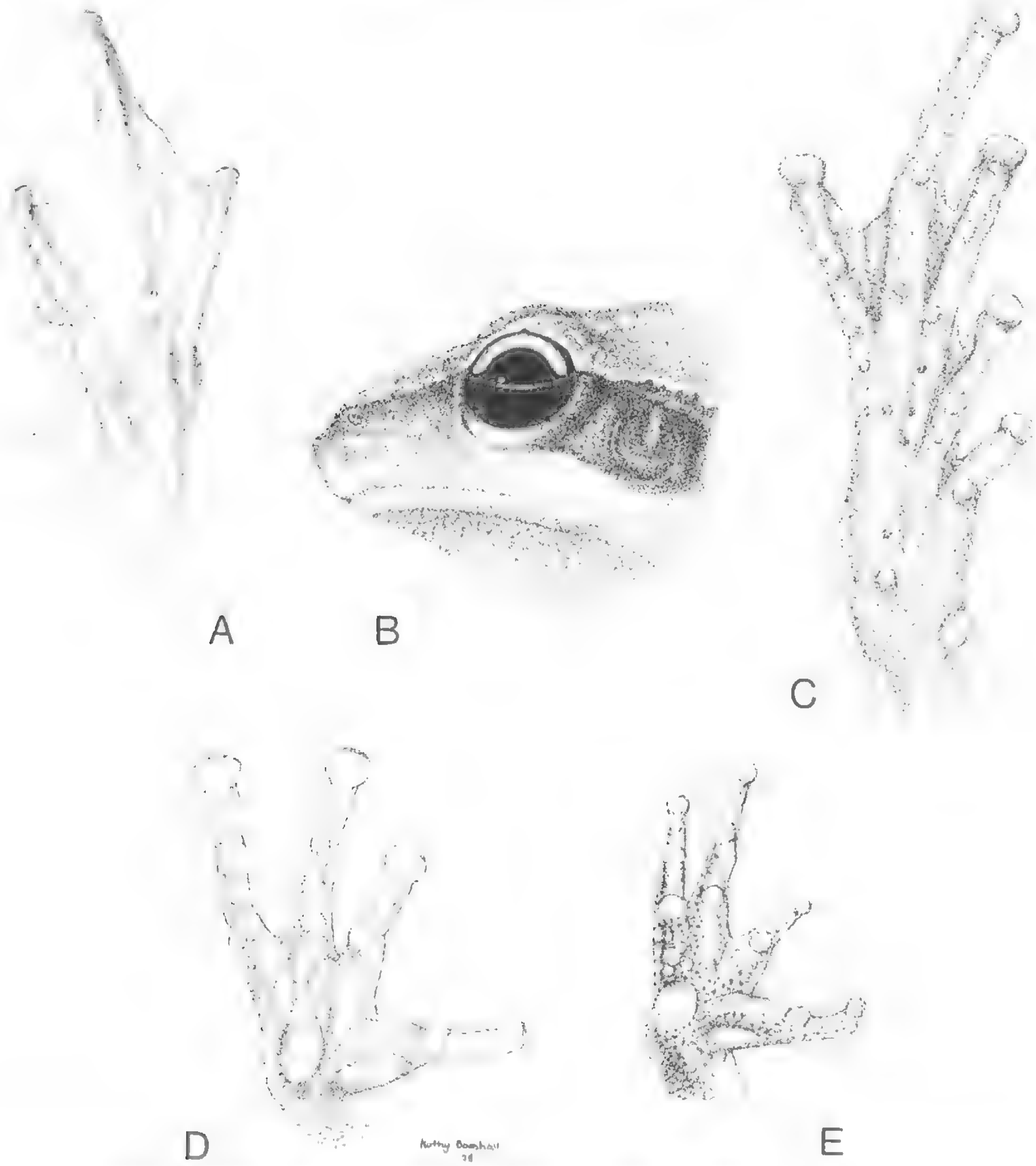

Fig. 1. A. Plantar surface of foot of *Litoria wotjulumensis* SAM R.16857; B. Lateral surface of head of *L. personata;* C. Plantar surface of foot of *L. personata;* D. Palmar surface of hand of *L. personata;* E. Palmar surface of hand *L. tornieri* SAM R.16779.

River Region, Northern Territory, by M. Davies, G. Miles, and M. J. Tyler on 27.xi.1977.

Definition: A small rock-dwelling species (female 32.8 mm; males 28.8–28.9 mm S-V length), characterised by its unwebbed fingers with distinctly expanded terminal discs, first finger longer than second; moderately long hindlimbs (TL/S–V 0.51–0.60); broad, dark stripe on the side of the head; tadpole with striking, dorsolateral gold or yellow stripes on the body and tail.

Description of holotype: Head longer than broad (HL/HW 1.15); head length more than one third of the snout to vent length (HL/S–V 0.37). Snout prominent, projecting in profile and slightly rounded when viewed from above and in profile (Fig. 1B). Nostrils more lateral than superior, their distance from end of snout two-thirds that from eye. Distance between eye and naris less than internarial span (E–N/IN 0.86). Canthus rostralis slightly defined and straight, its nature accentuated by dark rostral stripe. Eye relatively small and inconspicuous, its diameter equivalent to eye to naris distance. Tympanum completely visible; diameter slightly more than two-thirds eye diameter (Fig. 1B).

Vomerine teeth on short, oval elevations between anterior edges of choanae. Tongue broadly oval.

Fingers long and slender, lacking lateral fringes (Fig. 1D); in decreasing order of length 3 > 4 > 2 > 1. No webbing between fingers. Terminal discs moderately well developed, extending laterally beyond lateral edges of penultimate phalanx. Subarticular and palmar tubercles prominent.

Hind limbs long (TL/S–V 0.59). Toes in decreasing order of length 4 > 5 > 3 > 2 > 1 (Fig. 1C). Webbing reaching half-way up penultimate phalanx on toe 5 and below subarticular tubercle at base of antepenultimate phalanx of toe 4. Subarticulate tubercles prominent. Small oval inner and smaller rounded outer metatarsal tubercles.

Dorsum very finely tubercular; abdomen, pectoral region and undersurface of thighs coarsely granular; submandibular area smooth. Slightly developed tarsal fold, but no supratympanic fold.

In preservative pale grey with a conspicuous, very dark stripe extending from nostril to eye, and posteriorly to above insertion of forearm (Fig. 2). A narrow white stripe from lower margin of eye to posterior extremity of mandible. Ventral surface pale cream.

In life background colouration similarly grey or pale brown. Ova, viewed through a transparent portion of body wall, small and unpigmented.

Dimensions of holotype: S–V 32.8 mm; TL 15.9 mm; HL 10.3 mm; HW 9.1 mm; E–N 2.7 mm; IN 3.2 mm; E 3.5 mm; T 2.3 mm.

Etymology: The specific name is derived from the Latin, *personatus,* masked, in reference to the dark stripe through the eye.

Variation

There are twelve paratypes: SAM R.16774, an adult male collected as a recently metamorphosed juvenile on Cannon Hill Station, N.T. by G. Miles in August 1977. This specimen was reared at the University of Adelaide, and preserved in alcohol when it reached adulthood; SAM R.16775, a sub-adult male collected with the preceding specimen; died in captivity; SAM R.16776 (cleared and stained),

Fig. 2. Live *Litoria personata.* Paratype SAM R.16774.

an adult male, Bradshaw Ck, Cannon Hill, G. Miles, 2.ii.1977; NTM A.123–125, juveniles, G. Miles, 1.ii.1977; SAM R.16829, 16855–56, metamorphosing juveniles, Cannon Hill, G. Miles and M. J. Tyler, 26.iv.1978; SAM R.16830–32, adults and juveniles from Birndu, G. Miles and I. Morris, 20.v.1978.

The adult males measure 28.8 and 28.9 mm S–V respectively, and the females 30.6 and 32.2 mm. The cleared and stained specimen had very large pigmented nuptial pads on the first finger. The other specimen lacks nuptial pads, but possesses a submandibular vocal sac. The head is elongate and the snout prominent and tapering in both specimens.

Hind limb length is highly variable, and proportionately less than or greater that that of the holotype (TL/S–V 0.51–0.60 in the adult and sub-adult paratypes).

Six of the juveniles exhibit the adult pattern of markings: the seventh is in a state of transition, exhibiting traces of the conspicuous pale stripes that characterise the tadpole of this species (described below).

Larval morphology

Five larvae collected at Cannon Hill on 1.ii.77 are in stages 27–41; their total length ranges from 23.7 to 44.1 mm and their body length from 10.3 to 16.7 mm. Six larvae collected on 26.iv.78 are more advanced, including specimens at stages 41–45. Their total length ranges from 41.8 to 55.1 mm and their body length from 16.6 to 18.6 mm. Fig. 3A shows a larva at stage 41. Dimensions of this individual are: total length, 52.9 mm; body length, 18.6 mm; maximum body width, 9.0 mm; maximum body depth, 7.5 mm; maximum tail depth (including fin), 8.6 mm.

The mouth is subterminal and the anus opens to the right of the tail fin. The eyes are lateral. The spiracle is sinistral and ventrolateral; it is not visable in a dorsal view of the larva. In its general body form the larva resembles those of other Australian ground hylids from lotic habitats, e.g. *L. lesueuri* (Martin 1967). The body is flattened and the tail fin is narrow, while the tail musculature is powerful. The mouth structure is also typical of Australian hylid larvae which live in flowing water; there are two upper and three lower rows of labial teeth, and the papillary border is complete. The horny jaws are relatively weakly developed (Fig. 3B).

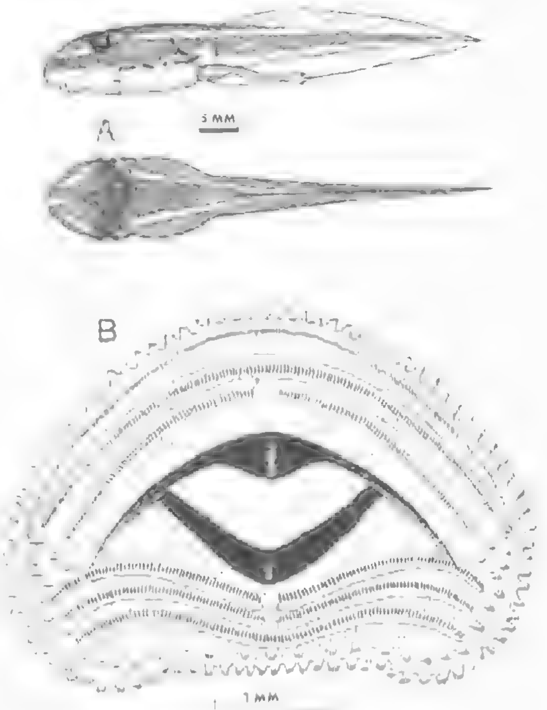

Fig. 3. A. Left lateral and dorsal views of larva of *Litoria personata* at stage 41; B. Mouth disc of larva of *L. personata* at stage 31.

In life larvae are dark brown on the dorsal surface and creamy white beneath. The dorsolateral stripes are gold to yellow. In preservative the dorsal ground colour is greyish-brown. There is an irregular dark grey transverse band between the eyes, and in front of this band there is an arrowhead-shaped dark grey patch. The dorsolateral stripes and the ventral part of the body and tail are creamy white. The tadpole's striking appearance stems from the dorsolateral stripe, and from the abrupt transition from dark to light pigmentation along the lateral midline.

Unfortunately the larval morphology of other members of the *L. latopalmata* complex has not been described; hence whether or not this spectacular appearance is diagnostic of the larva of *L. personata* is unknown.

Comparison with other species

(a) *External morphology:* The elongate body form, projecting snout, relatively long hind limbs, unwebbed fingers and poorly webbed toes are a combination of features exhibited by all terrestrial *Litoria*. The extreme of these adaptations is demonstrated by members of the *L. nasuta* group in which the elongation of head, body and limbs is most pronounced.

In northern Australia the *L. nasuta* species group is represented by *L. nasuta*. This species has longer hind limbs than *L. personata* (TL/S–V 0.64–0.78 in *L. nasuta*; 0.51–0.59 in *L. personata*). The head of *L. nasuta* is proportionately much longer (HL/HW 1.21–1.43 in *L. nasuta*; 1.13–1.17 in *L. personata*). The two species also differ in skin texture: very finely tubercular in *L. personata*; with numerous, longitudinally arranged plicae in *L. nasuta*.

The sympatric species *L. tornieri* of the *L. latopalmata* species group lacks the finger discs of *L. personata* (Fig. 1E) and has a disrupted lateral head stripe; the stripe is continuous in *L. personata*. The new species may also be slightly smaller than *L. tornieri*: S–V of the female *L. personata* are 30.6–32.8 mm, whereas the range in *L. tornieri* is 31.1–39.7 mm. The S–V of male *L. personata* (28.8–28.9 mm) is in the middle of the *L. tornieri* range (26.1–32.1 mm).

The habitus, finger discs and proportions indicate a close relationship between *L. personata* and *L. wotjulumensis* of the *L. nigrofrenata* species group. They differ principally in size and colour: *L. wotjulumensis* is considerably larger (males 33.8–37.7 mm; females 45.7–54.1 mm. Tyler 1968b and unpublished data) has fully webbed toes (Fig. 1A) and often is infused with lemon yellow on the abdomen, flanks and undersurface of the lower limbs.

(b) *Osteology:* Provisional comparisons suggested that the closest relative of *L. personata* is *L. wotjulumensis*, whose skull is illustrated by Tyler & Davies (1978). Dorsal, lateral and ventral views of the skull of *L. personata* are shown in Fig. 4.

In both species the skull is longer than broad, and the slightly elongate snout is rounded terminally in dorsal aspects. The nasals are moderately-sized, narrow, bones very widely separated medially by the sphenethmoid; they do not articulate with it. The sphenethmoid is double and moderately to well ossified; it projects between but not beyond the nasals.

There is minor variation in the form of the frontoparietals. They are moderately ossified, lack anterior contact with the nasals and do not overlap the crista parotica posteriorly in

Fig. 4. Skull of *Litoria personata*. Paratype SAM R.16776. A. Dorsal view; B. Lateral view; C. Ventral view.

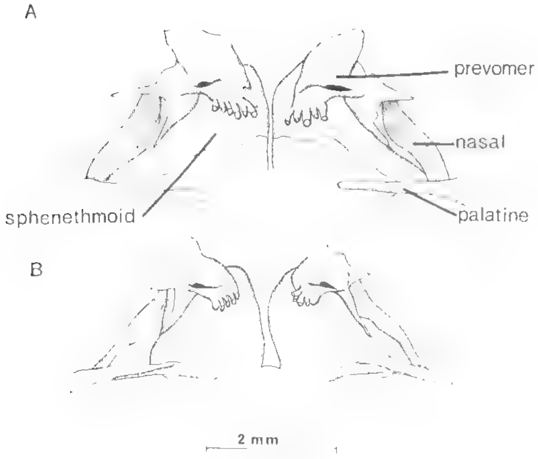

Fig. 5. Prevomers. A. *Litoria wotjulumensis;* B. *L. personata.*

both species. However, there is a slight posteromedial articulation in *L. wotjulumensis,* but not in *L. personata.* The frontoparietal fontanelle is large in both species and is continuous posteriorly in *L. personata.*

The crista parotica are moderately short and broad with prominent epiotic eminences, and the otic rami of the squamosals do not overlap the crista parotica. In *L. personata* this ramus is clearly separated from the crista parotica, whereas in *L. wotjulumensis* the relationship of these bones is more intimate. The short zygomatic ramus of the squamosals is longer than the otic ramus in *L. personata* whilst in *L. wotjulumensis* the arms are of approximately equal length.

The pterygoid is well developed and the median ramus is in bony contact with the prootic. The quadratojugal is well developed.

The pars facialis of the maxillary is shallow; the well-developed posterior process reaches the level of the maxillary process of the nasal in *L. personata,* but in neither species does it make bony contact. The alary processes of the premaxillaries are broad at the base, widely separated medially, and curve posteriorly after an initial vertical section. The palatine processes of the premaxillaries are well developed and do not abut medially or at their extremities.

The premovers are reduced medially, widely separated, and have short horizontal dentigerous processes (Fig. 5). The palatines are short and narrow.

Fig. 6. Type locality of *Litoria personata:* Escarpment at Birndu, N.T.

The cultriform process of the parasphenoid is extremely long and narrow; the alae are also long and narrow and are at right angles to the cultriform processes.

In the post-cranial skeleton the sacral diapophyses are broadly expanded in *L. personata* and moderately to broadly expanded in *L. wotjulumensis*. There is a flange on the distal head of the third metacarpal, and the intercalary structures are ossified in both species.

Habitat

The holotype was collected at night upon a flat shelf on an open rock face at the foot of the Arnhem Land escarpment; the type locality is shown in Fig. 6. Tadpoles and metamorphosing juveniles were taken in or around temporary pools upon the escarpment or at its foot. The area supported a 'Mixed Scrub' community (Story 1969) composed mainly of evergreen non-eucalypts, with *Pandanus* and shrubs rising to approximately 8 m; overall visibility is approximately 20 m.

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Finally we are indebted to Ansett Airlines of Australia for providing in-transit air-conditioned accommodation for the live specimens.

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EARTHFLOWS IN THE YANKALILLA AREA OF SOUTH AUSTRALIA: SIGNIFICANCE OF RAINFALL, SOIL PROPERTIES AND MAN'S ACTIVITIES

BY W. J. VAN DEUR

Summary

Thirty-three earthflows were located on Permian glacigene deposits east and southeast of Yankalilla, South Australia. Their formation relates to periods of intense, concentrated rainfall when excess soil moisture resulted in deformation by plastic flow. Dating of these earthflows revealed that while all have formed after European settlement, there has been a time-lag between occupance and the majority of mass-movements. The time-lag resulted from alterations in physical and chemical properties of the soil over time, leading to a gradual decrease in shear strength. Soil alterations were initiated by clearing of natural vegetation after settlement.

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by W. J. VAN DEUR*

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Thirty-three earthflows were located on Permian glacigene deposits east and southeast of Yankalilla, South Australia. Their formation relates to periods of intense, concentrated rainfall when excess soil moisture resulted in deformation by plastic flow. Dating of these earthflows revealed that while all have formed after European settlement, there has been a time-lag between occupance and the majority of mass-movements. The time-lag resulted from alterations in physical and chemical properties of the soil over time, leading to a gradual decrease in shear strength. Soil alterations were initiated by clearing of natural vegetation after settlement.

Introduction

The influence of man on the development of certain landforms is both significant and widespread in many parts of the world. Of particular importance is the acceleration of the processes of erosion resulting from removal of natural vegetation and the subsequent history of land use.

The Fleurieu Peninsula, about 80 km south of Adelaide, South Australia, an area cleared initially in the mid-nineteenth century by European settlers for the cultivation of wheat, clearly shows the repercussion of such enterprise in the form of gullies and mass-movements. It is estimated that these processes have together resulted in a reduction of at least 20% in the amount of available, arable land (Campana, Wilson & Whittle 1954). Thus these processes are of economic as well as geomorphological interest.

In an attempt to elucidate various aspects of the development of these mass-movements, and in particular the relationship between man's activities and landform development, an investigation of 33 examples of mass-movement was carried out in an area of approximately 100 sq. km south and southeast of Yankalilla (Fig. 1).

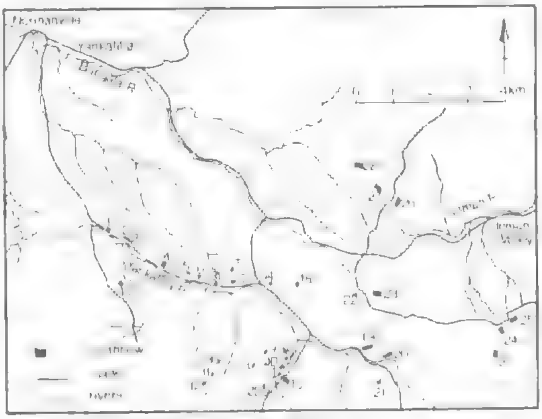

Fig. 1. Location of earthflows.

Found either in isolation or in coalesced groups (Figs 2 & 3), these mass-movements are earthflows as defined by Sharpe (1938) and Varnes (1958), whose classifications are based on the nature and rate of movement and the resultant morphological features. The volume and extent of earthflows varies, but in all instances movement is restricted to depths of 5 m or less. Observed variations in profile are thought to relate to stage of development, with the mature shape comprising a spoon-shaped hollow bounded by a steep, arcuate

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headscarp which becomes more fully inclined at the foot before bulging above the turf surface to form an elongate lobe, extending downslope (Fig. 2). Developing earthflows are distinguished by arcuate tension cracks resulting from subsidence and low level, sub-turf bulging. Older earthflows were located, although in these the main characteristics such as headscarps and lobes have been subdued by subsequent weathering and erosion

The majority of earthflows are found on overdeepened, glacial depressions, filled with unconsolidated glacial, fluvio-glacial and glacio-lacustrine drift of Permian age, resting unconformably on Precambrian and Cambrian rock (YANKALILLA and JERVOIS map sheets, Geological Atlas One Mile Series: Geol. Surv. S. Aust., Adelaide).

These readily eroded deposits were protected during the Mesozoic planation by virtue of the fact that they lay below the base level of stream incision (Campana, et al, 1954). Evidence for a Mesozoic age for peneplanation is to be found in the presence of a laterite capping on the present plateau surface. This laterite generally has been considered to be of a Tertiary age (Fenner 1930), but more recent investigations have assigned formation to the Triassic (Daily, Twidale & Milnes 1974; Twidale 1976).

Rejuvenation resulting from Tertiary faulting allowed rivers such as the Yankalilla, Bungala and Inman to cut back into the upland regions. Consequently, the Permian glacigene deposits were eroded and transported more rapidly than the resistant bedrock, thereby forming an area of comparatively low elevation and relief. Slopes developed on these deposits are graded, displaying well developed upper convexities and lower concavities, often separated by long rectilinear sections with an average inclination of 10°.

The resistant uplands comprise heavily metamorphosed and folded Precambrian and Cambrian deposits. In detail these consist of a centrally placed core of Archean micaschists and gneisses upon which the deposits of the Adelaide system rest unconformably. To the east and south, the Kanmantoo group of greywackes, phyllites, quartzitic schists and micaceous quartzites are found.

Several major problems need to be considered in an attempt to explain the development of these earthflows. First, the date of occurrence of each movement must be determined as accurately as possible to establish whether they are relict or modern. Second, in conjunction with this, it is necessary to show if these earthflows are active or dormant, and hence whether they relate to the present system of slope processes, or are evidence of past slope disequilibrium. Finally, their relationship not only to the anthropogenic factor but also to the geological, pedological and climatic controls operating in this region must be established.

Dating of earthflows

Since the anthropogenic factor has been postulated as one of the major factors influencing the development of these earthflows, it is of some importance to establish as accurately as possible the date of occurrence of each movement. Four dating techniques were employed:

1. Aerial photographs (the first of which were taken in 1949) show the location and morphology of some of the present earthflows. However, because runs were not made in consecutive years, it was possible to assign a particular earthflow to a range of years only.

2. Geological maps of the area (Campana, et al, 1954) indicate 16 'landslides' but do not distinguish type, size or nature of movement. Omissions have been found to occur when comparison was made with the 1949 aerial photographs.

3. Local residents were interviewed and, considering the limitations imposed by migration to and from the area as well as the accuracy of memory, much useful information was obtained. However, for earthflows developed more than ten years ago, it was only possible to assign movements to a range of years.

4. A statistical approach based on rainfall records was used. A recent earthflow was dated with accuracy using the methods outlined, and from this it was possible to calculate the amount of rainfall above the median necessary to produce movement. Years of above median rainfall were extrapolated to indicate periods where earthflowage could have occurred. However, total rainfall is of less importance than the distribution, for when well spaced, excess water can be removed without precipitating mass-movements (Sharpe 1938; Sharpe & Dosch 1942; Crozier 1969; So 1971; Nilsen, Taylor & Dean 1976). The rainfall records were therefore examined for evidence of unusually heavy concentrations.

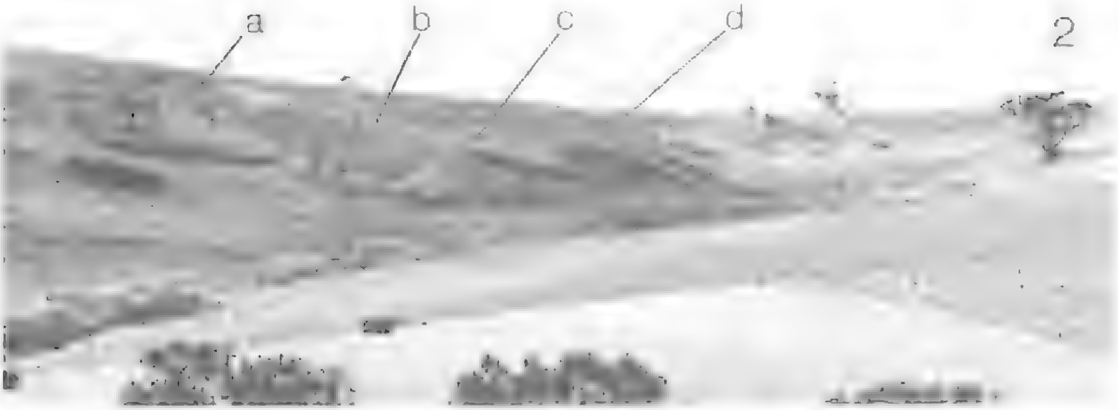

Fig. 2. Single earthflow (No. 9) (a) scarp (b) foot (c) lobe (d) toe.
Fig. 3. Coalesced earthflow (No. 20).
Fig. 4. Earthflow (No. 8) Note the incipient tension crack (a) and subturf bulge (b) to the left of the main movement, corresponding to the scarp and foot of the main earthflow.

TABLE 1
Age and Activity of Earthflows

Ref. No	Age in yrs. (from 1978)	Activity	Slope Angle
1	50+	D	14°
2	50+	D	13°
3	50+	D	12°
4	23	A	12°
5	4	A	11°
6	25–50	E	11°
7	?	D	11°
8	10	A	12°
9	31	A	10°
10	?	E	10°
11	22–23	D	12°
12	4– 5	A	9°
13	7	A	11°
14	31–32	D	10°
15	14	A	10°
16	7	A	10°
17	31–32	D	10°
18	50+	E	15°
19	50+	D	15°
20	22–23	A	16°
21	7	A	9°
22	7	A	9°
23	25–50	A	8°
24	25–50	A	11°
25	?	A	12°
26	10	A	12°
27	25–50	D	20°
28	20–25	A	11°
29	30–50	D	10°
30	?	A	7°
31	25–50	E	11°
32	25–50	E	14°
33	25–50	D	8°
			mean = 10.8°
			S = .92°

A = Active; D — Dormant; E = Extinct.

Twidale (1976) questions such an approach because of the possible variations in rainfall between the recording station and the site of the earthflow. Three points, however, lend validity to the application of the technique in this instance. First, there are a number of recording stations within a small area, with some data extending back over one hundred years, and use has been made of the records of local inhabitants to supplement official records (Mason 1954[1]; Robertson 1975).

Second for the earthflow used as a base, the rainfall data of a farmer about 0.5 km east of the earthflow was compared with the official records and found to be virtually identical. This is not to suggest that variation is not possible, but rather that because of the limited area being considered, this variation is minor. This dating technique is not intended to be used alone, but offers a means of delimiting years of possible movement which, when combined with the other methods, lends a greater degree of accuracy to the results.

The ages and present state of activity of earthflows are presented in Table 1. It is evident that the majority of movements have occurred over the last 50 years, with a large proportion of these post-dating 1945. These earthflows are generally active or in such a state of dormancy that they may be readily reactivated. For example when a portion of the toe of an apparently dormant earthflow was removed during road repair undermining and a consequent surge of the entire lobe occurred.

The time lag between settlement in 1839 and the initiation of widespread mass-movement after 1945 needs explanation. Earthflows probably developed prior to European settlement but on a much smaller scale, as is evidenced by the fact that no mass-movements are to be found on the few remaining areas of natural vegetation once common to the region (Light 1839). The vegetation consisted of savanna woodland on the glacial lowlands (*Eucalyptus leucoxylon; E. camaldulensis* and *E. odorata*) grading to sclerophyll on the plateau surface (Boomsma 1948[2]; Williams 1974). Vegetation was cleared initially for the cultivation of wheat but was later replaced by wattle trees. After 1910 grazing became the predominant form of agricultural activity (Pridham 1955[3]).

Investigation and analysis of earthflow

In order to appreciate the morphology of earthflows in terms of processes operating, an investigation of the physical and chemical properties of earthflow number four was undertaken. This movement, which was shown to have occurred initially in 1955 and developed to its present state in 1956, was selected because it is the largest, single earthflow within the area (although larger are known to have

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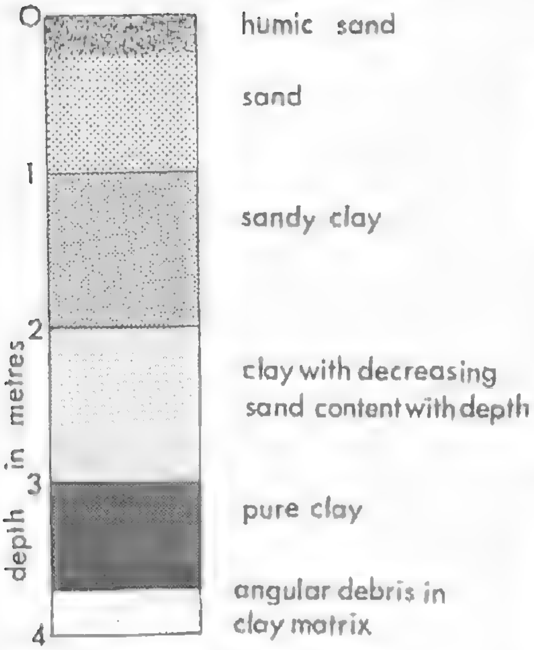

Fig. 5. Composite soil profile diagram.

existed), and it was known to be stable in the lobe zone, although minor headward extension by means of block slumping does occur. Stability was confirmed by eyewitness accounts (D. K. Crawford, per comm.) and by measurements taken over a period of months in winter.

To establish rates of movement, an highly active earthflow was selected (No. 8, Figs 1 & 4). This earthflow formed initially in 1968, and has continued to move downslope, as we found in 1975 and confirmed on subsequent visits in 1976 and 1977. Although smaller overall than earthflow four, measuring 91 m from scarp to toe, and 50 m in width, this earthflow exhibits the classical morphology of such movements.

A composite soil profile (Fig. 5) was established for earthflow four by sinking a series of auger holes on and adjacent to the main body of the movement. In all bores the quartz sand layer extends to an average of 1 m beneath which the percentage of clay increases to a depth of approximately 3.5 m. Below this a layer of highly compressed 'pure' clay is found, which in turn is underlain by a zone of angular debris set in a clay matrix.

Samples were taken at depths of 1.5 and 3 m and tested for variations in sand/clay ratio, and the chemical nature of the clays present analysed by means of X-ray diffraction. These results are presented in Table 2.

TABLE 2

X-ray diffraction analysis

	Bore 1, 1.5m	Bore 2, 3m	Bore 3, 1m
Kaolinite	30–40%	20–30%	10–20%
Illite	20–30%	40–50%	40–50%
Quartz	10–20%	0%	10–20%
Montmorillonite and or randomly stratified material	20–30%	20–30%	20–30%

The most important feature of these results is the decrease in stable kaolinite and quartz with depth, while illite and montmorillonite show an increase. Both of these latter clays are capable of expansion in the presence of moisture. Clay has a low permeability which would cause ground water to be confined, allowing time for absorption into the crystal lattice (this is evident in winter when waterlogging of the soils is seen to occur). The saturation conditions produced by heavy rainfall causes swelling and uplift of the over-burden. The instability of the slope is therefore increased.

Observations in gullies and man-made cuttings reveal the presence of such a clay, of varying thickness and at different depths, throughout the area. The role of this clay in the formation of earthflows is therefore considered to be of extreme importance.

The sample from 1.5 m was tested by the Casagrande technique to establish the Atterberg limits of plasticity and liquidity. Adopted from civil engineering, the application of these techniques to the study of mass-movements has been criticized on the grounds that the samples are not in situ. However, the amount of understanding of processes operating derived from the use of the Atterberg limits, warrants their application (see Crozier 1969). The liquid limit of the sample was found to be 38%, the plastic limit 13.5%, and the plasticity index 24.5%. These figures are in accordance with the parameters suggested by Nasmith (1964) for a sandy clay soil formed on glacial deposits (L.L. 41%, PL. 19%).

The water content by weight was found to be 19.79% at 1.5 m and 32.69% at 3 m. In both instances the plastic limit has been surpassed even when Nasmith's higher figure for plasticity is applied), and thus deformation by plastic flow under the influence of gravity may be expected. It is believed, however, that this does not occur until higher water contents, such as occasioned by heavy rainfalls, are experienced, for the slopes upon which earthflows are found are of low to moderate declivity, ranging from 7-16° (Table 1).

Nature and rate of movement

Using the results of the detailed investigations described above, as well as observations on other mass-movements in the area a model to describe the processes operating in the formation of an earthflow can be constructed.

Heavy rainfall results in the subsurface eluviation of fine materials which, along with flowage (probably in the vicinity of the clay layer) causes a disruption in drainage, leading to the formation of a 'soak'. Typically at such locations the ground surface assumes a hummocky appearance. Such disruption is known to have occurred at the present location of earthflow number four as a result of heavy and concentrated rains in both 1946 and 1947. Further rainfall accentuates subsurface flowage, eventually producing a minor subturf bulge. This flow however, subjects the upper slope to tension which, when coupled with subsidence due to eluviation, results in the formation of a tension crack. Such a situation is currently evident adjacent to earthflow number eight (Fig. 4) where the incipient scarp, in the form of a tension crack, corresponds to the main scarp, while subturf bulging is in line with the foot of the main movement. Eventually the lobe breaks the surface at this location, forms a minor recumbent fold, and then slides downslope on a planar glide surface composed of vegetable matter and lubricated by water. This results in the introduction of an auto-catalytic process, since water tends to accumulate in the scarp foot depression. This moisture, along with that which falls directly onto the lobe, is seen to exude from beneath the lobe at the toe.

The rate of motion of the lobe was established by measurements taken during August at three locations along the toe. The results are presented in Table 3. Taking a mean of the motion of the three test lines, the rate of movement is 23 cm/week, or 3.3. cm/day. However, movement is highly variable in response to the amount of rainfall, in summer the lobe being almost stationary. Observations in 1976 and 1977 indicate movement is still occurring and since the slope is constant to the valley floor, movement will continue until this point is attained.

The moisture content of samples taken at the scarp and the toe were found to be 18.5% and 28.13% respectively. The amount of moisture above the plastic limit (Nasmith's figure of 19%) is therefore minor, yet movement as indicated was comparatively rapid, supporting the hypothesis (Skempton 1964) that once an earthflow is set in motion, lower water contents than those necessary to initiate movement can cause a continuation of that movement. Further, as mentioned, flow is replaced to a large extent by planar sliding on a water lubricated surface.

Transversely, differential movement of the lobe is occurring, while a given section of the lobe moves at varying rates over them. This variation over time is explicable by reference to the level of rainfall, but the differential transverse movement poses a problem. It is possible that variations in the physical nature of the material occurs, but observations suggest a homogeneous character. If it is considered that the energy for plastic flow is derived from gravity, and that the degree of energy depends on mass, then where mass is greatest the energy level is greatest. For a given area of sliding surface this is where the lobe has maximum height. The increased friction expected due to greater mass, is compensated by the lubrication provided by the water. Mass however is comprised of not only the materials of the lobe; absorbed water also increases mass and the higher sections of the

TABLE 3

Rates of Movement, Earthflow Eight

	Initial Length Line			Present Length Line			Movement Line		
	1	2	3	1	2	3	1	2	3
5.viii.75	3.05	3.05	3.05	3.05	3.05	3.05	0	0	0
12.viii.75				2.78	2.96	2.53	0.27	0.09	0.52
17.viii.75				2.65	2.71	2.14	0.12	0.24	0.40
22.viii.75				2.53	2.56	1.98	0.12	0.15	0.15

Observations taken 30.x.75 showed line three to be completely covered. Movement of over 3.05 m has therefore occurred.

lobe have the potential to retain more moisture. Once in motion these sections of the lobe also possess a greater energy and thus will continue to move after the cessation of rainfall.

Earthflows increase their dimensions after the initial flow largely by movement of the lobe, but headward extension also occurs. This is mainly by means of block slumping at the scarp due to lateral pressure release, but may also occur by means of secondary earthflow, as found on earthflow number four in 1974.

Factors producing earthflows

In attempting to assign a process to mass-movement, the cause of individual earthflows is considered, although Varnes (1958) states: 'In most cases a number of causes exist simultaneously and so attempting to decide which one finally produced failure is not only difficult, but also incorrect. Often the final factor is no more than a trigger that sets in motion an earthmass that was already on the verge of failure.'

When analysing earthflows within the area, an association is established with high rainfall, but in fact it is a combination of climate, geology, soil properties and the role of man. All these variables must be considered.

For motion to have occurred, shear stress must have exceeded shear strength, that is the resistance of the soil to stress. Shearing strength in a normally unconsolidated soil is dependent upon the cohesion between soil particles and friction due to granular interlocking of these particles. A sandy soil which possesses negligible cohesion, has high levels of internal friction which in turn allows a high angle of repose. In comparison clay has low internal friction but high levels of cohesion. For slope failure to occur, two factors must act, singularly or in conjunction: either stress is increased beyond shear strength, or the latter is reduced. In the study area the major causes of mass-movement is a decrease in shear strength. Short term stresses, such as produced by seismic activity, were found to be of little or no consequence. However, long term stresses resulting from the loading of soil during heavy rainfall may be considered a triggering factor and therefore relate to the climatic characteristics of the Fleurieu Peninsula. These have been determined from records kept since about 1850 both officially and by local farmers (Mason 1954; Robertson 1975).

Distribution of rainfall fluctuates according to the season and with topography, the main source being frontal uplift during the winter months which, when accentuated by topography on the western margins of the Peninsula, results in annual falls of up to 900 mm. Within the area where the majority of earthflows are found, rainfall ranges from 550 mm along the coast in the vicinity of Normanville to 750 mm near Inman Valley.

Since unusually heavy concentrations of rainfall in short periods of time are more likely to lead to mass-movements, it is necessary to know the median amounts of rainfall, and relate these to the actual amount which fell at the time an earthflow was initiated. In winter the median is 250 mm, while in summer this decreases to 63 mm (Mason 1954). This summer figure is of greater importance when taken in conjunction with the amount of moisture required to prevent the loss of soil water (150 mm). This exceeds the amount of rainfall in the upper quartile range (125 mm) so that summer desiccation is to be expected. The opening of the surface layers of soil is considered to be of utmost importance, for it allows the deep penetration of moisture when the first rains fall, usually in April.

The major cause of earthflows is a decrease in the shear strength of the soil, and the shear strength of these glacigene deposits varies with sand/clay ratio and the degree of compaction. The superficial sand layers lack intergranular cohesion, but are held by intergranular friction and adhesion by water. Bulking of the sand allows a higher than normal angle of repose which, when coupled with the non-plastic nature of sand, results in there being no earthflows involving sand alone. The increasing clay content with depth is responsible for the plastic qualities of the soil, and it is a direct result of a decrease in cohesion of this clay that earthflows occur. A number of factors are responsible for this reduction in shear strength due to a decrease in cohesion, although the anthropogenic factor is of utmost importance.

The process of wetting and drying, which causes expansion and contraction of the illite and montmorillonite lattice, over time significantly reduces the cohesive force between clay particles. Desiccation is a common occurrence during summer months, when evaporation exceeds precipitation, not only on the body of the earthflow, but on the stable surrounding slopes of the area. Where an overburden of sand is present, capillary removal of ground water is sufficient to produce subsurface desiccation. Further, the cohesive strength of clay decrease with an increase of soil moisture, and thus the subsequent replacement of groundwater, causes an increase in pore-water pressures which brings about a further loss of cohesion as the normal intergranular forces are taken up by the interstitial water. The superincumbent mass of soil is therefore partially supported by this groundwater, resulting in a further decrease in shear strength.

Failure, as has been demonstrated by Skempton (1948), is not immediate and is considered to vary with slope, ranging from 6 weeks in the case of a highly colloidal clay at 90° to 50 years on a clay slope of 18°. Acknowledging the differences in clay type and proportions, it is felt that the low slope angles in the area contribute to the time lag between the clearing of vegetation and earthflow.

Cohesion is also reduced as a consequence of clearing, as a change to the clay-humus colloid results from base exchange. Humus has the important role of improving soil texture and structure by the creation of granular aggregates. These aggregates are destroyed with the loss of humus and the replacement by sodium ions. More importantly however, humus has the propensity to absorb 80-90% of its own weight in water, whereas clays can absorb only 15-20%. If a sufficient quantity of humus exists, rainfall is retained in the surface layer to a certain degree, thereby decreasing the amount of water in contact with the substratum. Since earthflow occurs at this level by plastic deformation, it is probable that the humus layer slows or prevents the attainment of plasticity. During summer months, water is retained by the humus and thus desiccation is reduced.

It has been suggested that vegetation stabilises slopes by root anchorage. Various studies have indicated the relationship between mass-movements and the depth and type of root systems (Rice, Corbett & Bailey 1969). So (1971) however, doubts whether this relationship is a clear cut as suggested, and infers that vegetation holds only the surface layers, and allows plastic deformation at a lower depth.

Within the area under discussion, the role of vegetation is vitally important. No large scale mass-movements are discernible on the little remaining vegetation, although minor movement has occurred in earthflow number twelve, where isolated trees and gorse are found. Rafting of trees was limited. Overall, therefore, earthflows are located on cleared slopes, while some have been stabilised by revegetation.

The time lag between clearing and subsequent earthflow is attributed to a number of factors. Because of low general slope angle gravitational shear stress is limited. More importantly, the cohesion supplied by the clay and clay-humus colloid decreased gradually over time by wetting and drying and base change on the clay-humus colloid. The holding power of roots was lost at an early stage, but earthflow did not occur until shear stress exceeded shear strength. Increased shear stress resulted from saturation of the soil produced by intense rainfall over short periods of time. Once movement causes minor subsidence, a water trap is formed and thus an autocatalytic process eventuates. Why an earthflow occurred at one point and not another may be related to minor differences in soil profile, rates of loss of cohesion in clay, the deterioration of the clay-humus colloid and ultimately the time of clearing of vegetation by European settlers.

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STRANDED SHINGLE BEACH RIDGES, UPPER SPENCER GULF, SOUTH AUSTRALIA: EVIDENCE FOR HIGH WAVE ENERGY DISSIPATION DURING THE LATE PLEISTOCENE

BY J. R. HAILS AND V. A. GOSTIN

Summary

Stranded shingle beach deposits have been traced over a distance of some 50 km from the near head of Spencer Gulf southwards along its western shore to Stony Point, near Whyalla. These deposits, which consist of moderately sorted rounded to sub-angular pebbles and cobbles, form well preserved ridges 3-5 m above present mean sea level. Entire, non-abraded shells of the estuarine bivalve Anadara trapezia (Deshayes 1840) are abundant in the beach deposits and, because this species is now extinct in South Australia, a Pleistocene age is indicated for the ridges.

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by J. R. HAILS* and V. A. GOSTIN†

Summary

HAILS, J. R. & GOSTIN, V. A. (1978) Stranded shingle beach ridges, upper Spencer Gulf, South Australia: evidence for high wave energy dissipation during the late Pleistocene. *Trans. R. Soc. S. Aust.* **102**(6), 169-173, 31 August, 1978.

Stranded shingle beach deposits have been traced over a distance of some 50 km from near the head of Spencer Gulf southwards along its western shore to Stony Point, near Whyalla. These deposits, which consist of moderately sorted, rounded to sub-angular pebbles and cobbles, form well preserved ridges 3-5 m above present mean sea level. Entire, non-abraded shells of the estuarine bivalve *Anadara trapezia* (Deshayes 1840) are abundant in the beach deposits and, because this species is now extinct in South Australia, a Pleistocene age is indicated for the ridges.

The movement of gravel by present-day waves in the northern part of Spencer Gulf is restricted compared with that indicated by the stranded, shingle beach ridges. During the Pleistocene it appears that the combination of a high sea level, large fetch, strong easterly winds and high wave energy dissipation along the shoreline emplaced the relict shingle beach deposits.

Introduction

Evidence for high stands of sea level during both the Pleistocene and Holocene epochs has been cited from several regions of Australia (Hails 1965; Thom *et al.* 1969; Gill & Amin 1975; Thom & Chappell 1975; Cook *et al.* 1977). Some of this evidence pertains to shore platforms which may have been abraded several times during eustatic changes of sea level in the past. The rate at which shore platforms are modified by marine abrasion varies widely because of differential weathering and erosion controlled by rock composition, texture and structure and, therefore, it is difficult to relate them to former still stands of sea level. Furthermore, such a correlation is almost impossible anyway, because modern sea level around Australia is believed to be within a metre or so of its former level during the late Pleistocene (Hails 1968; Chappell 1976).

The problem of dating Pleistocene sea levels in coral reef areas has been outlined by Chappell *et al.* (1974). In addition, many C^{14} dates reported from Pleistocene strandlines near present sea level have proved to be unreliable, and therefore other dating methods must be used before an accurate reconstruction of past events can be undertaken (Thom 1973). Because of these facts, it is now generally recognised by researchers conducting process studies in the coastal zone that depositional features, such as barrier beaches containing diagnostic fossils, datable organic material and soil horizons, are better indicators of relative changes in mean sea level.

During a recent survey of the coast of upper Spencer Gulf, as part of a detailed study of the submarine geology and nearshore processes within the region, the writers traced well preserved stranded shingle beach deposits from Black Point, 15 km northeast of Whyalla, northwards along the shoreline to a point opposite Snapper Point 8 km south of Port Augusta, a distance of about 50 km (Fig. 1). The term 'shingle' is used here to describe beach gravels composed predominantly of pebbles and cobbles.

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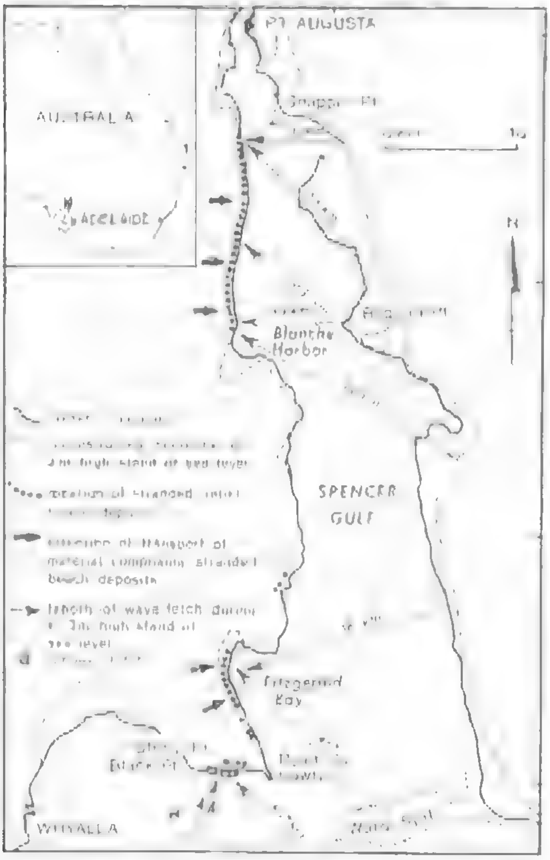

Fig. 1. Generalized map of upper Spencer Gulf to show distribution of stranded beach deposits and maximum fetches during a +3 m-high stand of Pleistocene sea level.

The purpose of this paper is to describe briefly the main diagnostic features of these deposits and to consider the conditions under which they may have been emplaced during a Pleistocene high stand of sea level. As far as the writers are aware, these deposits have only been recorded on the Cultana (1:63360) geological map, and in the Black Point—Point Lowly area by Crawford (1963) who described them as Quaternary 'emerged offshore bars' tectonically elevated to their present position. However, Firman (1965), without citing Crawford's earlier work, mentions a 10-ft Tertiary-Quaternary high stand of sea level and associated gravel beach ridges.

Stranded beach deposits

Most of the stranded beach deposits form sinuous, flat-topped ridges which stand 3-5 m above mean sea level (Fig. 2A). They are usually narrow, no more than 10-15 m wide, although at one locality, 15 km south of Port Augusta, one ridge is more than 75 m in width (Figs 2E and 2F). The seaward slope of these ridges usually exceeds 30°, which is generally steeper than the landward or lee slope. The 75 m-wide ridge shown in Figs 2E and 2F has an extremely gentle lee slope and resembles a washover fan, a feature deposited on a coast during hurricanes and cyclones when beach ridges are extensively eroded by storm waves. In some localities the shingle deposits form cliffs behind the modern beach. An intervening narrow 'flat' between the cliffs and the backshore is now used as a road for vehicular traffic, particularly between Port Augusta and Blanche Harbour. Many ridges are vegetated with low scrub, but this is generally absent from the flat, crestal surfaces because of the extreme permeability of the gravels.

Rounded to sub-angular pebbles and cobbles of Precambrian sandstones and quartzites are the main constituents of the ridges (Fig. 2B) These have been derived from either alluvial fans, dissected by ephemeral streams, or colluvium that mantles neighbouring cliffs usually cut in bedrock. A few of the cliffs, though, comprise remnant alluvial-fan deposits. In the Point Lowly area the shingle comprising the ridges is significantly more rounded than that on most other beaches where the material has been derived directly from cliffs and outcrops of Precambrian bedrock.

At most localities the stranded shingle is moderately sorted and varies in size from large flat cobbles, as in the Black Point-Point Lowly sector, to more ubiquitous sub-rounded, small cobbles and pebbles elsewhere along the Gulf coast. Some lateral reduction in mean clast size has been noted away from source areas, but the alongshore movement of gravel has been minimal, as evidenced by the absence of recurved spits.

The thick-shelled estuarine cockle *Anadara trapezia* is abundant in the relict beach deposits especially in Fitzgerald Bay and the northernmost part of the Gulf (Figs 2C and 2D). According to Gill (1977), this species migrated to Australia during the Pleistocene epoch, probably more than 400,000 years ago, and became abundant in southern Australia during the Last Interglacial. However, *A. trapezia* is absent from the modern sediments of South Australia except where it has been reworked from Pleistocene deposits. The shells found in the stranded shingle ridges are entire, non-abraded valves and therefore do not appear to have been reworked from early Pleistocene deposits.

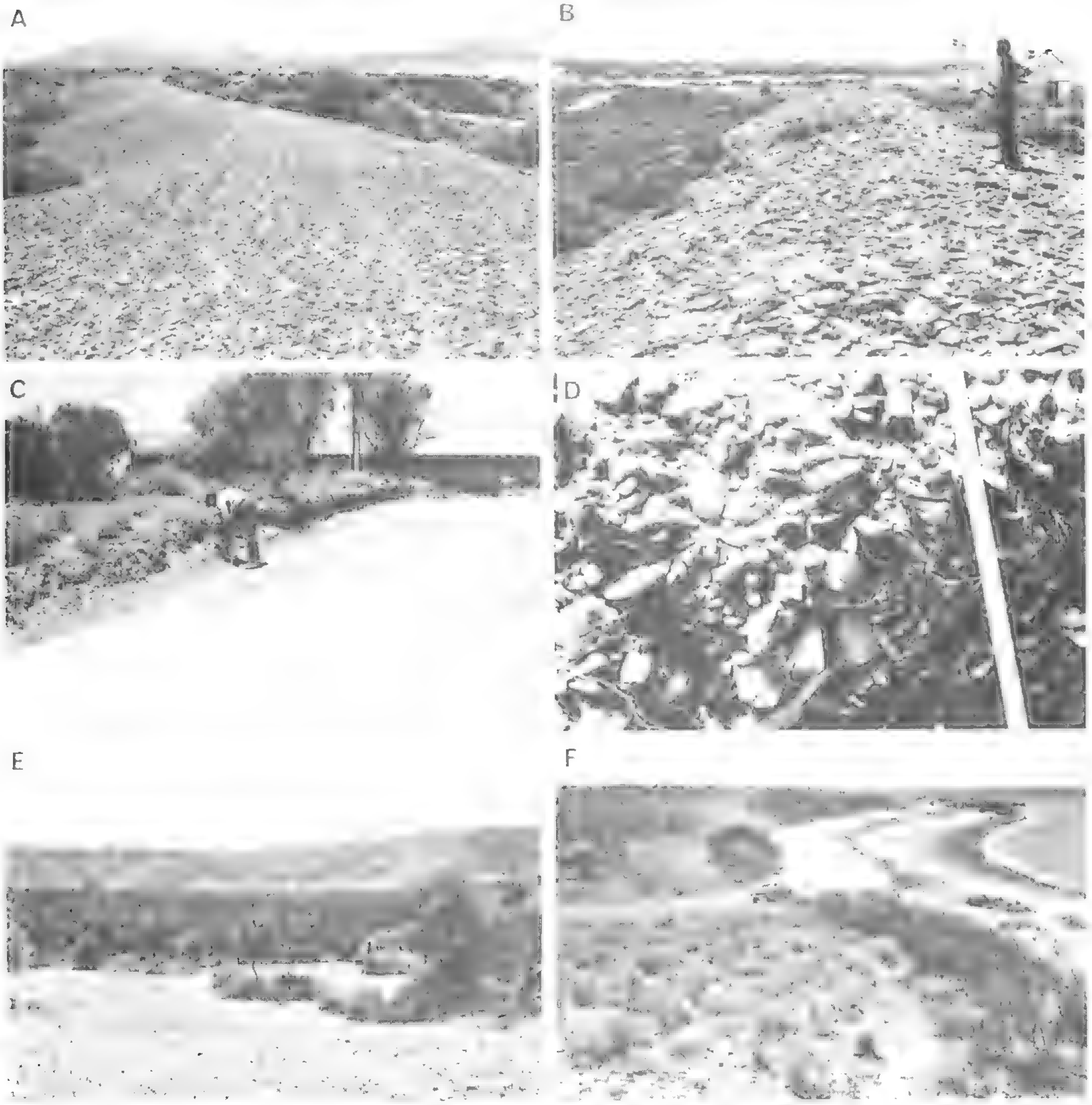

Fig. 2A Stranded sinuous shingle beach ridge, looking north, Fitzgerald Bay. (Map Ref. 568534, Cultana 6432-III, 1:50 000).
Fig. 2B. Cobbles and scattered boulders comprising 3m beach ridge, Stony Point. View looking east towards Point Lowly. (Map Ref. 575456, Mambray 6432-II, 1:50 000).
Fig. 2C. Road cut through stranded shingle beach, containing abundant shells of *Anadara trapezia*, Saints Bay. (Map Ref. 580825, Davenport 6432-I, 1:50 000).
Fig. 2D. Part of road-cut in Fig. 2C showing *in situ Anadara trapezia*.
Fig. 2E. Landward margin of non-vegetated part of washover fan shown in Fig. 2F, and located 15 km south of Port Augusta. (Map Ref. 586865, Davenport 6432-I, 1:50 000).
Fig. 2F. View looking north showing washover fan with road on seaward side. Location as in Fig. 2E.

Discussion

No marine gravels have been located above the Pleistocene shoreline reported here, and very little gravel has been recovered in 3-5 m long, undisturbed vibrocores obtained from the seabed immediately offshore from the stranded shingle beach ridges. Therefore, it may be inferred that there has never been a substantial offshore reservoir of shingle in upper Spencer Gulf. Also, the fact that the shingle ridges display minimal grading, and no marked variation in width in an alongshore direction, suggests that there has been only minor northerly or southerly movement of beach material along the embayed western shore of the Gulf in the past. The shingle has been derived from either outcrops of Precambrian quartzite or, more commonly, adjacent dissected alluvial fans which, as stated previously, form cliffs in some localities. It appears that the shingle was moved a short distance offshore, abraded in the nearshore zone and ultimately deposited as beach ridge material. In the relatively confined and sheltered parts of northern Spencer Gulf today, the movement of beach gravel is somewhat restricted within the inter-tidal zone by the mangrove *Avicennia marina* var. *resinifera* ((Forst. f.) Bakh v.d. Brink 1921) which grows on sub-angular sandy gravel and often between blocks of cemented Pleistocene conglomerate

If Gill's thesis on the migration of *Anadara trapezia* is correct the stranded beach ridges which contain *A. trapezia* could have been built during either the Last Interglacial (120,000 years BP) or during a late Pleistocene interstadial, about 30,000 years BP because, as stated above, there is no evidence of an earlier Pleistocene sea level in upper Spencer Gulf The presence of entire and unweathered shells, the well-preserved beach ridge surfaces, and the lack of fine windblown sediment on the ridge tops collectively suggest a very late Pleistocene age, but dating is obviously needed to establish an absolute age.

Regardless of the age of the stranded beach ridges, their presence is significant in determining past wave and wind regimes in the northern part of the Gulf. In this context, it is pertinent to consider the factors involved in the formation of such ridges. In the area of generation, the height of sea waves and their period are functions of the duration that the wind (storm) blows (D), the wind velocity (U), and the length of fetch (F) or the distance over which the wind blows. The fetch length is a major factor because it determines not only the time during which wind energy is transferred to the sea surface, but also the wave height (H) and period (T). Thus, for relatively short fetches, waves depend upon the fetch length (F) and wind velocity (U), and for long fetches on wind velocity and duration (D). This relationship can be written symbolically as $H,T = f(U,F,D)$.

It can be seen in Figure 1 that winds would have been mainly southeasterly in order to build most of the shingle ridges because smaller waves are generated from other directions. Even if easterly winds occurred less frequently than all others they were, nevertheless, the dominant winds that generated waves able to move shingle and form beach ridges. Fine sand and mud could have been moved selectively by currents and carried alongshore in suspension. It is also known that variation in wave energy is partly responsible for variations in particle size parallel to the shoreline and that larger particles are associated with greater energy. Theoretically, wave heights of about 3-5 m above mean sea level can be generated by winds of 50 knots blowing over a fetch of 90 km—one which far exceeds those in upper Spencer Gulf today—but waves of this height are usually destructive.

On the other hand, shingle can be deposited a few metres above a given datum by constructive swell and, in the light of this fact, it should be considered whether or not the stranded ridges were emplaced during a +3 m, or slightly lower, stillstand of the sea during the Pleistocene. Certainly, the 2 m difference in the maximum height of ridge crests reported here could reflect degree of exposure to, and variations in, wave enegy as determined by the length of fetch in the past, and coastal configuration.

The present tidal range in the Gulf is about 2 m, but Radok & Raupach (1977) have shown in recent studies that weather systems raise mean sea level against the south coast of Australia because of barometric pressure and wind stress operating over large areas of the Southern Ocean. Waves and tides, in turn, are superimposed on this mean sea level. Because changes in mean sea level are relatively slow, they are able to penetrate into confined water bodies like Spencer Gulf and Gulf St Vincent in South Australia, and may consequently induce notable water exchange and sediment movement. Coastal erosion along the southern margin of Australia today can, in fact, be linked to these variations. If similar meteorological conditions existed in the late Pleistocene, and isobaric pressure gradients were steeper, there is little doubt that shingle ridges could also have been constructed as a result of higher wave energy in upper Spencer Gulf.

It is worth mentioning that studies by Veeh (1966) in the Central Pacific have shown that sea level stood approximately 2-6 m above modern datum during the Last Interglacial. However, wide-scale correlations can be suspect because of regional and local factors, some of which have been discussed here with regard to South Australia.

As only a small area of the Gulf is under review in this paper the writers cannot debate with justification whether the ridges have been elevated as a result of tectonic activity as proposed for the Black Point-Lowly Point area by Crawford (1963). Although tectonism cannot be ignored on a much larger regional scale it seems unlikely, for the reasons just cited, that it can exclusively account for the 3-5 m beach ridges.

In conclusion available evidence indicates that the stranded shingle ridges in upper Spencer Gulf are Pleistocene in age, and were most likely built during a +3 m high stand of sea level when easterly winds predominated in the region and large waves from the southeast dissipated their edges along the western shore. No corresponding shingle ridges are known along the eastern counterpart of the Gulf despite the fact that southwesterly waves travel across the longest fetch today.

Acknowledgement

The writers wish to acknowledge the support of an ARGC grant for the detailed study of Spencer Gulf which is currently in progress.

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OSTRACOD (CRUSTACEA: PODOCOPIDA) FROM SOUTHERN AUSTRALIAN SALT LAKES, WITH THE DESCRIPTION OF RETICYPRIS NEW GENUS

BY K. G. MCKENZIE

Summary

Ostracoda are idntified from collections made in South Australian and Western Australian salt lakes. The new genus, Reticypris, new species Cyprinotus edwardi, Diacypris paracompacta, D. occidentalis, Reticypris herbsti, R. dedeckkeri, Cyprideis westraliensis, ?Microcytherura difficilis, Cytheroma sudaustralis and new subspecies Mytilocypris tasmanica chapmani are described.

OSTRACODA (CRUSTACEA: PODOCOPIDA) FROM SOUTHERN AUSTRALIAN SALT LAKES, WITH THE DESCRIPTION OF *RETICYPRIS* NEW GENUS

by K. G. McKenzie*

Summary

McKenzie, K. G. (1978) Ostracoda (Crustacea: Podocopida) from southern Australian salt lakes, with the description of *Reticypris* new genus. *Trans. R. Soc. S. Aust.* **102**(7), 175-190, 30 November, 1978.

Ostracoda are identified from collections made in South Australian and Western Australian salt lakes. The new genus, *Reticypris*, new species *Cyprinotus edwardi*, *Diacypris paracompacta*, *D. occidentalis*, *Reticypris herbsti*, *R. dedeckkeri*, *Cyprideis westraliensis*, *?Microcytherura difficilis*, *Cytheroma sudaustralis* and new subspecies *Mytilocypris tasmanica chapmani* are described.

Introduction

The continental Ostracoda of Australia are gradually becoming better known, thanks to the impetus given to taxonomic studies by limnologists. For an arid continent the study of saline lake environments has obvious relevance and, since Ostracoda are one of the commoner groups in such environments, it is regrettable that little relevant taxonomic work has been undertaken. The opportunity to improve this situation came with an invitation from W. D. Williams to study the ostracodes in saline lake collections made by him in southern South Australia and Western Australia in 1971 and 1972. The chemical composition of these environments and detailed locality maps are provided in Williams & Buckney (1976).

Previously, the large endemic species have been studied by De Deckker (1974, 1975, 1976) and McKenzie (1966), and valuable work was done by Herbst (1957, 1958) on the endemic genera *Platycypris* and *Diacypris*. In addition to species described by these workers, a new genus, eight new species and a new subspecies were identified in the course of the present study.

Materials and methods

Soft parts have been drawn using a Wild M-20 camera lucida. External carapace morphology was photographed by scanning electron microscopy but internal features have been drawn.

The German taxonomic terms Zahnborsten and Strahlen are used commonly in the general ostracode literature. Zahnborsten are spine-like bristles on the maxillule third lobe which are often barbed. Strahlen are pilose setae on the respiratory epipods of the mandible, maxillulue and maxilla (P I). The terms P I, PII, PIII refer to paired thoracic limbs on the rear of the body. The α, β, and γ sensory bristles on the mandible endopod were defined and illustrated in McKenzie (1977a).

The conventions: L = length; H = height; B = breadth; RV = right valve; LV = left valve; have been used throughout. The term "population" means at least a dozen individuals of a species, including adult males and females and juveniles.

Types are stored at the Australian Museum, Sydney and the remainder of the material has been returned to W. D. Williams, University of Adelaide. Copies of appendices which give locality details (Appendix I), ostracode determinations and numbers of specimens by locality (Appendix II), and associated fauna (Appendix III) may be obtained from the author.

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Systematic descriptions

Superfamily: CYTHERACEA Baird, 1850
Family: CYTHERIDEIDAE Sars, 1925
Subfamily: CYTHERIDEINAE Sars, 1925
Genus: CYPRIDEIS Jones, 1857

Cyprideis westraliensis sp. nov

FIGS 1–3, 21–28

Holotype: AM P26650, adult male.

Paratypes: AM P26651; 2 adult females, 1 adult male.

Type locality: Causeway at Lake Preston, W.A.

Material: Populations from Lakes Preston and Coolongup, W.A.

Description: Shell whitish, but appearing brownish because of yellow-brown soft body inside; medium sized; elongate subrectangular in lateral view; inequivalved with LV distinctly larger, and RV possessing small posteroventral spine in some individuals; ornamented with large shallow pittings; dorsum straight, slightly inclined posteriorly; anterior more broadly rounded than posterior; venter weakly inflexed anteriomedially; greatest height just in front of central muscle scars, and about half length. In dorsal view subelliptical; tapering anteriorly, rounded posteriorly; displaying sex dimorphism: females broadened posteriorly whereas males are not; greatest breadth medial and under half length in males, but posteromedial and about half length of females. Internally: lamellae moderately broad; narrow anterior and posterior vestibules present; inner margin regular; marginal pore canals numerous, often branched; normal pore canals scattered, sieve type; central muscle scars comprising 4 adductors in subvertical row, a large V-shaped frontal scar, a fulcral scar and at least one large mandibular, some dorsal scars observed also; hinge entomodont, consisting in RV of elongate, distinctly crenulate terminal tooth-like projections, and medially with crenulate furrow anteriorly which becomes weakly crenulate ridge posteriorly; LV complementary.

Antennule robust, 5-segmented; segmental length ratios 25:22:10:10:11; armature comprising mainly strong claw-like spines, terminal segment about 3½ times as long as wide. Antenna powerful, 4-segmented; segmental length ratios 35:7:33:5; armature normal; flagellum long, 2-segmented. Mandible coxa powerful; coxal teeth decreasing regularly in size from front to rear; endopod normal; epipod with 5 Strahlen. Maxillule palp and lobes normal; epipod with 17 Strahlen, including one which points downwards. Thoracic limbs (P I to P III) all functioning as walking legs, and displaying asymmetry between right and left limbs, especially in male P II, which is typical for this genus. Brush shaped organs present in male. Furca much reduced. Posterior of female body flattened and produced into a pointed lobe. Cups of nauplius eye fused. Hemipenes large, comprising an ovate posterior girdle strengthened by numerous muscle bands, and acuminate anterior lappet; this combination typical for genus. Natural colour of soft body yellow-brown.

Dimensions: Holotype, adult male—L = 0.90 mm, H = 0.44 mm, B = 0.44 mm. Paratype, adult female—L = 0.92 mm, H = 0.45 mm, B = 0.46 mm.

Discussion: The genus *Cyprideis* is well known, not only because it is polyhaline and regularly encountered in a variety of fresh, brackish and saline environments, but also because its distribution is cosmopolitan, extending to every continent except Antarctica. Long ago it was hypothesised that this cosmopolitan distribution was effected by birds, and some recent

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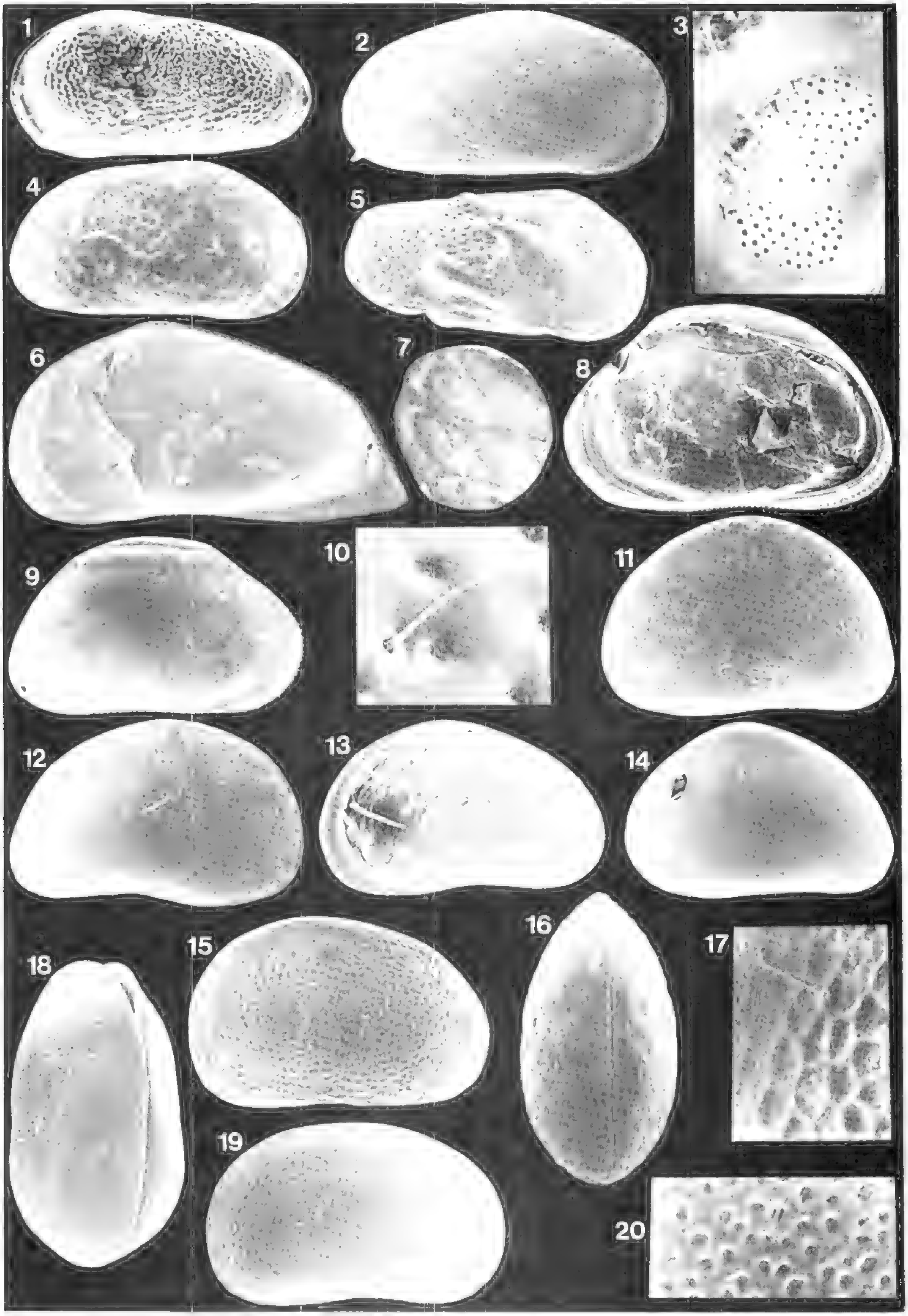
Figs 1–20. Figs 1–3: *Cyprideis westraliensis* sp. nov., holotype. 1: external LV, x 40; 2: external RV, x 45; 3: sieve type normal pore canal, x 1500. Fig. 4. ? *Microcytherura difficilis* sp. nov., holotype, external RV, x 120. Fig. 5, *Limnocythere mowbrayensis*, female, external RV, x 100. Fig. 6, *Mytilocypris tasmanica chapmani* ssp. nov., holotype, internal RV, x 15. Fig. 7, *Diacypris occidentalis* sp. nov. paratype AM P26674, detail muscle scars internal RV x 375; Figs 8–10: *Cyprinotus edwardi* sp. nov. 8, paratype, AM P26664, internal RV, x 25; Fig. 9, holotype, male, external RV, x 25; Fig. 10, rimmed simple normal pore canal of holotype x 800. Figs 11, 12: *Diacypris paracompacta* sp. nov., paratype, AM P26670, female. 11: external LV, x 60; 12: external RV, x 60. Figs 13–14: *Diacypris occidentalis* sp. nov., paratype, AM P26674, female. 13: internal RV, x 65; 14: external LV, x 55. Fig. 15, *Reticypris herbsti* gen. nov. sp. nov., holotype, male, external LV, x 60. Fig. 16, ? *Microcytherura difficilis* sp. nov. holotype, dorsal view x 110. Fig. 17, *Reticypris herbsti* gen. nov., sp. nov., holotype, rimmed simple normal pore canals, x 300. Figs 18, 19: *Renicypris dedeckkeri* gen. nov., sp. nov., paratype, AM P26682, female. 18: dorsal view, x 60; 19: external LV, x 60. Fig. 20, *Diacypris occidentalis* sp. nov., paratype AM P26674, female, rimmed, simple, normal pore canal x 450.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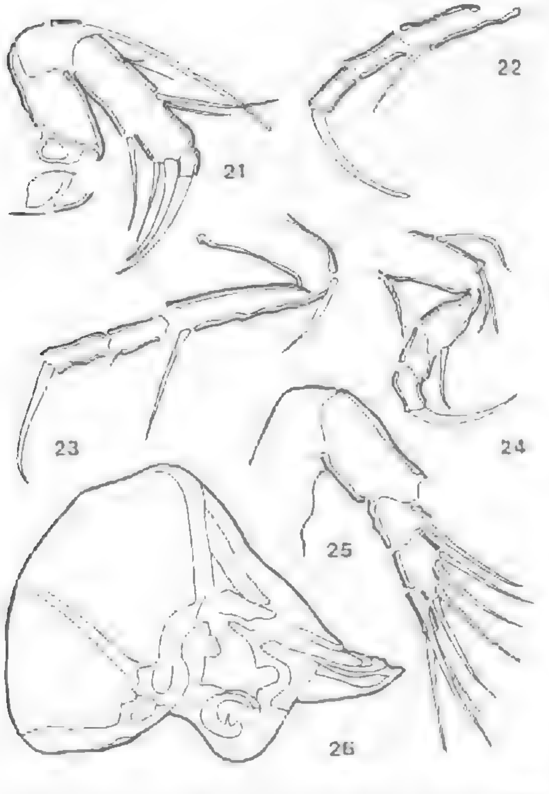


Figs 21–26. *Cyprideis westraliensis* sp. nov., holotype, male; 21: antenna; 22: distal P II; 23: distal P III; 24: P I; 25: antennule; 26: hemipenis. All magnifications x 300.

experimental confirmation has been obtained (Löffler & Leibetseder 1965). Because *Cyprideis* broods its first instar in the shell, the passive transport of both sexes or of impregnated or brooding females is necessary to effect distribution across barriers such as the oceans and great deserts (McKenzie 1973).

Over 30 species of *Cyprideis* have been described but, because the carapace morphology can vary intraspecifically and is similar in practically all species, distinctions often rest on differences in the male hemipenis, which follows a pattern characteristic of the genus. However, the hemipenis of *Cyprideis westraliensis*, in particular the morphology of the internal chitinised process, is not matched in any previously described species.

Derivation of name: From Western Australia.

Family: CYTHEROMATIDAE Elofson, 1939
Subfamily: CYTHEROMATINAE Elofson, 1939
Genus: CYTHEROMA Müller, 1894

Cytheroma sudaustralis sp. nov.

FIGS 30, 35–42

Holotype: AM P26652, adult male.

Paratypes: AM P26653–26654, 2 adult females, 1 adult male.

Type locality: Coastal pond between Port Clinton and Wakefield, S.A.

Material: Five topotypic adults.

Description: Shell whitish; medium sized; elongate subreniform in lateral view; inequivalved, left valve (LV) slightly larger than right valve (RV) and overlapping it ventrally; shell smooth; dorsum gently convex; anterior rounded; posterior broadly rounded; venter weakly inflexed anteromedially; greatest height just behind adductor muscle scars, and about half length. In dorsal view regularly elliptical; greatest breadth medial and about half length. Internally: lamellae broad; line of concrescence marginal; anterior vestibule large, posterior vestibule large and elongate; inner margin regular; marginal pore canals short and numerous; normal pore canals large, sieve-type, numerous; central muscle scars comprising 4 adductors in subvertical series, plus broadly V-shaped frontal scar, fulcral scar, and two mandibular scars; hinge very weakly lophodont, RV with lobate anterior antislip projection and low weakly crenulated posterior projection, LV with complementary antislip projection, weakly developed median bar and shallow posterior groove.

Antennule 6-segmented; segmental length ratios 7:7:2:1.5:2.5:3; armature consisting mainly of strong claw-like spines; terminal segment about 5 times as long as wide. Antenna broad and short; segmental length ratios 9:11:4; armature normal; flagellum 2-segmented; antennal gland lobate. Mandible coxa normal, second tooth from anterior slightly more prominent than others which otherwise diminish in strength regularly from front to rear; endopod normal; epipod with 2 very long Strahlen and 1 or 2 shorter Strahlen. Maxillule palp and lobes normal; epipod with a single aberrant Strahl and 14 feathered Strahlen. Thoracic limbs normal, increasing in size from P I to P III as illustrated. Posterior of body hirsute in both sexes. Cups of the nauplius eye fused.

Carapace sex dimorphism very weak, females slightly larger and broader than males. Hemipenes large, about 40% of body length, pointed anteriorly and similar to those illustrated for other cytheromatids, being characterised by prominent penifera.

Dimensions: Holotype, adult male—L = 0.53 mm; H = 0.26 mm; B = 0.27 mm. Paratype, adult female—L = 0.56 mm; H = 0.28 mm; B = 0.29 mm.

Discussion: Cytheroma has been described rarely in the literature. Hartmann (1964) notes five species, of which *C. similis* Skogsberg, 1959 is probably a *Paracytheroma*, and Schornikov (1969) has described a sixth. Further, Species DG Maddocks, 1966 may be a *Cytheroma*. These other species all differ in shape from the new species.

The distributions of other genera in the family form an interesting biogeographic pattern. *Paracytheroma* Juday, 1907 and *Megacythere* Puri, 1960 (which some authors have synonymised) occur in the Caribbean and on both coasts of the Americas as far south as Valdivia, Chile (Hartmann 1962). *Pontocytheroma* Marinov, 1960 is restricted to the Black and Azov Seas (Schornikov 1969). The other *Cytheroma* species occur in the North Atlantic, Mediterranean and Red Sea, possibly even to Madagascar (Maddocks 1966). There are no records of these genera from the southern coasts of Africa (Hartmann 1974).

Cytheroma sudaustralis therefore may be considered as a palimpsest of an earlier Tethyan distribution pattern, once continuous for many groups from the Gulf of Mexico to Australasia (Ekman 1953, McKenzie 1967b).

Derivation of name: From South Australia.

Family: CYTHERURIDAE Müller, 1894
Subfamily: CYTHERURIDAE Müller, 1894
Genus: MICROCYTHERURA Müller, 1894

? **Microcytherura difficilis** sp. nov.

FIGS 4, 16, 34, 43–51

Holotype: AM P26655, adult male.

Paratypes: AM P26656–26657, population of males, females and juveniles

Type locality: The Coorong, opposite Mount Mills, S.A.

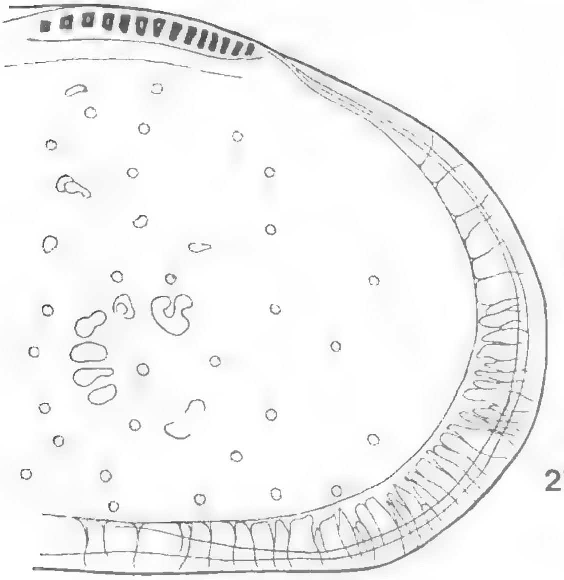
Material: A topotypic population.

Description: Shell whitish; small; subrectangular in lateral view; equivalved; weakly reticulate over entire surface, reticulations forming concentric pattern anteriorly and ventrally; dorsum straight; anterior rounded, trending anteroventrally; posterior rounded; venter weakly inflexed anteromedially; greatest height slightly in front of muscle scars and about half length. In dorsal view, elliptical; narrowing anteriorly, but more rounded posteriorly; greatest breadth medial, and just over half length. Internally: lamellae moderately broad; anterior vestibule and small posterior vestibule present; marginal pore canals number about 10 anteriorly and 5 ventrally, all short and straight; normal pore canals scattered, sieve type; central muscle scar pattern consisting of subvertical row of 4 adductors, a V-shaped frontal scar and 2 mandibulars; hinge merodont, comprising terminal crenulate teeth in RV with intervening furrow and terminal crenulate sockets in LV with an intervening ridge. Shell sex dimorphism not marked, but females tend to be shorter and relatively broader than males.

Antennule 6-segmented; segmental length ratios 14:17:5:5:6:8; terminal segment about 4 times as long as wide; armature less powerful than in *Cyprideis* and *Cytheroma*. Antenna 4-segmented; segmental length ratios 13:5:26:3; flagellum extending to about tip of terminal claw and bent distally; terminal claw short and stout. Forelip denticulate distally. Mandible coxa with anterior tooth projecting distinctly forwards of others (typical for this genus); endopod normal, segments relatively wide. Maxillule partially destroyed during dissection, comprising an epipod with about 10 Strahlen and a normal palp and lobes; length ratio of 2 palp segments 13:4. Walking legs (P I to P III) increasing in length from P I to P III. Hemipenis (Fig. 51) comprising a large posterior part and small pointed anterior lappet.

Dimensions: Holotype, adult male—L = 0.37 mm; H = 0.21 mm; B = 0.20 mm. Paratype, adult female—L = 0.35 mm; H = 0.20 mm; B = 0.20 mm.

Discussion: This species proved to be a taxonomic problem, being like *Microcytherura* in carapace characters except that the posterior cauda, which is weakly expressed in the European species of the genus, appears to be absent or almost absent in this species. But the Australasian genus *Loxocythere* Hornibrook, 1952 is also similar in carapace characters. As far as the soft parts are concerned, this species has the prolonged anterior tooth on the mandible coxa which characterises *Microcytherura*, and the typical antennal flagellum and slender antennule of cytherurines, but the walking legs are less slender than in cytherurines and the hemipenis only vaguely resembles the *Microcytherura* pattern (Sars 1926, description of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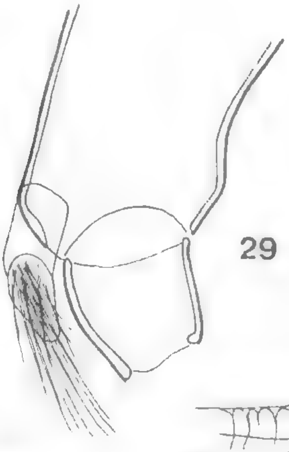
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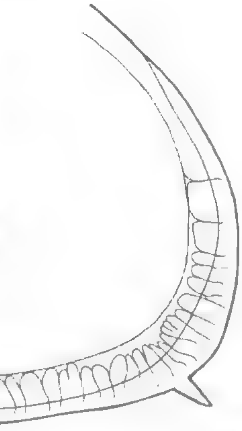
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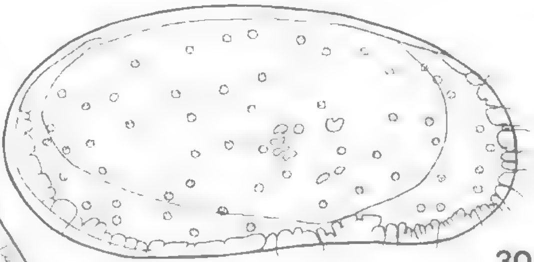
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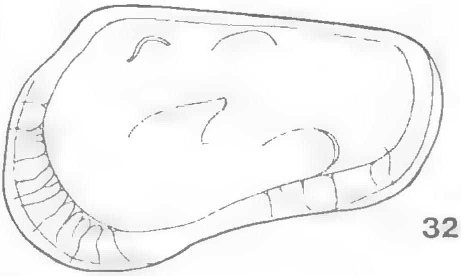
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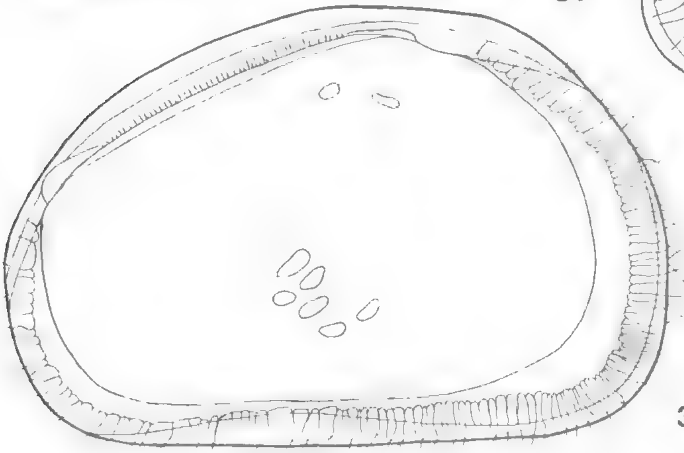
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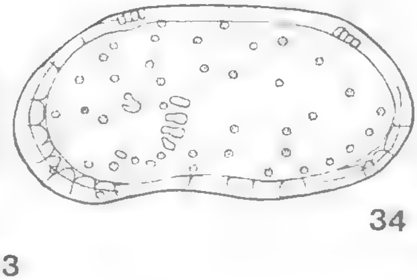
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M. fulva). On balance, the difficulties in making a confident generic placement remain.

This taxon is distinct from two previously described Australian species assigned to the genus (McKenzie 1967a) of which one, *M. triebeli*, is confirmed in the genus on soft parts as well (McKenzie, unpublished data).

As a generalisation, most of the difficulties in the taxonomy of such ostracodes stem from their small size and the need to dissect a minute body from the small carapace before examining it further. Often, critical details are destroyed as a result.

Derivation of name: From Latin: difficilis = difficult.

Family: LIMNOCYTHERIDAE Klie, 1938
Subfamily: LIMNOCYTHERINAE Klie, 1938
Genus: LIMNOCYTHERE Brady, 1868

Limnocythere mowbrayensis Chapman, 1914

FIGS 5, 32

Limnicythere (sic) *mowbrayensis* Chapman, 1914
Limnicythere (sic) *sicula* Chapman, 1919
Limnicythere (sic) *percivali* Brehm, 1939
Limnicythere (sic) *mowbrayensis*: Hornibrook, 1955

Locality: Lake Coolongup, W.A.

Family: CYPRIDIDAE Baird, 1835
Subfamily: MEGALOCYPRIDINAE Rome, 1965
Tribe: MYTILOCYPRIDINI De Deckker, 1975
Genus: MYTILOCYPRIS McKenzie, 1966

Mytilocypris tasmanica McKenzie, 1966

Localities: Several in W.A., from Lake Walungup to a lake near Lort River (see Appendix II).

Mytilocypris tasmanica chapmani subsp. nov.

FIG. 6

Holotype: AM P26659, adult male.

Paratype: AM P26660, adult female.

Type locality: Lake Coolongup, W.A.

Material: A topotypic population + 5 individuals from W.A.

Description: Shell whitish-yellowish; large; acutely subtriangular (mytiliform) in lateral view; equivalved; smooth; dorsum straight and inclined towards rear; anterior broadly rounded; posterior broadly acuminate; venter weakly inflexed anteromedially; greatest height anteromedial and slightly less than half length. In dorsal view subelliptical, narrowing at both extremities; greatest breadth medial and about 2/5 length. Internally: lamellae broad anteriorly and posteriorly, narrow ventrally; line of concrescence submarginal; inner margin regular; marginal pore canals numerous and straight; normal pore canals scattered, simple, open; central muscle scars a rosette of 4–6 adductors plus 2 mandibulars and small frontal scar; hinge of usual ridge and groove type.

The soft body is like that of *Mytilocypris tasmanica* but the male of *chapmani* differs at least in that it has only about 50 rosettes on the Zenkers Organ (about 60 in *tasmanica*). The hemipenis, however, is not very different. Other well marked differences are in the shell proportions, with *chapmani* being higher with respect to its length than *tasmanica*. In addition, these characters have not been reported previously for the genus but are likely to be constant at the generic level: rake-like organs with 9-10 teeth, one bifid; mandible endopod ventral α bristle long and slender, ventral β bristle pilose, shorter and stout, distal γ bristle thick and tapering with spiky hairs distally.

Dimensions: Holotype, adult male—L = 2.68 mm, H = 1.25 mm, B = 1.10 mm. Paratype, adult female—L = 2.88 mm, H = 1.45 mm, B = 1.33 mm.

Discussion: The taxon is described as only a subspecies because although it differs in several carapace and soft part characters, the hemipenis is closely similar to that of the nominate subspecies. It appears to differ sufficiently from other species in the genus described by Chapman (1966) and De Deckker (1978) to sustain a new taxon; in particular because the

Figs 27–34. Figs 27, 28: *Cyprideis westraliensis* n. sp., paratype, AM P26651, female: 27: internal LV anterior, 28: internal RV posterior, with posteroventral spine, x 150. Fig. 29, *Cyprinotus edwardi* sp. nov., paratype, AM P26664, female, mandible endopod, detail γ bristle, x 600. Fig. 30, *Cytheroma sudaustralis* sp. nov., holotype, male, internal LV, x 150. Fig. 31, *Diacypris paracompacta* sp. nov., paratype, AM P26672, male, internal LV, x 150. Fig. 32, *Limnocythere mowbrayensis* Chapman 1914, AM P26658, female, internal RV x 150. Fig. 33, *Reticypris herbsti* gen. nov., sp. nov., paratype, AM P26678, female, internal LV, x 150. Fig. 34, ? *Microcytherura difficilis* sp. nov., holotype, male, internal RV, x 150.

valve proportions (length:height) are unlike those in the other species. Sympatry with the nominate subspecies does not occur, but since Ostracoda are readily transported by birds and other agencies (McKenzie 1973) it cannot be ruled out as a future possibility, in which case the resulting introgressions should make an interesting study.

Derivation of name: For M. A. Chapman who described several large Australian species.

Genus: AUSTRALOCYPRIS De Deckker, 1974

Australocypris hypersalina De Deckker, 1974

Localities: Eleven localities in S.A. and W.A. (see Appendix II): the commonest species in the collection.

Australocypris robusta De Deckker, 1974

Locality: Moderately long, shallow lake 45 km N of Kingston, S.A.

Subfamily: PLATYCYPRIDINAE Hartmann & Puri, 1974

Genus: PLATYCYPRIS Herbst, 1957

Platycypris baueri Herbst, 1957

Localities: Several localities in S.A. and W.A. (see Appendix II).

Subfamily: CYPRINOTINAE Bronstein, 1947

Genus: CYPRINOTUS Brady, 1886

Cyprinotus edwardi sp. nov.

FIGS 8–10, 29, 52–57

Holotype: AM P26663, adult male.

Paratypes: AM P26664, adult female and three adult males.

Type locality: Wagin Lake, W.A.

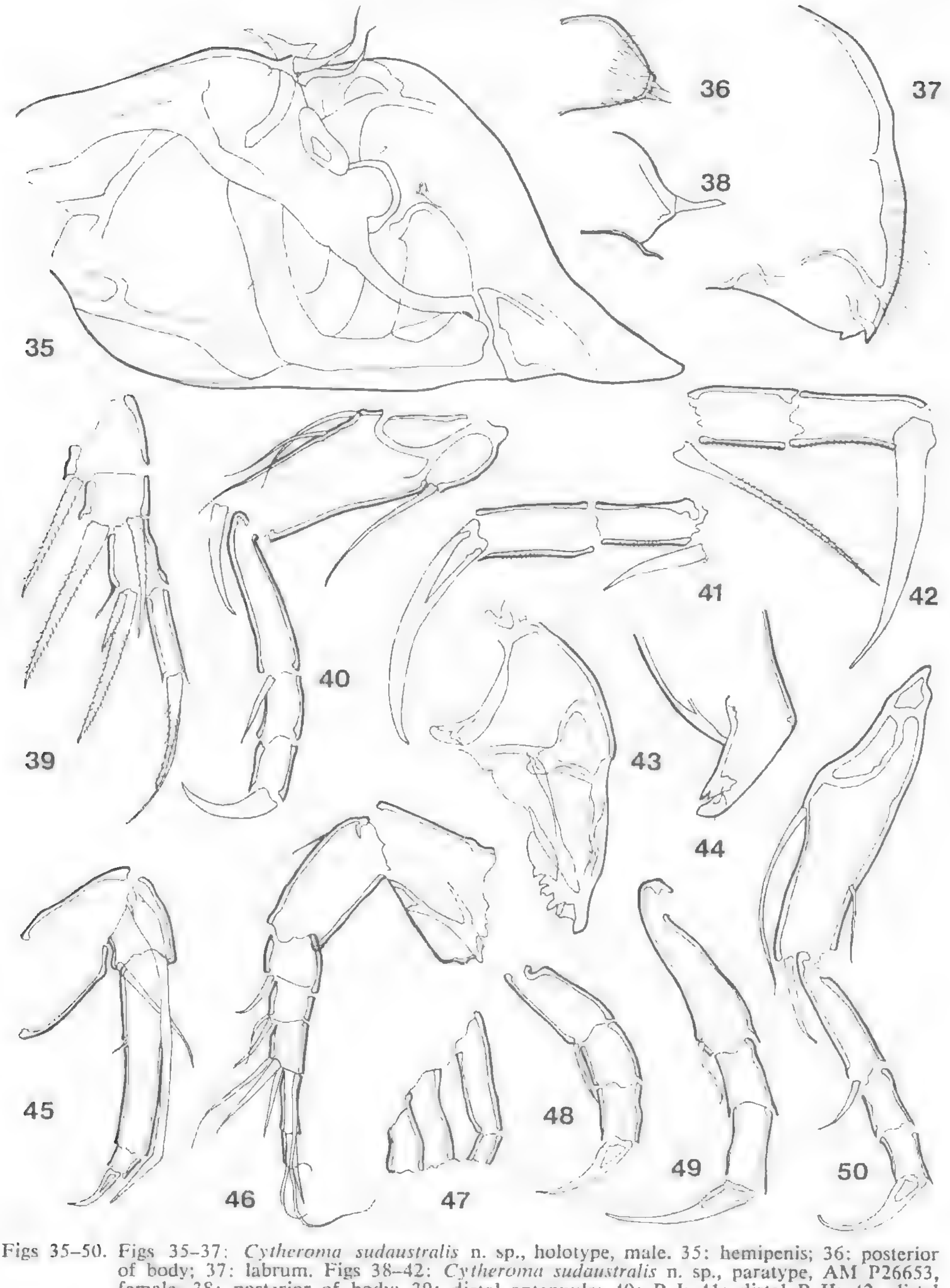
Material: Nine topotypic adults.

Description: Shell yellowish to brownish; large; subtrapezoidal in lateral view; markedly inequivalved, RV overlapping LV by a prominent dorsal hump, LV larger without any dorsal hump but overlapping RV anteriorly and ventrally; shell punctate except in muscle scar region; dorsum straight and inclined posteriorly in LV, hump-like in RV; anterior rounded, pointing anteroventrally; posterior more broadly rounded; venter inflexed medially, ventral margin of RV denticulate anteriorly and posteriorly; greatest height just behind muscle scars and 5/8 of length in RV but about half length in LV. In dorsal view somewhat flexuous; hump turning outwards as does anterior margin; narrowly elliptical with greatest breadth medial and over 1/3 length (in males). Internally: lamellae rather narrow; line of concrescence marginal; inner margin regular; marginal pore canals short and numerous; selvage very prominent in RV but absent in LV; LV with series of shallow ventral indentations to match RV denticulation; normal pore canals scattered, simple, open; central muscle scars of usual cypridid pattern, comprising 4 adductors and 2 mandibulars; hinge consisting of RV ridge and LV groove. Carapace sex dimorphism: females larger and slightly broader than males.

Antennule 7-segmented; segmental length ratios 64:17:22:13:11:9:9; terminal segment over twice as long as wide; "natatory" setae more than twice as long as 5 distal segments combined. Antennal endopod 3-segmented, length ratios of segments 22:18:1.5; flagellum reaching almost to middle of first endopod segment; "natatory" setae distal on this segment, reaching to tips of terminal claws. Mandible coxa normal; epipod with about 6 Strahlen; endopod α and β bristles both slender and pilose, γ bristle thick and tapering, adorned near its end with spiky hairs. Maxillule epipod with 3 downwards directed and 20 other Strahlen; second palp segment cylindrical and narrow; third lobe with 2 toothed Zahnborsten. Maxilla (P I) epipod with 6 Strahlen; female palps similar with 3 terminal bristles, 2 subequal, third about twice as long; male palps dissimilar and modified as clasping organs. Walking leg (P II) endopod 4-segmented; segmental length ratios 16:7:8:3; terminal claw about half again as long as last 3 segments combined. Cleaning limb (P III) reflexed, slender, normal. Chitin support with simple distal point; branched proximally, dorsal branch short and sharply curved, ventral branch less curved and relatively long. Furca with 2 claws and 2 bristles; length ratios for furcal shaft:anterior claw:posterior claw 35:20:12; length:width of shaft 15:1; bristles subequal, posterior one separated by definite gap from posterior claw. Zenkers Organ (males) with 30–31 whorls. Hemipenis subtriangular with prominent anterior process and distinctly downturned flap. Cups of nauplius eye fused.

Dimensions: Holotype, adult male—L = 1.59 mm; H = 1.13 mm; B = 0.63 mm. Paratype, adult female—L = 1.90 mm; H = 1.43 mm; B = 0.85 mm.

Discussion: Cyprinotus is one of the more distinctive continental ostracode genera, and is easily placed on carapace characters alone by the RV dorsal hump and ventral marginal den-



Figs 35–50. Figs 35–37: *Cytheroma sudaustralis* n. sp., holotype, male. 35: hemipenis; 36: posterior of body; 37: labrum. Figs 38–42: *Cytheroma sudaustralis* n. sp., paratype, AM P26653, female. 38: posterior of body; 39: distal antennule; 40: P I; 41: distal P II; 42: distal P III. Figs 43–50: ? *Microcytherura difficilis* n. sp., holotype, male. 43: labrum; 44: distal mandible covale; 45: antenna; 46: antennule; 47: maxillule palp and lobes (segments only); 48: distal P I; 49: distal P III; 50: P II. All magnifications x 600.

ticulations. This species is more flexuous in dorsal view than other known species, including the two species previously described from Western Australia—*C. dahli* Sars and *C. kimberleyensis* McKenzie. Recently, *C. edwardi* was found in a collection made in December 1976 by W. D. Williams on Kangaroo Island, S.A., so the species has a wide distribution in southern Australian salt lakes.

Derivation of name: For D. H. D. Edward, who has made several excellent large collections of Western Australian entomostracans.

Subfamily: DIACYPIDINAE McKenzie

Diagnosis: A subfamily of cypridid Ostracoda characterised by small-medium sub-triangular or subrectangular smooth or reticulate carapaces and either lacking epipods on the PI altogether or having epipods with only 2 Strahlen. Confined to Australia.

Although first noted as distinctive by McKenzie (1977b) the above constitutes its formal designation.

Discussion: The endemic Australian genus *Diacypris* has been regularly referred to the Eucypridinae Bronstein, 1947 (Danielopol and McKenzie 1977). But unlike the eucypridine genera, which are relatively large and typically mytiliform in lateral view, *Diacypris* is smaller and more regularly subtriangular in lateral view; also, whereas all eucypridines have well developed epipods with 6 Strahlen on the P I, the diacypridine genera either lack an epipod altogether, or have one with 2 Strahlen. McKenzie (1971) suggested that the presence or absence of a P I epipod alone is insufficient to separate genera which otherwise are very similar. In this instance, however, the character is only one of several by means of which eucypridines and diacypridines can be easily distinguished, as indicated above and as will appear from the descriptions below. Originally the group was proposed as a new tribe, but its status is now raised to subfamily following the rationale of Hartmann & Puri (1974) in their recent general classification of Ostracoda.

McKenzie (1977b) noted that diacypridines occupy in Australia the niches filled in South Africa by cypridopsines. This is an instance of habitat convergence, since taxonomically the groups are very distinct.

Genus: DIACYPRIS Herbst, 1961

Diacypris dietzi (Herbst, 1958)

Localities: Several in S.A. (see Appendix II). This is the most common *Diacypris* in the collection.

Diacypris fodiens (Herbst, 1958)

Localities: Several localities in S.A. (see Appendix II).

Diacypris whitei (Herbst, 1958)

Localities: Several localities in S.A. (see Appendix II).

Diacypris paracompacta sp. nov.

FIGS 11, 12, 31, 58–62

Holotype: AM P26669, adult male.

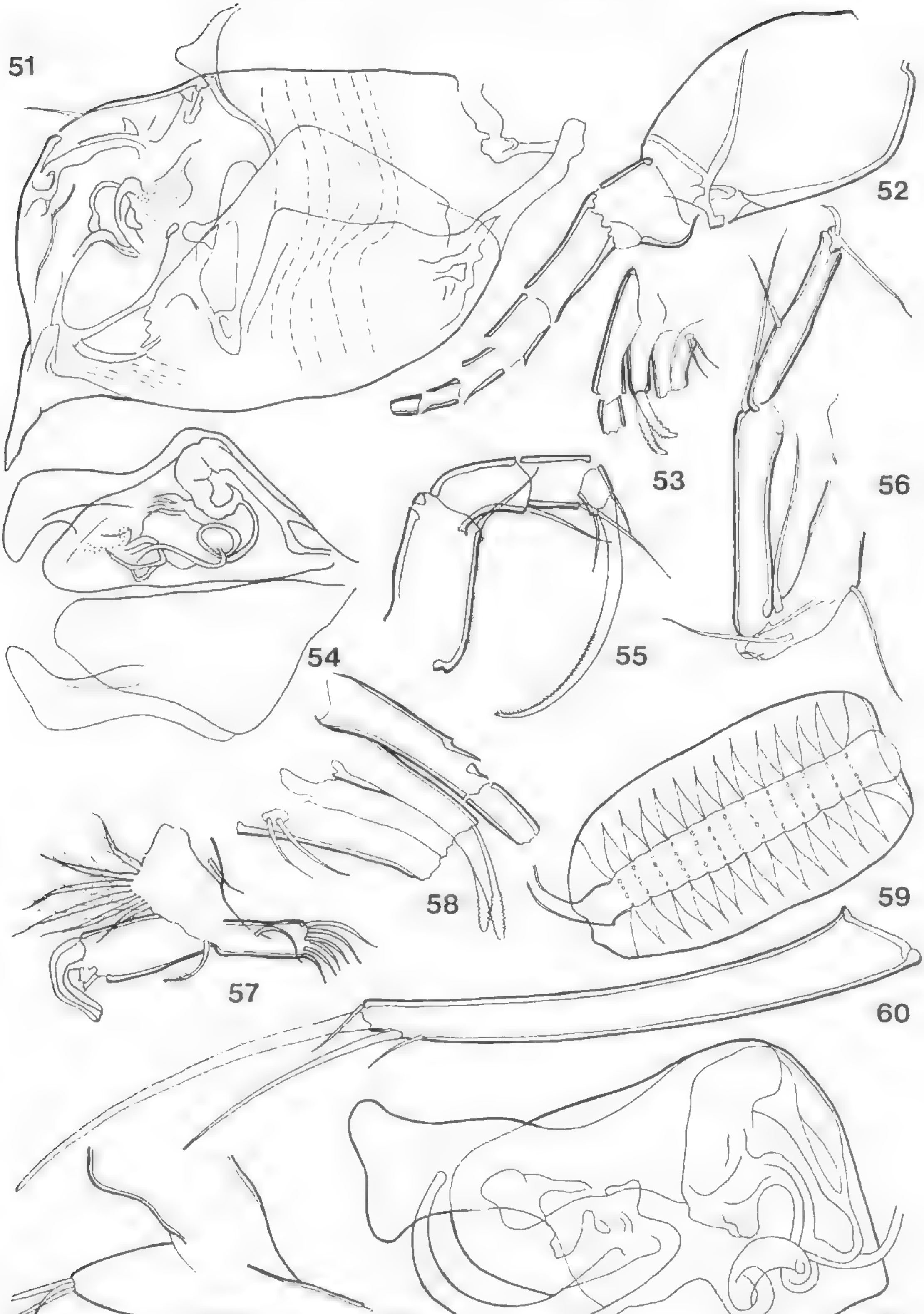
Paratypes: AM P26670-26672, 3 adult females, 1 adult male.

Type locality: Very large shallow lake 15 km N of Kingston, S.A.

Material: A topotypic population and individuals from a small salt lake about 16 km N of Meningie and two samples from the cut-off portion near "Cantara", The Coorong.

Description: Shell whitish; small-medium sized; regularly subtriangular in lateral view; LV larger than RV, and overlapping it dorsally by a low elongate ridge; micropunctate; dorsum strongly convex, more so in LV; anterior broadly rounded; posterior more narrowly rounded, trending posteroventrally; venter inflexed medially; greatest height medial, about 2/3 length. In dorsal view subelliptical, narrowing anteriorly, more rounded posteriorly; greatest breadth medial and just under half length. Internally: lamellae broad; line of concrescence submarginal; inner margin regular; marginal pore canals numerous short and straight anteriorly and posteriorly, longer ven-

Figs 51–62 Fig. 51, ? *Microcytherura difficilis* sp. nov., holotype, male, hemipenis, x 600. Figs 52–57: *Cyprinotus edwardi* sp. nov., holotype, male. 52: antennule (segments only), x 150. 53: maxillule palp and lobes (segments only) with Zahnborsten, x 150; 54: hemipenes, x 62.5; 55: P II, x 150; 56: P III, x 150; 57: P I, x 150. Fig. 58, *Diacypris paracompacta* sp. nov., paratype, AM P26670, female, maxillule palp and lobes (segments only) with Zahnborsten, x 600; Figs 59, 60, *Diacypris paracompacta* sp. nov., holotype, male. 59: Zenkers Organ, x 600; 60: furca, x 600. Fig. 61, *Diacypris paracompacta* sp. nov., paratype, AM P26670, female, P I (without setation), note absence of epipod, x 600. Fig. 62, *Diacypris paracompacta* sp. nov., paratype, AM P26672, male, hemipenis, x 600.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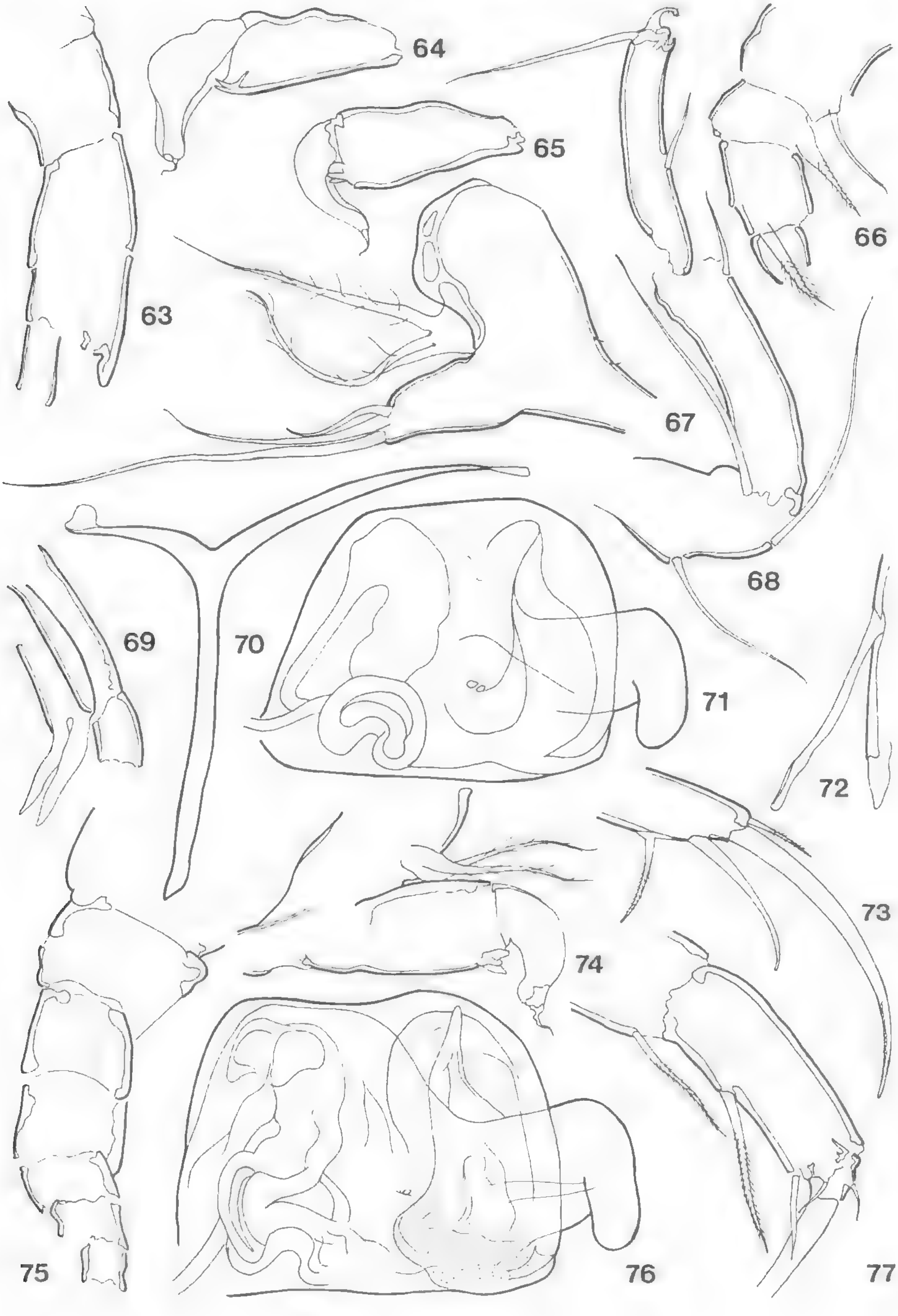
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trally; normal pore canals scattered, simple, open; muscle scar field posteromedial, comprising rosette of 4 adductors plus 2 mandibulars; hinge consisting of RV ridge and LV groove. Shell sex dimorphism weak, females usually larger and with greater size range than males.

Antennule 7-segmented; segmental length ratios 70:20:20:18:15:8:8; "natatory" setae about four times as long as 5 distal segments combined. Antennal endopod 3-segmented; length ratios of segments 23:14:4; "natatory" setae extending beyond terminal claws and originating mediodistally on first endopod segment; flagellum reaching distal end of this segment. Mandible coxa normal; epipod with about 6 Strahlen; endopod normal, α and β ventral bristles slender and pilose, γ bristle thick and tapering, about twice as long as terminal segment. Maxillule epipod with about 20 Strahlen; palp cylindrical, narrow; length ratio of palp segments 20:9; third lobe with 2 weakly toothed Zahnborsten; 2 short bristles proximally on first lobe. Maxilla (P I) epipod absent; endopod in female with 3 terminal bristles, one short, second about twice as long and third very long; in males, endopods modified as asymmetric clasping palps, right broader and less flexuous than left. Walking leg (P II) endopod 3-segmented (penultimate segment undivided); segmental length ratios 16:18:3; terminal claw about as long as endopod segments combined. Cleaning limb (P III) reflexed, normal. Chitin supports with simple point distally; branched proximally, with dorsal branch about 2/3 length of ventral branch. Furcal shaft gently curved, with normal complement of claws and bristles; shaft:anterior claw:posterior claw length ratios 40:30:13; shaft length:width about 20:1; bristles subequally long, posterior bristle slightly displaced from posterior claw. In males, Zenkers Organ has 12-13 whorls. Hemipenis with relatively straight weakly bilobate anterior process; basal process well chitinised and strongly curved. Rake-like organs each with 8 teeth, one bifid. Cups of nauplius eye fused.

Dimensions: Holotype, adult male—L = 0.55 mm; H = 0.40 mm; B = 0.25 mm. Paratype, adult female—L = 0.58 mm; H = 0.41 mm; B = 0.28 mm.

Discussion: The posteromedial muscle scar field and the relatively shortened antennule segments are further characters which separate diacypridines from eucypridines. Male characters, such as the number of whorls in the Zenkers Organ and the hemipenis morphology, are also distinct and unlike such features in eucypridines.

The new species is very close to *D. compacta* (Herbst, 1958) but in that species there is no dorsal overlap by the LV of the RV, such as characterises *paracompacta*. This feature also separates *D. paracompacta* from the following species.

Derivation of name: From the Latin para = similar, and the species name compacta.

Diacypris occidentalis sp. nov.

FIGS 7, 13, 14, 20

Holotype: AM P26673, adult male.

Paratypes: AM P26674, 2 adult females, 1 adult male.

Type locality: Lake Dumbleyung, W.A.

Material: Topotypic material and populations from Lake Chidnup, Lake Stubbs, and Newdigate, a shallow salt water lake near Lake Grace, all in W.A.

Description: Shell greenish in life; small-medium sized; regularly subtriangular in lateral view; almost equivalved; smooth; dorsum strongly convex; anterior broadly rounded; posterior more narrowly rounded, trending posteroventrally; venter inflexed medially; greatest height medial and over 2/3 length. In dorsal view subelliptical; narrowing anteriorly and rounded posteriorly; greatest breadth medial and about half length. Internally: similar to *D. paracompacta*. Sex dimorphism weak, females usually larger than males.

The soft parts are closely similar to those of *D. paracompacta* except for these differences:

Figs 63–77. Figs 63–65, *Reticypris herbsti* n. gen., n. sp., holotype, male. 63: antenna endopod (segments only); 64: P I, right palp; 65: P I, left palp; Figs 66–69: *Reticypris herbsti* n. gen., n. sp., paratype, AM P26678, female. 66: mandible endopod (segments only) with α, β and γ bristles; 67: P I; 68: P III, 69: maxillule palp and third lobe with Zahnborsten. Figs 70, 71: *Reticypris* n. gen., n. sp., holotype, male. 70: chitin support; 71: hemipenis. Figs 72–77: *Reticypris dedeckkeri* n. gen., n. sp., holotype, male. 72: detail antennal sensory seta; 73: distal furca; 74: right P I; 75: antennule (segments only); 76: hemipenis; 77: distal P II. All magnifications x 600.

The length ratios furcal shaft: anterior claw: posterior claw in *D. occidentalis* are 44:29:13, i.e. the shaft is slightly longer than in *D. paracompacta*. Further, the basal process of the hemipenis in *D. occidentalis* is thicker than in *D. paracompacta*, and of similar thickness throughout its length, not tapering as in *D. paracompacta;* also, the anterior process does not extend as far beyond the basal process as in the South Australian species. The Zenkers Organ has 11-12 whorls.

Dimensions: Holotype, adult male—L = 0.56 mm; H = 0.38 mm; B = 0.25 mm. Paratype, adult female—L = 0.60 mm; H = 0.43 mm; B = 0.28 mm.

Discussion: D. occidentalis, like *D. compacta* (Herbst, 1958) does not have the same definite LV overlap which characterises *D. paracompacta.* It is a distinctly smaller species than *D. compacta* which has a length of about 0.71 mm and 14 whorls on the Zenkers Organ. Nevertheless, the three species must be considered a closely allied group since their hemipenes are so alike.

Derivation of name: From the Latin, occidentalis = western, a reference to the species' Western Australian provenance.

? **Diacypris** sp.

Localities: Two localities in W.A. (see Appendix II) but the taxon is known to occur also in South Australia (De Deckker pers. comm.).

Discussion: The shell of this species is characterised by a pronounced overlapping hump in the LV; and by the presence of several strong spines on the carapace, one or two anteriorly and one posteroventrally on each valve. It is unlike any previously described *Diacypris* in shell characters, and there were no soft parts in the specimens encountered in this collection. De Deckker (pers. comm.) has indicated that the soft anatomy is like *Diacypris.* Of the three specimens available, the largest measured 0.70 mm.

Reticypris gen. nov.

Type species: **Reticypris herbsti** sp. nov.

Diagnosis: Diacypridine genus characterised by small-medium size; reticulate carapace; maxilla (P I) epipod with 2 Strahlen; rectangular hemipenis with downturned flap on anterior process; relatively smooth Zahnborsten on third lobe of maxillule. Otherwise, like *Diacypris* in its soft anatomy.

Discussion: It is apparent that *Reticypris,* especially in its reticulate carapace, is very different from *Diacypris.* However, there are some points of strong resemblance even in the carapace, notably the posteromedial muscle scar field. The differences are probably enough to justify a new tribal category for *Reticypris.* But with only one genus known with certainty for each tribe such a move seems premature, although consistent with modern taxonomic practice in which even subfamilies have been named for single ostracode genera.

Derivation of name: From the Latin, rete = a net and the generic suffix cypris; for the reticulate carapace. The genus is feminine.

Reticypris herbsti sp. nov.

FIGS 15, 17, 33, 63–71

Holotype: AM P26676, adult male.

Paratypes: AM P26677–P26679, 3 adult females.

Type locality: Very large shallow lake 15 km N of Kingston, S.A.

Description: Shell whitish-brownish, small-medium sized; subquadrate in lateral view; inequivalved, LV larger and overlapping dorsally; reticulate and with weak ventral ridge which is more noticeable in RV; dorsum gently convex, inclined towards rear; anterior broadly rounded; inflexed anterodorsally in RV where LV overlaps it; posterior more narrowly rounded; venter inflexed medially; greatest height anteromedial (LV) and about 2/3 length. In dorsal view subelliptical; narrowing anteriorly, more rounded posteriorly; greatest breadth medial and about half length. Internally: lamellae broad; line of concrescence submarginal; inner margin regular; weak selvage present in LV; marginal pore canals numerous and straight; normal pore canals scattered, simple, open; muscle scar field posteromedial, comprising rosette of 4 adductors plus 2 mandibulars; hinge consisting of narrow RV ridge with small triangular anterior projection (antislip element) and accommodation groove in LV. Shell sex dimorphism not marked, females usually larger than males.

Antennule 7-segmented; segmental length ratios 93:25:23:22:13:15:12; "natatory" setae about 4 times as long as 5 distal segments combined. Antennal endopod 3-segmented; segmental length ratios 22:13:15; flagellum extending beyond distal end of first endopod segment; "natatory" setae extending well beyond tips of terminal antennal claws and originating mediodistally on first endopod segment. Mandible coxa normal; epipod with 6

Strahlen plus basal seta. Maxillule normal; epipod with about 20 Strahlen; length ratio of palp segments 5:2; Zahnborsten of third lobe relatively smooth. Maxilla (P I) normal; epipod small but distinct, bearing 2 Strahlen; male palps asymmetric as in *Diacypris*. Walking leg (P II) with the penultimate segment undivided; terminal claw powerful, curved and about twice as long as penultimate segment. Cleaning limb (P III) normal; terminal segment small but distinct. Furcal shaft evenly curved, length ratios of shaft:anterior claw:posterior claw 45:21:12; bristles about equal, posterior one separated from posterior claw by small gap. Chitin support with bluntly pointed distal tip and forked proximally, ventral branch almost twice as long as dorsal branch. In males, Zenkers Organ has 10–11 whorls; hemipenis is rectangular, anterior process with a downturned flap. Cups of nauplius eye fused. Posterior of body without any prominent lobe.

Dimensions: Holotype, adult male—L = 0.54 mm; H = 0.38 mm; B = 0.25 mm. Paratype, adult female—L = 0.58 mm; H = 0.40 mm; B = 0.28 mm.

Derivation of name: For H. V. Herbst, who described *Diacypris*.

Reticypris dedeckkeri sp. nov

FIGS 18, 19, 72–77

Holotype: AM P26680, adult male.

Paratypes: AM P26681–26682, 3 adult females, 1 adult male.

Type locality: Small pond south of Yorketown, S.A.

Description: Shell whitish-brownish; medium sized; subreniform in lateral view; inequivalved, but not as markedly so as *R. herbsti*; reticulate, without ventral ridge; dorsum gently convex but not so inclined towards rear as in *R. herbsti*; anterior and posterior about equally broadly rounded in LV, anterior more broadly rounded in RV; venter inflexed medially; greatest height anteromedial and about 3/5 length. In dorsal view; with subparallel flanks; more narrowed anteriorly than posteriorly; greatest breadth medial in males, slightly posteromedial in females and about half length. Internally; similar to *R. herbsti*. Shell sex dimorphism not marked, females usually larger and slightly broader than males.

The soft part morphology is very similar to that of *R. herbsti*, except that the length ratios of furcal shaft:anterior claw:posterior claw are 50:23:12, i.e. the shaft is slightly longer in *R. dedeckkeri*. In males, the Zenkers Organ has 10 whorls in *R. dedeckkeri* and the hemipenis differences can be checked on the illustrations (figs 71, 76).

Dimensions: Holotype, adult male—L = 0.68 mm; H = 0.40 mm; B = 0.31 mm. Paratype, adult female—L = 0.68 mm; H = 0.41 mm; B = 0.34 mm

Discussion: The two species of *Reticypris* described above can be readily distinguished on shell characters alone. Of the two, *R. dedeckkeri* is much the larger, has a subreniform, rather than subquadrate, shape in lateral view and no ventral ridge and differs also in dorsal view.

At present *R. dedeckkeri* is known only from the type locality.

Derivation of name: For P. De Deckker, who has recently described two new Australian ostracode genera.

Other species

Several other species are present in the material (Appendix II). But they are listed in open nomenclature and, except in the case of ? *Diacypris* sp. which is very distinctive, no further details on them are included. Usually, there are not enough specimens to base a description upon. In other cases, the available specimens are either juvenile or occur as fragments only. One specimen in sample S.A. 40, a *Diacypris* sp. with spinose ventral margins and measuring 0.88 mm, was destroyed during scanning electron micrography of the fauna.

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NOTES ON THE BIRDS OF PEARSON, DOROTHEE AND GREENLY ISLANDS, SOUTH AUSTRALIA

BY SHANE A. PARKER AND JOHN B. COX

Summary

Ornithological results of an expedition to Pearson, Dorothee and Greenly Islands off the west coast of Eyre Peninsula in November 1976 include field observations, details of specimens collected, and, for a few species, remarks on taxonomy, distribution, and food. Previous records are summarized. New records are: White-faced Storm-Petrel (Pearson), Great Cormorant, White-faced Heron and Turnstone (Dorothee and Greenley), Spur-winged Plover and Barn Owl (Dorothee) and Fairy Tern and Little Grassbird (Greenly). On Big Veteran, a rock between Pearson and Dorothee from which no birds have previously been reported, we noted six species: Great Cormorant, Sooty Oystercatcher, Turnstone, Silver Gull, Pacific Gull and Rock Parrot. Also of special interest are breeding colonies of Short-tailed Shearwater on Dorothee and Greenly, breeding colonies of White-faced Storm-Petrel on Dorothee, a probable breeding colony of the Fairy Tern on Seal Rock off Greenly, and breeding of the Welcome Swallow on Dorothee.

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by Shane A. Parker* and John B. Cox†

Summary

Parker, S. A. & Cox, J. B. (1978) Notes on the birds of Pearson, Dorothee and Greenly Islands, South Australia. *Trans. R. Soc. S. Aust.* **102**(7), 191-202, 30 November, 1978.

Ornithological results of an expedition to Pearson, Dorothee and Greenly Islands off the west coast of Eyre Peninsula in November 1976 include field observations, details of specimens collected, and, for a few species, remarks on taxonomy, distribution, and food. Previous records are summarized. New records are: White-faced Storm-Petrel (Pearson), Great Cormorant, White-faced Heron and Turnstone (Dorothee and Greenly), Spur-winged Plover and Barn Owl (Dorothee) and Fairy Tern and Little Grassbird (Greenly). On Big Veteran, a rock between Pearson and Dorothee from which no birds have previously been reported, we noted six species: Great Cormorant, Sooty Oystercatcher, Turnstone, Silver Gull, Pacific Gull and Rock Parrot. Also of special interest are breeding colonies of Short-tailed Shearwater on Dorothee and Greenly, breeding colonies of White-faced Storm-Petrel on Dorothee, a probable breeding colony of the Fairy Tern on Seal Rock off Greenly, and breeding of the Welcome Swallow on Dorothee.

Introduction

In November 1976 a biological survey of Pearson I. and Dorothee I. (Investigator Group) and Greenly I. was undertaken by A. C. Robinson, T. J. Fatchen, A. Spiers and J. B. Cox (S.A. National Parks and Wildlife Service) and W. Zeidler and S. A. Parker (S.A. Museum). Here we present the ornithological results, including some sightings made in Coffin Bay on the opposite mainland, and on passage between Coffin Bay and the islands.

Previous observations (summarized here) are available from Pearson for 1914, 1920, 1960, 1969, 1973 and 1974, from Dorothee for 1969, and from Greenly for 1947. Cleland (1923) gave details of birds noted on Pearson in January 1923, and Paton (1971) of birds on Pearson and Dorothee in January 1969. Both authors referred to observations made on Pearson by E. R. Waite in September 1914 and F. Wood Jones in November 1920. In addition, Paton included observations made by J. M. Thomas and S. J. Edmonds on Pearson in January 1960. Hornsby (1978) presented observations made on Pearson in February 1973 and February 1974. The previous records from Greenly are those of Finlayson (1948) for November 1947 and Mitchell & Behrndt (1949) for December 1947.

List of species

Eudyptula minor (Forster), Little Penguin

Pearson I. Noted on all previous visits, on all sections, burrows being found up to more than 150 m a.s.l. (Paton 1971, Hornsby 1978). We found many burrows (Fig. 1) in the friable soil in crevices among boulders, and in steep slopes, usually under low shrubs, *e.g. Rhagodia crassifolia, Olearia ramulosa.* These contained eggs, chicks at various stages, and moulting adults.

Dorothee I. Previously recorded by Paton (1971). We found fewer than on Pearson I., and only on the northern half (Fig. 2), mainly in crevices among rocks under dense low shrubs; one bird was incubating an egg.

Greenly I. Reported by Finlayson (1948) and Mitchell & Behrndt (1949) on the slopes of the south section up to *ca* 123 m. The latter

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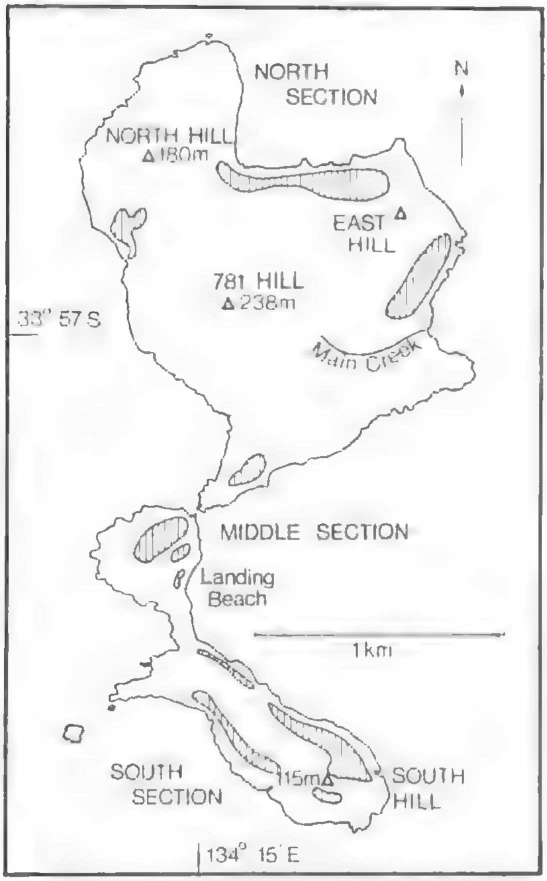

Fig. 1. Pearson Island (key as for fig. 2).

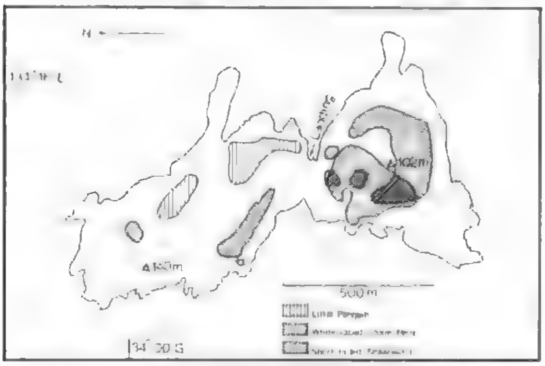

Fig. 2. Dorothee Island.

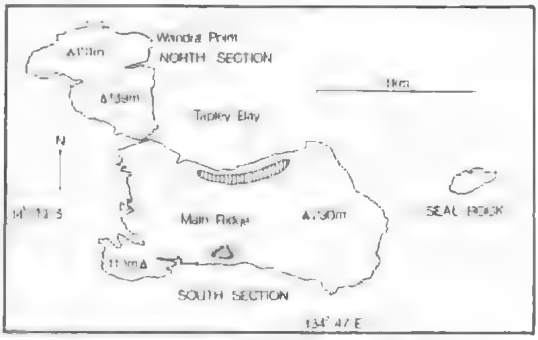

Fig. 3. Greenly Island (key as for fig. 2).

authors noted that in December 1947 breeding appeared to be over. We found the species halfway along the sloping north face of the south section (Fig. 3), in burrows in soil-filled rock crevices usually overhung by tussocks of *Poa poaeiformis*. All birds in the burrows were in heavy moult.

The species was also noted breeding on islands in Coffin Bay, 1.xii.1976: one dead chick on the main island of The Brothers; two adults, one on eggs, on Garden I., with at least twelve burrows in all, in soil beneath a 3m limestone overhang.

Diomedea melanophrys Temminck. Black-browed Albatross

Greenly I. One adult flying west, close inshore, 29.xi.1976.

Diomedea chlororhynchos Gmelin. Yellow-nosed Albatross

Pearson I.: two swimming round fishing boats in bay east of middle section, ii.1974, and others between Pearson I. and the mainland (Hornsby 1978). Greenly I.: one flying west, inshore, 29.xi.1976; single birds 4 km and 10 km north of Greenly I. 1.xii.1976. Near mainland: single birds 15 km south-southwest and 3 km southwest of Point Sir Isaac, Coffin Bay Peninsula, 1.xii.1976.

Diomedea cauta Gould. Shy Albatross

One following boat continuously between Dorothee I. and Greenly I., 27.xi.1976; two inshore at Greenly I. 29-30.xi.1976; one 3 km off Point Sir Isaac, 1.xii.1976 (all immatures).

Puffinus carneipes Gould. Fleshy-footed Shearwater

First seen (one bird) 2 km northwest of Point Sir Isaac, thence continuously (singly or in small groups) to 40 km from Pearson I., 22.xi.1976. Common from Dorothee I. to Greenly I., 27.xi.1976, in parties of up to 40, often mingling with flocks of Short-tailed Shearwater *P. tenuirostris*. Many seen from Greenly I. to Point Sir Isaac, 1.xii.1976. At sea, *P. carneipes* was more frequently encountered than *P. tenuirostris*; individuals of the former were scattered over a wider area and tended not to form large flocks, whereas individuals of the latter were usually seen in very large flocks. *P. tenuirostris* was less abundant than *P. carneipes* over inshore waters of the mainland, but about the islands the reverse was usually the case.

McKean (1963) presented evidence that some individuals from the colony on Lord Howe I. foraged off the coasts of New South Wales and southern Queensland during the breeding season. Such long-distance foraging raises the possibility that the large numbers seen in South Australian waters during the breeding season are from Western Australian colonies, rather than from as yet undiscovered colonies in South Australia (see also Serventy *et al.* 1971, Cox 1976).

Puffinus tenuirostris (Temminck). Short-tailed Shearwater

Pearson I. We noted five single birds within 10 km of the island on 22.xi.1976, and from then till 25.xi.1976 saw large numbers offshore each day in the late afternoon or evening. Serventy *et al.* (1971) listed Pearson I. as a breeding station, but although we searched the island by day and by night, we found no signs of a breeding colony.

Dorothee I. No previous records. We discovered a breeding colony of *ca* 800 pairs on the southern half of the island (Fig. 2), in an area of granitic shale with pockets of softer soil. The burrows tended to be in the soil, and many had their entrances overhung by the succulent *Disphyma clavellatum*. Each burrow examined contained a bird sitting on an egg. This colony overlapped a colony of the White-faced Storm-petrel, whose burrows tended, however, to be among *Atriplex paludosa* in the shaly ground.

Greenly I. Finlayson (1948) found mummified remains beneath what appeared to be the feeding tree of a White-bellied Sea-Eagle on the ridge of the south section. Mitchell & Behrndt (1949) observed several birds flying about the boat as it approached Tapley Bay, and on the eastern end of the south section found a series of burrows that had apparently not been used for several seasons. We located a breeding colony on the steep southern slope of the south section (Fig. 3); it occupied the only patch of sand and soft travertine noted by us on the island. Most of the *ca* 200 burrows had their entrances curtained by shrubs of *Enchylaena tomentosa*, and most of those examined contained birds sitting on eggs.

Many individuals were seen inshore at Greenly I., mainly in morning and late afternoon, 28-30.xi.1976. The species was common between Greenly I. and 20 km northeast on 1.xii.1976, becoming progressively scarcer towards the mainland. On 27.xi.1976 we observed large flocks of up to 150 individuals continuously between Dorothee I. and Greenly I., well away from land.

Specimens: B30463, Greenly I., 30.xi.1976, adult male, testes slightly enlarged (regressing); skull fully pneumatized; colours (2 hrs after death): legs pale lilac grey on inner faces, blackish outer, outer toe blackish, two inner toes pale lilac grey, webs cream with greyish and blackish streaks (heavier on undersurface); iris very dark brown; upper mandible: unguis black, rest blackish grey; lower mandible: ramicorn light grey, rest dark grey; eyerim blackish; stomach contents: beaks of small cephalopods. Bird taken 1030 hrs while incubating egg (B30487, dead fresh) in large bare sandy burrow about 1 m long, entrance curtained by bush of *Enchylaena tomentosa*; large brood-patch on abdomen.

B30464, Dorothee I., 26.xi.1976, adult female, oocytes slightly enlarged (? regressing); skull pneumatization not recorded; colours (5 mins after death): legs lilac grey on inner faces, blackish grey on outer, outer toe blackish grey, two inner toes lilac grey, webs greyish cream above, cream with blackish streaks below; iris very dark brown; upper mandible: latericorn brownish grey, rest blackish; lower mandible: ramicorn medium grey, unguis blackish, rest blackish distally, lightening to grey at base; mouth: greyish white tinged with pink, tongue creamy pink; eyerim black; stomach contents: black beaks of small cephalopods. Bird taken late afternoon incubating egg (B30486, dead fresh), in large bare burrow about 1 m long, roof 75 mm thick, under shrubs of *Disphyma clavellatum*.

Pelagodroma marina (Latham). White-faced Storm-Petrel

Pearson I. No previous records. After dark on 24 and 25.xi.1976 we noted one or two flying above our camp on the middle section; one of these was collected. We also found a few feathers on the northern slope of South Hill on the south section. We failed to find any burrows, however, despite spotlighting and daytime searches; possibly here, and on Greenly I., the species is discouraged from breeding by the presence of the Southern Bush-rat *Rattus fuscipes*.

Dorothee I. Paton (1971) found the wings of at least ten of these petrels in front of small burrows. We located three breeding colonies (Fig. 2), mainly among *Atriplex paludosa*, *Threlkeldia diffusa* and *Rhagodia crassifolia* on high shaly slopes, the burrow-entrances difficult to find among the dense shrubs. The most northerly colony consisted of *ca* 70 pairs, the middle colony of *ca* 200 pairs and the large colony around the southern hill of 1100-1200 pairs. The last overlapped a colony of Short-tailed Shearwaters, who tended to burrow in patches of softer ground amidst the shale. Many wings and feet of the storm-petrels were littered about these colonies. The Southern Bushrat does not occur on Dorothee I., and the other noted predator of the White-faced Storm-Petrel, the Black Tiger Snake *Notechis scutatus* (Wood Jones 1937), was also apparently absent. We suspect that the predators were Pacific Gulls (see Littler 1910) and a pair of Barn Owls (see below).

We noted six solitary birds about midway between Dorothee and Greenly on 27.xi.1976, and three others feeding together over calm water in Coffin Bay *ca* 1 km east of Point Longnose on 1.xii.1976.

Specimens: B30465, Pearson I. (middle section). 24.xi.1976, adult female, oocytes slightly enlarged (? regressing); colours (10 mins after death, taken in artificial light): legs black, toes black except for light blue-grey borders where they met webs, webs cream with greyish-black stripe in centre of each; iris umber; bill black; mouth: palate dark grey, pharynx pinkish white; eyerim black; stomach contents (preserved) planktonic larvae of crabs. Bird shot 2230 hrs (after dark), possibly attracted by campfire.

B30466, Dorothee I., 26.xi.1976, adult female, oocytes very slightly enlarged (? regressing), oviduct dilated and convoluted; most of skull apparently one-layered but hard; colours (before death): legs and toes black, centres of webs cream; iris very dark brown; mouth flesh-grey; eyerim black; moderate subcutaneous fat. Bird caught 1120 hrs incubating egg (B30488, incubation 0.2) at end of burrow; colony of *ca* 70 burrows on east-facing slope of granitic rocks and shale, entrances difficult to find among low shrubs of *Threlkeldia diffusa*, *Atriplex paludosa* and *Rhagodia crassifolia*.

B30467, Dorothee I., 26.xi.1976, adult male, testes very slightly enlarged (? regressing); skull fully pneumatized; colours (before death): as B30466; stomach contents one small stone; moderate subcutaneous fat. Bird caught 1135 hrs incubating egg (B30489, incubation 0.3) at end of burrow, same colony as B30466.

Sula serrator (G. R. Gray), Australasian Gannet

Hornsby (1978) reported one seen regularly off Pearson I. in February 1974. We noted two off Pearson I. on 23 and 26.xi.1976, eight between Greenly I. and Coffin Bay Peninsula on 1.xii.1976, and single birds off Point Longnose and 2 km off Point Sir Isaac on 22.xi.1976.

Phalacrocorax carbo (Linnaeus), Great (Black) Cormorant

Noted in small numbers on Pearson I. in 1923, 1960, 1969 and 1974. We observed up to five together on Pearson I., and small numbers on Dorothee, Big Veteran and Greenly.

Phaeton rubricauda Boddaert, Red-tailed Tropic-bird

Cleland (1923) recorded two on the north section of Pearson I. There are only two other records from the Eyre Peninsula region: a female (SAM B2421) collected on Grantala Farm, North Shields, north of Port Lincoln, 13.5.1919 (Cleland 1923), and a bird shot on Flinders I., xii.1960 (Eckert 1970, Bedford 1972).

P. rubricauda is a rarely reported visitor to South Australia, records falling in the period December-May. This period is its breeding season in Western Australia (Serventy *et al.* 1971, Tarburton 1977). Eckert (1970) speculated that it may have bred undetected on islands off the South Australian coast.

Ardea novaehollandiae Latham, White-faced Heron

Pearson I. Noted 1923, 1969, 1973 and 1974. We recorded one bird on the northern tip of the north section, on rocks among *Casuarina stricta*.

Dorothee I. We saw two single birds at opposite ends of the island, among boulders halfway up the slopes.

Greenly I. One noted by us, among *Casuarina stricta* on the ridge of the south section.

Egretta sacra (Gmelin), Reef Heron

Recorded on Pearson I., 1920, 1923, 1973 and 1974. We observed one dark-phase individual on the south section, perched on a boulder halfway up the slope.

Cereopsis novaehollandiae Latham, Cape Barren Goose

Pearson I. Noted on all previous visits. In 1976 we recorded two immatures and a dead adult on the north section, in low open *Melaleuca lanceolata*.

Dorothee I. Previously recorded by Paton (1971). We noted a party of nine adults on the southern coast.

Greenly I. Recorded by Finlayson (1948) and Mitchell & Behrndt (1949).

Pandion haliaetus (Linnaeus). Osprey

Recorded only by Hornsby (1978), who in February 1974 saw one flying along the eastern coastline of Pearson I.

Haliaeetus leucogaster (Gmelin). White-bellied Sea-Eagle

Pearson I. Cleland (1923) noted at least one on the north section, and found an old nest possibly of this species near the summit of the south section. Paton (1971) reported an unoccupied nest on the south section. Hornsby (1978) recorded two adults and a large immature, mainly on the north section, in 1973, and in 1974 two nests on the north section, one unoccupied but containing the skull of a Southern Bush Rat, the other attended by two adults. We noted two adults, mainly over the north section.

Dorothee I. Paton (1971) observed two birds over the island, and found an unoccupied nest on the peak on the southern part.

Greenly I. Finlayson (1948) reported a "Sea-eagle or Fish-Hawk . . . seen at a distance several times . . . could not be positively identified". He photographed a nest containing what he thought was a large fledgeling Osprey. We consider the photograph (cover of *S. Aust. Orn.* 18(8)) of insufficient quality for one to be able to say whether the bird is a young Osprey or an adult or subadult White-bellied Sea-Eagle. Finlayson also reported a feeding tree of a sea-eagle on the high ridge of the south section; beneath this were the remains of a Short-tailed Shearwater, a Galah, Tammar wallabies (*Macropus eugenii*) and a Barracouta (*Leionura atun*). He noted that the wallaby mortality on Greenly was considerable, and considered the White-bellied Sea-Eagle the most likely predator.

Mitchell & Behrndt (1949), under "White-headed Osprey", noted that a pair had taken up "permanent residence" on the island. They found two enormous nests near the summit of the south section and another on the north section. About the nest-sites, and beneath several large *Casuarina* trees, were the remains of numerous wallabies. The predator involved was again almost certainly the White-bellied Sea-Eagle. We noted two adults on Greenly, usually over the high *Casuarina*-clad ridge of the south section.

Falco cenchroides Vigors & Horsfield. Nankeen Kestrel

Pearson I. Recorded 1923, 1969, 1973 and 1974, from all three sections but no more than two birds each time. We noted a pair with flying young on North Hill (north section), and located a second pair, possibly nesting, on South Hill (south section), from an inaccessible stick nest on the south face of which came the sounds of cheeping. A single bird was also seen hunting over the plain of *Disphyma clavellatum* and *Atriplex paludosa* on the eastern side of the north section.

Dorothee I. Two noted by Paton (1971). We observed two single birds at opposite ends of the island.

Greenly I. Mitchell & Behrndt (1949) reported a single bird preying on the abundant skink *Egernia multiscutata*. We noted one bird over the dense *Melaleuca lanceolata* thickets on the steep southern slope of the south section.

Haematopus fuliginosus Gould. Sooty Oystercatcher

Pearson I. Recorded on all previous visits except 1920. We noted at least eight pairs on the rocky flats and shorelines. One pair on the middle section had a large flightless young one that hid in low *Atriplex*; the parents were vociferous, and one gave the broken-wing display. All adults were in pairs save for the party of seven that flew over the middle section early on 25.xi.1976.

Big Veteran. A pair seen from the boat.

Dorothee I. Paton (1971) recorded three adults and a flightless young. We noted five lots of three, three, three, five and one adults, but saw no signs of breeding.

Greenly I. Finlayson (1948) recorded a pair at the landing in Tapley Bay in November 1947. The following month, Mitchell & Behrndt (1949) noted many in the same bay. We saw a pair on the north section, but none on the south section.

Vanellus novaehollandiae Stephens. Spur-winged Plover

Pearson I. Cleland (1923) noted three in January 1923. Hornsby (1978) recorded three in February 1973 and two in February 1974.

We recorded two over the sea to the east of the middle section, and one over the sea off the southern coast of the south section.

Dorothee I. We made two sightings, of two and four birds.

Charadrius rubricollis Gmelin. Hooded Dotterel

Recorded only by Hornsby (1978), who in February 1973 saw two feeding among the intertidal rocks of the isthmus between the north and middle sections of Pearson I.

Arenaria interpres (Linnaeus). Turnstone

Pearson I. Paton (1971) noted eight on the north section. Hornsby (1978) recorded the species in 1973 and 1974, including a flock of 40 in 1974. We noted a flock of 19 on the rocky eastern shore of the middle section.

Big Veteran. Four seen from the boat.

Dorothee I. We noted four on the southern end.

Greenly I. We noted two in the channel between the two sections.

Calidris ruficollis (Pallas). Red-necked Stint
C. alba (Pallas). Sanderling

Pearson I. In January 1960 Thomas and Edmonds recorded individuals of either *C. ruficollis* or *C. alba* (Paton 1971). Hornsby (1978) made similarly indeterminate sightings in February 1973 and February 1974. We noted four *C. ruficollis* on the landing beach on the eastern side of the middle section.

Stercorarius parasiticus (Linnaeus). Arctic Jaeger

This is the most frequent small skua in South Australian waters, occurring as a non-breeding, mainly summer, visitor. We saw single birds 15 km northwest of Point Longnose on 22.xi.1976, and midway between Dorothee and Greenly on 27.xi.1976. The two pairs of small skuas noted by Finlayson (1948) on Greenly in November 1947 may well have been of this species.

Larus novaehollandiae Stephens. Silver Gull

Pearson I. Noted on all previous visits except 1914.

Dorothee I. Recorded by Paton (1971).

Greenly I. Recorded as not plentiful in November 1947 by Finlayson (1948), and in the following month as visiting the island in big flocks and roosting on Seal Rock by Mitchell & Behrndt (1949).

We noted the species on all three islands and on Big Veteran, singly and in groups of up to 12, frequenting the coasts.

Larus pacificus Latham. Pacific Gull

Pearson I. Noted on all previous visits. We recorded eight pairs of adults and five subadults, mainly inland and on the sandy beach of the middle section. One pair kept flying over a large flightless chick that skulked in low shrubs and crevices in a flat rocky area of the middle section. Wood Jones found a nest with two eggs on 25.xi.1920 (Cleland 1923).

Dorothee I. Two adults recorded by Paton (1971). We noted three pairs (one with a large flightless chick) and three subadults.

Big Veteran. We saw one pair from the boat.

Greenly I. Recorded by Finlayson (1948) and Mitchell & Behrndt (1949). The latter authors reported the species as numerous, and found a nest on the north section containing two well-developed young. We recorded one pair of adults and a subadult near the channel between the two sections.

Specimens: B30468, Pearson I. (middle section), 22.xi.1976, subadult female, oocytes not enlarged, oviduct not convoluted; skull fully pneumatized; colours (10 mins after death): legs and feet pale yellow faintly tinged greenish, claws black; iris cream, heavily tinged dusky; bill waxy yellow, tinged greenish, tips of mandibles orange-scarlet with black along distal sections of tomia and black smudges elsewhere in the scarlet field; mouth: palate pale yellowish buff, tongue pale fleshy orange, rest light greenish yellow; eyerim ochraceous yellow; stomach contents a few chiton fragments. Collected 1645 hrs among boulders on coast; one of four birds, two adults and one other subadult. Plumage adult except for wings and tail.

B30469, Pearson I. (middle section), 22.xi.1976, adult female, four oocytes slightly enlarged (? regressing), oviduct convoluted; skull fully pneumatized; colours (5 mins after death): legs and feet dull lemon, with pale grey in creases and on webs, claws black; iris cream; bill dull waxy yellow tinged green, tips orange-scarlet with distal tomia black; mouth: pharynx orange-pink, tongue orange, rest dull yellow; stomach contents: three chitons. Collected 1620 hrs, flying over sandy bay backed by large smooth boulders.

B30470, Dorothee I., 26.xi.1976, adult (skeletonized, not sexed), skull fully pneumatized; colours (10 mins after death): legs and feet yellow-grey, claws black; iris white; bill rich yellow, tips red with distal tomia black; mouth; palate yellow, gape and tongue orange; eyerim orange-yellow. Collected 1935 hrs on rocky slope; with another adult and two immatures, and attending one large flightless juvenile.

B30471, Greenly I. (north section), 28.xi.1976, adult male, testes somewhat enlarged (? regressing), skull fully pneumatized; colours (immediately after death): legs and feet bright yellow, claws black; iris white; bill rich yellow, tips red, distal tomia black; mouth: palate yellow, gape and tongue orange; eyerim orange. Collected 1850 hrs, flying over rocks.

Food. The two stomachs examined contained only the remains of chitons. Stirling *et al.* (1970) reported many chiton shells in regurgitated pellets at a nest on the South Neptunes. Other items of food recorded for South Australian populations include turbos (molluscs) and various sea-urchins, both dropped from a height and smashed (Condon 1938, Cotton 1960), the gastropods *Subninella undulata, Ninella torquata* and *Euninella gruneri* (Cotton 1960), rock crabs (Cleland 1923), parrot-fish pirated from fishing lines (Mitchell & Behrndt 1949), placentas and vomit of the Fur Seal *Arctocephalus forsteri* and seeds of *Nitraria schoberi* (Stirling *et al.* 1970) and immatures and adults of the White-faced Storm-Petrel (Wood Jones 1937; see also Littler 1910). (For comments on the dropping behaviour of this gull, see Farr 1978.)

Taxonomy: Our specimens are referable to the western subspecies *L.p. georgii* Vigors, which breeds eastwards to Kangaroo Island and which differs from the nominate subspecies of Tasmania in having a blackish patch along the distal tomia of both mandibles in the adult (Van Tets in Frith 1977).

Sterna nereis (Gould). Fairy Tern

Pearson I. Paton (1971) recorded two fishing off the eastern bay of the north section. In February 1974 Hornsby (1978) found two colonies of about 30 birds each on the limestone plateau of the south section, nesting amidst the low *Atriplex.* The nests contained eggs and newly-hatched young. We noted up to five birds fishing in the calmer waters of the three bays west and east of the middle section.

Greenly I. We recorded *ca* 100 on Seal Rock. Many were sitting, possibly on eggs. Individuals from this colony were seen to fly westwards along the coast of the south section to fish near the channel, then return to Seal Rock.

Specimens: B30472, Pearson I. (middle section), 24.xi.1976, adult male in breeding dress, testes much enlarged, skull fully pneumatized; colours (5 mins after death): legs and feet orange yellow; iris very dark brown; bill bright yellow, tip blackish, extreme tip whitish; mouth flesh grey; eyerim black. Collected 0820 hrs over sea near beach; with three others.

B30473, Greenly I. (south section), 29.xi.1976, adult male in breeding dress, testes much enlarged, skull fully pneumatized; colours (shortly after death): legs and feet orange yellow, claws black; iris very dark brown; bill rich yellow, tip of upper mandible blackish; mouth: pharynx pale purplish-pink, palate creamy pink, inner bill and gape dull yellow; eyerim black; stomach empty. Collected 0925 hrs, diving along rocky coast.

Sterna bergii Lichtenstein. Crested Tern

Pearson I. Recorded on all previous visits except 1914. We noted a flock of 210 sitting on rocks near the landing on the middle section, and one and four birds off the south and middle sections respectively.

Dorothee I. Paton (1971) recorded *ca* 100 resting on the rocks at the southern end. We saw two single birds flying offshore.

Greenly I. Mitchell & Behrndt (1949) recorded several small flocks about Tapley Bay. We noted a flock of 127 on the north section, just south of Wandra Point, behaving as though about to breed—grouped mainly in pairs and behaving aggressively.

Cacatua roseicapilla Vieillot. Galah

Pearson I. Hornsby (1978) recorded this species twice in February 1973—a pair, and later a large flock, flying from Pearson I. towards Dorothee.

Greenly I. Finlayson (1948) found the remains of a Galah beneath the feeding tree of a White-bellied Sea-Eagle on the south section.

Other offshore islands on which this species has been recorded (mainly since the 1930s) are Kangaroo, Wardang, Troubridge, Althorpe, South Neptunes, Reevesby and Flinders. On Althorpe I. it has been reported nesting in the cliffs, and may also do so on Kangaroo I. and Flinders I.[1]

Neophema petrophila (Gould). Rock Parrot

Pearson I. Recorded on all previous visits. We noted at least 16 on the south section, five on the middle section and seven on the north section. Two specimens collected on the south

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[1] Parker, S. A., Eckert, H. J., Ragless, G. B., Cox, J. B. & Reid, N. C. H. (in prep.). An Annotated Checklist of the Birds of South Australia.

section, 23.xi.1976 (see below), were judged by B. Hutchins and F. Lewitzka (pers. comm.) to be ten weeks old *i.e.* to have fledged three weeks previously. The species was recorded in all habitats, including bare flat granite rocks, low *Atriplex* and the *Casuarina* woodland on the north section. We noted the call as a high double-whistle, repeated.

Big Veteran. We observed four from the boat.

Dorothee I. A few recorded by Paton (1971). We counted 33-35 birds, including a flock of 20 moving restlessly through *Atriplex* shrubs among boulders on a steep slope.

Greenly I. Mitchell & Behrndt (1949) recorded several flocks arriving and others departing in a direct line to the mainland in December 1947. None was recorded by Finlayson (1948) the previous month, nor did we encounter it. Mitchell & Behrndt suggested that they migrated to the island to feed on pigface (Aizoaceae) seeds.

In South Australia the Rock Parrot breeds on several islands off Eyre Peninsula east to the Sir Joseph Banks Group, and on an island in Pondalowie Bay, southern Yorke Peninsula. In the non-breeding season it disperses to the opposite mainland, to other islands (including Kangaroo I.) and eastwards and southwards along the coast at least as far as the Baudin Rocks near Robe[1]. It is noteworthy that there are no breeding records of this parrot from Pearson, Dorothee or Greenly; this may be due to the paucity of observations during the breeding season (eggs late Aug.-early Nov.), or to the absence or near-absence of suitable nesting-sites on these islands (crumbling, fissured limestone faces draped with succulents).

Specimens: B30474, Pearson I. (south section), 23.xi.1976, immature male about 10 weeks old, testes not enlarged, skull fully pneumatized; colours (5 mins after death): legs pale buffy grey, toes greyer, claws black; iris very dark brown; upper mandible and cere mainly dull grey, with nostrils, proximal tomia and distal culmen orange buff; lower mandible orange buff; mouth pale orange-yellow tinged grey; eyerim dark grey; crop contents (preserved): seeds. Collected 1100 hrs among large granite boulders above small bay; with one other bird.

B30475, locality-skull data as B30474; colours (immediately after death): legs and feet creamy grey; iris very dark brown; upper mandible olive-horn, tomia yellow; lower mandible yellow; cere greyish yellow; mouth pinkish yellow; eyerim blackish; crop contents (preserved): seeds. Collected 1105 hrs among large granite boulders on coast; with one other.

Food: The crop of B30474 contained chiefly the seeds of *Lepidium foliosum*, *Correa reflexa* and a species of *Atriplex*; a minute reddish seed of an aizoaceous species (either a *Carpobrotus* sp. or *Disphyma clavellatum*) was also present, in a small quantity. The crop of B30475 contained only the seeds of a *Rhagodia* sp. (L. Williams *in litt.* 5.vii.1977)

Melopsittacus undulatus (Shaw). Budgerygah

Recorded only by Paton (1971), who saw two on the north section of Pearson I.

Chrysococcyx basalis (Horsfield). Horsfield's Bronze Cuckoo

At least two seen by Cleland (1923) on Pearson I.

Tyto alba (Scopoli). Barn Owl

Pearson I. Under *Owl*, Cleland (1923) wrote: "A large bird seen once at night and pellets found near the northern summit, suggest the presence of an Owl." Hornsby (1978) reported a Barn Owl in the upper part of Main Creek, north section, in February 1973 and February 1974.

Dorothee I. On 26.xi.1976 we flushed two Barn Owls from a crevice among large boulders near the top of the cleft running across the waist of the island. In the crevice were feathers of the White-faced Storm-Petrel (*q.v.*).

In South Australia the Barn Owl is known mainly from the eastern part of the State, with records also from the Nullarbor Plain and Eyre Peninsula. Apart from those mentioned above, it has been recorded on the following islands, presumably mainly as a vagrant during irruptions: Kangaroo, Goose, Wardang, Thistle, Waldegrave, Franklin (Parker 1977)

Apus pacificus (Latham). Fork-tailed Swift

Paton (1971) recorded at least 20 hawking over the northern peak of Dorothee on 11.i.1969.

Hirundo neoxena Gould. Welcome Swallow

Pearson I. Recorded on all visits except 1914 and 1920. We saw it frequently on all sections, in ones, twos, threes and fours, and once in a flock of *ca* 30 above *Casuarina stricta* woodland on the sheltered northeastern slope of 781 Hill on the north section

Dorothee I. Noted by Paton (1971) as probably the most common species on Dorothee and Pearson next to the Silvereye *Zosterops lateralis*. We saw a pair at the northern tip and a single bird on the southern coast.

Greenly I. Recorded by Finlayson (1948) and Mitchell & Behrndt (1949). We noted at least six on the north section and saw the species frequently in ones and twos all over the south section, from the *Casuarina*-clad ridge to the sea-cliffs.

Nesting: At the north base of South Hill, Pearson I., we found an old nest in a crevice, made entirely of mud. Mitchell & Behrndt found nests on Greenly and remarked on "the far greater use of sheoak needles and other organic matter in the nests of these birds on an island where good binding earth is absent". Eckert (1971) reported nests from Franklin I. made mostly of fibrous material with no mud apparent.

Anthus novaeseelandiae (Gmelin), Richard's Pipit

In February 1974 one was regularly seen on the limestone plateau of the south section of Pearson I. (Hornsby 1978). The species is common on Flinders I. (Eckert 1970).

Sericornis frontalis (Vigors & Horsfield) White-browed (Spotted) Scrubwren

On 16.ii.1974 P. Martinsen tentatively identified a scrubwren of this group in thickets on the upper slopes of the north section of Pearson I. (Hornsby 1978). There are no other records from Pearson I., though the species is common on Flinders I. (Eckert 1970).

Megalurus gramineus (Gould), Little Grassbird

We encountered this species only on the north section of Greenly, where it was fairly common on the shrub-clad slopes. Its (apparent) absence from the south section of Greenly may be attributable to grazing by the Tammar Wallaby, which is not present on the north section.

In South Australia this species occurs mainly in the eastern part, including Eyre Peninsula. Although its occurrence on offshore islands has not been appreciated, it has been recorded from several: Waldegrave, Williams, Hopkins, Reevesby, island in Pondalowie Bay, Troubridge, Kangaroo, Bushy, Beatrice and Baudin Rocks[1] (see also Whinray (1976) for notes on its occurrence in the Furneaux Group, Bass Strait)

Specimen: B30476, Greenly I. (north section), 28.xi.1976, adult male, testes slightly enlarged, skull fully pneumatized; colours (immediately after death): legs and feet flesh-grey, soles creamy; iris brown, upper mandible with blackish culmen and pale cream tomia; lower mandible creamy grey at base, dark grey at tip; mouth creamy flesh; eyerim grey; stomach contents elytra of small black beetles and other chitinous fragments. Collected 1805 hrs in low shrubs on rocky hillside.

Taxonomy: Keast (1956) recognized two mainland subspecies of *M. gramineus*: the southwestern *M.g. thomasi* Mathews and the eastern and southeastern *M.g. goulburni* Mathews, the former distinguished in being darker above and having generally heavier ventral striations than the latter. The specimen from Greenly is fairly dark above, but matches specimens of *M.g. goulburni* in the lightness of its ventral streaking.

Petroica goodenovii (Vigors & Horsfield), Red-capped Robin

Pearson I. Recorded all visits except 1914. We found the species common in *Casuarina stricta* woodland and in the area of burnt *Melaleuca lanceolata-M. halmaturorum* on the north section. Several pairs were attending well-fledged young.

Dorothee I. In the absence of *Casuarina* and *Melaleuca* it presumably does not occur

Greenly I. Noted by Finlayson (1948) and Mitchell & Behrndt (1949) in *Casuarina stricta* and *Melaleuca lanceolata* on the main ridge. The latter authors found a nest with young. We noted numerous individuals in the above habitat, including several pairs feeding fledgelings.

Specimens: (all collected 0945-1545 hrs. 24.xi.1976, north section, Pearson I.). B30477, imm. female, solitary; gonads undeveloped, skull fully pneumatized. B30478, adult male, solitary; testes enlarged (? regressing), skull fully pneumatized. B30479, adult male, solitary; testes small, skull fully pneumatized. B30480, adult male, solitary; testes enlarged (? regressing), skull fully pneumatized; B30481, imm. male, with adult male-phase bird, calling a high *seep seep seep*; testes minute, dome of skull largely unpneumatized. B39482, adult male, with adult female-phase bird; testes enlarged; skull fully pneumatized. B30483, adult female, with adult male-phase bird; oocytes regressed, oviduct dilated and convoluted, large broodpatch on abdomen; skull fully pneumatized; possibly the mother of B30481.

Colours of unfeathered parts (within 10 min of death):

Adult males: legs and feet blackish, soles dull buffy yellow, buffy yellow or yellow-grey; iris very dark brown; upper mandible blackish; lower mandible blackish, some with rami and basal tomia horn or dull yellow; gape buffy, dull yellow, dull buffy yellow or orange yellow; mouth rich yellow, dull orange yellow, orange yellow, or dull yellow; eyerim black, blackish or blackish brown.

Adult female: legs and feet blackish brown (soles not noted); iris damaged; bill blackish grey; gape yellow; mouth bright orange yellow; eyerim dark grey.

Imm. male: legs and feet greyish black, soles ochraceous buff; iris dark brown; bill blackish brown; gape buffy yellow; mouth deep bright yellow; eyerim blackish brown.

Imm. female: legs and toes black, soles buffy yellow; iris very dark brown; bill blackish brown; gape dull yellow; mouth orange yellow; eyerim blackish brown.

Taxonomy: Specimens collected on Pearson I. by us and by Cleland (1923) do not appear to differ morphologically from specimens of the mainland populations. In our opinion, however, the song of the Pearson I. population is distinctly different from that of mainland birds (song not heard on Greenly).

Pachycephala pectoralis (Latham). Golden Whistler

Pearson I. only. Recorded on all visits except 1960 and 1973. Apparently confined to the north section, where we found it fairly numerous (and singing) in dense *Casuarina stricta* and *Melaleuca lanceolata* thickets.

Specimens: B30484, Pearson I. (north section), 24.xi.1976, adult female, oocytes not enlarged, skull fully pneumatized; colours (shortly after death): legs and feet pale grey; iris reddish; upper mandible black, lower mandible blackish; mouth creamy flesh; eyerim blackish. Collected *ca* 1500 hrs in *Casuarina stricta* and other scrub on rocky hillside; alone.

B30485, Pearson I. (north section), 24.xi.1976, adult male, testes enlarged, skull smashed by shot; colours (5 mins after death): legs and feet blackish, soles creamy; iris red; bill black; mouth creamy flesh; eyerim black. Collected *ca* 1500 hrs in *Casuarina stricta* and other scrub on rocky hillside; with another adult-male phase bird.

Taxonomy: The populations of Pearson I. and Flinders I. are referable to *P.p. fuliginosa* Vigors & Horsfield, of southern Western Australia, southern South Australia (except the lower South-East) and northwest Victoria. This subspecies is characterized mainly by females and uncoloured males having the underparts buffy cinnamon.[1]

Zosterops lateralis (Latham). Silvereye

Pearson I. Recorded on all previous visits. The commonest passerine on the island, occurring in small flocks mainly on the north and south sections. We noted it in dense thickets of *Melaleuca*, and in the chenopods and other low dense shrubs on level ground and on the boulder-strewn slopes.

Dorothee I. Noted as common by Paton (1971). We recorded it in small numbers all over the island, among low windswept shrubs of the slopes and summits.

Greenly I. Mitchell & Behrndt (1949) reported it as common on the south section, favouring the stunted *Melaleuca lanceolata* on the precipitous slopes and ledges below 76 m. They noted several young birds incapable of sustained flight. We noted it as common from sealevel to the ridgetop, mainly in *Casuarina stricta* and *M. lanceolata*, with a flock of *ca* 30 in a clump of *Muehlenbeckia adpressa*. It was also common on the north section in the dense low ungrazed shrubs on the steep slopes.

Lichenostomus virescens (Vieillot). Singing Honeyeater

Recorded only by Paton (1971), who saw one bird on Pearson I. in January 1969.

Phylidonyris novaehollandiae (Latham). New Holland Honeyeater

Mitchell & Behrndt (1949) recorded three "somewhat bedraggled" individuals on Greenly I., one of which they collected (SAM B23768).

Ephthianura albifrons (Jardine & Selby). White-fronted Chat

Pearson I. only. Cleland (1923) noted it as "one of the commonest birds on the islands" in January 1923. Recorded by Thomas & Edmonds, January 1960 (Paton 1971). Paton recorded a few small flocks, each of about six birds, feeding mainly in the saltbush, and banded an immature, whose conspicuous yellow gape suggested that the species had bred on the island. We saw only one, a bird in female plumage, on bare granite boulders on the south section; on being disturbed, it flew out over the eastern bay.

Ephthianura tricolor Gould. Crimson Chat

Five noted on the northern slope of the north section of Pearson I. on three consecutive days in January 1969 by Paton (1971).

Two small red-rumped birds seen flying out to sea from the north section of Greenly I. by us were almost certainly of this species.

Passer domesticus (Linnaeus), House Sparrow

Cleland (1923) entered a "very doubtful" sighting of two or three birds on Pearson I. in January 1923. Paton (1971) recorded a flock of *ca* 40 on the eastern point of the north section of the island in January 1969, and a few on Dorothee I. We recorded a few on the north section of Pearson, and two on Dorothee. Possibly the species is a vagrant from Flinders I. (where it is very common) that has so far failed to establish itself.

Sturnus vulgaris Linnaeus, Starling

Cleland (1923) recorded a small flock over Pearson I., but added, "This record cannot be considered as established beyond all doubt". Paton (1971) noted that the species was as numerous as the House Sparrow (on Pearson I.), observing 20–30 at one time, including many immatures. Hornsby (1978) noted one or two birds on the middle section in 1973 and 1974. We noted two parties on the south section of Pearson (one of 5–6, one of *ca* 30), and five lots on the north section (of 1, 10, 12, 2 and 3 birds). On Dorothee we recorded four lots of 10, 4, 2 and 2 birds

Artamus personatus (Gould), Masked Woodswallow

Noted on Pearson I. only. Cleland (1923) tentatively identified two pale bluish woodswallows as this species. Paton (1971) noted one bird only, and referred to others seen by Thomas and Edmonds in 1960. We saw a pair on the north section in an area of *Casuarina stricta* and burnt *Melaleuca*.

Corvus coronoides (Vigors & Horsfield) Australian Raven

Pearson I. Waite noted "crows" on 27.ix.1914, and Wood Jones found corvids resting in *Casuarina* on 25.xi.1920 (Cleland 1923). Cleland noted "some 30 or 40", of which he collected two adults and a subadult (B4247–8, 28515); he also reported an unoccupied nest on the north section. Details of the stomach contents of Cleland's specimens, which included vegetable matter, insects and a rat, were given by Cleland (1923) and Lea (1923).

Thomas and Edmonds noted corvids in January 1960 (Paton 1971). Paton recorded *C. coronoides* in January 1969, identifying the species by its call. She wrote "usually in pairs, though sometimes as many as six might be seen feeding together on wave-washed debris on the rocks. . . . An old nest, probably of this species, was seen in a *Casuarina*." Hornsby (1978) recorded the species in 1973 and 1974, on all three sections, the largest number observed being 14. The birds were seen to pick at crabs and small fish stranded by the tide, and on one occasion several were seen at a freshly-dead Little Penguin.

We recorded the species mainly among the high rocks of the north and south sections. We estimated a maximum of six birds, which ranged regularly the length of the island.

Dorothee I. Paton (1971) recorded four. We saw a party of three.

Greenly I. Finlayson (1948) noted under *Corvus* sp.: "Two birds seen and more often heard on the main ridge." The following month Mitchell & Behrndt (1949) noted seven corvids roosting regularly in two large *Casuarina* trees just below the summit of the south section; these trees contained several nests, only one of which appeared to have had recent use. We noted a maximum of five *C. coronoides* (identified by their wailing call), along the *Casuarina*-clad main ridge.

The occurrence of the Australian Raven on South Australian offshore islands has not been fully appreciated. It has been collected or reliably recorded on St Francis, Franklin Is., Flinders, Pearson, Dorothee, Waldegrave, Greenly, Thistle, Hopkins and Kangaroo I., and is probably the corvid involved in sightings on Spilsby, Wedge, and the South Neptunes. The only island from which the Little Raven *C. mellori* has reliably been recorded is Kangaroo I.[1]

Acknowledgments

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DEEP SEA FAN SEDIMENTATION OF THE KANMANTOO GROUP, KANGAROO ISLAND

BY D. J. FLINT

Summary

The Kanmantoo Group sediments cropping out between West Bay and Breakneck River, Kangaroo Island, are predominantly immature metasandstones with lesser metasiltstones and metamorphosed lutites (schists). Lithologies and sedimentary structures show ordering in two distinct types of cyclic sedimentation (sequence 1 and 2). Cyclic sedimentation units (1-3 m thick) are arranged in sets (0.5-3 km thick) of only one cycle type. Vertical separation in the stratigraphic succession of the cycle types into broader sets is a distinct and important feature. It highlights different depositional processes.

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Summary

FLINT, D. J. (1978) Deep sea fan sedimentation of the Kanmantoo Group, Kangaroo Island. *Trans. R. Soc. S. Aust.* **102**(8), 203-222, 30 November, 1978.

The Kanmantoo Group sediments cropping out between West Bay and Breakneck River, Kangaroo Island, are predominantly immature metasandstones with lesser metasiltstones and metamorphosed lutites (schists). Lithologies and sedimentary structures show ordering in two distinct types of cyclic sedimentation (sequence 1 and 2). Cyclic sedimentation units (1–3 m thick) are arranged in sets (0.5–3 km thick) of only one cycle type. Vertical separation in the stratigraphic succession of the cycle types into broader sets is a distinct and important feature. It highlights different depositional processes.

Sequence 1 deposits have a relatively limited variety of sedimentary structures, and are characterised in part by a thick massive sandstone base and lutite top. Sequence 2 deposits contain a very wide variety of depositional and syndepositional deformation structures, within predominantly metasandstones. Medium scale foresets are abundant in areas of sequence 2 units, but occur randomly within these units. Both sequences are interpreted to have been deposited from turbidity currents with a bed load phase, but exhibit strong differences in the relative importance of traction and fallout processes.

The sediments are interpreted to have been deposited in a middle fan environment, i.e. channelled suprafan and suprafan depositional bulge. The size, abundance and random positioning of foresets makes these very unusual turbidite deposits.

Introduction

Kanmantoo Group metasediments cropping out between West Bay and Breakneck River, Flinders Chase, Kangaroo Island, South Australia (Fig. 1) were examined to determine their depositional, structural and metamorphic history. Structural and petrographic details are discussed in Flint & Grady (in press). Sedimentological aspects were investigated to determine mode and environment of deposition, transport processes, pretectonic orientation of palaeocurrents and palaeoslope and possible provenance.

Previous work in Flinders Chase is limited. The regional geology of Kangaroo Island was established by Wade (1915), Sprigg (1954), Daily (1956), Thomson (1969) and for Flinders Chase by Major & Vitols (1973). They concluded that during the Cambrian, when Kanmantoo Group rocks were being deposited the sea floor in the position of Kangaroo Island area subsided (Waitpingan Subsidence) synchronously with uplift (Cassinian Uplift) of the Gawler Craton to the northwest. Grey, medium to coarse grained greywacke-arkoses with sharply truncated crossbedding to 1 m high, scour channels and slump folds typify the Kanmantoo Group rocks cropping out in Flinders Chase (Major & Vitols 1973). Slumping is in the same direction as the dip direction of foresets, with a westerly source indicated. Lack of sorting, abundant submarine slump structures and sudden thickening across fault hinge zones were interpreted to indicate rapid transport and sedimentation with violent downward movements of the sea floor during sedimentation.

In Flinders Chase, Kanmantoo Group rocks examined here are exposed along 8 km of coastline in a strip often only 20 m wide from sea level to clifftop. Inland, Quaternary consolidated aeolian limestone, with minor piso-

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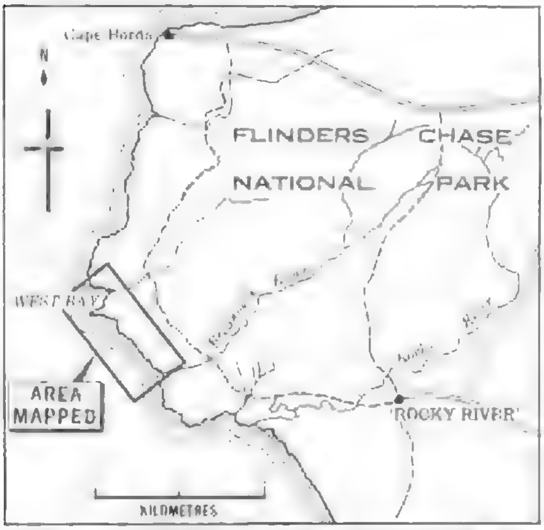


Fig. 1. West Bay area, Kangaroo Island.

litic laterite and siliceous sands, blanket the older rocks. The Kanmantoo Group comprises predominantly quartz-rich metasandstones, metalutites and quartz-mica schists, with less abundant types being pelitic and biotite-rich lutites, calc-silicate boudins, and actinolitic, biotite-rich and heavy-mineral-rich sandstones. Most rocks are quartz-rich (to 30% by vol.) and argillaceous (now recrystallised to biotite and muscovite). A very wide variety of traction, liquefaction, collapse and syndepositional deformation structures are developed. Lithification prior to regional deformation and only low pressure intermediate facies metamorphism during the lower Ordovician (Dasch *et al.* 1971; Milnes *et al.* 1977), have preserved many sedimentary structures.

This report describes and interprets the sedimentary characteristics of the Kanmantoo Group, so interpretive rock names such as lutite, siltstone and sandstone are used, even though the rocks have been metamorphosed to the andalusite-staurolite zone of the amphibolite facies (Flint & Grady in press). As the precise depositional processes and transport mechanisms are very interpretive, non-genetic terminology (sequence 1 and 2 units) has been adopted for the two distinct cycles of sedimentation exhibited. A Markov analysis technique is used to illustrate statistically the sedimentary cycles present. Sequence 1 and 2 units occur in separate intervals of the succession and are not interbedded mesoscopically (Fig. 2). This type of sedimentological analysis involving Markov modelling represents the first on Kanmantoo Group sediments.

Sequence 1 deposits

Description

Deposits of sequence 1 units consist of consecutive cycles of upward fining units with a massive homogeneous basal sandstone and a lutite upper portion (Fig. 3, Traverse A). Within each unit variation of grain size is gradational and the basal contact with the underlying lutite (now quartz-mica schist) is sharp and planar, except where tectonically deformed (Figs 4–5). Units vary in thickness from 0.1 m to 4 m (average approximately 1 m). Sandstone to lutite ratio averages 1:1 and the greatest uninterrupted massive sandstone interval is 80 m. The major sedimentary structures observed within sequence 1 deposits are ellipsoidal intraclasts, small scale ripple cross-stratification and small slump breccias, rare load and flame structures, ripped-up clasts and sandstone dykes and sills. Tectonism and metamorphic differentiation have destroyed nearly all of the sedimentary structures within the lutites (Fig. 5).

Intraclasts are ellipsoidal quartz-rich sandstones with maximum axial lengths of 0.25 and 0.15 m and oriented with the long axes parallel to bedding. Clasts occur throughout the lower half of the units. Similar clasts are described by Stauffer (1967), Fisher (1971), and Hampton (1972).

Slump breccias occur near the top of many massive sandstone divisions and consist of small elongate sandstone clasts in a sandstone matrix (Fig. 5). Clast orientation is now related to tectonic structures and Flint & Grady (in press) conclude from differential states of strain in tectonic structures, that transposition of sedimentary layering was penecontemporaneous with sedimentation. Reorientation of the transposed bedding occurred during tectonic deformation.

Small ripple cross-stratification and plane parallel laminae are observed as thin divisions above the slump breccias and near the centre of many units. Below, sandstones are massive, while above, former lutites are extensively folded, crenulated and differentiated.

Rarer structures in sequence 1 deposits are load casts and sandstone dykes and sills. Sandstone lobes (load casts) into underlying lutite are developed where the lutite has been preserved. Load casts are either symmetrical, possibly indicating formation after deposition of

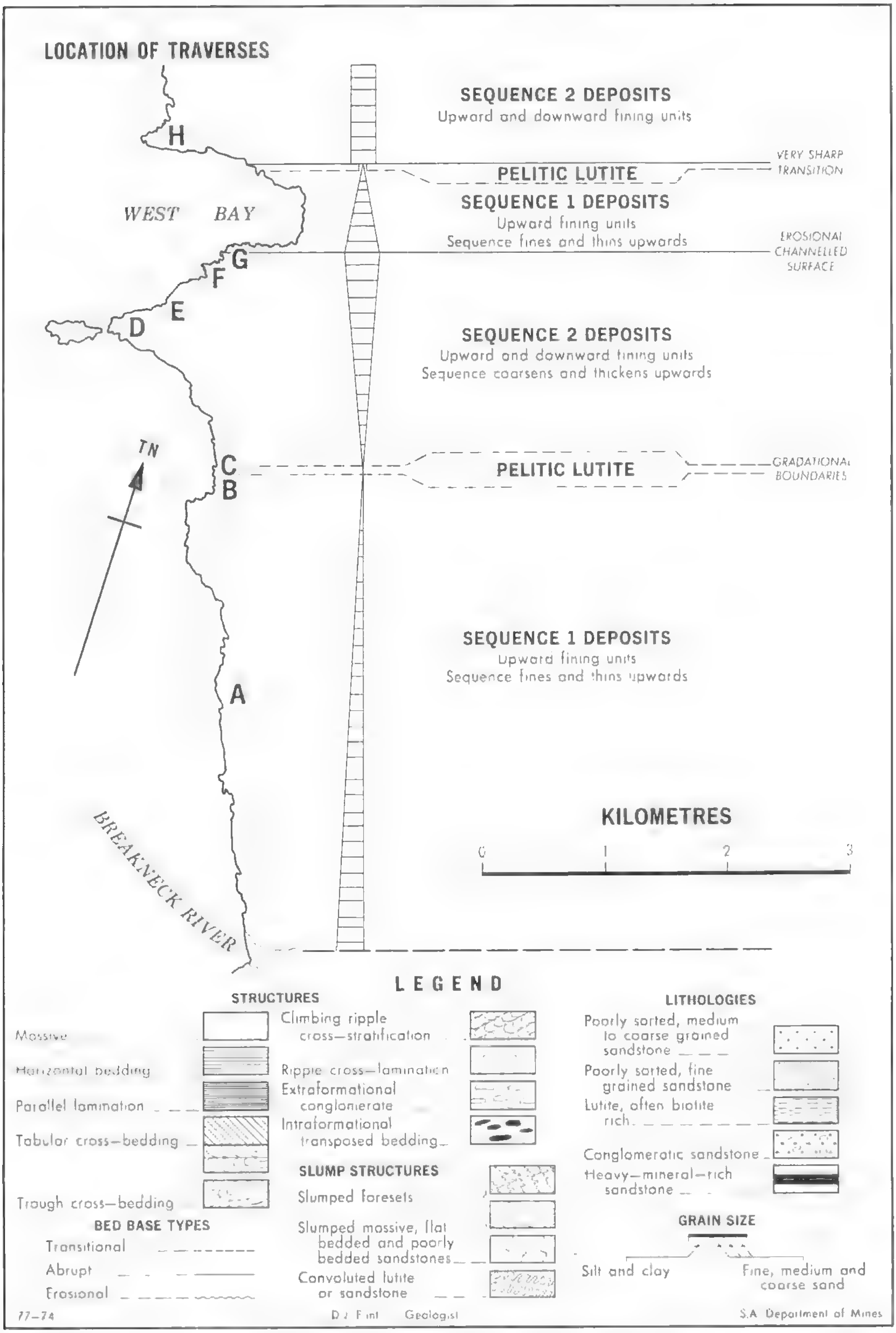


Fig. 2. Distribution of sequence 1 and 2 deposits and pelitic lutites in the West Bay-Breakneck River area. Note lack of mesoscopic intermixing of deposit types. Legend for and location of lithological logs in Fig. 3.

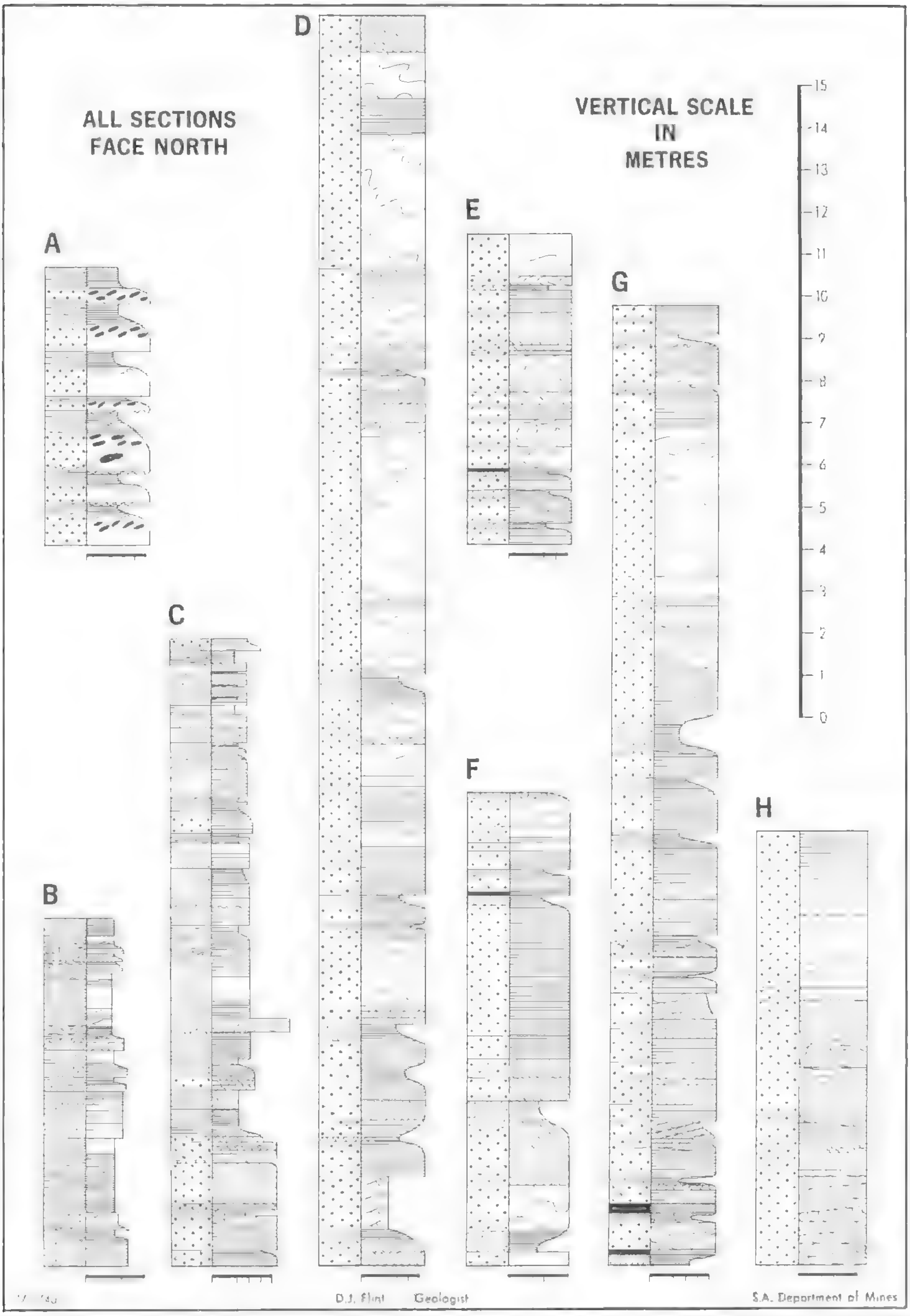


Fig. 3. Observed detailed lithological logs for sequence 1 deposits, transitional pelitic lutites and sequence 2 deposits.

the sandstone, or asymmetrical, suggesting syndepositional deformation. Injected laminated lutites between sandstone lobes resemble flame structures. Load cast height is invariably less than 7 cm. Small sandstone dykes and sills are observed in only one locality and consist of massive coarse sandstones of similar grain size to adjacent massive sandstones. Sills (fed by the dykes) are discontinuous, while the dykes have an orientation similar to slump fold axial planes, suggesting that dyke formation is along a plane of weakness formed by downslope penecontemporaneous creep.

Thinly laminated to massive sulphide-rich and actinolitic sandstones occur sporadically between sequence 1 units. They comprise less than 1% of the total thickness of all sequence 1 deposits.

Process of deposition

The sequence of thick massive sandstone division at the base, followed progressively upwards by a thin division of rippled and laminated fine sands and silts, and then a thick lutite division correlates well with Bouma's "acde" sequence (Bouma 1962). The sediment in sequence 1 units is interpreted to have been transported by turbulent mass flows with a basal sand slurry flow.

The first phase of deposition appears to be from rapid settling of grains out of suspension, probably as a "quick bed" from a basal slurry flow to the turbidity current; the mechanism of quick bed sedimentation is as outlined in Carter (1975), Walker (1976) and Rust (1977). Occasional clasts are trapped throughout these beds, and their presence in other deposits at various levels has been related to a finite yield strength of the slurry flow (Hampton 1972). Near the top of many "a" divisions are slump breccias which are probably related to mass shearing and dewatering during consolidation. This interval may once have had diffuse parallel lamination and equate to Bouma's "b" division. "Streaked-out laminae" have been described in a similar setting by Skipper & Middleton (1975) but their example involves more plastic syndepositional deformation. This basal division of massive sandstone, with scattered clasts and diffuse lamination, has many similarities to grain flows and debris flows of Stauffer (1967), Fisher (1971) and Carter (1975).

The finely rippled and laminated division near the centre of most units is correlated with Bouma's "c" division and lower flow regime currents. When present, it is always thin and according to Walker & Mutti (1973) a common observation is that the greater the number of sequences which begin with Bouma's "a" division, the more uncommon is parallel and rippled lamination within those units.

The lutites at the top of each unit are often of comparable thickness to the basal massive sandstones; these units are equated with the normal graded beds of Corbett (1972). Sedimentological analysis of structures within these lutites is limited due to extensive development of folds and other tectonic structures, including new differentiation layerings (Fig. 5). Deposition from waning, low velocity currents in the dilute tail of the turbidity current is interpreted as the likely depositional mode.

The sedimentation process for sequence 1 units is interpreted to be rapid deposition from waning currents. In this way, few traction structures would be developed, with the sediment being buried as soon as it is deposited. Transportation of the sediment is as a turbulent mass flow with a basal bed flow (slurry flow).

Transitional lutite deposits

Developed above intervals dominated by sequence 1 units are two pelitic lutites to 30 m thick (Fig. 2). Parallel lamination is the dominant sedimentary structure (Fig. 6) and rare structures are pseudonodules, sand ripples and thin (less than 1 cm) sand sheets (Fig. 7). In one instance (Fig. 3, Traverses B & C), the pelitic lutite has gradational boundaries both with the underlying sequence 1 deposits and overlying sequence 2 deposits. These lutite intervals are transitional between the thick sets of cyclic sedimentation units.

The two pelitic lutite intervals indicate periods and/or areas of relatively quiescent sedimentation. Sand ripples, thin sand sheets and predominantly clayey silt sedimentation, suggest deposition and reworking from slow moving currents with a low sediment concentration.

Sequence 2 deposits

Description

A wide variety of sedimentary structures are observed in sequence 2 deposits in contrast to their relative scarcity and lack of variety in sequence 1 deposits. Structures developed are bedding (massive, plane parallel, slumped and

FIG 4

Fig. 4. Several sequence 1 units occurring in upper portion of interval of sequence 1 deposits, with single phase deformation at a low angle to bedding. Pen for scale 13 cm long.

FIG 5

Fig. 5. Several sequence 1 units strongly deformed in lutite portions; most common style in outcrop. Note slump breccia above the upper massive sandstone bed.

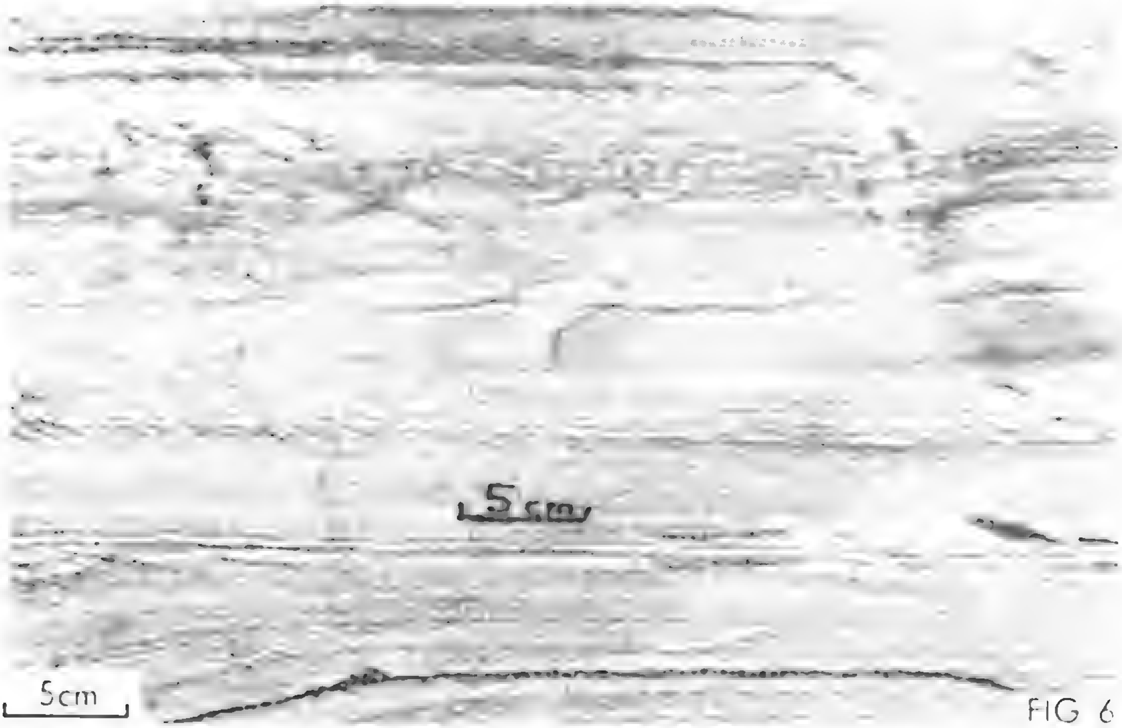


FIG 6

Fig. 6. Finely laminated and rippled lutite from within transitional lutite sequence.

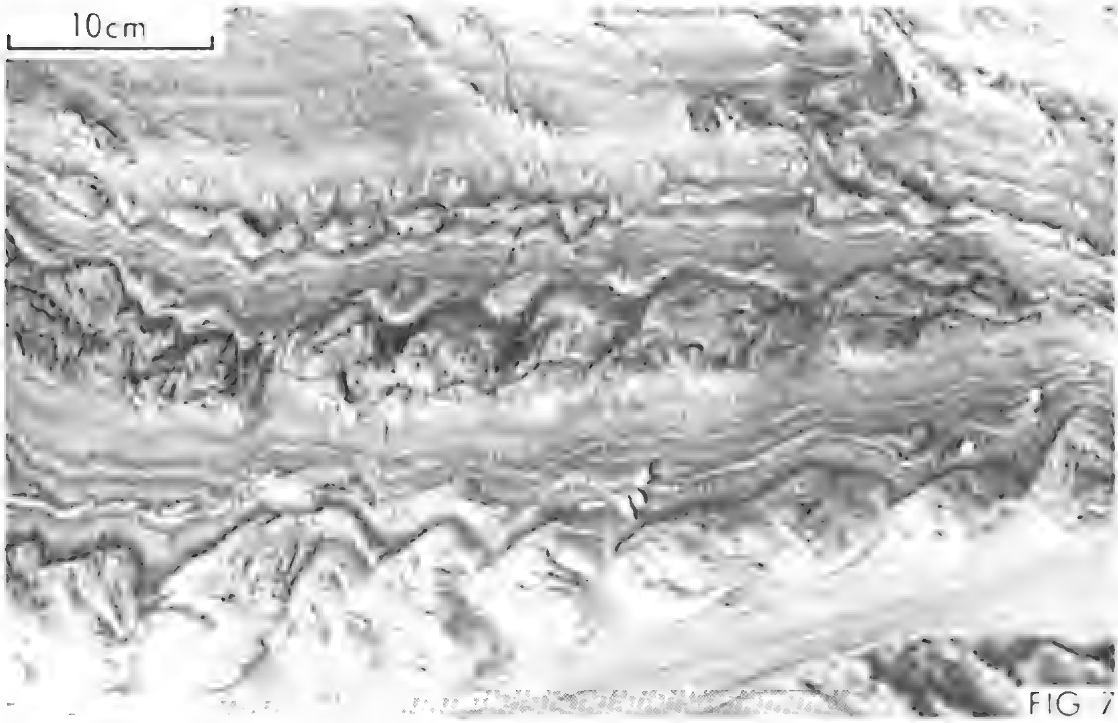


FIG 7

Fig. 7. Rippled sands and a thin disrupted sand bed within lutites of transitional lutite sequence.

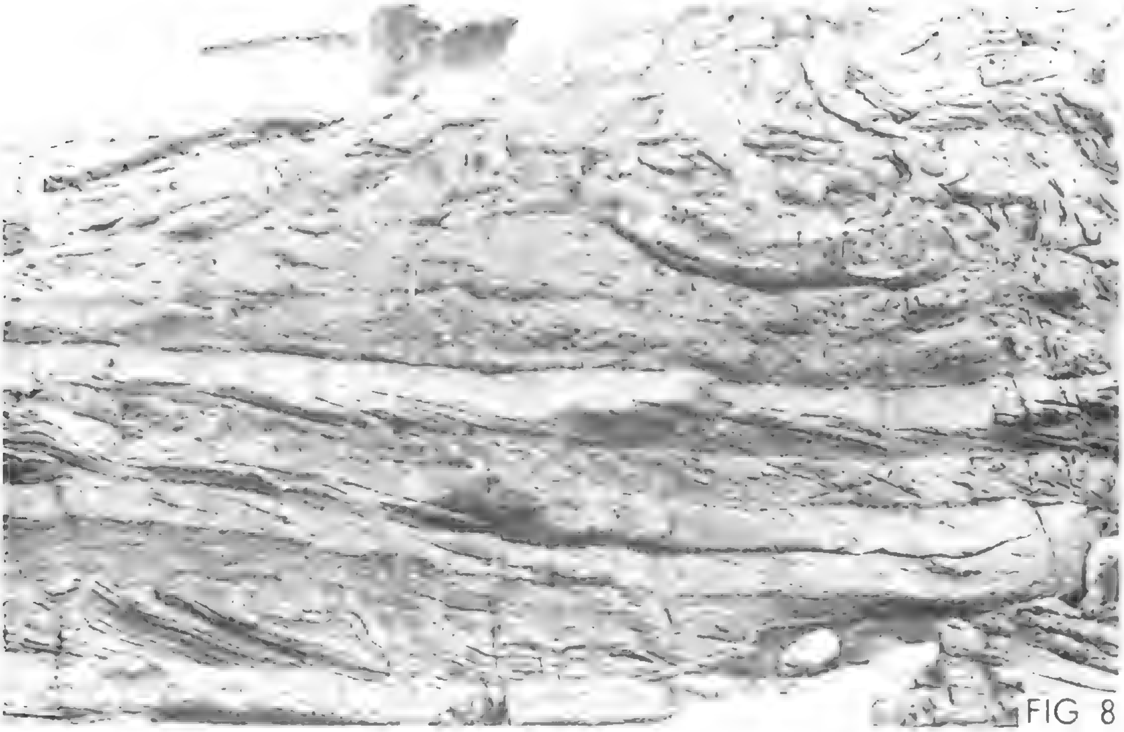


FIG 8

Fig. 8. Sequence 2 deposits with foresets, extensive slumping in upper portion of exposure.

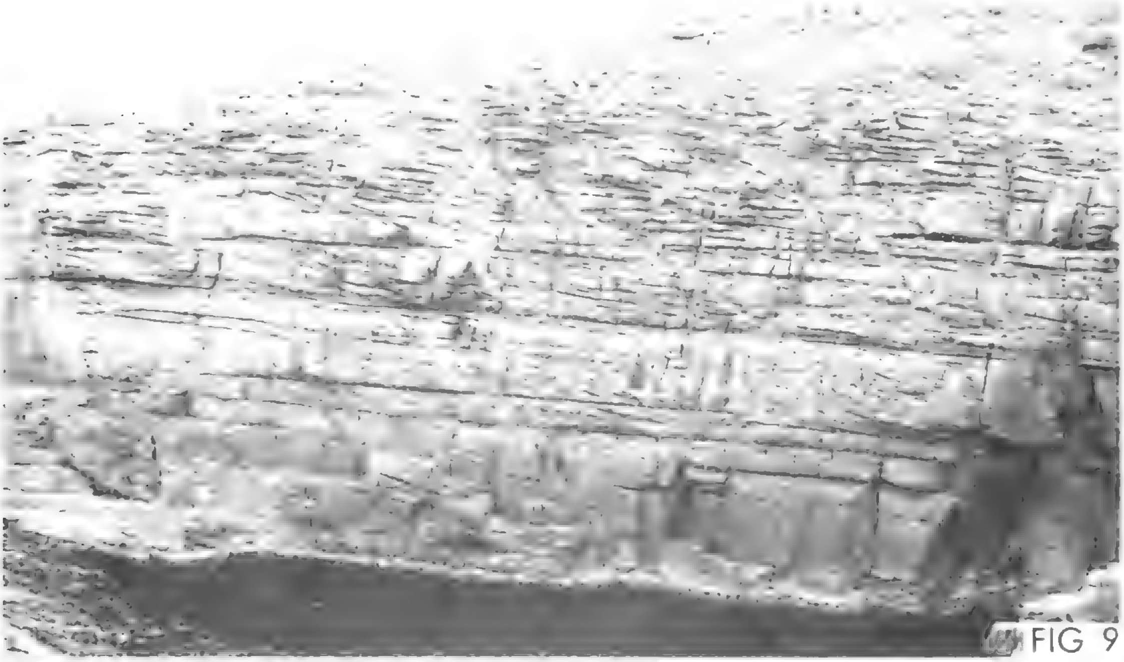


FIG 9

Fig. 9. Very thick interval of superimposed foreset divisions in a 40-m cliff-face, north side of West Bay: sequence 2 deposits.

convoluted), cusp structures, oriented clasts, climbing ripple cross-stratification, small diapir-like features and liquefaction structures. The rock types are predominantly medium to coarse grained, immature quartz-rich sandstones with concentrations of zircon (Flint 1976).

Observed sequences of lithologies and structures are shown in Fig. 3 (Traverses D to H) and Fig. 8, and have been subjected to Markov analysis.

At or near the base of many sequence 2 units are massive to poorly bedded, poorly sorted sandstones which have an average thickness of 1.3 m (0.11–4.25 m); they represent 35% of the total thickness of sequence 2 deposits. Clasts are occasionally present in this sandstone type, and their orientation varies from parallel to eroded base to imbricated with clasts dipping in the direction of flow. Clasts are consistently less than 0.1 m long and predominantly of biotitic lutite. Near the base of many units (but above the massive sandstone divisions) are coarse, flat bedded sandstones which form the most common lithology, both in the number of beds present and total thickness (40% of sequence 2 deposits). Thickness of individual flat bedded sandstones averages 0.9 m (0.18–4.60 m).

Foresets and inclined strata represent 12% of the total thickness, have an average thickness of 0.5 m (0.03–1.8 m). Most foresets are distinctly tabular with asymptotic foreset bases and sharply truncated tops. In profile, tabular foresets vary from lensing out over a few metres, to continuous over 50 m but with gently undulating upper and lower bounding surfaces (Fig. 9). Some foresets are trough shaped and deposited in asymmetrical scours, up to 2 m deep, with steep upcurrent sides while the downcurrent depositional surface is nearly tangential to bedding. Within that part of the stratigraphy of only sequence 2 units, foreset development varies considerably from small intervals of no foresets to intervals of abundant and superimposed foresets (Fig. 9). The extent of foreset development has no discernible relationship with any other characteristic of sequence 2 units. Intraformational recumbent folds with axial planes parallel to bedding are developed from slumping of foresets (Fig. 10). Identical structures are recorded in Pettijohn & Potter (1964, plate 110) and have been observed elsewhere within Kanmantoo Group sediments in Flinders Chase (Major & Vitols 1973). Selective slumping is common, with only a few in a succession of foresets being slumped. Partial slumping within individual foresets also occurs, with a marked tendency for homogenisation towards foreset tops.

The upper portion of many intervals consists of either massive or finely laminated lutite, with alternating biotite-rich and quartz-rich layers. Lutites represent 11% of the total thickness of sequence 2 deposits, and have an average thickness of 0.4 m (0.02–1.64 m). Heavy-mineral-rich sandstones (less than 0.1% total thickness) are commonly developed above the laminated lutite and exhibit gradational contacts. Banding within the heavy-mineral-rich sandstones is comprised of alternating layers (mm thick) of quartz-rich and heavy-mineral-rich sandstones and lutites, which grade up into a massive, heavy-mineral-rich upper portion. Laterally, lutites and overlying heavy-mineral-rich lutites are lenticular, and are truncated by the next sedimentation unit.

Slumped and convoluted bedding is ubiquitous for all of the areas characterised by sequence 2 deposits. Slumping of whole sequences of structures is more common than convolution of single beds.

Highly chaotic slumping with continuity of layering is typical (Fig. 11) and folds vary in style through planar-cylindrical to cusp-shaped. In some instances, contorted bedding suggests collapsed megaripples. Vertical thickness of slump-folded bands ranges from a few centimetres to 6 m.

Rare diapiric structures to 0.15 m high, and liquefaction structures (elutriation columns of Corbett, 1972) are observed in sandstones containing slumped bedding and cusp structures. Liquefaction features have developed from upward and downward movement of parallel bedded sandstones. Resultant structures include disrupted domes, and sinking "tear-drop" shaped sandstones in a homogeneous matrix (Figs 12–13). Similar small diapiric structures (ruptured layering) in Japan are described by Nagahama *et al.* (1975).

Lateral variations of lithologies and structures are observed even within the narrow exposure limits of only 20 m. Massive, poorly bedded and flat bedded sandstones are generally laterally continuous, but foresets and laminated lutites often thin and lense out laterally. Downcurrent fining is noticeable in some exposures, with foreset sandstones grading to climbing ripple cross-stratification or

FIG 10

Fig. 10. Overturning of upper portion of foreset laminae is very common, and produces intrafolial folds, sequence 2 deposits.

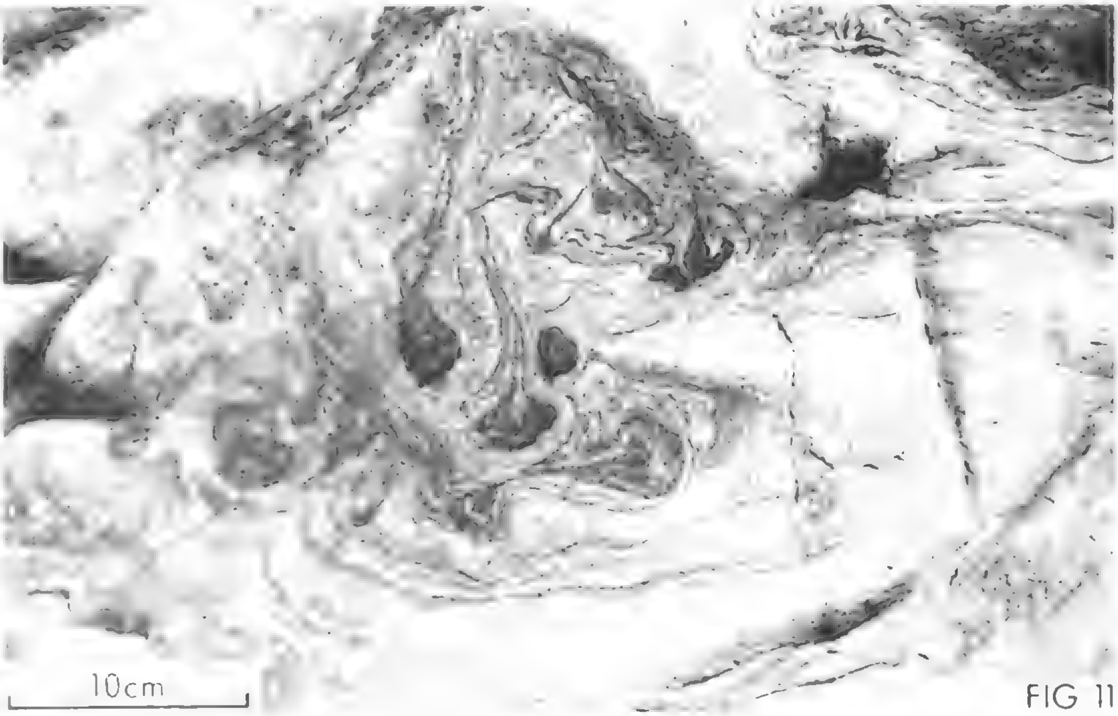


FIG 11

Fig. 11. Chaotic hydroplastic slumping within sequence 2 deposits is prevalent: example from a layered, fine-grained sandstone.

inclined laminated lutite. Small channels (less than 1 m wide and 0.15 m deep) are filled with massive or finely laminated lutite.

Markov analysis

Observations suggested that sedimentation within sequence 2 units involved cycles of lithologies and structures. To test the hypothesis of cyclic sedimentation, statistical testing methods (Markov analysis) were used. The technique of Markov analysis in its application to illustrating sedimentation cycles is outlined in Gingerich (1969), Krumbein (1967) and Krumbein & Dacey (1969) and Pettijohn *et al.* (1972).

Tests are made to prove whether a dependence exists of one lithology or structure on the previously deposited lithology or structure. Two types of observational methods were adopted:

1. Recording lithologies and structures at a fixed interval of 1 m.
2. Recording transitions at lithologic contacts and wherever sedimentary structures vary.

Some of the divisions used in the latter method are illustrated in Fig. 14.

Although the units have been modelled as for a Markov process, the original sedimentation process may not be Markovian, i.e. may not have a built-in memory. Krumbein (1967) outlines statistical criteria for testing the null hypothesis.

The greatest thickness of uninterrupted exposure was chosen and consisted of 179 m of sequence 2 deposits. It was found that sampling at a fixed interval of 1 m generates random sequences of lithologies and structures. The same 179 m traverse was subjected to another Markov analysis by noting all transitions of lithology and structure. Results of this analysis are tabulated in Figs 15-16. The sample statistic to test the null hypothesis, calculated from the N ln P matrix, is 150.2 which is greater than the tabled Chi-square value for 36 degrees of freedom at the 0.05 level of confidence. The hypothesis of an independent trials process for sedimentation within sequence 2 units is rejected.

The sequence of structures and lithologies can be extracted from the probability difference matrix (Fig. 16). Those transitions with positive entries have a higher than random probability of occurring. The cycle extracted from the probability difference matrix is ABE:

Transition	*Probability difference*
A–B	0.29
B–E	0.08
E–A	0.03

The cycle does not contain the foreset beds (C) as no higher than random probability exists for transition up into foreset phase; however, once in the foreset phase, a high probability exists for passing up into laminated lutite (E). For the 179 m traverse, the sequence A B E is observed 11 times and the next most frequent sequence is A B C E three times.

Amalgamation of sequence 2 units appears to be very common which is in marked contrast to sequence 1 units. The complete sequence (ABE) is observed only 11 times because of amalgamation and the random distribution of the foreset division.

The number of observations in this stratigraphic interval on bed types F and G are too restricted to allow meaningful interpretations of their relationships to other lithologies and rock types.

Examination of the observed profiles for sequence 2 deposits (Fig. 3) indicates that upward fining and upward coarsening units exist. However, observed profiles and the Markov analysis reflect the dominance of upward fining units. A unit based on average bed thicknesses would be 2.6 m thick. The fully developed cycle and foreset beds (A, B, C, & E) total 96% of the total thickness of sequence 2 deposits (Fig. 15).

Where sedimentation produced inclined bedding, vertical sequences (A B E) are also observed laterally.

Palaeoslope and palaeocurrents

Streaming lineations on flat bedded sandstones (as illustrated in Conybeare & Crook, 1968, Plate 80A) and foresets give a downcurrent direction concentrated in the range 015° to 135° (Fig. 17). Fold axes and axial planes of slump folds suggest a pretectonic palaeoslope dipping towards 115°.

No current directions or slump folds were measured in sequence 1 deposits or the transitional lutite deposits. Rare ripples and slumps are observed but are strongly tectonically deformed. All palaeocurrent and palaeoslope estimates are from sequence 2 foresets, flat bedded sandstones, laminated lutites and their slumped equivalents. Bedding normals to these lithologies are distributed about a fold axis plunging horizontally towards 079° true north

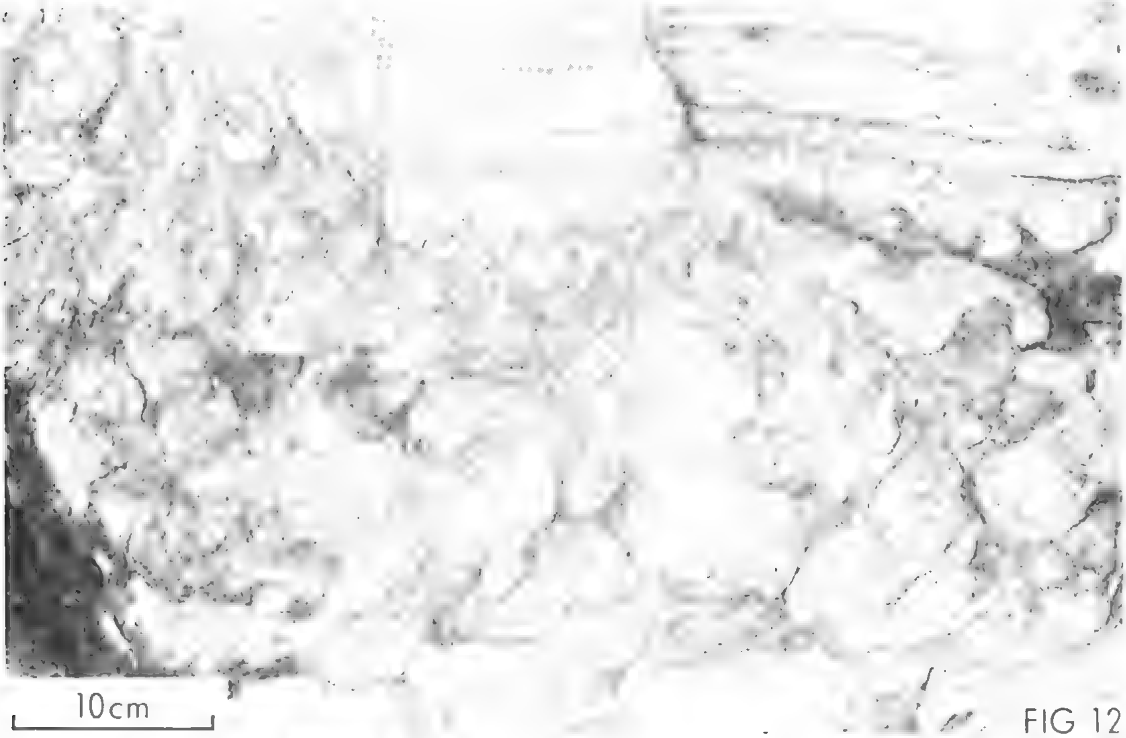


FIG 12

FIG 13

FIG 14

(Flint & Grady in press). Single axis rotation was performed until bedding became horizontal.

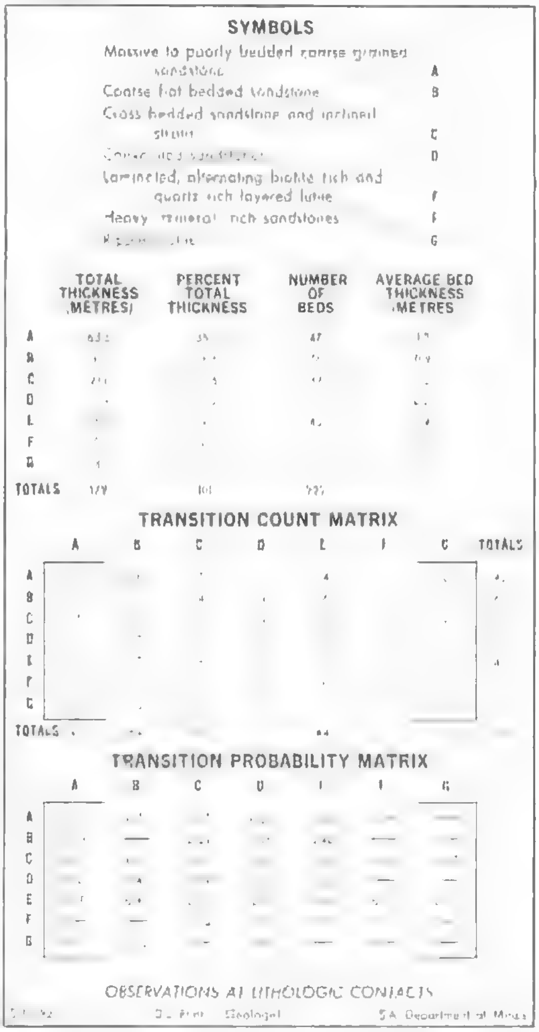
Slumping is assumed to be largely down the palaeoslope so that slump folds developed have axial planes striking along the palaeoslope. Slump fold geometry strictly reflects the palaeoenergy slope; here the two slope types are assumed to be equivalent

The spread of current directions may be from single or multiple source flows. If a ± 15° error is assumed in accuracy of palaeoslope determination, then 90% of palaeocurrents indicate flow in a 90° arc between down the palaeoslope and along the palaeoslope towards the northeast. The largest concentration of currents is north of the assumed palaeoslope direction. Differences in current directions were not observed to be related to variation in lithology, structures, or their spatial relationships.

Process of deposition

The fully developed cycle in sequence 2 units, as developed from the Markov analysis, is compared with the idealised Bouma turbidite sequence (Bouma 1962). Divisions "a", "b" and "d" of Bouma and their ordering are the same as sequence 2 units in Flinders Chase. Although both sequence 1 and 2 deposits are interpreted to be turbidites there are distinct differences between them: the strong difference in the development of a thick well bedded "b" division, the abundant foresets and the much thinner "de" divisions of sequence 2 units. Similarly to sequence 1 units which also start with the massive "a" division, Bouma's "c" division of ripple cross-lamination is almost entirely lacking in sequence 2 units.

Massive and very poorly bedded sandstones at the base of many units represent rapid deposition from the bed load (slurry flow) of the turbidity current, and are analogous to sequence 1 slurry flows. The flat bedded sandstones differ from the usual diffuse horizontal parallel laminated sandstones in many turbidite descriptions (e.g. Bouma 1962; Walton 1967; Walker 1967) in that the bedding planes are strongly developed, sharply defined and spaced several centimetres apart. These flat bedded sandstones appear to represent transition from bed load conditions to fairly uniform, upper flow regime velocities. The average and maximum bed thickness of 0.9 m and 4.6 m re-



SYMBOLS

Massive to poorly bedded coarse grained sandstone	A
Coarse flat bedded sandstone	B
Cross bedded sandstone and inclined strata	C
Convoluted sandstone	D
Laminated, alternating biotite rich and quartz rich layered lutite	E
Heavy mineral rich sandstones	F
[illegible]	G

TRANSITION COUNT MATRIX

TRANSITION PROBABILITY MATRIX

OBSERVATIONS AT LITHOLOGIC CONTACTS

Fig. 15. Symbols and observations at lithologic contacts for the Markov analysis, sequence 2 deposits. Note for each of the divisions, the average bed thickness and percent of total thickness.

Fig. 12. Syndepositional liquefaction structure with collapse and disruption of sandstone beds producing tear-drop forms, sequence 2 deposits.

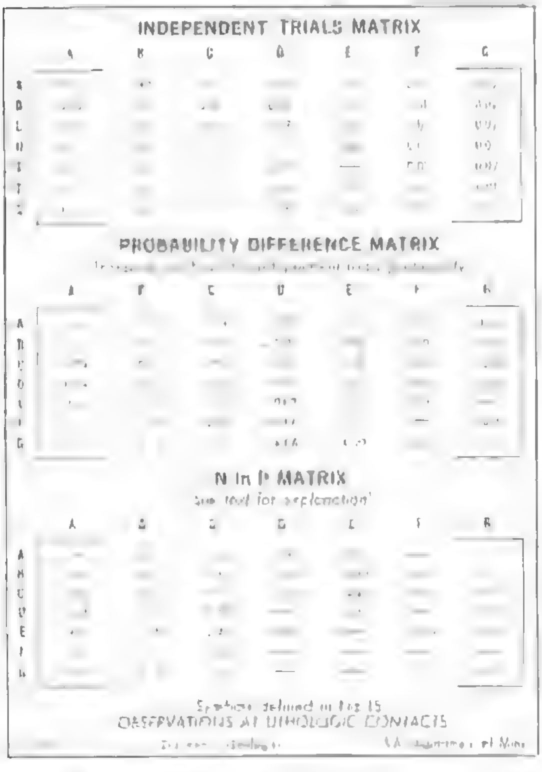
Fig. 13. Syndepositional liquefaction structure with disruption and upward doming of layered sandstone, sequence 2 deposits.

Fig. 14. Some of the divisions used in the Markov analysis; poorly bedded sandstone, overlying laminated biotitic lutite, overlying convoluted sandstone; sequence 2 deposits. Pen for scale 13 cm long.

spectively for these beds and their abundance (40% of total thickness) illustrate that these conditions were common, and that the current decay was very slow.

Cross bedded sandstones and inclined strata are a very important phase of deposition. Markov analysis strongly suggests that the foresets do not occupy a fixed position in sequence 2 units, but occur randomly throughout the cycle and are overlain by layered lutites. Thomson & Thomasson (1969) established a sequence of "a-dunes-bede" for calcareous turbidites in the Dimple Limestone (Texas). Walton (1967) and Allen (1969) indicate that, based on studies of current velocities and their decay, medium scale forests could form but the structures recorded in turbidites depend strongly on the rate of decay of the turbidity current. The general absence of foresets in turbidites is an indication that currents apparently decay too rapidly.

The foresets represent a stable, aggradational bed form which probably formed from sand dunes (averaging 0.5 m high) migrating downcurrent. Flat bedded sandstones grade into cross-bedded sandstones via low angle inclined strata. The close relationship of these bedforms was also observed by Corbett (1972) in a proximal flysch sequence, Tasmania. Foreset divisions apparently represent deposition from sediment laden currents maintained at a constant velocity in the upper portion of the lower flow regime (from the bed form-flow regime studies of Harms & Fahnestock (1965)). As the flat bedded and cross-bedded sandstones represent 52% of the total thickness of all sequence 2 deposits, then the currents were consistently at velocities transitional to the upper and lower flow regimes. Conditions of uniform flow with a slow rate of deposition are known from turbidites (Middleton 1969; Blatt *et al.* 1972) and lead to units with traction structures. Mutti (1977) also indicates that foresets represent traction processes without substantial fallout. The extent of turbulence within these currents is problematical; Sanders (1965) suggests that turbidity currents will not give rise to large scale traction structures while Walker (1967) concludes that foresets represent fully turbulent flow.


INDEPENDENT TRIALS MATRIX

PROBABILITY DIFFERENCE MATRIX

N ln P MATRIX

(see text for explanation)

Symbols defined in Fig 15

OBSERVATIONS AT LITHOLOGIC CONTACTS

Fig. 16. Markov analysis of data presented in Fig. 15. Significant transitions are those with a positive entry in the N 1nP matrix.

The flat bedded and cross-bedded sandstone divisions are overlain (statistically) by flat bedded lutites without the development of small ripples. The thinly bedded biotite-rich and quartz-rich lutites indicate deposition from the final waning stages of the turbidity current. Heavy-mineral bands at the top of some units with interbedded quartz-rich and heavy-mineral-rich layers, show that currents continued to flow after sand and lutite deposition at velocities sufficient to winnow the lutite fines and redeposit heavy minerals. A variety of current types are possible for these deposits, including oceanic contour currents, tidal currents or the tail of turbidity flows. Middleton & Hampton (1973) postulate a dilute entrained layer which flows after the turbidity curent body and reworks upper portions of the turbidite deposit, and this is considered the most probable explanation for the heavy-mineral concentrates. These concentrates have significant differences to those attributed to deposition from contour-following bottom currents of Bouma & Hollister (1973, Table 1). Contourite concentrations are supposedly as placers in small scale stratification within laminated silt and clay deposits, whereas concentrates of sequence 2 deposits are often massive, not associated with ripples, always within sandy sequence 2 deposits rather than lutites and involve both winnowing and redeposition of heavy minerals. Traction, pulsating currents causing lenticular sands with laminae of heavy mineral concentrations have been observed in vehicle dives and measured in current meters (Shepard *et al.*, 1969) at La Jolla submarine canyon and fan valley, California.

Upward fining and upward coarsening individual units indicate the abundance and pulsating nature of the currents. Thomson & Thomasson (1969) and Walker & Mutti (1973) state that the order of occurrence of Bouma's divisions is very rarely inverted, but Glaister & Hopkins (1974) interpret units with gradational upper and lower contacts as representing continuous deposition from pulsating turbidity currents.

Lateral lensing and amalgamation of sequence 2 units is very common and, along with observing vertical sequences laterally over a distance of metres to tens of metres when the strata are inclined, suggest that the depositional surface was channelled, or at least had an uneven topography. If the lutite divisions originally were thicker, then preservation of them to only 11% of the total thickness (Fig. 15) would result from amalgamation of sequence 2 units.

Environment of deposition

Water depth during sedimentation is difficult to estimate for a succession dominated by turbidites. Calcsilicate mineralogy in sediments deposited between turbidites during periods of relative quiescence, suggests deposition above the contemporary calcite compensation depth. No structures are observed to indicate deposition above the storm wave base.

Turbidites have been described from many environments, but a thick turbidite succession is most likely to be preserved in an area of consistently deep and quiet water (Walker 1976). The succession of sequence 1 and 2 deposits is compared with models for deep sea fans and sandy tectonic delta complexes. The preceding sections have established that both sequence 1 and 2 units were deposited from waning turbidity currents with a substantial bed load component but substantially different rates of deposition and current decay rates. A distinctive feature is the perfect spatial separation of the two types of turbidity deposits.

Deep sea fans

Where observed (Fig. 2) the intervals of sequence 1 deposits thin and fine upwards, and have a thick massive sandstone base up to 80

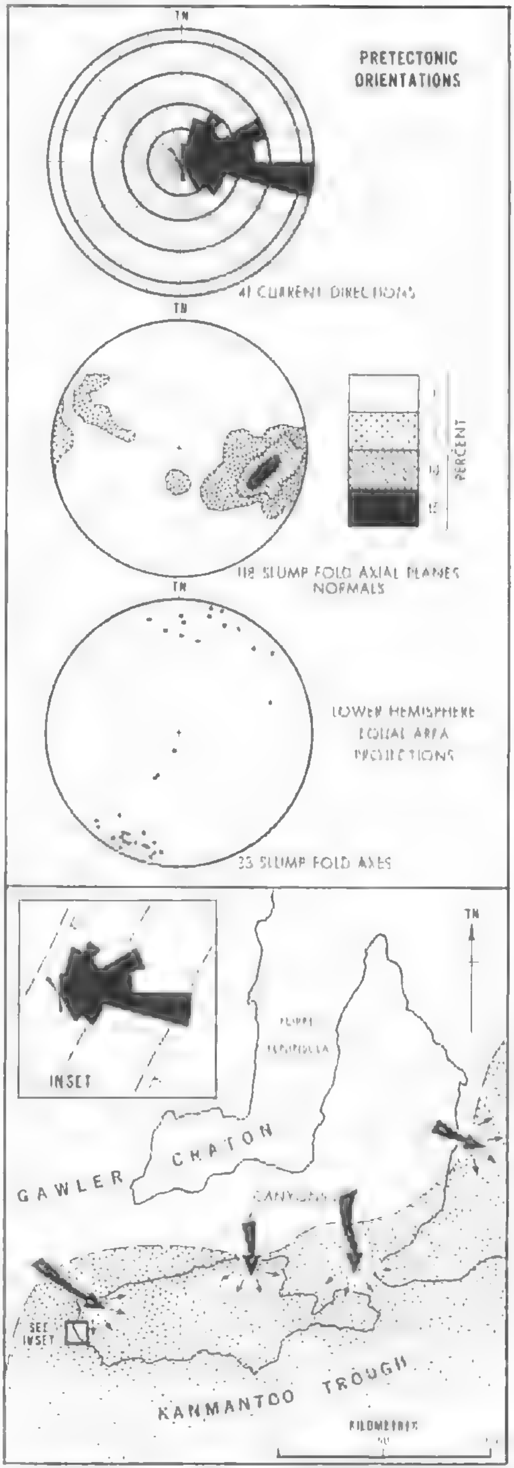


Fig. 17. Palaeocurrents and pretectonic slump fold geometry, and their relationship to the inferred palaeogeography of Thomson (1975).

m thick directly above a scoured, erosive base. This style of upward fining and thinning of sequences dominated by Bouma "a" divisions is widely recognised as sedimentation in deep sea fan valleys or channels (e.g. Nelson & Kulm 1973; Middleton & Hampton 1973; Ricci-Lucchi 1975; Rust 1977; Walker 1977) The massive, structureless sands at the base of the succession are interpreted to be from rapid deposition from mass flows of high sediment concentration and low turbulence (Rust 1977), to amalgamation from channel meandering (Walker 1976). Sequences dominated by "ae" divisions are found in channels from upper to lower fan environments (Haner 1971), but vary from "a" division predominating in upper fan channels to "e" division dominant and with base cut-outs in lower fan channels. The most complete "ae" units are in middle fan channels or lower reaches of the upper fan valleys (Nelson & Kulm 1973; Nelson & Nilsen 1974). Inner fan deposits usually consist of large lenticular channel sands within thick mudstone sequences (Mutti 1974; Walker & Mutti 1973), but in the West Bay area they are surrounded by a succession of sandy sequence 2 deposits. It is concluded that sequence 1 deposits in Flinders Chase represent sedimentation in a channel of the middle fan (suprafan).

Transitional lutite sequence developed at the top of the channel fill deposits may represent interchannel sedimentation, a levee facies or deposition from contour-following bottom currents. Well developed levees are known to exist along deep sea channels and fan valleys (e.g. Shepard & Marshall 1969; Piper & Normark 1971; Nelson & Kulm 1973) and contain laminated silts and muds with a few thin sands, very similar to the lutites above the succession of sequence 1 deposits. If a middle fan environment is correct, then deposition from oceanic bottom currents (deposits as described in Hubert (1966) and Bouma & Hollister (1973)) is unlikely, as the current's driving mechanism is insufficient to drive it well up the slope of the depositional basin. A levee facies or interchannel deposition is concluded for the transitional lutite sequences.

Sequence 2 deposits are arranged in a thick upward coarsening and thickening set; this style of deposition is most often interpreted as a prograding depositional bulge on a deep sea fan (e.g. Walker & Mutti 1973; Nelson & Kulm 1973; Mutti 1974; Ricci-Lucchi 1975; Walker 1976). The unusual feature of sequence 2 deposits are the foresets which figure rarely in descriptions of turbidite deposits, with Potter (1967) listing large scale cross-beds as characteristically absent from turbidite sand bodies. Medium scale foresets (30–90 cm) of Stauffer (1967) occur with ripple marks of current and wave types, and have been interpreted as shallow water traction sediments rather than mass flow deposits. Foresets to 1 m high in the Dimple Limestones (Texas) have been interpreted as part of a proximal turbidite facies with deposition under "high energy" conditions on the outer shelf or upper slope (Thomson & Thomasson 1969). Large scale low angle cross-bedding has also been observed in interpreted proximal turbidites by Corbett (1972) and Link (1975), while Stanley (1964) regarded them as representing deposition as submarine depression fillings and as fan shaped accumulations at the base of steep palaeoslopes.

Mutti (1977) has defined a channel mouth facies for the Eocene Hecho Group in Spain, which has marked similarities to sequence 2 deposits. That is, the deposits occur in a thickening and coarsening upward sequence, individual beds lense, wedge and amalgamate over short distances, large scale cross laminae are common, and internal depositional structures are indicative of mainly tractional processes without substantial fallout. Mutti comments on the dissimilarities to previously described turbidites and other mass flow deposits. The proposed model of Mutti is for deposition of excess sand from the turbidity current as it leaves the confines of a channel and spreads out as a sheet flow across the lower fan. Sand dropped from the by-passing turbidity current forms a bed of loose sediment that is reworked through dune and ripple phases by the same or subsequent currents. Thus prograding sand lobes develop at the debouching terminus of channels, as is interpreted for deposition near middle fan channels of the San Salvatore Sandstone (Mutti 1974). The middle fan environment is known to have a hummocky topography from surface echo sounding profiles (Normark 1974) and is interpreted to contain small delta or fanlike deposits at the end of leveed valleys (Normark 1970). The dune phase of Mutti (1977) has probably been observed. Shepard *et al.* (1969) noted large sand waves with wavelengths of 15–30 m and up to 1 m high in the outer fan valley of the La Jolla fan valley, where the channel merges with the flat floor of the San Diego Trough. The effect of the transition from confined to unconfined turbidity flows is probably the same as a decrease in slope of the depositional surface.

Sequence 2 deposits are interpreted to represent a prograding sand bulge or lobe from deposition at channel mouths. Alternatively, they may represent channelised turbidites near a significant change of slope, e.g. palaeoscarps or transition from canyon to fan system. From the random position of foresets in sequence 2 units, reworking of the loose sediment into dune phases is likely to be from the current which carried the sediment, rather than subsequent currents. The most likely environment for channel mouth sedimentation is on the middle fan (suprafan) depositional lobe, which has been interpreted as the area of most rapid aggradation (Piper & Normark 1971; Nelson & Kulm 1973).

Based on the present-day models for deep sea fans, sequence 1 and 2 deposits appear to represent sedimentation on a channelled suprafan and a suprafan depositional lobe. The combined thickness is several kilometres which is well within the size estimates of 0.3–12 km for modern deep sea fans (Nelson & Kulm 1973; Nelson & Nilsen 1974; Reineck & Singh 1973). Predominantly sand deposition from abundant and pulsating currents suggests a close proximity to the source area(s). Ancient landmasses to the northwest, west and southwest (Gawler Craton extensions or Antarctic Shield) are indicated by the palaeoslope and palaeocurrents.

Tectonic delta complexes

Occurrences of modern and ancient deltaic complexes with significant sand deposition and which have many similarities to Kanmantoo Group sediments are:

1. Eocene Coaledo Formation, Oregon (Dott 1966);
2. Carboniferous sequence of Mam Tor Series to Kinderscout Grit, Northern England (Walker 1966; Collinson 1969);
3. Holocene fluviomarine phases of the Rhône Delta Complex (Oomkens 1970);
4. Devonian Chemung lithofacies of the Catskill Delta Complex, New York (Friedman & Johnson 1966);
5. Upper Ordovician Oswego Sandstone and Reedsville Shale, Central Appalachians (Horowitz 1966);
6. Tertiary debris flow and shallow-water density flow deposits of the Mackenzie Delta, Canada (Glaister & Hopkins 1974).

Of these, the greatest similarity in sedimentary structures and lithologies of the Kanmantoo Group is with the Eocene Coaledo Formation. The deltaic model for Kanmantoo Group lithologies would be sequence 2 deposits representing a distributary channel environment on a delta platform, with sequence 1 deposits as slumps off the delta margin. Such a rapid transition from cross-bedded sandstone facies to proximal turbidites has been interpreted for the Matilija Sandstone (California) by Link (1975). Density currents off the delta have been interpreted for the late Cretaceous to Paleocene Difunta Group of northern Mexico (Galloway 1975) while deltas with an associated submarine slope and fan system are described by Asquith (1970) and Galloway & Brown (1972). Although those deltaic deposits are sandy in parts, sandy lithologies are no more than hundreds of metres thick and grade into lithologies with readily recognisable tidal and subaerial characteristics. In Flinders Chase no structures were observed to indicate deposition above the storm wave base.

Although sediments similar to Kanmantoo Group lithologies are known from tectonic delta complexes, it is concluded that the deposits of Flinders Chase represent accumulation on a deep sea fan.

Stratigraphic correlation

Recognition of some Kanmantoo Group sediments in Flinders Chase as probable deep sea fan deposits necessitates re-assessment of regional correlations and depositional environments of Kanmantoo Group sediments in other areas. A knowledge of the probable sedimentary environments and possible regional marker horizons are necessary before regional correlations are undertaken. Correlation of formations based on individual structures or gross lithologies are not necessarily meaningful.

Sedimentary environments represented by Kanmantoo Group sedimentation previously have not been evaluated fully. Sprigg & Campana (1953) compare sedimentation with "the Alpine Flysch", but Daily & Milnes (1973) emphasise the possibility of shallow water sedimentation. A deep water origin is presumed by Skinner (1958) for the Nairne Pyrite Formation.

On available information (Daily & Milnes 1971, 1973) the most likely correlative of West Bay to Breakneck River sediments is the Tapanappa Formation, which is equivalent to part of the Inman Hill Formation of Thomson (1969). Other possible equivalents are the Backstairs Passage and Balquhidder Formations. However, this involves correlations over 100 km with little intervening control, and with deposition in a tectonically active environment producing numerous local and regional variations. Nevertheless, the similarity of Flinders Chase sediments to these other formations suggests a wider occurrence of deep sea fan sediments within the Kanmantoo Group.

Acknowledgments

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A NEW GENUS *ADELONEMA* (NEMATODA: OXYURIDAE) FROM AUSTRALIAN PHALANGERID MARSUPIALS

BY PATRICIA M. MAWSON

Summary

Adelonema n.g. is proposed for Oxyuris (s.l.) trichosuri syn. Syphacia trichosuri Johnston & Mawson, hitherto known only from the female. Males are described from the type host Trichosurus vulpecula and from T. caninus. The new genus is close to Austroxyuris J. & M. differing in the development of structures in the buccal cavity, particularly clearly seen when examined by scanning electron microscope.

A NEW GENUS *ADELONEMA* (NEMATODA: OXYURIDAE) FROM AUSTRALIAN PHALANGERID MARSUPIALS

by Patricia M. Mawson*

Summary

Mawson, P. M. (1978) A new genus *Adelonema* (Nematoda: Oxyuridae) from Australian phalangerid marsupials. *Trans. R. Soc. S. Aust.* **102**(8), 223-226, 30 November, 1978.

Adelonema n.g. is proposed for *Oxyuris* (s.l.) *trichosuri* syn. *Syphacia trichosuri* Johnston & Mawson, hitherto known only from the female. Males are described from the type host *Trichosurus vulpecula* and from *T. caninus*. The new genus is close to *Austroxyuris* J. & M. differing in the development of structures in the buccal cavity, particularly clearly seen when examined by scanning electron microscope.

Introduction

Female oxyurids were first recorded from *Trichosurus vulpecula* in Queensland as *Syphacia trichosuri* Johnston & Mawson (1938). The description was revised later (Mawson 1964) from fresh material in which only females were present. Recently both males and females have been taken from several host animals. The species is found to differ from other oxyurids so far described and a new genus is proposed for it.

Adelonema gen. nov.

Diagnosis: Oxyuridae: Post oesophageal lateral alae present. Head marked off from body by annular constriction and bearing four single submedian papillae and two lateral amphids. Mouth opening more or less circular; buccal capsule more or less circular in transverse section with six longitudinal ridges projecting anteriorly as three large and three smaller pseudolabia. Anterior end of oesophagus projects as three lobes into base of buccal cavity. Oesophagus long; excretory pore post oesophageal. Male: with ventral and lateral caudal inflation, ending just behind cloaca, body ending in long spike. Four pairs of pedunculated and one pair sessile caudal papillae. Spicule single. Female: tail long, tapering; vulva about mid body, uteri opposed; eggs not operculate. Parasitic in Australian phalangerid marsupials. Type species: *Adelonema trichosuri* (Johnston & Mawson).

Discussion

Austroxyuris Johnston & Mawson, *Paraustroxyuris* Mawson and *Macropoxyuris* Mawson are distinguished from other oxyurids (Petter & Quentin 1976) by the presence of a buccal capsule with inter-radial lamellae. These lamellae are present in the new genus, projecting as small lip-like cones. In addition three radial lamellae are developed at the anterior end of the buccal capsule and project as three cuticular lobes. These six projecting structures are referred to as 'pseudolabia', as they appear to arise from within the buccal capsule, not from the cuticle around the mouth.

Adelonema trichosuri (Johnston & Mawson)

FIGS 1–6

Syphacia trichosuri Johnston & Mawson 1938, p. 194 (from *Trichosurus vulpecula*, Queensland).

Oxyuris (s.l.) *trichosuri* (Johnston & Mawson): Tiner (1948), p. 89; Mawson (1964), p. 259 from *T. vulpecula*, Queensland).

Hosts and localities: *Trichosurus vulpecula* Kerr, Kangaroo I., S. Aust.; *T. caninus* Ogilby, Clouds Creek, N.S.W.

Males 1.7–2.1 mm long, females 5.1–6.2 mm. Body of male almost cylindrical, ending suddenly in tail spike, that of female tapering very slightly to head and gradually in region of tail. Lateral alae present in both sexes, from base of oesophagus nearly to anal region.

Cuticle around mouth thickened, cushion-like, with central circular mouth through which

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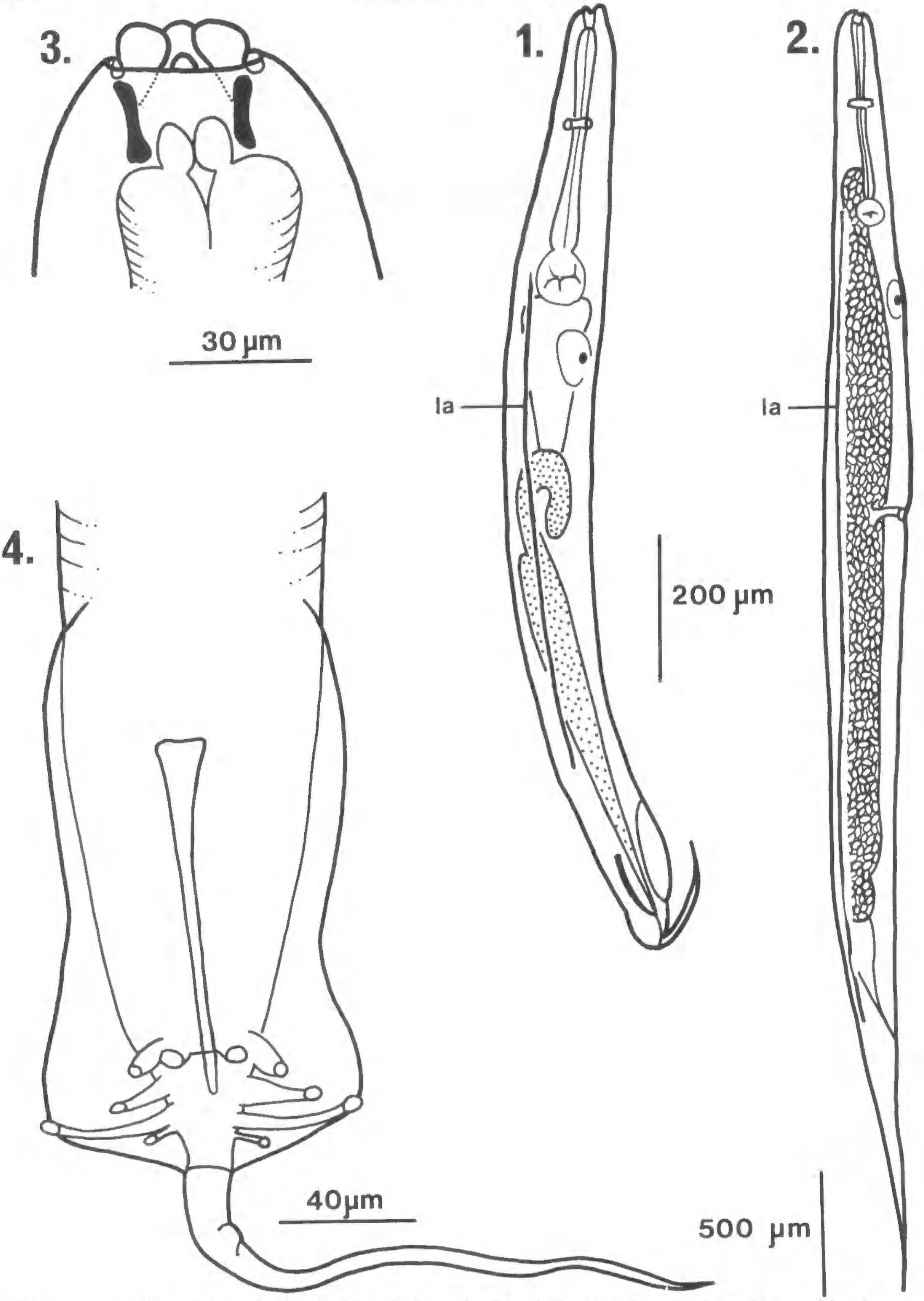
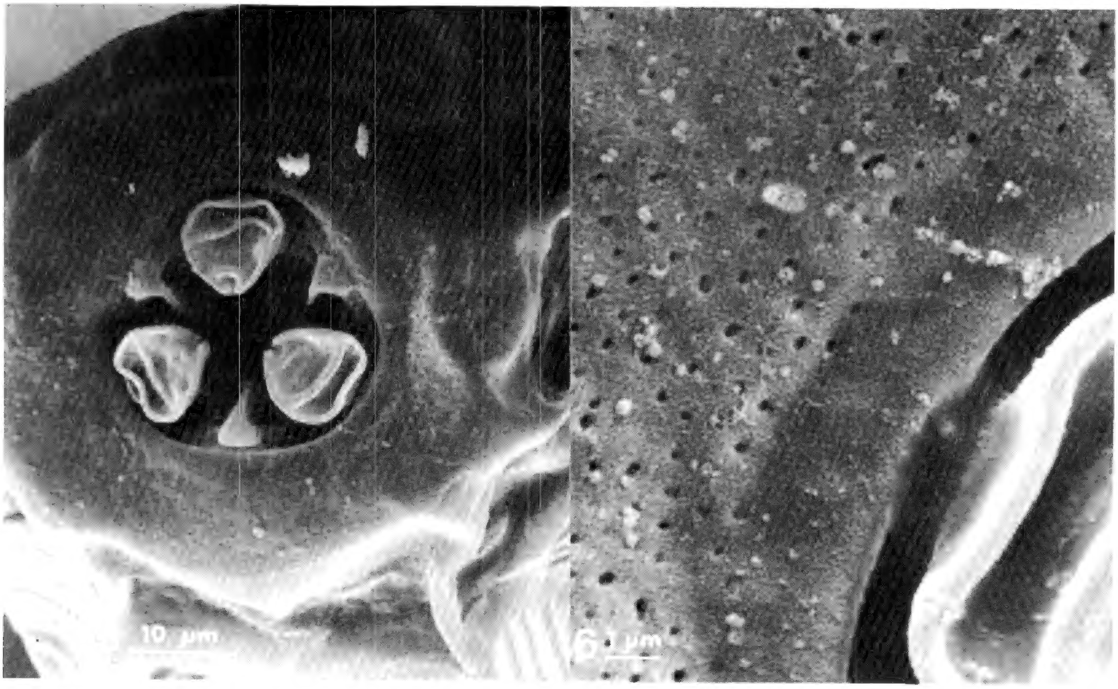


Adelonema trichosuri. Fig. 1: Male. Fig. 2: Female. Fig. 3: head of female, lateral view. Fig. 4. posterior end of male, ventral view.



Adelonema trichosuri. Fig. 5: anterior end of female. The three lips have lost their turgidity during the drying process. Fig. 6: enlargement of part of Fig. 5, showing pores in cuticle, and part of one (radial) pseudolabium.

project three prominent radial and three small triangular inter-radial pseudolabia. Buccal capsule more or less cylindrical thickened externally both anteriorly and posteriorly. Three radial and three inter-radial ridges arise internally from buccal capsule at about its midlength, becoming larger anteriorly and projecting as six pseudolabia.

Oesophagus (345–375 µm in male, 850–1100 µm in female), about 1/5–1/6 (male) or 1/5–1/8 (female) of body length, with nerve ring a little in front of its midlength. Excretory pore post-oesophageal.

Male: ventral and lateral cuticle of posterior end inflated, particularly just behind cloaca. One pair of sessile and four pairs of pedunculate papillae of which third pair is very long. Tail ends in spike 170–200 µm long. Spicule 100–120 µm long, single, tapering, the distal 20 µm less chitinised.

Female: Tail 960–1300 µm long. Vulva between 1/3–1/2 body length from anterior end. Eggs 49–50 x 25–26 µm, without operculum.

This species was considered by Mawson (1964) to lack inter-radial plates in the buccal capsule, but examination with scanning electron microscope showed that these are present (Fig. 5). The same procedure showed the presence of numerous fine pores over part of the cuticle at the anterior end (Fig. 6). Specimens from *T. caninus* are very slightly shorter than those from Kangaroo Island.

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