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# LANDSURFACE DEVELOPMENT IN THE MID NORTH OF SOUTH AUSTRALIA

BY N. F. ALLEY\*

## Summary

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The landsurface of the Mid North has resulted from a complex tectonic and erosional history. During the Cainozoic, faulting formed large basins in which terrestrial and marine sediments were deposited. The earth movements also initiated two major phases of erosion.

Remnants of a landsurface established in (?) pre-Tertiary times are found high in the relief as weathered hills and plateaux in places capped by laterite (*laterite surface*). A probable mid Tertiary phase of planation is represented by silcrete capped remnants (*silcrete surface*). It is underlain by deeply weathered bedrock and occurs only a few tens of metres below the laterite level. The present broad valley floors, wide intermontane plains and coastal plains (*plains and valley surface*) had developed by the Late Quaternary. Etch surfaces are found adjacent to remnants of the two earlier surfaces.

There is considerable structural control of landforms. Resistant quartzites and sandstones form the highest parts of the relief, as they also did during previous phases of erosion. Argillaceous strata have been eroded to form broad valleys, which follow the regional meridional strike. Differential erosion of these contrasting lithologies, combined with stream piracy, has led to the development of a trellised drainage system. The River Broughton is the only stream, which has maintained its westerly, consequent course throughout the Cainozoic, but stream captures have led to large changes in the drainage patterns of the Light and North Para Rivers.

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## Introduction

The Mid North forms an area of moderate relief between the fold ridges of the Flinders Ranges to the north and the upfaulted plateau of the Mt. Lofty Ranges to the south (Fig. 1). The occurrence of fluvio-lacustrine and marine sediments on ridge tops, along river valleys and in structural basins indicates that this region has had a complex history. Remnants of weathered residuals capped by laterite or silcrete provide further evidence of this complexity.

It is the purpose of this paper to trace the sequence of geomorphic events which led to the formation of these features and their preservation in the present landscape.

## Geological Setting

### *The Adelaide System Rocks*

The northern part of the area is underlain by Willouran, Torrensian and Sturtian strata (Wilson 1952; *Clare* 1 : 63, 360 sheet; Forbes 1965<sup>1</sup>). These rocks are arranged in an echelon folds in the northwest but parallel folds occur in the east (Fig. 1). South of Riverton faulting has resulted in the termination and breaching of the folds (*Kapunda* 1 : 63, 360 sheet; *Truro* 1 : 63, 360 sheet). The Kanmantoo Group occurs here and is underlain by a sequence of Lower Cambrian sediments (Coats 1960<sup>2</sup>).

### *Importance of Lithology and Faulting*

The major topographic features reflect the contrasting rock lithologies. Between Clare

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<sup>1</sup> Forbes, B. G. (1965).—The geology of the Clare 1 : Mile area. Unpublished report, Geological Survey of South Australia.

<sup>2</sup> Coats, R. P. (1960).—The geology of the Kapunda—Truro Military Sheets. An explanation of the Geological Maps. Unpublished report, Geological Survey of South Australia.

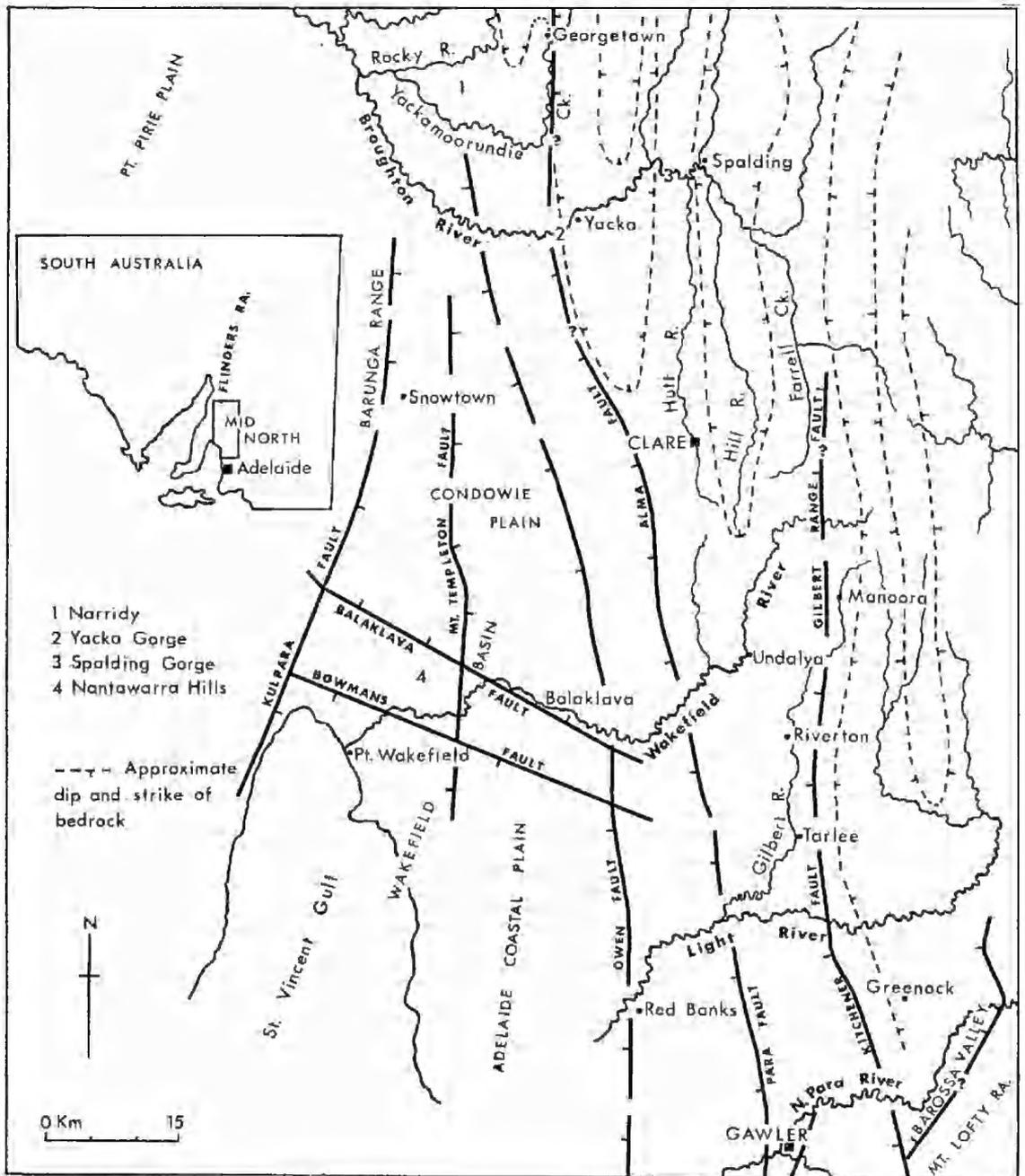


Fig. 1. Location, points of reference and general structure of the Mid North. Only the major faults and bedrock structures are shown.

and the Murray Plains, the *Gilbert Range Quartzite* underlies the major ridges whereas dominantly argillaceous strata underlie the valleys (Fig. 5).

Apart from the quartzite ridges, fault scarps form the most important physiographic breaks. The most conspicuous of these is one resulting

from movements along the Alma Fault west of Clare. This fault and others divide the Mid North into a series of north-south trending blocks (Fig. 1). The youthfulness of many scarps and the seismicity of the area (Sutton & White 1968) suggest that the faulting continues.

**Cainozoic Sediments**

Although Tertiary marine strata abut the eastern and western flanks of the ranges, terrestrial sediments of similar age occur in several basins and valleys within the uplands (Table

1). Two of the most important of the latter are the Wakefield and Barossa Basins. Buried beneath the sediments in these basins is a partly dissected, weathered and faulted land-surface.

TABLE 1  
*Terrestrial Sediments of the Mid North*

Name	Description and occurrence	Age
Unnamed	Mottled and calcareous red sandy-clays. Found in major river valleys, intermontane basins and coastal plains.	(?) Pleistocene to Early Recent
Koolunga Gravels and silicified sands and gravels	Fluvio-lacustrine sands, gravels and boulders widespread in the Broughton catchment particularly on the eastern margins of the Wakefield Basin.	Late Tertiary to Quaternary
Rowland Flat Sands	Fluvio-lacustrine sands and gravels found in the Barossa area. Lignitic at depth in the Barossa Valley.	Miocene
Snowtown Sands	Interbedded fluvio-lacustrine sands, clays and lignites found below the Condowie Plains.	Miocene
Clinton Coal Measures	Interbedded sands, silts, clays and lignites of estuarine origin. Confined to the Wakefield Basin.	Middle-Upper Eocene

## A. FLUVIO-LACUSTRINE AND MARINE SEDIMENTS

### 1. WAKEFIELD BASIN

The pattern of faults demonstrate that the basin is of tectonic origin (Fig. 1). As it forms the northern apex of the St. Vincent Basin, the periodic earth movements and subsequent sedimentation evidenced in both are necessarily related.

#### *Deeper Basin Sediments*

Bores drilled through the Inkerman-Balaklava and Whitwarta coal measures penetrated a considerable thickness of estuarine (Harris *pers. comm.* 1968), marine and lacustrine deposits (Johnson 1959; Hillwood 1960). The sequences of the Balaklava area are complex and interpretation of the deposits, in particular the estuarine lignites, is uncertain. However, recent studies refer the latter to the Middle-Upper Eocene (the Clinton Coal Measures of Harris 1966), and the overlying marine beds to the Oligo-Miocene (Hillwood 1960). The northern and eastern limits of the marine beds lie along the Bowmans and Mt. Templeton Faults. At Snowtown the marine deposits are absent but interbedded carbonaceous clays, silts and sands of Miocene age overlie the

Middle-Upper Eocene beds (Harris *pers. comm.* 1968). The Miocene strata are lacustrine and terminate in the south along the Balaklava Fault. Because of their stratigraphic relationship to the Early Tertiary beds and their dominantly sandy lithology, the Miocene strata are separated from the former and here named the *Snowtown Sands*. The type section is from stratigraphic borehole 4A on the northern edge of Snowtown and the stratigraphic relationships are shown in Figure 6.

The mid Tertiary marine sequences and the Snowtown Sands are separated from each other by a horst, known as the Nantawarra Hills, which resulted from uplift along the Bowmans and Balaklava Faults (Fig. 1). The absence of the Oligo-Miocene sediments from the surface of the horst and their occurrence at the foot of the bounding fault scarps on the north and south suggests that the faulting predates the Middle Tertiary.

#### *Marginal Sediments*

Numerous deposits of highly siliceous sands and gravels occur along the fringes of the Wakefield Basin. Small outcrops abut the eastern front of the Barunga Range but larger deposits occur in the valley of the River Broughton on the eastern edge of the basin.

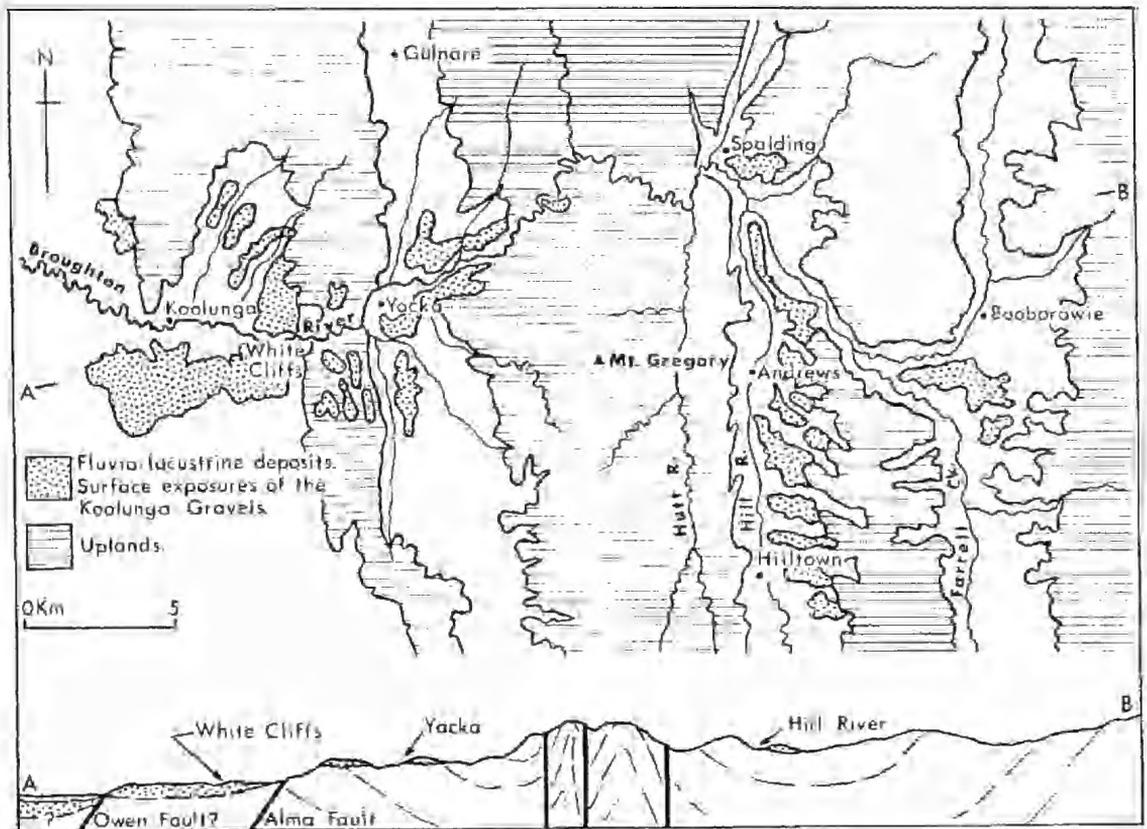


Fig. 2. The distribution of the Koolunga Gravels in the middle and upper Broughton drainage basin. The dips of the faults in the Mt. Gregory Range are unknown.

The most prominent crop out near Koolunga, Yacka and Spalding (Fig. 2). These deposits are here named the *Koolunga Gravels* and the type section is located at White Cliffs, 4 km east of Koolunga in the south bank of the Broughton River (Fig. 10).

The western edge of the Koolunga Gravels is marked by a low rise which may represent the northern extension of the Owen Fault Scarp, for bore logs indicate that they continue at depth further westwards. At White Cliffs the gravels overlie an irregular surface eroded across Precambrian bedrock (Fig. 10). Movement along a fault zone in the latter has led to a 5 m dislocation of the overlying deposits.

The best exposure of the beds occurs in the Yacka Valley where deltaic sands and gravels containing boulders of siltcrete overlie gently dipping Precambrian sandstone. These deposits can be traced across the ridge marking the western flank of the valley, but the Alma Fault scarp separates them from the Koolunga sequences (Fig. 2). Because of their similar

pebble lithologies, in particular the presence of siltcrete in both, the Yacka and Koolunga beds were probably deposited contemporaneously and have since been displaced by faulting with the downthrow to the west.

Whether the highly siliceous gravels south and east of Spalding were deposited in the same lake is a matter for conjecture, for they stand 100 m higher than those at Yacka (Fig. 2). The difference in height between the two deposits may reflect a falling lake level or faulting, or the Spalding gravels may not be correlative with the Yacka beds and instead be entirely fluvial. However, the presence of siltcrete boulders in the Spalding gravels indicates that they may have been deposited contemporaneously with the Koolunga Gravels.

Although no fossils were recovered from the Koolunga Gravels, there is evidence to suggest that they post-date the mid Tertiary. At White Cliffs and Yacka the gravels contain boulders of siltcrete, a rock assigned to a probable Middle

Tertiary weathering phase (see below). North and west of Yacka, outcrops of the gravels overlie an etch surface related to the erosion of the silcrete surface (Fig. 3). Thus, the Koolunga Gravels do not represent a shoreline facies of the Snowtown Sands but were deposited at different times in a lake occupying the same basin.



Fig. 3. The stratigraphic relationship between the Koolunga Gravels and the silcrete surface in the Yacka area. Only the surface exposures of the gravels are shown.

## 2. BAROSSA BASIN

These include the fluvio-lacustrine sediments deposited east of the Para Fault in the Barossa and Stockport-Freeling areas (Fig. 4).

The structure of the Barossa Valley is not completely known. It has been described as a graben (Hossfeld 1949), a fault angle valley (Chugg 1955), and an asymmetrical syncline with a fault or flexure along the southeastern

flank (Dalgarno 1961<sup>3</sup>; Olliver 1962). Nevertheless, the nature of the Tertiary strata contained by the valley is well documented (for a review of this work see Dalgarno 1961, and Harris & Olliver 1965). West of Rowland Flat a basal deltaic unit is overlain by a sequence of sands and gravels characterized by medium and large scale deltaic bedding (the Rowland Flat Sands Conglomeratic Lens and the Rowland Flat Sands of Dalgarno 1961), whereas lignitic sands have been encountered at a depth of 30 to 100 m during boring in the Rowland Flat-Tanunda plain (Chugg 1955). As there is no stratigraphic evidence for separating the conglomeratic lens from the overlying sands, it is proposed that it be included as part of the *Rowland Flat Sands*.

Scattered outcrops of the sands extend westwards across the Kitchener Fault to the Gawler area, and northwards to Stockport (Fig. 4). They were probably deposited contemporaneously with the Rowland Flat Sands as the beds occur within the same range of elevation (Fig. 4). Moreover, the Lyndoch-Sandy Creek deposits are characterized by the same mineral assemblage as those at Rowland Flat and are thus regarded as the westerly extension of the Barossa sequences (Olliver & Weir 1967).

Although the Rowland Flat Sands have been assigned a variety of ages, recent palynological evidence indicates a Miocene age, making them time correlative with the deposits northeast of Gawler (Harris *pers. comm.* 1969).

## B. ALLUVIAL DEPOSITS

Red alluvium covers most of the low-lying areas, varying from a few metres in minor creeks to 36 m in depth at Balaklava. In the Barossa Valley and near Red Banks, bores show that the sandy clays exceed 30 m in thickness. Although the alluvium is 15 m deep in the Yackamoorundie Valley downstream from Georgetown, it rarely exceeds 6 m in the upper reaches of other main valleys. In most areas the alluvium is mottled and calcareous, suggesting some measure of weathering since its deposition.

The alluvial clays are interpreted as a Pleistocene deposit in the Port Wakefield area (Johnson 1959; Hillwood 1960; Horwitz 1961)

<sup>3</sup> Dalgarno, C. R. (1961).—Geology of the Barossa Valley. Unpublished M.Sc. Thesis. University of Adelaide.

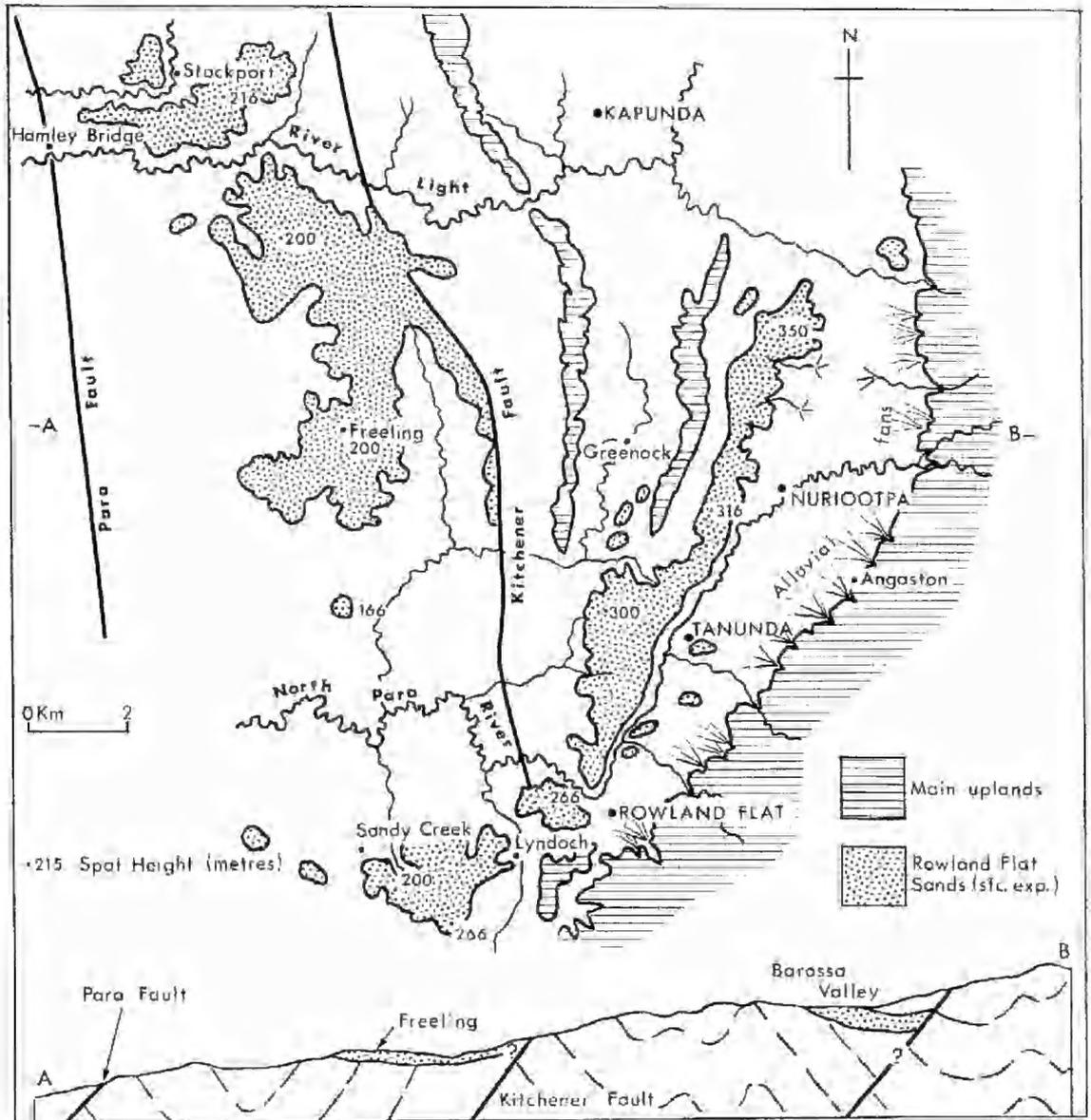


Fig. 4. The distribution of the Rowland Flat Sands in the Barossa-Freeling area. The differences in height of the deposits in the latitude of Freeling may be related to post Miocene earth movements.

and the Barossa Valley (Campana 1955; Chugg 1955). On the basis of radiocarbon dating, the red clays north of Adelaide have been assigned to the Late Pleistocene (Williams 1969). Mottled clays (the Hindmarsh Clay of Firman, *pers. comm.* 1968), overlying a Pliocene marine bed at Red Banks are believed to be of Pleistocene age.

On this basis the heavily calcified red clays in the Mid North have been placed tentatively

in the Pleistocene to Early Recent though they may vary in their precise age or age-range from locality to locality.

#### C. WEATHERED LAND SURFACES BURIED BENEATH THE CAINOZOIC SEDIMENTS

In the Snowtown area only a few bores penetrate to the Precambrian but these reveal that the basin floor is irregular and weathered.

At a depth of 69 m, stratigraphic bore No. 4A located at Snowtown, penetrated 27 m of highly weathered sandstone. Three kilometres north of Snowtown unweathered bedrock occurs at 49 m, but less than 1.5 km east of this location the basin floor deepens to 111 m.

The weathering of the basement rocks probably predates the deposition of the overlying Tertiary sequences for bore logs indicate that the latter are essentially unweathered.

The nature of the buried surface beneath the Rowland Flat Sands is better known. Bore logs

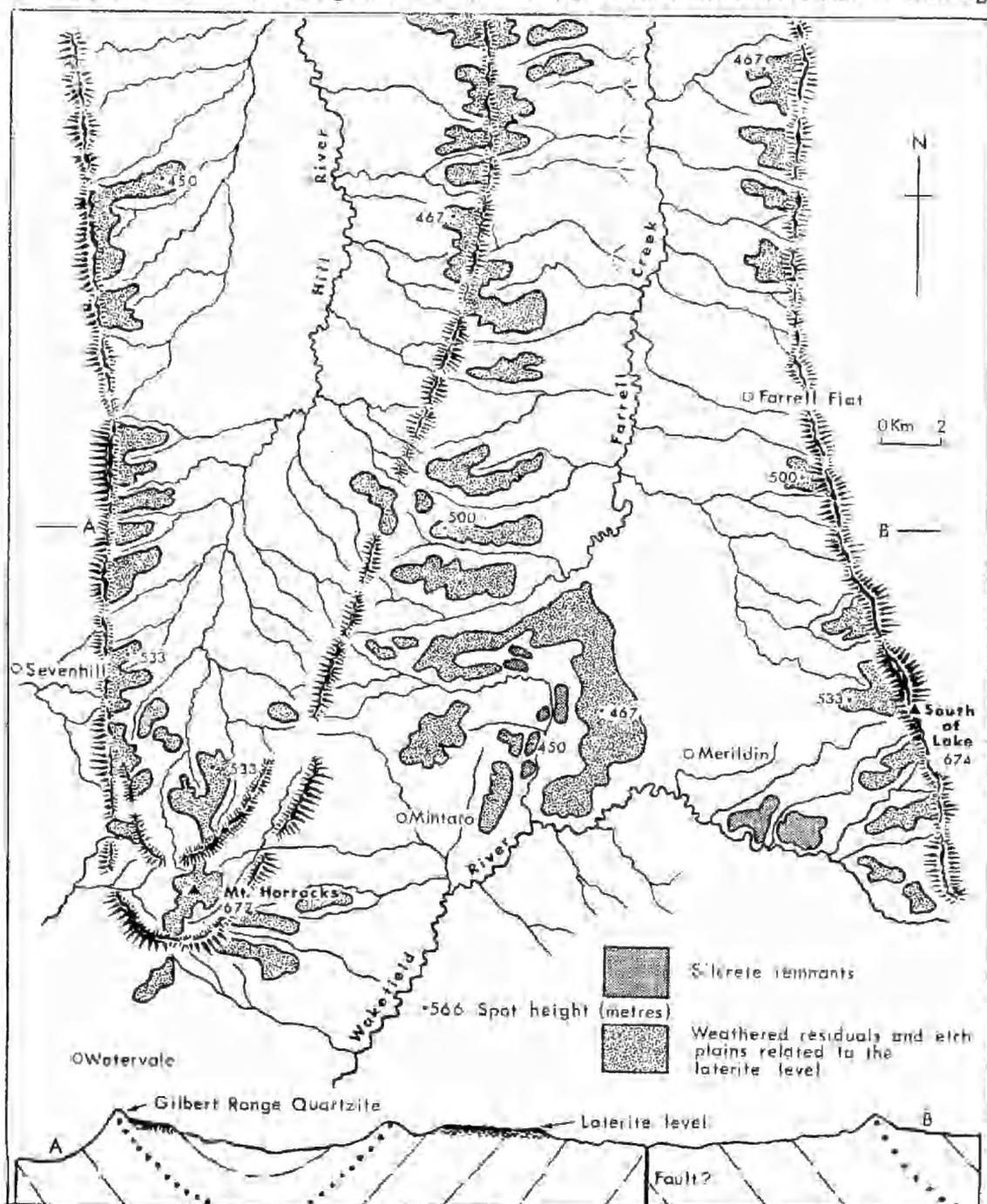


Fig. 5. Remnants of the laterite and silcrete surfaces near Merildin. The Gilbert Range Quartzite underlies the major ridges, while dominantly argillaceous strata crop out in the valleys.

indicate that the basement rocks are weathered in the Barossa Valley (Chugg 1955). At Rowland Flat the unconformity surface has a local relief of up to 15 m (Olliver & Weir 1967) and the Rowland Flat Sands overlie both fresh and weathered bedrock (Fig. 11). At C. R. Hueppauf's quarry, on the north bank of the North Para River, Torrensian bedrock is weathered and highly ferruginized. Between Sandy Creek and Warpoosiding, highly kaolinized mica schist underlies the sands. South and west of Freeling the sands were deposited on subhorizontal bedrock surfaces, though only small remnants of the Tertiary sequences remain. Thus it appears that the Rowland Flat Sands were deposited on a partly dissected erosion surface underlain by highly weathered and ferruginized bedrock.

### Surfaces of Degradation and Deposition

Investigations reveal that remnants of three major surfaces of erosion and deposition occur in the Mid North. The highest and oldest of these is capped discontinuously with laterite. Below this is another erosional surface which supports a thick crust of silcrete. The youngest surface is largely depositional and the alluvial clays underling it are heavily calcified. Etch plains of considerable extent developed as a result of the dissection of the laterite and silcrete surfaces.

#### Laterite Surface

Apart from the prominent ridges underlain by quartzite and sandstone, remnants of the laterite surface form the highest parts of the landscape. Where the laterite truncates thick Precambrian argillaceous strata, slopes vary between 1° and 2° (Fig. 12). However, near the quartzite ridges remnants of pediments exhibiting slopes of up to 7° are found. Such residuals are common in the ranges east of Clare (Fig. 5) and Riverton. Remnants of the laterite surface are more numerous at the stream heads. Nevertheless, by virtue of their resistant capping they also form prominent hills standing nearly 100 m above valley floors, some distance from the ridges (Fig. 13).

The laterite capping, which consists essentially of angular quartz set in a matrix of iron oxides, is underlain by heavily weathered and locally kaolinitic bedrock (Fig. 14). Only the massive quartzites and sandstones remain unaltered and these stand 30–180 m above the

general surface level. A zone of intense weathering often lies at the head of the pediment remnants which slope away from these scarps whereas the laterite crust is consistently thickest on the lower slopes.

The etching away of the weathered strata from beneath the laterite has led to the exposure of broad bedrock surfaces. It is usually the case that these etch surfaces lie 15–30 m below the laterite surface and separated from it by steep scarps. Because of strong lithological control during weathering and subsequent erosion, the etch surfaces are often irregular with argillaceous strata forming the valleys, and sandstones the ridges (Fig. 13).

#### Silcrete Surface

Evidence of a former erosion surface capped by silcrete and consistently lower than the height of the laterite is found throughout the Mid North (Fig. 15). It reaches its optimum development around the northeastern fringe of the Wakefield Basin (Fig. 6). Here slopes can be less than 1° whereas slopes as great as 4° have been encountered elsewhere. Like the laterite, the silcrete surface truncates rocks of all types, except the thick quartzites, and is underlain by some 15 m of intensely kaolinized bedrock. North of Narridy the weathering reaches a depth of 30 m, but this is probably due to the porosity of the underlying sandstone. Ferruginous horizons are common in the weathered zone developed across argillaceous strata (Fig. 7).

The nature of the silcrete crust is variable (Figs. 7, 16). Higher parts of the surface are weakly silicified or support a thin capping of consolidated regolith. Silcrete lower in the relief is generally thicker and finer grained. In many areas where the silcrete has been broken up, a thick lag of boulders remains as a protective veneer over the weathered bedrock.

An extensive etch plain developed following dissection of the silcrete surface, particularly where the main streams cut deep gorges through the silcrete level. Thus prominent bedrock benches occur along the Rocky River downstream from Gladstone and the Yackamoorundie Creek west of Gulgare. This surface is often capped by a silicified conglomerate containing fragments of silcrete derived from adjacent silcrete remnants (Fig. 17). Because the conglomerate has all the charac-

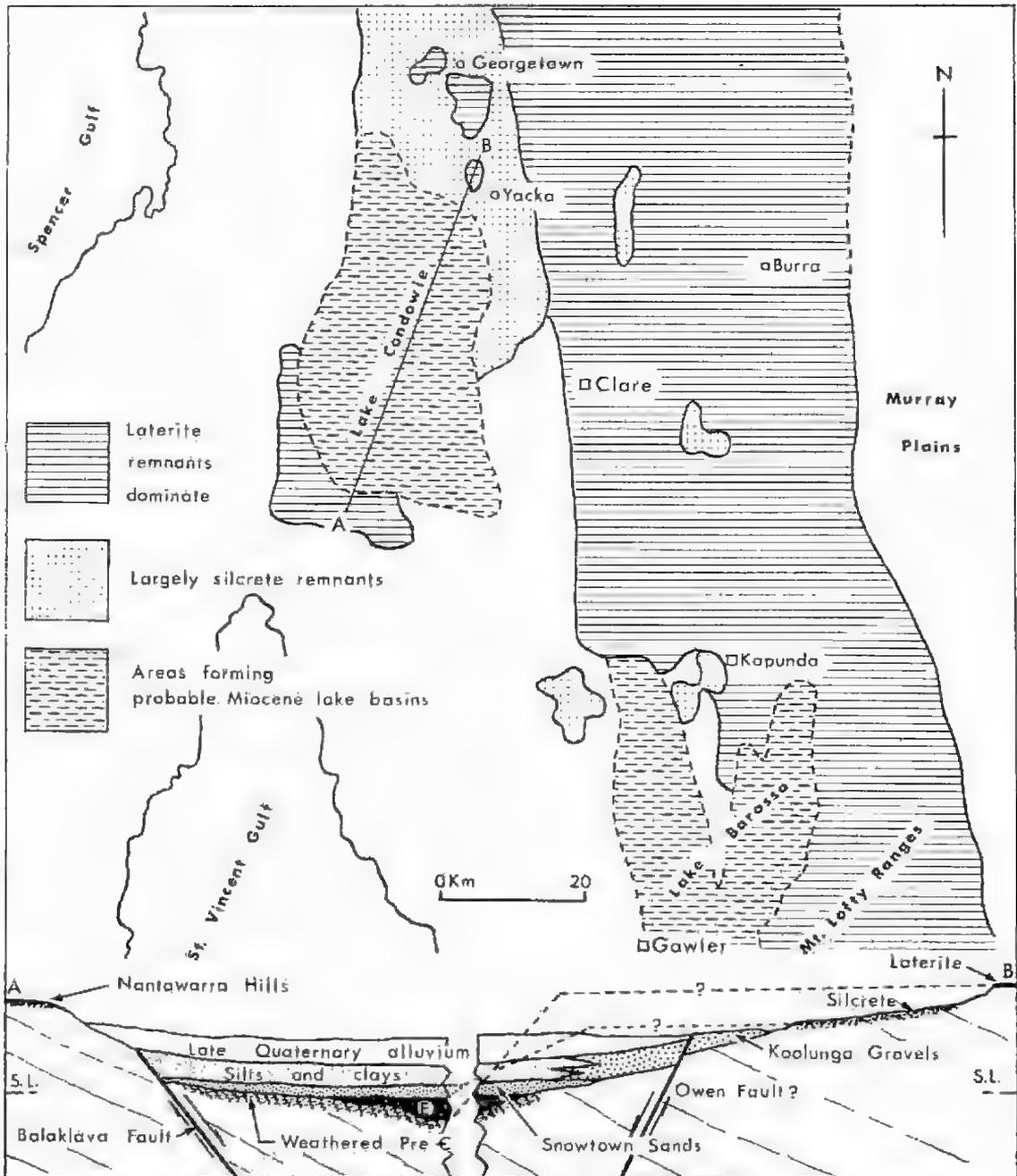


Fig. 6. The distribution of laterite and silcrete remnants in the Mid North, and the stratigraphic relationship between the surfaces bordering the Wakefield Basin. The diagrammatic section (not to scale) has been constructed from bore logs. From the surface, 15 m of plains and valley alluvium are underlain by 15 m of silts and clays, 23 m of Miocene Snowtown Sands and 35 m of Middle-Upper Eocene Clinton Coal Measures (E). Both the latter units vary considerably in thickness. The Mt. Templeton Fault occurs in the breached part of the section.

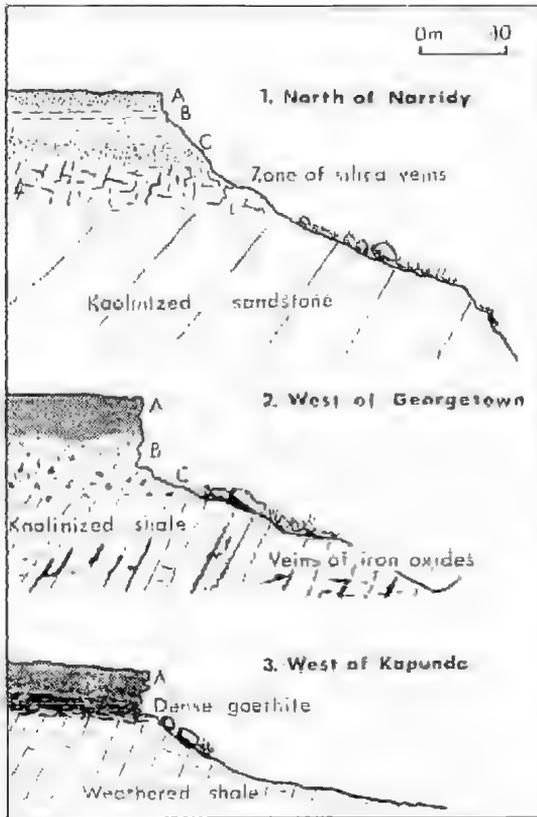


Fig. 7. Variations in the silcrete crust and its underlying weathering profile in the Mid North.

*Section 1:* Zone A consists of pisolitic silcrete; B laminar silcrete; C is a complex zone grading downwards from silicified sandstone to very resistant porcelanitic silcrete.

*Section 2:* Zone A, massive cryptocrystalline silcrete; B, weakly silicified sandstone; C, very weathered rock containing abundant angular fragments of quartz.

*Section 3:* Zone A, massive cryptocrystalline silcrete containing numerous rounded quartz pebbles near its base.

teristics of a sedimentary rock and unconformably overlies fresh Precambrian at numerous sites, it is not interpreted as a second period of silcrete formation and is referred to as *silicified sands and gravels*. On the basis of its relationship to the etch surface these sediments were probably deposited in valley bottoms contemporaneously with the Koolunga Gravels.

#### *Relative Ages of the Laterite and Silcrete*

The laterite surface forms the flat upland of the Nantawarra Hills (Fig. 6). To the east

and north of the hills, the surface has been downfaulted and the Middle Tertiary sediments occur at the base of the fault scarps suggesting that the laterite surface in this area may be Early Tertiary or older. In this case, the surface buried beneath the Middle-Upper Eocene lignites in the Snowtown region could be the equivalent of the laterite surface. On the other hand, if the lateritized surface underlying the Rowland Flat Sands is correlative with the laterite surface, the latter must have persisted in the Barossa area until the mid Tertiary when earth movements led to its dissection and partial burial.

It is difficult to assign an age range to the silcrete surface, although mapping reveals that it is consistently lower than the laterite surface even where they truncate the same strata (Fig. 8). Thus the difference in their heights is due to erosion rather than lithology, and it can be inferred that the silcrete is younger than the laterite surface. However, the optimum development of the silcrete surface occurs around the fringes of the Wakefield Basin. There is evidence to suggest that the early Tertiary

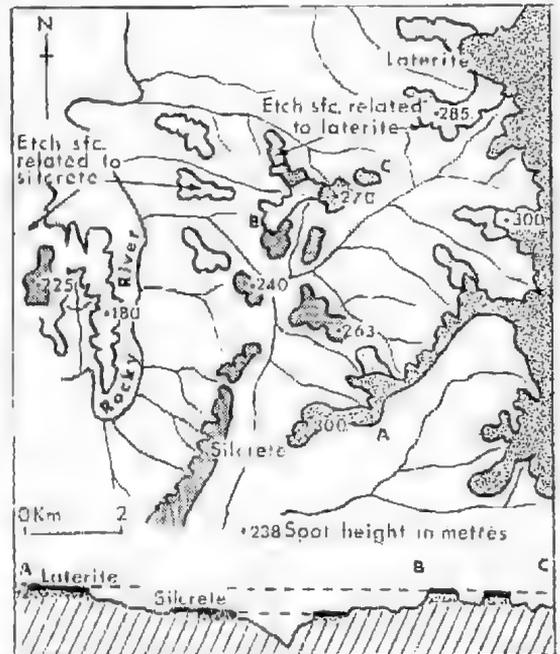


Fig. 8. The altitudinal relationship between the laterite and silcrete surfaces west of Georgetown. The bedrock strike is approximately north-south, and both surfaces are eroded across the same strata.

estuarine swamps and then the Miocene lake which occupied this basin may have formed the base level of erosion for the silcrete surface in the surrounding area. First, the surface slopes gently towards the basin. Second, the Eocene estuarine and the Miocene lacustrine sequences are generally fine, suggesting that deposition was contemporaneous with the erosion of a plain of low relief which is consistent with the gentle slopes observed on the silcrete remnants. Third, no silcrete is recorded from the boreholes drilled through the Tertiary sediments.

#### *Present Valley Floors and Plains*

The most extensive surface of aggradation in the study area is the Condownie Plain (Fig. 1). Near Snowtown the plain measures almost 40 km from east to west, whereas in the northern part near Redhill the basin is less than 8 km wide. The Condownie Plain continues southwards and gradually merges with the Adelaide coastal plains south of Balaklava. In the latitude of Snowtown the surface of the plain is gently undulating but asymmetrical with a long fall from the Alma Fault scarp on the east. No streams traverse the plains except along the northern fringes where the Broughton and its two large tributaries, Rocky River and Yackamoorundie Creek, are incised up to 9 m in the red alluvium.

Two other intermontane basins occur: the Barossa Valley and the Yackamoorundie Valley south of Georgetown, the latter containing an alluvial fill 54 m in depth. The surface of the Barossa is similar to the Condownie Plain, displaying east-west asymmetry. Broad alluvial fans front the Barossa Ranges near Rowland Flat, gradually giving way to a gently sloping surface further north. Along the western edge of the basin the plain extends across outcrops of the Rowland Flat Sands as a lightly ferruginized erosional surface.

#### *Age of the Plains and Valley Surface*

Throughout the Mid North, the red calcareous clays are the most common deposits underlying the surface. This alluvium has been assigned a Pleistocene to Recent age (see above), and thus the surface must be approximately the same age. In the Barossa where it truncates the Middle Tertiary lake sediments, portion of the surface may belong to the Late Tertiary

### **Development of the Drainage System**

The Mid North is drained by two sets of river systems: the Broughton, flowing to Spencer Gulf, and the Wakefield, Light and North Para Rivers, to St. Vincent Gulf. The history of change in this drainage pattern can be determined by an examination of the nature of the Tertiary sediments and landsurfaces.

#### **A. INFLUENCE OF LITHOLOGY AND STRUCTURE**

The perfection of lithological adaptation of the drainage is a feature of the area. In broad view lithology determined the direction of drainage on the two duricrusted surfaces. Once the weathered mantle was removed from these surfaces, intricate irregularities in lithology controlled the course of erosion. Consequently, the present drainage exhibits a trellised pattern, the long subsequent (strike) streams flowing in valleys underlain by argillites while the resistant sandstones and quartzites remain as the ridges. The north-south trending pattern of the major streams results from the meridional strike of the fold axes (Fig. 1).

#### **B. CHANGES IN THE PATTERN DURING THE CENOZOIC**

The long meridional trending reaches of the streams have been interpreted as the dismembered drainage of a Tertiary peneplain (Howchin 1933; Hossfeld 1935; Langford-Smith 1949). Such a postulate may only be applied to the St. Vincent Gulf drainage.

##### **1. THE RIVER BROUGHTON**

Based on the evidence of elbows of capture, abandoned valleys containing riverine gravels and increased gradients in the gorge sectors of the newly formed valleys, Langford-Smith (1949) demonstrated that stream piracy occurred amongst minor tributaries in the Jamestown area. In view of the elbows and gorges along the Broughton, he applied the theory to the whole drainage basin. He proposed that the river captured a system of southerly flowing streams from the west subsequent upon uplift of a Tertiary landsurface. Faulting aided local ponding of the stream and hastened the speed of capture.

However, investigations cannot substantiate the theory. Only two gorges occur along the Broughton, one west of Yacka and the other west of Spalding. No knickpoint is found in the Yacka reach while those in the Spalding gorge result from lithology or structure. There is no

evidence of a former south flowing stream system, the development of which was prohibited by the geologic structure of the area and the resistance of the Gilbert Range Quartzite. Upstream from Yacka the drainage pattern may have been in existence since Early Tertiary times, for remnants of the laterite surface slope towards major streams whereas their heights decrease down-valley in the direction of present drainage. Many of the Cainozoic gravels, some of them lacustrine, occur both on intervening ridges and in several gorges, instead of only in the broad strike valleys. As uplift of the Tertiary landsurface occurred along N-S trending faults, there should have been no local impounding of south flowing rivers. Moreover, the disposition of the Cainozoic sequences in the Yacka-Spalding area suggests faulting after deposition, not before. Finally, if stream piracy has occurred, it is the Broughton system which is being captured not the reverse (Fig. 9).

The middle and upper reaches of the Broughton have remained essentially unmodified and it is only downstream from Yacka

that the evidence supports changes in the pattern.

Eocene lignites extend at depth to within a few kilometres of Koolunga where the Broughton turns north-westwards to flow across the northern perimeter of the Condownie Plain. If the upper reaches have altered little since the Early Tertiary, it is logical that the river made its way to the present St. Vincent Gulf area through the tectonic valley which came into existence at this time (see above). It is probable that uplift of the Nantawarra horst in the mid Tertiary blocked the valley, leading to the formation of a lake. A larger lake resulting from reactivation of upwarping in the Late Tertiary or Quaternary either overflowed the Barunga Range or was captured from the west (or both) and the Broughton flowed into Spencer Gulf.

## 2. ST. VINCENT GULF DRAINAGE

A striking feature of the drainage pattern of these rivers is the absence of major south bank tributaries (Fig. 1). An examination of the Cainozoic sediments and the Tertiary landsurfaces reveals that only stream piracy can account for the anomaly.

The long quartzite ridge east of Tarlee was a major drainage divide in Early Tertiary times. All laterite remnants slope away from it as far north as Manoora and south as Greenock. Erosion of this surface by separate drainage systems is indicated by large differences in the height of residuals on opposite flanks of the ridge. The river east of the ridge occupied the valley of the upper River Light and flowed southwards along the present Barossa Valley area whereas the other approximately paralleled the course of the Gilbert River. However, there is no evidence to suggest that the River Wakefield had yet been established.

Consequent upon the mid Tertiary earth movements were the dissection of the laterite surface and the formation of a lake in which the Rowland Flat Sands were deposited. The two south flowing streams probably entered the lake at the northern edge of the Barossa Valley and near Stockport. This is borne out in these areas by the coarseness of the gravels, the palaeocurrents and the mineral assemblage (Dalgarno 1961; Alley 1969<sup>4</sup>).

In Late Cainozoic times the major stream east of the divide was captured from the west

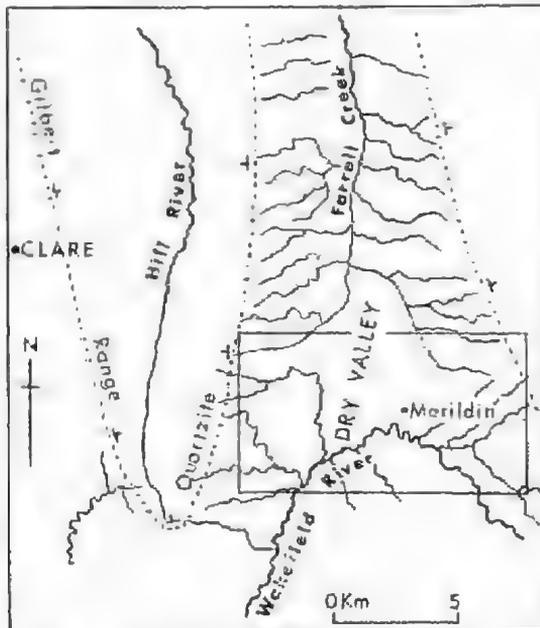


Fig. 9. Stream capture of the upper Farrall Creek near Merildin. The nature of the barbed drainage within the enclosed section and the pronounced elbow of the Wakefield downstream from Merildin indicates that the pirate stream was the River Wakefield.

by two separate streams, one forming the present lower reaches of the River Light now confluent with the Gilbert River, and the other, the North Para River. Stream piracy is supported by several lines of evidence. First, prominent elbows occur on the rivers where they turn westwards to flow across the strike of the bedrock (Fig. 1). Second, an abandoned valley due south of Rowland Flat and infilled with Tertiary sediments may represent the former channel of the beheaded stream. Third, both portions of the newly formed streams have cut deep channels into the Rowland Flat Sands, suggesting that the excavation post-dates the mid Tertiary.

Although a prominent elbow occurs on the River Wakefield at Undalya, where the river turns into a gorge and flows across the strike of extremely resistant quartzites, there is

nothing other than the lack of major south bank tributaries to suggest that capture may have taken place.

### Landscape History

Remnants of three major landsurfaces have been described and discussed (Table 2). Since the dissection of the laterite surface, differential erosion has led to increasing relief. Where the ridges formerly stood 90 to 180 m above the level of the laterite surface, they now project more than 300 m above valley floors.

Early Tertiary earth movements in and around the Wakefield Basin probably led to the disruption of the laterite surface in the Broughton drainage system and the establishment of a new phase of erosion during which the silcrete surface developed. Broad etch sur-

TABLE 2  
*Surfaces in the Mid North*

Surface	Description and origin	Probable age
Plains and valley	Major valley floors, intermontane basins and coastal plains. Narrow erosional piedmont zone fringing these areas. Mainly aggradational.	Late Tertiary (?) to Early Recent
Etch	Unweathered bedrock surfaces standing below and adjacent to the silcrete surface in the Broughton catchment. Developed subsequent to removal of weathered zone beneath the silcrete. Buried by lacustrine gravels in some localities but exhumed in others.	Initiated in the Late Cainozoic
Silcrete	Silicified mesas and valley sides occurring throughout the Broughton catchment. Isolated remnants near Kapunda, Freeling and Owen. Resulted from erosion and weathering.	Mid Tertiary
Etch	High unweathered bedrock benches developed below and adjacent to the laterite surface as a result of removal of the weathered mantle from below the laterite.	Initiated in the Early Tertiary
Laterite	Broad plateaux and mesas capped by laterite and, apart from quartzite ridges, forming the highest parts of the relief. Resulted from erosion and weathering.	(?) Early to pre Tertiary. Persisted to mid Tertiary in the Barossa area.

faces resulted from the removal of the deeply weathered mantle much of which was deposited lower in the relief as the Middle-Upper Eocene sediments, and later in the Miocene as the Snowtown Sands. The laterite surface

persisted in the Barossa area until the mid Tertiary when renewal of the faulting led to its dissection. The earth movements probably dammed streams, leading to the formation of a basin in which the Rowland Flat Sands ac-

<sup>4</sup> Alley, N. F. (1969).—The Cainozoic history of the Mid North of South Australia. Unpublished M.A. Thesis, University of Adelaide.

cumulated. As these sands and the Snowtown Sands are contemporaneous but deposited in separate tectonic basins, it is logical to argue that the earth movements were widespread during the mid Tertiary.

There is evidence to suggest that the faulting continued. In the north, earth movements account for the dissection of the silcrete surface, the development of broad etch plains and the deposition of the Koolunga Gravels contemporaneously with the silicified sands and gravels. Recent earth movements were responsible for the dislocation of the Koolunga Gravels at White Cliffs and in the vicinity of Yacka. Deposition of the plains and valley alluvium and the alluvial fans abutting the Alma and Kulpara Fault scarps may also have been initiated during this period.

If the buried surfaces beneath the Tertiary sediments in the Wakefield Basin and the

Barossa Valley are analogous to the laterite surface, it has suffered faulting or warping in the order of 300 and 180 m respectively in these areas.

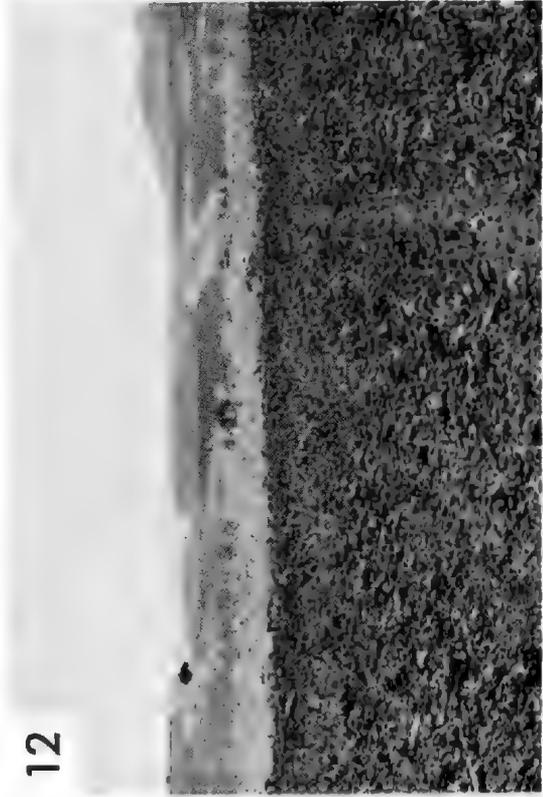
#### Acknowledgements

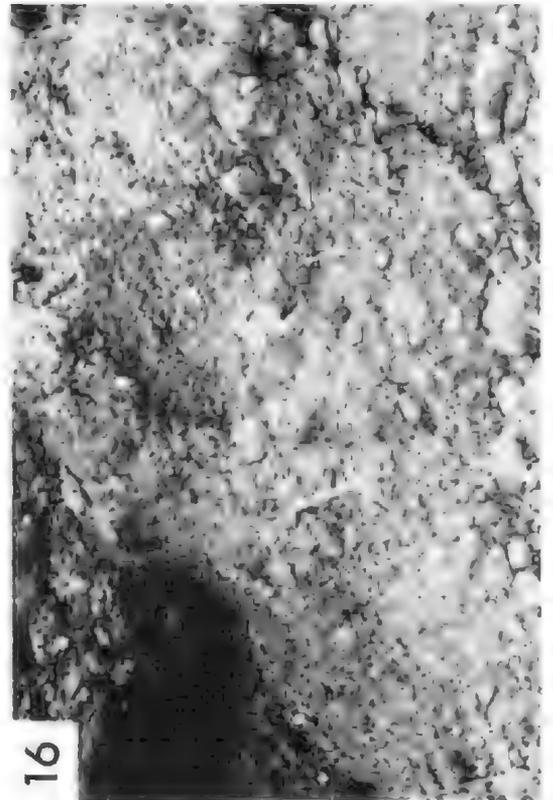
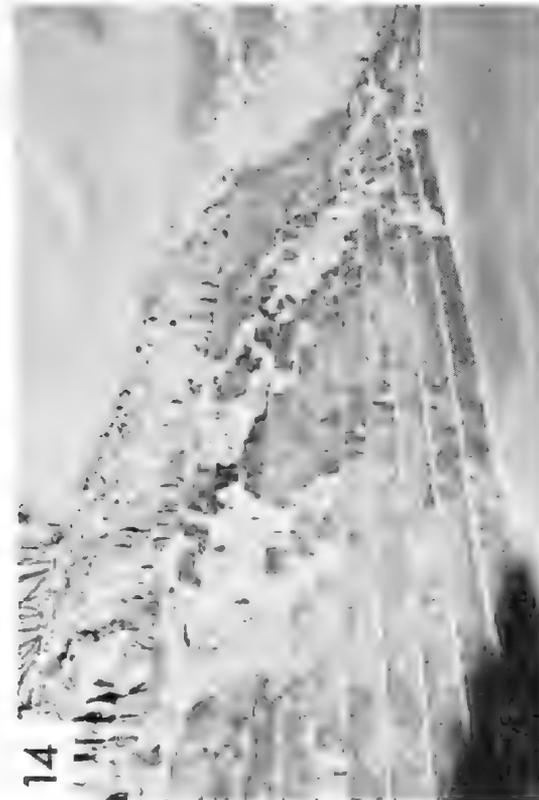
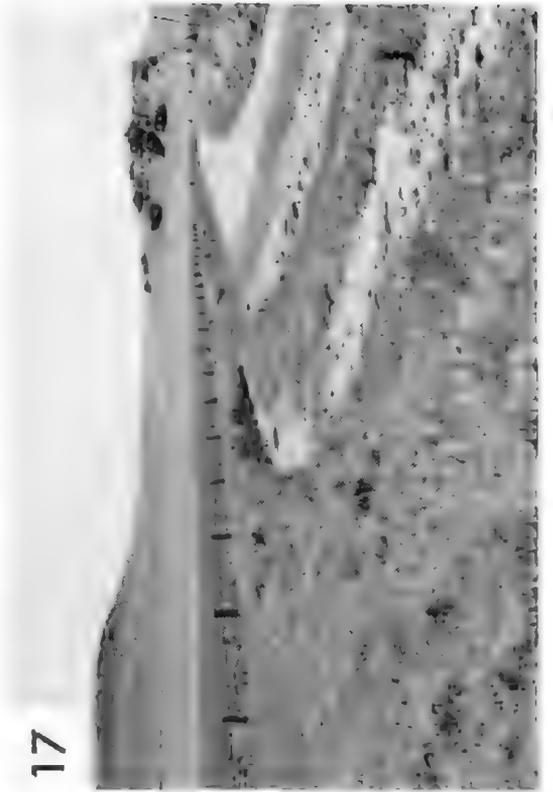
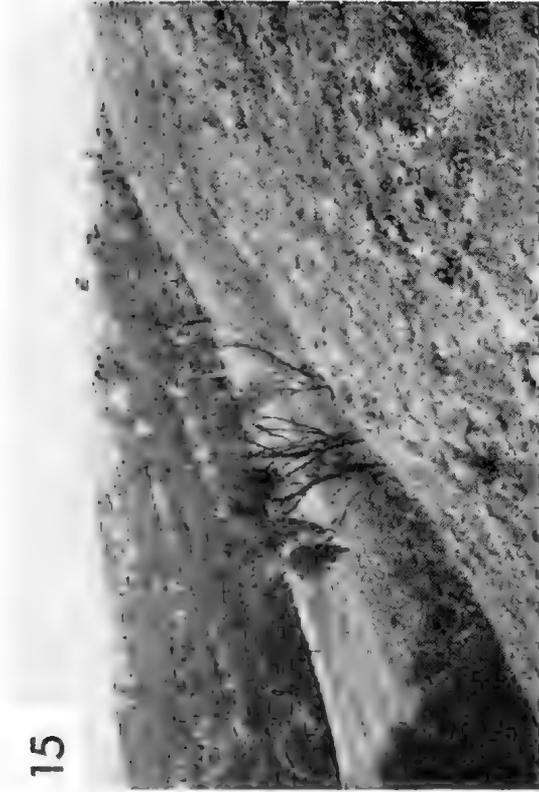
The thanks of the writer are due to: the South Australian Department of Mines for making bore log data and unpublished reports available; Mr. W. K. Harris, S. Aust. Department of Mines, for his advice on the Tertiary stratigraphy; Mr. A. R. Milnes, Department of Geology, University of Adelaide, for his guidance in the analysis of the duricrust profiles; Mr. M. J. C. Walker, University of Edinburgh, for his critical reading of the text; and Dr. C. R. Twidale, Department of Geography, University of Adelaide, for his valuable comments in the field and on this paper.

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- Fig. 10. At White Cliffs, 4 km east of Koolunga, Late Cainozoic (?) fluvio-lacustrine sands and gravels containing boulders of silcrete have been folded. The monoclinical fold (M) indicates that 4 to 5 m of displacement has occurred. The folding is of the posthumous type and has resulted from movements in the underlying contorted Precambrian phyllitic shales which appear in the lower left (P).
- Fig. 11. The irregular unconformity surface between the subhorizontally bedded, Miocene Rowland Flat Sands and steeply dipping Precambrian schists in a quarry west of Rowland Flat.
- Fig. 12. A few kilometres west of Georgetown remnants of the laterite surface occur. Here the surface slopes gently away from an unweathered core of Precambrian rocks known as Mt. Herbert (right). The laterite crust is underlain by 20 to 25 m of kaolinized shales some of which can be seen forming the white areas on the flanks of the two residuals.
- Fig. 13. Mt. Allen, a lateritic, weathered residual eroded across green silty shales in the snout of a syncline 8 km due north of Kapunda. The arcuate, low ridge covered by gums and almost surrounding Mt. Allen consists of unweathered Marinoan quartzite (A.B.C.). Differential erosion of adjacent weathered strata has accentuated the prominence of the ridge and resulted in an irregular etch surface.





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- Fig. 14. Highly weathered Sturtian slates and gritty shales exposed beneath the laterite surface in Bartsch's quarry west of Kapunda. The rock is locally kaolinitic, the latter being closely related to bedding planes and joints. Height of the section is about 15 m.
- Fig. 15. Silcrete capping the crest of an erosional scarp several kilometres north of Narridy. In places the underlying porous sandstone is weathered to a depth of 30 m or more (Fig. 7, Section 1). An etch surface occurs to the left and lower than the silcrete.
- Fig. 16. Pisolitic silcrete capping portion of the scarp north of Narridy (see Fig. 15). The larger concretions consist entirely of slightly ferruginous silcrete, but smaller nodules contain porcelainous kaolin, small rounded grains of silica and a few minor pockets of iron oxides. The pisoliths are set in a matrix of slightly silicified sandstone. Pen provides scale.
- Fig. 17. Boulders of the silicified sands and gravels (right) scattered over an etch surface developed adjacent to the silcrete surface (left), in the valley of the Rocky River several kilometres south of Gladstone. The gravels unconformably overlie steeply dipping unweathered Torrensian slates and shales.

**AUSTRALIAN ACANTHOCEPHALA, NO. 14. ON TWO SPECIES OF  
*PARARHADINORHYNCHUS*, ONE NEW**

*BY S. J. EDMONDS\**

**Summary**

EDMONDS, S. J., 1973. Australian Acanthocephala, No. 14. On Two Species of *Pararhadinorhynchus*, one new. *Trans. R. Soc. S. Aust.* 97 (1), 19-21, 28th February, 1973.

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### Introduction

Johnston & Edmonds (1947) erected a new genus *Pararhadinorhynchus* based on *P. mugilis*, a parasite from *Mugil cephalus* Linnaeus. On several occasions during the last ten years, a second species of the same genus has been found in South Australia in the mullet *Aldrichetta* (= *Agonostomus*) *forsteri* (Cuvier & Valenciennes). The new species is described here and the re-checked dimensions of the introvert and egg of *P. mugilis* are given. How specific the two parasites are in their distribution is not clear because collectors have sometimes confused the two hosts. The identifications of the fishes carrying the parasites are based on the descriptions given by Scott (1962).

### *Pararhadinorhynchus coorongensis* n.sp.

#### FIGS. 1-5

*Host:* *Aldrichetta forsteri* (Cuvier & Valenciennes).

*Localities:* (1) Coorong, S.A.; coll. J. Harris, 1962. (2) Port Willunga, S.A.; coll. T. H. Johnston, 1927: (H.C. 1055). (3) Fish from Adelaide Fish Market (class material, coll. S. J. Edmonds, 1969, 1971). (4) Fish from Adelaide Fish Market: coll. H. Manter, 1967.

*Type specimens* (male and female): Australian Museum, Sydney.

*Description:* Size moderate; shape cylindrical to sub-spindle-like, slightly broader in anterior third or quarter. Posterior region may taper

slightly. Posterior extremity sometimes rounded or slightly swollen.

Trunk of female 9-15 mm long x 0.45-0.55 mm. Trunk of male 7-11 mm x 0.40-0.70 mm. Trunk without spines.

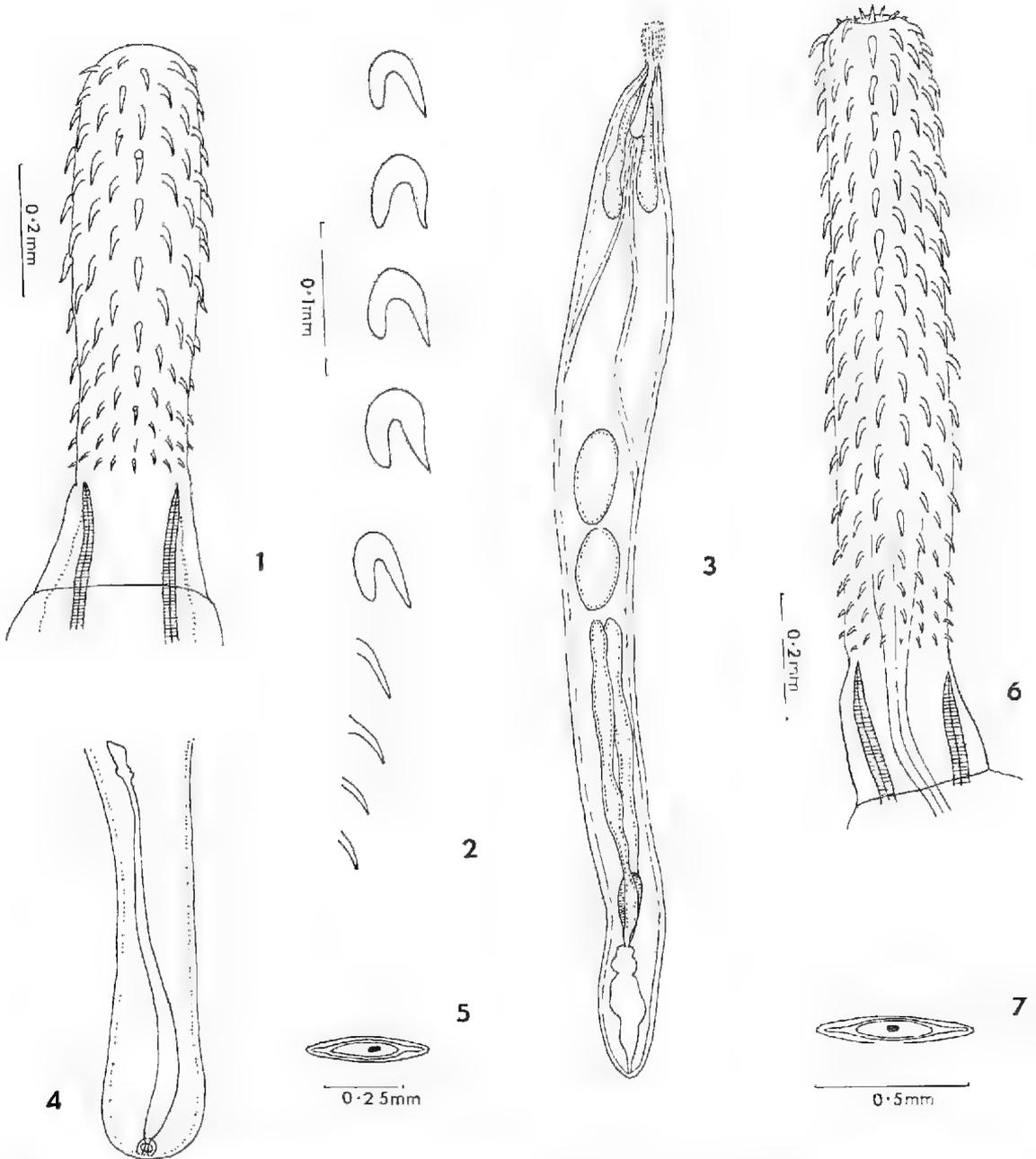
Introvert cylindrical to club-shaped; the part bearing hooks 0.51-0.62 mm long in female and 0.50-0.58 mm in male. Maximum width 0.15-0.22 mm in female and 0.12-0.23 mm in male. Fourteen to sixteen, usually 16, longitudinal rows of 8-10, usually 9, hooks per row (Fig. 2). Short unarmed neck (0.15 mm long) in some specimens. Introvert sheath double walled, 0.6-0.8 mm long x 0.18-0.26 mm wide. Lemnisci about twice as long as sheath and usually slightly swollen posteriorly. Position of brain not known.

Female complex relatively long, 2.8-3.4 mm. Female aperture terminal. Ripe eggs, possessing prolongations of middle shell, 0.042-0.046 mm x 0.008-0.010 mm.

Testes ellipsoidal to subglobular and placed in tandem; anterior one 0.45-1.05 mm x 0.35-0.45 mm and posterior one 0.50-0.91 mm x 0.34-0.43. Cement glands, two, long and slender, sometimes constricted at some points. Male aperture terminal. No genital ganglion. like that found in male specimens of *P. mugilis*, present.

*Systematic position:* The specimens fall within the order Palaeacanthocephala Meyer. *P. coorongensis* differs from *P. mugilis* Johnston & Edmonds, 1947, the latter possessing a

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Figs. 1-5. *Pararhadinorhynchus coorongensis*. Fig. 1.—Introvert. Fig. 2.—Row of nine hooks. Fig. 3. Male. Fig. 4.—Posterior of female. Fig. 5.—Egg.  
 Figs. 6-7. *Pararhadinorhynchus mugilis*. Fig. 6.—Introvert. Fig. 7.—Egg.

longer introvert armed with 18 longitudinal rows of 16–17 hooks per row. It also differs from *Diplosetis amphacanthi* Tubangui & Masilungan, 1937, in which the introvert bears 12 longitudinal rows of 8–9 hooks per row and in which the lemnisci are enclosed in a membranous sac.

*P. coorongensis* is the second acanthocephalan species found in *A. forsteri*. *Neoechinorhynchus aldrichettae* Edmonds (1971) is the other.

**Pararhadinorhynchus mugilis** Johnston & Edmonds, 1947: 15.

#### FIGS. 6–7

The material from which the type description was made contained only two specimens

with everted introverts. Recently a few more specimens in a fully extended condition became available and consequently the measurements given in 1947 have been rechecked. The host was the type host, *Mugil cephalus* Linnaeus.

Introvert (Fig. 6) cylindrical. Length of armed region 0.88–0.94 mm and width 0.16–0.25 mm. Sixteen to eighteen, usually 18, longitudinal rows of 16–17, usually 17, hooks per row. Unarmed neck, 0.15–0.25 mm long. Ripe eggs, with polar prolongations of the middle shell, measure 0.052–0.056 mm x 0.013–0.015 mm.

*Type specimens* (male and female): Australian Museum, Sydney (not the South Australian Museum, as stated by Johnston & Edmonds 1947).

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**A NEW GENUS AND SPECIES OF EARTHWORM  
(MEGASCOLECIDAE: OLIGOCHAETA) FROM SOUTH AUSTRALIA**

BY S. J. EDMONDS\* AND B. G. M. JAMIESON†

**Summary**

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The genus *Gemascolex* is erected for the new species *G. newmani*, from South Australia. The genus is morphologically very similar to *Spenceriella* Michaelsen, differing primarily in lacking the extramural calciferous glands of the latter genus. Both genera are assigned to the tribe Megascolecini. *G. newmani* is the fourth megascolecid species described from South Australia, but of those previously described, *Megascolex fletcheri* Shannon is considered to be a junior synonym of *M. stirlingi* (Fletcher), leaving the total number of described South Australian megascolecid species at three.

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### Introduction

Three species of Megascolecidae, the only earthworm family indigenous in Australia, have previously been named from South Australia. They are *Megascolex stirlingi* (Fletcher, 1888), placed in *Perichaeta* by Fletcher; *M. zietzi* Michaelsen, 1907a; and *M. fletcheri* Shannon, 1920. *M. fletcheri* Shannon is a homonym, the binomen having been used by Michaelsen, 1907a, for a distinct species from New South Wales. Shannon's account, though long, is inadequate in many respects and the type-specimens are no longer traceable. It nevertheless conforms sufficiently with the description of *M. stirlingi* to suggest, though not unequivocally, that *M. fletcheri* Shannon is a junior synonym of *M. stirlingi*. The latter species has been rediscovered by both authors in recent collecting in South Australia and will be described in a future monograph (Jamieson, in preparation) in which the status of *M. zietzi* will also be considered.

The new species erected here has been used for some years for undergraduate teaching and for research in the Department of Zoology of the University of Adelaide. It is referred to a new genus which is defined below. Evidence

for including *Megascolex stirlingi* (Fletcher) and other species in the new genus will be deferred to the later publication.

### GEMASCOLEX gen. nov.

Terrestrial. Setae numerous (more than 8) in each segment. A pair of combined male and prostatic pores on XVIII. Clitellum annular, anterior to 18/19. Intersegmental accessory genital markings present. Female pore unpaired, midventral, in XIV. Spermathecal pores anterior to IX.

Dorsal blood vessel single. Posterior hearts latero-oesophageal, each arising from the short supra-oesophageal vessel and from the dorsal blood vessel. Latero-oesophageal vessels present median to the hearts. Subneural vessel absent. Gizzard large, anterior to septum 6/7. Oesophagus lacking extramural calciferous glands. Intestine commencing in XVII; a low ridge-like dorsal typhlosole present; caeca and muscular thickening absent. Excretory system meronephric. Four pairs of tufted nephridia, in II-V, their ducts (all?) enteronephric, entering the buccal cavity. Succeeding segments with astomate, exonephric, micromeronephridia in lateral bands. Caudally with numerous enteronephric meronephridia, each with a pre-

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septal funnel, discharging into the intestine in each segment. Testes and funnels in X and XI; testis-sacs absent; seminal vesicles in XI and XII.

Ovaries and funnels in XIII; ovisacs absent. Prostates tubuloracemose: linear, lobulated, with axial lumen throughout which receives lateral canaliculi; vasa deferentia joining their muscular ducts. Spermathecae with diverticula. (*Gemascolex*, gender male, anagram of *Megascolex*).

*Type species: Gemascolex newmani* sp. nov.  
*Distribution:* South Australia (see species description).

*Remarks:* The closest morphological affinities of *Gemascolex* lie with two endemic Australian genera, *Spenceriella* Michaelsen, 1907b, and *Oreoscolex* Jamieson, 1973. The three genera are the only members of the indigenous Australian Megascolecidae known to possess more than one pair of stomate nephridia per segment, and are assignable to the tribe Megascolecini Jamieson, 1970. *Spenceriella* and *Gemascolex* are especially close, as in both, some at least of the caudal nephridia are enteronephric, opening into the intestine, whereas in *Oreoscolex* caudal enteronephry has been deduced only very questionably in the type-species and is unknown in other species. Multiple nephrostomes and enteronephry have been demonstrated in *Spenceriella* for the first time by Jamieson (in preparation). *Oreoscolex* further differs from *Gemascolex* and *Spenceriella*, among other respects, in having only eight setae per segment.

The chief distinction between *Gemascolex* and *Spenceriella* is the presence of extramural calciferous glands in *Spenceriella*. Both genera differ from the type-species of *Megascolex* in having stomate nephridia and in their enteronephry (Bahl 1946). Only the non-racemose condition to the prostates would have separated them from *Megascolex* in some former classifications.

*Gemascolex newmani* sp. nov.

#### FIG. 1

The following account refers to the holotype (H) and one paratype (P1); variation in other specimens is discussed subsequently.

Length 180(P1)–234(H) mm, width (mid-clitellar) 9 mm, number of segments 192(H); 193(P1). Colour in life: dorsal surface brownish purple, ventral surface pale grey; a dark purplish colour more noticeable at the extremities; some iridescence present. Cross sec-

tion approximately circular. Prostomium epilobous 1/3, bisected by a longitudinal furrow, appearing epitanylobous, owing to longitudinal grooves continuing its lateral limits to the first intersegmental furrow, but numerous equally developed parallel grooves present around the peristomium. Peristomium not bisected ventrally though in some specimens a mid ventral groove is more conspicuous than others. First dorsal pore 4/5. Perchaetine setae of each side more closely spaced laterally than dorsally and ventrally; *bc* slightly wider than *ab*. Numbers of setae per segment 32(H)–33(P1) in XII, 26(P1)–30(H) in XX, 31(P1)–32(H) fifteen segments from the caudal end; *a* lines straight, *z* lines irregular; a ventral and a dorsal break in the setal circlelet appreciable throughout. Setae *a* and *b*, but not *c*, absent in XVIII.

INTERSEGMENTAL DISTANCES IN  
*Gemascolex newmani*

	mm					standardized as % of circumference ( $\mu$ )			
	<i>aa</i>	<i>ab</i>	<i>zy</i>	<i>zz</i>	<i>u</i>	<i>aa</i>	<i>ab</i>	<i>zy</i>	<i>zz</i>
Segment XII									
Holotype	2.2	0.8	0.9	6.2	28	7.9	2.9	3.2	22.1
Paratype 1	2.1	0.8	1.0	6.3	28	8.2	2.9	3.6	22.5
Segment XX									
Holotype	1.8	0.6	0.9	5.6	30	6.0	2.0	3.0	18.7
Paratype 1	2.1	0.6	1.3	4.9	27	7.8	2.2	4.8	18.1

Nephropores not externally recognizable. Clitellum annular, not fully developed, embracing XIV–XVII, but some clitellar modification present dorsally from 2/3 XIII–XVIII (=5 1/3 segments); intersegments and setae retained but only *a* and *b* conspicuous; dorsal pores 13/14–17/18 occluded. Male pores *a* pair in XVIII, transverse slits in *ab*(H) or *b*(P1) and almost as wide as *ab*, each on a low transversely oval papilla, the two papillae outlined by a common medianly narrowing field; the pores 2.8–3.2 mm, 0.08–0.09 circumference apart. Accessory genital markings unpaired, midventral, transverse, elevated pads, with lateral limits in *ab*, in 15/16(H, P1), 16/16 and 19/20(H), each pad transversed by a glandular trench corresponding with the intersegmental furrow but not reaching to the ends of the pad. Female pore unpaired, midventral, in a deep transverse groove at the anterior border of the setal annulus of XIV. Spermathecal pores 3 pairs of sunken orifices, concealed in intersegments 6/7, 7/8 and 8/9, very shortly lateral of setal lines *a*, 2.8–2.9 mm, 0.09 circumference apart.

Strongest septa 10/11–12/13, very strong. Dorsal blood vessel single, continuous onto the pharynx. Dorsoventral commissural vessels

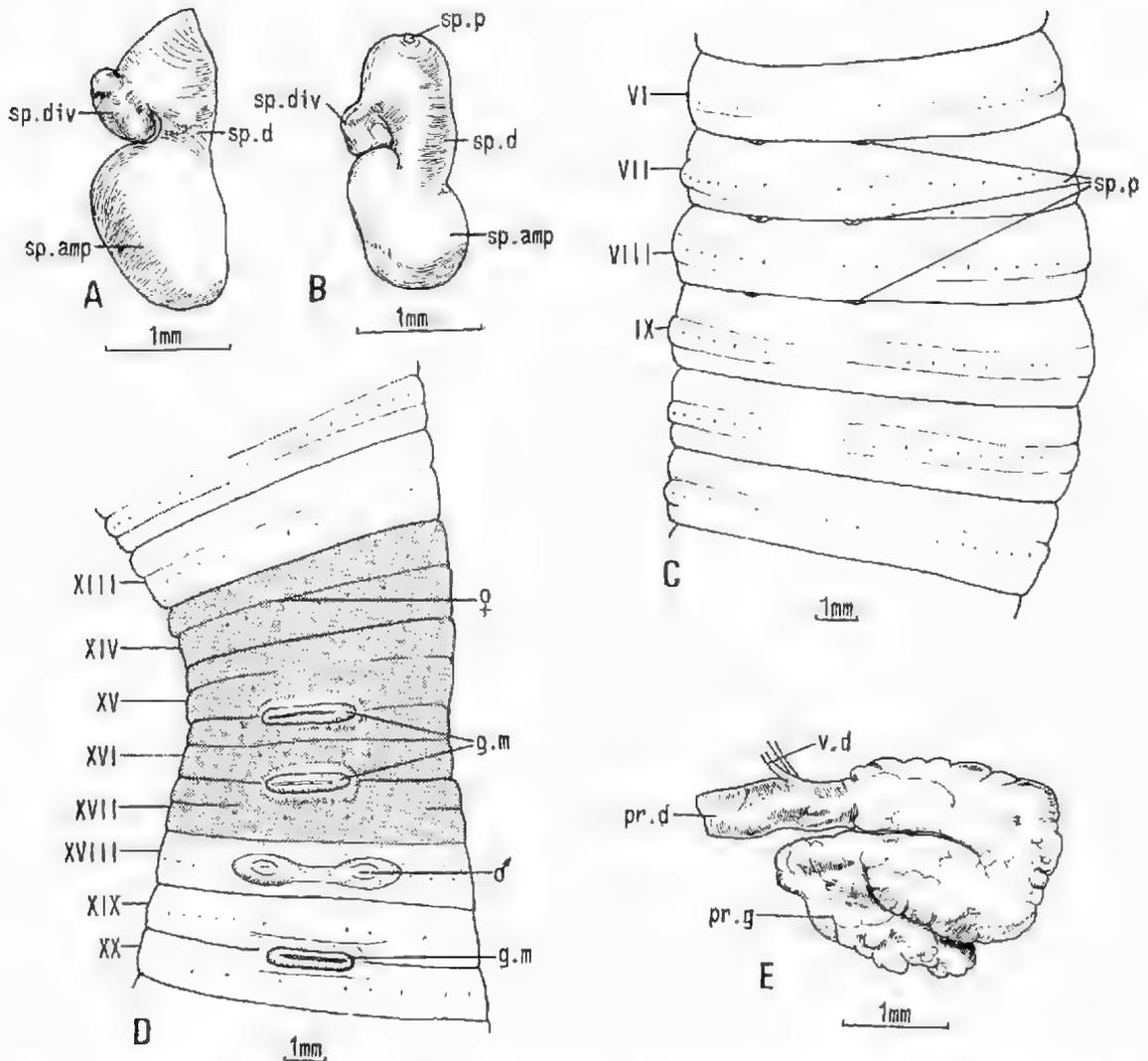


Fig. 1. *Gemascolex newmani* sp. nov. A, ventral view of right spermatheca of IX (holotype); B, dorsal view of right spermatheca of IX (paratype 2); C, spermathecal pores (holotype); D, male genital field (holotype); E, right prostate (paratype 2). Clitellum shaded. All by camera lucida. ♀, female pore; g.m, accessory genital marking; ♂, male pore; pr.d, prostate duct; pr.g, glandular portion of prostate; sp.amp, spermathecal ampulla; sp.d, spermathecal duct; sp.div, spermathecal diverticulum; sp.p, spermathecal pore. Roman numerals are segment numbers.

in V–XIII; those in X–XIII forming large latero-oesophageal hearts, each originating from the supra-oesophageal vessel but also receiving, at its junction with the latter, a slender short connective from the dorsal blood vessel; these hearts otherwise unbranched. Commissurals in V–IX dorso-ventral only, lacking supra-oesophageal connectives, but giving branches to the posterior septum, gut and lateral parietes; all commissurals, including the hearts, valvular. A pair of large vessels originating on

the parietes in IV passes posteriorly as a pair of large ventrolateral trunks (latero-oesophageal vessels), median to the dorsoventral commissurals, into IX at the posterior septum of which they give branches to the ventral wall of the oesophagus and to the septum. Similar paired trunks (suboesophageal vessels) present in XI–XVI, closely adherent to the ventral surface of the oesophagus and lying under its peritoneum; no continuity demonstrable between the latero-oesophageal vessels in IX an-

teriorly and the suboesophageal vessels in XI posteriorly; both pairs of vessels give a pair of vessels to the oesophageal plexus in each segment. Suboesophageal vessel absent. Gizzard moderately large, fusiform, and firmly muscular in VI; septum 5/6 adherent to its anterior end; its posterior end projecting a little behind intersegment 7/8; the oesophagus much narrower in V, short and narrow in VII; dilated and vascularized with low internal rugae, but no calciferous glands, in VIII–XV, narrow and short in XVI. Intestinal origin XVII; a low ridgelike dorsal typhlosole commencing in XXIII; caeca and muscular thickening absent. Nephridia: meronephric; large paired tufts, with very many spiral loops, in II, III, IV and V increasing in size posteriorly and very large in V. Those in V and IV sending anteromedianly thick sheaves of numerous ducts, which loosely aggregate as a composite duct common to both pairs of tufts, the ducts passing forward to join the lateral wall of the buccal cavity in front of the brain. Those in III and II sending slender composite ducts to the lateral walls of the buccal cavity immediately behind the mouth. Nephridia in succeeding segments astomate, exonephric, micromeronephridia: very dense transverse bands of spiral tubules, which laterally may be considered to form tufts, anterior in VI, their numerous discrete or partly aggregated ducts discharging exonephrically at the anterior limit of the segment; some exonephric nephridia present posteriorly in the segment; VII–X each with an anterior and a posterior parietal band of numerous nephridia; XI, XII and XIII with similar but rather sparse bands; XIV with sparse anterior and dense posterior bands; XV with denser anterior and sparse posterior bands; XVI (the last oesophageal segment) and succeeding intestinal segments with only anterior bands; bands dense in XIV–XVII.

Caudally, commencing at segment 120 (in holotype with 192 segments), with numerous enlarged nephridia (almost megameronephridia) in each segment on the anterior wall of the segment near to and encircling the intestine, the nephridia about five deep and each with a long-stalked conspicuous preseptal funnel, the nephridial ducts in each segment running medially as a common duct on each side to enter the wall of the intestine anteriorly in the segment on each side of the dorsal blood vessel, though some individual nephridial ducts reach the wall of the intestine independently in the vicinity of their nephridial bodies. Concen-

tric with and external to the enlarged, enteronephric nephridia are parietal astomate, apparently exonephric, micromeronephridia in dense transverse bands. The number of enlarged nephridia decreases, and that of the micromeronephridia greatly increases; in the last twenty or so segments.

Holandric; sperm funnels iridescent in X and XI; testis-sacs absent; seminal vesicles large lobulated sacs in XI and XII; similar, smaller, structures on the anterior septum of X are of unknown function but cannot be seminal vesicles. Ovaries (webs of large oocytes) and funnels in XIII; ovisacs absent. Prostates limited to XVIII, flattened, lobulated S-shaped glands with short slightly tortuous muscular ducts joined near their ental ends by the vasa deferentia. Penial setae absent. Spermathecae 3 pairs, in VII, VIII and IX, diverticulum (inseminated) single, subspherical, internally multifoliate, with a short stalk (H, P1).

*Field Variation:* In 16 clitellate type-specimens, including the holotype, a transverse median genital marking is present in 15/16 and 16/17 in 9 specimens, and in 19/20 in 10 specimens. Seven of these specimens have the full complement of markings, in 15/16, 16/17 and 19/20; 2 specimens have the genital marking in 15/16 only; 2 have them in 16/17 and 19/20 only; 1 has a marking in 19/20 only; and 4 have no markings.

*Material Examined:* Cudlee Creek, 34°50'S., 138°49'E., from below apple orchard of Mr. G. Newman, *Edmonds*, August 1971—H, P1–9; N. Maier, 21.viii.1972—P13–15. Hahndorf, 35°02'S., 138°48'E., G. Peterson, 25.viii.1972—P10–12.

H, P2–4, deposited in the Australian Museum, Sydney; P1, 5, British Museum (Natural History); P6, 7, South Australian Museum; P8–12 Jamieson collection.

*Remarks:* Material used in undergraduate studies and not retained cannot be designated type-material but, nevertheless, variation in it may be noted. In 50 specimens the length was 200–270 mm; the width was 7–9 mm generally but 8–11 mm in the region of crop and gizzard. The clitellum embraced XIV–XVII but sometimes included part of XIII and of XVIII. Numbers of spermathecal pores and location of the male pores and of the female pore were constant. Accessory genital markings, when present, were usually at 15/16, 16/17 and 19/20. The intestine usually began in XVIII, a condition also noted in some of the type-

specimens. The flattened S-shaped form of the prostates was constant. The supra-oesophageal vessel occupied VII–XIV, ramifying on the oesophagus at each end. In one hundred specimens the number of segments was 155–198.

The course of the suboesophageal blood vessels has not been unequivocally determined and, with that of the latero-parietals, requires further examination. The structures resembling seminal vesicles anteriorly in X do not show spermatogenesis in serial sections, whereas the seminal vesicles in XI and XII do.

*Gemascolex newmani* is distinguished from the equally large *Megascolex stirlingi*, so far as it is described by Fletcher, 1888, in (a) location of the spermathecal and male pores in *ab* lines whereas in *M. stirlingi* they are markedly more lateral, in setal lines 6 and between setal lines 3 and 4 respectively; (b) the unpaired instead of paired accessory genital markings and their forward extension to intersegment 15/16; (c) the S-shaped, not straight, prostates and in other respects.

Noteworthy differences from *M. zietzi*, as described by Michaelsen, 1907a, are (a) the more median location of spermathecal and male pores, (b) location of the male pores well lateral of paired accessory genital markings in *M. zietzi*, (c) presence of further paired markings on the anterior border of the male porophores in the latter species; (d) restriction of the prostates to XVIII and their S-shaped form; (e) the subspherical sessile spermathecal diverticulum of *newmani* contrasted with the very long tortuous tubular diverticulum of *M. zietzi*.

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**AERIAL DISPERSAL OF ADULT *CARDIASPINA DENSITEXTA*  
(HOMOPTERA:PSYLLIDAE) IN SOUTH AUSTRALIA**

*BY T. C. R. WHITE\**

**Summary**

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## Introduction

Clark (1962) concluded as a result of his observations and experiments with adults of *Cardiaspina albitextura* Taylor that emerged in the autumn, that they tend not to disperse far from their point of origin, and that therefore this is "... not a strongly dispersing insect."

Studies of the closely related *Cardiaspina densitexta* Taylor (White 1970a) suggested that although this seemed to be true of the generation of adult *C. densitexta* that emerged in the summer and autumn, it did not seem to be true of the generation that emerged in the spring. During summer and autumn, trees that were isolated from the established infestations were rarely colonized. Also at this time of the year, adults seemed to show great "reluctance" to leave the foliage on which they had developed. On the contrary, during spring it was commonplace for isolated trees to be colonized quickly. Also direct observation of the behaviour of adults at this season of the year showed that they had a strong tendency to fly up and away from the foliage on which they had lived as nymphs.

These observations led to the hypothesis that *C. densitexta* exhibits two types of seasonal behaviour: (1) non-dispersive, serving to concentrate summer and autumn adults—and subsequent egg-laying—on favourable foliage; (2) dispersive, serving to distribute the adults

emerging in the spring away from depleted foliage and increasing the chance of some of them finding fresh foliage.

This would suggest that the adults that emerged in the spring were the effective dispersive stage in the life cycle of *C. densitexta*, most probably in the manner proposed by Lewis & Taylor (1965). Their analysis of many aerial samples demonstrated that "high altitude and long distance migration is very highly correlated with flight by day and small size."

Such an hypothesis presupposes that adults of *C. densitexta* which emerged in the spring were present high in the air where they would be widely and randomly dispersed by air currents and winds. In 1964 an attempt to demonstrate this was unsuccessful. By the time a suitable technique had been developed, numbers of *C. densitexta* had fallen to very low levels, reducing to near zero the probability of catching the few individuals that might have been present in the aerial plankton.

This paper reports a second attempt to catch airborne adult *C. densitexta* at a time when they were abundant.

## Materials and Methods

Nets mounted on a steel ring 38 cm in diameter were towed from the wing of a Cessna 172 aeroplane flying at 152 and 305 m above the ground. Details of the construction

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of the nets and the ring, and of the method of operating, were described previously (White 1970b).

All samples were of 15 minutes duration. Each net was released when the aeroplane had levelled off at the required height and was cruising at 121-131 km/h. Height and speed were maintained as accurately as possible for the duration of each sample.

All nets were kept sealed in plastic bags until immediately before being used. At the completion of each sample a knot was tied in the net before it was detached from the ring and resealed in a plastic bag. All bags were returned to the laboratory before being opened and the nets immersed in 70% alcohol before the knots were untied.

All collections were made over a relatively small area between Keith and Willalooka in the southeast of South Australia (White 1970b, fig. 2). At the time the host plants (*Eucalyptus fasciculosa* F.v.M.) in this locality were carrying a moderate to high population of *C. densitexta*, and about 50% of the adults had emerged.

### Results

Forty-one samples (Table 1) were collected during five days, thirty at 152 m and eleven at 305 m. Twenty eight contained adult *C. densitexta*, the catch varying from one to nine per sample at 152 m, and one to five per sample at 305 m. A total of 60 adults were caught, there being approximately equal numbers of males and females. Several were observed crawling around in the nets after these had been placed in plastic bags.

TABLE 1  
The number of adult *C. densitexta* captured

Date	No. of Samples	Altitude	♂	♀	?+	Total
1.xi.71	11(7)*	152 m	5	5	1	11
2.xi.71	7(7)	152 m	6	8	2	16
3.xi.71	8(3)	152 m	2	2	1	5
11.xi.71	4(3)	152 m	4	5	2	11
	4(3)	305 m	—	2	1	3
12.xi.71	7(5)	305 m	5	6	3	14
Total	41(28)	—	22	28	10	60

\* Number of samples containing *C. densitexta* in parenthesis.

+ Damaged individuals lacking an abdomen.

A net with a diameter of 38 cm, pulled through the air at a mean speed of 126 km/h, would sift 221 m<sup>3</sup> of air per minute—3315 m<sup>3</sup> in a 15 minute sample. But because of the

"cushion" of air formed in front of the net, it is improbable that this volume of air would have passed through the net. Much of it would have been deflected around the sides of the net. No attempt was made to assess the "effective" diameter of the nets—it may well have been no more than 2.5 cm to 5 cm but if a conservative 7.5 cm margin is deducted to allow for deflection an effective diameter of 23 cm remains. Then 1188 m<sup>3</sup> of air would have been sampled in 15 minutes.

A 152 m high block of air above a hectare of land contains 1,520,000 m<sup>3</sup> of air; at 305 m, 3,050,000 m<sup>3</sup>. If the adult psyllids were distributed at random through this air, the sampling indicated densities of from about 1,300 to 11,500 per hectare to a height of 152 m and from 2,500 to 12,800 per hectare to 305 m.

### Discussion and Conclusion

The number of unknowns makes any attempt to quantify the density of adult psyllids in the aerial plankton unrealistic. Quite apart from the problem of the effective size of the sampling unit, it is likely that the distribution of air-borne psyllids was far from random. The time of day, ambient temperature, wind speed and the extent and duration of the warm air "thermals" rising from the ground would all have contributed to a patchy and variable distribution, both vertically and horizontally.

Almost certainly this sampling underestimated the number of these insects in the air over any area of land. But equally certainly it demonstrated that there were very many of them carried to considerable heights above the trees on which they emerged; sufficient to ensure that they would have been scattered over many square km of land. As the air cooled each evening and they returned to earth, relatively few of them would have been fortunate enough to land on a suitable host plant. But the few that did would have survived, and, with their huge capacity for increase, soon utilized the available food.

The evidence from this sampling, combined with that previously reported (White 1970a), demonstrated that the adults of *C. densitexta* that emerge in the spring are the means by which this species of psyllid is widely and effectively dispersed.

Other records of adult psyllids captured high in the air (Glick 1961; Erceman 1945; Hardy

& Milne 1938) and as far as 298 km from the nearest land (Yoshimoto & Gressitt 1963; Harrell & Yoshimoto 1964) suggest that this method of dispersal is common within the Psyllidae.

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# LIFE HISTORY, LARVAL MORPHOLOGY AND RELATIONSHIPS OF AUSTRALIAN LEPTODACTYLID FROGS

BY G. F. WATSON AND A. A. MARTIN\*

## Summary

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Disagreement exists regarding the phylogeny, relationships and classification of Australian leptodactylid frogs. Analysis of their life history patterns indicates that one of the present two subfamilies, the Myobatrachinae, is a close-knit natural group, whereas the other, the Cyclorantinae, is more heterogeneous. In particular, the genus *Cyclorana* does not conform with the cycloranines, and in terms of life history has strong affinities with the Hylidae. No close relationship between the Myobatrachinae and the Cyclorantinae is evident from life history data.

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## Introduction

In the first substantial monographic study of Australian anurans, Parker (1940) divided the Australian representatives of the family Leptodactylidae into two subfamilies: Cyclorantinae and Myobatrachinae. The major characters used to define the two groups were the structure of the tongue, hyoid apparatus, larynx and thigh musculature. Martin (1967a) noted that biological characteristics, particularly life history, were broadly consistent with Parker's division. Lynch (1971), using a complex of morphological, osteological and ecological characters, substantiated Parker's taxonomic interpretation; he further divided Parker's Cyclorantinae into two tribes, Cycloranini and Limnodynastini. Tyler (1972a) investigated the superficial mandibular musculature and vocal sac structure of Australian leptodactylids, and came to conclusions similar to those of Parker and Lynch, with one important exception. Tyler found that *Cyclorana* Steindachner did not conform with either the Cyclorantinae or the Myobatrachinae; and he questioned its familial disposition, noting that it shared some characters with the family Hylidae.

The generic classification of Australian leptodactylids has undergone considerable

modification since Parker's work. *Heleioporus*, as recognized by Parker, was divided into two genera, *Ileleiporus* Gray and *Neobatrachus* Peters, by Main (1957a); and the new genera *Kyarranus* Moore, 1958 and *Taudactylus* Straughan & Lee, 1966 have been erected. Tyler (1972b) removed *Crinia darlingtoni* to a new genus, *Assa*. Blake (in press), using a polythetic numerical approach, finds that *Crinia* is divisible into three genera, and groupings corresponding to these genera are used here. They are referred to as the *Crinia haswelli* group (including *C. haswelli* and *C. georgiana*); the *Crinia laevis* group (including *C. laevis*, *C. leali*, *C. lutea*, *C. rosea* and *C. victoriana*); and the *Crinia signifera* group (including all other species of *Crinia*). Blake (in press) also finds that *Metacrinia* Parker does not warrant separation from *Pseudophryne* Fitzinger and he intends to synonymise these two genera; hence they are not treated separately here. The current composition of the Australian leptodactylids is shown in Table 1.

The present contribution summarizes the available data on the life histories and larval morphology of Australian leptodactylids. Such information is useful from two points of view. First, life history stages provide morphological characters independent of those exhibited by

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adults, and can therefore be used to test phylogenetic relationships based on studies of adults (such as the suggested hylid affinities of *Cyclorana*), provided that care is taken to recognize convergence (Inger 1958; Griffiths 1963). Second, life history is an indicator of general adaptive ecology, and generic definition is currently based on ecological as well as morphological characters (Mayr 1969). Inger (1958) has demonstrated the utility of life history data in anuran classification at the infrafamilial levels, and this approach was used by Martin & Watson (1971) in an analysis of the family Hylidae. Although Lynch (1971) took life histories into account in his analysis of the leptodactylids, most of his data on Australian forms is derived from the literature, and is often inadequate or erroneous.

TABLE 1  
Infrafamilial classifications of Australian leptodactylids.

Adelotus Kyarranus Lechriodus Limnodynastes Phyllorhina	} Tribe Limnodynastini (Lynch 1971)	} Subfamily Cycloranimae (Parker 1940; Lynch 1971)	} Subfamily Cycloranimac (Tyler 1972a)
Heteidoporus Mistophyes Neobatrachus Notaden Cyclorana			
Asxa Crinia haswelli group Crinia laevis group Crinia signifera group Glaupertia Myobatrachus Pseudophryne Taudactylus Uperoleia	} Subfamily Myobatrachidae (Parker 1940; Lynch 1971; Tyler 1972a; Blake in press)		

### Material and Methods

Material representing all but four of the 17 genera of Australian leptodactylids has been examined. The four genera not studied are the cycloranine *Notaden* Gunther and the myobatrachines *Asxa* Tyler, *Glaupertia* Loveridge and *Myobatrachus* Schlegel. For these genera data have been drawn from the literature. One or more species of each of the other genera have been examined; all observations not supported by a reference are original. In some cases (e.g. *Limnodynastes*, the *Crinia signifera* group) enough species have been studied to be fairly confident that the limits of intrageneric variation in life history have been detected; in others (e.g. *Taudactylus*), only one species has been examined and the present account may therefore not be characteristic of the genus.

Identity of life history stages was established by rearing eggs of known parentage, or by rais-

ing to metamorphosis a portion of each tadpole sample. The only exception is *Taudactylus*, where identification of the larvae is based on the fact that they were collected at the type locality of *T. diurnus*, and are distinct from the larvae of any other anuran known to inhabit the area.

Although data on numerous characters were assembled, five major features of the life history showed consistent variation and were employed in our analysis. These features, most of which are illustrated in Martin (1965), are:

- (1) Type of egg mass: whether foamy or not.
- (2) Larval development: whether terrestrial or aquatic.
- (3) External gills: whether present or absent in embryonic development.
- (4) Number of rows of teeth in the upper labium of the larval mouth: whether none, two, or more than two.
- (5) Disposition of labial papillae in the larval mouth: whether completely surrounding the mouth disc (no gaps), or with an anterior gap, or with both anterior and posterior gaps.

One additional character commonly employed in larval descriptions—whether the anus is median or dextral—is included for the sake of completeness, but in many groups it is too variable (even within genera) to be useful in the analysis of affinity (Lee 1967; Lynch 1971). The larval morphology of each genus is illustrated by drawings of the tadpoles of one or more species in lateral view, and of the larval mouth discs. Larvae between stages 30 and 38 of Gosner (1960) were used for illustration. Where material was available for several species in a genus, the species selected for illustration and description is generally one which has not been considered in our previous publications (e.g. Martin 1965, 1967a). The description refers to the species illustrated, and variations in other species are noted. Drawings were made with the aid of a stereoscopic microscope, using photographs, a camera lucida, or an ocular micrometer and squared paper.

### Survey of Life Histories

#### *Adelotus* Ogilby

Species examined: *A. brevis*, from Mt. Nebo, Qld.

The egg mass is foamy and is deposited in standing or flowing water; development is

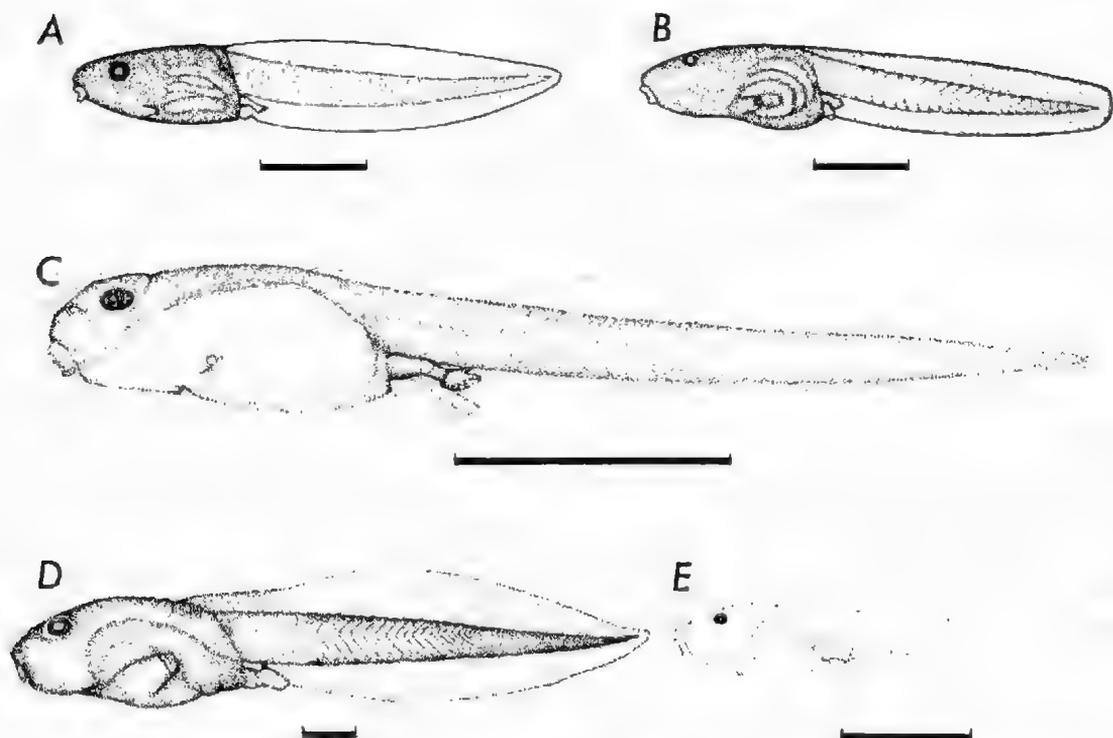


Fig. 1. Left lateral view of larvae of: A, *Adelotus brevis*; B, *Lechriodus fletcheri*; C, *Kyarranus sphagnicolus*; D, *Limnodynastes interioris*; E, *Philoria frosti*. In each case the bar represents 5 mm.

aquatic. The eggs lack pigment and have a diameter of 1.7 mm (Martin 1967a). There are no external gills. The anus is dextral, and the larva has an unspecialized body form (Fig. 1A). There are three upper and three lower rows of labial teeth (not two upper and three lower as stated by Lynch 1971), and a gap in the labial papillae along the anterior margin of the mouth disc (Fig. 2C).

*Adelotus* is a monotypic genus.

#### **Kyarranus Moore**

Species examined: *K. sphagnicolus*, from Point Lookout, N.S.W.

The foamy egg mass is placed out of water, in damp sphagnum moss, and the larvae do not feed, though they may become free-swimming (J. M. de Bavay, *pers. comm.*). Small external gills are present. The larva has a relatively long tail and broad fin; the anus is median (Fig. 1C). The mouth parts are reduced, with well-developed jaws but no labial teeth; the papillary border is broken anteriorly (Fig. 2D).

The life history of *K. loveridgei* is very similar (Moore 1961).

#### **Lechriodus Boulenger**

Species examined: *L. fletcheri*, from Cunningham's Gap, Qld.

Development is aquatic, often in highly ephemeral situations. The egg mass is foamy and the ovidiameter is about 1.7 mm (Martin 1967a). Long, filamentous external gills are present. The larvae (Fig. 1B) are carnivorous and development is rapid (Moore 1961). The anus is median. The mouth disc (Fig. 2A) has large jaws, and six upper and three lower rows of labial teeth. Labial papillae are absent from the anterior margin of the mouth disc. *Lechriodus* is incorrectly described by Lynch (1971) as having only two upper labial tooth rows.

*L. fletcheri* is the only representative of the genus in Australia, but there are several species in New Guinea (Parker 1940).

#### **Limnodynastes Fitzinger**

Species examined: *L. dumerili*, *L. fletcheri*, *L. interioris*, *L. peroni*, *L. salmini*, *L. tasmaniensis*, *L. terraereginae*.

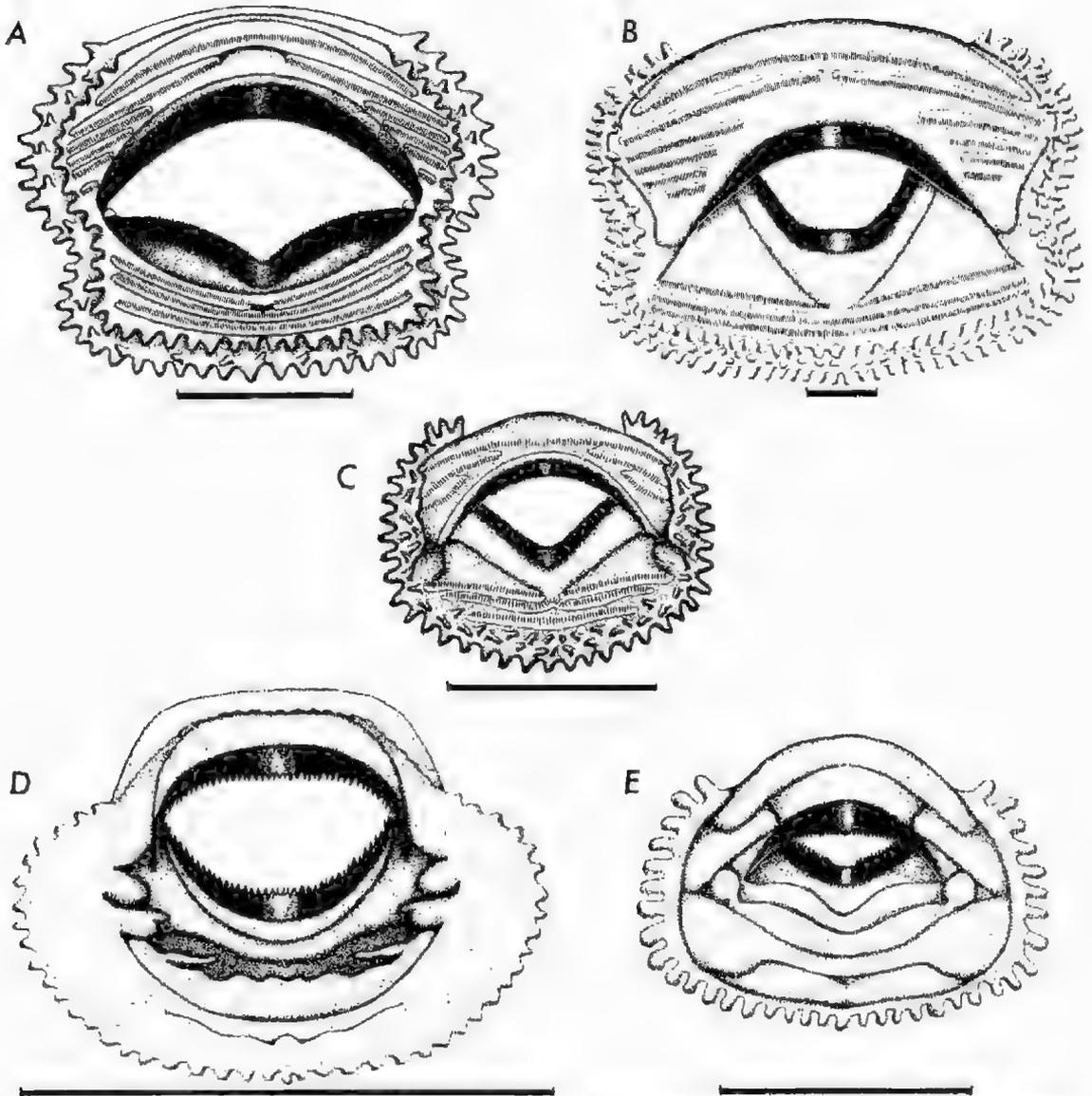


Fig. 2. Larval mouth discs of: A, *Lechriodus fletcheri*; B, *Limnodynastes interioris*; C, *Adelotus brevis*; D, *Kyarranus sphagnicolus*; E, *Philoria frosti*. In each case the bar represents 1 mm.

Species described: *L. interioris*, from Boree Creek, N.S.W.

The egg mass is large and frothy, and is deposited in water among vegetation, under logs or rocks, or in water-filled burrows in stream banks (Martin 1967a); development is aquatic. The ovidiameter is about 1.7 mm. External gills are small and unbranched. The larva (Fig. 1D) has a generalized body form; the anus is median. There are six upper and three lower rows of labial teeth, and labial papillae surround the mouth disc except for the anterior margin (Fig. 2B).

This life history pattern seems fairly constant throughout the genus. In southern Victorian and Tasmanian *L. peroni*, the eggs are unpigmented (Littlejohn 1963a). Egg counts range from 1,100 in *L. tasmaniensis* to 3,900 in *L. dumerili* (Martin 1967a). All species have at least 4, and usually 5-6, rows of teeth in the upper labium.

#### *Philoria* Spencer

Species examined: *P. frosti*, from Mt. Baw Baw, Vic.

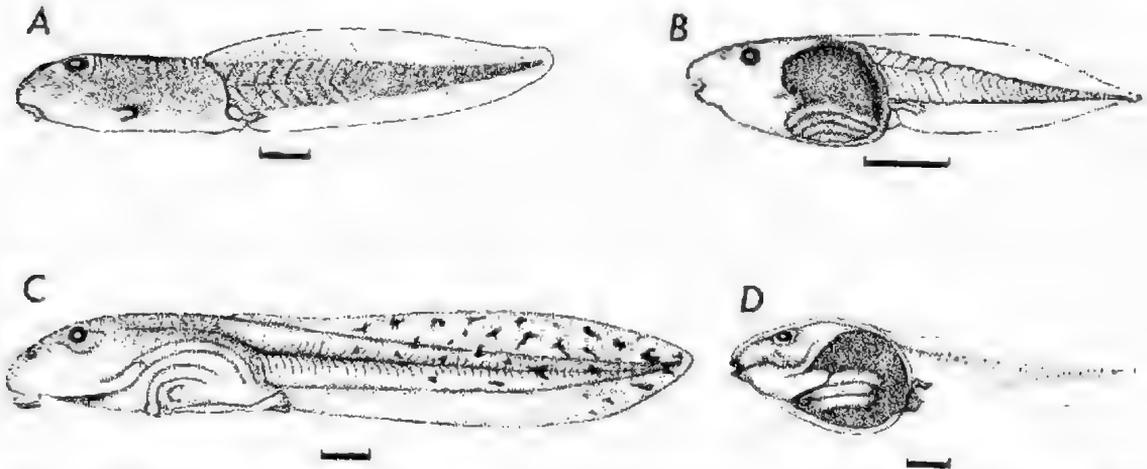


Fig. 3. Left lateral view of larvae of: A, *Heleioporus australiacus*; B, *Cyclorana cultripes*; C, *Mixophyes balbus*; D, *Neobatrachus pictus*. In each case the bar represents 5 mm.

The frothy egg mass is placed in damp sphagnum near water; the eggs are unpigmented and have a diameter of 3.9 mm (Littlejohn 1963b). Small external gills are present. The larvae may be free-swimming but apparently do not feed. The anus is median and the tail fin large in proportion to the body (Fig. 1E). The mouth has well-developed jaws, and papillae on the lateral and posterior margins of the disc, but labial teeth are absent (Fig. 2E).

*Phylloria* is a monotypic genus.

**Heleioporus Gray**

Species examined: *H. australiacus*, from 12 km S. of Walhalla, Vic.

The eggs are unpigmented and measure 2.6 mm in diameter; egg counts of four masses ranged from 775–1,239 eggs. The egg mass is foamy and is deposited in standing or flowing water concealed in vegetation or in burrows; development is aquatic. The external gills are prominent. The larvae (Fig. 3A) are unspecialized, with a median anus. The mouth disc has six upper and three lower rows of labial teeth, and an anterior gap in the papillary border (Fig. 4A).

Lee (1967) has described the life histories of the five Western Australian species of *Heleioporus*: In these, the eggs (mean ovidiameters 2.6–3.8 mm; mean egg counts 160–480 eggs) are laid in dry burrows which are later flooded, and the larvae undergo aquatic development. The anus may be median or dextral, and there are 5–6 rows of teeth in the upper labium.

**Mixophyes Gunther**

Species examined: *M. balbus*, *M. fasciolatus*.  
Species described: *M. balbus*, from Point Lookout, N.S.W.

The eggs (ovidiameter about 2.8 mm) are pigmented and are laid in clusters on rocks or gravel near the edge of flowing streams. Each egg has a distinct separate capsule, and the mass is not frothy. External gills are present. Development is aquatic, and the larva is a large and powerful lotic form (Fig. 3C). The anus is dextral. The mouth disc has a complete papillary border, and six upper and three lower rows of labial teeth. There are also 5–6 lateral rows on each side near the angle of the jaw (Fig. 4B). The hind limbs develop in a membranous sac and are not visible until late in development.

The life histories of *M. balbus* and *M. fasciolatus* appear to be essentially identical (Martin 1967a). Details of life history in the other two members of the genus are not recorded.

**Neobatrachus Peters**

Species examined: *N. centralis*, *N. pictus*.  
Species described: *N. pictus*, from Saverlake, N.S.W.

The eggs are pigmented and about 2.2 mm in diameter. They are laid in strings of jelly wound among submerged vegetation in standing water, and development is aquatic. Small external gills are present. The larvae are active swimmers with relatively plump bodies and short

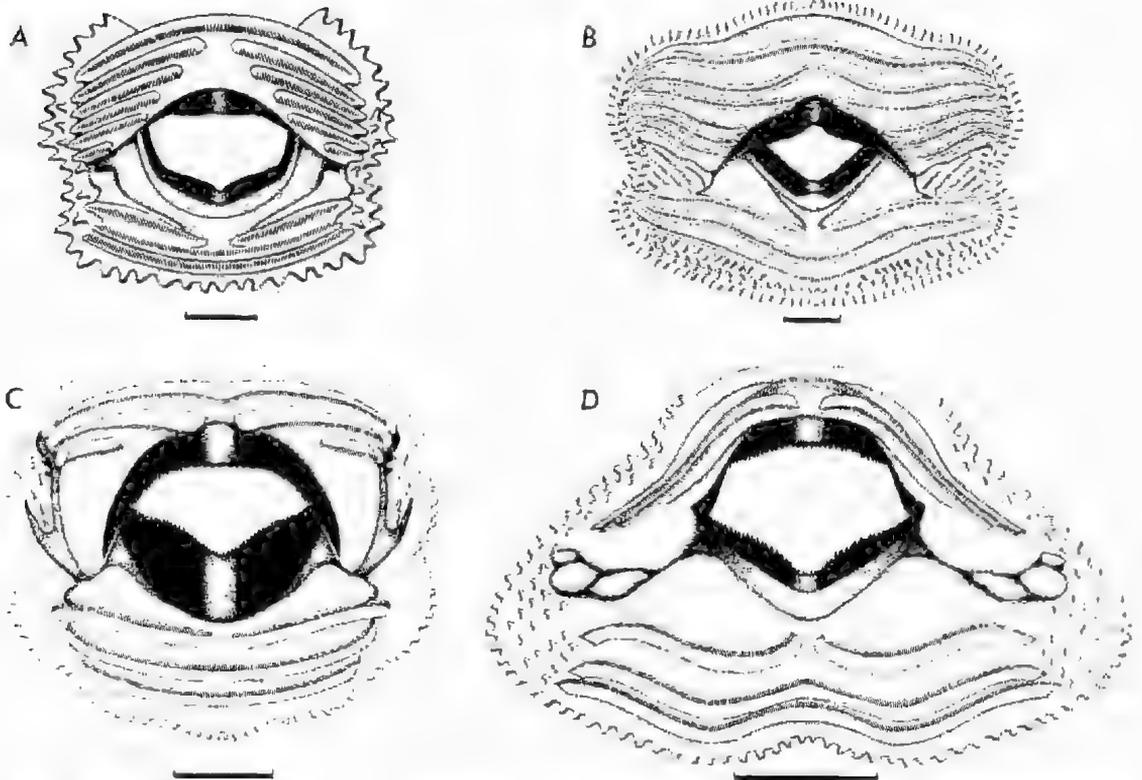


Fig. 4. Larval mouth discs of: A, *Heleioporus australiacus*; B, *Mixophyes halbus*; C, *Neobatrachus pictus*; D, *Cyclorana cultripes*. In each case the bar represents 1 mm.

tails (Fig. 3D). The anus is median or slightly displaced to the right. Papillae are absent from the anterior margin of the mouth disc, and there are three rows of teeth in each labium (Fig. 4C). The jaws are very robust, presumably reflecting the fact that the larvae feed by ingesting large fragments of plant and insect material (M. J. Tyler, *pers. comm.*).

In eastern populations of *N. centralis* the eggs have discrete capsules and are laid separately or in loosely adherent clumps. The three endemic Western Australian species lay their eggs in long strings (Main 1965, 1968).

#### Notaden Gunther

Species described: *N. nicholli*, from Munkayarra, W.Aust.

This account is taken from Slater & Main (1963). The eggs are 1.3 mm in diameter and pigmented; they are laid in temporary pools and development is aquatic. The form of the egg mass, and whether or not external gills develop, are not recorded. The anus is median. There are three upper and three lower rows of labial teeth, and papillae extend around the sides and back of the mouth disc.

There is no information on record concerning the life history of the other members of this genus, *N. bennetti* and *N. melanoscaphus*.

#### Cyclorana Steindachner

Species examined: *C. australis*; *C. cultripes*; *C. platycephalus*.

Species described: *C. cultripes*, from Pine Creek, N.T.

Development is aquatic. The eggs are small and pigmented and are laid in clusters, without distinct separate capsules, in water (Main 1965). Embryonic development is not recorded. The larva (Fig. 3B) has a distinctive acuminate tail tip; the anus is dextral, though often only slightly displaced from the midline. There are two upper and three lower rows of labial teeth, and papillae occur along the lateral and posterior margins of the mouth disc (Fig. 4D).

The eggs and larvae of *C. platycephalus*, and the larvae of *C. australis*, are similar to those of *C. cultripes*. No data are available for other species in the genus.

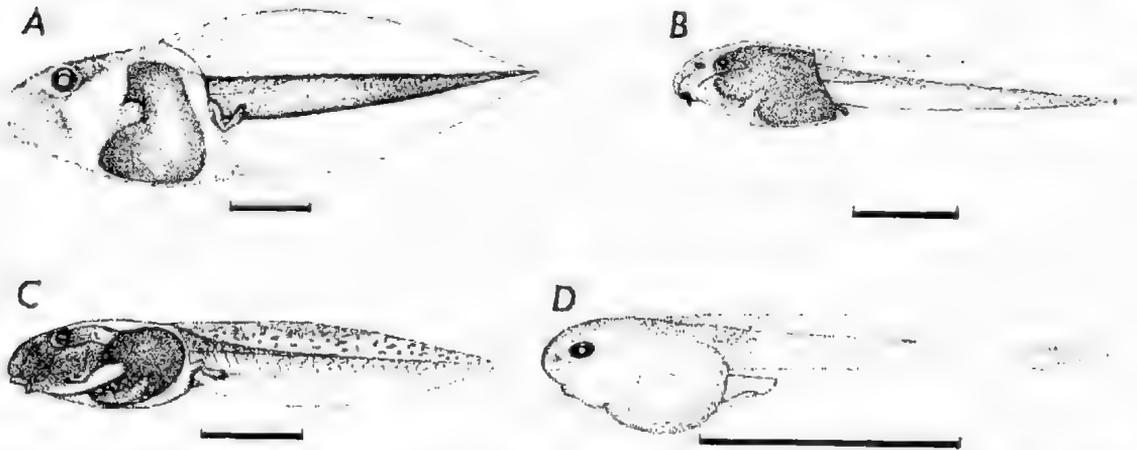


Fig. 5. Left lateral view of larvae of: A, *Crinia haswelli*; B, *Pseudophryne corroboree*; C, *Crinia laevis*; D, *Crinia rosea*. In each case the bar represents 5 mm.

Assa Tyler

Species described: *A. darlingtoni*, from the Macpherson Range, Qld.

The eggs are unpigmented and average 2.5 mm in diameter. Oviposition and embryonic development are not recorded. The larvae develop in a brood pouch of the male, but details of their morphology have not been described (Straughan & Main 1966).

The genus *Assa* is monotypic.

*Crinia* Tschudi

CRINIA HASWELLI group

Species examined: *C. haswelli*, from 7 km W. of Orbust, Vic.

The eggs measure about 2 mm in diameter and are pigmented, with distinct individual capsules. They are laid in water and development is aquatic. External gills are absent. The larva (Fig. 5A) is a specialized nektonic form with high fins. The anus is dextral. The tadpole appears to feed largely on plankton. The mouth has two upper and two lower rows of labial teeth, and a single row of papillae bordering its lateral and posterior margins (Fig. 6A).

The Western Australian *C. georgiana*, the only other member of this group, has a markedly different pattern of development (Main 1957b, 1965). The eggs are laid in permanent streams and soaks. Larvae are of the lotic type, being flattened, and with long, slender tails (see Main 1957b, Fig. 2a). There are three rows of teeth in each labium, and the papillary border has both anterior and posterior gaps.

CRINIA LAEVIS group

Species examined: *C. laevis*, *C. rosea*, *C. victoriana*.

Species described: *C. laevis*, from Wynard, Tas. and *C. rosea*, from Pemberton, W.A.

In *C. laevis* the eggs are pigmented, about 3 mm in diameter, and with discrete capsules. They are laid in concealed sites on land, and embryonic development is intracapsular. There are no external gills. After the eggs are flooded by winter rains the larvae (Fig. 5C) hatch and undergo aquatic development. The anus is dextral. The mouth has two upper and three lower labial tooth rows, and papillae are absent from the anterior and posterior margins of the mouth disc (Fig. 6C).

In *C. rosea* the eggs are unpigmented and have a diameter of 2.35 mm (Main 1957b). The entire development takes place on land, and the larva (Fig. 5D) is highly modified, with no mouth disc (the mouth is a simple slit), a large yolk sac and an elongate tail. The anus is median.

All members of this species group have one or other of these modes of development: the *C. laevis* pattern is shared by *C. leai* and *C. victoriana*, and the *C. rosea* pattern by *C. lutea* (Littlejohn & Martin 1964; Main 1957b, 1963).

CRINIA SIGNIFERA group

Species examined: *C. parinsignifera*, *C. riparia*, *C. signifera*, *C. sloanei*, *C. tasmaniensis*.

Species described: *C. parinsignifera*, from 6 km S.E. of Wandong, Vic.

The eggs are 1.3 mm in diameter, pigmented, and with distinct individual capsules.

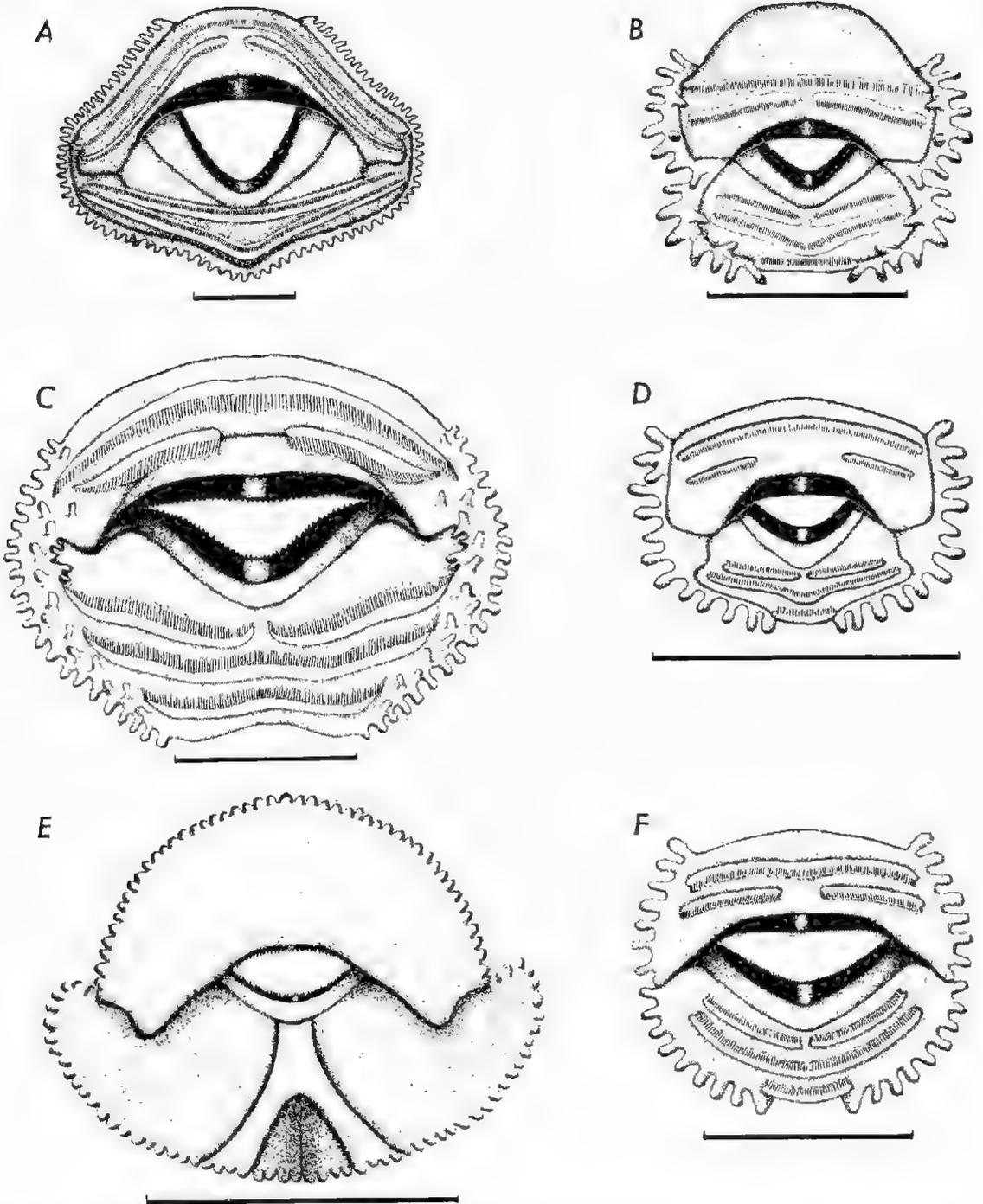


Fig. 6. Larval mouth discs of: A, *Crinia haswelli*; B, *Pseudophryne corroborae*; C, *Crinia laevis*; D, *Crinia parinsignifera*; E, *Taudactylus diurnus*; F, *Uperoleia marmorata*. In each case the bar represents 1 mm.

Oviposition and development are aquatic. External gills are absent. The larva (Fig. 7A) is unmodified, with a dextral anus. The mouth has an incomplete papillary border, with both anterior and posterior gaps, and there are two upper and three lower rows of labial teeth (Fig. 6D).

There is little variation in life history in this group. The same basic pattern is shared by *C. glauerti*, *C. insignifera*, *C. pseudinsignifera*, *C. subinsignifera* and *C. tinnula* (Main 1957b, 1965; Straughan & Main 1966). In *C. tasmanfensis* and *C. riparia* the eggs are larger (ovidiameters 1.96 and 2.27 mm respectively), and the latter has terrestrial oviposition and a lotic type of larva (Martin 1967b; Littlejohn & Martin 1965).

**Glauertia** Loveridge

Species described: *G. russelli*, from Western Australia.

The eggs have a diameter of about 1.4 mm and are laid in water; development is aquatic (Main 1968). No other details of the life history have been recorded, and the life history of *G. mjobergi* is entirely unknown.

**Myobatrachus** Schlegel

Species described: *M. gouldi*, from Western Australia.

The eggs reach a diameter of 5.5 mm (Watson & Saunders 1959). No other life history data are on record, but from the large egg size and general adult ecology it is very probable that development takes place on land (Main 1968).

*Myobatrachus* is a monotypic genus.

**Pseudophryne** Fitzinger

Species examined: *P. australis*, *P. bibroni*, *P. curiacea*, *P. corroboree*, *P. dendyi*, *P. semimarmorata*.

Species described: *P. corroboree*, from Mt. Ginini, A.C.T.

The eggs are pigmented and have a diameter of about 3 mm. They have firm, discrete capsules and are laid on land, in tunnels in sphagnum. Embryonic development occurs within the capsule and there are no external gills. The larvae (Fig. 5B) develop in water. The anus is dextral and the mouth has two upper and three lower rows of labial teeth. There are gaps in the papillary border at both the front and rear margins of the mouth disc (Fig. 6B).

This pattern of life history—large eggs laid on land, intracapsular embryonic development, and aquatic larval development—is consistent throughout the genus (Martin 1965, 1967a), with the exception of the Western Australian *P. douglasi*, in which oviposition is aquatic (Main 1964). Blake's (in press) revision of the myobatrachines includes *Metacrinia nichollsi* in *Pseudophryne*, but nothing is known of its life history (Main 1968).

**Taudactylus** Straughan & Lee

Species examined: *T. diurnus*, from Mt. Glorious, Qld.

Ovarian eggs reach 2.2 mm in diameter, but oviposition and embryonic development are not recorded (Straughan & Lee 1966). We found larvae (Fig. 7B) in a slow-flowing creek. The anus is dextral. The mouth structure (Fig. 6E) is unusual. The jaws are weakly developed and there are no labial teeth; but the disc is greatly expanded and umbrella-like, with a complete papillary border.

The life history of *T. acutirostris* is not recorded, and therefore whether or not this unique larval form is typical of the genus is unknown.

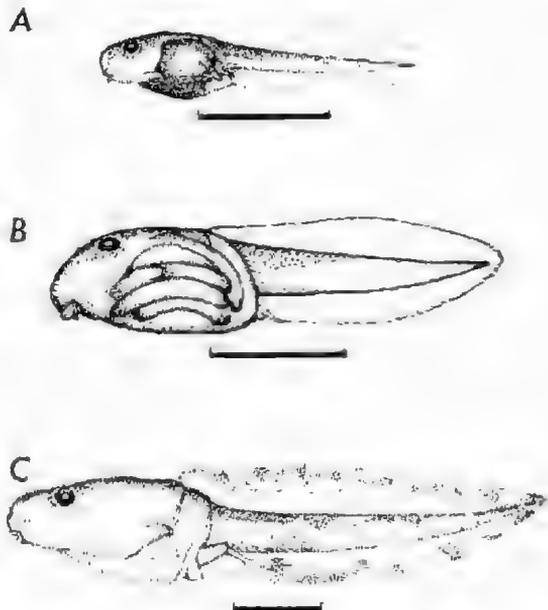


Fig. 7. Left lateral view of larvae of: A, *Crinia parinsignifera*; B, *Taudactylus diurnus*; C, *Uperoleia marmorata*. In each case the bar represents 5 mm.

**Uperoleia Gray**

Species examined: *U. marmorata*, *U. rugosa*.

Species described: *U. marmorata*, from 38 km N. of Bateman's Bay, N.S.W.

The eggs are pigmented and have discrete capsules; the ovidiameter is about 1.5 mm. Development is aquatic. External gills do not develop. The larva is unspecialized (Fig. 7C); the anus is dextral. The mouth (Fig. 6F) has

two upper and three lower rows of labial teeth, and gaps in the papillary border at both front and rear. Moore (1961) incorrectly states that the papillae extend around the posterior margin of the mouth disc; and both Moore (1961) and Lynch (1971) erroneously record that there is only one upper labial tooth row.

The life history of *U. rugosa* is very similar.

Life history characters are summarized in Table 2.

TABLE 2  
*Life history characteristics of Australian leptodactylid genera*

Genus	Species	Egg Mass		Development	External Gills		Upper Labial Tooth Rows			Gaps in Labial Papillae				
		Foamy	Not Foamy		Aquatic	Terrestrial	Present	Absent	0	2	>2	None	Anterior	Anterior and Posterior
ADELOTUS		+	-	+	-	-	+	-	-	+	-	+	+	-
LECHRIODUS		++	-	+	-	-	+	-	-	+	-	+	+	-
LIMNODYNASTES		+	-	+	-	-	+	-	-	+	-	+	+	-
KYARRANUS		+	-	-	+	-	+	-	-	-	-	+	+	-
PHILORIA		+	-	-	+	-	+	-	-	-	-	+	+	-
HELEIOPORUS		+	-	+	-	-	+	-	-	+	-	+	+	-
MIXOPHYES		+	-	+	-	-	+	-	-	+	-	+	+	-
NEOBATRACHUS		-	-	+	-	-	+	-	-	+	-	+	+	-
NOTADEN		-	-	+	-	-	+	-	-	+	-	+	+	-
CYCLORANA		-	+	+	-	-	+	-	-	+	-	+	+	-
ASSA		?	-	+	*	-	+	-	-	?	-	?	?	+
CRINIA	georgiana	-	+	+	-	-	+	-	-	+	-	-	+	+
	haswelli	-	-	-	-	-	+	-	-	+	-	-	+	+
	laevis	-	-	-	-	-	+	-	-	+	-	-	+	+
	rosea	-	+	-	+	-	+	-	-	+	-	-	No papillae	+
	signifera group	-	+	+	-	-	+	-	-	+	-	-	+	+
GLAUERTIA		-	+	+	-	-	+	-	-	+	-	-	+	+
MYOBATRACHUS		-	+	+	+	-	+	-	-	+	-	-	+	+
PSEUDOPHRYNE		-	+	+	+	-	+	-	-	+	-	-	+	+
TAUDACTYLUS		-	+	+	-	-	+	-	-	+	-	-	+	+
UPEROLEIA		-	+	+	-	-	+	-	-	+	-	-	+	+

\* In brood pouch of male

**Discussion****(i) Status of the subfamilies**

Life history data support the division of the Australian leptodactylids into the two subfamilies currently recognized. The Myobatrachinae are a close-knit, natural group of genera sharing several life history features. These are: eggs with discrete capsules; egg masses not foamy; no external gills; a dextral anus; two upper and three lower rows of labial teeth; and anterior and posterior gaps in the papillary border. The few exceptions are species of *Assa*, *Crinia* and *Taudactylus* whose larvae are modified for development in a parental pouch, or in other specialized niches.

The Cyclorantinae are a more heterogeneous assemblage. Leaving aside *Cyclorana* (which is discussed below), there is still a variety of

developmental patterns and larval forms in this group. The frothy egg mass has apparently evolved at least twice, in view of the occurrence of two different methods of foam production. In *Adelotus*, *Kyarranus*, *Lechriodus*, *Limnodynastes* and *Philoria* the foam is formed by the female "paddling" with her forelimbs, which have specialized flanges on one or more fingers, during amplexus. This paddling causes a stream of bubbles to pass backward beneath her body and become entrapped in the mucus which accompanies extrusion of the eggs (Martin 1967a). *Heleioporus* females lack these flanges, and in this genus the foam is presumably produced by a different (but presently unknown) method (Martin 1970). Again excluding *Cyclorana*, life history features common to most cyclorantines are: eggs with discrete capsules, sometimes in foamy masses;

external gills present; 3-6 upper rows of labial teeth; and no posterior gap in the papillary border. The anus is usually median, but is often slightly offset in *Neobatrachus*, and fully dextral in *Adelotus* and *Mixophyes*.

Lynch's (1971) division of the Cyclorantinae into tribes is based on breeding biology and the position of the vomerine teeth. The Limnodynastini consists of the genera in which foamy egg masses are produced with the aid of the flanged fingers of the female. This group is of course relatively homogeneous in terms of life history, since it was partly defined in this way. The Cycloranini, on the other hand, exhibit a variety of life history patterns, and from this point of view do not appear to constitute a natural group.

(ii) *The bearing of life history data on generic delimitation*

The current generic delimitation of Australian leptodactylids is broadly consistent with what is known of their life histories. In cases where genera have very similar life histories, e.g. *Neobatrachus* and *Notaden*, *Pseudophryne* and the *Crinia laevis* group, there is sufficient differentiation in adult morphology and ecology to warrant generic separation. The removal of *Crinia darlingtoni* to *Assa* by Tyler (1972b) and the subdivision of the remainder of *Crinia* by Blake (in press) are supported by life history evidence. The developmental biology of *Assa* is unique among Australian leptodactylids, and the *Crinia laevis* and *C. signifera* groups are also definable in terms of life history. The two members of the *C. haswelli* group have rather different life history patterns, but both are distinct from those of the *C. laevis* and *C. signifera* groups.

*Kyarranus* and *Phylloria* are the only genera whose status seems questionable in the light of life history data. The similarity between them in most aspects of both adult and larval morphology and ecology has already been commented on by Littlejohn (1963b) and Brattstrom (1970), and the latter has indicated his intention to synonymise *Kyarranus* with *Phylloria*. Such a change is clearly supported by evidence from their life histories.

(iii) *The position of Cyclorana*

Tyler's (1972a) contention that *Cyclorana* does not conform with the currently accepted concept of the Cyclorantinae, and has hylid affinities, is strongly supported by life history data. Indeed, if regarded solely in terms of life history, *Cyclorana* coincides very closely with

the pattern typical of Australian hylids (Martin & Watson 1971). Characters which it shares with them, and which are almost unique among Australian leptodactylids, are the indistinct egg capsules, the general body form of the tadpole (particularly the acuminate tail), and the presence of two upper labial tooth rows combined with the occurrence of papillae along the posterior margin of the mouth disc. Data from other sources, e.g. karyotype and mating call structure, are needed before a final decision can be made; but for the present it should be recognized that the subfamilial disposition of *Cyclorana* and the definition of the Cyclorantinae require revision.

(iv) *Phylogeny of the Australian leptodactylids*

The phylogenetic relationships of the Australian leptodactylids are disputed. Parker (1940) speculates that the myobatrachines may have been derived from the cyclorantinae; whereas Tyler (1972a) regards the myobatrachines as the primitive, and the cyclorantinae as the derived, group. Lynch (1971) believes that the two groups are not closely related, and that they represent independent descendants from a primitive leptodactyloid stock.

Our data do not contribute significantly to resolution of this question. If *Cyclorana* is left out of consideration then there are three main distinguishing features in the life histories of the two subfamilies. These are (1) the absence of external gills in the myobatrachines, and their presence in nearly all cyclorantinae; (2) the presence of two upper labial tooth rows in the myobatrachines, and of three or more in the cyclorantinae; and (3) the gap in the lower labial papillae of the myobatrachines. The latter two characters suggest that the myobatrachines are the more primitive group, but not necessarily that the cyclorantinae were derived from them. The presence of only two upper labial tooth rows is common in many families of anurans, e.g. most hylids, bufonids and Neotropical leptodactylids (Duellman 1970; Martin & Watson 1971; Lynch 1971). The papillary gap is also a bufonid characteristic. Thus Lynch's (1971) suggestion that the myobatrachines may be a relatively unmodified derivative of the proto-bufonid stock (i.e. the leptodactyloid group which was ancestral to the bufonids) seems reasonable. Bufonids do, however, possess external gills. Life history data do not assist in the interpretation of cyclorantine phylogeny. In terms of life history characters alone the only conclusions that can

**Key to Genera of Australian Leptodactylid  
Larvae**

(excluding *Glauertia*, *Myobatrachus*)

1. Larvae in brood pouch of adult male .....	<i>Asta</i>
1. Larvae not in brood pouch of adult .....	2
2. Mouth without labial teeth or papillae .....	<i>Crinia laevis</i> group (part)
2. Mouth with labial teeth and/or papillae .....	3
3. Labial teeth absent .....	4
3. Labial teeth present .....	6
4. Larvae unpigmented; free-swimming in streams; Mt. Glorious area, Qld. ....	<i>Taudactylus diurnus</i>
4. Larvae unpigmented or lightly pigmented .....	5
5. Larvae in pools or damp sphagnum; Mt. Baw Baw, Vic. ....	<i>Philoria</i>
5. Larvae in pools or damp sphagnum, or in depressions in earth; Point Lookout, N.S.W.; Macpherson Range, Qld. ....	<i>Kyarranus</i>
6. Papillae completely surrounding mouth .....	<i>Mixophyes</i>
6. Papillary border incomplete .....	7
7. Papillary border with an anterior gap .....	8
7. Papillary border with both anterior and posterior gaps .....	12
8. Mouth with 2/2 labial tooth rows .....	<i>Crinia haswelli</i>
8. Mouth with more than 2/2 labial tooth rows .....	9
9. Mouth with 2/3 labial tooth rows <sup>1</sup> .....	<i>Cyclorana</i>
9. Mouth with more than 2/3 labial tooth rows .....	10
10. Mouth with 3/3 labial tooth rows .....	11
10. Mouth with 4-6/3 labial tooth rows .....	<i>Heleioporus</i> <i>Lechriodus</i> <i>Limnodynastes</i>
11. Anus dextral .....	<i>Adelotus</i>
11. Anus median or near-median .....	<i>Neobatrachus</i> <i>Notaden</i>
12. Mouth with 3/3 labial tooth rows .....	<i>Crinia georgiana</i>
12. Mouth with 2/3 labial tooth rows <sup>2</sup> .....	<i>Pseudophryne</i> <i>Crinia laevis</i> group (part) <i>Crinia signifera</i> group <i>Uperoleia</i>

<sup>1</sup> Tadpoles of nearly all Australian Hyliidae whose larvae are known also key out in this category.

<sup>2</sup> Tadpoles of *Bufo marinus* also key out in this category.

be drawn are that the cycloranines are a more specialized and less homogeneous group than the myobatrachines, and do not show any close affinities with them.

The phylogenetic position of *Cyclorana* cannot yet be decided. In terms of life history it shows greatest affinity with the hylids, less with the myobatrachines, and virtually none with the cycloranines. It is conceivable that it represents a relict of a primitive stock which was ancestral to both leptodactylids and hylids. M. J. Tyler (*pers. comm.*) is currently engaged in an analysis of the affinities of *Cyclorana*, and until his work is completed further speculation is not warranted.

(v) *Larval characters as an aid to diagnosis*

The larval morphology and biology of most genera of Australian Leptodactylids are sufficiently distinctive to enable generic diag-

nosis to be made in terms of these characteristics; they form the basis of the following dichotomous key.

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# STUDIES ON THE ECOLOGY OF THE AGAMID LIZARD *AMPHIBOLURUS MACULOSUS* (MITCHELL)

BY F. J. MITCHELL\*

## Summary

MITCHELL, F. J., 1973. Studies on the Ecology of the Agamid Lizard *Amphibolurus maculosus* (Mitchell). *Trans. R. Soc. S. Aust.*, 97 (1), 47-76, 28th February, 1973.

*Amphibolurus maculosus* (Mitchell), the Lake Eyre Dragon, is restricted to arid salinas in the northern part of South Australia. The lizards live near the margins of the salinas where a suitable burrow area of fine, wind-blown sand underlies the buckled salt crust. Their essential refuge from the harsh environment is in the permanently damp sediments, which occur below these dry aeolian deposits underlying the salt crust.

Preliminary laboratory experiments suggest that this lizard has a high temperature tolerance (CTM 48.9°C) and low evaporative water losses (1.1 mg/g/hr at 37.5°C)

The harvest ant, *Melophorus* sp., which occurs in the same habitat, is an important food item for the lizards, and the elevated rims of the ant nests provide shade and basking sites.

Seasonal emergence, following 3-4 months of hibernation, begins when ground temperature reaches about 19°C. At this temperature the lizards head-bask, emerging fully from the burrow when body temperature is raised to about 22°C. Under these conditions the dominant males emerge and establish territories in mid-August.

Basking postures are adopted to raise body temperature to 37.5°C (eccritic temperature determined in laboratory tests). In the field, behavioural thermoregulation maintains body temperature at about 39°C during higher air temperatures. If temperature cannot be held down within this range, the lizard retreats to the humid layer below the dry sand in the burrow zone.

Within the population, dominant, sub-dominant and subservient males can be recognised by behaviour and coloration during the breeding season (September to December). Among the females, two breeding groups, related to time of hatching, occur. Sperm retention is evident in one of these groups, in which ovulation occurs about 2 months after fertilization.

Sexual dimorphism in relation to colour pattern is not thought to be the basis of sex recognition since colour changes occur in both male and female. It seems likely that acute perception of size difference is the basis of sex recognition.

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\*Late of the South Australian Museum. This paper was compiled from the late F. J. Mitchell's draft manuscripts and field and laboratory notes by Ann Mitchell (Department of Botany, University of Adelaide, S. Aust. 5001).

## 1. Introduction

*Amphibolurus maculosus* is a highly adapted lizard, restricted in distribution to the salinas of the Lake Eyre Basin in the north of South Australia. It was first collected in 1929 by C. T. Madigan, who lodged with the South Australian Museum 20 specimens taken at the southern end of Lake Eyre North in the area now known as Madigan Gulf. These earless lizards were identified as a variety of *Tympanocryptis lineata* by H. M. Hale, then Director of the South Australian Museum (in Madigan 1930). In a revision of *Tympanocryptis*, a genus of "earless" dragons, Mitchell (1948) described the lizard as a new species, *T. maculosa*.

Subsequent osteological studies (Mitchell 1965) showed that the affinities of this species lie with the genus *Amphibolurus* and that it represents an extreme specialization within the genus. The enclosure of the tympanic membrane, which had led to its assignment to *Tympanocryptis*, was considered likely to be a secondarily developed characteristic. This may be an evolutionary adaptation to burrowing in dry sand, and may have arisen on more than one occasion in agamid lizards.

Lake Eyre, occupying an area of 9300 km<sup>2</sup>, is the largest of several extensive salinas in the arid north of South Australia (Fig. 1), lying at the southernmost and lowest end (14 m below sea level) of the Lake Eyre Basin. This Basin lies within the 125 mm isohyet in the driest area of the Australian continent. The usually dry river systems draining towards Lake Eyre serve a catchment area of over 1,300,000 km<sup>2</sup>. Some of this catchment lies within areas of comparatively heavy and regular rainfall but only under particular circumstances does sufficient water reach Lake Eyre to fill the Lake. Following exceptionally heavy summer rains in western Queensland in March 1949 and March 1950, Lake Eyre by September 1950 had filled with water for the first time in living memory. Scientific surveys, sponsored by the Royal Geographical Society of Australia (South Australian Branch) and led by C. W. Bonython, were carried out until the Lake had again dried out by November 1952 (Bonython 1955, 1956, 1960).

During this period the lizard was again observed and collected. Its ability to spend long periods foraging on the open surface of the salt crust of the Lake, withstanding both predation and desiccation, aroused considerable interest.

In 1964, Donald Campbell successfully attempted a land speed record on the surface of Lake Eyre. In order to gain access to the solid salt crust, a causeway was constructed from the shore-line across the marginal zone where the salt crust is thin. The track to the causeway permits vehicular access to the shore-line, and the causeway itself, projecting west from Prescott Point at the tip of Sulphur Peninsula (Figs. 1, 6), has subsequently served as a natural "trap" and developed a population of these lizards suitable for behavioural studies in their natural environment. A study area was set up at the causeway, where meteorological observations and records of behavioural responses of a marked population of the lizards were made during visits between February 1965 and October 1968.

This paper is based largely on field observations of the lizard on Lake Eyre, together with briefer studies of populations on other inland salinas. These field observations were supported by vivarium studies at the South Australian Museum. Preliminary experimental work is reported briefly.

## 2. Materials and Methods

### (1) Field Studies

The ecological simplicity of the habitat and the lack of a predator sense in *A. maculosus* make it an attractive animal for study once problems of distance, inaccessibility and trying working conditions are accepted. The lizards are very alert and because of cryptic coloration almost impossible to detect except during their sudden, rapid movements to maintain a few metres distance from an approaching observer. During the breeding season, however, territorial challenges, fighting and mating continue uninhibited by close-range observation.

Early in the field studies some 10 km of shoreline were surveyed, but later observations were restricted to the causeway population and all meteorological records reported here were taken in that area.

In all, 16 trips were made to the study area during the period February 1965 to October 1968. Average time spent at the study area on these trips was 7 days. In addition, during September and October 1967, an extended survey was made of the major salinas extending in an arc around the northern end of the Flinders Ranges, regarded as potentially suitable habitats for the lizards.

Field data have been derived from several sources. Continuous temperature records of air and sand at various depths were obtained using an EILCO thermistorised twelve-outlet, twin channel, recording thermometer, while single readings were taken with a Thermophil electronic thermometer. Rectal temperatures were obtained with a Schultheis, quick-reading mercury thermometer. All instruments were checked and calibrated in the laboratory before each trip. Relative humidity was variously measured with cobalt thiocyanate papers,

lithium chloride cell equipment and a whirling psychrometer.

Behavioural data were obtained from direct observation and from the marking and recapture of specimens in the causeway population at Prescott Point. Quadrats were marked out along the edges of the causeway and movements of lizards in relation to these areas were recorded during the period of study. Lizards were permanently marked by toe-clipping, and colour-coded for rapid identification of marked specimens in the field.

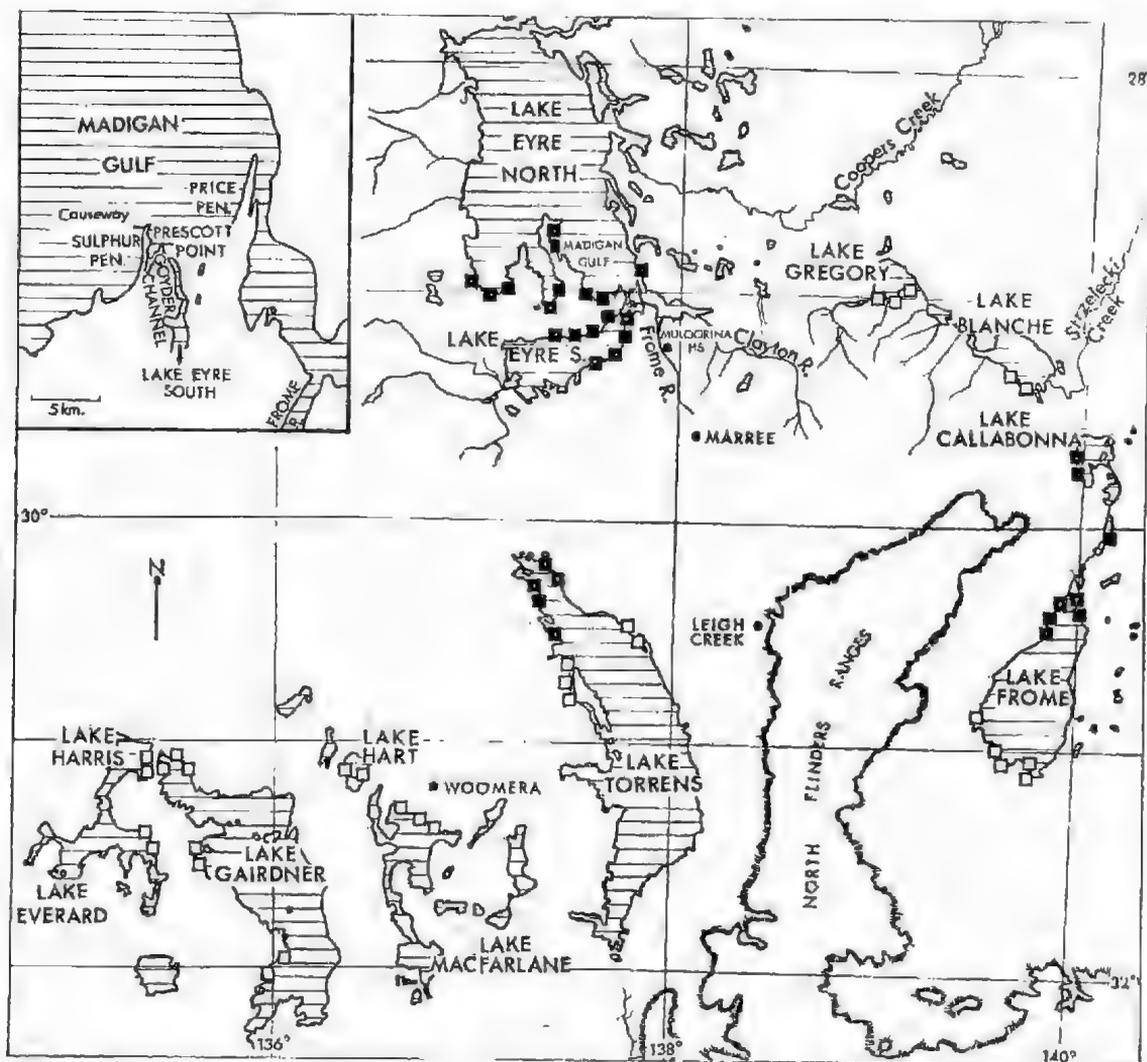


Fig. 1. Map showing the major salinas of northern South Australia and the known distribution of *Amphibolurus maculosus*. Inset map (upper left) shows portion of Madigan Gulf (the type locality), and the location of the causeway at Prescott Point which was the main study area. A black square indicates areas in which populations of *A. maculosus* have been observed; a white square indicates areas where survey of the salina margins revealed no specimens of *A. maculosus*.

### (2) Laboratory data

Experiments on thermal criteria and temperature tolerance of *A. maculosus* were carried out in an oven preheated to 45°C. Regular temperature increments of 1°C were made at 5 minute intervals.

Rates of water loss were derived from experiments carried out in a thermostatically controlled, water-jacketed incubator under temperature conditions controlled to  $\pm 0.5^\circ\text{C}$ . The test chamber was also desiccated over silica gel to ensure a relative humidity of less than 5% at all temperatures.

Experiments to determine water loss through the integument were undertaken with the vent of the animal sealed with waterproof adhesive tape and the head inserted through a thin rubber membrane across the mouth of a container partly filled with silica gel to absorb any water lost through the integument. The silica gel was overlain by a piece of thin card on which the lizard's body rested.

The test animals were acclimated for at least seven days to conditions involving the daily attainment of their maximum voluntary activity temperature (39.8°C). Animals were tested between 1000 and 1500 hours during their period of maximum activity.

For long-term behavioural studies, a terrarium was set up which successfully simulated lake shore conditions. A layer of gypseous clay, maintained in moist condition, was overlain by 15 cm of dry sand from the lake shore. Over the sand, pieces of consolidated salt crust provided a surface similar to the burrow zone area.

Both light and heating were provided by a battery of high-power incandescent lamps mounted under an adjustable hood. Time switches controlled day length, and the position of the hood controlled the maximum temperature. Strong correlation between field observations and laboratory records was found for daily and seasonal activity cycles and the onset of reproductive activities.

### 3. Morphology of *Amphibolurus maculosus*

*Amphibolurus maculosus* shows several features of morphology, physiology and behaviour which reflect its adaptation to arid salinas. Its dorsal surface is white to very pale grey with a row of very dense black blotches on either side of the vertebral line. Dorsally and laterally there are smaller black and rusty-brown pigmented areas. This colour

pattern gives excellent cryptic colouration on the salt surface, the dark areas blending with the shadows of small holes and pinnacles on the rough salt (Figs. 9, 10, 15). The ventral surface is white with a dark streak extending longitudinally along the centre of the throat to the gular fold. Colour variations related to the environment, and the striking colour patterns developed during the breeding season will be discussed later in this paper.

The adult male attains a total length of about 11.5 cm (snout-vent length 7 cm), the adult female being smaller at about 10.0 cm (snout-vent length 6 cm).

The eye is small and deeply sunken and is protected from salt glare by prominent serrated eyelids with dark pigmented linings (Fig. 4). The nostrils, while showing a circular external opening, open into the nasal cavity by only a narrow slit, directed forward and downward. This structure prevents the nasal passages from becoming blocked when the lizard burrows through loose sand. Special nasal structure has been described by Stebbins (1943) in the American genus *Uma*, which is a sand-burrowing form. He has shown (Stebbins 1948) that other American iguanid genera including *Uta*, *Holbrookia* and *Phrynosoma*, all of which habitually burrow in loose sand, have similarly adapted nasal structure.

### 4. Habitat and Distribution

The type locality of *A. maculosus* is Madigan Gulf, Lake Eyre North, out from the mouth of the Frome River. The species is widely distributed around the southern shoreline of Lake Eyre North and around the northern and south-eastern shorelines of Lake Eyre South. Throughout the study every opportunity was taken to search other lakes for additional populations and practically all of the major salinas in the State were at least cursorily examined for signs of habitation by these lizards. Two additional populations were found; a population in the saline areas at the southern end of Lake Callabonna and extending southwards through the salt channels into the northern tip of Lake Frome, and another population along the north-western shoreline of Lake Torrens. Fig. 1 shows the area searched, the localities from which specimens have been taken, and the range over which this species is known to occur.

The geomorphology and the history of landforms in the Lake Eyre Basin have been discussed by Wopfinger & Twidale (1967). Evi-

dence from fossil deposits suggest that extensive areas of brackish water or saline swamps existed within the basin from mid-Tertiary to the end of the Pleistocene. The origin of the salt in Lake Eyre has been subject to debate but it seems likely that both cyclic salt and connate salt, accumulated from waters brought into the basin from the extensive drainage system, have contributed (Bonython 1956; Wopfner & Twidale 1967; Twidale 1968). The present isolated populations of *A. maculosus*, which although spatially widely separated are virtually morphologically indistinguishable from one another, may be relict from a more widespread species evolved in association with the shore-lines of the large brackish lakes and swamps that were a feature of the Lake Eyre Basin during Pleistocene and early Recent periods.

**THE HABITAT OF THE LAKE EYRE POPULATION**

The habitat within the study area can be divided into three distinct zones, the "beach", the "burrow zone" and the "wet salt zone" (Fig. 5). This zonation can be readily identified throughout the distribution of the Lake Eyre population examined, but is much less distinct in the area of the other two populations.

1. *The beach:* In the area along the southern shore-line of Lake Eyre North which was most intensively studied, the beach is backed by near-white sandhills varying from low consolidated hummocks stabilised by low shrubby vegetation (*Nitrota, Scaevola*) to high drifting dunes encroaching upon the lake. In many areas low cliffs varying in height from about a metre to approximately 12 m above the lake bed expose Recent to Cretaceous sediments to face the lake. Continuous wind erosion transports large quantities of gypsiferous clay and grit and other aeolian fines out over the beach and on to the surface of the lake. The beach is usually a narrow strip of consolidated sand frequently intermixed with areas of very coarse sand and pebbles. In areas where it is not overlain by recent drift it remains damp during the cooler months. Typical pebble beaches occur in some areas and the height and form of some of these beaches suggest sustained periods of strong wave action in the very recent past.

2. *The burrow zone:* This term has been adopted to cover the zone in which most of the activity of the lizards takes place. It consists of an area of distorted, dry, crusty sur-

face, varying from a few metres wide (in areas where flooding approaches close inshore or where little gypsiferous drift is brought out by the prevailing wind) to 400-500 m wide in seldom-flooded embayments where wind-drifted deposits have accumulated on the surface (Fig. 5). This 5-15 cm thick layer of fine gypsiferous clay and sand rapidly dries out and in doing so expands and distorts the salty crust which furms over the top of it. In section, this provides a burrowing substrate consisting of an irregular, salt-impregnated, crust up to 2 cm thick, lying above approximately 10 cm of fine, dry, windblown sediments underlain by sand which is kept continually damp from the water-table 40-70 cm below.

The lizards break through the salty crust at a weak point and then literally "swim" through the fine mobile sediments below until they encounter the high humidity associated with the damp consolidated sand at lower levels. They remain there until their re-emergence is triggered by rising temperatures or some internal stimulus. They follow the thermal gradient back to the surface, frequently emerging at a different point to that of entry.

3. *The "wet" salt zone:* The solid salt crust of the lake varies from about 2 cm in thickness in inshore areas to about 40 cm in thickness towards the centre of Madigan Gulf. This crust, overlying wet gypseous clay, becomes distorted and buckled as the salt recrystallises on drying out (Figs. 7, 8). Although most of the activity of this lizard takes place within 250 m of the shore, both the lizards and the nests of the ant *Melophorus* sp. (their principal item of food) have been observed more than 1400 m from the shore line. During the territorial season, many young subordinate males are forced to live outside the burrow zone and are frequently found well offshore. While little weight can be placed on the salt surface without bringing water to the surface, the actual surface "skin" is dry most of the time except in certain efflorescent areas close to shore which are continually damp. Relative humidity readings using cobalt thiocyanate papers set 1 cm off the salt under a shield, gave readings as high as 55% over these efflorescent areas, but in other areas the reading was below 15% and equalled the reading at 100 cm above the surface.

**THE LAKE CALLABONNA POPULATION**

Essentially the same conditions prevail as at Lake Eyre, with the lizards living around the

southern margins of the lake on isolated patches of aeolian drift in association with dry saline crust. A suitable habitat is not present in northern parts of the lake, where fresh water from the Strzelecki Creek has leached the bulk of the sodium and calcium salts from the surface deposits and the water table is deeper because of extensive Recent lacustrine deposits on the surface.

#### THE LAKE TORRENS POPULATION

The surface of Lake Torrens is wet and muddy and the lake frequently contains water. As a consequence the population has adjusted its behaviour to living among low vegetation along the immediate shoreline and upon low-relief islands covered with chenopodiaceous shrubs.

#### PHYSICAL FEATURES OF THE BURROW ZONE

Field and laboratory observations suggest that there are three essential habitat characteristics which influence the distribution of this lizard.

1. *A surface crust:* Specimens placed in a laboratory cage containing either loose sand or consolidated sand lacking a surface crust were unable to burrow. They were only able to scoop out a shallow depression. Several field observations related to this were made during the 1952 flooding of the lake when most of the lizards were forced onto the damp beach. Some did succeed in finding crusted areas back among the vegetation but several lizards were found in shallow depressions against driftwood along the beach. Presumably the surface crust is essential in providing initial purchase against which these lizards start their "swimming" procedure in burrowing through the sand. The consolidated surface crust need not necessarily be saline and in fact, gypsiferous sediments humd together by filamentous blue-green algae may well have provided a suitable habitat surface over wide areas in the past and may prove to be a contributing factor at present.

2. *A layer of fine dry sand (and/or clay) about 10 cm thick under the crust:* In order to provide adequate insulation from the extreme heat of the summer, the fine sand or sand-gypsiferous clay mixture must be dry and about 10 cm thick. It is probably important that the sediments contain gypsum to promote expansion and rapid drying after wetting.

3. *A constant source of humidity for the retreat:* Because of the water balance problems inherent in living upon a salt surface subject to extreme temperature, it is essential that the environment provide a refuge in which both evaporative and respiratory water losses be minimised during the periods of retirement underground. The sediments at about 10 cm below the surface crust must be permanently damp.

#### PRESENT KNOWN DISTRIBUTION

At most of the localities examined along the shore of Lake Eyre North and Lake Eyre South, lizards (or signs of their presence) were observed whenever a combination of the three factors described above were found. This applied equally well to Lake Callabonna except that suitable habitat there is much more limited. Most of the northern part of Lake Callabonna and Lakes Blanche and Gregory have a very friable surface deposit of fine gypsiferous clay which is not bound by a surface crust. This is not a suitable habitat. Lake Torrens lies on the "weather" side of the Flinders Ranges and is therefore subject to more frequent flooding than the other lakes around the northern end of these ranges. The lake surface is therefore permanently wet and does not provide a suitable habitat, but at the northern end and particularly along the western side, suitable conditions occur along the actual shoreline and upon low insular areas where the pale gypsiferous clay supports sparse halophytic vegetation. Many of these areas dry out during the warmer months, and form a suitable habitat with a distinct surface crust underlain by varying depths of dry pale yellow to red gypsiferous clayey silt. This habitat is exploited by the Lake Torrens population. Specimens have been collected up to 275 metres back into the vegetated zone away from the margin of the lake.

Other lakes examined were Lake Harris, Lake Gairdner, Lake Everard and Lake Hart (Fig. 1). Although knowledge of the shoreline conditions gained during this survey was very fragmentary, the general information gathered is considered adequate to suggest that if any additional populations are found on any of these lakes, they will not be found living upon the surface of the lakes as at Lakes Eyre and Callabonna, but along the margins as at Lake Torrens. The surface conditions of these Lakes are similar to Lake Torrens, the surface being too wet to support the ants

(*Melophorus* sp.) which provide the principal item of diet for these lizards; these ants, or other species of similar burrowing habit, are restricted to the shore-line areas. In many of the lakes, the ecological situation occupied by the ants at Lake Eyre is taken over by a species of Fighting Spider (*Geolycosa* sp.). Cicindeline beetles are also frequent and active predators over these damp lakes and in part replace the ants as surface scavengers. They dig vertical burrows into the damp muddy surface and have only been seen at the Lake Eyre study area when layers of fresh silt from floodings were overlying the salt.

### 5. Microclimate of the Habitat

*A. maculosus* has a strict preference for the margins of the salinas and does not invade the white sandhills despite its competitive dominance, in cage experiments, over the only agamid species which occurs there (*Amphibolurus pictus* Peters). It was noted also that *A. pictus* makes burrows over a metre long and up to 20 cm deep in mid-summer, despite the fact that its thermal tolerances are only slightly inferior to those of *A. maculosus* (see Table 2). This suggested that the lake surface environment may have some thermal advantage over the adjacent sandhills. Climatic conditions prevailing within the habitat were studied in an effort to determine the reason for the strict habitat preference and also to provide a foundation for an analysis of the activity and behavioural patterns observed.

#### (1) Temperature

Using the thermistorised recording thermometer, an attempt was made to compare the temperature profiles of the sections of the burrow zone preferred as a refuge by the lizards with parallel situations in the adjacent sandhills. Comparison between summer (February) and winter (July) temperature patterns for both the burrow zone area and the nearby white sand-dune area is given in Fig. 2. Summer soil temperature profiles for burrow zone and sand-dunes are shown in Fig. 3. The data obtained proved difficult to evaluate, probably because of the difficulty of obtaining strictly comparable test sites. The ground humidity varies from place to place with the local soil structure conditions and the thickness of the surface drift, and the extent to which the ground water has penetrated towards the surface also varies. It is

not possible to assess these factors without breaking the surface crust and thereby disturbing the stratification of the protective layers under which the lizards normally rest. Therefore, while the lizards were found consistently to prefer to rest on or just in the damp sand underlying the mobile dry sand, it was seldom possible to determine when the tip of the thermistor probe was lying in this same position. Also the protective value of the surface soil was greatly reduced by local rain which increased its conductivity. All of these factors reduce the comparative value of the data.

The data, however, do allow two conclusions to be drawn with reasonable confidence. Firstly, during the cooler weather when both the burrow zone deposits and the adjacent sandhills are damp to the surface, the thermal characteristics are essentially the same. Secondly, in midsummer the temperature at average refuge depth (10 cm) in the burrow zone, probably due to the thermal capacity of the water table 40–70 cm below, is lower and subject to less fluctuation ( $30 \pm 1.5^\circ\text{C}$ ) than the temperature in an equivalent situation in the adjacent sandhills ( $34 \pm 4^\circ\text{C}$ ) (Figs. 2, 3).

#### (2) Humidity

Surface temperatures were recorded using a contact thermistor and a Thermophil electronic thermometer. Because of the saturation of the lake floor right to the surface and the periodic appearance of free water on the surface of the more thickly salt encrusted area, it was anticipated that evaporative cooling would contribute to lowering surface temperature of the lake and raising humidity, particularly at the "living level" of the lizards (1 cm), both being features which would improve its suitability as a habitat during the warmer months. However, careful testing with the thermistor probe revealed the actual surface of the "wet" salt to be dry and at the same temperature as the crust in the burrow zone and the sand in the sandhills. Similarly, tests with cobalt thiocyanate humidity papers at 1 cm and 100 cm above the lake surface and 100 cm above the adjacent sandhill surface usually gave the same reading. Over the temperature range 30 to 40°C, during which lizards could be expected to be active over the "wet" salt surface, the readings were usually below the minimum sensitivity of the paper, indicating relative humidities below 15%.

Humidity readings, derived from each of the sources described above, varied from less than 5% to 55% relative humidity. The higher readings invariably followed light rain or thundery conditions and were the same for sandhills and lake surface sites. As air temperature increases each day, over the solid salt crust, the "wet" salt begins to "sweat" and brine appears at the tips of small, self-sealing, salt pinnacles. Due to the high temperatures and high evaporative rate it is likely that any humidifying effect of this brine is restricted to a micro-layer, of perhaps only a few mm, just above the evaporative surface. However, it was not possible to detect higher humidity over the "wet" salt surface and this is possibly due to inadequate instrumentation.

### (3) Salinity

The salinity of the wind-blown silts deposited in the burrow zone varies with depth. Salts dissolved out from the superficial layers were 7-11% of the silt; 3-5 cm down, 4-8% and 5-10 cm down, 3-4%. Below this level the salinity steadily increases again up to saturation at the water table 40-70 cm below the surface. The decrease in salinity nearer the surface is probably due to the recent origin of the surface deposit and to condensation along the line of demarcation between the permanently dampened sands and the overlying dry sediments leaching the salt out over a period of time. The lizards normally rest in this zone of lower salinity but whether this is of any advantage is unknown. The sand along the foreshore also contains 2-4% salt and the observed salinity stratification may be due to an increase in surface salinity by wind drift from the sandhills rather than to desalination of the intermediate layers.

Several small areas of white efflorescent salts were found just outside the burrow zone and these areas are continually losing water to the atmosphere. Although no lizards were ever observed using one of these areas on a hot day, the large number of fecal pellets

present on and around them suggest that their thermal advantages may be utilised by the lizards. The surface temperature of such an area of about 3 m<sup>2</sup> near the main study site was compared with that of the surrounding salt and found to be up to 9.5°C lower.

It appears that the lake surface confers no advantages upon an inhabitant, either in terms of surface temperature or humidity, over the condition prevailing in the surrounding sandhills. Despite the abundance of free saline water throughout the habitat it may still be inadequate to prevent the high evaporative rate [about 220 cm per annum (Bonython 1955)] from creating sufficient dry hygroscopic salt throughout the habitat to place greater strain on the water balance of this species than other desert-adapted lizards.

The permanently damp layer under the protective crust in the burrow zone provides a high humidity retreat into which the lizards can retire overnight or, if under social or environmental stress, for much longer periods without endangering their water balance. This is regarded as the key factor in restricting the species to the marginal areas of the salinas.

### 6. Food and Predation

The main food source for *A. maculosus* is the harvest-ant, *Melophorus* sp. In addition to providing food, the nest-mounds of these ants are important "features" in the generally featureless habitat, providing lookout points, basking sites and the only source of shade.

Colonies of *Melophorus* generally occur on the "wet-salt" surface usually within 750 m from the beach zone; preference is shown for areas where the salt-crust is no more than 2 cm thick and underlain by relatively clean sand down to the water-table 40-70 cm below. The colonies are regularly spaced over the lake surface, each being about 10 m equidistant from the next (Fig. 8). Investigation of a nest revealed a series of upper galleries just beneath the salt crust and a single vertical hole going down about 40 cm to a second set

Fig. 2. Comparison between summer and winter thermal characteristics of the burrow zone and adjacent white sand dunes. Figures from continuous recorder traces of temperature were plotted at 30 minute intervals.

- temperature at -10 cm
- temperature at -1 cm
- ..... air temperature at 40 cm above ground

- (A) Burrow zone temperatures over 34 hour periods in February, 1965 and July, 1966. Temperature range at -10 cm for the February period was 3.5°C, about a mean of 33.6°C.
- (B) Sand dune temperatures over 34 hour periods in March, 1965 and July, 1966. Temperature range at -10 cm for the March period was 11.5°C, about a mean of 34.6°C.

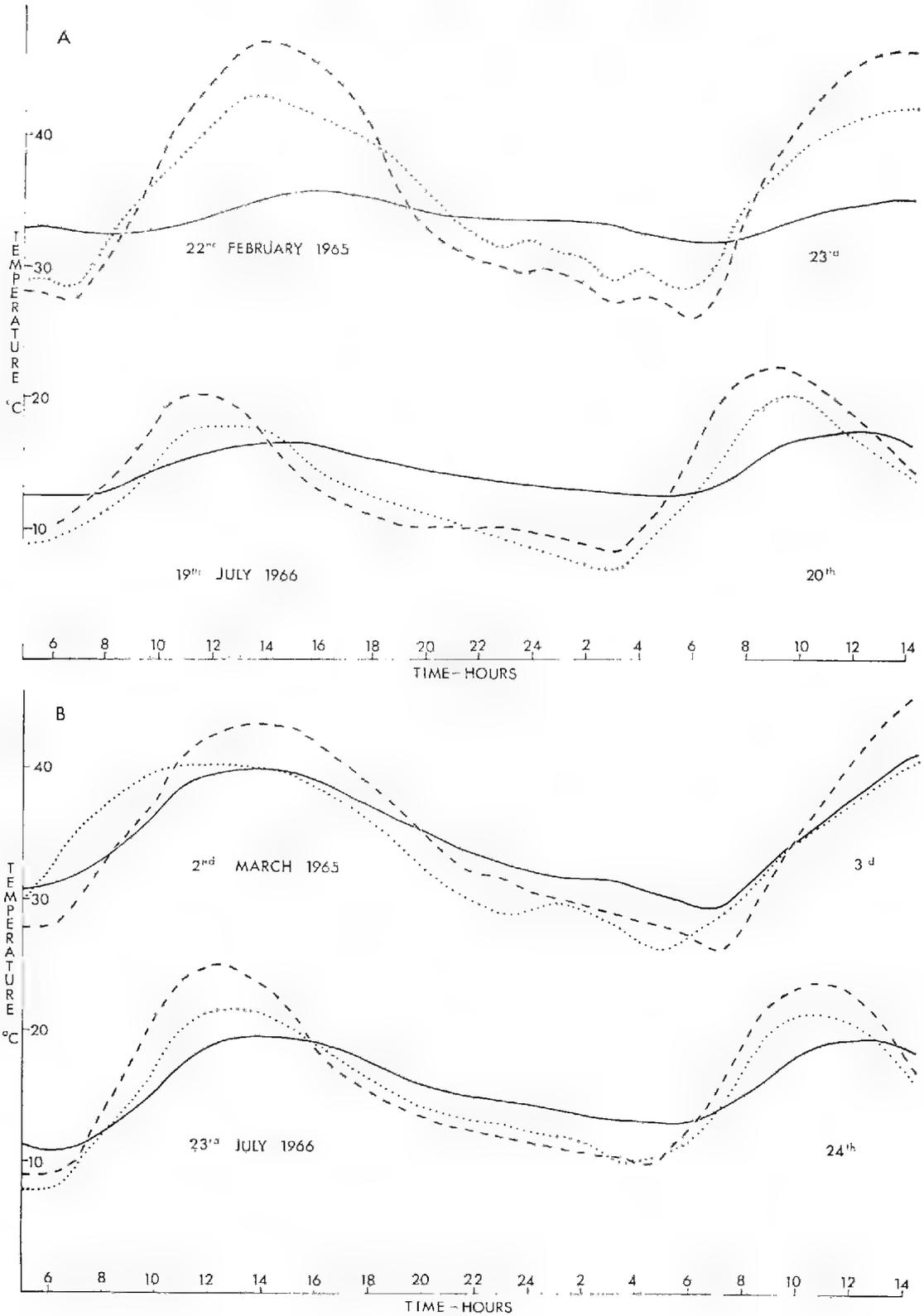


FIG. 2

of galleries at or along a consolidated layer of clay just above the water-table. The construction of these galleries produces, on the surface, a distinctive crateriform mound up to 20 cm in height. The sand below the salt crust is usually covered by a fine layer of clay which probably accounts for the reddish-brown debris, brought from below, being in marked contrast to the white salt crust.

At any time, only a small proportion of the total number of nests contain active colonies. The ants show limited activity during the day, appearing at the surface only to deposit sand grains from the workings below ground.

In view of the limited above-surface activity of the ants, it has been suggested (Madigan 1930) that *Melophorus* harvests micro-organisms either in the salt crust (blue-green algal cells) or in the damp sand above the water table (*Dunaliella* spp.). The nests usually, however, contain insect remains and the ants have been observed gathering bodies of insects trapped on the salt. Probably most foraging activity by the ants occurs at night.

*A. maculosus*, also, is an opportunistic feeder and when other insect life is available on the lake surface, the lizards feed on a wide range of different insect species. On most nights numbers of insects are stranded on the salt surface. Their presence may be explained in several ways. With an offshore wind many insects may be blown out over the lake; others may be attracted by the rise in humidity over the lake surface at night; aquatic insects (particularly on moonlit nights) may mistake the white lake surface for water. Overall the lake surface produces a vast "white sheet" effect—a commonly used form of insect trap—and many insects are trapped on the hygroscopic salt surface and killed when temperature increases next morning. During the spring months, September–November, vast quantities of insect life may occasionally be stranded on the lake surface. The bodies of insects which have been neither captured by *A. maculosus* nor later scavenged by *Melo-*

*phorus* become incorporated within the surface salt layers.

It is of interest that the characteristic insect fauna developed in the vegetation of the shoreline and sand-hills is rarely stranded on the salt surface of the lake, while the majority of species stranded on the salt are seldom seen about the shore.

The period of greatest feeding activity of *A. maculosus* (February to April) frequently coincides with drought conditions in the surrounding country, and consequent limited supply of windborne insect life.

In view of the limited number of ants active on the surface, the lizards must forage out over the lake surface for long periods at high temperatures. The lizards dig into the sides of the ant nests to retrieve ants from inside, and the more frequently visited ant-nests closer inshore become very battered in appearance. Shallow depressions scraped out at the base of the nests provide small areas of shade into which the lizards may retreat.

The Lake Eyre population of *A. maculosus* displays no response to overhead predators, relying for safety on their cryptic coloration. The only possible protective cover on the lake surface is provided by buckles and cracks in the surface of the salt crust (Figs. 7, 13). Although these would seem to provide ideal retreats they are rarely used by the lizards. The crystalline salt in the crust provides a "glasshouse" effect and the temperature below the crust may be several degrees higher than the surface of the salt. When pursued over the surface until exhausted, the lizards are more likely to come to rest in the shade of the pursuer than to retreat below the salt crust. There is little evidence of other potential predators moving out across the salt surface.

Hawks constitute one of the main predators of *A. pictus* from the sandhills adjoining the lake. On several occasions dead specimens of *A. pictus* have been observed well off-shore on the lake surface. Presumably these have been dropped by hawks. The fact that these

Fig. 3. Taurochrones (soil-air temperature profiles at different times during the day) recorded on 6th March, 1965 for (A) burrow zone area and (B) sand dune area. Differing thermal characteristics of the two localities result in the more rapid and greater heating in the sand dune area. At 10 cm (average burrow depth of *A. maculosus*) in the burrow zone there is a temperature range from 30.9 to 35.6°C over the time period recorded. At the same depth in the sand dune area there is a temperature range from 31.4 to 41.4°C over a similar time interval. In (B), due to the limited range of the thermometer used (calibrated up to 120 F (49°C)), no figures are available for the 2 cm and 4 cm depths at the 1120 and 1515 readings. Field notes recorded that, at these times and depths, the temperature was "120°F+ and rising rapidly".

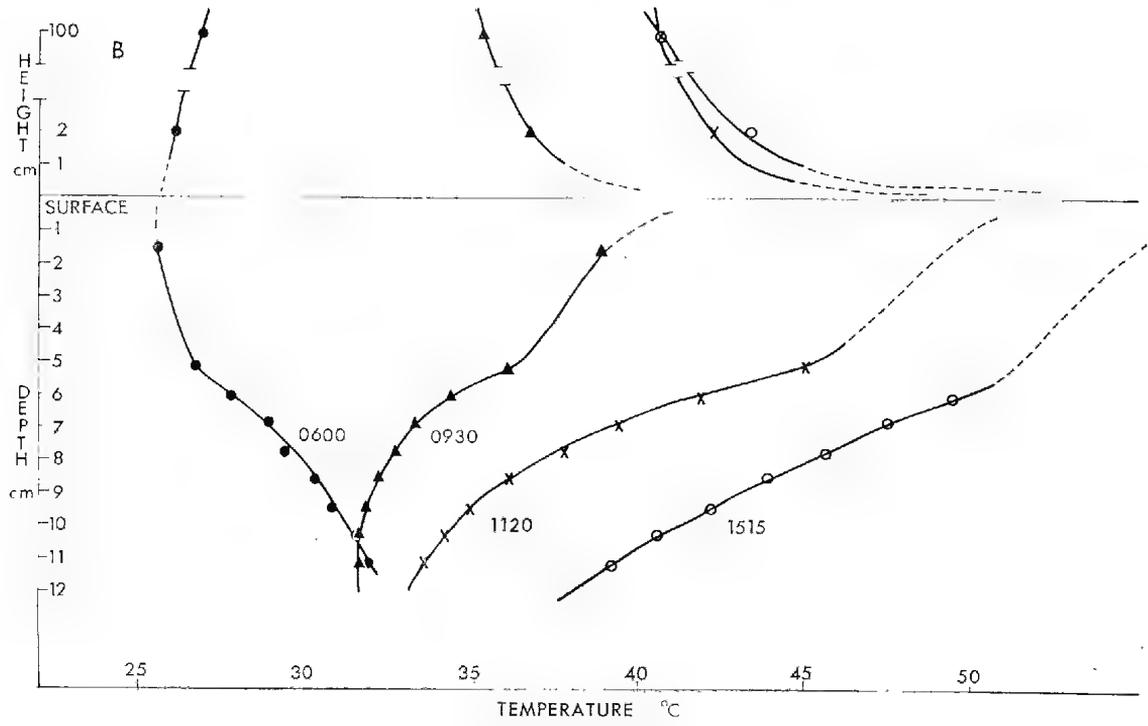
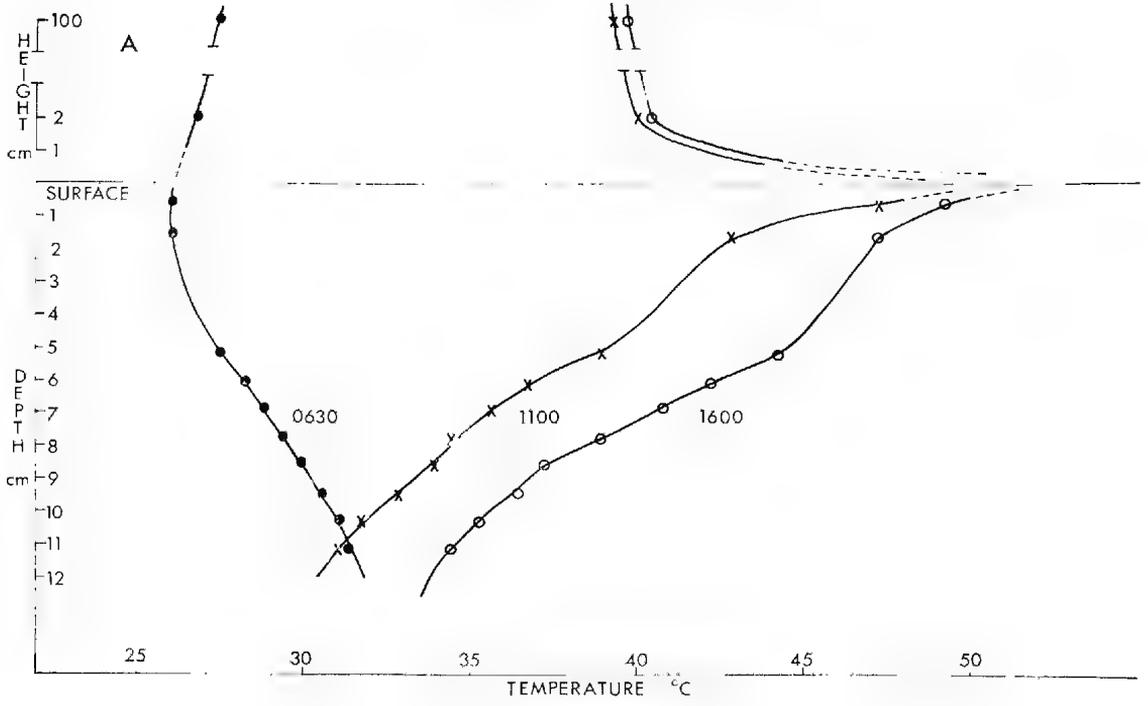


FIG. 3

captures have not been retrieved would suggest that the glare from the lake surface may confuse aerial predators.

### 7. Flooding of the Habitat

The periodic flooding, either of the whole of Lake Eyre or, following more localised rains, of restricted areas, must affect both *Melophorus* and *A. maculosus*.

*Melophorus* colonies withstand flooding for considerable periods by becoming sealed off below the water. As water disappears from the lake surface, the colonies soon "break out" and rework the galleries and nest. The shape of the above-surface mound would give protection to the opening of the nest during light flooding.

When the normal burrow zone is flooded, *A. maculosus* retreats to the shore line and lives, precariously, in the sand there. The lizards are frustrated in attempts to retire underground since there is no consolidated crust to provide leverage for burrowing, and they have no refuge from predators such as the Ground Goanna (*Varanus gouldii* Gray) against which they have adequate protection in their normal habitat. Among the lizards forced ashore by flooding, colour changes occur in which the background colour of the lizard becomes a deeper grey and the areas of black and rusty-brown pigmentation become more numerous and intense, giving a speckled appearance more similar to the pebbly beach sands. At times of flooding, large numbers of Silver Gulls (*Larus novae-hollandiae* Stephens) are attracted to the area and these probably constitute the greatest predation hazard for *A. maculosus*.

An interesting response to flooded conditions has been observed in *A. maculosus*. During winter at low ground temperatures (down to 16°C) the lizard is in torpor. In vivarium experiments at low ground temperatures (14–16°C), flooding of the substrate aroused lizards which had been below the surface in torpor for 3–4 weeks. Emergence to the surface involved a greater degree of muscular co-ordination than is usually shown at these temperatures and may be triggered by lack of oxygen. Inflation of the body when it emerges from underground ensures that the lizard floats on the surface of the water. It would appear possible that such a reaction would assist survival of the animal in face of encroaching floodwaters.

Localised areas of water in the lake show marked response to changes of direction and velocity of wind. A flooded inshore area may, within a few hours, appear as an exposed salt surface and vice versa. This must impose additional problems in the re-establishment of both *Melophorus* and *A. maculosus* in their preferred habitat.

### 8. Activity patterns and Thermoregulation

Like other ectothermic animals, the activity of *Amphibolurus maculosus* depends on temperature. The lizards show definite behavioural responses at certain temperatures and these responses serve to keep the body temperature within a preferred activity range. Throughout the season of lizard activity, variations occur in the means and ranges of these temperatures. These variations, imposed by the age and sex of the particular lizard and its position in the social structure of the population, are considered later. The basic range of temperatures associated with various activities, summarised in Table 1, is discussed here.

During the winter months (May to August), *A. maculosus* remains in torpor below ground. Emergence threshold air temperature is 19°C, at which temperature there is early season emergence (August–September), under stress of hunger and drive for the establishment of territory, in males. At this temperature only the head of the lizard is thrust through the salt crust. It is darkly pigmented in the pineal region and the eyelids are extended, indicating accumulation of blood in the cephalic sinuses. The morphology of venous shunts in the cephalic region, and their role in head-body temperature regulation, have been described for *Phrynosoma cornutum* by Heath (1964, 1966). Although the anatomy of the head of *A. maculosus* has not been examined, there is similarity in head-basking behaviour between this lizard and *Phrynosoma*, which is known to use this aid to rapid stimulation of the central nervous system and elevation of body temperature. It seems likely that *A. maculosus* uses a similar mechanism. The head-basking position is only maintained until the body temperature is raised to 22°C, at which temperature the body is fully exposed at the mouth of the burrow. It is at this temperature that most lizards first emerge for the season in September–October. During early basking stages the body of the lizard is orientated with the back exposed to the sun (or source of heat in the vivarium), and the body is inflated laterally and closely

pressed to the substrate, with the hind legs spread out flat behind the body in a "swimming" position.

Under laboratory conditions, with air temperature at 23°C, the adult lizards emerged, with eyes still closed, as soon as the lights came on. Within 10 minutes all were fully emerged and awake in the flattened basking position. Within 30 minutes rectal temperatures had risen to 30°C at an air temperature of 23.9°C.

During summer, mean burrow temperature (at about 10 cm depth) is 32°C. Under these conditions daily emergence occurs with first light, and temperature is no longer the controlling factor.

The basking position is maintained until body temperature reaches 26–27°C, when the lizards first start to move away from the burrow and are sufficiently co-ordinated to feed.

At a body temperature of 32°C, the lizards are capable of full range of movement and activity and, in hot weather, they move out onto the salt crust at this temperature. The ecriotic or preferred body temperature, was determined in the laboratory by use of a saw-tooth thermocline. Under laboratory condi-

tions the top temperature of the basking range is 37.5°C. At this temperature there is re-orientation of the lizard from the positive to negative with respect to heat source.

In the vivarium, the lizards can retreat under-ground at any time, whereas in the lake habitat, they must return from the wet salt surface to the burrow zone to retire under-ground. In the vivarium they retreat under-ground at a body temperature of 37–37.5°C, while in the field they remain active on the salt surface away from the burrow zone with body temperature held at about 39°C.

Except under very hot conditions, the lizards have a normal activity cycle of about 8 hours per day. This long period of scavenging is correlated with food supply and is necessary to ensure that they obtain sufficient food. In summer, during much of this time air and surface temperatures would be over 45°C. At these temperatures the body of the lizard is held high off the salt surface, the only points of contact with the hot surface being the feet and end of the tail. If stationary for any length of time, the toes of the hind feet are raised from the surface so that there is contact only with the limited area of the heel.

During thermoregulatory maintenance of body temperature at about 39°C, use is made of the diversity of substrate conditions provided by the buckled salt crust, of the small areas of shade cast by the ant nests and of the few small pieces of driftwood embedded in the salt surface which are used as elevated perches.

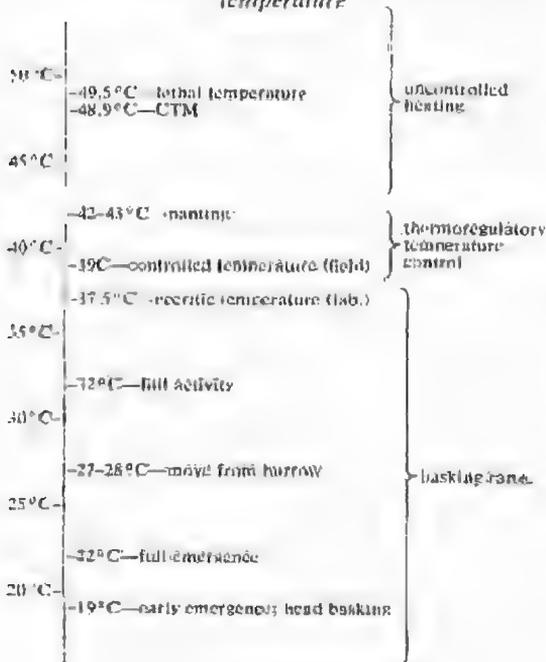
Since, during the hotter summer months, there is an established behavioural pattern of daily movement out from the burrow zone onto the "wet" salt crust as the temperature rises, it seems likely that the lizards achieve some thermoregulatory advantage in this area.

While measurements revealed no consistent decrease of temperature or humidity over the "wet" salt, this may simply reflect the technical difficulty of detecting small changes on the actual surface of the crust.

Slight pressure on the "wet" salt crust releases moisture to the surface, accompanied by a rapid, transitory fall in temperature due to evaporative cooling (particularly when a wind is blowing). The lizards, by scratching at the surface of the crust, may achieve this same cooling effect for parts of the body in contact with the surface. It is noticeable that

TABLE I

Activity of *A. maculosus* in relation to body temperature



during the hot months, which coincide with the defence of territory by the dominant males, the young males forced to spend considerable time out over the salt surface develop accumulations of salt on the digits of all limbs (Fig. 11). There may also be salt encrustation along the ventral surfaces of these lizards. This salt accumulation may be caused by the lizards scratching at the surface of the salt crust in attempts to benefit from any slight evaporative cooling effects.

When no longer able to control body temperature by adjusting position and stance, the lizard must retreat to the burrow zone and retire underground. In order to reach the cooler, wet sand layer near the water table, the lizard must first penetrate the loose sand below the salt crust. The upper layer of this loose sand may reach a temperature of 60°C. *A. maculosus* must have a short-term tolerance to this extreme temperature in order to benefit from the humid layer below.

If forced to remain active at higher temperatures, *A. maculosus* begins to "pant" at a body temperature of 42–42.5°C. In this action the mouth is opened wide (Fig. 10), and there is a steady rate of deep breathing at 60 breaths/minute. Unlike some other lizards (e.g. *Varanus* spp., *A. pictus*, *A. inermis*) there are no associated movements of the gular pouch during panting in *A. maculosus*.

Tolerance of temperatures above 42°C, at which thermoregulation begins to break down, are discussed below.

Preferred body temperatures and thermoregulatory behaviour of several other species of *Amphibolurus* have been described by Bartholomew & Tucker (1963), Bradshaw & Main (1968), Brattstrom (1971), Heatwole (1970), Lee & Radham (1963), Licht, Dawson, Shoemaker & Main (1966), and Pianka (1971 a, b).

### 9. Survival in the Preferred Habitat

The habitat preference of *Amphibolurus maculosus* is unique among vertebrate animals and many factors would appear to count against survival in such a harsh, extreme environment. There are obvious problems in maintaining water balance, arising from the hygroscopic salt surface on which the lizard

spends much of its time, compounded by lack of access to free water from which to supplement its supply, and the need to handle a higher than average sodium intake. (The ants, *Melophorus* sp., have a high salt content (Braysher 1972<sup>1</sup>) and many of the insects trapped on the lake surface have salty encrustation on their body and legs). The survival of an insectivorous animal in a vegetation free habitat, periodic flooding of the lake, high summer temperatures, and lack of cover from the sun, are all matters which require special physiological or behavioural adjustment.

However the lizard has the ability to exploit this habitat successfully. The low rate of reproduction (one to four eggs per female per annum) suggests that its biology is more than adequate to meet the environmental stresses. As with all desert-adapted animals, behavioural avoidance of environmental extremes (Schmidt-Nielsen 1964) has been shown to be a key factor in survival in this harsh environment, but the study also indicated that the environmental stresses encountered require considerable physiological adjustment to ensure survival. The wide scope of this study has only permitted superficial examination of these adaptive mechanisms, and more detailed studies have been undertaken by other workers.

#### *Tolerance to temperature and water stress*

Survival of *Amphibolurus maculosus* in the Lake Eyre habitat involves ability to withstand high temperatures and to cope with the lack of free water.

Preliminary experiments were carried out to determine some of the thermal criteria and rates of evaporative water loss. Although the results are based on very few readings, the data are presented here since they are the only records available for this species. Comparison is made with published data for two other species of *Amphibolurus*: *A. pictus* Peters and *A. inermis* (De Vis). Both of these species are widely distributed in desert areas and occur in the sand dune country adjacent to Lake Eyre. *A. inermis* is generally found in red sand and *A. pictus* shows preference for white sand. Comparisons between *A. maculosus*, *A. pictus* and *A. inermis* are summarised in Table 2.

<sup>1</sup> BRAYSHER, M. I. (1972).—Water and electrolyte balance in the agamid lizard *Amphibolurus maculosus* (Mitchell), and the structure and function of the nasal salt gland of the sleepy lizard, *Trachydosaurus rugosus* (Gray). Unpublished Ph.D. Thesis, University of Adelaide.

TABLE 2

Thermal criteria and rates of evaporative water loss for *A. maculosus*, *A. pictus* and *A. inermis*

	<i>A. maculosus</i>		<i>A. pictus</i>		<i>A. inermis</i>				
	Mitchell, present study	Mitchell, present study	Warburg (1965b)	Mitchell, present study	Warburg (1965b)	Licht, Dawson & Shoemaker (1966)	Bradshaw & Main (1968)	Heatwole (1970)	Bradshaw (1970)
Ecotic temperature	37.0°C								
CTM	48.9°C	46.5°C	45°C	48.5°C	46.5°C			46.5°C	
Lethal temperature	49.5°C							49.3°C	
Survival	390 min. at 45°C		240 min. at 42°C		480 min. at 44°C	103 min. at 46°C	62-6.48 min. at 46°C		
EWL	1.10 mg/g/hr at 37.5°C		1.58 mg/g/hr at 37.5°C		0.87 mg/g/hr at 37.5°C				1.05 ± 0.0913 mg/g/hr at 35°C

The critical thermal maximum (CTM), defined by Cowles & Bogert (1944) as that temperature at which a reptile loses muscular co-ordination, has been determined for a number of Australian lizards (Warburg 1965 b; Heatwole 1970).

Comparisons between these data are difficult to make because of differences in experimental procedures. Also, the usefulness of this thermal criterion has been criticised because some lizards, after losing muscular co-ordination and passing into a coma, are capable of recovery if held at that temperature or if the temperature is lowered. Other lizards do not recover after these muscular spasms and die quickly; or within a few hours.

The CTM for *A. maculosus* was determined using only 5 specimens. The test lizard was placed in a beaker in an oven maintained at 45°C. After 15 minutes the temperature was raised at the rate of 1°C every 5 minutes. The average CTM for *A. maculosus*, derived from these five test animals, is 48.9°C. Two of these (one male, one female) recovered fully when the temperature was lowered after the test. The temperature from which there has been no recovery after cessation of muscular spasms has been recognised as the lethal temperature for this species.

The survival times at high temperatures have been regarded by some authors as more meaningful criteria and these have been determined for several Australian agamid lizards (Warburg 1965 a, b; Licht, Dawson & Shoemaker 1966; Bradshaw & Main 1968).

For *A. maculosus*, a survival time of 6.5 hours at 45°C was recorded, and over this period an 8% loss of body weight occurred. Tests carried out at 42°C resulted in death between 22 and 25 hours following a loss of 6.8% of the body weight.

If death at this low level of body weight loss (cf. 34-48% loss at death for some

iguonids (Hall 1922)] were due to desiccation only, it would indicate a rather low tolerance to desiccation for *A. maculosus* and its dependence on retreat to the humid region above the salt water-table of the lake. Further evidence of low desiccation tolerance has been observed in the vivarium where deaths occurred when the artificial "water-table" was not maintained and sub-surface humidity level dropped.

Evaporative water losses have been determined for a number of Australian lizards (Warburg 1965 a,b, 1966; Dawson *et al.* 1966; Bradshaw 1970). Attempts to measure evaporative water losses of *A. maculosus* were carried out using test animals either fresh from the field or which had been acclimated to a 24 hour cycle involving the attainment of temperatures in excess of their maximum voluntary activity temperature. Animals were tested between 1000 and 1500 hours, their most active part of the day.

The five animals tested varied from 8 g to 14.5 g in weight (mean 10.5 g). Although the measured EWL rate for *A. maculosus* varied, probably in relation to the degree of activity of the test animal, the average value was 1.10 mg/g/hr (0.8-1.5 mg/g/hr). Of this total EWL, pulmonary losses contributed 0.83 mg/g/hr (0.52-1.15) and 0.27 mg/g/hr (0.42-0.29) was due to cutaneous loss.

Bradshaw (1970) has found significantly lower cutaneous and pulmonary water loss in the desert-adapted *A. inermis* than in other species of *Amphibolurus* from more temperate habitats. His results suggest that the improved water economy of the desert-living species is due both to reduction in the metabolic rate and to alterations in the integument.

In Table 3 comparison is made between cutaneous and pulmonary water loss in *A. maculosus* and *A. inermis*.

The low proportion of total EWL attributable to cutaneous loss in the present figures

for *A. maculosus* suggests that the integument may be further modified against evaporative losses.

More detailed work is required to accurately define the critical ambient and body temperatures, and rates and sites of evaporative loss, in *A. maculosus*. However, available data do

TABLE 3

Rates of cutaneous and pulmonary water loss in *A. maculosus* and *A. inermis*

	<i>A. maculosus</i>	<i>A. inermis</i>
n	5	6
bodyweight	10.5g	24.1±0.97g
total EWL	1.10 mg/g/hr	1.05±0.0913 mg/g/hr
cutaneous	0.27 mg/g/hr	0.45±0.0931 mg/g/hr
pulmonary	0.83 mg/g/hr	0.57±0.0778 mg/g/hr
C/P	0.33	0.80

suggest that its temperature tolerance is among the highest known for Australian lizards, and that evaporative water losses are among the lowest recorded.

In its natural habitat, *A. maculosus*, like other heliothermic reptiles, uses a series of behavioural postures and movements to maintain body temperature within a preferred activity range. This activity range of temperature is higher in the field than the ecritic or preferred temperature selected by the lizards in a laboratory temperature gradient. However, except under some conditions imposed by the social hierarchy, the lizards can avoid intolerable heat levels by retreat to the damp sand of the burrow zone. Subservient males, kept away from the burrow zone by the dominant males, are forced to spend long hours on the salt surface with a consequent high level of body heat. Survival under these conditions must indicate the existence of physiological capacities to withstand high temperature and to restrict water loss. High body temperature is tolerated passively and water is conserved by lack of evaporative cooling mechanisms.

#### 10. Establishment and Defence of Territory by the Male.

The early emergence, in late August, of dominant males of the previous season is usually preceded by these lizards positioning themselves just below the salt crust where they can more quickly respond to increasing temperatures. By mid-September the territories

established by these dominant males are under challenge by the younger males which have subsequently emerged. An old male challenged and displaced by a young male retreats underground for the remainder of the breeding season (September to late December). By mid-October the territorial situation has become fairly stable, and remains so throughout the breeding season.

Apart from the juveniles (snout-vent length <40 mm), three categories of male can be recognised in the dominance hierarchy.

- (1) *Dominant*: lizards which exhibit display behaviour and fight and never retreat from another male. These lizards develop marked breeding coloration with bright orange-yellow ventro-lateral markings grading to brilliant reddish-orange ventrally with a pale patch mid-ventrally. The reddish-orange markings extend onto the base of the tail and under the thighs.
- (2) *Sub-dominant*: lizards which exhibit display behaviour and which retreat instantly from a dominant male but will fight to a decision among themselves. Among these lizards a "peck order" is established despite their individual territories. These lizards also develop good breeding coloration.
- (3) *Subservient males*: lizards which do not exhibit display behaviour, and which retreat from all other males or roll over into submissive posture on their backs if attacked. Only very faint yellow ventro-lateral colours are developed by these lizards.

The territorial defence of the dominant males follows a classical pattern. Each territory is centred upon a look-out site, usually a small mound of salt 10–20 cm above the surrounding salt, or a piece of salt-encrusted driftwood embedded in the lake. The area of territories varies about an average of 15 m radius and is, in part, dependent on the virility of the controlling male. Orientation within their own territory and that adjacent to it is, at least partly, by sight and the boundary between the territory of two dominant males is known to those two males to an accuracy of a metre or so. The forcing of one male over the boundary immediately precipitates an approach and challenge from the adjacent male. This technique can be used to determine hierarchy patterns in the field in areas where territories of dominant males are adjacent. Male II will

flee if forced onto the territory of male I, but will fight (and win) against male I in his home territory.

The display behaviour of the dominant males involves a typical push-up movement in which the forelimbs are flexed and the whole of the forepart of the body moves. A short frog-like leap is followed by two quick push-ups. In challenging another male, the gular pouch is lowered and full threat display follows in which the body is raised high and compressed laterally so as to increase apparent size by enlarging the profile during a lateral confrontation (Fig. 12). This also displays fully the bright ventro-lateral markings. Usually the mouth is opened wide (Fig. 13). This display is usually adequate to deter intruders from entering the territory. When male to male fighting does occur an established pattern of events is observed. There is long-range recognition and challenge at distances of up to 14 m, then the commanding dominant closes the distance until a counter challenge is issued at a distance of about 3 m, after which the two males approach each other to a distance of about 0.5 m. There follows up to 10 minutes of bluff behaviour, side stepping, continual facing-up and counter-facing in an effort to get the tail into position to lash the opponent's head and forelimbs, and the head in a position where it is possible to bite the opponent's hind legs and back of the tail (Fig. 13). Head-on encounters also occur with the opponents' jaws becoming interlocked in tenacious biting.

In a eleven minute encounter, the longest observed, between males I and II in the hierarchy, three physical clashes occurred. The biting was directed at the hind limbs and each clash was over in an instant, the attacker being flung vertically by the momentum of the lunge and the evasive endeavour of the opponent.

There may be overlap in the territories established by the sub-dominant males. While the dominants remain "on guard" in their territory throughout most of the day, the sub-dominant males adjust their emergence times so that only one is active within the territory at one time.

Subservient males adjust their emergence times to periods when they are less likely to be pursued by the dominant males—in the heat of the day or late in the afternoon. Their level of tension in the presence of the dominant male is reflected in their respiration rate which may be as high as 120 breaths/minute as com-

pared with 35 breaths/minute for the dominant. They spend a very limited amount of time on the surface and then avoid recognition by flattening themselves, with head down, against the salt and remaining motionless for long periods. If challenged they immediately turn over onto their backs in submissive posture.

Once ground temperature exceeds the threshold the dominant males will emerge at about the same time ( $\pm 10$  minutes) each morning independent of light intensity or temperature. Heath (1962) records a similar temperature and light-independent emergence in *Phrynosoma*, suggesting the presence of endogenous circadian rhythm. During the breeding season this emergence time gets earlier by about 30 minutes each month. After the breeding season emergence becomes random and the dominant males generally spend more time underground. At this time there is an increase in activity of the subservient males which spend longer periods active on the surface of the lake. There is a lowering of tension between dominants and subservients (reflected in the fact that respiration rates are similar for both), and the subservients are less inclined to retreat underground or to remain "frozen" and thereby inconspicuous for long periods. Territoriality is not actively enforced after the end of December and, while the dominant male spends considerable periods underground, the subservient males embark on an active period of feeding which involves frequent excursions out over the lake in search of the ants which, at this time of year, constitute the main food item. In the absence of the dominants, the subservient males may establish territories between existing territorial areas.

The dominant males show a renewed burst of activity in early April, presumably feeding intensively before retiring underground. The dominant males and late developing females extend their activity period into May, whereas all others retire into torpor during about the third week of April.

The dominant males and the juveniles are the first to emerge and last to retire both daily and annually. Under vivarium conditions, with temperature maintained at 27°C for 12 months, the dominant males and juveniles remained active throughout the 12 months. The subservient and sub-dominant males and the females went into normal torpor despite the maintenance of temperature. These lizards emerged for 1-3 hours every 16-30 days. The

reason for these arousals from torpor is not known.

In the confined conditions of the vivarium, the dominance hierarchy of the "population" is established within about an hour. Hierarchical structure can be readily determined by observation of respiratory rates which range from 30 breaths/minute in the dominant male to 120 breaths/minute in the subservient males.

Carpenter *et al.* (1970) have described the display and aggression behaviour of three species of *Amphibolurus* (*A. barbatus*, *A. reticulatus inermis* and *A. muriceus*) and comment on the close similarity between the display patterns of these agamid lizards and the Iguanidae which have been more fully studied (Carpenter 1967). The display action patterns appear to be species-specific both in the Iguanidae and the Agamidae. The display patterns of *A. maculosus* have not been fully analysed but the same range of postural changes, involving head and forelimbs, described by Carpenter *et al.* (1970) have been observed. Brattström (1971) discusses the range of postures associated with social and thermoregulatory behaviour in *A. barbatus*.

### 11. Reproductive Behaviour

The adult females of *Amphibolurus maculosus* do not emerge until some weeks after the dominant males have established their territories. First to emerge at 21°–23°C in mid-September are the older females, followed, through to mid-October, by the younger females. The females establish burrows around the margin of the dominant male territories and do not, at this time, move far from the burrows. A small group of six to eight burrows, all within a metre or so of one another, usually indicates the presence of a female. At this time of year the burrows are frequently re-occupied and enlarged whereas later, in the hotter weather, a burrow is seldom used twice. During the first week or so after emergence the females are not ready for mating, and adopt two methods to repel the advances of a male. The first of these is circumduction. All females of reproductive size (>45 mm) circumduct with either forelimb in the presence of a male, and the rate of circumduction is accelerated if they are approached by the male or come into competition with the male for food (Fig. 14). Secondly, should circumduction fail as a deterrent, the female twists over on her back and lies immobile. Both these manoeuvres serve to distract the male by des-

troying the "female image" to which he has responded.

Most mating activity, and much of the territorial fighting, takes place at 34°–36°C, several degrees below the temperature (39°C) at which the body is maintained by thermoregulatory behaviour. Consequently during the mating season (October to December) greatest activity occurs between 0900 and 1100 hours. While feeding and territorial defence take place at 39°C, preoccupation with thermoregulation prevents sexual activity.

The male approach to the female usually begins with the male elevating his head to maximum height in order to confirm identification of sex. He then undertakes a series of energetic head-bobs, followed by one or two "frog-leaps" during his rapid approach to the female. A receptive female turns slowly from the oncoming male and waits to be overtaken. The male approaches the female directly from behind and with his jaws grasps her by a fold of skin just behind the occipital region. Using this nape grasp, the male rolls the female over on her side. With the tail of the male under the tail of the female, the cloacae lie close together and a hemipenis is inserted. The pair remain rolled on their sides for the duration of copulation (about 25 seconds) with the body of the female arched back with forelimbs clear of the ground (Fig. 15).

Following copulation, the female usually lies in a subservient position, with the head flat on the salt, for 15–20 seconds before moving. During this time the male "frog-leaps" away. Females undertake weak head-nodding during the breeding season, involving a simple dip and rise of the head. The exact purpose of this is unknown but, in view of the cryptic coloration, it may possibly serve to make known their presence to other lizards.

Following ovulation and fertilization, a number of changes occur in the appearance and behaviour of the females. In a fertilized female, ventro-lateral coloration changes from pearly-white to a bright orange-red, the edges of the lower jaw become orange, and there develop two orange patches between the forelimbs and two elongate orange patches along the flanks. Also circumduction ceases, and more efficient defensive behaviour is adopted. Upon the approach of a male, confrontation takes place with the female raising the head as high as possible and swivelling it around to prevent the male from getting over or past

her. If this fails, or if the male's approach is so rapid that this bluff is unlikely to succeed, the female rolls over onto her back, frequently well before the male makes physical contact with her (Fig. 16). Distracted by the changed image the male usually withdraws several feet, with some head-bobbing. After 15-20 seconds the female rights herself, inflates the gular pouch and stomach, and compresses the body to display the orange ventro-lateral surfaces and so present the largest possible profile to the male. The female then adopts a stiff-legged attitude which lifts the body clear of the substrate and with slow, deliberate steps advances straight towards the male. She usually passes close in front of him, often forcing him to withdraw a few steps or to transfer his body back on to the hind limbs, lifting the front part of the body to allow the female to pass close under his snout. After passing the male, the female continues to walk with the stiff-legged gait, stopping on each rise in the salt crust to look back at the male over her shoulder. When about 6 m away, her pace quickens and finally she relaxes and runs at high speed over the salt to disappear behind a fold of the salt crust.

In contrast to their timidity early in the season, females, once fertilized, become quite aggressive and will attack a male should he compete for food at close quarters. While carrying developing eggs the female emerges at the same time as the dominant males and spends maximum possible time in basking postures. Perhaps the orange ventro-lateral coloration of the female at this time increases heat absorption from the substrate. Ventral colour change in the gravid female has been reported in the American lizard *Crotaphytus collaris* by Fitch (1956) and in *Callisaurus*, *Crotosaurus* and *Holbrookia* by Clarke (1965).

Eggs are laid 20-25 days after fertilization. The female digs a distinctive burrow for egg-laying. Normally these lizards merely nose their way under the salt crust and "swim" at a shallow angle through the fine, dry drift sand, down to the damp consolidated substratum. The egg-laying female carefully selects a site, usually along the shore-line, of consolidated sand damp right to the surface. This egg-laying burrow is steeply angled (about 45°), extending down 21-25 cm, with a distinct chamber at the bottom in which the eggs are deposited. Young females lay only 2 eggs while older females produce 3 or 4. After deposition of

the eggs the entrance to the burrow is filled in again. Observations, both in the field and in the laboratory, suggest that each female digs and fills several egg-laying burrows before she finally deposits the eggs. Whether abandonment of these early burrows is due to disturbance or whether there is careful selection of some particular set of conditions, is not known. The salt content of the shore-line sand is 4-5% and this, apparently, does not impede development of the eggs. Attempts to hatch eggs under laboratory conditions indicate that maintenance of fairly high humidity during egg development is important. Females frequently emerge from egg-laying in poor condition and highly desiccated (Fig. 17). The ventro-lateral colouring fades from orange to yellow to white after deposition of the eggs.

Hatching occurs after about 70 days and the hatchlings (SV length 25-30 mm) first appear in January and continue to emerge until April.

## 12. Sex Recognition

In most animals showing marked sexual dichromatism it is the male which is more brightly coloured or strongly marked. On this basis it was accepted, in early stages of this study, that large specimens of *Amphibolurus maculosus* with bright yellow-orange-red ventro-lateral surfaces were male and that this brilliant colouring was a key factor in the signal pattern of male to male sex recognition in territorial behaviour. The sex of tagged lizards was recorded on this basis of presence or absence of ventrolateral coloration.

Recapture of marked specimens revealed two stages of development at which colour changes confused this simple interpretation. Firstly, there is the change from pseudo-female to male colour and behaviour at the time the male reaches the size of an adult female. In some cases, specimens showing weak male coloration were observed to show the usual female responses of circumduction and tonic immobility. On dissection, lizards of this group (all within 43-58 mm SV length), proved to be male. Recapture records revealed that, up to 58 mm SV length, the first-year males of *A. maculosus* show the yellowish ventro-lateral markings typical of the female after egg-laying. Lizards of this size (up to adult female size) and coloration are repeatedly identified as female by the dominant males and are driven out to the margins of the colony by the repeated unwanted advances of the males. This

suggests a possible dispersal mechanism within the population.

Secondly, some lizards which had been initially recorded as female, on subsequent recapture showed brilliant ventro-lateral coloration. Allied with change of colour, there was a change in behaviour with these lizards now counter-challenging an approaching male. This change from nearly-white female to brilliant orange pseudo-male coloration and the change in defensive behaviour and aggression following ovulation and fertilization have been described previously.

While sexual dichromatism exists, observations suggest that coloration has little if anything to do with sex recognition in *A. maculosus*. The female undergoes considerable change in intensity of coloration from complete lack of ventro-lateral coloration through pale yellow to brilliant orange after mating, but is pursued by the dominant males at all stages in the development of this colour pattern.

A first-year male, on the other hand, may show typical male colouring, with prominent rusty spots on the shoulders and weak gular pouch stripe and yet be repeatedly mistaken for a female. Thus, first-year males, whether they have developed male coloration or not, are recognised as female within the first-year female size range of 46–58 mm.

In an effort to determine the role played by colour in sex recognition, and to determine what colour pattern might act as an innate releasing mechanism in territorial display, dominant males in the vivarium were presented with a range of coloured models, simulating male coloration. None of these elicited any response other than an investigatory lick.

The above observations suggest size to be the basic factor involved in sex recognition and suggest that size judgement is particularly good.

In relation to elevation (most look-out sites in the habitat of the lizards are no more than 20 cm above the lake surface), *A. maculosus* shows remarkably acute vision. Observations of territorial challenges in the field have indicated that these lizards have perception of movement and recognition of posturing at distances of 50 metres.

Both laboratory and field observations indicate that there is some individual recognition between members of the line hierarchy established in the vivarium and between males of adjoining territories in the field population.

TABLE 4  
*Relationship of size to age in Amphibolurus maculosus*

	Mean SV length of <i>A. maculosus</i> (mm)	
	Female	Male
1st year	48	54
2nd year	59	64
3rd year	61	67
4th year	62	70

This significance of size and accuracy of size perception would also be a key factor in the effectiveness of the bluff behaviour. Unless the lizards had such an appreciation of size and its significance, the act of increasing the area to view by enlarging the lateral profile would not be effective as a bluff deterrent.

### 13. Growth Rate and Reproductive Cycle

Over the period of study, 376 body measurements (SV length and tail length) were recorded for marked and unmarked specimens.

Based on field recapture of marked specimens and vivarium specimens for which age histories were known, mean SV lengths of *Amphibolurus maculosus* in relation to age are shown in Table 4. The figures represent the mean maximum measurement recorded at the end of the active season for each year. Mean SV length of hatchlings is 30 mm. It seems likely that *A. maculosus* dies at the end of the third breeding season, at 3–3½ years. No older specimens have been recovered among the marked population at Lake Eyre.

When adult males emerge at the beginning of the season in September, the testes are fully expanded (9 x 5 mm). Smear tests show active spermatogenesis from September through to mid-December and active sperm have been found in the vas deferens in October, November and December. In late December there is a rapid contraction in size of the testes to 6 x 3 mm. No active sperm have been found in testes or epididymes from January to April. This decline in male fertility coincides with the onset of the period of reduced activity in the males. Between late December and early March the older males spend only short periods on the lake surface and longer periods underground. At this time, young males move back into the territorial area, subservient males emerge for longer periods and they and the females, exhausted after egg-laying, embark on long hours of feeding. There is little territorial defence, the dominant males only weakly

TABLE 5  
Summary of reproductive cycles in *Amphibolurus maculosus*

	Dominant Male	First yr. male	First yr. female (A)	First yr. female (B)	Adult Female
January	Inactive	} Active feeding	} Hatching	} Ovulation	} Active feeding
February	Inactive				
March	Active feeding	} Hatching	}	} Egg laying	}
April	Active feeding. Testes and fat bodies expand				
May	} Hibernation	} Hibernation	} Hibernation	} Hibernation	} Hibernation
June					
July					
August	First emergence	} Identified as female. Retreats to edge of territorial area.	}	}	} Ovulation
September	Establishment of territory. Spermatogenesis				
October	Spermatogenesis. Mating with adult females	} Returns to territorial area	} Ovulation	} Mating	} Colour change to pseudo-male
November	Spermatogenesis. Mating with adult females.				
December	Spermatogenesis. Mating with 1st year females. Contraction of testes		} Mating	} Egg-laying	

defending (with a slight lowering of the gular pouch) a small area immediately around their burrow site.

The older males show a more active feeding period through mid-March and April. During this time the testes, together with abdominal fat bodies, expand rapidly prior to the onset of hibernation.

Information from recapture of tagged specimens, as well as laboratory observations, indicates that among the first-year females of the population there is a bimodal pattern of ovulation.

Females hatched during January-February ovulate in November-December. A second series of females, hatching late in April, ovulate in February. Both these groups of females show maturity (as evidenced by ovulation) at 10 months. Of these 10 months, at least 4 winter months (May, June, July and August) are spent in torpor. In the earlier part of the active breeding period (October to December) the dominant males mate with the adult females. Towards the end of the breeding period the 1st-year females, down to 46 mm SV lengths, are successfully mated by the dominant males.

Sperm retention in the female is indicated by the decline of male fertility in December and

the fact that ovulation in the late-hatched females, which had been mated in December, does not occur until February. In March these females lay eggs which hatch in April.

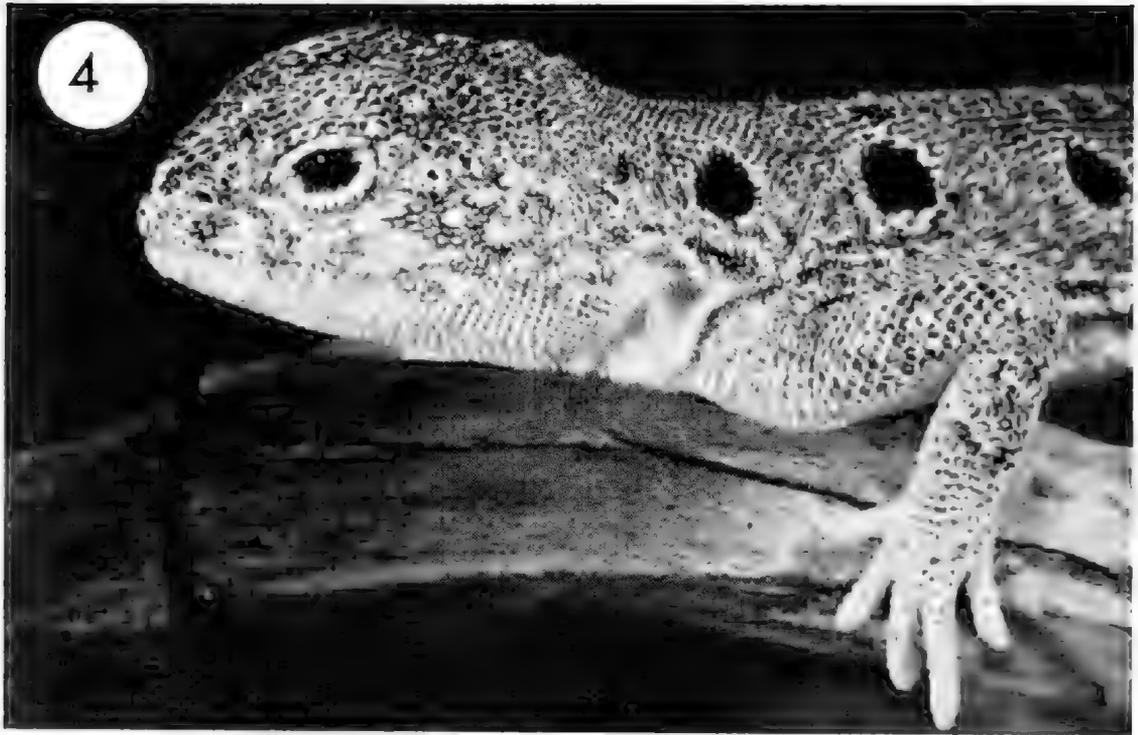
The males hatched in January and February are sub-adult (with female coloration and behaviour) in November-December. Table 5 summarises male and female reproductive cycles of *A. maculosus*.

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## CAPTIONS TO FIGURES 4-17

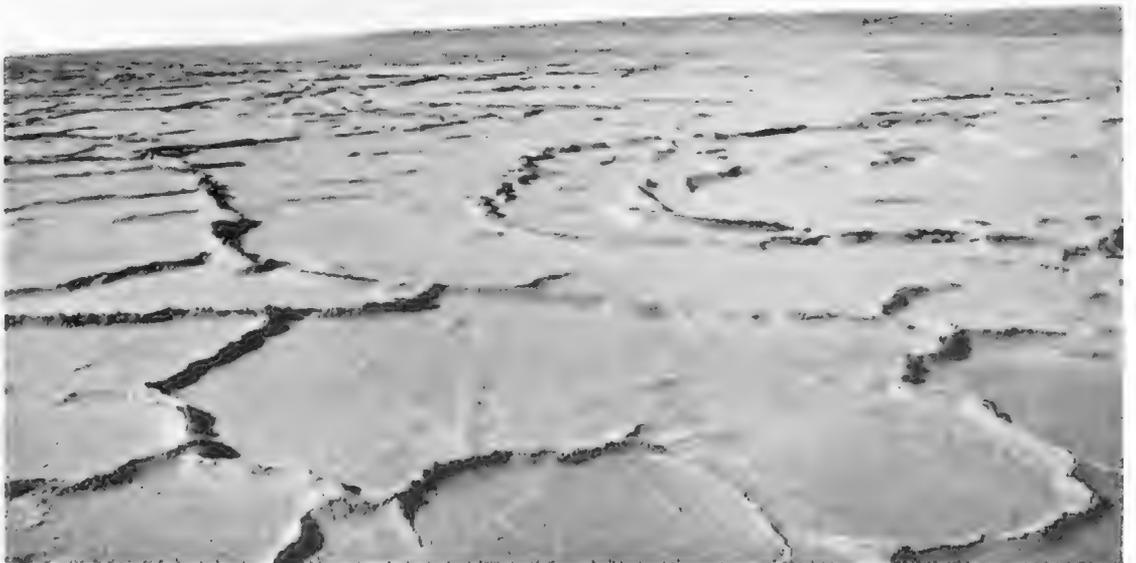
- Fig. 4. *Amphibolurus maculosus*, showing detail of the head with deeply sunken eye, visor-like eyelid, and absence of visible tympanic membrane.
- Fig. 5. Margin of Lake Eyre, looking north towards Prescott Point at the tip of Sulphur Peninsula. Instruments recording continuous air and sub-surface temperatures are set up in the burrow zone area. The beach is backed by low white sand dunes and to the left the thin distorted crust of the burrow zone merges into the thicker, smoother salt crust of the "wet" salt zone.
- Fig. 6. View back along the causeway towards Prescott Point (October, 1966). Quadrats were set up along this causeway and movements of tagged lizards were recorded in the area over several years.
- Fig. 7. Buckled surface of salt crust on Lake Eyre. View towards Prescott Point.
- Fig. 8. Nests of the ant, *Melophorus* sp., are regularly spaced through the "wet" salt zone. The above-surface mounds of these nests are visible here as dark spots (from their shadows) in contrast to the white salt surface.
- Fig. 9. *A. maculosus* male against the disturbed base of *Melophorus* nest-mound. These mounds are used for basking and shelter and as vantage points by the lizards.
- Fig. 10. *A. maculosus*, overheated by pursuit, showing panting reaction typical at raised body temperatures. Note deep "lens-hood" protection for the eyes.
- Fig. 11. Salt clods on digits of a forelimb.
- Fig. 12. Dominant male in full threat display. Body raised and laterally compressed, gular pouch and stomach inflated.
- Fig. 13. Dominant males fighting. Specimen in background shows compressed and raised body, gular pouch lowered, and mouth open for biting. The tails are brought into play to whiplash the head and forelimbs of the opponent. (Dark areas at base of tail are identification marks.)
- Fig. 14. Circumduction by *A. maculosus* female.
- Fig. 15. *A. maculosus* in copulation. The male biting and holding the female by skin fold behind the head.
- Fig. 16. *A. maculosus* female (left) showing post-fertilization colour development on lower jaw (the under abdomen is also bright orange) and the typical defensive position relative to the male on the right.
- Fig. 17. Female, after egg-laying, showing lateral skin flaps under conditions of starvation and dehydration.



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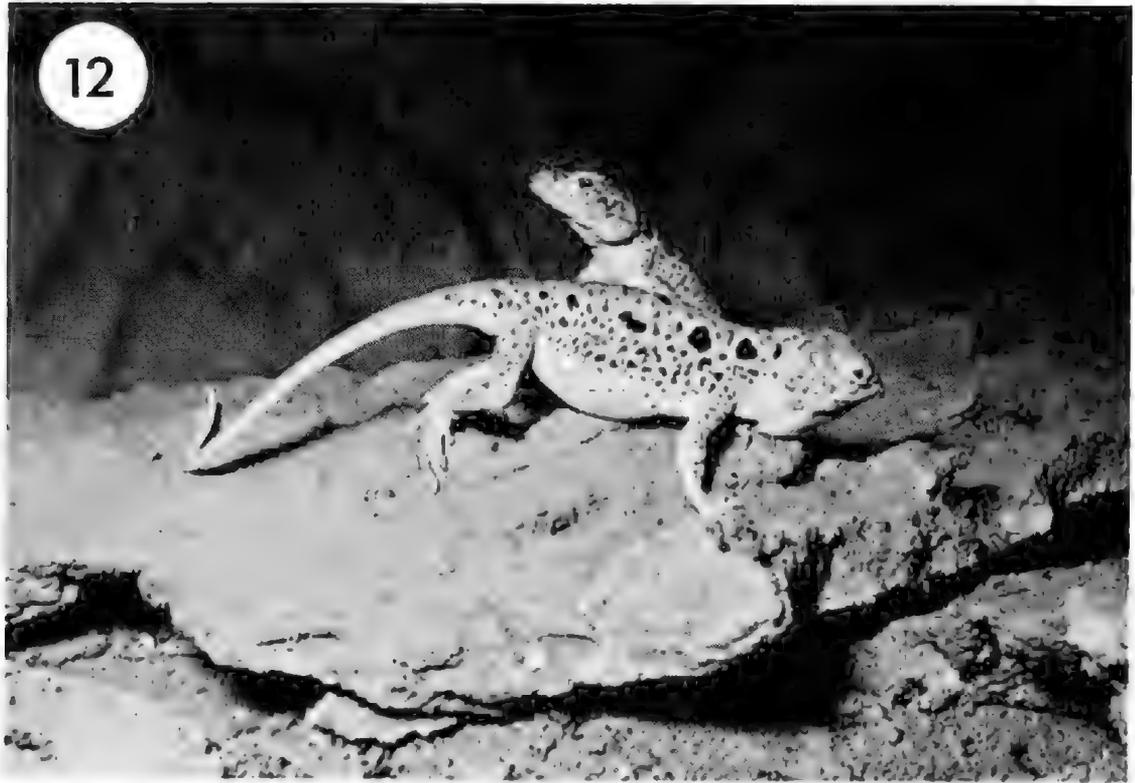


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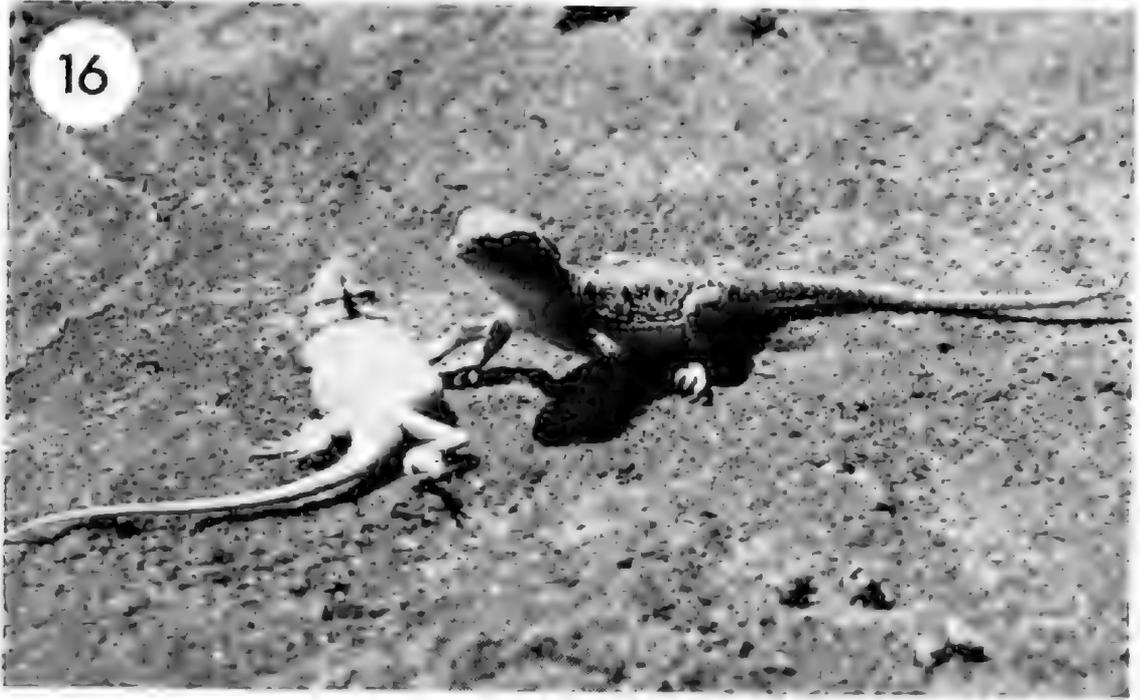












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# A NOTE ON MAJOR STRUCTURES IN THE WILLYAMA COMPLEX

BY R. W. R. RUTLAND\*

## Summary

RUTLAND, R. W. R. (1973).- A note on major structures in the Willyama Complex. *Trans. R. SOC. S. Aust.* 97(2), 77-90, 31 May, 1973.

The schistosity in the transect studied forms divergent fans about the axial planes of one major, upright, open synform which covers the greater part of the area, and a complementary antiform in the east. This suggests a genetic relationship between the schistosity and the major structure although the schistosity is not strictly congruous to the synform, since bedding tends to show a dextral relation to schistosity in both limbs.

Minor folds with approximately axial plane schistosity (Group One folds), lineations, and schistosity-layering intersections do not show a simple relation to the major folds but exhibit a wide variation in plunge in a NNE trending zone corresponding to the dominant attitude of the schistosity. Group One folds tend to have northerly plunges in the east of the area in the hinge and east limb of the Mt. Vulcan Antiform, and south-easterly plunges in the west of the area in the west limb of the Parnell Synform. The intervening shared limb of the two structures shows variable plunges from moderate northerly in the east through reclined to southerly. The schistosity-layering intersections show a much wider variation in any one sub-area than the Group One folds. Group Two folds which fold the schistosity show a closer correlation with the schistosity-layering intersection which may therefore control their orientation.

The complexity of this pattern is apparently related to an important earlier major deformation episode, which produced major isoclinal folds. Schistosity sub-parallel to layering in the limbs of the major structures may belong to this earlier episode.

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The complexity of this pattern is apparently related to an important earlier major deformation episode which produced major isoclinal folds. Schistosity sub-parallel to layering in the limbs of the major structures may belong to this earlier episode.

### Introduction

Early work on the major structure of the Broken Hill District is summarised in Andrews (1922) and King & Thomson (1953). The mining companies in the district have also carried out much regional mapping, some of which is incorporated in the new map (1971) of the New South Wales Geological Survey.

The published regional syntheses referred to above are based on mapping carried out before the development of modern methods of structural analysis. They also tended to rely on the dubious assumption that certain distinctive lithologies (especially amphibolites and garnetiferous gneisses) could be treated as stratigraphic marker bands. It is unlikely, in fact, that rocks of probable igneous parentage such as amphibolites were always stratigraphically conformable, or that genuine meta-sedimentary or meta-volcanic units were originally persistent layers. The possibility of transposition of

layering during the complex deformation history must also be recognised. Extrapolation of rock units through the large areas of poor exposure is therefore hazardous.

Nevertheless, certain broad regional differences in rock type and in metamorphic grade are well known, and the significance of these has been discussed recently by Vernon (1969) and by Hobbs *et al.* (1968). The review by the latter authors offers no discussion of the regional structure although they make some general comments in their discussion of the structural history of the orebody.

Hobbs (1966) and Hobbs *et al.* (1968) distinguish between Group One folds which have "the widespread schistosity of the area as the axial plane schistosity and a lineation defined by needles of sillimanite parallel to the fold axes" and Group Two folds which "deform the older axial plane schistosity and often fold the sillimanite lineation". Hobbs *et al.* also state

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that "Throughout the entire Broken Hill region these (Group One) fold axes and the associated lineation are observed to plunge fairly consistently towards the SW at low angles". On the basis of these statements, it should be possible by making a study of schistosity-layering relationships to establish the broad Group One structure of the region relatively quickly, and the present study was made to test this possibility. It was recognised, however, that there might be more than one period of schistosity formation in the region and that Group One folds in one locality might be of the same age as Group Two folds in another. It was decided therefore to try to provide continuity of data on the style and complexity of deformation for a transect right across the region. It was thought that this would permit structural and metamorphic correlations to be attempted and would serve to indicate productive lines of further research. The method used would not be very useful if transposition were of great importance so that bedding and schistosity were often parallel and facing variable.

The transect chosen for study (Figs. 1 and 2) lies between Mt. Franks and The Sisters and thus runs from lower grade, amphibolite facies, rocks in the West to granulite facies rocks in the east (Binns 1964). In this transect there is relative continuity of outcrop. The transect was divided into sub-areas which were studied by Honours students working in pairs under the writer's supervision. Study was concentrated on the metasediments and in particular on schistosity-layering relationships.

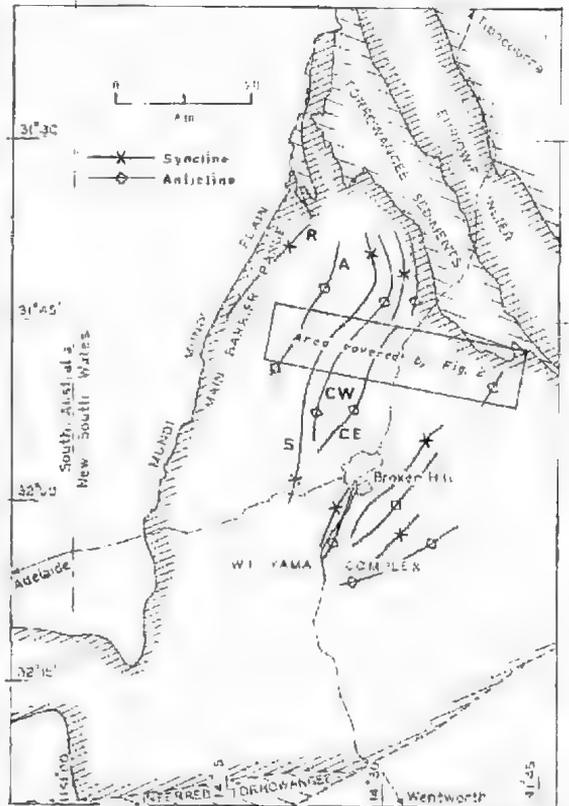
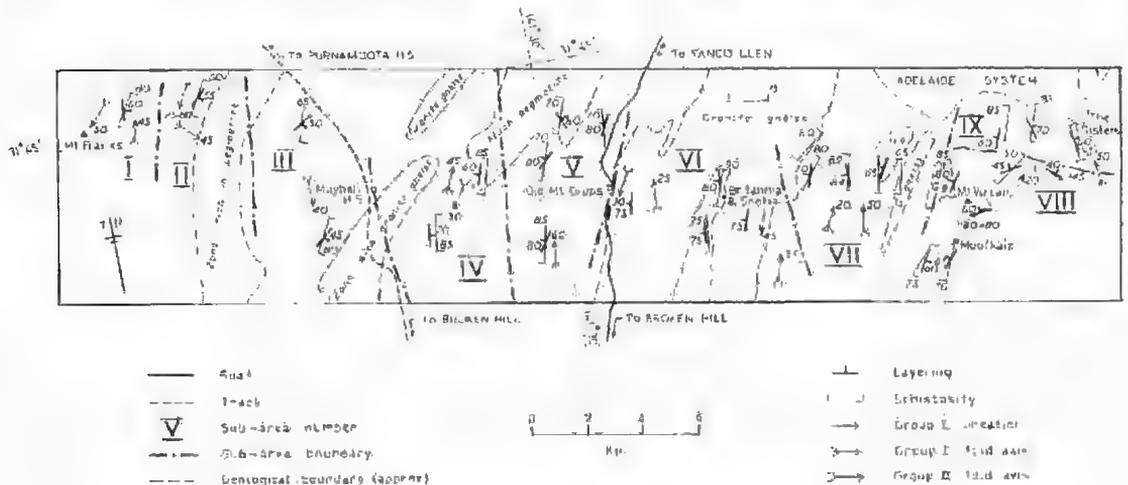


Fig. 1. Locality map to show the area of the transect studied (Fig. 2). The approximate axial traces of folds postulated by King & Thomson (1953) are shown. R - Mt. Robe Syncline; A = Apollyon Anticline; S = Stirling Vale Syncline; CW and CE - Corruca West and Corruca East Anticlines.



Structural Elements of a Transect of Broken Hill Region between Mount Franks and The Sisters

Fig. 2. Structural elements of the transect. The elements shown are representative attitudes based on the data collected in each sub-area (Fig. 3).

Schistosity-layering intersections were measured or calculated at numerous localities and can be compared with independent measurements of Group One and Group Two fold axes and lineations. The work was of a reconnaissance nature only but it has produced interesting new results which have provided the background for the further work now in progress.

### Structural elements

It is believed that most of the layering measured in the meta-sediments corresponds to original bedding ( $S_1$ ). This is clear when the lithological variation is considerable and when the layering lies at a significant angle to the schistosity. Often, however, the layering and schistosity are virtually parallel and some transposition may have occurred.

Metamorphically produced layering is usually characterised by a regular alternation of two, and only two, distinct lithologies. Commonly, for example, thin mica- or amphibole-rich laminae are separated by thicker quartzofeldspathic laminae. Such a metamorphic layering was rarely observed in the meta-sediments and then was parallel to the main schistosity. The main area of Granite Gneiss east and west of Britannia and Scotia is also characterised by such a layering and locally this layering has become involved in Group One as well as Group Two folds. It is not strictly parallel to the main schistosity and thus appears to provide evidence for a metamorphic deformation episode earlier than the main schistosity of the area. It is proposed to make a separate special study of the granitic gneisses in the transect studied.

Schistosity has a remarkably similar attitude over the whole region. Schistosity layering intersections often do not correspond with Group One fold axes or lineations however, and it seems probable that the deformation responsible for the present schistosity attitude was superimposed on earlier deformations. Locally therefore the main schistosity ( $S_1$ ) may represent a but little modified earlier schistosity. Folds of a later episode which are generally of Group Two style also locally develop a new axial plane schistosity ( $S_2$ ) of similar attitude. Thus the schistosity of the region although of fairly constant attitude may be the composite result of at least three deformation episodes. (There is also a fourth schistosity developed in the retrograde schist zones.)

Folds can be classified into three geometrical types according to their relation to the local schistosity. Group 1 and Group 2 folds are as defined by Hobbs (1966) except that it is not implied, as required by the definition of Hobbs *et al.* (1969) that mineral lineations are parallel to Group One fold axes and indeed this is often not the case (Rutland 1969, Anderson 1971). Folds earlier than Group One can scarcely be recognised if the Group One schistosity is parallel to their axial planes but where the schistosity has been superposed across their axial planes, they can be distinguished as Group Nought folds.

In any one locality the age relations of the three groups of folds are clear but determination of age relationships over a larger area depends on the correct identification of the associated schistosity. If most Group One folds are related to a single deformation episode ( $D_1$ ) responsible for the main schistosity ( $S_1$ ) there may nevertheless be earlier Group One folds ( $D_n$ ) where an earlier schistosity ( $S_n$ ) has been preserved and later Group One folds ( $D_2$ ) where a new schistosity ( $S_2$ ) has locally obliterated the main schistosity.

### Major structures

The structure of the transect studied is dominated by a major Group One synform, here called the Parnell Synform (Fig. 2) since it appears to correspond with a fold recognised on different grounds, and named the Parnell Syncline by Cordwell (unpublished map for New Consolidated Goldfields, 1962). The axial trace lies between the Corruga West and Corruga East anticlines of King & Thomson (1953). In the east the hinge of a Group One antiform complementary to the Parnell Synform has been recognised and is here called the Mt. Vulcan Antiform. According to Cordwell it represents the northern end of his Darling Range anticline (the Darling Range Basin of Andrews (1922)).

In the west the transect has been extended only as far as Mt. Franks. North and west of Mt. Franks, Anderson (1971) has mapped a major structure, the Mt. Robe synform which folds the only schistosity recognised in the area. However, no clear evidence has been found for a major antiform between the west limb of the Parnell Synform and the east limb of the Mt. Robe synform although King & Thomson (1953) show an anticline in this region (Fig. 1), the Apollyon anticline, which they describe (p. 550) only as a "broad ill-

defined anticlinal structure". Elucidation of the relationship between the Parnell and Mt. Robe synforms, which may be a faulted relationship, must await the further work which is now planned. In the most westerly sub-area mapped the layering generally dips east across a steeper schistosity and thus it appears to correspond to the west limb of the Parnell synform.

In Fig. 4 the angles of dip of layering and schistosity of individual localities are related to each other. It emerges that in the region between the axial traces of the Mt. Vulcan and Parnell folds, both schistosity and layering tend to dip west, but the schistosity is steeper than the layering (Fig. 4b). Across the hinge zone of the Parnell synform both schistosity and layering change attitude so that in the west limb the schistosity dips easterly more steeply than the layering (Fig. 4c). Similar changes take place across the hinge zone of the Mt. Vulcan antiform (Fig. 4a). The schistosity is therefore not strictly axial plane but is a generally congruous divergent type in both antiforms and synforms. It is therefore clear that this schistosity (defined as  $S_1$ ) was generated during the formation of the Parnell Synform and Mt. Vulcan Antiform.

It should be noted, however, that the observations plotted in Fig. 4 are biased in favour of localities where a clear difference in attitude between layering and schistosity was observed. In many localities, especially in the east limb of the Parnell Synform and in sub-area II of the west limb, layering and schistosity are nearly parallel. The Parnell Synform, however, is a relatively open structure so that these relations are perhaps not fully explained by the divergence of the  $S_1$  schistosity. This work therefore suggests the possibility that the schistosity parallel or nearly parallel to layering may represent a but little modified earlier schistosity ( $S_0$ ) corresponding to an earlier deformation episode<sup>1</sup>.

Analyses of the structure of the Broken Hill region have suggested the presence of various other major folds in the limbs of the Parnell Synform. Some congruous subsidiary folding has been recognised on the limbs of the Synform but in general, if major folds such as the postulated Corruga East and West anticlines exist in this transect (Fig. 1), the schistosity layering relationships suggest that they must be of an earlier generation (i.e.  $D_0$ ) than the

Group One Parnell Synform ( $D_1$ ) and its associated  $S_1$  schistosity.

For the purpose of further description the transect has been divided into four units, viz:

- (1) The Sisters-Mt. Vulcan area: the Mt. Vulcan Antiform
- (2) The Maybell area: The Parnell Synform
- (3) The Springs-Old Mt. Gipps area
- (4) The Mt. Franks area.

(1) *The Sisters-Mt. Vulcan area: the Mt. Vulcan Antiform*

This area is occupied by a group of fairly uniform quartz-feldspathic semi-schists, poor in mica. Neither layering nor schistosity is well developed so that collection of structural data is difficult. Amphibolite bands occur locally and appear to be roughly conformable and the group has been intruded prior to the development of the main schistosity by a roughly concordant body of coarse granitic gneiss with large feldspars.

The main antiformal hinge zone has been recognised in the area WNW of the Sisters in a km wide belt close to the Torrowangee unconformity (Sub-area IV, Fig. 2, and Fig. 5). The antiform here is clearly a Group One structure with nearly vertical schistosity of similar strike on both sides of the axial trace. The diagram (Fig. 3, sub-area IX) of poles to the layering indicates a northerly plunge of about 40° in general agreement with the trend of minor Group One folds. The main schistosity of this Group One antiform will be defined as  $S_1$  and the age of the schistosity in other localities will be discussed with reference to it.

The Sisters Synform which is clearly outlined by the Quartz-magnetite rock member (see Figs. 2 and 12, King & Thomson 1953) may be a complementary synform to the Mt. Vulcan Antiform or, more probably, an earlier isoclinal fold on which the  $S_1$  schistosity has been superposed. The schistosity in the western limb of The Sisters fold appears to be appropriate for a congruous axial plane schistosity but the near vertical schistosity does not change in attitude across the hinge of the fold, and thus crosses both limbs (which both dip east) in the same sense. A complicating factor is that the schistosity must have undergone some modification during the deformation which produced the parallel cleavage in the overlying Torrowangee, but it does seem likely

<sup>1</sup> A clear case for two episodes of high-grade schistosity formation based on superposition has now been established from subsequent work in adjacent areas (Rutland *et al.*, in preparation).

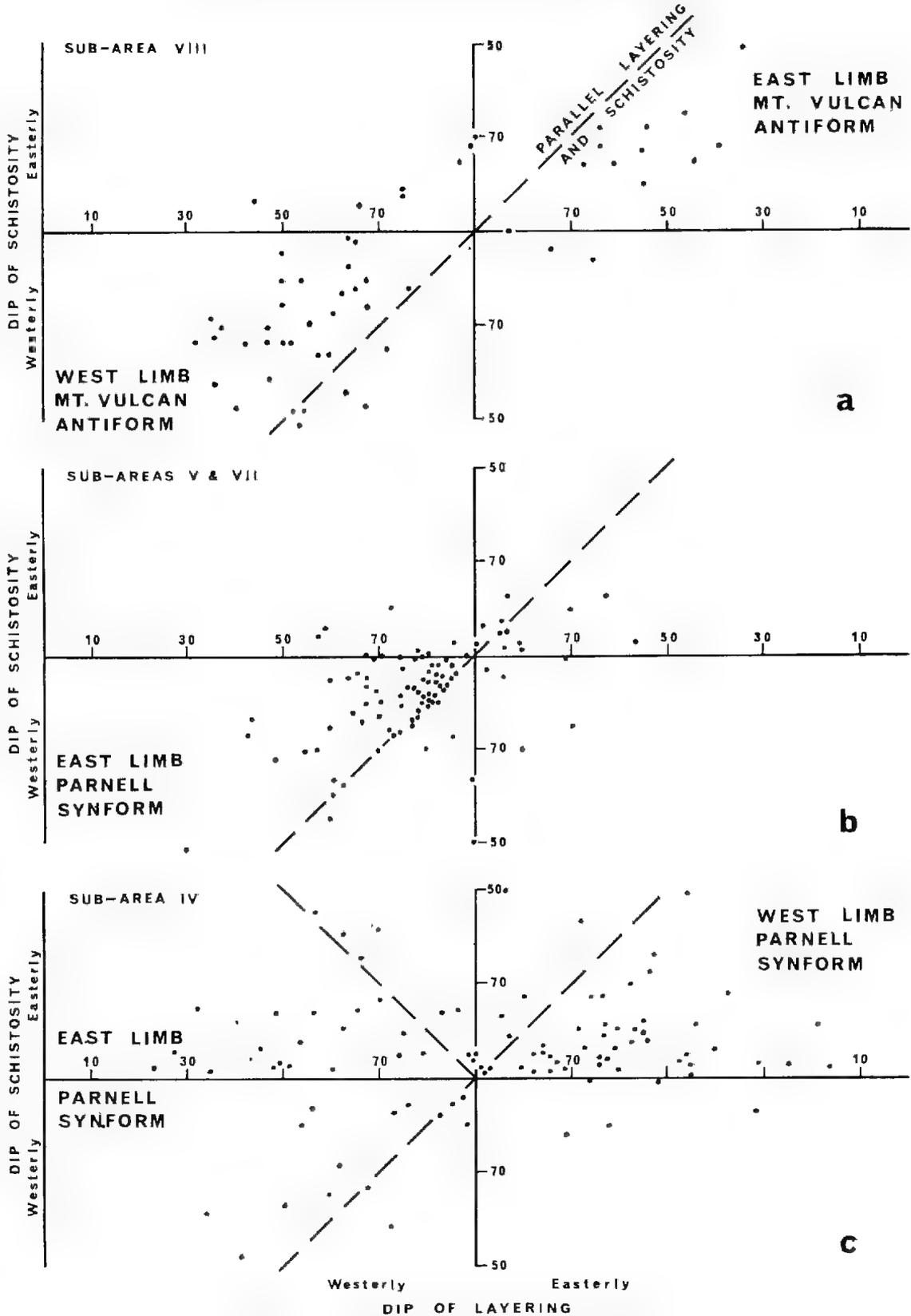


Fig. 4. Relative dips of layering and schistosity.

that the Sisters fold is of an earlier generation than the Group One Mt. Vulcan antiform and the associated  $S_1$  schistosity, and there is clear evidence of minor folding earlier than the schistosity.

Most minor folds in the hinge of The Sisters synform are Group One structures of distinctly variable northerly plunge. One excellent example of earlier minor folding occurs on the hinge of a Group One structure. The earlier fold on which the schistosity has been superposed has a nearly horizontal plunge and an east-north-east trend. Conceivably therefore the main Sisters fold is a reclined earlier structure on which the main schistosity and associated Group One minor folds have been superposed. Vernon (1969, p. 52) also notes that "small isolated isoclinal fold hinges in quartzite layers can be traced around the hinges of the relatively large folds" at the Sisters.

Further south in the traverse ESE of the Springs H.S. (sub-area VIII, Fig. 2) a further complication occurs with the recognition of two schistositities. The main schistosity generally dips north-west in the western limb of the Mt. Vulcan antiform. In the north draining valley about two miles east of the Springs H.S., however, both the layering and this schistosity are folded round the hinge of an antiform which is therefore Group Two with reference to this schistosity. A new schistosity is locally developed in the hinge, however, so that with reference to the later schistosity the fold is Group One.

It is not clear which of the schistositities should be correlated with the single prominent schistosity immediately to the north. If the earlier schistosity is so correlated (as is favoured by its intensity) then it may be described as  $S_1$  and the later schistosity can be regarded as a local development of  $S_2$ . If, however, the later schistosity is correlated with that to the north (as is favoured by their orientations) then the earlier schistosity must be regarded as one preserved from an earlier period of deformation, i.e. it would be an  $S_0$  schistosity. Further work is needed to determine unequivocally whether the major antiformal structure is related to the earlier or the later schistosity but the second alternative is here preferred.

Further south again in the traverse between Razor Back and Moorkaie the schistosity-layering relations indicate the presence of a Group One synformal structure east of the main antiform (Fig. 2). West of the Springs H.S., however, layering again dips west more

gently than schistosity and the Moorkaie synform is therefore regarded as a relatively subsidiary fold on the west limb of the major Mt. Vulcan antiform.

It is notable that both Group One and Group Two folds and lineations in this region have northerly plunges (Fig. 3, sub-areas VII, VIII and IX). Schistosity-layering intersections, however, are much more variable and may have any plunge within the NE striking zone corresponding to the general attitude of the schistosity.

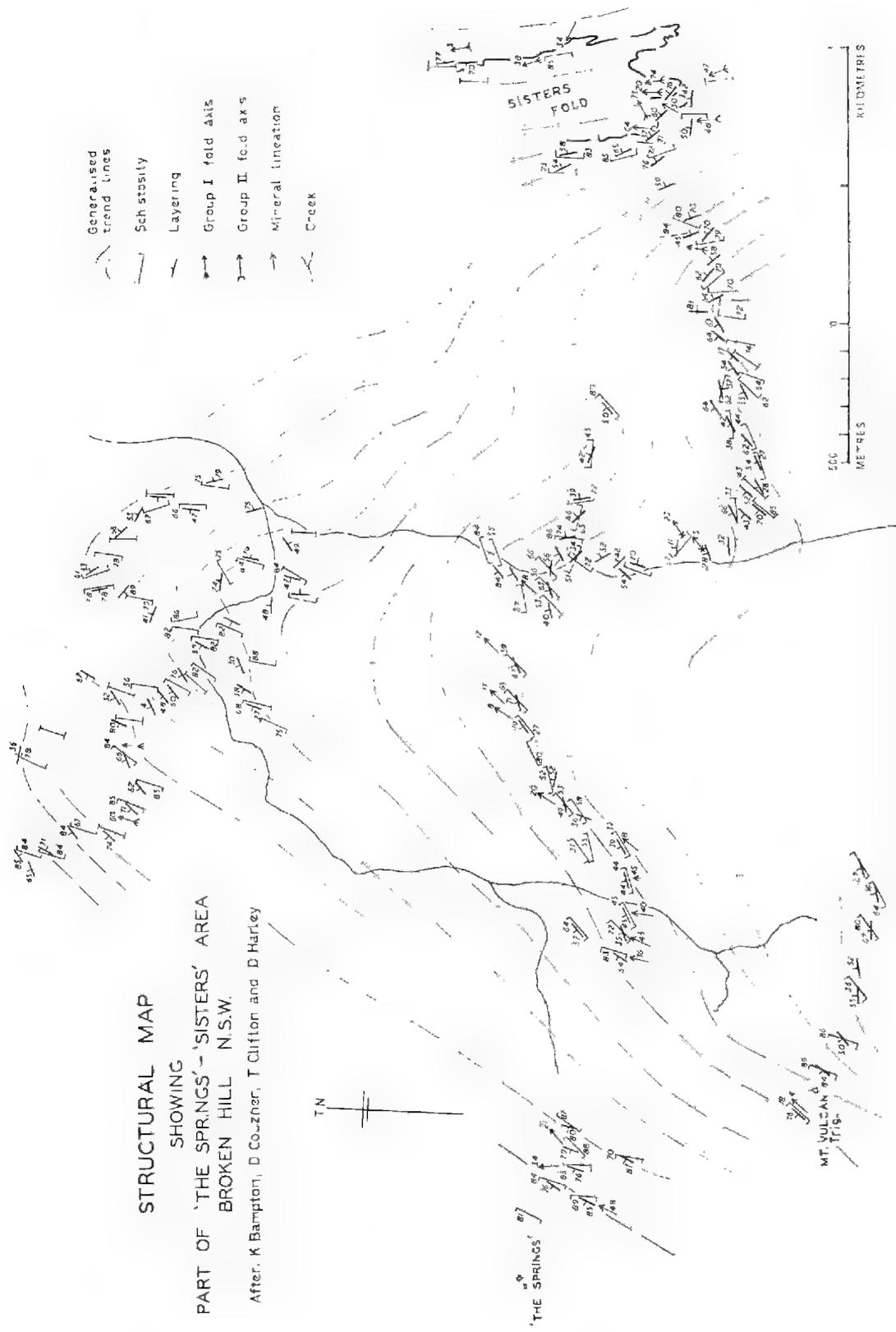
It is inferred, therefore, that the Mt. Vulcan antiform as defined, is a Group One structure superposed on isoclinal folding represented by the Sisters Synform. It is evident from the relations described, however, that this Group One structure could correspond in age to Group Two structures elsewhere, which fold an earlier schistosity. It cannot be assumed that the antiform is an anticline or that it folds a simple succession of constant facing.

#### (2) *The Maybell area: the Parnell Synform*

The hinge zone of this structure occurs in sub-area IV in a group of mica schists with quartzite and quartz-rich gneiss interbeds. Both schists and gneisses are commonly garnetiferous.

The well-developed layering and schistosity in these rocks has facilitated folding which is tighter and of smaller wavelength than in the Mt. Vulcan antiform. The hinge zone is made up of several folds so that the main axial trace is not easily drawn without detailed mapping (Fig. 6). The map suggests that the axial trace has suffered some right-lateral offset on the ENE trending shear zones which cross the area.

The diagram of mesoscopic data for this structure (Fig. 3, sub-area IV) is somewhat diffuse so that a plunge variation from gentle north to gentle south can be inferred. At least part of the spread is due to Group Two folds and these generally plunge to the south. The main fold, however, is clearly a Group One structure and minor Group One folds more commonly plunge to the north (Fig. 3). Evidence along the main hinge line in the northern part of the area for example gives a plunge of  $16^\circ/020$  while dextral folds on the west side of the gneiss in the south of the area plunge  $54^\circ/028$ . A few hundred yards west of the latter outcrop, however, Group One folds in interbedded quartzites and schists plunge  $30^\circ/196$ . Mineral lineations have occasionally been observed to plunge north at moderate angles



STRUCTURAL MAP  
 SHOWING  
 PART OF 'THE SPRINGS' - 'SISTERS' AREA  
 BROKEN HILL N.S.W.  
 After: K Bampton, D Co-zner, T Clifton and D Harley

Fig. 5. Structural elements in the Sisters-Mt. Vulcan area.

in both limbs of the major structure but others have been observed to plunge gently to moderately south.

The layering-schistosity intersections again show much greater variation than the fold axes (Fig. 3). This shows that strain axes and geometric symmetry axes were not coincident and suggests that the schistosity may be superposed on a complex and possibly polyphase fold system. The clearest evidence of this is in the presence, in the gneisses, of what appears to be a metamorphically produced layering which has been folded with the main schistosity as axial plane. If the main schistosity is again defined as  $S_1$  and the associated Group One folds as  $D_1$ , then the metamorphic layering provides evidence of an earlier  $D_0$  metamorphic deformation episode.

In sub-area IV (Fig. 2 and Fig. 3) schistosity and layering trends are roughly parallel, though dextral relations are more common in the west limb and sinistral relations in the east limb, suggesting a closure to the north<sup>2</sup>. Over a wider area, however, a notable feature is that the layering tends to show a dextral relation to the schistosity in both limbs of the fold, i.e. in sub-areas III and V (Fig. 2). This would imply a generally southerly plunge of the schistosity layering intersections in the west limb and a northerly plunge in the east limb. In fact Group One fold axes do commonly have a northerly plunge in the east limb although in sub-areas V and VI the plunges are often very steep. Group One folds in the west limb (sub-area II) do have a south-easterly plunge. It can be inferred therefore that the schistosity lies slightly incongruously across the structure, although the divergent attitude of the schistosity with respect to the axial plane confirms that the major structure and the schistosity are genetically related.

The limb areas of the Parnell Synform are discussed in more detail below.

### (3) *The Springs-Old Mt. Gipps area*

Schistosity and layering are often nearly parallel in this area but where their dips have been distinguished the layering generally dips west less steeply than the schistosity. The schistosity-layering intersections show the usual

variation in a NE trending great circle. In sub-area V (Fig. 3) the schistosity-layering intersections more commonly plunge steeply to the south as do observed mineral lineations in the schists. Group One fold axes, however, vary from steep south-easterly plunges to steep and moderate northerly plunges while Group Two folds vary from steep southerly to steep northerly plunges. On the east side of the main granite-gneiss body, however, in the schists of sub-area VII (Fig. 3) schistosity-layering intersections plunge less steeply either NNE or SSW and observed Group One fold axes have exclusively NNE plunges. This contrast between the variable plunge of schistosity layering intersections and the more consistent plunges of Group One fold axes is similar to that already noted for the hinge area of the Parnell synform and reinforces the suggestion that the main schistosity is slightly oblique on the major structure.

In the east limb of the Parnell Synform no earlier major folds (Group Nought) have been recognised but if the folds postulated by King & Thomson (1953) and Conlwell (unpublished map for New Consolidated Goldfields, 1962) exist they would belong in this category. Brief comments on these postulated folds are made below.

#### (a) THE MULGA SYNCLINE

This fold was inferred to lie with a NNE trending axial trace in the schists in sub-area VII (Fig. 2) east of the main body of granite gneiss. There is no evidence of repetition of the succession in the meta-sediments on either side of this trace although the aeromagnetic map does suggest the possible repetition by folding of the distinctive quartz-magnetite rock unit. Bodies of granite gneiss do flank the schists on both sides of the proposed fold but this rock type is probably intrusive, although it was emplaced before the development of the main schistosity. Layering and schistosity are often nearly parallel in this area and schistosity-layering intersections may plunge either north or south. Where distinguished, however, the layering dips west more gently than the schistosity. Thus the area of this postulated fold lies wholly in the western limb of the main Mt

<sup>2</sup> The schistosity-layering relationship is described as dextral when the layering trace in profile (or on a horizontal surface) is clockwise from the schistosity trace. Thus any minor tuck or "drag" folds to which the schistosity is axial plane are also dextral and have a dextral schistosity-layering relationship in their long limbs. Conversely the schistosity-layering relationship is described as sinistral when the layering trace in profile (or on a horizontal surface) is anticlockwise from the schistosity trace.

Vulcan antiform and, if it exists, it is earlier than the axial-plane schistosity of that fold.

#### (b) YANCO ANTICLINE

The main outcrop of granite gneisses north of Britannia and Scotia was inferred to lie in the core of an anticline. Southwards this Yanco anticline was supposed to be divided into two subsidiary anticlines (occupied by the two southerly projections of granite gneiss), separated by a syncline of metasediments south of Britannia and Scotia mine. Insufficient data has been gathered to evaluate this hypothesis fully but several relevant points can be made (Fig. 7).

The granite gneisses display a complex inter-layering with the metasediments, a relationship which may be primary or due to subsequent deformation. There is evidence of three deformation episodes in the gneisses. The main schistosity  $S_1$  ( $D_1$  deformation) is superposed on an earlier metamorphic layering in the gneiss ( $D_{11}$ ) and it is folded into Group Two folds ( $D_2$ ). The prominent southerly lineation may be related to  $D_{11}$  or  $D_1$ .

A Group Two fold of more than one hundred metres wavelength occurs in granite gneiss about 1500 m south of old Mt. Gipps. This is a large sinistral parasitic fold with a southerly plunge on a general westerly dip. Other Group Two folds are dextral with northerly plunges but all are parasitic folds and there is no evidence of any major Group Two fold which might repeat the succession.

Schistosity-layering relationships are complex: generally schistosity and layering are nearly parallel and the attitude of their intersections is very variable; where the angle between schistosity and layering is substantial the schistosity generally has the steeper westerly dip but in some cases the layering dips eastwards less steeply than the schistosity. This suggests the presence of some Group One folds and a clear example, dextral with northerly plunge, can be seen nearly 3 km NE of Old Mt. Gipps. Again, however, no systematic variation in schistosity-layering relations was found which might indicate a major Group One fold and in general the layering dips west more gently than schistosity on both sides of the main granite-gneiss outcrop. It is therefore inferred that, if the granite-gneiss areas do lie in the hinges of major folds, such folds must be earlier than the Parnell Synform and Mt. Vulcan antiform. No positive evidence for such folds has been found but further study of this area is required.

#### (c) NINE-MILE SYNCLINE AND MAYBELL ANTICLINE

These folds were inferred by Cordwell in the essentially metasedimentary area west of Old Mt. Gipps (the Maybell anticline corresponds approximately to the Corrua East anticline of King & Thomson 1953). They were apparently based partly on the supposed repetition of amphibolites and of a para-gneiss unit. These repetitions have not been substantiated by the present work. Distinctive lithologies of pale calcareous schists occur along the old tramway north-west of Old Mt. Gipps and these have not been found further west.

However, schistosity and layering show a variety of relationships although in general the layering dips west more gently than schistosity in a dextral relationship and plunges are northerly (Fig. 7). Along the old tramway, however, the layering dips east more gently than the steep schistosity and the prominent Group One folds are dextral on a southerly plunge (as in the west limb of the main Parnell synform). There is some inconclusive evidence in these outcrops that the Group One folds re-fold an earlier set of Group Nought folds. These relations of Group One structures suggest the presence of a minor dependent antiform in the east limb of the main Parnell Synform, but, as with the major structure, the plunge variation suggests that the schistosity is oblique to the axial plane of the fold.

#### (4) THE MT. FRANKS AREA

In sub-areas II and III the layering generally dips east more gently than the schistosity in a dextral relationship on a southerly plunge, often steep. This is especially well seen in a coarse schist unit defining a number of dextral folds in the area south of Florida Mine. There is some evidence that this unit closes southwards in a major fold with a core of Parnell gneiss (resembling Potosi gneiss) but both limbs dip east across the vertical schistosity and the Group One folds have the same dextral sense in both limbs. This suggests that the possible major fold is a Group Nought fold, with reference to the axial plane schistosity of the Parnell synform. No evidence for the northward continuation of the Stirling Vale syncline (King & Thomson 1953) was found in this sub-area.

In sub-area II the schistosity and layering are generally nearly parallel and Group One Minor folds are rare. Most commonly the layering dips east across a steeper schistosity in

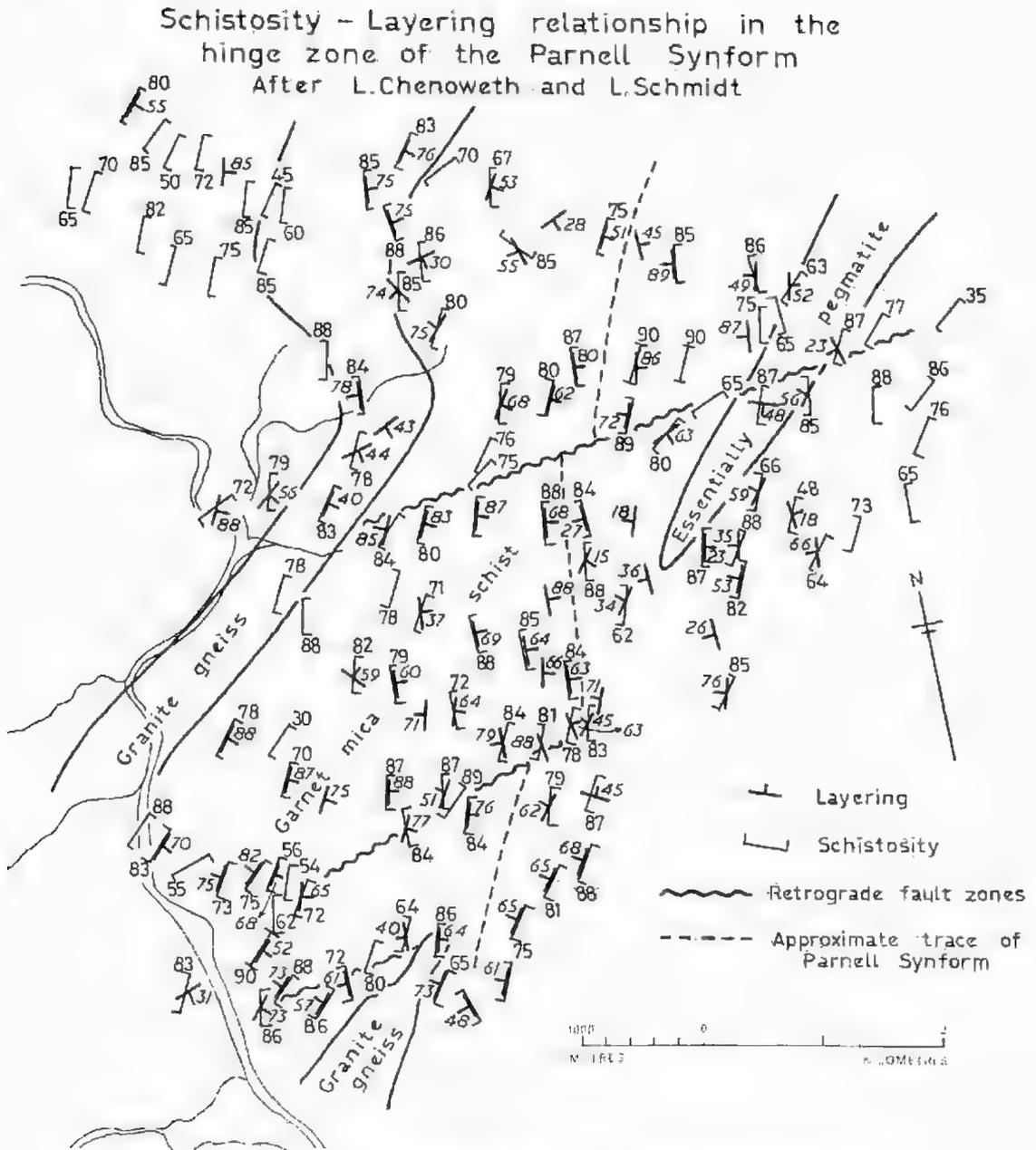


Fig. 6. Structural elements in the Maybell area; the Parnell Synform.

a dextral relationship on a southerly plunge but near the eastern margin of the sub-area some sinistral minor folds occur, also on a southerly plunge since the layering here dips east more steeply than the schistosity. This suggests the presence of an overturned south plunging antiform-synform pair on the western limb of the main Parnell synform. The axial trace of the Apollyon anticline as mapped by

King & Thomson (1953) runs through this area and further work is required.

Also in this sub-area, close to the track east of Mt. Franks the quartzo-feldspathic sediments show a strong "elongation" lineation plunging south-east in relatively low angle schistosity. These rocks are also invaded by abundant pegmatite and they provide a strong structural contrast with the rocks further west.

Possibly the lineation and the schistosity which is sensibly parallel to layering are preserved from a deformation episode earlier than the Parnell synform.

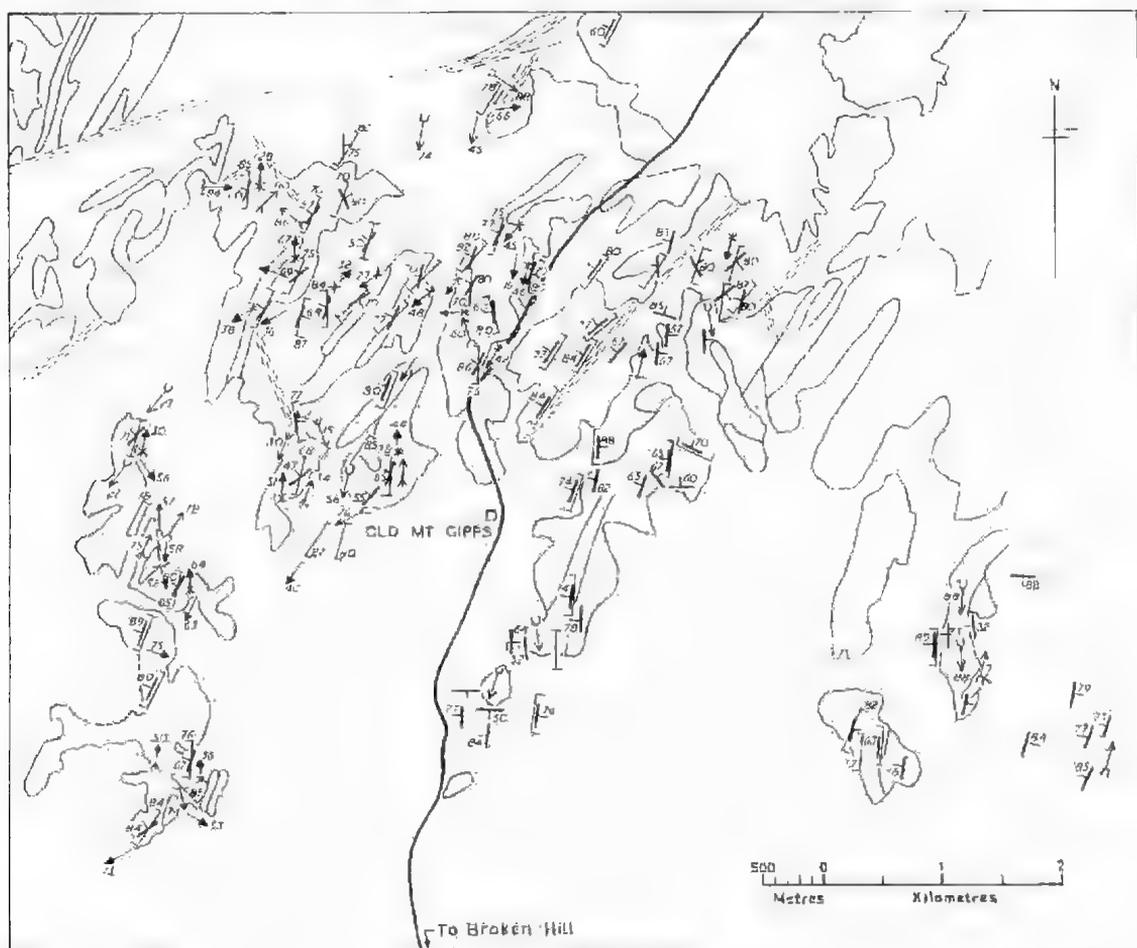
In sub-area I there is relatively little pegmatite and the rocks are commonly phyllitic, though some members are rich in andalusite porphyroblasts, around which the schistosity is deflected. The layering again generally dips east more gently than schistosity but in contrast to sub-areas II and III the relationship is now generally sinistral and the plunge of the Group One minor folds is to the north. The layering actually trends about N-S and the schistosity about 030°.

Thus the relationships are still consistent with a position in the western limb of the main Parnell synform but the trend of the layering

has changed and the plunge has changed from southerly to northerly. These changes might be attributed to the presence of a southward closing Group Nought fold between sub-areas I and II. No evidence of such a fold has been found and the strong contrast of structural style between the two sub-areas rather suggests the presence of a thrust fault.

Nearer to Mt. Franks there is a reversion to a dextral relation between schistosity and layering and to a southerly plunge since the layering continues to dip east across a nearly vertical schistosity.

On Mt. Franks itself there is a large dextral fold and crenulation cleavage is strongly developed. It is apparent, however, that the  $S_1$  schistosity which has suffered crenulation was itself formed at a high angle to the layering.



- |               |                      |   |
|---------------|----------------------|---|
| — Road        | ↗ Group I fold axis  | ✱ Interserion of layering and schistosity |
| ┆ Layering    | ↘ Group II fold axis | ┆ Crenulation cleavage                    |
| ┆ Schistosity | → Mineral lineation  | ○ Areas of sand rock outcrop              |

Fig. 7. Structural elements in the Old Mt. Gipps area.

It is inferred therefore that the main Mt. Franks structure is essentially a large Group One dextral fold modified by Group Two folds and crenulation cleavage. As noted above, the elucidation of the relationship of these observations to the interpretation by Anderson (1971) of the Mt. Robe area must await further work.

### Conclusions

Minor folds of Group Nought, Group One and Group Two styles have been recognised and would suggest the presence of three periods of deformation if it is assumed that the schistosity is everywhere of the same age. Some doubt is cast on this assumption by the fact that in some areas (particularly the hinge zones of the major structures) the schistosity is consistently steeper than layering and makes a distinct angle with it while in others (especially in the limbs of the major structures) it is nearly parallel to the layering.

The Parnell Synform and Mt. Vulcan antiform are apparently of Group One character since the undoubted  $S_1$  schistosity is roughly congruent and forms divergent or reversed fans. Since the schistosity attitude varies systematically according to its position in these folds it seems probable that the folds and the divergent schistosity, non-parallel to layering, were formed during the same deformation episode. Nevertheless the fact that the layering generally shows a dextral relation to schistosity in both limbs of the Parnell Synform suggests that the schistosity has been superposed slightly obliquely on the fold, after the initiation of buckling. This oblique superposition may be partly responsible for the difference in plunges in the two limbs of the Parnell Synform but there is some evidence that earlier folding is also significant.

The dominant dextral relation of layering to schistosity suggests that Group One folds related to the schistosity should plunge south-east in the west limb and north in the east limb of the Parnell Synform. In fact schistosity-layering intersections and fold axes (Figs. 3 and 8) show a wide variation in attitude in a great circle zone striking NNE. This suggests that the layering attitude on which the schistosity was superimposed was variable, possibly due to earlier folding. Moreover, there is not a close correlation between the attitude of

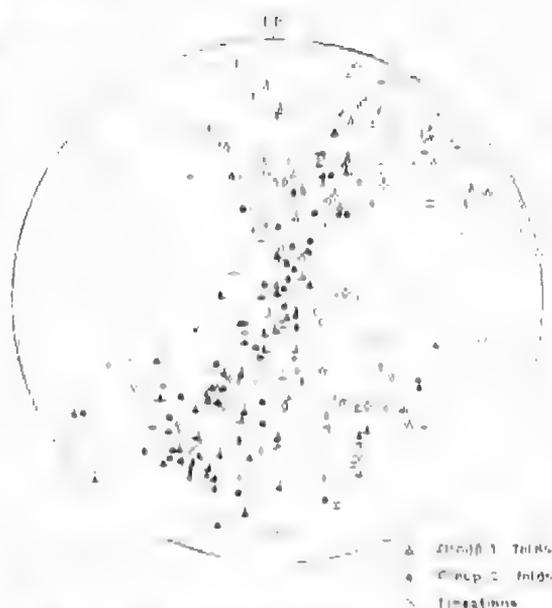


Fig. 8. Lower hemisphere equal-area projection of fold axes and lineations for the whole transect.

Group One folds and schistosity-layering intersections. There is a closer correlation between layering-schistosity intersections and Group Two folds suggesting that the latter have been controlled by the former.

Minor folds of Group Nought character which can unequivocally be said to be earlier than the schistosity are rare however. The divergent schistosity inevitably approximates to the axial plane of any earlier nearly isoclinal folds and the distinction can be made only in areas of favourable lithology and exposure<sup>3</sup>. It has already been noted, however, that an earlier schistosity may be preserved, and the evidence in gneisses of a metamorphic layering earlier than the  $S_1$  schistosity provides convincing evidence of an earlier deformation episode. On the map-scale moreover, the Sisters fold and some others appear to be isoclinal major structures earlier than the Parnell synform and its related schistosity. Since the axial planes of these isoclinal folds are approximately parallel to the limbs of the Parnell synform it follows that they were recumbent before the deformation which produced the Parnell synform (Fig. 9).

<sup>3</sup> A good example outside the area under discussion can be seen south-east of the main road, about one km north-east of the Flying Doctor base. There the schistosity-layering relationship is sinistral and congruent Group One minor folds occur with south-westerly plunges of about 50°. The schistosity cuts across occasional earlier dextral folds which plunge north-north-east.

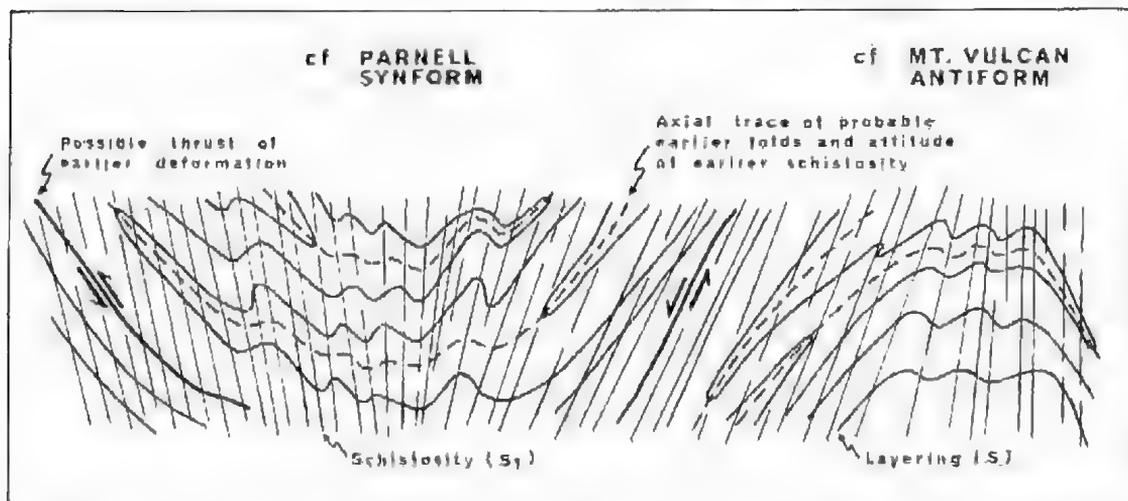


Fig 9. Diagram to show general form of the Parnell Synform and Mt. Vulcan Antiform and their possible relationship to major structures of the inferred earlier generation. No attempt is made to show specific early structures which have been postulated.

Three major deformation episodes are therefore inferred:

1.  $D_0$ : Formation of tight Group Nought folds (apparently Group One if the later  $S_1$  schistosity is roughly parallel to the axial plane or if  $S_0$  is preserved) including the Sisters synform. Original attitude possibly recumbent but now upright with steep plunges.
2.  $D_1$ : Development of the main folds, the Parnell synform and Mt. Vulcan antiform together with their associated ( $S_1$ ) schistosity.
3.  $D_2$ : Formation of relatively minor Group Two folds, plunging south except in hinge area of Mt. Vulcan antiform.

Further work is now in progress on a further east-west transect, immediately north of Broken Hill. It is hoped to test the conclusions presented here, to extend knowledge of the major structures and to correlate the deformation phases recognised with those established

by other workers (Hobbs 1966; Williams 1967; Anderson 1971).

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# THE SYSTEMATICS OF SOUTH AUSTRALIAN PRECAMBRIAN AND CAMBRIAN STROMATOLITES. PART II

BY W. V. PREISS\*

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### Introduction

This paper is a continuation of Preiss (1972) in which the principles of stromatolite classification were outlined and several new forms of stromatolites were described. The glossary appended to Part I also applies to this paper.

### Systematics

#### Group CONOPHYTON Maslov

*Conophyton* Maslov 1937: 334, Korolyuk 1963: pl. 5, Fig. 3, Komar, Raaben & Semikhatov 1965: 27, Komar 1966: 72, Cloud & Semikhatov 1969: 1037, Bertrand 1968: 170, Walter 1972: 102.

*Type Form*: *Conophyton lituum* Maslov, from the Derevnin Suite, Lower Tunguska River.

*Diagnosis*: Non-branching or extremely rarely branching columnar stromatolites with conical laminae, usually thickened and/or contorted in their crestal parts.

*Content*: *C. cylindricum* Maslov; *C. metuluni* Kirichenko; *C. circulum* Korolyuk; *C. garganicum* Korolyuk; *C. miloradovici* Raaben; *C. lituum* Maslov; *C. baculum* Kirichenko; *C. gaubltza* Krylov; *C. ressoji* Menchikoff; *C. cadilnicus* Korolyuk and *C. confertum* Semikhatov.

*Conophyton garganicum garganicum* Korolyuk (emend.)

FIGS. 1, 2a, 9a, 11, 12a

*Conophyton* cf. *garganicum* (partim), Glaessner, Preiss & Walter 1969: 1056.

*Material*: Eleven specimens from Paratoo, S. Aust.

### Description

*Mode of Occurrence*: These stromatolites have been found only in a diapiric raft in the Paratoo Diapir. The basal portion consists of flat-laminated stromatolite, passing up into large domal structures up to 1 m diam. (Fig. 11c). Domes are usually laterally linked, occasionally separated by small interspaces, then dividing into discrete columns, 15–40 cm in diam., with conical laminae. Transverse sections of columns round to oval or lanceolate (Fig. 11b). Columns 1–4 cm apart, with some massive bridges, often slightly bent, with axes non-parallel, diverging at up to 30° (Fig. 11a). Some of this divergence may be due to tectonic disturbances. The original mode of occurrence is not clear because of the discontinuous outcrop; it may have been a bioherm or thick biostrome, perhaps 30 m thick. The only evidence as to the facing of the bed is the upward passage from flat-laminated to conical stromatolites, with apices growing upwards.

*Column Shape*: Field observation shows that columns are somewhat irregular cylinders, with ragged edges, massive bridges and overhanging laminae. Only one specimen was suitable for reconstruction (Fig. 2a). Columns of round transverse section have a linear crestal zone, while those of elliptical and lanceolate sections have crestal planes in the long axis of the ellipse (Fig. 11b). Specimens studied in the laboratory also show both types.

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The margin structure is very irregular, with numerous large bumps, overhanging peaks and short cornices (Figs. 2a, 11a). Bridges vary in thickness from one or two to several lens of laminae.

**Branching:** No true branching except actual separation of columns from the domed and flat-laminated base. Rarely a small projection with convex, non conical laminae occurs on the margin of a column.

**Lamina Shape:** In longitudinal axial sections laminae steeply conical, apical angle generally acute (50–90°) but obtuse angles occur near the base of the columns. Away from crestal zone, laminae usually straight and parallel in longitudinal section, but in places bent downwards near the column margins, producing a shape resembling gothic arches (Fig. 9a).

**Crestal Zone:** All laminae more or less thickened in crestal zone. Some light laminae greatly thickened. Dark laminae arched up and contorted, often leaving irregular voids filled with sparry dolomite, within the thickened light laminae (Fig. 11f). The crestal line, joining apices of successive conical laminae, is very wavy, with frequent sharp displacements of crests (Fig. 1a). The overall shape of crestal zone is however straight (Fig. 12a); it corresponds mostly to Type III (after Komar, Raaben & Semikhatov 1965, p. 23, Fig. 5) with uneven thickenings and sharp lateral displacements, but some examples of Type II (without lateral displacements) occur. In places, laminae are deflexed immediately outside the crestal zone (Fig. 12h). The diameter of the crestal zone is taken as the width between the limits of thickening of laminae. Out of 33 measurements, 63% lie between 7 and 9 mm, 24% between 5 and 7 mm, and 12% between 9 and 12 mm.

**Lamination:** Very distinctly banded and striated in better preserved specimens, consisting of straight, parallel, smooth, very thin laminae, either very continuous, or formed by chains of elongated lenses, aligned in definite layers (Figs. 11e, 11f). Two types of primary laminae occur: light ( $L_1$ ) and dark ( $L_2$ ). In some specimens  $L_2$  layers grouped into fairly distinct macrolaminae, in which light laminae are thin and subordinate, separated by layers of predominantly  $L_1$  type (Fig. 11f). The appearance of macrolaminae has been exaggerated by the preferential recrystallization of light laminae.  $L_1$  laminae relatively pure and transparent, mostly 0.08–0.1 mm thick, generally of very constant thickness from the edge of the crestal zone to the column margin, never

lensing out. They are internally homogenous, composed of xenotopic, almost equigranular dolomite, of grain size from 0.01–0.03 mm. Many grains slightly inequidimensional. Occasional lenticular spar-filled cavities have dark laminae draped around them (Fig. 11e).  $L_2$  laminae darker, much less transparent and somewhat finer grained than  $L_1$  laminae, the fine crystals stained by a pale brownish, possibly organic coloration (Fig. 11e). Most dark laminae 0.02–0.10 mm thick, not as continuous as  $L_1$  laminae, frequently splitting into series of lenses, 0.2–1.0 mm long, and 0.1–1.0 mm apart, aligned parallel and separated by pale laminae. Some dark laminae are continuous for several cm; some have slight, rounded, lenticular swellings. These, as well as the lenses, may be blunt ended, rounded, or pointed. Rarely, they contain significant swellings, the underlying and overlying laminae being draped around them. Relatively large (0.5–2.0 mm) nodules, within a pale lamina (e.g. Fig. 11c) are probably detrital carbonate grains.  $L_2$  laminae composed of equidimensional, equigranular, xenotopic dolomite, of grain size 0.006–0.015 mm. Boundaries of  $L_1$  and  $L_2$  laminae distinct and smooth, but slight recrystallization has made them a little diffuse in places. Macrolaminae, consisting of sets of  $L_1$  laminae, very prominent in some specimens, are 0.4–1.0 mm thick, composed of 5–10  $L_1$ – $L_2$  lamination pairs, bounded by predominantly light macrolaminae 0.2–0.5 mm thick, often sparry and recrystallized (Fig. 11f).

**Statistical Study:** Numerous measurements were made on six large thin sections, of the following parameters: (1) thickness of light laminae  $L_1$ ; (2) thickness of dark laminae  $L_2$ ; (3) ratio of thicknesses of adjacent dark and light laminae  $L_2/L_1$  and (4) coefficient of thickening, i.e. ratio of thickness of a lamina in crestal zone, to thickness of same lamina outside crestal zone.

The distribution of thicknesses of laminae  $L_1$  and  $L_2$  were plotted graphically for thickness intervals of 0.02 mm; the frequencies of intervals were plotted against the mid-point of each interval, for the six specimens (Fig. 1b to g). A comparison of the six graphs for each lamination type shows some variation between specimens, especially for  $L_2$  laminae, which is interpreted as being due to the difficulty of distinguishing single dark laminae and the thinner macrolaminae in some specimens. This difficulty is increased with greater recrystallization, so that one would expect the more re-

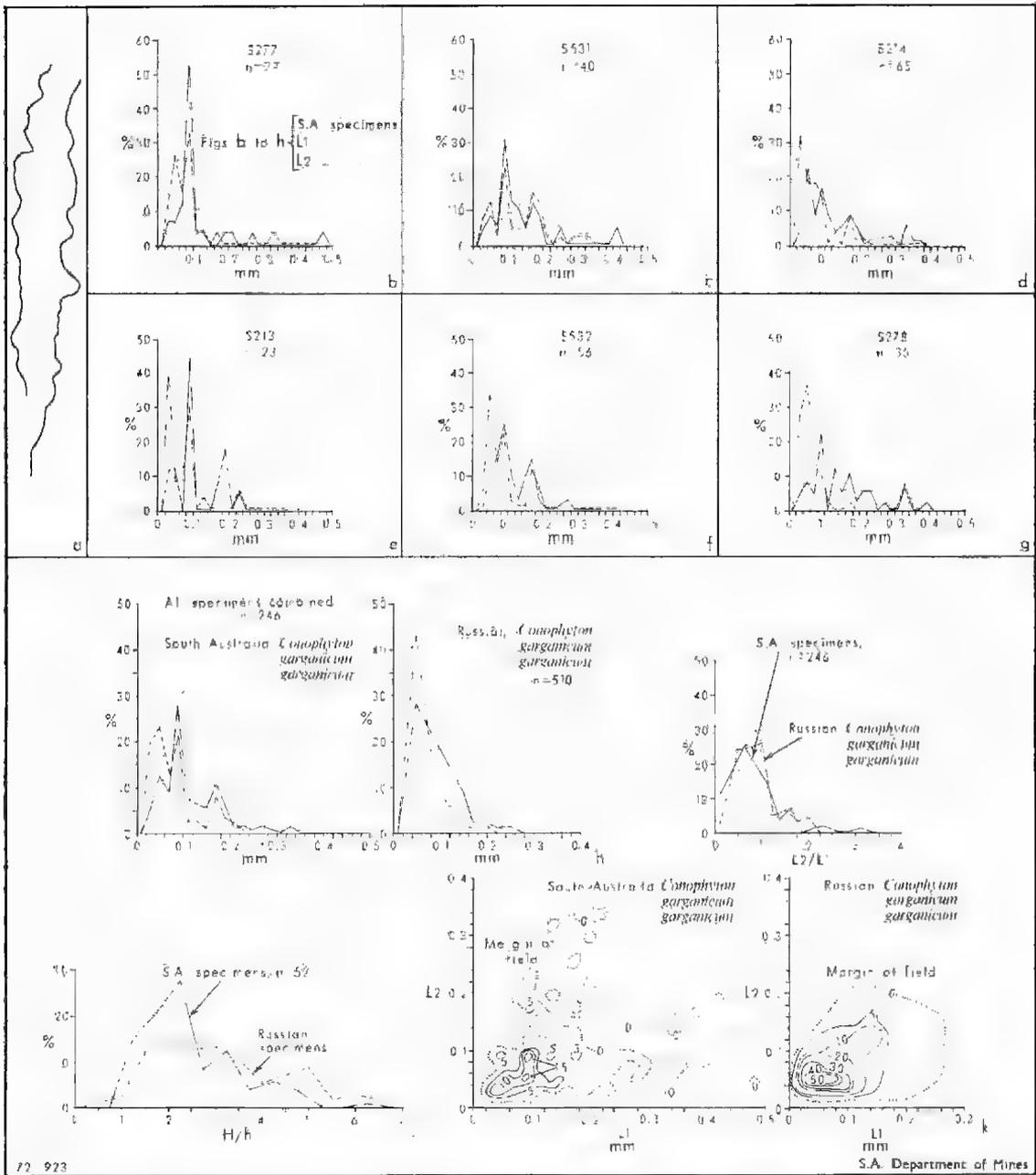


Fig. 1. Diagnostic characters of *Conophyton*: (a)—The traces of the crestal lines of two specimens (S214 at left and S532 at right) drawn from thin section (x1/3); (b) to (g)—Frequency distributions of thicknesses of light laminae L<sub>1</sub> and dark laminae L<sub>2</sub> for 6 separate specimens; (h)—Pooled frequency distributions of lamina thicknesses for all six specimens, compared with data for Russian conophytons; (i)—Frequency distribution of the ratio of thicknesses of adjacent dark and light laminae (L<sub>2</sub>/L<sub>1</sub>), pooled for all specimens, compared with data for Russian conophytons; (j)—Frequency distribution of the coefficient of thickening of laminae in the crestal zone, compared with Russian conophytons; (k)—Comparison of contour diagrams of the frequency distributions of dark and light laminae (contoured in numbers of readings).

crystallized specimens to have proportionately more numerous thicker laminae (actually thin macrolaminae), i.e. the mean thickness should be higher than for less recrystallized ones. The following table compares mean thickness (in mm) of  $L_1$  and  $L_2$  with degree of recrystallization observed;  $L_2$  means have much greater spread about the total mean than  $L_1$ , and the highest means of  $L_2$  correspond to the most recrystallized specimens.

Specimen number	$L_1$ mean	$L_2$ mean	Degree of Recrystallization
S214	0.128	0.073	Well preserved
S213	0.107	0.066	Slight
S278	0.145	0.065	Slight
S277	0.111	0.084	Slight
S532	0.115	0.089	Strong
S531	0.087	0.134	Strong
Total mean	0.116	0.085	

The data for the six specimens were combined, replotted, and compared with the distribution curve of the Russian *Conophyton garganicum garganicum* (Fig. 1h). While the  $L_2$  curves are very similar,  $L_1$  has a higher mode in the South Australian form (0.08 to 0.10 mm), with a secondary peak in the interval 0.04 to 0.06 mm, which characterized the Russian form. To some extent, the bimodality is due to errors of measurement arising from the judgement of lamina thickness relative to the scale of the graduated eyepiece, and to the presence of thinner macrolaminae as discussed above.

**Ratio  $L_2/L_1$  for Adjacent Laminae:** Results from all six specimens were pooled and plotted in intervals of 0.25. The graph compares very closely with that of the Russian form (Fig. 1i). The data may also be represented in the form of a contoured frequency diagram of  $L_2$  against  $L_1$ . The shape and position of the maximum are compared with those of contoured Russian plots; they differ only in that the South Australian form has a displaced secondary peak at  $L_1 = 0.08$  to 0.10 mm,  $L_2 = 0.08$  to 0.10 mm (Fig. 1k).

**Coefficient of Thickening:** Randomly selected light and dark laminae, and macrolaminae, were measured outside the crestal zone (h), then traced into the crestal zone and remeasured (H).  $H/h$  was plotted at intervals of 0.5. In a total of 52 measurements, the modal value of  $H/h$  is the interval 2.0 to 2.5 (26.9%) while only 15.5% exceed 3.5, and none less than 1.0 occur (Fig. 1j).

**Interspaces:** Interspace fillings between columns are strongly altered, consisting of homogeneous recrystallized dolomite. Some is of granular texture, composed of xenotopic equidimensional (0.005–0.01 mm) grains, forming patches 0.05–0.10 mm in diam., set in a sparry matrix of grain size 0.1–0.3 mm. The only observed remnants of primary structure are possible small intraclasts in one specimen.

**Secondary Alteration:** Fracturing of laminae is restricted almost entirely to the crestal zones of some specimens and marginal zones of others. Portions of the crestal zone are more or less brecciated and recemented in place (Fig. 11d). Contortion frequently occurs within the crestal zone. Immediately outside it, laminae are deflexed; this and the brecciation are effects probably due to compaction during burial. The brecciation of macrolaminae into cleanly broken fragments several millimetres long suggests that the carbonate was already lithified during the deformation (Fig. 11d). In places, on the column margins, laminae truncate underlying laminae. Whether this is due to penecontemporaneous erosion or to sliding of the overlying laminae during compaction could not be determined, but associated brecciation around the column margin suggests the latter possibility. No overfolds or diapiric structures as in *Conophyton garganicum australe* Walter (1972) were observed, supporting the idea that columns were lithified soon after growth.

Columns and interspaces consist entirely of dolomite. The preservation of very fine lamination suggests that dolomitization was probably penecontemporaneous. All laminae are more or less recrystallized; the dark laminae are coarser and more transparent than in the Russian or Western Australian forms. Recrystallization may be due to the low grade regional metamorphism which has affected the Mt. Lofty-Orary Arc. Pale laminae between dark macrolaminae are preferentially recrystallized, emphasizing the distinctness of the macrolaminae. These recrystallized laminae consist of sparry, hypidiotopic to xenotopic inequigranular dolomite, of grain size 0.02–0.10 mm. The most recrystallized specimen is a fine marble, in which dark macrolaminae, approximately 1 mm thick, contain no preserved internal laminae, and consist of xenotopic equidimensional carbonate with interlobate crystal boundaries, of grain sizes 0.02–0.05 mm. The grain size of the light laminae is 0.05–0.10 mm, and in places much coarser. One specimen is extensively silicified. Silicification post-

dates the growth of the whole column, and may be related to tectonics and diapiric emplacement rather than to sedimentation. Silica consists of xenotopic quartz aggregates, of grain size 0.05–0.10 mm, in places containing small dolomite rhombs. Portions are completely redolomitized.

#### Conspicuous

The conical lamination with thickened crestal zone, and the absence of branching distinguish this stromatolite from all groups except *Conophyton*. It differs from most conophytons in that the columns are not always parallel, but their original growth orientation is not clear, due to structural disturbance. On microstructural features, it falls into the *Conophyton garganicum* subgroup (*Conophyton garganicum*, *C. miloradovici*, *C. gaubitzia*, and perhaps, *C. basalticum* Walter). The closely allied *C. miloradovici* has more irregular and lenticular laminae. *C. basalticum* Walter also has very thin smooth continuous laminae, but lacks the distinctive Types II & III crestal zone. The absence of numerous knotted lenses and sharp swellings distinguishes it from the variety *C. garganicum nordicum*. On these features it was assigned to *Conophyton* cf. *garganicum* by Glaessner *et al.* (1969).

The statistical study confirms the identification as *C. garganicum garganicum*, and distinguishes it clearly from *C. garganicum australe* Walter and *C. garganicum nordicum*. The modes of thicknesses  $L_1$  and  $L_2$  most closely resemble *C. garganicum garganicum*, especially  $L_2$  (mode at 0.04 to 0.06 mm), while most other conophytons have modes at much higher values. *C. garganicum nordicum* has a modal value of  $L_2$  at 0.10 mm, and *C. garganicum australe* Walter at about 0.08 mm. The ratio  $L_2/L_1$  is the most distinctive character for *Conophyton garganicum garganicum*. The modal value is the interval 0.50 to 0.75, which falls within the broader peak of the Russian form (0.50 to 1.00), but distinguishes it from *C. garganicum nordicum* Komar, Raaben & Semikhatov (mode 2.00) and from *C. garganicum australe* Walter (1.0 to 1.5). The coefficient of thickening is less distinctive: the mode at 2.0 to 2.5 does not distinguish *C. garganicum garganicum*, *C. miloradovici* and *C. cylindricum* but excludes *C. garganicum nordicum* and probably *C. g. australe*.

**Distribution:** Lower Subsuite of the Yumas-takh Suite of the west and east slopes of the Anabar Massif; the Kyutingdin, Arymas and Debengdin Suites of the Olonek Uplift; the

Gonam Suite of the Uchur-Maya Region, Ust'-sakhari Suite of Western Priverkhoyan'ye, Mongashin Suite of the southeast part of the Eastern Sayan, Bul'bukhtin Suite of the Baikalo-Patom Mountains, Salkin Suite of the Southern Urals; in pre-upper Burra Group sediments, Paratoo Diapir, S. Aust.

**Age:** Early and Middle Riphean in S. Aust., it is assumed to be early Adelaidean.

#### Group GYMNASOLEN Steinmann

*Gymnosolen* Steinmann 1911: 18. Semikhatov 1962: 219. Krylov 1963: 84. Komar 1966: 88. Krylov 1967: 36. Raaben 1969: 73 (in part). Glaessner, Preiss & Walter 1969: 1057.

**Type Form:** *Gymnosolen ramsayi* Steinmann, from the Dolomitic Suite of Kanin Peninsula; also widespread in the Southern Urals, the Polyudov Mountains, Kildin Island, and Tien-Shan, USSR.

**Diagnosis:** Smooth to gently bumpy, swelling and constricting, walled columns with frequent,  $\gamma$ -parallel, often multiple branching, less frequently slightly divergent branching.

**Content:** *Gymnosolen ramsayi* Steinmann; *G. levis* Krylov; *G. furcatus* Komar; *G. alius* Semikhatov; "*G. confragosus*" (in part) Semikhatov and *G. asymmetricus* Raaben. Raaben (1969) has included part of the group *Minjaria* Krylov in *Gymnosolen*, chiefly on the basis of microstructural similarity, but Krylov (1963) has clearly distinguished *Minjaria* from *Gymnosolen* by its regular, subcylindrical shape of columns, of constant diameter, and relatively rare and simple branching.

**Age:** Late Riphean.

#### *Gymnosolen* cf. *ramsayi* Steinmann

FIGS. 2b-g, 3a-c, 9b, 10b, 12b,c, 13a

*Gymnosolen* sp. Glaessner, Preiss & Walter, 1969: 1057.

**Material:** Five specimens from near Wilson

#### Description

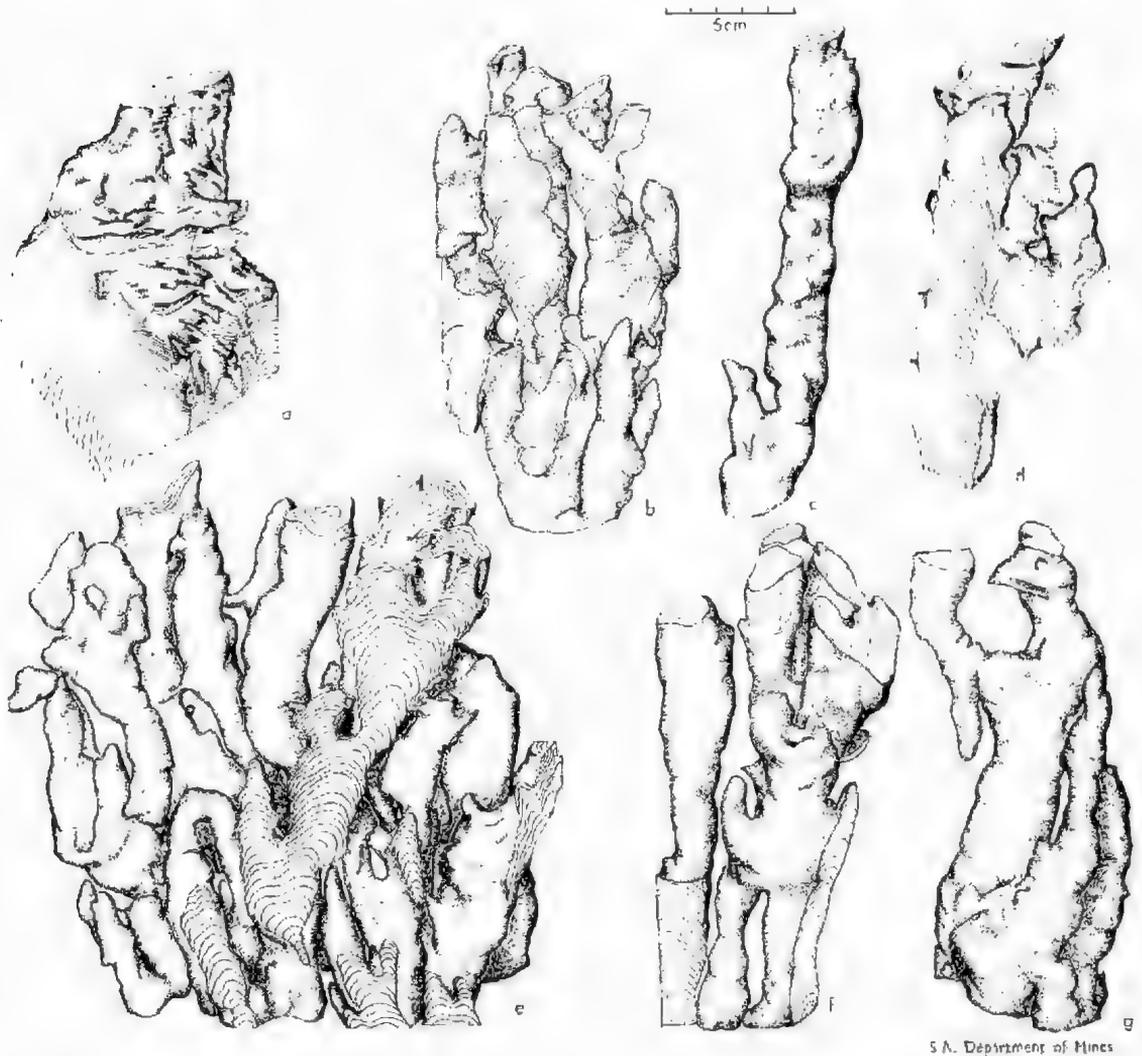
**Mode of Occurrence:** All specimens are boulders from conglomerate and breccia beds within the Tapley Hill Formation on the flank of a small diapir. Only one specimen shows completely separate, discrete, vertical columns, and is interpreted to have been derived from the central portion of a bioherm (Fig. 13a). Of two specimens showing much coalescing and bridging, one also has markedly inclined columns (Fig. 12c). These are considered to

represent the marginal portions of bioherms. The provenance of the boulders has not been determined.

**Column Shape and Arrangement:** Columns straight to gently curved, erect, 1–5 cm diam., with gentle swellings and constrictions (Fig. 2b–g). Transverse sections generally circular to oval, but lobate and rounded-polygonal at branches (e.g. Fig. 3a). Length of columns between branches 5–20 cm. Some columns short (only 2–5 cm long), with rounded or

pointed terminations (Fig. 2c,e). Columns presumed to be marginal in bioherms are inclined (as inferred from the asymmetry of laminae and occasional interspace lamination). The gross morphology of marginal columns differs only in their frequent coalescing and bridging, and narrow interspaces (Fig. 3b). One specimen with apparently erect columns is markedly humpy (Fig. 2d).

**Branching:** Slightly divergent to  $\beta$ - or, most commonly,  $\gamma$ -parallel. The column expands



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Fig. 2. (a)—*Conophyton garganicum garganicum*, from dolomite raft in Paratoo Diápir. Part of a large column illustrating margin structure. S528; (b) to (g)—*Gymnosolen* cf. *ramsayi*, from boulders in a conglomerate in the Tapley Hill Formation, near Wilson; (b), (c), (e), (f), (g)—Vertical columns interpreted to be derived from a bioherm centre. S388; (d)—Poorly preserved vertical columns. S390.

rapidly, then branches suddenly into two, three or four columns, some branches terminating as pointed projections. Even in the discrete specimens, adjacent columns may occasionally coalesce. The inclined-column specimens branch similarly, but widening of a column before branching is more marked. In these specimens adjacent branches either are frequently linked by massive bridges, or coalesce.

**Margin Structure:** The surface of columns bears low, rounded humps, 1 to 2 cm wide, with a relief of a few millimetres. Short, transverse or inclined ribs are exceptional. Mostly it is covered by a wall, up to 3 mm thick, composed of from one or two to ten laminae (Fig. 12b, c). Generally, the marginal zone of columns is recrystallized, but in places, laminae bend down near the column margin and extend parallel to it for up to 2 cm. Even where wall recrystallized, outer lamina sharp, well preserved. In places, an unlaminate selvage, up to 0.5 mm thick, lines the column surface. This post-dates the wall formation, and pre-dates the interspace sediment. In the discrete column specimen, bridges rare; occasionally where two columns are closely spaced, a few laminae may bridge across. Rarely, overhanging peaks occur; especially if draped over an adjacent intraclast; some columns arise from laminae grown over intraclasts. Columns in the inferred marginal specimens partly un-walled; laminae thin and wedge out, forming a smooth margin, but do not extend over it.

**Lamina Shape:** Varies within broad limits. Gently convex laminae most frequent, varying in section from rectangular to hemispherical. Frequently, laminae develop two or more crests prior to branching, but in some cases, incipient branches are immediately bridged over, and growth of the original column resumed (e.g. the column on the right of the photograph in Fig. 12b). Different lamina shapes occur close together in a column, i.e. degree of inheritance of shape is low. Fig. 9b illustrates commonly occurring shapes. Of laminae measured, 69% have h/d ratio between 0.2 and 0.6, the mode (26%) being the interval between 0.2 and 0.3 (Fig. 10b). (In determining lamina shape, the poorly visible, downturned marginal portions of laminae in the wall had to be excluded). Laminae mostly slightly wavy, with wavelength 2 or 3 mm, and amplitude 0.2–0.5 mm.

**Microstructure:** Microstructure extensively recrystallized. Where alteration minimal, alternating light and dark laminae of greatly vary-

ing thickness form a distinct streaky microstructure (Fig. 12b). *Light laminae* are 0.1–0.5 mm thick. Occasional thicker light laminae (up to 1 mm) may actually be recrystallized macrolaminae. Light laminae are continuous across the column, but thin in the wall zone. Very rarely, they are truncated by micro-unconformities. They are wrinkled and wavy, corresponding to irregularities in the dark laminae, and consist of sparry, equidimensional, xenotopic to hypidiotopic calcite, of grain size 0.01–0.05 mm. Irregular patches, approximately 0.05 mm diam, are stained with a pale brownish (organic?) pigment. *Dark laminae* are 0.05–0.3 mm thick, but pinch and swell rapidly along their length. In many places, they are lenticular, consisting of contiguous lenses or nodules 0.1–0.5 mm long. Usually dark laminae persist across the column, but occasionally lens out completely, so that adjacent light laminae merge. The dark laminae which are thickest in their crests, consist of brown pigmented xenotopic, equidimensional calcite, of grain size 0.005–0.015 mm. In places, dark laminae limonitic. In areas of more pervasive recrystallization, grumous textures are developed in which clotty remnants of dark laminae are set in a matrix of sparry hypidiotopic calcite. Poorly differentiated macrolaminae, 0.5–2.00 mm thick, consisting of up to 8 light-dark lamination pairs, occur in many parts of columns. The internal structure of these is often not preserved, resulting in more or less homogeneous thick dark laminae with wavy, sharp, upper surfaces.

**Interspaces** 2 mm–5 cm wide; where columns more widely spaced, interspaces filled with silty intramicrite. Intraclasts are flat pebbles 0.5–3 cm long (Figs. 12b, c; 13a), subrounded, variously oriented, and loosely packed (matrix supported). Many stand vertically in the interspace. Some intraclasts are curved, suggestive of a mud-cracked origin. The matrix consists of broadly laminated silty, recrystallized lime mud; fine laminae, 2–5 mm thick, consist of xenotopic calcite of grain size 0.003–0.01 mm, while coarse laminae, of about the same thickness, consist of hypidiotopic 0.03–0.05 mm grain size calcite, with much subangular quartz silt. Laminations of the interspace sediment abut against the column walls, having accumulated after the development of significant relief of columns.

**Secondary Alteration:** Laminae are extensively altered especially in the marginal wall zone. In places the lamination is completely disrupted

around centres of recrystallization, but commonly faint lamination or rows of dark clots are preserved, to indicate the presence of originally continuous dark laminae in the wall zone. The outer few millimetres of columns are commonly recrystallized to coarser, twinned hypidiotopic calcite, of grain size up to 0.3 mm with inclusions of dark lamination relics. In places, an acicular texture is developed in the wall zone, perpendicular to the column margin. The central parts of columns are less affected, but even here, laminae are commonly reduced to dark clots in a sparry calcite matrix. Dolomitization of both interspace and columns is found in some specimens, where anhedral to subhedral rhombs of dolomite, 0.02–0.06 mm in grain size, are scattered more or less uniformly throughout a recrystallized sparry calcite mosaic. Frequently, lenses of coarsely crystalline, clear calcite occur within the lamination. Coarsely sparry patches, cutting across all earlier structures, are probably infillings of solution cavities, since they are closely associated with discordant stylolites. Stylolites are rather rare, and of two generations. The first are concordant with laminae, and contain concentrations of limonite. These are cut by major calcite veins, which in turn are offset by the discordant stylolites mentioned above.

#### Comparisons

The stromatolites are assigned to *Gymnosolen* on the basis of their column shape, frequent  $\gamma$ -parallel and slightly divergent branching, and wall. In overall column shape and type of branching, presence of pointed projections, shape of laminae and microstructure, the South Australian form closely resembles the type *G. ramsayi*. Slight differences include unwalled patches of columns, occasional peaks and bridges, and in places a slightly bumpier margin structure. *G. cf. ramsayi* is distinguished from *G. furcatus* by the absence of markedly  $\gamma$ -parallel, multiple branching and by the presence of pointed projections, and from *G. leviss* by its more widely spaced, less markedly humpy columns. *G. altus* Semikhatov has apparently been affected by a strong cleavage, and its columns are slightly deformed, making comparisons difficult, but it appears to have a more continuous, banded lamination. *G. asymmetricus* Raaben has thinner, smoother laminae than *G. ramsayi*. *G. confragosus* Semikhatov has in part (specimens from the Shurikhin Suite) been reassigned by Raaben (1969) to *Inzeria* (*I. confragosa*);

these specimens are distinguished from *G. ramsayi* by their irregular columns, interrupted wall and more frequent peaks and cornices. Semikhatov's specimens from the Dashkin Suite, now considered as Vendian (Krylov in Rozanov *et al.* 1969, p. 215), have much smaller, bumpier columns than *G. ramsayi*.

*Distribution*: Sub-Inzer Beds of the Katav Suite and Minjar Suite of the Karatau Series of the Southern Urals; Niz'ven Suite of the Polyudov Mountains; Carbonate Beds of the Metamorphic Series of the Kanin Peninsula; Kil'din Series of Kil'din Island; possibly the Sparagmites of Norway; Bystrin Suite of Southern Timan; Chatkaragai Suite of Tien-Shan; as clasts in Tapley Hill Formation, 8 km E of Wilson, southern Flinders Ranges, S. Aust.

*Age*: Late Riphean, in S. Aust., not younger than the Tapley Hill Formation.

#### Group INZERIA Krylov

*Inzeria* Krylov 1963: 71. Krylov 1967: 29. Cloud & Semikhatov 1969: 1042. Raaben 1969: 77. Glaessner, Preiss & Walter 1969: 1057.

*Type Form*: *Inzeria tjomusi* Krylov, from the Katav Suite of the southern Urals, and the Demin Suite of the Polyudov Mountains, USSR.

*Diagnosis*: Subparallel, usually unwalled, sub-cylindrical, ribbed columns, frequently with niches containing projections. Branching mostly  $\alpha$ - to  $\beta$ -parallel to slightly divergent, rarely  $\gamma$ -parallel or markedly divergent.

*Content*: *I. tjomusi* Krylov, *I. toctogulji* Krylov, *I. intia* Walter, and probably *I. dzejimi* Raaben and *I. nyfrysländica* Raaben. *I. (Minjaria) nimbifera* Semikhatov may be included, but Raaben (1969a) has placed it in synonymy with *I. tjomusi*, and has partly reassigned *Gymnosolen confragosus* Semikhatov to *Inzeria* (*I. confragosa*). Raaben has, however, considerably broadened the concept of *Inzeria*, placing little importance on Krylov's (1963) criteria of ribbed columns with niche-projections. On this basis, *Aldania* Krylov (in Rozanov *et al.* 1969) could perhaps be better included in *Inzeria*. Descriptions of *I. macula*, *I. variusata*, *I. sovintica* and *I. chunnbergica* Golovanov were unavailable, but Raaben's (1969, Fig. 21) illustration of *Inzeria macula* does not resemble any other described *Inzeria*. The new S. Aust. forms are *I. multiplex* and *I. conjuncta*.

*Age and Distribution:* Late Riphean, widespread in the USSR; Bitter Springs Formation, Central Aust.; Brighton Limestone and Wundowie Limestone, S. Aust.; Hinde Dolomite, and doubtfully, Dook Creek Formation, N.T.

**Inzeria** cf. *tjomusi* Krylov

FIGS. 3f, g, 4a-g, 13b-e

*Material:* Three specimens from Burr Well.

*Description*

*Mode of Occurrence:* The stromatolites form a lenticular bed, interbedded in green shales, and consist of four or five contiguous gently domed bioherms (Fig. 13c), 2-4 m diam., with a maximum thickness of about  $\frac{1}{2}$  m. Towards the west, the bed thins and lenses out gradually; in the easterly extension, columnar stromatolites give way to flat-laminated limestone. The lower portion of a domed bioherm consists of flat-laminated stromatolitic limestone, or contiguous, very broad cumuli (part of which are seen in Fig. 13d), up to 20 cm thick; overlying this (but never seen in sedimentary contact with it), is a zone, up to 20 cm thick, of discrete, vertical, subcylindrical columns, 2-10 cm wide. The base of these columns is an intensely stylolitic zone, in which a thickness of up to several centimetres has been removed by solution (Figs. 13b, d). At the margins of bioherms, the columns become irregular and slightly inclined from vertical. Columns are bridged over by a thin, poorly exposed zone of flat-laminated stromatolites.

*Column Shape and Arrangements:* Columns short, subcylindrical, with some swellings and constrictions, of diameter 2-10 cm (Figs. 3f, g, 4a-g), height 10-20 cm (the whole thickness of the columnar zone). Transverse sections round, rounded polygonal or slightly lobate. Columns have vertical, straight axes in the central parts of bioherms, but become irregular at the edges.

*Branching* into discrete new columns rare, perhaps due to the small thickness of the bed. Niche-projections very frequent; they are short, narrow, usually rounded, sometimes slightly elongated, set into niches in the side of the main column, which, most commonly, resumes its former diameter at the top of the niche (Figs. 13b, c; 4a, d, e, g). Occasionally adjacent columns coalesce.

*Margin Structure:* Due to strong recrystallization of columns the margin structure is obscure. Laminae approach the margin at a high angle, and are not deflexed at their edges;

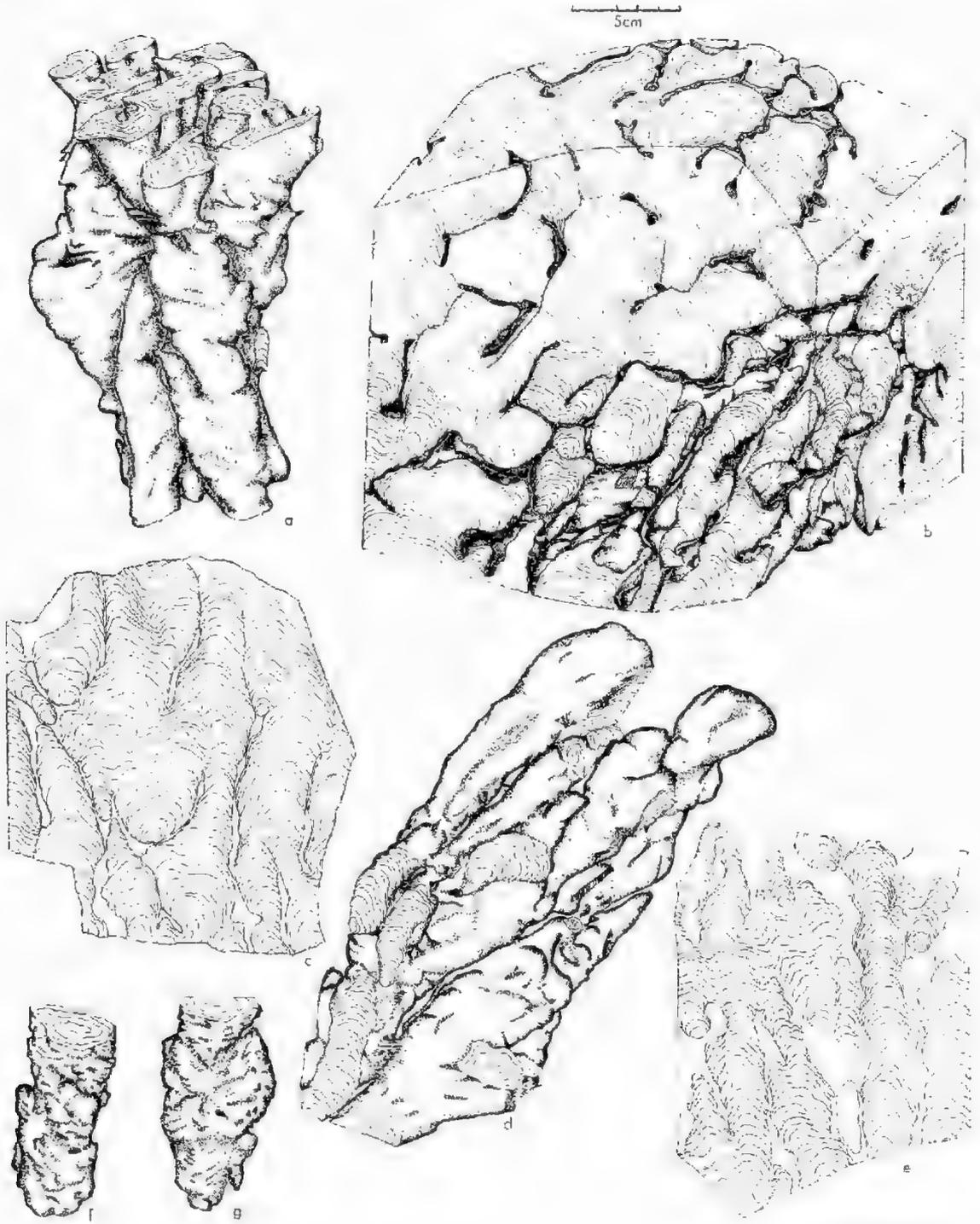
columns always unwallled. Lateral surface of columns with numerous short transverse ribs, up to 2 cm long, occasional overhanging laminae and peaks. In places, adjacent columns linked by bridges up to 5 mm thick.

*Laminae Shape:* Always gently convex, varying in shape from continuously curved domes to very low, obtuse cones, as illustrated in Fig. 9c. Lamina shape inherited from underlying laminae, without rapid changes in convexity. Ratios of h/d usually low; 91% of laminae have h/d between 0.2 to 0.4 (Fig. 10c). Fine-scale structure of laminae smooth to gently wrinkled.

*Microstructure:* Strongly recrystallized throughout columns, but in places the gross indistinctly banded structure of laminae is moderately well preserved (Fig. 13e). Relatively thicker light laminae alternate with thinner dark laminae but recrystallization has in places obliterated the distinction. All laminae have diffuse boundaries. *Light laminae* 0.2-2.5 mm thick, commonly significantly thicker at their crests than their edges, especially in the obtusely-conical laminae. They consist of a sparry, equigranular, hypidiotopic mosaic of calcite, of grain size 0.015-0.02 mm, with included small, irregular patches of darker pigmentation. *Dark laminae* either smooth or finely wrinkled (largely due to embayment by recrystallized adjacent light laminae), thickness 0.2-1.0 mm, generally thinner than adjacent laminae. Occasional thinner dark laminae are lenticular, but whether this feature is primary or due to recrystallization is unresolved. Like the light laminae, they are slightly thickened in their crests. Dark laminae consist of xenotopic, slightly inequigranular calcite, grain size 0.005-0.03 mm, stained with a pale brownish pigment.

*Interspaces* filled with homogeneous recrystallized lime mud, with occasional intraclasts. Calcite xenotopic to hypidiotopic, grain size 0.01-0.03 mm, contains about 5% angular quartz silt. Quartz grains corroded by recrystallized calcite. Occasional flat intraclasts up to 1 cm long, with diffuse boundaries, in parts of interspaces, recrystallized to sparry calcite mosaic, grain size 0.02-0.03 mm.

*Secondary Alteration:* The whole rock is pervasively altered. While columns are pale grey, transparent in thin section (Fig. 13c), the dark laminae perhaps tinted with organic matter, interspaces are pale buff, probably due to the presence of small amounts of limonite. Neither columns nor interspaces are dolomitized. The



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FIG. 3

boundary between interspace and column is always diffuse, obliterated by recrystallization in both. This reduces the reliability of the reconstructions. Highly irregular stylolites with large lobes separate the basal laminated sediment from the discrete columns, with a zone up to 5 cm thick of intense brecciation and late-stage infilling of fractures by coarsely crystalline calcite. Possible remnants of the lower portions of columns, highly enriched in limonite, are sometimes preserved between cross-cutting stylolites (Fig. 13e). Large sub-spherical nodules, up to 5 cm diam., of coarsely crystalline calcite are very common in the limestone at this locality, mostly located within columns. Twinned calcite crystals in these highly elongated, 1–3 mm wide, up to 3 cm long, vertical or radially arranged. Most crystals terminated upwards; their acute terminations project into the laminated limestone of columns. The major cross-cutting stylolites post-date the coarsely crystalline nodules. Over large areas, columns are completely recrystallized so that lamination is partly or totally obliterated. Such areas consist of xenotopic, to hypidiotopic mosaic calcite, grain size up to 0.5 mm. Where recrystallization incomplete, irregular fragments of disrupted dark laminae surrounded by sparry, recrystallized mosaic calcite.

#### Comparisons

The presence of ribbed columns with numerous niche-projections places the stromatolites in the group *Inzeria*. They are differentiated from all other Australian forms of *Inzeria* and from *I. tociogullii* Krylov and *I. djedini* Raaben by their very infrequent branching, consistently gently convex laminae (grading to low-conical rather than rectangular), and their short length of columns. In having subcylindrical, erect, ribbed columns with numerous niche-projections, they closely resemble Russian specimens of *I. tjomusi* Krylov, but differ in the thinness of the zone of columns; the absence of branching may simply be a consequence of the short length of columns. Unlike *I. tjomusi* from the Southern Urals, steeply convex laminae are absent. The microstructure with pinching and swelling or wrinkled dark laminae is similar, but the prominent concentrations of iron oxides along

concordant solution surfaces are absent. Until bioherms are found in which the columns had the opportunity to grow to a greater height, so that the mode and frequency of branching can be determined, and which are less recrystallized, so as to preserve the margin structure, no reliable identification is possible.

*Distribution:* Middle limestone band of the Wundowie Limestone Member, Umberatana Group; Burr Well, northern Flinders Ranges, S. Aust.

*Age:* Late Adelaidean, correlated with the Late Riphean or Vendian of the USSR.

#### *Inzeria conjuncta* f. nov.

FIGS. 4h-m, 9d, 10d, 14a, b

*Material:* Three specimens from near Depot Creek.

*Holotype:* S402 (Figs. 4a, b, i, j, 14a), from the Brighton Limestone equivalent, 3 km north of Depot Flat H.S., southern Flinders Ranges, S. Aust.

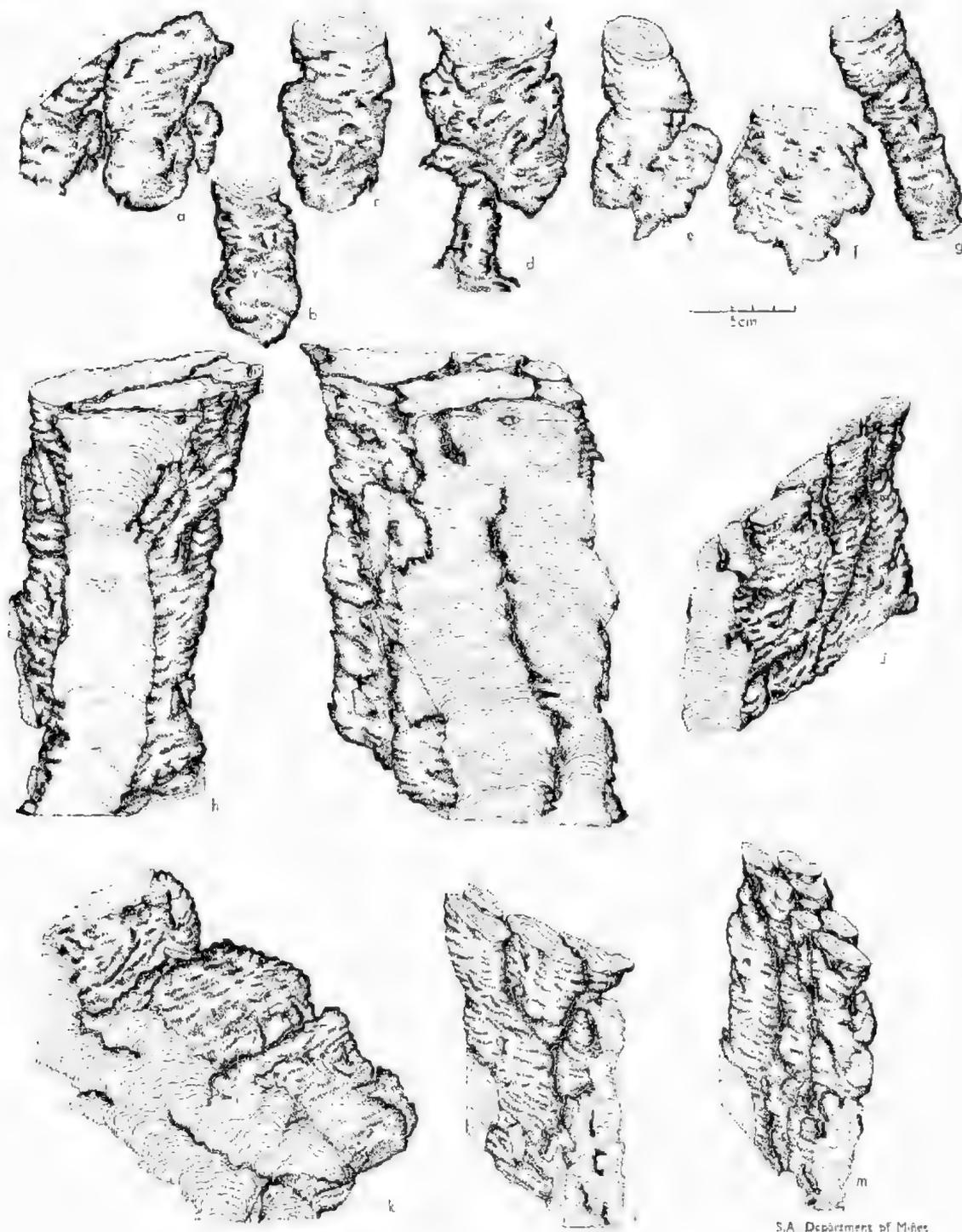
*Name:* Latin *conjuncta*, meaning joined, refers to the frequent coalescing and bridging of columns.

*Diagnosis:* *Inzeria* with broad, unwalled, rarely branching, frequently bridged and coalescing basal columns, which divide by  $\alpha$ -parallel branching into narrower, unwalled upper columns with occasional  $\alpha$ - and  $\beta$ -parallel branches. Niche-projections moderately frequent. Laminae nearly flat to rectangular or gently convex, wavy or wrinkled, with a distinct streaky microstructure.

#### Description

*Mode of Occurrence:* Field examination of bioherms is hampered by the very extensive lichen cover on rock faces and by the discontinuous outcrop. Three domed bioherms, up to 50 m long, 3 m thick, occur interbedded in massive oolitic and intraclastic limestone, and cannot readily be differentiated from *Acaeciella augusta* in the field. The basal, central portion of bioherms consists of flat-laminated stromatolitic limestone, passing up gradationally into broad columns, 5–20 cm wide with frequent coalescing and massive bridges. Flat-laminated intervals may intervene. At slightly different levels, the broad columns divide by  $\alpha$ -parallel branching into 1–5 cm wide columns.

Fig. 3. (a) to (e).—*Gymnosolen* cf. *ramsayi* from near Wilson; (a)—S388, vertical columns probably from a bioherm centre; (b) and (d)—S387, inclined columns interpreted to be derived from a bioherm margin; (c)—S389; (e)—S390, irregular and frequently coalescing columns. Traced from slabs; (f) and (g).—*Inzeria* cf. *tjomusi*. Wundowie Limestone Member, Burr Well, northern Flinders Ranges. S479.



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Fig. 4. (a) to (g)—*Inzeria* cf. *tjomusi*, Wundowie Limestone Member, Burr Well, Northern Flinders Ranges. (a), (b) and (c), S542; (d), (e), and (g)—S480; (f)—S479; (h) to (m)—*Inzeria conjuncta*, Brighton Limestone equivalent, Depot Creek; (h), (i), and (j)—Holotype S402, broad basal columns branching into narrow columns; (k)—S403; elongate columns from a bioherm margin; (l) and (m)—S398; narrow upper columns.

**Column Shape and Arrangement:** Broad columns in lower part of bioherms subcylindrical, up to 30 cm high in their discrete portions, commonly with rounded polygonal transverse sections. Where adjacent columns coalesce, or a wider column branches, transverse sections may be complexly lobate. Overlying narrow columns slightly elongated, from 1 x 2 cm to 3 x 5 cm in transverse section, up to 15 cm long between branches. Columns within central part of bioherm straight, erect (Fig. 4h, i, j) while at margins, they become inclined at 45°, slightly curved and strongly elongated (Figs. 4k, 14b), with swellings and constrictions.

**Branching:** Niche-projections are formed by unequal,  $\alpha$ -parallel branching, or, less commonly, divergent branching; the narrower column is set into the niche in the main wide column, which generally resumes its former diameter after the termination of the projection. Where projections branch divergently, they protrude beyond the margin of the main column. Projections 0.5–4 cm long. Within broad column level, branching (other than by niche-projections) rare. Broad columns then divide by  $\alpha$ -parallel, rarely  $\beta$ -parallel branching, into narrower 1–5 cm wide columns, which branch again, less frequently, by  $\alpha$ - or  $\beta$ -parallel branching. In marginal zone of bioherm, branching  $\beta$ - to  $\gamma$ -parallel, often with constriction at branching; niches still common, but elongated parallel to the long axes of platy columns (Fig. 4k).

**Margin Structure:** Lateral surface uneven, with very frequent transverse ribs, some small projections, bumps, bridges, and occasional small peaks. Ribs, 0.5–1 cm wide, may be followed around the column periphery for a few centimetres. Both massive and delicate bridges occur between adjacent columns, and, sometimes, between columns and projections. Niches in the column margins  $\frac{1}{2}$  to several centimetres deep; some niches partly closed at one end (Fig. 4h). Occasional niches elongated transversely, grading into prominent ribs (Fig. 4h, j). There is no wall; at the column margins, laminae thin only slightly, and either end abruptly or turn down and wedge out; they do not envelop the lateral surface of the column (Fig. 14a).

**Lamina shape** varies greatly from broad columns to upper narrow columns. In broad columns most laminae flat, gently convex, or rectangular (Fig. 9d). In places laminae develop two or more crests, then either the column

branches (if near the branching level) or the interspace is bridged over, and the column resumes its normal growth (Fig. 14a). In broad columns, measured values of  $h/d$  are below 0.25. In the narrow, upper columns, laminae are consistently more steeply convex. Of those measured, 81% lie between 0.3 and 0.6. Columns in the marginal zone of bioherms have laminae strongly asymmetrical towards the exterior of the bioherms, commonly as steeply convex as in the upper narrow columns (60% of  $h/d$  between 0.3 and 0.4). Fig. 10d illustrates the distribution of lamina convexities. All laminae wavy, with wavelength 2–4 mm, and locally wrinkled.

**Microstructure** distinctly streaky with both lenticular and continuous, wavy, swelling and constricting laminae. **Dark laminae** 0.05–0.3 mm thick, wrinkled and wavy, with non-parallel upper and lower boundaries, sometimes grading into aligned clots and lenses. They consist of equigranular hypidiotopic to idiotopic dolomite, grain size 0.005–0.01 mm. Crystals equidimensional and stained a pale green tint, responsible for the green colour of the laminae. No individual grains of pigment could be resolved even at 1200 x magnification. Amplitude of waves and wrinkles 0.2–0.5 mm, and thickness of laminae changes rapidly within a few millimetres. **Light laminae** consist of white to pale grey partly dolomitized sparry calcite of xenotopic to hypidiotopic texture, grain size 0.005–0.035 mm, tending to lens out near column margins where adjacent dark laminae merge. They also contain some coarser detritus, including fine sand-sized, well rounded quartz and feldspar, and small dolomite rhombs similar to those of the dark laminae but less pigmented. Over most of the area of thin sections, dark laminae tend to be grouped into macrolaminae 1–5 mm thick, which, like individual laminae, pinch and swell markedly. There is evidence of minor contemporaneous erosion of thickenings and wave-crests of macrolaminae.

**Interspaces:** Both lower broad and upper narrow columns are separated by narrow interspaces, 1–20 mm wide, but columns from bioherm margins are almost in contact. The infilling sediment is layered, either by sandy laminae, or by single stromatolitic laminae bridging between columns. Interspace laminae are depressed, concave upwards (Fig. 14a). The carbonate of interspaces is a dolomitized limestone; slightly inequigranular hypidiotopic calcite (partly recrystallized lime mud), grain

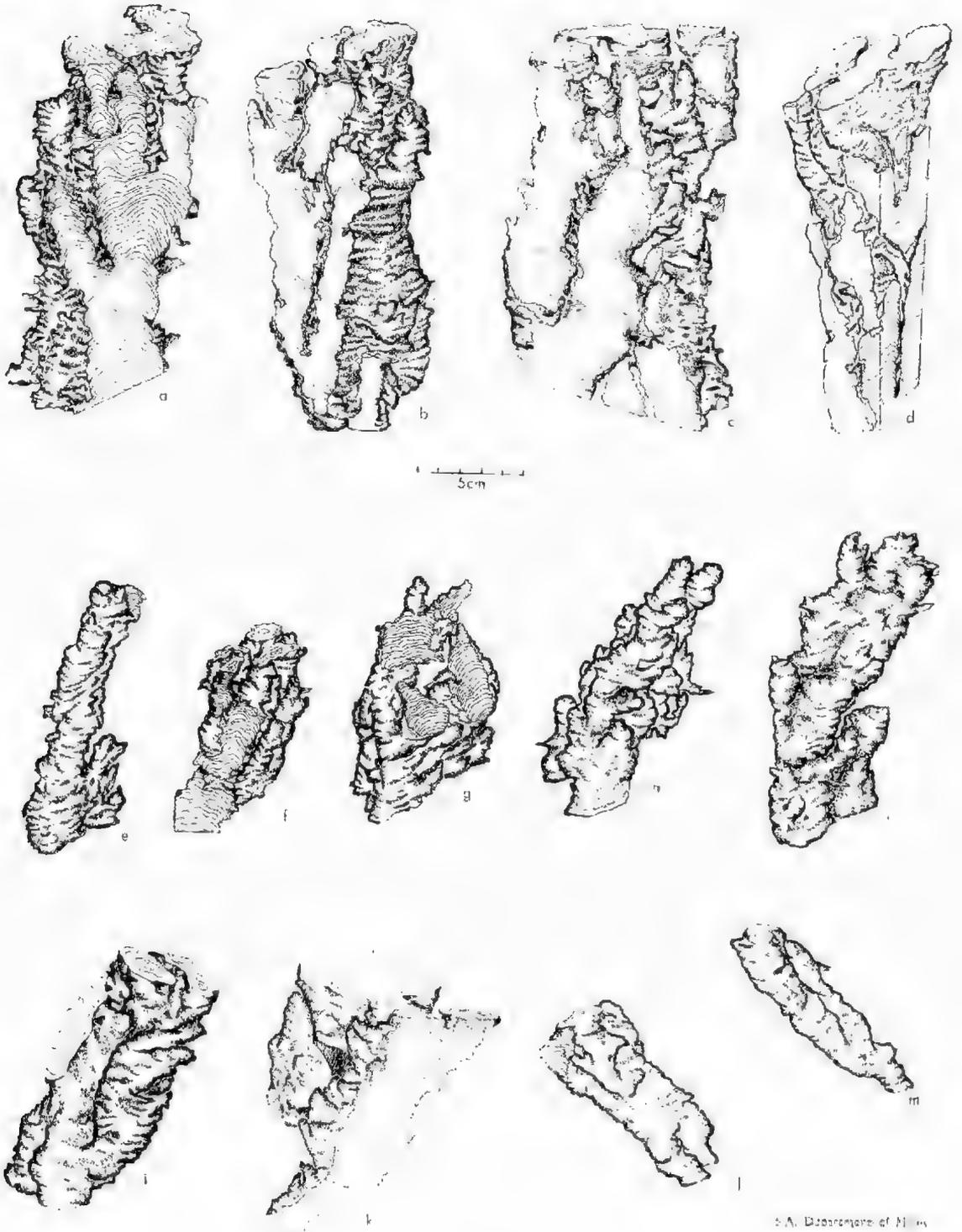


FIG. 5

size 0.005–0.02 mm, contains subhedral rhombs of dolomite, 0.005–0.05 mm diam. In places, quartz sand laminae up to a few millimetres thick abut against the column margins, suggesting that they post-date the growth of that portion of the adjacent column. No carbonate allochems were observed. At times of bridging, the structures had a relief of less than one centimetre, and bridging laminae may be only one or two centimetres apart.

**Secondary Alteration:** Quartz and feldspar grains, both in columns and interspace sediment, have corroded boundaries; in places their margins are completely replaced by carbonate. While the dark laminae are almost completely dolomitized, the lime mud comprising the light laminae and the interspace filling is only patchily dolomitized and also contains hypidiotopic, coarser calcite due to partial recrystallization. The dolomitization is probably secondary. Stylolites rare except in the bioherm margins, where they separate contiguous columns. Small vughs, up to 3 mm diam., filled with coarse, twinned sparry calcite occasionally cut across the lamination. The origin of the green coloration of dark laminae is not clear, since no particles of pigment could be resolved; the dolomite crystals themselves are tinted. Surface oxidation during weathering either partly removes the colour, or deposits yellow-brown limonite in interspaces or along stylolites.

#### Comparisons

The stromatolites are difficult to distinguish in the field from *Acaciella angusta* Preiss, but are assigned to *Inzeria* on the following characters: ribbed lateral surface, absence of wall, dominance of parallel branching, and niche-projections. The upper narrow columns also resemble *Katavia* and *Kulparia* but are distinguished by the presence of long transverse ribs, the absence of a wall, and by microstructure; unlike *Katavia* and *Kulparia*, their projections are usually rounded, and set in niches. *I. conjuncta* differs from *I. tjomusi* Krylov and *I. intia* Walter in having frequently coalescing columns, and consistently gently convex, wavy and wrinkled laminae; it lacks the consistently elongated niche-projections and the complex bioherms of *I. intia*. Unlike *I. djefimi* Raaben, its columns are straight, with frequent niche-

projections, and rarer branching. *I. conjuncta* is distinguished from *I. toctogulii* Krylov by its less frequent, dominantly  $\alpha$ -parallel branching, and by its coalescing and bridging. *I. conjuncta* is especially similar to *Aldania sibirica* in margin structure and microstructure, but has more irregular and coalescing columns. As pointed out above, *Aldania* might be better included in *Inzeria*.

**Distribution:** Brighton Limestone equivalent, 3 km north of Depot Flat H.S., southern Flinders Ranges, S. Aust.

**Age:** Late Adelaidean, correlated with the Late Riphean of the USSR.

#### *Inzeria multiplex* f. nov.

FIGS. 5, 9e, 10e, 14c, d, 15a

**Material:** Six specimens from near Melrose and Yednaluc.

**Holotype:** S385, from the Brighton Limestone equivalent, 8 km NW of Mt. Remarkable, near Melrose, S. Aust. (Figs. 5a–i, 14c, d).

**Name:** Latin *multiplex*, meaning complex, manifold or with many parts.

**Diagnosis:** *Inzeria* with frequent, dichotomous to multiple,  $\alpha$ - and  $\beta$ -parallel to slightly divergent branching, and rarer branches arising from niches. Columns have irregular transverse sections. Margin bears ribs, bumps and short projections. Laminae gently convex, smooth to wrinkled, with regularly streaky microstructure.

#### Description

**Mode of Occurrence:** Due to poor outcrop, the exact mode of occurrence at Mt. Remarkable is not known; a large bioherm is inferred, since, when followed along strike, the stromatolitic bed passes into massive intraclastic limestone, but the contact is not exposed. At Yednaluc, the stromatolites form a very thick bed, which has not been traced laterally. In outcrop, the stromatolites at Mt. Remarkable resemble laterally linked forms, and columns become discernible only when the rock surface is cut.

**Column Shape and Arrangement:** Columns tuberos to subcylindrical, erect to inclined (Figs. 5; 14c, d), with straight or gently curved axes; occasional columns sharply bent, especially when associated with coalescing. Height

Fig. 5. (a) to (m)—*Inzeria multiplex*, Brighton Limestone equivalent, southern Flinders Ranges: (a–i)—Holotype S385, west of Mount Remarkable; (j, k)—S499. Float specimen, east of Yednaluc; (l, m)—S498. Outcrop specimens, east of Yednaluc.

of columns between branching 4–20 cm. Transverse sections of columns round or rounded polygonal to irregular and lobate at points of branching or coalescing. Columns which may be variously elongated, vary from 1 to 5 cm in diam. At top of bed, columns frequently bridged by continuous, laterally linked layers.

**Branching** very frequent and complex, either arising from niches in the parent column (Fig. 5i), or, most commonly, by equal division (Fig. 5a, b, c), usually  $\beta$ -parallel, rarely  $\alpha$ - or  $\gamma$ -parallel, or slightly divergent (Figs. 14c, 15a). Adjacent columns frequently coalesce, especially in the upper part of bed.

**Margin Structure:** Column margins irregular, with numerous, short transverse ribs, low bumps and some slightly overhanging laminae. Bumps and ribs locally grade into very short, outgrowing projections, less than 1 cm long, which are more common than projections set in niches, especially in the Mt. Remarkable specimens (Fig. 14d). There is no wall; commonly gently convex laminae terminate at the column margin, without bending over, sometimes overhanging to form small peaks and cornices. Small portions of column margins relatively smooth. Bridges involving any number of laminae are common, especially near top of bed.

**Lamina Shape:** Almost always gently convex (Fig. 9c); even in the narrowest columns h/d does not exceed 0.5. Of laminae measured, 93% have h/d between 0.1 and 0.4, the mode (40%) being in the range between 0.2 and 0.3 (Fig. 10c). Laminae may be doubly-crested, prior to branching. On a small scale, laminae broadly wavy, and in places slightly wrinkled.

**Microstructure:** Alternation of light, sparry laminae and dark, iron-stained laminae, with indistinct boundaries and varying continuity. In places, laminae grouped into macrolaminae 1 or 2 mm thick. Boundaries between laminae frequently wrinkled. *Light laminae* 0.1–1.5 mm thick; usually constant across the column width, smooth, wrinkled or wavy (Fig. 14c), with parallel upper and lower boundaries. Varying abundances of fine quartz sand and silt are incorporated in the light laminae, which consist of hypidiotopic to idiotopic carbonate, grain size 0.01–0.03 mm. Grains equidimensional, sometimes cubical. *Dark laminae* thinner, generally 0.1–0.5 mm, but pinch and swell across the column width; crests of laminae commonly thickest. Dark laminae

grade from smooth to wrinkled, and frequently become discontinuous, forming chains of clots and lenses up to 1 mm long, separated by sparry carbonate (Fig. 14c). Dark laminae, clots and lenses composed of reddish-brown iron-stained, xenotopic carbonate, grain size 0.003–0.01 mm.

**Interspaces:** Columns generally closely spaced, interspace width 1 mm–3 cm. The sediment is different in the two areas of occurrence.

(1) At Mt. Remarkable, it is broadly laminated reddish dolomitic; laminae 1–4 mm thick, generally flat or slightly concave upwards. Darker laminae generally thinner (up to 1 mm); of xenotopic dolomite of grain size 0.003–0.005 mm, alternating with thicker, paler, laminae, up to 4 mm thick, of xenotopic dolomite, 0.005–0.015 mm grain size, with a high percentage of terrigenous detritus (angular quartz silt of grain size 0.02–0.05 mm, and occasional mica flakes). Intraclasts up to 1 cm long, 2 mm thick, locally present in interspace, generally standing vertically or inclined (Figs. 14c, d).

(2) At Yednalue, the interspaces are filled with unlaminated sandy limestone, with quartz and feldspar grains, 0.1–1.0 mm grain size, sub-rounded to well rounded, all embayed by hypidiotopic to idiotopic calcite cement of grain size up to 0.6 mm. Sand grains mostly tightly packed, in places separated by a greenish argillaceous matrix (Fig. 15a).

**Secondary Alteration:** Specimens from Mt. Remarkable consist entirely of dolomite, while those from Yednalue are calcite. Mt. Remarkable specimens are, however, better preserved: the idiotopic and hypidiotopic dolomite probably formed during early diagenesis, but did not destroy the fine structure of the stromatolites. The dolomitic rock may have proved more resistant to later recrystallization, which has in both areas disrupted the fine lamination to a greater or lesser extent. In addition, cleavage is well developed at Yednalue, and the columns are slightly deformed, so that metamorphism may partly account for the greater recrystallization here. Occasional concordant slightly sutured stylolites follow the lamination, sometimes affecting several adjacent columns, but all are cross-cutting on a fine scale. Greenish argillaceous material is concentrated in the stylolites. Some stylolites follow column margins and thus remove the minor surface features of columns (Fig. 15a). Tectonic veins are filled with quartz or calcite.

### Comparisons

The stromatolites are assigned to *Inzeria* because of their ribbed columns with projections, but they frequently resemble *Baicalia* in their tuberous shape; *Baicalia*, however, much more often has divergent branching, more overhanging laminae, and a distinctly banded microstructure. In having some  $\alpha$ -parallel branching, they resemble *Kussiella* Krylov and *Acaciella* Walter, but are distinguished by their frequent  $\beta$ -parallel branching and branching from niches. *Inzeria multiplex* is distinguished from *I. thomasi* Krylov, *I. imia* Walter, and *I. confincta* Preiss by its very frequent branching, and rare projections set in niches. In these features it resembles *I. toctogulii* Krylov and *I. djefimi* Raaben, but *I. toctogulii* has more regular, cylindrical columns, while *I. djefimi* has steeply convex laminae.

**Distribution:** Brighton Limestone equivalent; 8 km NW of Mt. Remarkable and 12 km E of Yednaluc, southern Flinders Ranges, S. Aust.

**Age:** Late Adelaidean, correlated with the Late Riphean of the USSR.

### Group JURUSANIA Krylov

*Jurusania* Krylov 1963; 81. Raaben 1964; 93. Krylov in Rozanov *et al.* 1969; 195. Cloud & Semikhatov 1969; 1045. Semikhatov, Komar & Serebryakov 1970; 166. Bertrand-Sarfati 1972; 52.

**Type Form:** *Jurusania cylindrica* Krylov, from the Katav Suite of the Southern Urals.

**Diagnosis:** Even, parallel, subcylindrical columns with round or oval transverse sections and rare, dichotomous  $\alpha$ -parallel branching. Columns partly walled, partly bear downward directed peaks and overhanging laminae, frequently covered with an unlaminated selvage.

**Content:** *Jurusania cylindrica* Krylov, *J. tumuldurica* Krylov, *J. nivensis* Raaben and *J. judomica* Komar & Semikhatov. *J. sibirica* Jakovlev has been transferred by Krylov (1969) to a new group, *Aldania*, but Semikhatov, Komar & Serebryakov (1970) retain its assignment to *Jurusania*. Bertrand-Sarfati (1972) has erected new forms *J. derbalensis*, *J. lissa*, *J. alta*.

**Age:** Late Riphean to Vendian.

### *Jurusania burrensis* f. nov.

FIGS. 6a-h, 9f, 10f, 15b-c, 16a

**Material:** Four specimens from Burr Well.  
**Holotype:** S543 from the upper limestone

hand of the Wundowie Limestone Member, Burr Well, northern Flinders Ranges, S. Aust. (Figs. 6d, e, f, 15e).

**Name:** After the Burr River, on the bank of which the stromatolites occur.

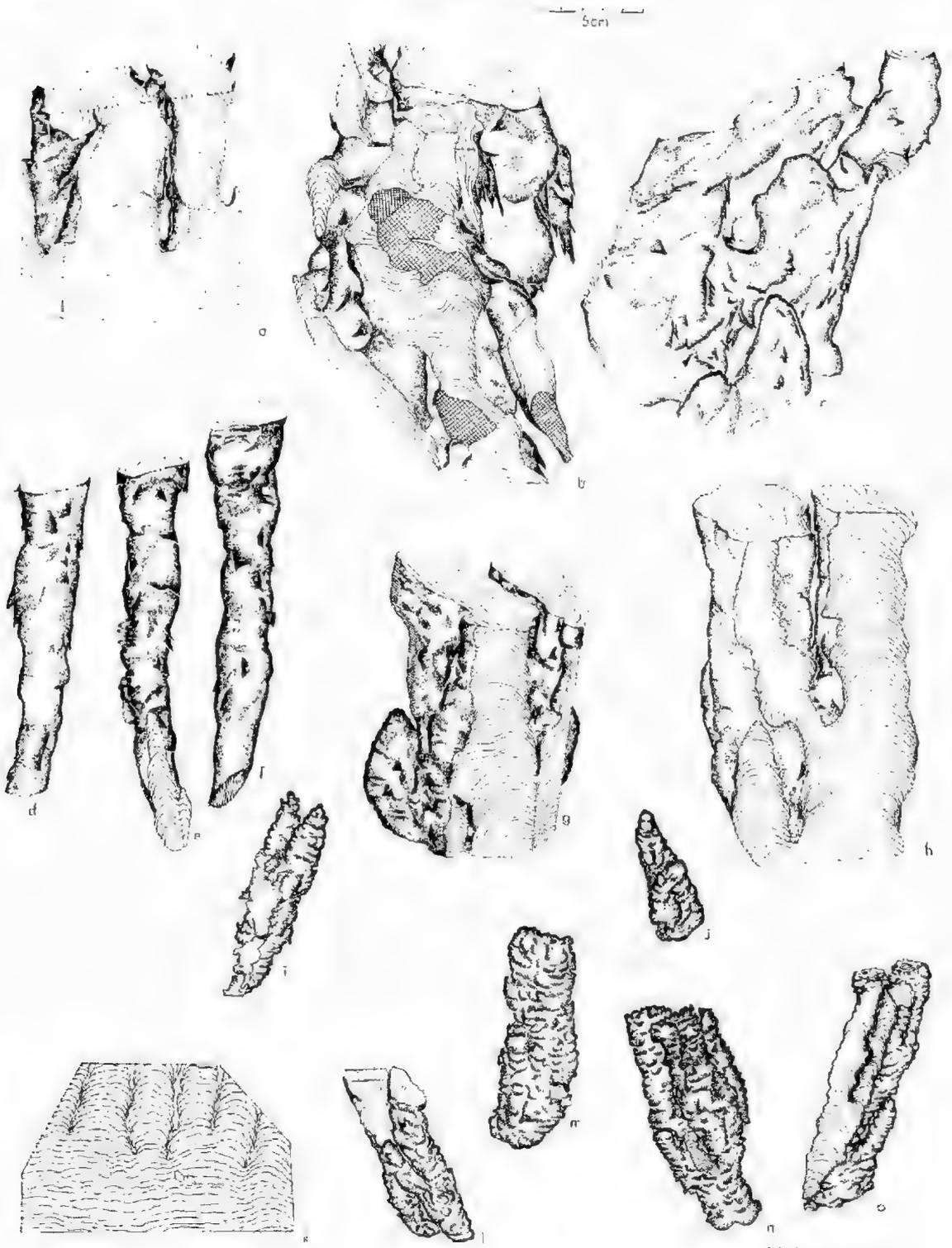
**Diagnosis:** *Jurusania* with smooth to gently bumpy, partly walled columns and local, short peaks and overhanging laminae. Lamina shape gently convex to subconical, laminae lenticular with diffuse, streaky microstructure. Columns partly covered by an unlaminated selvage.

### Description

**Mode of Occurrence:** The stromatolites occur in lenticular beds of contiguous spherical and subspherical bioherms up to 2 m diam. (Fig. 15c). The bioherms consist of 3 concentrically arranged zones, capped by an undulating columnar zone. Bioherm cores up to 50 cm thick consist of irregularly pseudocolumnar and columnar-layered stromatolites of dark grey limestone, overlying sandy limestone with large, reworked intraclasts. Cores surrounded by concentrically laminated zone, from which long straight, parallel columns arise. At bioherm margins, columns slightly inclined, rarely subhorizontal; generally columns remain subparallel throughout the bioherm, but show more bridging and coalescing at margins. Spherical bioherms, mutually in contact, overlain by flat or broadly undulating 1 m thick beds of columns with numerous bridges and pseudocolumns.

**Column Shape and Arrangement:** Columns long, straight, parallel or radially arranged, cylindrical or subcylindrical. In one specimen from near the base of a bioherm, columns somewhat inclined, irregular, tuberous, and of strongly elliptical or lobate transverse section (Fig. 6b, c); otherwise transverse sections round or slightly elliptical. Columns mainly smooth, with only occasional low, broad bumps (Figs. 6a-d, 15b, d, e); single columns generally have constant diameter, 5-10 cm for basal columns (Fig. 6h) and 2 cm for upper, narrow columns (Fig. 6d, e, f). Length of columns between branches may exceed 30 cm; the whole columnar zone of bioherms is up to 1 m thick. Columns in the overlying undulating bed rather short, and frequently bridged, apparently arising from basal, flat-laminated stromatolites (Figs. 6a, 16a, specimen S481, but the exact location of this specimen in the bioherm is not certain).

**Branching** rather infrequent especially in narrow, uppermost columns, which may be up to



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FIG. 6

30 cm long between branches, but more often terminate their growth before branching. Branching always dichotomous, either  $\alpha$ - or slightly  $\beta$ -parallel (Figs. 6g, h). Occasionally two neighbouring columns may coalesce, especially in upper parts of bioherms.

**Margin Structure** generally smooth, walled or unwalled, bearing only broad low bumps several cm wide and of relief up to 5 mm (Figs. 6a-h). Laminae generally approach the margin at an acute angle, but the actual margin is frequently removed by stylolites. In areas not affected by stylolites, laminae either terminate at margin, or extend down for a distance of up to 1 cm to form a patchy wall (Fig. 15d, e). In a few places, laminae overhang slightly to form small peaks, a few mm long (Fig. 6e, f, g). Large overhanging peaks developed only on the irregular columns (Fig. 6b), from the lower parts of bioherms. Considerable areas of smooth columns coated with a selvage, 0.2–1.0 mm thick, of unlaminated very fine grained calcite (Fig. 15d).

**Lamina Shape** varies to some extent with column width, but most laminae gently convex with relief about 1 cm (85% have h/d between 0.2 and 0.5, Fig. 10f); a few narrow columns have steeply convex to subconical laminae (Fig. 9f). Laminae smoothly curved, micro-unconformities rare. Lamina shape always inherited from the underlying laminae, so that no marked, rapid changes occur. Fine scale structure of laminae lenticular and very gently wavy, with wavelength of 2–5 mm, amplitude 0.1 mm.

**Microstructure:** The dark limestone comprising the pseudocolumnar bioherm cores is almost entirely recrystallized, and even the lamination is rarely preserved. Lamination in columnar parts of bioherms diffuse, streaky, consisting of alternating, finely wavy, lenticular, dolomitized sparry pale laminae and darker, micritic laminae, which intergrade. *Micritic laminae* recrystallized to microspar, grain size 0.005–0.015 mm, of xenotopic, polygonal, equigranular texture; they have very vague boundaries, and vary in thickness from 0.2–0.5 mm over short distances. In places, laminae thin and terminate laterally, or consist of short,

aligned lenses a few millimetres long. *Sparry laminae* 0.1–0.5 mm thick, pinching and swelling but more continuous across column width, consist of hypidiotopic to xenotopic calcite, grain size 0.01–0.03 mm, with scattered subhedral dolomite crystals, grain size 0.015–0.06 mm. In places, laminae almost completely dolomitized, consisting of closely packed hypidiotopic dolomite with remnant interstitial sparry calcite. Sparry laminae may also be completely recrystallized, with little dolomitization, to a hypidiotopic mosaic of grain size up to 0.2 mm. The unlaminated selvage present in places on column margins consists of xenotopic calcite mosaic, grain size 0.005–0.02 mm; its origin is not clear (see secondary alteration).

**Interspaces:** Columns 0.5–2.0 cm apart. Interspaces filled with poorly bedded intramicrite, partially dolomitized. Intraclasts mostly flat limestone pebbles, 0.5–3 mm thick, 2–30 mm long, generally lying parallel to bedding, or standing vertically in narrowest interspaces (Fig. 15d). The flat pebbles, which commonly have rounded margins, consist of xenotopic, equigranular mosaic calcite of grain size up to 0.01 mm, and contain scattered subhedral dolomite crystals, grain size 0.010–0.015 mm. Subrounded to well rounded quartz and feldspar sand grains occur in places. Intraclasts moderately loosely packed, so that some in contact, some not; sediment was probably matrix-supported. The matrix, probably originally micritic calcite, recrystallized to xenotopic inequigranular texture, grain size up to 0.015 mm, occasionally with scattered dolomite crystals. The matrix may be preferentially dolomitized. In the specimen apparently from the undulating bed capping bioherms, interspaces filled with markedly upward concave laminated, recrystallized lime mud, without intraclasts; laminae somewhat thicker (approximately 3 mm) and more regular than those of the stromatolite columns.

**Secondary Alteration:** Even the finest calcite laminae have probably undergone some recrystallization to form a very fine grained calcite mosaic. Dolomitization apparently postdates this, as subhedral dolomite crystals cut across the calcite mosaic. In places, especially near

Fig. 6 (a) to (h)—*Jurusania buerensis*, Wundowie Limestone Member, Burr Well, northern Flinders Ranges: (a)—S481; basal columns arising from undulating stromatolites; (b), (c)—S483; irregular columns at bioherm margin; (d), (e), (f)—Holotype S543; regular narrow upper columns; (g), (h)—S482; regular broad, lower columns; (i) to (o)—*Katavia costata*, Brighton Limestone equivalent, Depot Creek, southern Flinders Ranges; (i), (j), (l), (m), (n), (o) Holotype S175; narrow, subcylindrical columns; (k)—S519; basal columns arising from undulating stromatolite.

column margins, laminae are completely reconstituted to a coarse, xenotopic, polygonal calcite mosaic, grain size up to 0.5 mm; these, in turn, contain subhedral dolomite crystals, as well as disrupted remnants of micritic laminae. The origin of the unlaminated selvage is not clear; wherever it was observed, laminae are somewhat coarsely recrystallized immediately adjacent to it inside the column, and the selvage may simply be the outermost lamina of the wall preserved from recrystallization, but this is not certain since the selvage is unlaminated, and laminae cannot usually be traced directly into it. There are at least two generations of calcite veins: the earlier ones are more irregular, finer grained, and contain dolomite rhombs, suggesting that they pre-date at least one period of dolomitization. The younger veins are straight, more coarsely crystalline, and post-date dolomitization. Dolomitization in these stromatolites is, at least in part, very late diagenetic.

#### Comparisons

In having long, straight, infrequently branching columns without rapid changes in diameter, these stromatolites are distinguished from all but *Minjaria* Krylov and *Jurusania* Krylov. They are distinguished from other  $\alpha$ - or  $\beta$ -parallel branching stromatolites (*Boxonia* Korolyuk, *Acaciella* Walter and *Katavia* Krylov) by their infrequency of branching. *Minjaria* Krylov, however, has a ubiquitous wall and lacks peaks and overhanging laminae. *Jurusania* Krylov may have either a patchy wall or no wall, numerous peaks, and frequently a selvage covering columns. *J. hurrensis* is intermediate between *Minjaria* and *Jurusania* but is assigned to the latter because of its patchy wall and the presence of peaks. *J. hurrensis* differs from *J. cylindrica* Krylov in having a better developed wall, smaller and fewer peaks, and less well defined lamination; however, lamina shape is similar. *J. tumulidurica* Krylov is distinguished by its consistent, well defined ribs and general absence of a wall. *J. hurrensis* is distinguished from *J. nixensis* Raaben by its much more even, smooth columns which do not grade into or alternate with pseudocolumns and laterally linked stromatolites; also, there are no sharp changes in lamina shape as in the latter form. *J. judonijica* Komar & Semikhatov has larger, often strongly elongated columns, lacking a wall. *J. derbaleus* Bertrand-Sarfati and *J. alta* Bertrand-Sarfati also lack walls and have ragged column margins. *J. lissa* Bertrand-Sarfati is

distinguished by the absence of peaks and corners, and by more frequent branching.

*Distribution:* Upper limestone band of Wundowie Limestone Member, Burr Well, northern Flinders Ranges, S. Aust.

*Age:* Late Adelaidean, correlated with the Late Riphean or Vendian of the USSR.

#### Group KATAVIA Krylov

*Katavia* Krylov 1963: 94. Raaben 1969: 83. Glaessner, Preiss & Walter 1969: 1057.

*Type Form:* *Katavia karatavica* Krylov, from the Katav-Suite of the Southern Urals.

*Diagnosis:* Predominantly  $\beta$ -parallel branching straight, subcylindrical, walled columns with a markedly bumpy margin structure.

*Content:* *Katavia karatavica* Krylov and *Katavia costata* f. nov.

*Age:* Late Riphean.

#### *Katavia costata* f. nov.

*Katavia* sp. nov. Glaessner, Preiss & Walter 1969: 1057.

FIGS. 6i-o, 9g, 10g, 16b-d, 17u

*Material:* Seven specimens from near Depot Creek, S. Aust.

*Holotype:* S175 (Figs. 6i, j, l, m, n, o, 16d) from the Brighton Limestone equivalent, Depot Creek, southern Flinders Ranges, S. Aust.

*Name:* Latin *costata*, meaning "ribbed", refers to the short ribs present on the lateral surface of columns.

*Diagnosis:* *Katavia* with very closely spaced parallel columns, a thin wall, very indistinct and wrinkled laminae, and a prominently bumpy and ribbed margin structure with some very short pointed projections.

#### Description

*Mode of Occurrence:* The stromatolites form two lenticular bioherms, 5 m thick, and up to 100 m long, in the upper, pink dolomite member of the Brighton Limestone equivalent. The basal one metre consists of wrinkly flat-laminated dolomite, with concordant stylolites. This zone gives rise directly to narrow, parallel columns (Fig. 6k), which continue throughout the height of the bioherm (Fig. 16b). At frequent intervals columns cut by horizontal, concordant stylolites. The upper surfaces of bioherms not exposed. At margins of bioherms columns become inclined at about 45° (Fig. 17a), but no horizontal columns were observed.

*Column Shape and Arrangement:* Columns long, straight, very closely spaced, diam. 0.5-3

cm, most commonly 1–2 cm (Fig. 16d). Most columns vertical, except near bioherm margins. Cross-sections round to polygonal; often resembling mud-cracked polygons (Fig. 16c). Columns may be 5–20 cm long between branches; occasional columns only a few cm long have pointed terminations (Figs. 6i, j, l, m, n, o).

*Branching* moderately frequent, predominantly  $\beta$ -parallel: a column 1.0–1.5 cm diam. widens gradually to 2–3 cm, then divides into two, less often three, narrower columns (1–1.5 cm in diameter).  $\alpha$ -parallel branching from broad columns does not occur. Some branching very slightly divergent.

*Margin Structure:* Lateral surface of columns markedly bumpy and ribbed (Fig. 6i–o). Equidimensional humps, 0.3–1.0 cm diam., with a relief of 2–5 mm most common. These grade into transversely elongated ribs, which partly surround the columns. Small, pointed projections up to 1 cm long moderately frequent (Fig. 6i, l), and in places slight niches in the column margin (Fig. 16d). Overhanging peaks extremely rare; bridges absent in specimens studied. Near column margin, laminae turn down steeply to cover lateral surface for short distances, so that only two or three laminae form the wall (Fig. 16d), which is developed almost everywhere, covering all humps, ribs and projections.

*Lamina Shapes:* Laminae in basal, flat-laminated portion poorly preserved, but appear to be wavy and wrinkled. The lowest narrow columns generally have gently convex, wavy and wrinkled laminae, but degree of convexity increases upwards. Undulations have wavelength 2–5 mm. Fig. 9g illustrates commonly occurring lamina shapes. 62% of laminae measured have h/d between 0.3 and 0.5 (Fig. 10g). Most laminae hemispherical, some approach rectangular shape. Laminae near the most bumpy column margins commonly strongly wavy.

*Microstructure:* Lamination in all specimens extremely indistinct. Where best preserved, it consists of alternating relatively lighter and darker, pale brownish stained dolomite laminae, many of the light laminae containing detrital quartz sand grains, restricted to the central parts of columns. *Light laminae* have extremely indistinct boundaries, are 0.3–2.0 mm thick, and thin markedly towards column margins. Included sand grains subrounded to subangular, grain size 0.05–0.5 mm. Dolomite hypidiotopic, of inequidimensional crystals,

grain size 0.005–0.025 mm, often showing approximate rhombic outlines. There are variations in the intensity of the brownish pigmentation present in the crystals. *Dark laminae* extremely fine grained, more densely stained reddish-brown, 0.05–0.5 mm thick, most clearly visible and thickest in marginal portions of columns, but thin, markedly wrinkled, and discontinuous, frequently consisting of lenses only 1 or 2 mm long, in central part. Towards margin, dark laminae frequently merge.

*Interspaces* extremely narrow, 1–5 mm wide, most commonly 1–2 mm. Sedimentary filling unlaminated, consists of equal proportions of sand and dolomite matrix. Quartz sand grains subrounded, commonly 0.2–0.5 mm diam., a few up to 2 mm. Feldspar and red, extremely fine grained, possibly igneous rock fragments sub-ordinate. Matrix consists of hypidiotopic to xenotopic dolomite, with equidimensional crystals of grain size 0.005–0.03 mm, patchily recrystallized to hypidiotopic sparry dolomite of 0.03–0.05 mm grain size. Intraclasts of pale brownish fine grained dolomite, up to 5 mm long, 2 mm wide occur in places mixed with sand grains. These probably represent fragmented algal laminae.

*Secondary Alteration:* The generally poorly preserved microstructure of stromatolitic and interspace dolomite and its corrosion of quartz grains suggest that it is secondary. Small irregular patches of recrystallized, fine sparry dolomite are scattered throughout columns and interspaces. Layering in stromatolitic columns is extremely indistinct, and defined only by slight variations in grain size and pigmentation; this general homogeneity may be partly due to dolomitization. Dark laminae are in places disrupted, perhaps by recrystallization of the intervening light laminae. All detrital quartz grains have corroded margins, usually surrounded by a thin rim of finely crystalline sparry dolomite. Authigenic chlorite is developed in places in the interspace sediment near column margins. Small stylolites are developed locally near column margins but are unimportant. Frequent large stylolites, concordant with bedding, were seen in the field (Fig. 17a). These are up to 1 cm wide, and contain marked concentrations of sand and authigenic chlorite.

#### Comparisons

The stromatolites are assigned to the group *Katavia* because of their  $\beta$ -parallel branching, bumpy, walled columns. They are distinguished

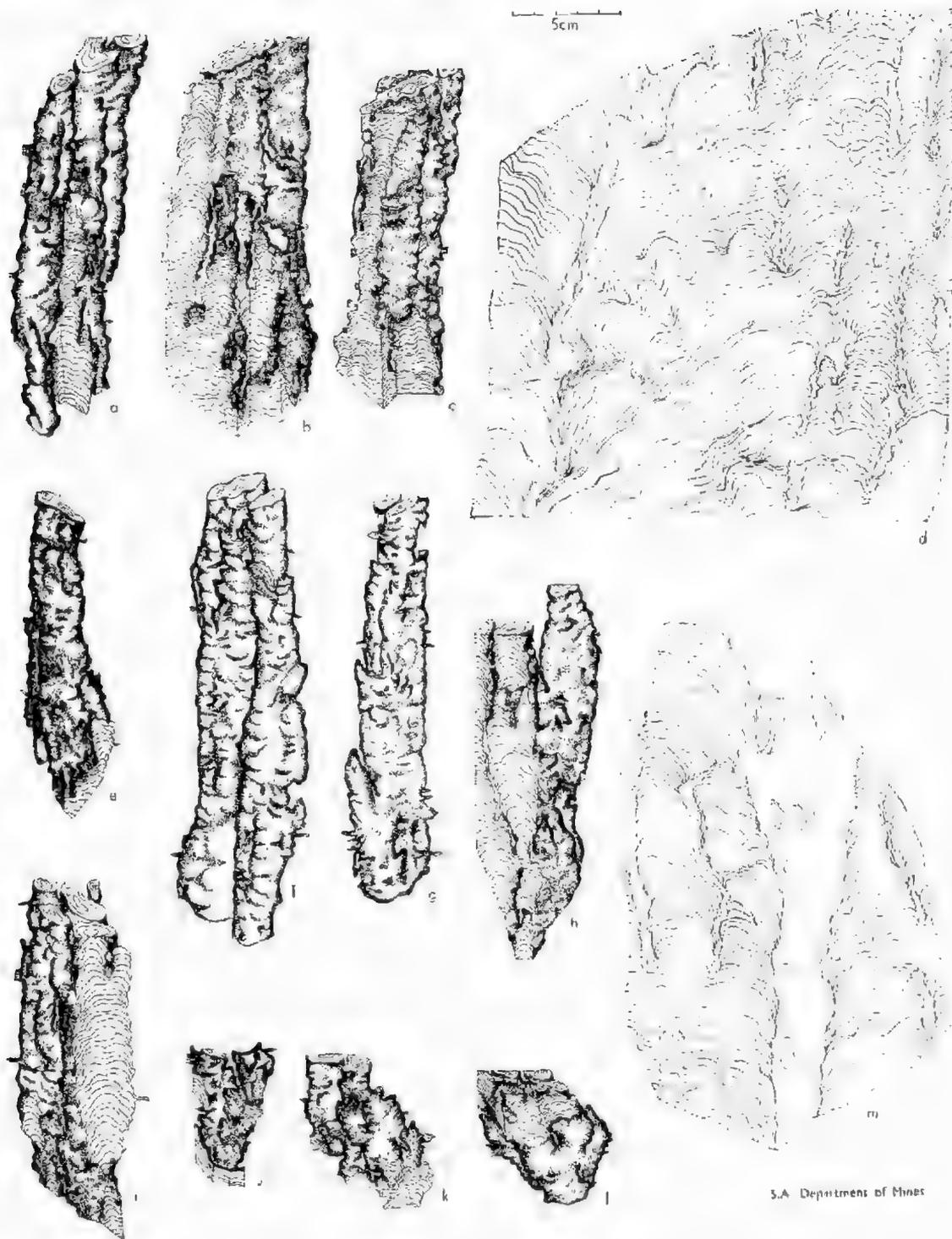


Fig. 7. (a) to (m)—*Kulparia kulpurensis*, Etina Formation equivalent, near Kulpara, northern Yorke Peninsula: (a), (b), (c), (e), (i)—Holotype S380, from unit C (Fig. 8); (d), (m)—S419; junctions between two contiguous domes, unit C (Fig. 8), (m) is cut by a sand dyke, including stromatolitic fragments; (f), (g)—S420, from unit E (Fig. 8); (h)—S271, from unit C (Fig. 8); (j)—S381, (k), (l)—S270, from unit A (Fig. 8).

from most other walled stromatolites by their markedly bumpy margin structure, and from *Patomia* Krylov by their predominantly simple,  $\beta$ -parallel branching. Like the illustrations of *Katavia karatavica* Krylov, *K. costata* has a few very short pointed projections. It is extremely similar to *K. karatavica* in its gross form, microstructure and margin structure, and is distinguished only by its more closely spaced columns and by the possession of short transverse ribs.

**Distribution:** In two bioherms, upper (dolomite) member of the Brighton Limestone equivalent, 3 km N of Depot Flat H.S., southern Flinders Ranges, S. Aust.

**Age:** Late Adelaidean, correlated with the Late Riphean of the USSR.

Group KULPARIA Preiss & Walter  
(in Walter 1972: 151)

*Patomia* sp. nov., Glaessner, Preiss & Walter (1969, p. 1057).

**Type Form:** *Kulparia kulporensis* Preiss, from the Etina Formation equivalent, Umerakana Group; Yorke Peninsula, S. Aust.

**Name:** After the township of Kulpara, northern Yorke Peninsula, S. Aust.

**Diagnosis:** Long, nearly straight, parallel bumpy columns, erect or radially arranged with very frequent coalescing and bridging, moderately frequent  $\alpha$ - and  $\beta$ -parallel branching and a wall between bridges; projections may be moderately frequent.

**Content:** *K. kulporensis* Preiss and *K. alicia* (Cloud & Semikhatov) Walter.

**Comparisons**

In gross form, *Kulparia* resembles *Minjaria* Krylov and *Baxonia* Korolyuk, but is distinguished by its bumpy column margins with frequent bridging and coalescing. Like *Katavia* Krylov and *Patomia* Krylov, it has a walled, bumpy margin structure; *Katavia* columns have  $\beta$ -parallel branching, no bridges and they rarely coalesce, while *Patomia* has frequent slightly divergent branching and very numerous pointed projections. Some illustrations of *Patomia ossica* Krylov, from the Malokaroy Suite, resemble *Kulparia* in having bumpy, long subparallel columns with fewer projections, but lack the frequent coalescing and delicate bridges of *Kulparia*. *Kulparia kulporensis* was initially assigned to *Patomia* on the basis of this similarity (Glaessner, Preiss & Walter 1969). *Kulparia* differs from *Linella* Krylov in lacking gnarled and tuberous

columns, and from *Gymnosolen* Steinmann in lacking  $\gamma$ -parallel branching. In gross form, *Kulparia* also resembles the walled parts of *Inzeria intia* Walter but is distinguished by the absence of niches and elongated projections.

**Distribution:** Etina Formation equivalent, S. Aust. and Bitter Springs Formation, C Aust.

**Age:** Adelaidean.

***Kulparia kulporensis* f. nov.**

FIGS. 7, 8, 9h, 10h, 16c, 17b-f

**Material:** Eleven specimens from Kulpara, S. Aust.

**Holotype:** S380 (Figs. 7a, b, c, e, l, 17d, e) from the Etina Formation equivalent, Kulpara.

**Name:** After the township of Kulpara. **Diagnosis:** *Kulparia* with very frequent delicate bridges, moderately frequent pointed projections and variable lumina shape, from gently to steeply convex. Microstructure diffuse, irregularly streaky.

**Description**

**Mode of Occurrence:** A bed traced for at least 400 m, its northern extension not known, while its termination in the south can be located only approximately, due to lack of exposure. Stromatolitic bed up to 13 m thick, occurs at passage from flaggy pale grey clean limestone to massive, gritty, cross-bedded limestones. The basal portion of the bed (A) (Fig. 8), commencing conformably upon the flaggy limestones, consists of short, partly divergently branching columns and pseudocolumns, in thin beds up to 15 cm thick, with numerous bridges and continuous, nearly flat-laminated layers. This is overlain by a broadly domed biostrome (C) of long, narrow, vertical, parallel, very closely spaced columns, arising from a laterally linked zone and short, broad, basal columns (B). The upper surface of the biostrome of long parallel columns bends downwards sharply at the junctions between domes, columns becoming inclined, and to some extent pseudocolumnar. The domed biostrome pattern is repeated in the overlying undulose and pseudocolumnar bed (D), again passing up into long, parallel columns (E), once more overlain by laterally linked and pseudocolumnar layers (F). Gritty, cross-bedded limestone overlies the stromatolitic sequence. Contacts between the various units cannot be accurately placed in the field, due to poor exposure and lichen cover, but were

partly deduced from laboratory study of specimens (Fig. 8).

**Column Shape and Arrangement:** Unit (A) consists of short, vertical to slightly inclined columns, 5–20 mm wide branching frequently from a wavy laminated layer. Columns swell and constrict slightly, bear rounded humps and occasional ribs, and coalesce frequently. Some columns terminate their growth as pointed projections (Figs. 7j, k, l, 17f); overlying unit (B) in part columnar. If present, columns broad, up to 6 cm wide, with very irregular, bumpy outlines and numerous massive bridges, grading laterally and vertically into pseudocolumns with occasional interspaces. In the main columnar units (C) and (E), columns 1–3 cm wide, swelling and constricting slightly (Fig. 17d, e). A few branches develop only into short, pointed projections (Fig. 7f, g). Length of long, parallel columns between branches 5–20 cm; the unit as a whole attains a thickness of up to 2 m, but columns not continuous throughout, as pseudocolumnar horizons intervene. Transverse sections generally rounded polygonal, lobate, elongated or irregular; circular sections relatively rare. At dome edges, columns slightly inclined (never at less than 60° to the horizontal), and bridged to a greater extent, forming pseudocolumns resembling those in units (B) and (D) (Fig. 7d, m).

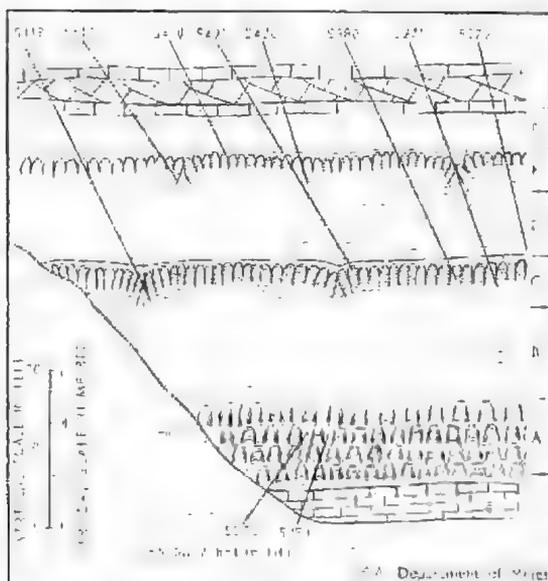


Fig. 8. Diagrammatic section of stromatolitic bed near Kulpara. The relative positions of the specimens were partly determined in the field and partly deduced from laboratory specimens.

**Branching:** Basal columns of unit (A) characterized by frequent, slightly divergent branching (Fig. 7j, k, l). Long, parallel columns of units (C) and (E) entirely  $\alpha$ - and  $\beta$ -parallel branching. Near their bases, broad columns and pseudocolumns (4–6 cm wide) branch into several 1–3 cm columns. Above this level,  $\alpha$ - and  $\beta$ -parallel branching moderately frequent. Coalescing of neighbouring columns is as frequent as branching.

**Margin Structure:** All columns have a markedly bumpy lateral surface; bumps 0.5–1.0 cm wide, with a relief of 1–5 mm most common. Most equidimensional, some grade into short transverse ribs, others into short pointed projections (Fig. 7f, g). Longer pointed projections (up to 3 cm) moderately rare (Fig. 7g). Delicate bridges, composed of only one or two laminae very frequent, linking most adjacent columns (Fig. 17d), usually depressed, U-shaped (only the more prominent bridges could be shown on reconstructions). Massive bridges up to 2 cm thick moderately rare. Successive delicate bridges in places only 5 mm apart. Occasionally very short peaks project down from the column margins. Wherever peaks and bridges do not occur, wall well developed. Wall most extensive in the long, narrow columns. Laminae thin towards margin, and coat surface for a distance of up to 1.5 cm. The wall involves from one to five laminae (Fig. 17d, e). The short basal columns of unit (A) have only a patchy wall, as do some of the long columns with gently convex laminae (Fig. 17b).

**Lamina Shape:** very variable; generally narrowest columns have steepest laminae, while broad basal columns and pseudocolumns have gently convex and rectangular laminae. Of the laminae measured, 69% have ratios of  $h/d$  between 0.3 and 0.8, but narrow columns and projections usually have  $h/d$  greater than 1.0 (Fig. 10h). Fig. 9h illustrates commonly occurring lamina shapes. Most laminae gently wavy, usually with wavelength 2–3 mm.

**Microstructure:** Lamination indistinct and streaky (Fig. 17d, e). Where best preserved, fairly continuous wavy dark laminae persist from wall to wall, and alternate with light laminae. Dark laminae composed of very fine grained silty limestone, consisting of equidimensional xenotopic calcite of grain size 0.003–0.01 mm, with included subrounded quartz and a little feldspar, of grain size up to 0.08 mm. Dark laminae 0.05–0.4 mm thick.

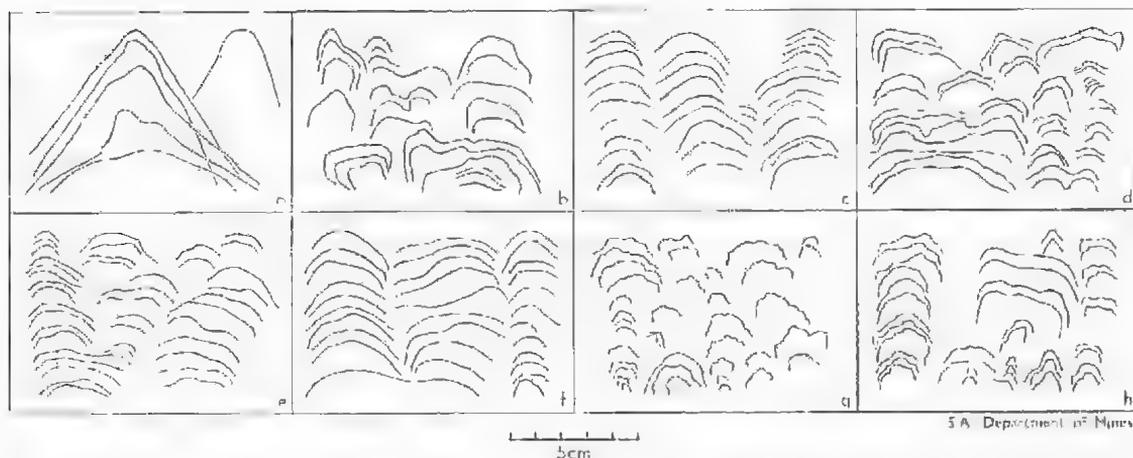


Fig. 9. Examples of lamina shapes of the stromatolites, traced from thin sections. (a)—*Canophyton garganicum garganicum*; (b)—*Gymnosolen* cf. *ramsayi*; (c)—*Inzeria* cf. *tjomusi*; (d)—*Inzeria conjuncta*; (e)—*Inzeria multiplex*; (f)—*Jurusania burrensis*; (g)—*Katavia costata*; (h)—*Kulparia kulparensis*.

generally thickest in central part of a column. Boundaries diffuse. At column margins, dark laminae thin to a thickness of about 0.05 mm and coat surface of column. Intervening light laminae thinned more, and lens out some distance down the wall, so that here dark laminae merge. Light laminae up to 0.7 mm thick in central parts of steeply convex laminated columns, but thin rapidly towards the edges. They consist of inequigranular xenotopic to hypidiotopic calcite of grain size 0.015–0.05 mm, with minor rounded quartz silt, of grain size up to 0.08 mm. In the short columns of unit (A) lamination is better preserved (Fig. 17f). Dark, homogeneous laminae, 0.15–1.0 mm thick, are composed of pale brownish and greenish pigmented, almost equigranular xenotopic calcite, of grain size 0.003–0.01 mm, with inclusions of detrital quartz silt of grain size 0.02–0.04 mm. In places, they have sharp

lower boundaries, but grade upwards into light laminae, which are 0.3–1.5 mm thick, but thin towards the column margins, and are composed of slightly coarser, silty, xenotopic calcite, of grain size 0.015–0.02 mm. Detrital quartz grains are up to fine sand size (0.2 mm). All laminae extend uninterrupted across the width of columns, unlike laminae in the upper, long parallel columns.

*Interspaces* generally very narrow (1–5 mm) in units (C) and (E), but wider in basal columns of unit (A). Their sedimentary fill includes medium to coarse clastics, both terrigenous and carbonate. Generally, quartz much coarser than that incorporated into columns. The sediment consists of approximately 40% quartz (well-rounded, grain size 0.5–3 mm, finer grains tending to be subangular), 5% feldspar (rounded to subangular cloudy micro-

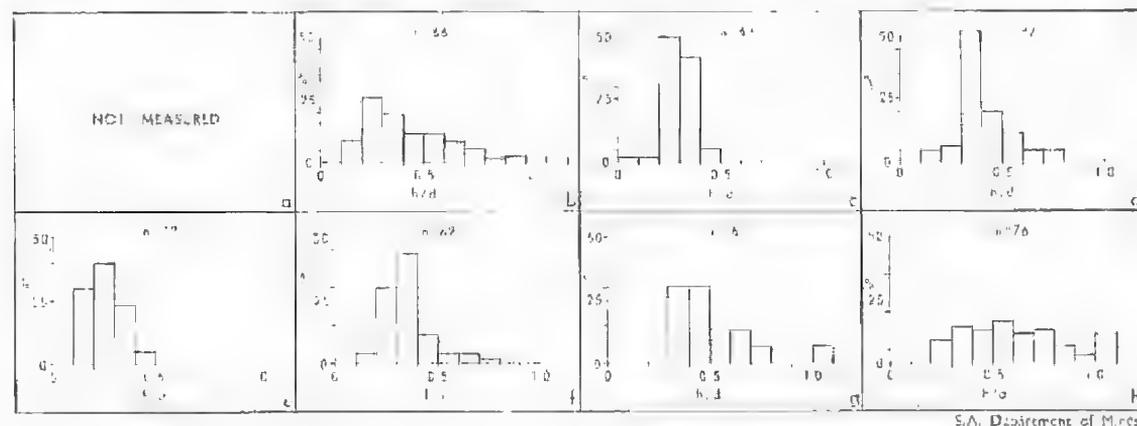


Fig. 10. Frequency distribution of lamina convexities  $h/d$  for stromatolites illustrated in Fig. 9.

cline, up to 3 mm grain size), 5% rock fragments (rounded fragments, up to 4 mm, of quartz-feldspar rock, quartzite and rare chert), 30% carbonate allochems (including flat pebbles 2-4 mm long, flat pebbles coated with 3 or 4 pale and dark laminae, recrystallized ooids with dolomitic rims and rare composite grains cemented by dark dolomitic rims) and 20% cement (sparry, hypidiotopic mosaic calcite, of grain size 0.015-0.06 mm cementing allochems and terrigenous detritus, in places replacing the rims of these grains). Sediment poorly bedded. Presence of wall between bridges on columns indicates that sediment was filled in periodically. After one influx of sediment, a bridge formed over it, then the interspace remained vacant while the column grew another centimetre or so, before the next influx.

*Secondary Alteration:* During diagenesis, the carbonate of the long columns was partly recrystallized and dolomitized; some dark laminae were preferentially dolomitized, and clays were apparently redistributed into a fine network of cracks and stylolites (Fig. 17e). In places, the shape of laminae is completely disrupted. Near the dome margins, lenticular patches of sparry calcite occur within columns, either concordant with the laminae or at a high angle to them. These structures predate clastic dykes which cut both stromatolite columns and interspace sediment (both of which must have been lithified at the time) (Fig. 17b). The filling of the dyke consists of angular to subrounded, poorly sorted quartz, of grain size 0.05-1 mm. The sand is tightly

packed, the finest angular grains forming the matrix. Calcite cement is almost totally absent; quartz grains are coated with iron oxide rims. In places, the filling process has actively eroded the walls of dykes, so that disoriented fragments of the surrounding limestone occur as inclusions in the sand (Fig. 17b). The dykes probably formed by jointing of the already lithified stromatolitic bed, especially between adjacent domes. Concordant stylolites, concentrated at definite levels in the structures, where they are only 1 or 2 mm apart, clearly post-date the sand-dykes. Stylolites partly follow the lamination, and partly cut across it. Vertical calcite veins up to 1 cm wide, consisting of coarse, euhedral crystals, post-date the stylolites, and are especially prominent in the junctions between domes, which were persistently subject to jointing. Dolomitization apparently post-dates the formation of veins and stylolites, and is therefore very late diagenetic.

#### Comparisons

These stromatolites have already been compared to other groups. *Kulparia kulparensis* is distinguished from *K. alicia* (Cloud and Semikhov) Walter, by its frequent delicate bridges, generally more steeply convex laminae, and by the presence of moderately frequent pointed projections.

*Distribution:* Etina Formation equivalent, Umheratana Group, 7 km south of Kulpara, northern Yorke Peninsula, S. Aust.

*Age:* Late Adelaidean, correlated with the Late Riphean or Vendian of the USSR.

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- Fig. 11. *Conophyton garganicum garganicum*, from a raft in the Paratoo Diapir: (a)—Near-axial section in outcrop of two adjacent columns illustrating margin structure. The pen is 15 cm long. Arrows indicate irregular column margins; (b)—Transverse sections of columns in outcrop, illustrating both circular and lanceolate shapes. The pen is 15 cm long; (c)—Outcrop section of broadly domed basal zone, which gives rise upwards to conically laminated columns. (d)—Thin section of crestal zone, brecciated perhaps by compaction of lithified laminae. Specimen No. S277; (e)—Details of lamination, illustrating macrolaminae, detrital carbonate granules (indicated by arrows), and swelling of some laminae. Thin section, specimen No. S214; (f)—Details of crestal zone illustrating contorted and thickened lamination. Axial longitudinal section. Thin section, specimen No. S532.
- Fig. 12. (a)—*Conophyton garganicum garganicum* (Spec. No. S214). Longitudinal axial thin section illustrating crestal zone, lamination, and deflexed margins of laminae. The thick continuous bands are actually macrolaminae. Natural size; (b), (c)—*Gymnosolen* cf. *ramsayi*, from boulders in a conglomerate in the Tapley Hill Formation, near Wilson, Flinders Ranges: (b)—S388, Longitudinal thin section of vertical, branching columns, with intraclast breccia in interspaces. Natural size; (c)—S387, Longitudinal thin section of inclined columns interpreted as derived from a bioherm margin.
- Fig. 13. (a)—*Gymnosolen* cf. *ramsayi* from near Wilson. Longitudinal slab of regular, walled columns interpreted to be derived from a bioherm centre. Specimen No. S388; (b) to (c)—*Inzeria* cf. *flamula*, from the middle limestone of the Wundowie Limestone Member, Burr Well, northern Flinders Ranges: (b)—Columnar portion of a bioherm illustrating columns with niche-projections. Note stylolites at base; (c)—Domed basal part of bioherm with continuous lamination; the upper columnar portion is separated by a stylolitic zone. Hammer is 30 cm long; (d)—Columnar zone overlying continuously laminated basal portion of bioherm. Note stylolitic zone at pencil point. Pencil 17 cm long; (e)—Longitudinal thin section, illustrating subcylindrical columns with altered margins and interspaces, gently convex to low conical laminae and a niche-projection. The basal part is intensely cut by stylolites. Specimen No. S452.
- Fig. 14. (a), (b)—*Inzeria conjuncta*, Brighton Limestone equivalent, Depot Creek, southern Flinders Ranges: (a)—Longitudinal thin section of broad, basal columns with niche-projection. The laminae are alternating dark, dolomitic, and light, calcitic. Holotype, S402; (b)—Longitudinal thin section of inclined, tuberos columns from bioherm margin. Specimen No. S403; (c), (d)—*Inzeria multiplex*, Brighton Limestone equivalent, west of Mount Remarkable, southern Flinders Ranges: (c)—Longitudinal thin section of vertical columns. Natural size. Holotype, S385; (d)—Longitudinal slab of same specimen.
- Fig. 15. (a)—*Inzeria multiplex*, Brighton Limestone equivalent, east of Yednalue, southern Flinders Ranges. Longitudinal thin section. Specimen No. S499; (b) to (c)—*Juraxania hurrensis*, upper limestone of the Wundowie Limestone Member, Burr Well, northern Flinders Ranges: (b)—Smooth cylindrical vertical columns near a bioherm margin. Hammer is 30 cm long; (c)—Contiguous spherical bioherms; (d)—Longitudinal thin section illustrating dichotomous  $\alpha$ -parallel branching in cylindrical columns. Specimen No. S482; (e)—Longitudinal thin section of narrower cylindrical columns with streaky microstructure. Holotype S543.
- Fig. 16. (a)—*Juraxania hurrensis*. Longitudinal thin section of columns arising from undulating stromatolites at base. Specimen No. S481; (b) to (d)—*Katavia costata*, from dolomitic "member" of the Brighton Limestone, Depot Creek: (b)—Long, vertical columns in longitudinal outcrop section. Hammer is 30 cm long; (c)—Transverse section of columns in outcrop. Pen is 15 cm long; (d)—Longitudinal thin section illustrating indistinct lamination and walled columns. Interspaces are filled with sandy dolomite. Holotype, S175. Natural size. (e)—*Kulparia kulparensis*, Etina Formation equivalent, Kulpara. Part of outcrop of cylindrical columns. Pen is 15 cm long.
- Fig. 17. (a)—*Katavia costata*, Brighton Limestone, Depot Creek, southern Flinders Ranges, Margin of a bioherm showing inclination of columns at right of photograph; (b) to (f)—*Kulparia kulparensis*, Etina Formation equivalent, Kulpara, northern Yorke Peninsula: (b)—Longitudinal thin section illustrating a sand dyke post-dating the lithification of the stromatolites. Incorporated in the dyke filling are fragments of the wall rock. Specimen No. S420; (c)—Outcrop transverse sections of lobate columns. Pen is 15 cm long; (d), (e)—Longitudinal thin sections of columns; holotype S380; (f)—Small irregular columns from Unit A at the base of the bed; longitudinal thin section. Specimen No. S270.

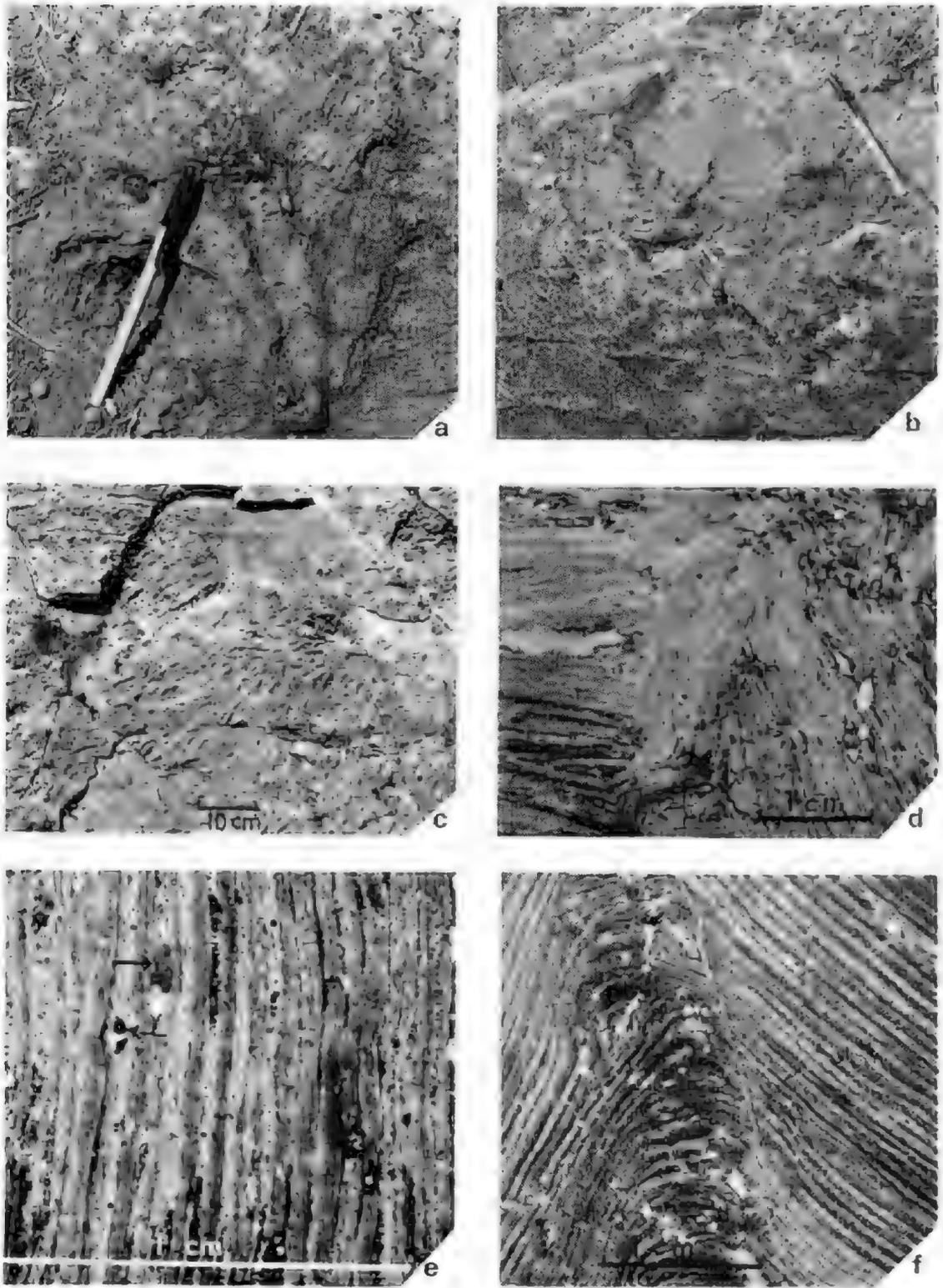


FIG. 11

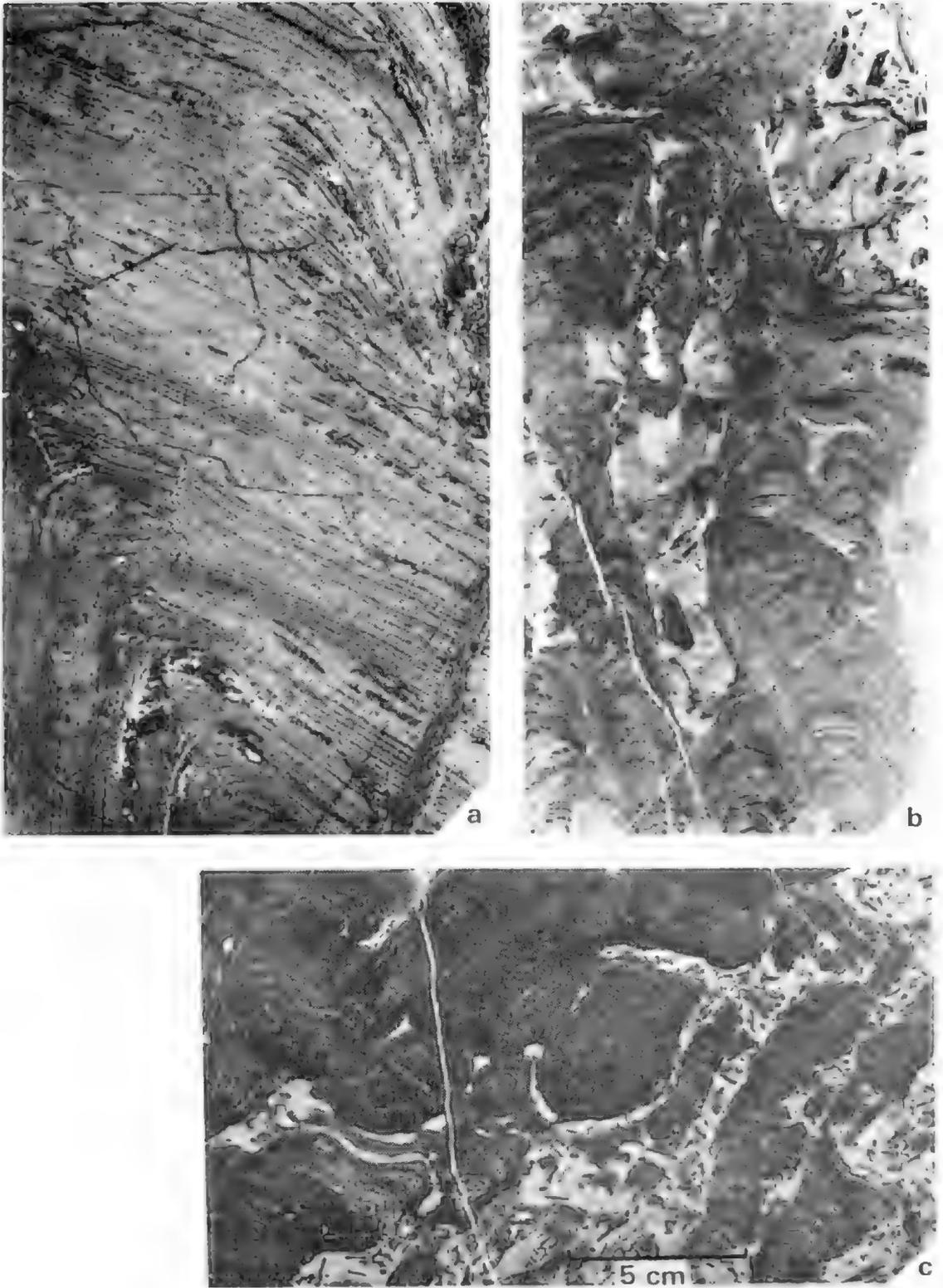


FIG. 12

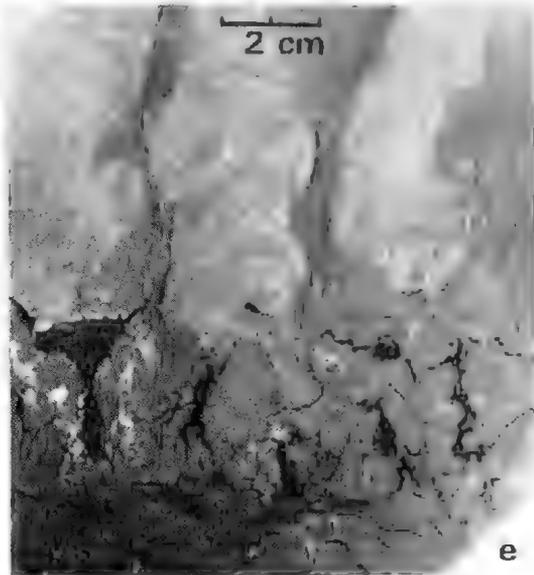
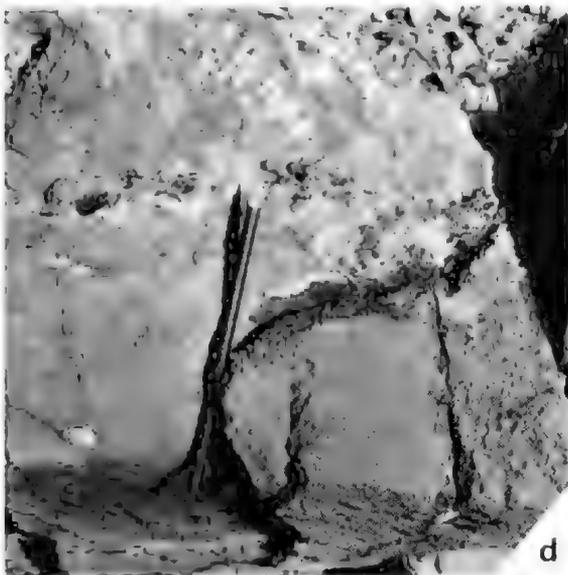
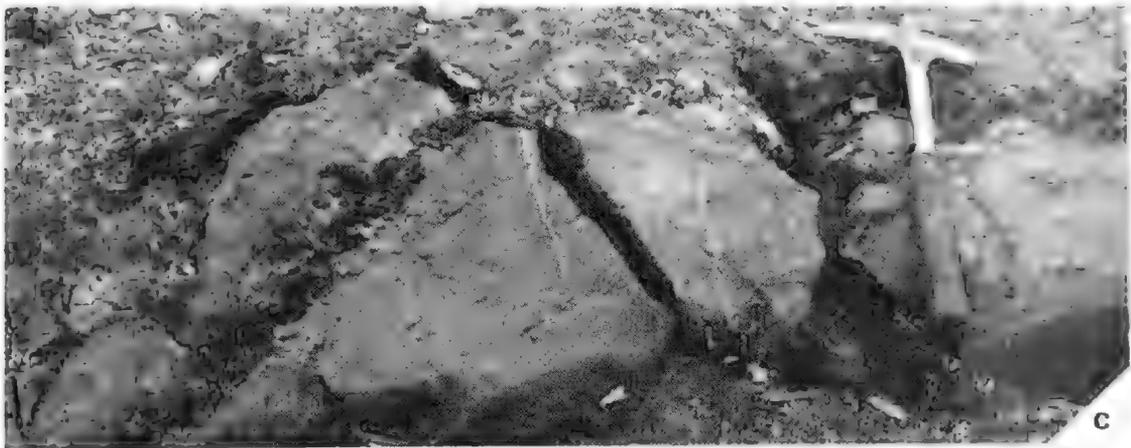
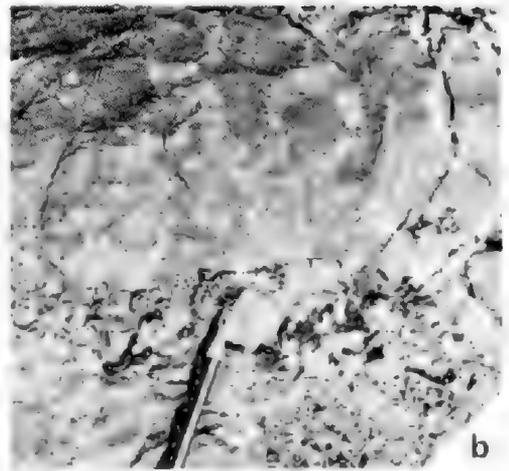


FIG. 13

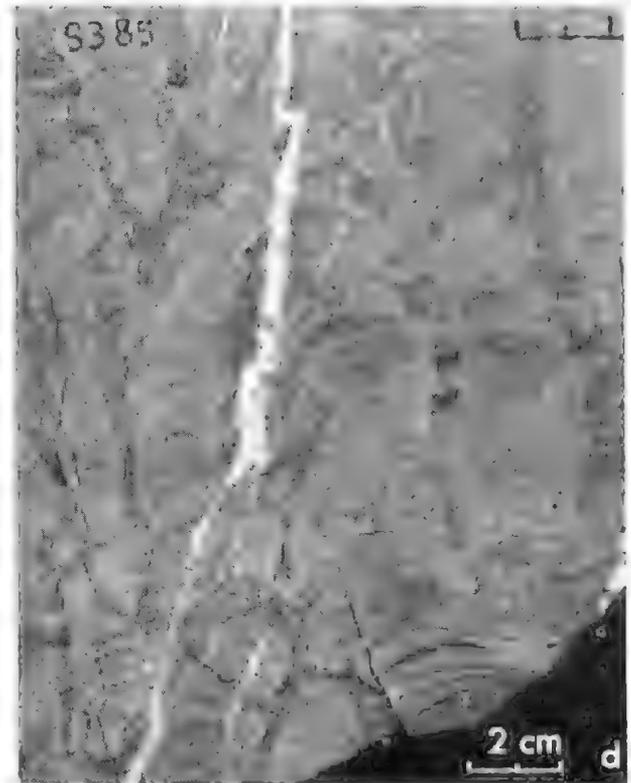
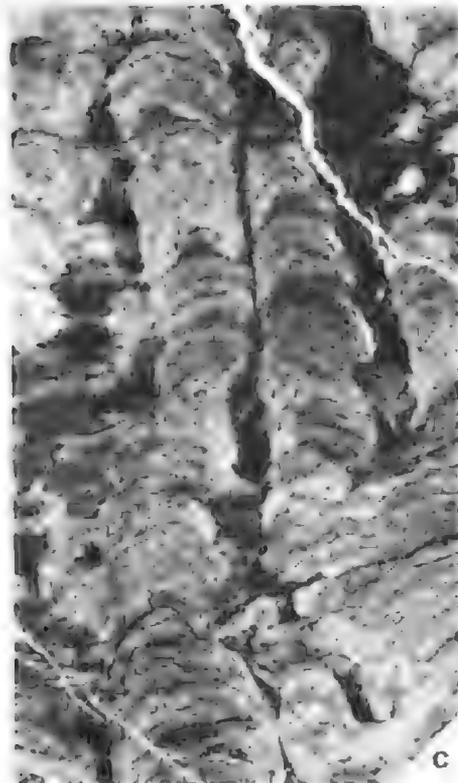
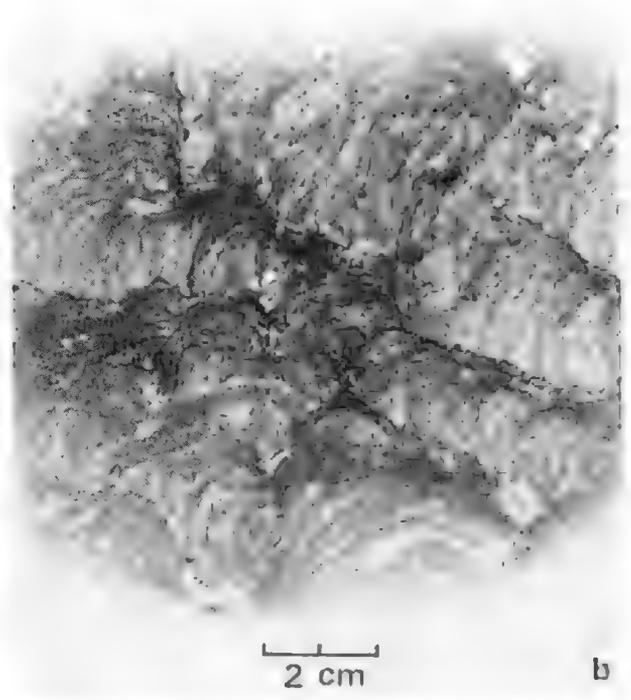
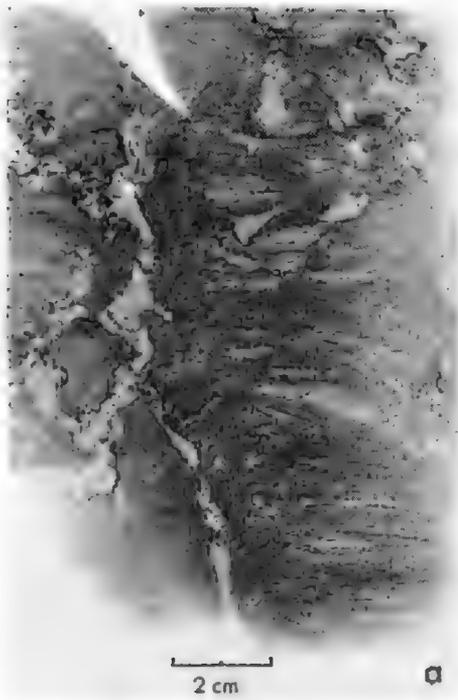


FIG. 14

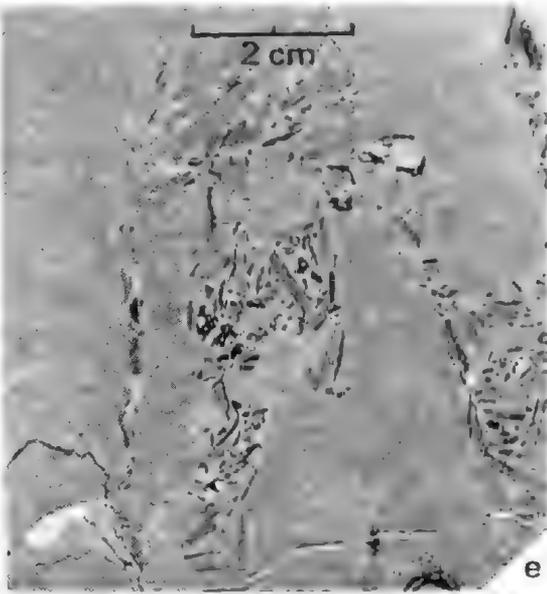
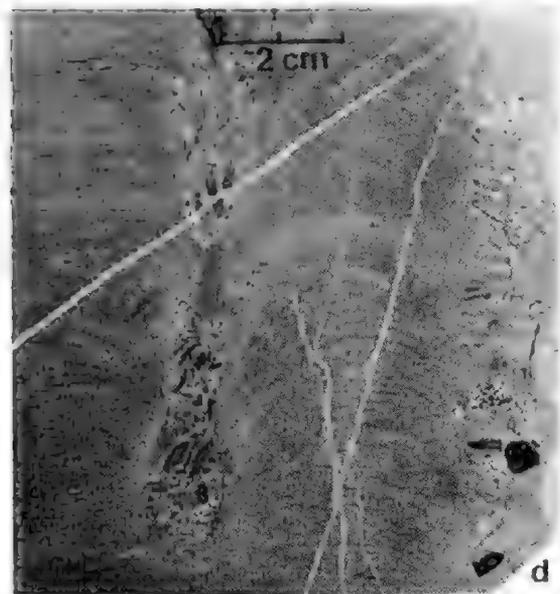
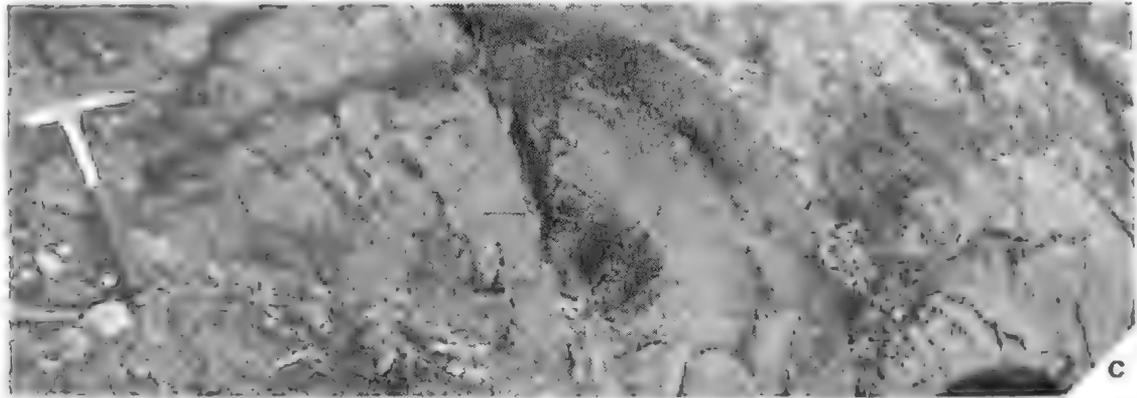
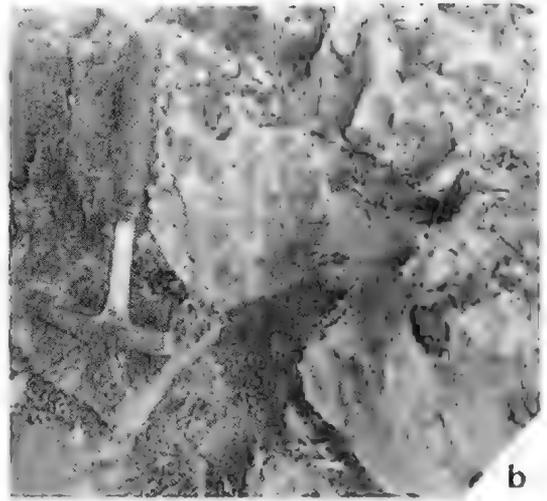
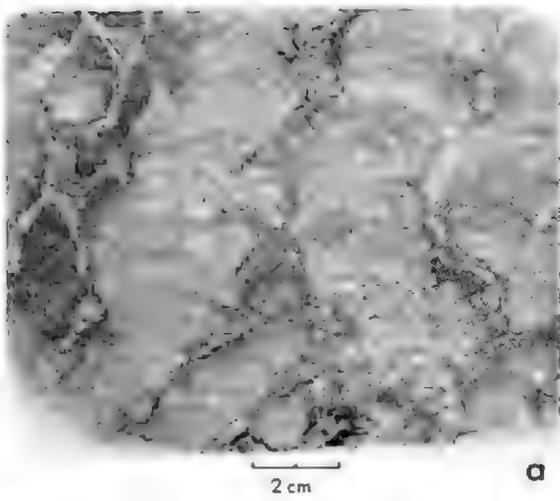


FIG. 15

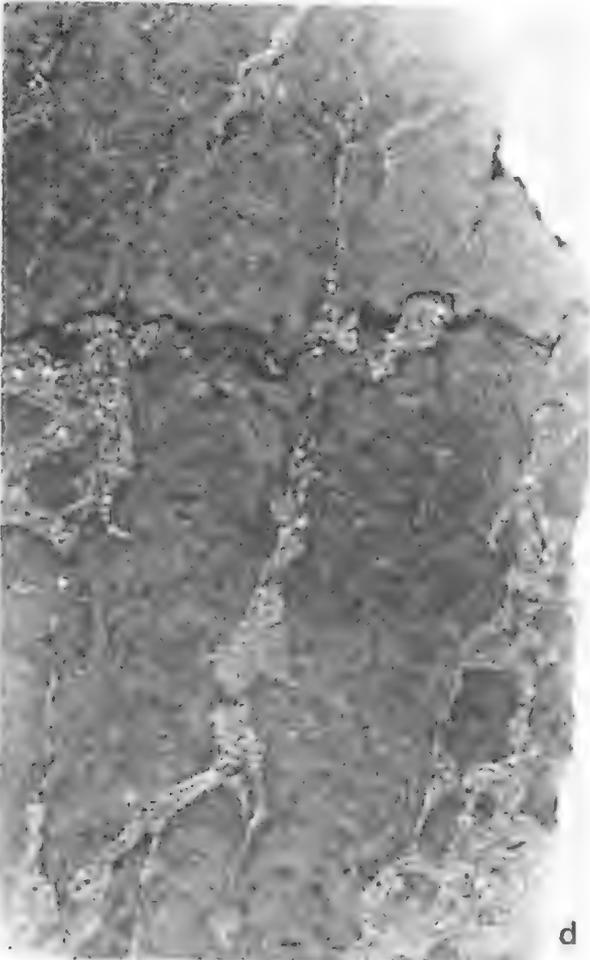
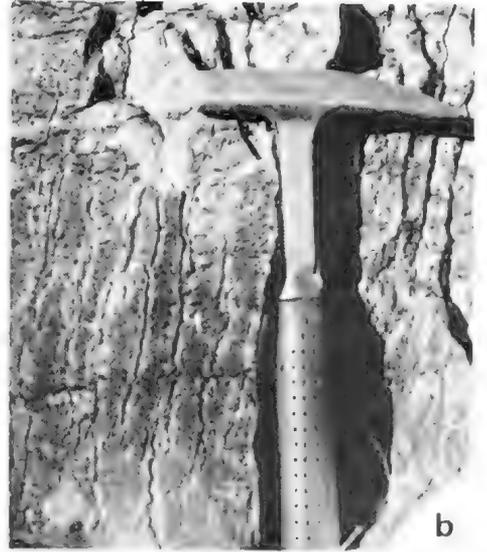
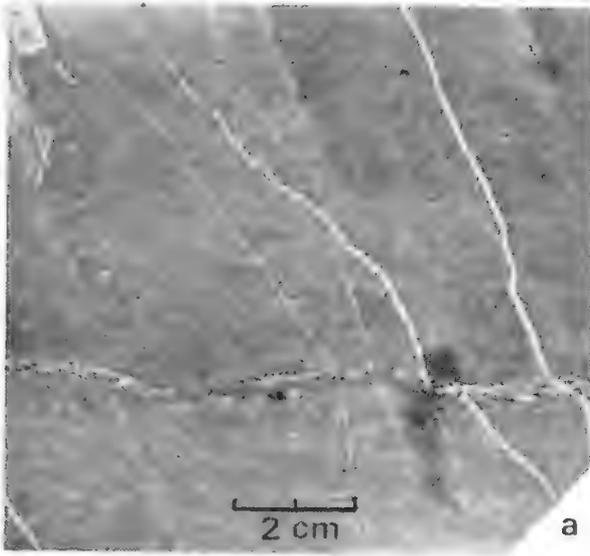


FIG. 16

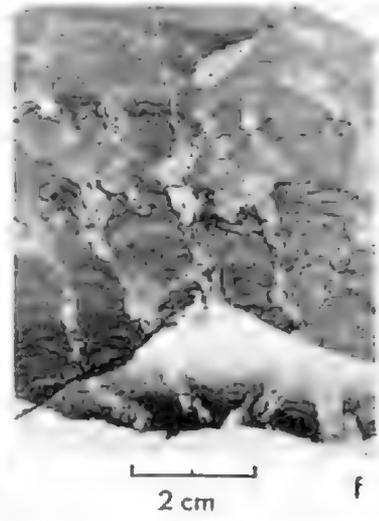
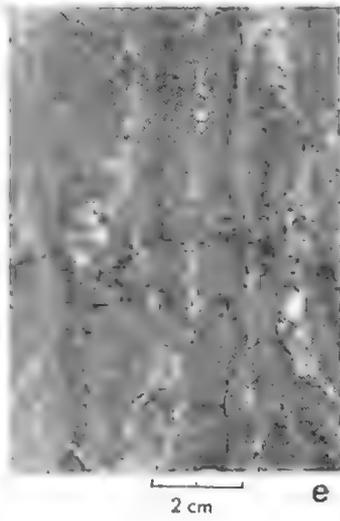
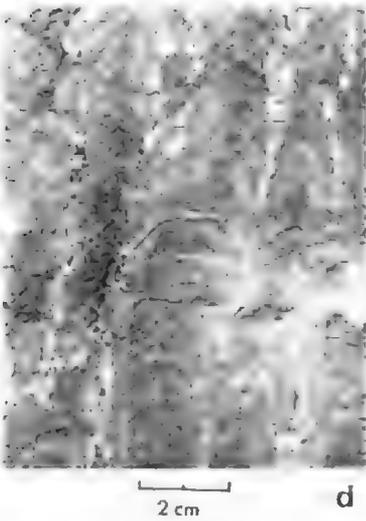
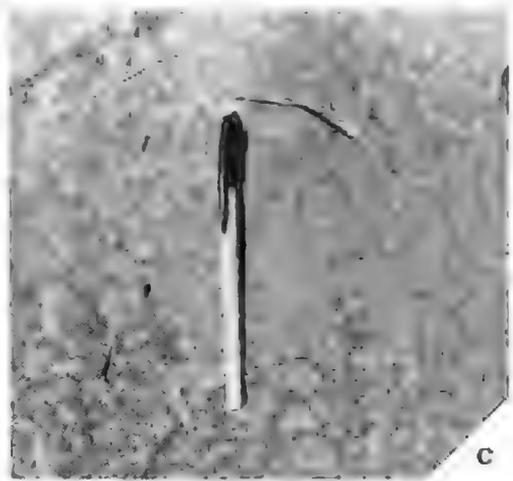
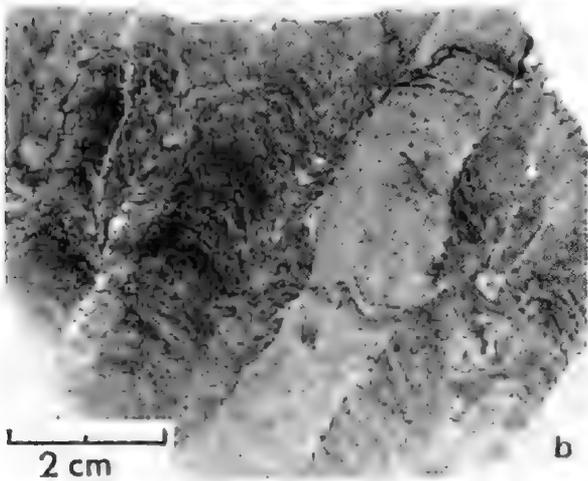


FIG. 17

# STUDIES ON SOME SPECIES OF *HAKEA* (PROTEACEAE)

BY J. R. MACONOCHIE\*

## Summary

MACONOCHIE, J. R. (1973).-Studies on some species of *Hakea* (Proteaceae). *Trans. R. Soc. S. Aust.* 97(2), 127-133, 31 May, 1973.

*Hakea standleyensis* sp. nov. is described from Standley Chasm, central Australia. This species is allied to *H. collina* C. White of south-west Queensland but differs in leaf size and flexibility, and fruit shape.

An examination of collections under *H. multilineata* has led to the recognition of five species: *H. multilineata* Meisn., *H. francisiana* F. Muell. and *H. grammatophylla* (F. Muell.) F. Muell., and two new species, *H. minyma* Maconochie and *H. coriacea* Maconochie. *H. bucculenta* Gardn. which is allied to this group, is readily separated by its narrower uninerved leaves. The possible evolutionary origins of the species in the group are discussed in relation to their distribution.

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### 1. *Hakea standleyensis* Maconochie sp. nov.

*Frutex* erectus diffusus, usque ad 1 m altus. *Folia* linearia, teretia, erecta, infirme pungentia, circa 1.5 mm diam., 30-65 mm longa (sed usitate 50-60 mm). *Inflorescentia* axillaris, racemosa, parva, 6-9-flora, rachide ca. 2 mm longa. *Flores* ca. 8-11 mm longi, per pilos longos scriceos albos villosa, perianthio 4-6 mm longo atque pedicello 4-5 mm longo. *Ovarium* glabrum paene sessile, ca. 1 mm longum; stylus glaber, ruber, ca. 9 mm longus; stigma late conicum, glabrum. *Torus* obliquus, glans rubra, semiannularis ad elongatam, ca. 1 mm longa. *Fructus* ca. 15 mm longus, late falcatus, ca. 5 mm latus (ad partem latissimam), pericarpio verruculoso, pedunculo ca. 10 mm longo. *Seminis corpus* obovatum, ad apicem attenuatum, ca. 5 mm longum; ala ca. 5 mm longa, reticulo tenui brunneo praedita.

*Holotypus*: D. J. Nelson 1556, Standley Chasm (23°41'S, 133°27'E), 53 km W of Alice Springs, N.T. 19.ix.1967 (NT).

*Isotypi*: AD, BRI, NSW.

*Specimens examined* (all from Standley Chasm). *Chippendale & Johnson* (NT 3997), 16.x.1957 (AD, BRI, CANB, K, MEL, NSW, NT, PERTH); *Maconochie* 464, 25.viii.1967 (NT); *Nelson* 1555, 19.ix.1967 (MEL, NT); *Must* 356, 9.xii.1968 (NT).

Erect straggling shrub up to 1 m high. *Leaves* linear, terete, weakly pungent-pointed, erect on stems, about 1.5 mm in diam. and (30-) 50-60 (-65) mm long. *Inflorescence* a small

axillary raceme of 6-9 flowers, the rachis about 2 mm long, villous with long white silky hairs. *Flowers* about 8-11 mm long, perianth 4-5 mm long, pedicel 4-5 mm long. *Ovary* glabrous, almost sessile, about 1 mm long; style glabrous, red, about 9 mm long; stigma broadly conical, glabrous. *Torus* oblique; gland red, semi-annular to elongate, about 1 mm long. *Fruit* about 15 mm long, broadly sickle-shaped, about 5 mm broad at the widest point; pericarp verruculose, peduncle about 10 mm long. Seed-body obovate, tapering to apex; about 5 mm long; wing about 5 mm long with fine brown reticulations.

*Habitat*: on and in quartzitic rock ledges and crevices almost at summit of main outcrop at rear of Standley Chasm.

This species is endemic to the Macdonnell Ranges, central Australia, being found only at high altitudes at Standley Chasm. Chippendale (1963) discussed the relic nature of plants found in the Macdonnell Ranges and it is probable that *H. standleyensis* is a relic species, possibly on the verge of extinction.

*H. standleyensis* is allied to *H. collina* C. White (1944, p. 79) and also *H. microcarpa* R. Br. *H. collina* is found on the sandstone tableland of south-west Queensland and *H. microcarpa* is restricted to southern highland areas of eastern Australia and extends down to Tasmania. The three species may be separated as follows:

\* Arid Zone Research Institute, N.T. Administration, Alice Springs, N.T. 5750.

- (1) Perianth glabrous. Leaves terete or triquetrous ..... *H. microcarpa*
- (1) Perianth villous. Leaves terete.
  - (2) Leaves flexible. (30-)50-60(-65)mm long, weakly pungent-pointed. Follicle about 15 mm long, 4-5 mm wide, incurved along ventral edge ..... *H. standleyensis*
  - (2) Leaves rigid, 20-40 mm long, strongly pungent-pointed. Follicle about 20 mm long, 6-8 mm wide, almost straight along the ventral edge ..... *H. collina*

**II. *Hakea multilineata* and its allies**

Bentham (1870) commented that he could see no major difference between the descriptions of *H. multilineata* Meisn. and *H. grammatophylla* (F. Muell.) F. Muell., except that the raceme of the latter species has a densely tomentose rachis. Bentham therefore considered *H. grammatophylla* as a variety of *H. multilineata*. Black (1948) followed Bentham. Bentham also placed *H. francisiana* F. Muell. under *H. multilineata* although he did not see

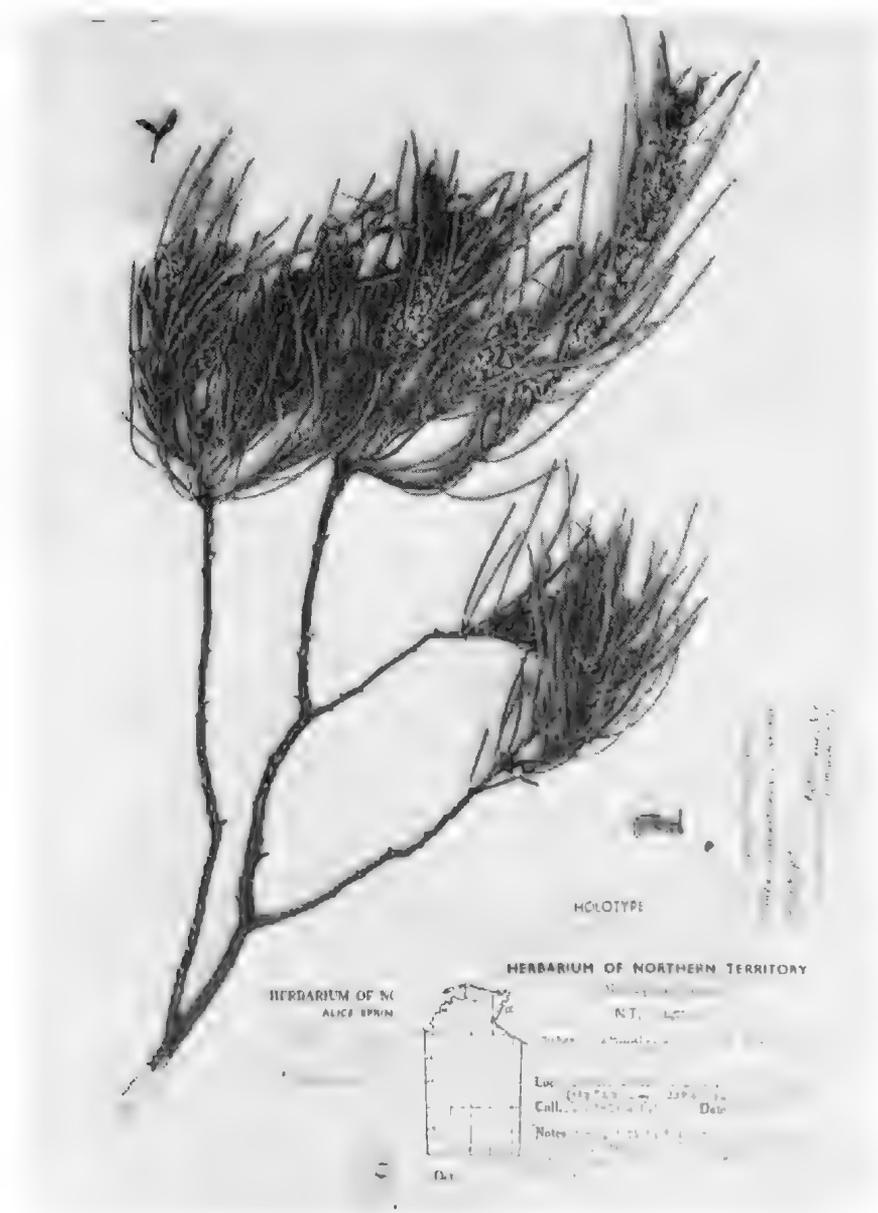


Fig. 1. Holotype sheet of *Hakea standleyensis* Maconochie.

any material of the first species. Eichler (1965) treated *H. francisiana* as a separate species.

To study this problem further, collections of this group of species were borrowed from the principal Australian herbaria and also two type sheets from Kew and New York Botanic Gardens. Data were compiled on inflorescence length, colour and texture, the shape and size of fruit and seed, and leaf dimensions and number of veins. The collections were initially sub-divided into six groups based on gross similarities and dissimilarities and then the mean and standard deviation of the number of veins per leaf (6 to 12 leaves per sheet) for each group calculated. A t-test was then applied to the data.

*H. multilinea* and its allied species have the following similarities: all are shrubs; leaves linear, flat with several to many nerves; inflorescence a many flowered raceme 2-10 cm long, enclosed in bracts at the bud stage; stigmatic cone long and narrow; fruit almost sessile.

In general, the flowers of *H. coriacea*, *H. francisiana*, *H. grammatophylla* and *H. multilinea* are very similar. *H. minyma* differs by having much smaller creamy-white flowers (pink to red in the other species).

*H. bucculenta* Gardn. (1936, p. 123) is allied to this group of species in that it has a raceme of similar size, shape and colour, similar fruit, but differs in that its leaves are much narrower and uni-nerved.

The mean number of veins per leaf, the standard deviation and sample size are presented below—

	Mean	St. Dev.	Sample size
<i>H. francisiana</i>	6.0	1.3	182
<i>H. grammatophylla</i>	7.1	1.4	84
<i>H. coriacea</i>	10.3	1.5	163
<i>H. minyma</i>	14.2	2.0	89
<i>H. multilinea</i>	15.1	3.4	156

The probabilities and t-values for difference of means between species are presented in Table 1.

TABLE 1

Species	1	2	3	4	5	
1 <i>H. coriacea</i>		28.6	15.6	16.8	17.4	
2 <i>H. francisiana</i>	<<.001		5.9	38.0	35.5	
3 <i>H. grammatophylla</i>	<.001	<.001		27.0	21.6	t-values
4 <i>H. minyma</i>	<.001	<<.001	<<.001		2.5	
5 <i>H. multilinea</i>	<<.001	<<.001	<<.001	.01<P<.02		
	Probabilities					

Thus at the 5% probability level, the sample means of all species significantly differ from each other. When the number of veins per leaf is used in combination with inflorescence length and size, pubescence on rachis, and fruit shape, then these species can be readily separated.

#### Key to *Hakea multilinea* and allies

1. Leaves with one distinct central vein ..... *H. bucculenta*
1. Leaves with several to many veins ..... 2
2. Mature fruit with distinct bicarinate ventral suture ..... *H. multilinea*
2. Mature fruit without bicarinate ventral suture ..... 3
3. Perianth creamy white ..... *H. minyma*
3. Perianth pink to red ..... 4
4. Rachis of inflorescence tomentose ..... *H. grammatophylla*
4. Rachis of inflorescence glabrous ..... 5

5. Main veins of leaves 5 or 7 (-8). Leaves 3-6 mm wide ..... *H. francisiana*
5. Main veins (8-) 9-10 (-13). Leaves 6-16 mm wide ..... *H. coriacea*

***Hakea bucculenta* Gardner 1936: 123.**

**Holotype:** Gardner 2571 (PERTH) (n.v.)

**Distribution:** Restricted to Western Australia from Galena in the north to Geraldton in the south (Fig. 4).

**Selected Specimens:** W. Aust., Blackall 4709, 48 km N of Galena, 18.ix.1951 (PERTH); Gilvins 1550, 51 km S of Warroo road house, north of Geraldton, Aug. 1967 (PERTH); Long 25, 129 km E of Geraldton, 1.viii. 1960 (PERTH).

***Hakea multilinea* Meisn. 1847: 261.**

**Holotype:** Drummond coll. III no. 275, Swan River (NY).

**Isotypes:** K (two sheets); MEL 1010212; MEL 1010216; PERTH.

**Distribution:** Restricted to an area in the

south-west corner of Western Australia (Fig. 5).

*Selected Specimens*: W. Aust., *Brooker* 1872, 66 km E of Brookton, 22.vii. 1969 (PERTH); *Drummond* 275, Swan River (Type) (K, MEL, NY, PERTH); *Filson* 8903, Holland's Track, 88 km SW of Coolgardie, 16.ix. 1966 (MEL); *Wilson* 3220, ca. 120 km W of Daniell on road to Lake King, 15.ix. 1964 (AD).

***Hakea grammatophylla*** (F. Muell.) F. Muell. 1867: 214.

*Basionym*: *Grevillea grammatophylla* F. Muell. 1865: 25.

*Holotype*: "In Australia centrali prope central Mount Stuart fructibus interspersa", *J. Macd. Stuart* (MEL 1010236).

Mueller (1867) cited R. T. Sullivan—"Gawler Ranges" and M. Weidenbach, "in vicinity of Port Lincoln", as *H. grammatophylla* but these two specimens are *H. francisiana* F. Muell. The fragmentary nature of the specimens probably explains the misidentification.

*Distribution*: Restricted to the ranges of central Australia (N.T.) (Fig. 5).

*Selected Specimens*: N.T. *Beaulehole* 23189, King's Canyon, George Gill Range, 5.vii. 1967 (NT, NSW); *Lothian* 76, Standley Chasm, July-Aug. 1954 (AD); *Maconochie* 443, Serpentine Gorge, 19.vii. 1967 (NT).

***Hakea minyma*** Maconochie, sp. nov.

*Fertex* 1–2 m altus, caulibus majoribus nonnullis praeditus. *Folia* erecta, linearia, elongata, plana, laevia, glabra, rigide coriacea, 8–15 cm longa, 5–8 mm lata, a 14–17 nervis (usitate 15) lineata, biflorescentia racemosa multiflora, thuchide glabra, 3–5 cm longa. Flores maturi et expansi 8–9 mm longi. *Perianthium* gilvum, glabrum; torus circa 1 mm longum, 0.5 mm latum, horizontalis vel aliquantum obliquus. Ovarium paene sessile, glabrum, 1–1.5 mm longum; stylus glaber, filiformis, 5–6 mm longus; stigma glabrum, erectum, conicum, 1 mm longum. Glans ovoideo-globosa, ad basin ovarii sita. *Fructus* ovoideo-globosus, 2–2.5 cm longus, 1–1.5 cm latus; pedicellus 1–3 mm longus vel minusculus; rostrum perconspicuum, saepe curvatum. *Pericarpus* laevis nisi pustulac parvae, plus minus stramineicolor. *Semina* corpus 8 mm longum; ala 1.7 cm longa, nigra, rhombiformis vel angulato-ovata, secus corpus unilatetraliter decurrens.

*Holotypus*: *Maconochie* 846, about 84 km W of Musgrave Park Station, S. Aust. (26° 20'S; 130° 30'E), 30.ix. 1969 (NT). Specimen with flowers, fruits and photograph.

*Isotypi*: AD, BRI, CANB, K, MEL, NSW PERTH.

***H. micronera*** C. A. Gardner—nomen invalidum in Fairall (1970).

*Shrub* 1–2 m tall, with several main stems. *Leaves* erect, flat, linear, elongate, smooth, glabrous, rigidly coriaceous, 8–15 cm long, 5–8 mm wide, with 14–17 nerves (mostly 15). *Inflorescence* a raceme with numerous flowers, rhachis glabrous 3.0–5.0 cm long. Open mature flowers 8–9 mm long. *Perianth* creamy-yellow, glabrous; torus about 1 mm long, 0.5 mm broad, horizontal to slightly oblique. Ovary almost sessile, glabrous, 1–1.5 mm long; style glabrous, filiform, 5–6 mm long; stigma glabrous, erect, conical, 1 mm long. Gland ovoid-globular, at base of ovary. *Fruit* ovoid-globular, 2–2.5 cm long, 1–1.5 cm broad; pedicel 1–3 mm or less; beak strongly developed, often curved. Wall smooth with small pustules, coloured beige to light tan, the latter colour often more pronounced on beak. The beak is often lost from fruit older than twelve months and the wall becomes gray in colour. Fruit then 1.9–2.0 cm long and 1.4–1.6 cm broad. *Seed body* 8 mm long; wing 1.7 cm long, black; rhombic or angulato-ovate in shape, decurrent along one side of the body.

The specific epithet is derived from the Pitjantjatjara word minyma (woman), an allusion to the fruit's resemblance to a woman's breast.

*Distribution*: This species extends from the Musgrave-Mann-Petermann Range complex of South Australia and the Northern Territory down to the Tammin-Merredin area in the south-west of Western Australia (Fig. 5).

*Selected Specimens*: N.T. *Dunlop* 2010, 48 km NE of Mt. Davies Camp, Mann Range, 31.x. 1970 (AD, CANB, NT); *Latz* 941, ca. 129 km NE of Mt. Davies Camp, edge of Pottoya Hills, N.T., 2.xi. 1970 (DNA, MEL, NT). S. Aust. *Eichler* 17285, between Mt. Harriet and Musgrave Park Homestead, 5.ix. 1963 (AD); *Maconochie* 846, ca. 84 km W of Musgrave Park Station, 30.ix. 1969 (Type) (NT). W. Aust. *Gardner* 839, Coolgardie, 4.x. 1920 (PERTH); *George* 2879, 35 km NE of Laverton, 23.viii. 1961 (PERTH); *George* 5639, 55 km SW of Wiluna, 29.vii. 1963 (PERTH); *Koch* 975, Cowcowing, Sept. 1904 (MEL, NSW, PERTH); *Royce* 4461, Comet Vale, 23.ix. 1953 (PERTH).

***Hakea francisiana*** F. Muell. 1858: 20.

*Type*: *G. Francis*, near bay, Spencer's Gulf. Specimen probably lost (search made at AD, K, MEL).

*Neotype*: *B. Copley* 2345, Thurlga Station, Gawler Ranges, S. Aust. 13.x. 1968 (AD).



Fig. 2 (above). Holotype sheet of *Hakea minyma* Maconochie.  
Fig. 3 (below). Holotype sheet of *Hakea coriacea* Maconochie.

*H. multilineata* var. *graminea* nomen invalidum in Fairall (1970).

**Distribution:** Widely distributed through the southern arid areas of South and Western Australia (Fig. 4).

**Selected Specimens:** S. Aust. *Cornwall* 56, ca. 55 km SE of Kimba, 17.vii. 1968 (AD, NT); *Ramsay* s.n., 113 km SSW of Camp 17, Elder Expedition, July 1891 (AD, NSW); *Wilson* 1573, 40 km NW of Ceduna, 11.ix. 1960 (AD). W. Aust. *Gardner* 6465, Bencubbin, 10.ix. 1942 (PERTH); *George* 5646, 122 km N of Sandstone, 29.vii. 1963 (NSW, PERTH); *Wilson* 3142 ca. 30 km SE of Londonderry, 14.ix. 1964 (AD, PERTH)



Fig. 4. Distribution of *H. bucculenta* (■), *H. coriacea* (▲), and *H. francisiana* (●).

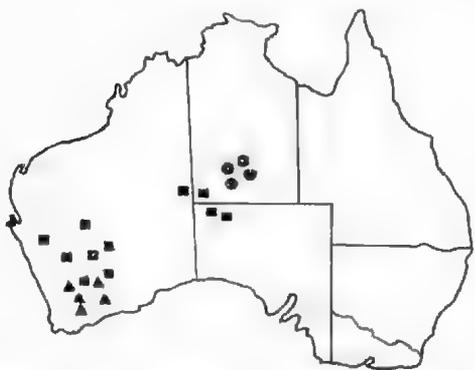


Fig. 5. Distribution of *H. grammatophylla* (●), *H. minyma* (■), *H. multilineata* (▲).

From Kangaroo I., South Australia, there have been two sterile collections made of a species close to *H. francisiana*, but until better material is available, its status is obscure.

***Hakea coriacea* Maconochie sp. nov.**

*Frutex* 3–4 m altus. *Folia* linearia elongata, plana, coriacea; intervenium pubescenti, 9–20 cm longa, usitate 14–17 cm, 6–16 mm lata usitate 8–10 mm.

8–13 nervis internis plerumque 9 vel 10. *Inflorescentia* racemosa multiflora rosea vel carneâ, rachide glabra, 6–11 cm longa. *Flos* glaber 23–25 mm longus, pedicellus 2–3 mm longus, perianthium 7–8 mm, stylus glaber 19–21 mm longus, stigma glabrum, conicum 1.5 mm longum. *Torus* aliquantum obliquus, glans semi-annularis. *Bractea* glabra vel puberula, caduca, margine ciliata. *Fructus* ovoideo-globosus, circiter 18 mm longus, 12 mm latus et crassus, pericarpus laevis nisi pustulae paucae parvae vel aliquando fissuris paucis. *Allinis Haekae francisianae* F. Muell. sed differt numero majoro nervorum et foliibus latioribus.

Shrub to 3 to 4 m high. *leaves* linear, flat, coriaceous, with a fine pubescence on the interveinal area, 9–22 cm long mostly 14–17 cm, 6–16 mm wide, mostly 8–10 mm with 8–13 nerves. *Inflorescence* pink-red, rachis glabrous 6–11 cm long, a raceme of many flowers. Flower glabrous 23–25 mm long, pedicel 2–3 mm long, perianth 7–8 mm, style glabrous 19–21 mm, stigmatic cone 1.5 mm long. *Bracts* glabrous or sometimes puberulous with ciliate margin, caducous. Fruit woody, shortly pedunculate (2–3 mm) about 18 mm long, 12 mm wide and broad, wall smooth with a few small pustules or sometimes with small fissures. Closely related to *H. francisiana* but differs in greater number of nerves and wider leaves.

**Holotypus:** C. A. Gardner 12155, between Perenjori and Jibberding, W. Aust., Sept. 1953 (PERTH).

**Distribution:** Restricted to an area in the WSW of W. Aust. (Fig. 4).

**Selected Specimens:** W. Aust. *Aplin* 1983, 3 km E of Tammin, 13.ix. 1962 (PERTH); *Drummond* 18, W. Aust. (MEL, NSW); *Koch* 1018, Cowcowing, Sept. 1904 (AD, MEL, NSW); *Melville* 4265, 0.8 km W of Dalwallina, 21.vii. 1953 (AD, BRI, K, MEL, PERTH).

**Phylogeny and Evolution**

These species form a natural group differing from the other members of Bentham's *Hakea* sect. *Conogynoides* ser. *Longistylae* by the distinctly elongate raceme, 2–10 cm long. The other members of this series all have a more compact raceme, resulting in a more globular inflorescence.

The phylogenetic relationships of this group are uncertain:

(1) The inflorescence, leaf and fruit structure of *H. francisiana*, *H. coriacea*, *H. grammatophylla* and *H. bucculenta* indicate they probably have a common ancestor, and that *H. multilineata* and *H. minyma* may have evolved independently.

(2) The similar distribution patterns of *H. francisiana* and *H. minyma* suggest that these two species may have had a common ancestor, and *H. coriacea*, *H. grammatophylla*, *H. bucculenta* and possibly *H. multilineata* were all derived from *H. francisiana*.

The south-west province of Western Australia appears to be the focus of origin of this group of species, as five of the six species occur there and the distribution tends to radiate from there into the more arid areas to the north and east.

The two records of *Hakea* cf. *francisiana* for Kangaroo Island suggest that, during an earlier geological period, Kangaroo Island acted as a migration bridge between Eyre and Yorke Peninsulas and Fleurieu Peninsula. Wood (1930) refers to this connection and regards it as recent in geological time.

The implication of these observations is that either (1) this group of species may have evolved, diversified and migrated during the period of a land connection between the Eyre

and Fleurieu Peninsulas or, (2) this was a period of rapid spread of *H. francisiana*.

The restricted distribution of *H. grammatophylla* to the ranges of central Australia and the distributional pattern of *H. francisiana* would indicate a north-eastern migration route from the south-west province of Western Australia. Subsequent periods of aridity would permit speciation to occur as there was a retreat to more favourable habitats.

#### Acknowledgements

The Directors and Curators of the following Australian Herbaria (AD, ADW, BRI, CANB, CBG, MEL, NSW, PERTH) are thanked for allowing examination of their collections and also Kew and the New York Botanic Gardens for making available Drummond's type sheets.

To Mr. J. H. Willis, I am indebted for two of the Latin descriptions and to Dr. H. Eichler for his advice on nomenclatural problems and comments on the manuscript.

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# PHOSPHORIAN LAVENDULAN FROM DOME ROCK MINE, SOUTH AUSTRALIA

BY A. W. KLEEMAN\* AND A. R. MILNES†

## Summary

KLEEMAN, A. W., & MILNES, A. R. (1973).- Phosphorian lavendulan from Dome Rock Mine, South Australia. *Trans. R. Soc. S. Aust.* **97**(2), 135-137, 31 May, 1973.

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## PHOSPHORIAN LAVENDULAN FROM DOME ROCK MINE, SOUTH AUSTRALIA

by A. W. KLEEMAN\* and A. R. MILNES†

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A new variety of the rare mineral lavendulan (— freirinite) has been found in Precambrian rocks in South Australia. It is notable for containing a significant amount of phosphorous replacing arsenic. Its formula, based on microprobe analysis, is  $(\text{Na}_{1.07}\text{Ca}_{1.01}\text{Cu}_{1.50})(\text{As}_{8.16}\text{P}_{.81})\text{O}_{16}\text{Cl}_{1.57}\cdot 4\text{H}_2\text{O}$ . Powder diffraction data are also recorded.

### Introduction

The Dome Rock mine is situated about 44 km ENE of Olary (148°27'E, 31°55'S). The detailed geology of the mine area is described by Dickinson (1942) and a brief description is given by Campana & King (1958). The country rocks are low grade metamorphics of the Willyama Complex; Dickinson considers the lodes to be replacements of a fine grained sandstone. The primary ore is reported by Campana & King to be chalcopyrite and pyrite. Some cobalt is found in the sulphides and erythrite stainings were reported by Mawson in an unpublished report to the Dome Rock Copper Mining Co. The lodes are oxidised to a depth of about 60 metres. The oxidised ore was mainly chalcocite, tenorite and cuprite, with olivenite and chrysocolla.

Bayliss *et al.* (1966) examined specimens of oxidised ore from Dome Rock and reported several arsenic minerals occurring as "encrustations along partings in siliceous ironstone". They identified clinoclasite,  $\text{Cu}_3\text{AsO}_4(\text{OH})_3$ , conichalcite,  $\text{CaCu}(\text{AsO}_4)(\text{OH})_2$ , and a third mineral which they called chlorotile,  $\text{Cu}_3(\text{AsO}_4)_2\cdot 6\text{H}_2\text{O}$  with the comment that it also resembled mixite,  $\text{Cu}_{11}\text{Bi}(\text{AsO}_4)_5(\text{OH})_{10}\cdot 6\text{H}_2\text{O}$ . However, chemical tests failed to reveal the presence of bismuth. They also record the identification of cornwallite,  $\text{Cu}_6(\text{AsO}_4)_2(\text{OH})_4\cdot \text{H}_2\text{O}$  but do not quote the authority. Their own identifications were

based on X-ray diffraction amplified by the chemical test on the "chlorotile".

Early in 1972, Mr. H. Gallasch submitted a sample from the 120 ft. level of Dome Rock mine, containing a mineral which proved to be quite different from any reported by Bayliss *et al.* The description of this mineral resembles that of clinoclasite given by Bayliss *et al.*, but the powder patterns are dissimilar. It occurs as rosettes of acicular blue crystals on a block of siliceous ironstone. The rosettes are about 2-4 mm in diameter and the individual crystallites are less than 0.02 mm across. Broadening of the lines in X-ray powder photographs indicates that the mineral is in fact extremely fine grained. The powder X-ray photograph suggested that it could be sampleite or lavendulan (Guillemin 1956). Accordingly it was decided to analyse it on the microprobe to confirm its identity.

### Methods

A polished thin section of some fragments of the mineral was examined in the C.S.I.R.O. Division of Soils' "Geoscan" (Cambridge Instruments) electron probe microanalyser. The elements As, Cu, Co, Ca, Cl, P, Mg and Na were detected during reconnaissance spectrometer scans. Chemical homogeneity of the mineral fragments was checked by photographing X-ray scanning images of the elements of interest. Selected areas of the mineral

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fragments were then analysed quantitatively for these elements.

Under normal conditions of analysis<sup>1</sup>, significant systematic drifts in count rate with time were observed for all elements. This effect is possibly due to a combination of photochemical degradation (McConnell 1969) and thermal decomposition of the mineral under the influence of the electron beam in the evacuated specimen chamber (Sweatman & Long 1969). Loss of alkali elements from silicate minerals with time under the influence of electron bombardment during microprobe analysis is a well known but not fully understood phenomenon (McConnell 1969; Siivola 1969), and can be minimised by reducing the beam current. In the present instance, however, the count rate drift was minimised by expanding the electron beam so that it sampled a circular area 50 microns in diameter at the specimen

surface, and by driving the specimen beneath the beam at 30 microns per second during analysis. The accelerating voltage and beam current were maintained at 20kV and 50nA respectively.

TABLE 1  
*Microprobe analysis*

	1	2
As <sub>2</sub> O <sub>5</sub>	36.4	44.8
CuO	38.2	36.3
CoO	0.03	nil
CaO	5.7	5.8
Cl	5.5	3.5
P <sub>2</sub> O <sub>5</sub>	6.0	n.d.
MgO	0.04	n.d.
Na <sub>2</sub> O	3.3	3.1
Total	95.2	
O=Cl	1.2	
Total	94.0	

1. Lavendulan, Dome Rock Mine (analyst A. R. Milnes)
2. Lavendulan, San Juan, Chile (Guillemin 1956)

TABLE 2  
*Structural Formula Based on As+P=4*

Na	1.070
Ca	1.014
Mg	0.010
Cu	4.800
Co	0.004
Total	6.898
As	3.161
P	0.839
Total	4.000
Cl	1.553

TABLE 3  
*Comparison of the X-ray diffraction pattern of the Dome Rock mineral with those of lavendulan and sampleite*

Lavendulan <sup>1</sup> Dome Rock		Lavendulan <sup>2</sup> San Juan, Chile		Sampleite <sup>2</sup>	
dÅ	I	dÅ	I	dÅ	I
9.20	vs	9.77	100	9.60	100
7.03	w	7.01	40	6.85	70
6.76	w				
4.98	w				
4.83	w	4.87	50	4.73	40
4.60	s				
4.37	s	4.41	40	4.30	80
4.17	s			3.89	70
3.50	vvw				
3.38	vvw				
3.24	vvw			3.23	50
3.18	vvw				
3.12	s	3.11	70	3.04	100
3.06	w				
2.98	vvw				
2.92	m	2.90	20	2.89	50
2.74	vw	2.76	20	2.80	50
2.69	m			2.69	50
2.61	m				
2.47	m	2.48	20	2.50	50
2.40	vw				
2.34	vvw				
2.24	vvw				
2.10	vw				
2.02	vw				
1.95	w	1.97	20	1.91	50
1.90	w				
1.84	vvw				
1.81	vvw	1.83	20	1.79	70
1.75	m	1.76	20		
1.72	vw			1.71	80
1.69	vvw				
1.66	vw			1.61	50
1.50	vw	1.55	20	1.45	70
1.40	w	1.47	20	1.44	
		1.42	20	1.37	70
		1.21	20	1.21	50

1. Diffraction data measured by J. G. Pickering (C.S.I.R.O.) using a 19 cm camera and CoK $\alpha$  radiation.
2. Diffraction data from A.S.T.M. cards Nos. 11-351 and 11-349.

<sup>1</sup> Normal conditions of electron probe microanalysis

Accelerating voltage 20 kV

Beam current 50nA

Flow proportional counters

Counting time: 10 seconds (line and one background position)

Spectrometers: LiF crystal—CuK $\alpha$ , AsK $\alpha$ , CoK $\alpha$ , CaK $\alpha$

Mica crystal—NaK $\alpha$ , PK $\alpha$ , ClK $\alpha$ , MgK $\alpha$

Beam fully focussed

The raw output data from the electron probe were refined by the CDC 3200 computer program MICANCOR (written by H. Rosser of C.S.I.R.O.), which incorporates the correction program MKRPRB6 (Oertel 1971). The mineral analysis reported in Table 1 is the average of analyses of eight selected areas of the mineral fragments in the polished section.

### Results

The X-ray diffraction pattern (Table 3) of the unknown mineral (measured by J. G. Pickering) is similar to the diffraction patterns

of the isostructural minerals lavendulan  $\text{Na}(\text{Cu,Ca})_6(\text{AsO}_4)_4\text{Cl}\cdot 4\text{H}_2\text{O}$  and sampleite  $\text{Na}(\text{Cu,Ca})_6(\text{PO}_4)_4\text{Cl}\cdot 4\text{H}_2\text{O}$ . Therefore a structural formula was calculated on the basis of a total of  $4(\text{As}+\text{P})$  atoms (Table 2).

The result given in Table 2 agrees quite closely with the data given by Guillemin (1956) except for the excess of Cl in our specimen.

We have used the name lavendulan rather than freirinite in accordance with the list of New Mineral Names (Fleischer 1957).

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# RHODACARIDAE (ACARI: MESOSTIGMATA) FROM NEAR ADELAIDE, AUSTRALIA. II. ECOLOGY

BY D. C. LEE\*

## Summary

LEE, D. C. (1973).- Rhodacaridae (Acari: Mesostigmata) from near Adelaide, Australia. II. Ecology. *Trans. R. Soc. S. Aust.* 97(2), 139-152, 31 May, 1973.

Serial collections of rhodacarid mites extracted by desiccating funnels from surface soil (greatest depth: 4 cm), moss and plant litter, at two sites on the western slopes of Mount Lofty, overlooking Adelaide, South Australia were studied, as were small collections of rhodacarids from two sites on the Adelaide Plain.

The presence of two communities of hemiedaphic rhodacarid mites is demonstrated by differences in the characteristic species of two sites and a significant association into two groups of the species of one subfamily (Ologamasinae). Population density is higher in the wet, cool winter and where there is substantial, decomposing plant litter. Variations are demonstrated between some species in the number of generations per year, the time for occurrences of particular life-history stages and the sex ratio. It is suggested that species of *Athiasella* prefer higher nutrient loamy soils, while *Gamasellus* is almost confined to low nutrient, sandy soils.

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### Introduction

Rhodacarids are mainly predatory mites, and are most common and diverse in form in Southern Temperate regions. The present work formed part of a study on rhodacarids from the environs of Adelaide, South Australia (Lee 1970<sup>1</sup>). Part I dealt with systematics (Lee 1973) and should be referred to for the authority to names of rhodacarids collected. Part III, dealing with behaviour, is to be published.

Most rhodacarids are hemiedaphic, being free-living in surface soil, plant litter, or in moss or other plants with a similar growth form. Some taxa, however, are not hemiedaphic. Thus, *Hydrogamasus*, *Litogamasus*, *Parasitiphis*, *Periseius* and *Tangaroellus* have only been found in or near the littoral zone, usually on rocky shores; *Rhodacaropsis* has only been found in the littoral zone on sandy shores; *Cyrtolaelaps* or *Euryparasitus* have generally been collected from bird or mammal

nests or from bat caves; *Tangaroellus porosus* Luxton has usually been found under the carapaces of barnacles; and the two species of *Laelaptonyssus* have been found closely associated with flies or termites. Ecological studies demonstrating more limited habitat preferences include only non-hemiedaphic rhodacarid mites. Thus, *Hydrogamasus littoralis* (G. & R. Canestrini) mainly occurs in rock crevices in a limited part of the littoral zone (Glynne-Williams & Hobart 1952, Morton 1954). *Rhodacarus* and *Rhodacarellus* are commoner in the deeper soil layers (i.e. they are euedaphic) and are limited to parts of sampled areas (Sheals 1957, Davis 1963, Wood 1967a, Emberson 1968<sup>2</sup>). *Cyrtolaelaps* and *Euryparasitus* are commoner in mammals' nests that are on the ground and made of moss (Mrciak, Daniel & Rosicky 1966).

There is a problem in defining precise habitats for ground inhabiting mites, because a species may occur in strictly limited habitats,

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<sup>1</sup> I.P.E. D. C. (1970).—The taxonomy and general biology of the Rhodacaridae (Acari: Mesostigmata). M.Sc. thesis, University of Adelaide, Australia (unpublished).

<sup>2</sup> EMBERSON, R. M. (1968).—The Mesostigmata of certain coniferous forest soils in Western Quebec, with a preliminary account of North American Rhodacaridae (Acarina). Ph.D. thesis, McGill University, Montreal, Canada (unpublished).

but at widely differing localities. For instance, it has been shown in three different studies that *Rhizolucarus roseus* Oudemans has a limited distribution. It occurred only in a limited area in mineral soil over iron-stone in grassland (Davis 1963); in non-calcareous drift around a limestone outcrop in moorland (Wood 1967a); and in alluvial saltmarsh (Luxton 1967). This type of distribution for a number of species of mite led both Davis (1963) and Wood (1967b) to suggest that many mite species consist of ecological races with different demands upon the environment and therefore occurring in quite different habitats.

The main aim of the present work was to demonstrate whether or not there are any habitat preferences amongst hemleduphic rhodacarid mites. Incidental information on seasonal fluctuations of populations and life-histories was also sought. In addition, because species association was considered in relation to habitat preferences, the correlation between taxonomic affinity and degree of co-existence is discussed.

Four sites were initially sampled before two were selected for serial sampling. The results of the preliminary sampling from the two sites that were not sampled again are also given, because they suggest a possible correlation between certain genera and environmental factors.

#### Methods

Two extraction methods were used; one for dealing with disturbed "bag" samples collected throughout a year and the other for undisturbed "core" samples collected in August.

##### 1. Bag Sampling and Extraction

Soil, down to a depth of approximately 4 cm, and the litter or moss on it, was scooped into a plastic bag with a trowel. The volume of a sample was about 1250 ml, and was taken from an area of approximately 250 cm<sup>2</sup>. This sample was poured into an aluminium tube (14 x 40 cm) with a wire mesh bottom, which was placed on a coarser wire mesh in a funnel (diameter of mouth—22 cm) leading down into a glass vial of 75% alcohol. The sample was heated from above by a 40 watt electric light bulb for five days.

Bag samples were collected once a fortnight for a year (24.iv.1968–23.iv.1969). On each occasion four samples were collected between 11 a.m. and 4 p.m.; 2 from the Summit Site (S1 or S1), and 2 from the Foothills Site (F1 or F1)—see appendix. One sample of moss on soil and another of plant litter on soil were taken from each site. A total of 108 samples were collected in the series.

##### 2. Core Sampling and Extraction

Steel core samples (5.15 cm diameter x 4 cm depth) were driven into soil covered by moss or litter, dug out, and then sealed by a lid at each end. The volume of each core was about 83 ml and from an area of approximately 20 cm<sup>2</sup>. The steel cores, without lids, were inverted on wire mesh in multiple Tullgren funnels, so that the deepest part of the soil was uppermost. These funnels incorporated forced draught ventilation to prevent water condensation. The samples were heated from above by thermostatically controlled electric coils to 25° C for 2 days, followed by 30° C for 2 days, 35° C for 2 days and finally 40° C for 1 day.

Core samples were only collected on 5.viii.1968 and 12.viii.1968. On each occasion 16 cores were taken from points evenly spaced throughout each of 4 plots (S1, S2, F1 and F2)—see appendix to this paper. Samples from 2 plots (S2 and F1) were covered by a substantial layer of fermenting plant litter, and the other 2 plots (S1 and F2) were covered by moss and a little raw leaf litter. A total of 128 core samples were collected in the series.

#### Sites

Four sites were sampled between the summit of Mt. Lofty and the coast-line of the Adelaide Plain. In the appendix, the Summit and Foothills Sites which were extensively sampled are described in detail, while the Plains and Coastal Sites from which only small collections were made are given a briefer description. Two plots at each of the two former sites are also described.

Temperature and rainfall had linear gradients between the coast and Mt. Lofty: the former decreasing and the latter increasing with nearness to the summit. On the other hand, the Summit and Coastal Sites were similar in having low nutrient, sandy soils, in contrast to the higher nutrient, loamy soils of the two inter-venient sites. Three sites had a predominately native flora, while the Foothills Site had an alien flora.

The sites that were extensively sampled (Summit and Foothills Sites) included areas which were either almost entirely covered by plant litter or similarly covered by moss. Core samples were only collected from rectangular plots in such uniform areas: one moss plot and one litter plot at each of the two sites. On the other hand bag samples were collected from larger areas including both plant litter and moss patches.

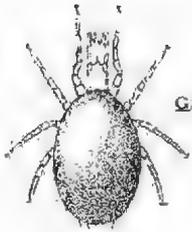
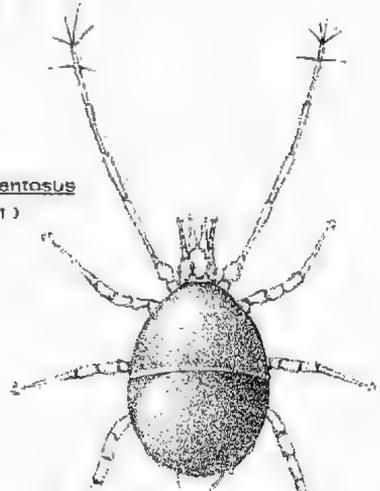
**RHODACARINAE**

Rhodacarus roseus  
(0,0/0,1)

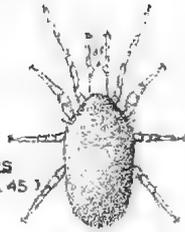


**GAMASIPHINAE**

Euepicrius filamentosus  
(143,136/60,11)

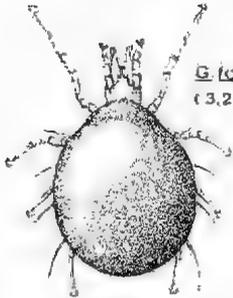


G. australicus  
(1,2/0,0)

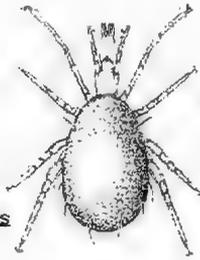


G. sarcus  
(70,33/87,45)

Gamasiphis

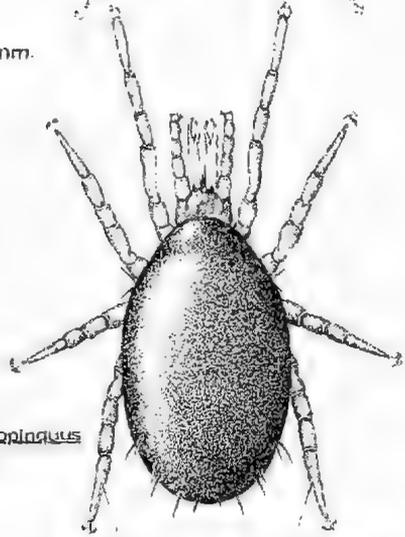


G. fornicatus  
(3,24/20,8)



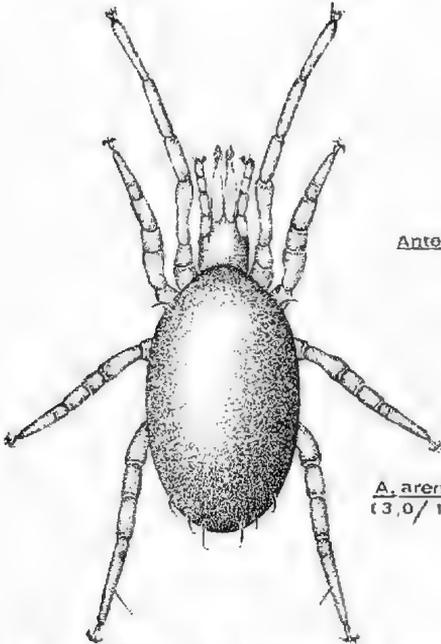
G. lenifornicatus  
(0,0/5,21)

1mm.

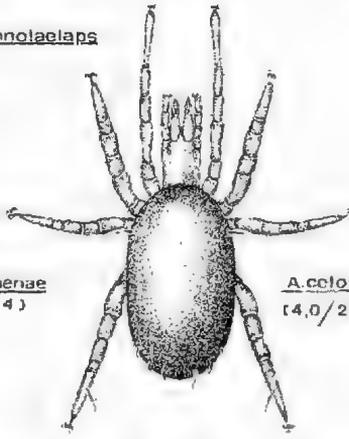


Gamasiphoides propinquus  
(0,0/30,3)

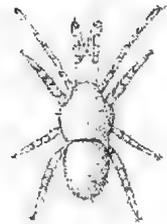
Antennolaelaps



A. aremenae  
(3,0/1,4)



A. ceclox  
(4,0/21,36)



Onchogamasus virguncula  
(0,0/1,0)

**SESSILUNCINAE**

Fig. 1. Species of Rhodacarinae, Gamasiphinae and Sessiluncinae collected during serial sampling. Dorsal views of adult females. Numbers given under names equal specimens (any stage) from the following environments: (Foothills Site moss, FS litter/Summit Site litter, SS moss).

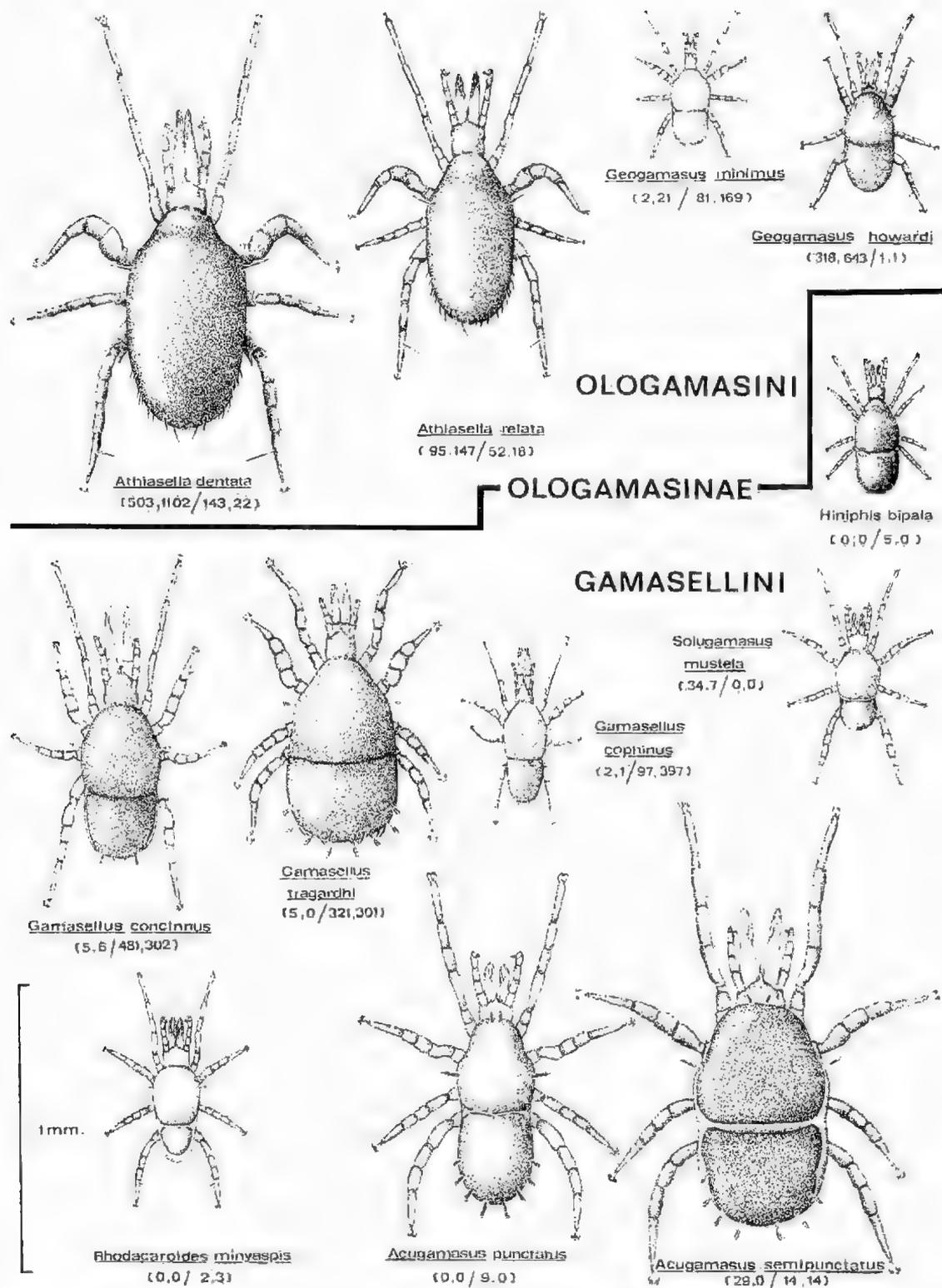


Fig. 2. Species of Ologamasinae collected during serial sampling. For further explanation see Fig. 1.

## Results

### 1. Species and forms represented

Preliminary bag samples from the Plains and Coastal Sites in May and June, 1965, produced the following rhodacarids (number of specimens in parenthesis): Plains Site—*Rhodacarus roseus* (18), *Gamasiphis australicus* (4), *Athiasella dentata* (29); Coastal Site—*Gamasellus grossi* (13), *Acugamasus elachyaspis* (8). It would have been valuable to have proceeded with serial sampling at these two sites, but because of a time limitation this was only done at the two other sites which supported more rhodacarid species.

Sizes and collection dates of preliminary samples from the Summit and Foothills Sites were not comparable with those of the other two sites and are therefore not listed. Serial samples from the Summit and Foothills Sites produced twenty-two species of rhodacarids (Figs. 1, 2). A female *Rhodacarellus silesiacus* was listed (Lee 1973) from the Foothills Site, but this was taken while collecting mites alive for laboratory cultures. Such collections otherwise only included species taken in serial samples.

Only a small proportion of immature rhodacarids were collected. The 3 species for which results are presented (Figs. 6, 7) produced a relatively high proportion of these stages. Further comments on immature stages are made below under Section 5 (Seasonal Variation).

The sex ratio (male/female) of the 12 commonest rhodacarids from serial samples is as follows: *Gamasiphis fornicatus*, 0.26; *Acugamasus semipunctatus*, 0.33; *Geogamasus minimus*, 0.34; *Geogamasus howardi*, 0.41; *Gamasiphis saccus*, 0.45; *Gamasellus cophinus*, 0.56; *Gamasellus concinnus*, 0.66; *Antennolaelaps celox*, 0.67; *Gamasellus tragardhi*, 0.73; *Athiasella dentata*, 0.83; *Euepicrius filamentosus*, 0.84; *Athiasella relata*, 1.23.

### 2. Differences between sites

Numbers of specimens were as follows: Summit Site, 2784 (bag samples, 2137; core samples, 647); Foothills Site, 3340 (bag samples, 2707; core samples, 633).

Number of species were as follows: Summit Site, 20; Foothills Site, 15. The majority (13) of species were found at both sites, but there was a considerable difference in the composition of the fauna. This difference is demonstrated by presenting the dominance and frequency of the 12 commonest rhodacarids (Figs. 3, 4). *Dominance* is the percentage of the total

specimens that belong to a species, and is represented by the size of a shaded area in a column. *Frequency* is the percentage of samples in which a species was found, and is represented by the numbers in the centre of a shaded area. Different species are characteristic (i.e. the most dominant and frequent) of different sites.

### 3. Differences between soil cover of litter compared with moss

Numbers of specimens were as follows: litter, 3558 (bag samples, 2696; core samples, 862); moss, 2566 (bag samples, 2148; core samples, 418). A similar indication is given if the results from the core samples alone are expressed as rhodacarids/m<sup>2</sup> as follows: Summit Moss Plot, 3450; Summit Litter Plot, 6660; Foothills Moss Plot, 3080; Foothills Litter Plot, 6810.

Numbers of species from Summit and Foothills Sites were as follows: litter, 21; moss, 19. The majority of species (18) were found in both litter and moss-covered soil. Comparing the dominance and frequency of individual species (Figs. 3, 4) it is evident that the species composition of a particular site is similar whether it is covered by litter or moss. The greatest differences are shown by the core samples when the whole plot was mainly covered by either litter or moss. Some species show distinct preferences: e.g. *Athiasella dentata* for litter; *Gamasellus cophinus* for moss. On the other hand, a preference at one site may be apparently reversed at the other site, e.g. *Geogamasus minimus*.

### 4. Species Association (only Ologamasinae)

Each site has different characteristic species (see Section 2), mainly belonging to the Ologamasinae. To establish whether or not two communities are present, the significance of associations in samples between species of Ologamasinae is examined. I have followed Debauche (1962) in using a correlation coefficient based on a contingency chi squared test as a measure of degree of association or dissociation of species.

The correlation coefficients from the results of bag samples (Table 1) produce the clearest pattern. Of the 28 terms, 18 are significant at the 1% level or less. The species fall into two groups. One group (*Athiasella dentata* and others) includes species characteristic of the Foothills Site. The other group (*Geogamasus minimus* and others) includes species characteristic of the Summit Site. Since *Athiasella dentata* and *A. relata* regularly occur at both

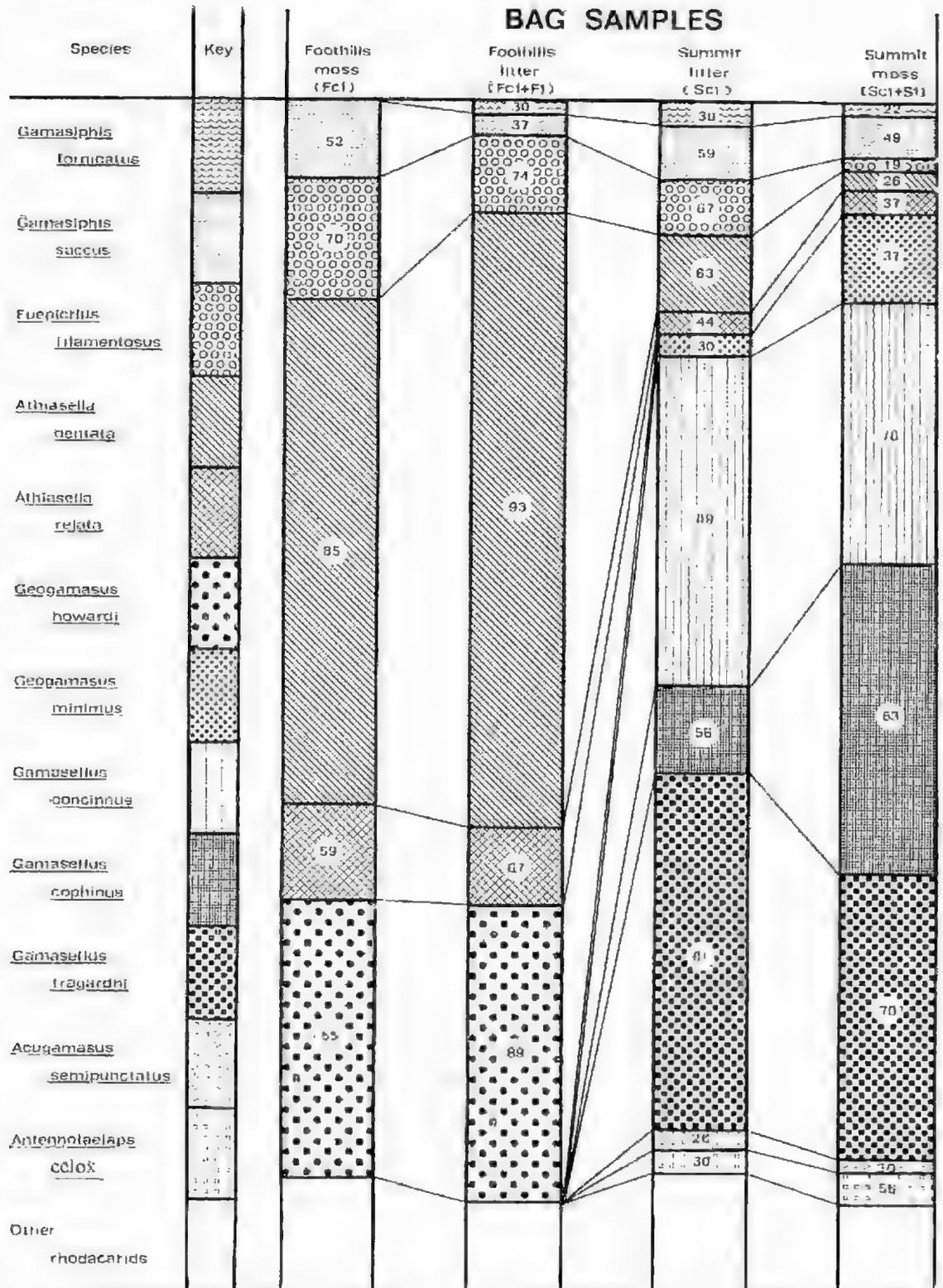


Fig. 3. The dominance and frequency of the 12 commonest species of rhodacarids in bag samples (collected from 2 sites throughout the year). For further explanation see text.

CORE SAMPLES

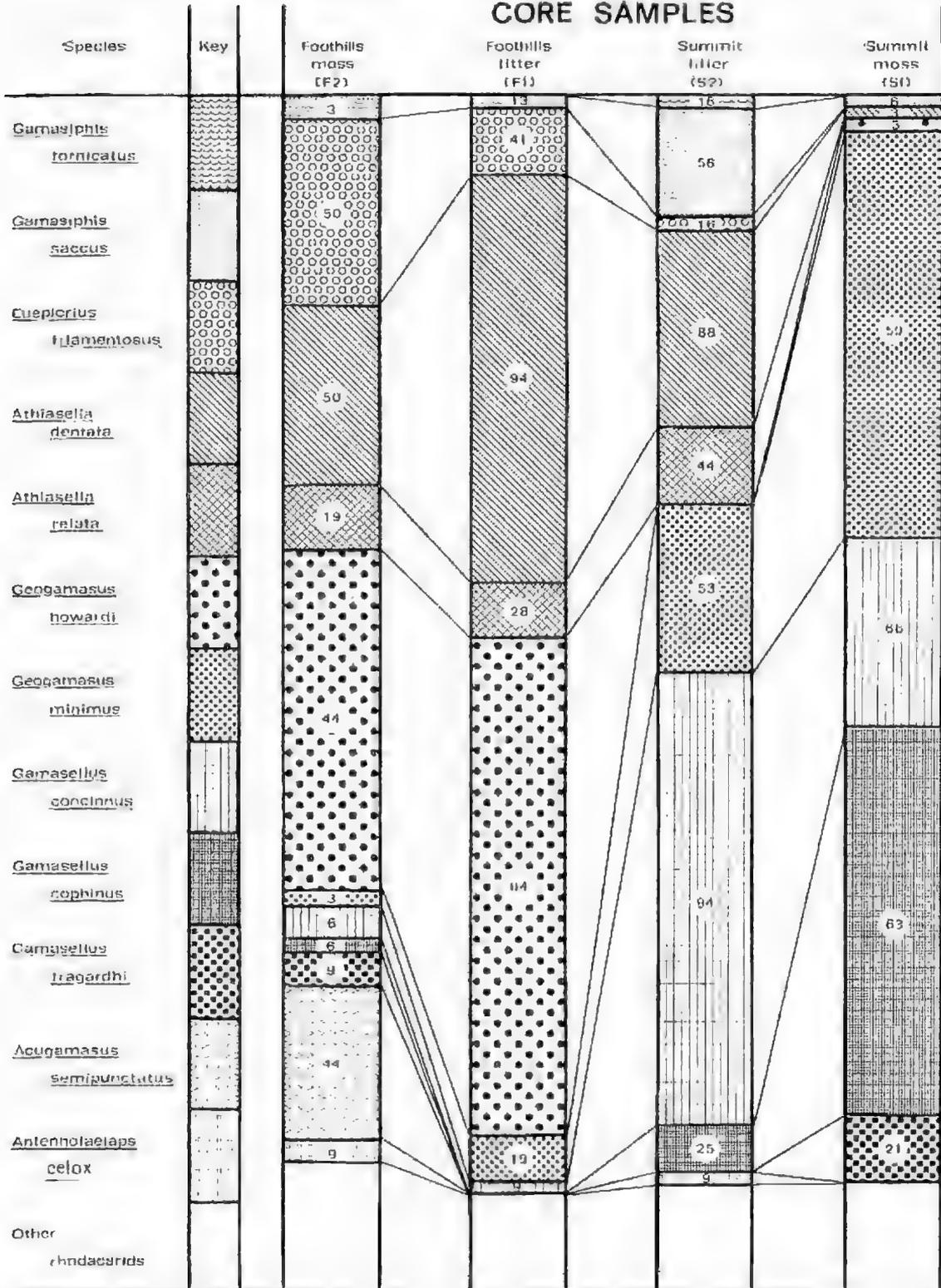


Fig. 4. The dominance and frequency of the 12 commonest species of rhodacarids in core samples (collected from 4 plots in early August). For further explanation see text.

TABLE 1.  
Correlation of Ologamasinae species in 108 bag samples containing 4,844 specimens.  
Correlation indices ( $C \times 10^3$ ), + (association), — (dissociation), upper limit is 707.

Species	A.den.	A.rel.	G.how.	G.min.	G.cop.	G.con.	G.tra.	A.sem.
<i>Athiasella dentata</i>		+355	+448	—49	—142	—256	—197	—36
<i>Athiasella relata</i>	(***)		+307	0	+57	—32	—48	—14
<i>Geogamasus howardi</i>	(***)	(***)		—319	—495	—583	—566	—299
<i>Geogamasus minimus</i>	0	0	(///)		+517	+394	+399	+58
<i>Gamasellus cophinus</i>	0	0	(///)	(***)		+580	+598	+287
<i>Gamasellus concinnus</i>	(//)	0	(///)	(***)	(***)		+656	+396
<i>Gamasellus tragardhi</i>	—	0	(///)	(***)	(***)	(***)	(***)	
<i>Acugamasus semipunctatus</i>	0	0	(//)	0	(**)	(***)		+349

	Significance of relations:		
	None	Positive	Negative
P > 0.1	0		
P < 0.1		+	—
P < 0.01		(**)	(//)
P < 0.001		(***)	(///)

the Summit Site as well as the Foothills Site, there is, in the main, only a significant dissociation between *Geogamasus howardi* and species at the Summit Site.

The correlation coefficients from the results of core samples (Table 2) are similar to those of bag samples but with a drop in significant associations. Of the 28 terms, 12 (6 associations, 6 dissociations) are significant at the 1% level or less. Although there are the same number of significant dissociations, 3 are for different pairs of species. The reduction in associations is only significant where a pair of species was either uncorrelated or significantly associated in bag samples while being significantly dissociated in core samples. This was true at the 1% level or less for three pairs

(*Athiasella dentata*—*Gamasellus cophinus*, *Athiasella dentata*—*Gamasellus tragardhi*, *Acugamasus semipunctatus*—*Gamasellus concinnus*). Such a significant dissociation in core samples could have had a number of causes: smaller sample size isolating niches; sampling separate moss or plant litter covered plots (one at each site was outside the area used for bag sampling), thus isolating niches and possibly introducing new ones; fewer mites per sample; no seasonal effects such as the absence of any rhodacarids from most summer samples. The conspicuous change in dominance between bag and core sampling of *Acugamasus semipunctatus* in "Foothills moss" samples and *Gamasellus tragardhi* in "Summit litter" samples suggests that the significant dissociation in core

TABLE 2.  
Correlation of Ologamasinae species in 128 core samples containing 1,280 specimens.  
Correlation indices ( $C \times 10^3$ ), + (association), — (dissociation), upper limit is 707.

Species	A.den.	A.rel.	G.how.	G.min.	G.cop.	G.con.	G.tra.	A.sem.
<i>Athiasella dentata</i>		+355	+369	—106	—382	—24	—327	—205
<i>Athiasella relata</i>	(***)		+10	+49	—88	+87	—156	—35
<i>Geogamasus howardi</i>	(***)	0		—344	—309	—418	—203	+30
<i>Geogamasus minimus</i>	0	0	(///)		+213	+322	+161	—166
<i>Gamasellus cophinus</i>	(///)	0	(///)	+		+264	+236	—102
<i>Gamasellus concinnus</i>	0	0	(///)	(***)	(**)		—20	—231
<i>Gamasellus tragardhi</i>	(///)	—	—	+	(**)	0		+355
<i>Acugamasus semipunctatus</i>	—	0	0	—	0	(//)	(**)	

	Significance of relations:		
	None	Positive	Negative
P > 0.1	0		
P < 0.1		+	—
P < 0.01		(**)	(//)
P < 0.001		(***)	(///)

samples of the above pairs including these species is due to the difference in areas sampled. The same cause may apply for the dissociation between *Athiasella dentata* and *Gamasellus cophinus*.

### 5. Seasonal Variations

Seasonal fluctuation in total numbers of rhodacarids at each site based on bag sampling are summarised in Fig. 5. There was a conspicuous fall in numbers of rhodacarids in samples collected during the summer (December-February). This is associated with a drying out of the environment and rainfall figures for Stirling (5 km SSE of Summit Site) are given as a factor closely associated with this process.

The low number of samples taken means that seasonal differences indicated for the two

sites are tentative. The number of rhodacarids from the Summit Site was fairly constant throughout the wetter months (May-November). At the Foothills Site the rhodacarid population apparently gradually increased in September and October to a peak, which was nearly twice the highest number at the Summit Site. If this change is true for the actual populations it could be related to the dominant genus at the Foothills Site, *Athiasella*, being multivoltine, while abundant species at the Summit Site are univoltine (see below).

Seasonal fluctuation in numbers of the different developmental stages and sexes of *Gamasellus concinnus*, *Gamasellus tragardhi* and *Athiasella dentata* are represented by histograms (Figs. 6, 7). Not enough immature

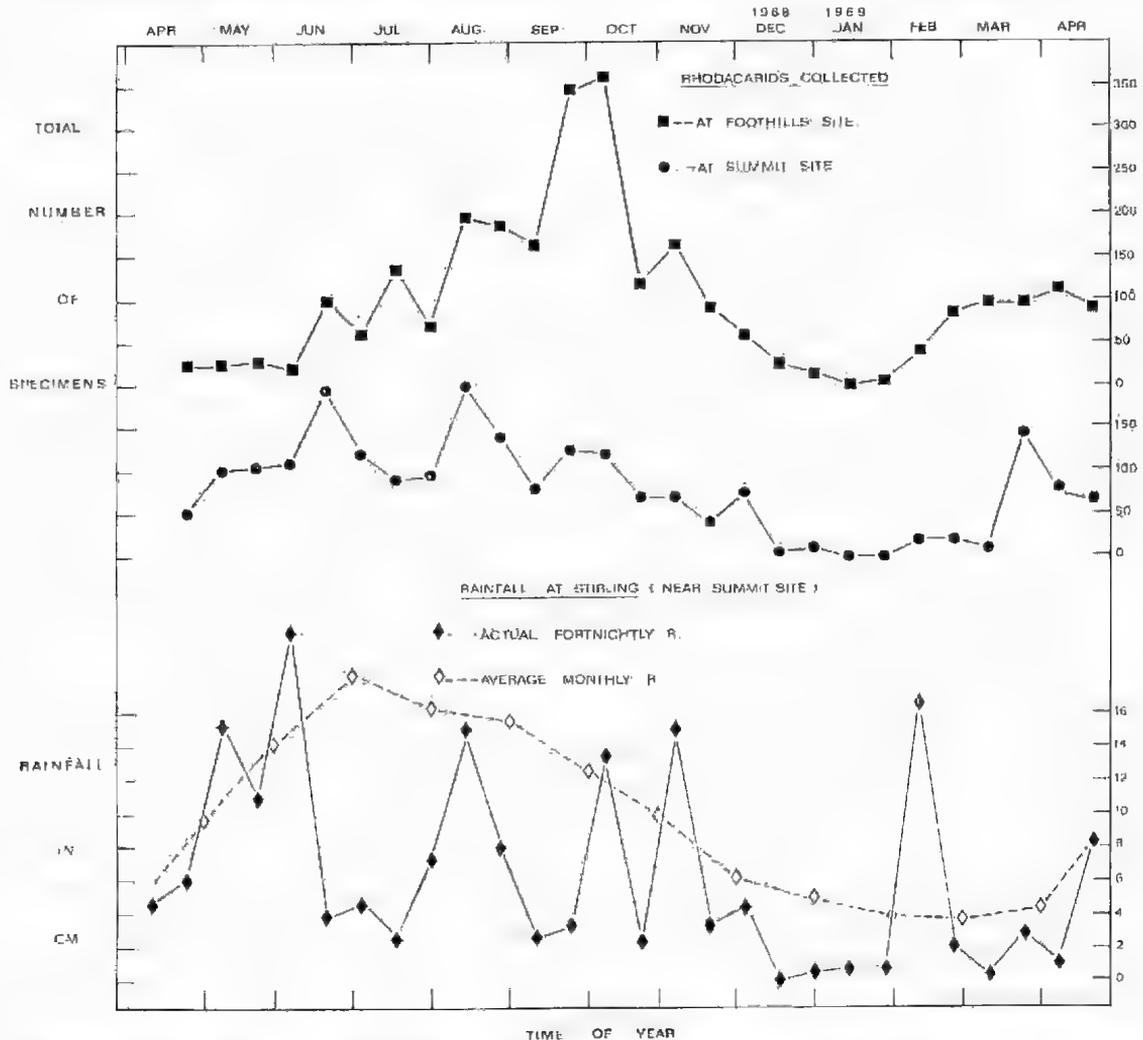


Fig. 5. Seasonal fluctuation in numbers of Rhodacaridae collected in bag samples at two sites during 1968 and 1969. Rainfall records are for nearby Stirling.

stages of the other rhodacarid species were collected to warrant presentation here.

In Canada, where the winter is extremely cold, *Gamasellus vibrissatus* (which is morphologically very similar to *G. tragardhi*) over-winters as adult females which give rise to a single generation in the following summer (Emberson—footnote 2). My results show that *Gamasellus tragardhi* (Fig. 6) has a similar life history, except that it over-summer as adult females and males which give rise to a single generation in the following winter. *Gamasellus concinnus* (Fig. 6) is also univoltine, but over-summer in the deutonymph stage, the males emerging before the females at the onset of the wet season. *Athiasella dentata* (Fig. 7) probably over-summer in the adult stage and it breeds for a longer period, probably being multivoltine. Results for some other species (Lee—footnote 1) are inadequate but suggest the kind of life-history that they have.

*Geogamasus howardi*, *Athiasella relata* and *Euepicrius filamentosus* appear to have similar life-histories to *Athiasella dentata*. *Gamasiphis saccus* and *Gamasellus cophinus* may be univoltine and over-summer in the egg or early immature stages.

It is noteworthy that the life-histories indicate that there are large numbers of rhodacarids (e.g. deutonymphs of *Gamasellus concinnus*) in the soil during the summer that were not represented in the samples considered here. Possibly they move down deeper than the surface 4 cm sampled. There is no clear indication that rhodacarid species stagger their life-histories so as to avoid exploiting the environment concurrently.

Discussion

The twelve commonest species of rhodacarids in serial samples were found at both Summit and Foothills Sites, but each site had

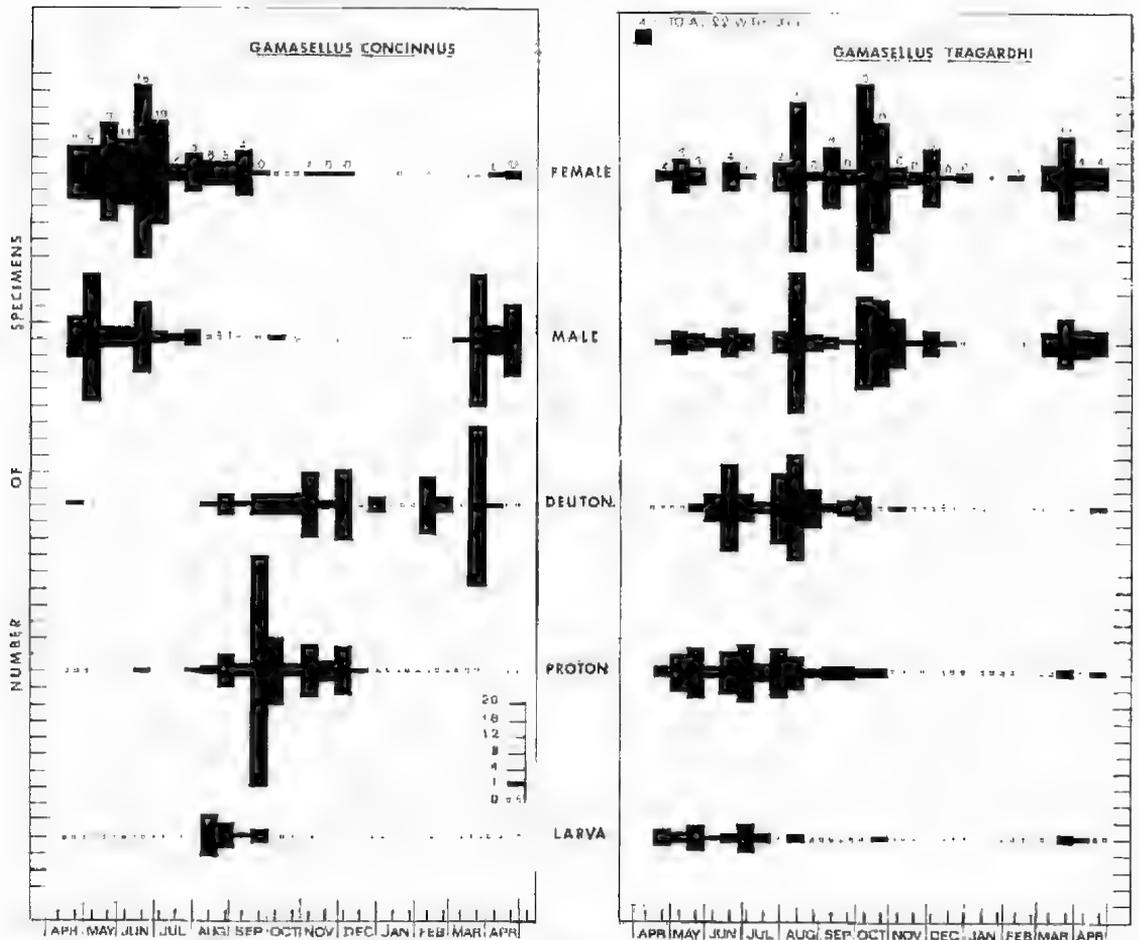


Fig. 6. Seasonal fluctuation in numbers of individuals at different developmental stages of *Gamasellus concinnus* and *G. tragardhi* collected in bag samples at two sites during 1968 and 1969.

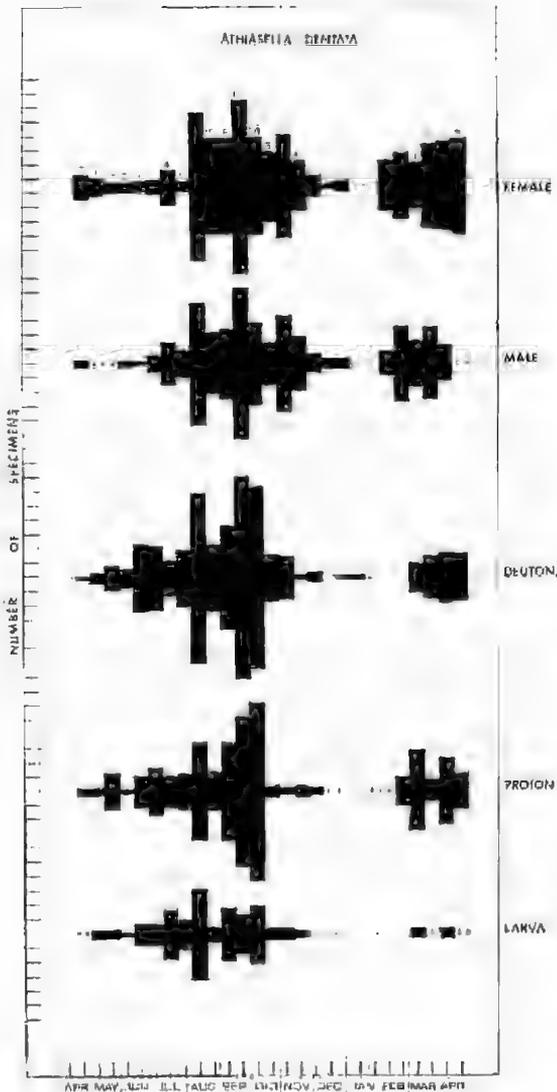


Fig. 7. Seasonal fluctuation in numbers of individuals at different developmental stages of *Athiasella dentata* collected in bag samples at two sites during 1968 and 1969.

different characteristic species and amongst members of the Ologamasinae there was a highly significant association between species characteristic of a site, thus demonstrating the presence of two rhodacarid communities.

Because serial samples were only taken from two sites (Summit and Foothills Sites), and environmental factors were not measured, it is impossible to confidently associate the rhodacarid taxa with particular factors in the environment. If, however, the few samples from the Plains and Coastal Sites are considered, there

appears to be a similarity between the rhodacarid faunas of the Foothills and Plains Sites, in that *Athiasella* had the biggest representation, and between the Summit and Coastal Sites in that *Gamasellus* had the biggest representation. It appears, therefore, that the coastal sand dunes as well as the low nutrient, sandy soils near the summit of Mount Lofty are favourable to *Gamasellus* while the higher nutrient, loamy soils of the foothills and plain are not favourable. The converse appears to be true for *Athiasella*. Factors such as temperature and rainfall, which have a linear gradient between the coast and the summit of Mount Lofty, do not appear to be directly favourable or unfavourable to particular taxa. It is noteworthy that although the flora at the Foothills Site was introduced, mainly from outside Australia, the gamasine fauna was predominantly rhodacarid, with characteristic species that are probably all endemic to South Australia and belong to genera probably endemic to Australia.

Although the composition of the rhodacarid fauna of a particular site was similar in soil samples covered by litter and those covered by moss, a few species showed a distinct preference for one or the other habitat. Other attributes revealed for certain taxa were the tendency for species in the same genus to have similar sex ratios and the species of one genus, *Gamasellus*, to follow quite different life-histories.

Species of some genera (*Athiasella* and *Gamasellus*) were characteristic of one site, while for other genera (*Geogamasus*) this was not true. Conflicting hypotheses on species association were resolved by Bagenal (1951), who stated that "related species are more likely to be found in similar, though not identical, habitats than are unrelated ones". Hurlbutt (1968), working on species belonging to families closely allied to the rhodacarids, reached a similar conclusion expressed as "species which are very different anatomically or very similar anatomically coexist less often than species which are moderately similar to each other". Certainly the three species of *Gamasellus* associated at the Summit Site are as dissimilar (see Fig. 2) from each other as it is possible to select from known species of *Gamasellus* and would probably be considered by Hurlbutt (1968) as 'moderately similar'. They must exploit different ecological niches within the volume of the small cores in which they were collected. The same is likely, although not so clear-cut for the two species of *Athiasella*.

The very slight but easily discernable morphological difference between *Gamasellus tragardhi* from the Summit Site and *Gamasellus grossi* from the Coastal Site (Lee 1973) suggests that the level of taxonomic distinction is closely associated with ease of anatomical diagnosis rather than genetic similarity. The *Rhodacarus* specimen from the Summit Site is possibly equally dissimilar to the *Rhodacarus* specimens from the Plains Site (Lee 1973), both of which I have referred to *R. roseus*. I suspect that many mite species which show limited distribution in widely differing geographical locations (see Introduction) are also grouped in one species because of difficulties in diagnosis.

### Acknowledgements

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### Appendix: Details of Sampling Sites and Plots

**Summit Site.** Location: Mt. Lofty, near to summit, approx. 18 km from the sea, Australian Map Grid co-ordinates: 290600 m E/6127230 m N, map no. 6628-48-j, Dept. of Lands, Adelaide. Height above sea level: 640-670m. Rainfall: mean annual rainfall approx. 120 cm; figures used in graph (Fig. 5) are for Stirling (5 km SSE of site) with a mean annual rainfall of 119.0 cm, and a total rainfall in 1968 of 161.6 cm; it should be noted that "a large percentage of rainfall is lost to the soil by run-off in the Adelaide Hills" (Specht & Perry 1948). Temperature: mean monthly min./max. temperatures for Stirling are January, 11.5°/24.5°C; July, 4.5°/10.5°C. Terrain: steep western slope of hill, near to summit.

**Soil:** Black Hill Association—"low nutrient reserves in most soils in which shallow depth is the chief limiting physical characteristic" (Litchfield 1960); shallow (10-35 cm), dark grey, loamy sand; an analysis of soil from Mt. Lofty Summit showed 0.0044% P<sub>2</sub>O<sub>5</sub> and 0.040% Nitrogen (Specht & Perry 1948). Vegetation: open-forest of Stringy Bark—*Eucalyptus obliqua* L'Hérit.—with a sclerophyllous understorey of small native heath shrubs including *Banksia ornata* F.V.M. ex Meisn., *Epacris impressa* Labill. and *Leptospermum juniperinum* Sm. Fifteen other species of native shrubs, herbs or grasses were collected from the site.

**General Summit Plot (Sc1).** A sub-rhomboid

area (approximately 19 x 12 m) which constituted a clearing amongst charred trees with a drainage channel running through the centre. A fire had passed through the plot three years before (February, 1966). The eastern half of the clearing had substantial vegetation, including abundant fireweed—*Saxodia achilleoides* R. Br. ex Ait., a short-lived, "high-fertility-demanding" species depending on the temporary rise in fertility-level due to the ashes of the burnt vegetation (Specht 1972). The western half of the clearing had a sparse vegetation of heath shrub seedlings and extensive patches of moss. Plant litter was almost absent from the mossy half of the clearing, but had accumulated as raw leaves and twigs around the bases of tree stumps, fallen branches and small shrubs in the other half. Bag samples were collected from this plot.

**Summit Moss Plot (S1).** A rectangular area (2 x 10 m) lying approximately at the centre of the western half of plot Sc1. Covered almost entirely by a mat of moss. All core samples, and after August some of the bag samples, were collected from this plot.

**Summit Litter Plot (S2).** A rectangular area (2 x 10 m) lying approximately 20 m east of plot Sc1, and separated from it by a bitumen road. No fire had been through the plot for 25 years. Understorey was thick with heath shrubs and decomposing plant litter (mainly 1.0 cm deep) covered most of the ground. Only core samples were collected from this plot.

**Foothills Site.** Location: Foothills of Mt. Lofty, approx. 16 km from the sea. Australian Map Grid co-ordinates: 288230 m E/6127620 m N, map no. 6628-49-e, Dept. of Lands, Adelaide, Height above sea level: 240-270 m. Rainfall: mean annual rainfall is approx. 94.0 cm. Temperature: mean monthly min./max. temperatures for Glen Osmond (5 km W of site) are January, 16°/28°C; July, 7°/15°C. Terrain: bottom of steep northern slope (south-facing aspect of ridge) of Waterfall Gully, just west of First Waterfall, beside an artificial pond formed by dredging and damming First Creek. Soil: Osmond Association—"Nutrient reserves . . . presumably intermediate between low levels . . . and the moderate levels in the red brown earths of the piedmont aprons" (Hitchfield 1960): shallow to deep (35-110 cm), alluvial red-brown loam, artificially moved to present position, possibly from creek bed. Vegetation: alien (as it mainly is on bottom 15-20 m of slope downstream from this point, further up slope from site there are Manna Gums—*Eucalyptus viminalis* var. *huberiana* (Naudin) Burbridge—and Drooping Sheoaks—*Casuarina stricta* Ait.); Fan-leaved palms (*Livistona* sp.), Olives (*Olea europaea* L.), Lilacs (*Syringa vulgaris* L.) and *Pittosporum undulatum* Vent. (native of eastern states); understorey of brambles, bracken and live species of herbs and grasses; only native plant found was a small herb—*Geranium pilosum* Forst.

**General Foothills Plot (Fcl).** A sub-rectangular area (approx. 20 x 8 m) which constituted a patch of quite thick alien vegetation on the north bank of the pond. Although the bank was steep, the understorey held the plant litter in most places, but where the bank was very steep, or the ground stony, there was little or no litter and moss or liverworts grew. Bag samples were collected from this plot.

**Foothills Litter Plot (F1).** A rectangular area (2 x 10 m) lying approx. at the centre of plot Fcl. Covered by plant litter (Olive leaves predominated, mainly 2.0 cm deep) and some herbs and grass tussocks. All core samples, and after August some of the bag samples, were collected from this plot.

**Foothills Moss Plot (F2).** A rectangular area (2 x 10 m) lying approx. 10 m west of plot Fcl, and separated from it by an artificially channelled creek bed, which was steep and usually dry. Some soil bare but mostly covered by moss or liverworts. Under a row of small trees (*Pittosporum undulatum*) evenly planted along the west bank of the creek. Only core samples were collected from this plot.

**Plain Site.** Location: Heywood Park, Unley, on the Adelaide Plain, approx. 8 km from the sea. Australian Map Grid co-ordinates: 280810 m E 6128350 m N, map no. 6628-50-e, Dept. of Lands, Adelaide, Height above sea level: 30-60 m. Rainfall: approx. 58 cm/year. Temperature: January, 16.5°/29.5°C; July, 6.5°/14.5°C. Terrain: small, flat suburban park, with tall trees surrounding clearing. Soil: Edwardstown Association; red-brown loam. Vegetation: savannah woodland of River Red Gums—*Eucalyptus camaldulensis* Dehn.—"is confined to grey-brown podsols on the slopes and ridges and alluvial soils in the valleys, both soils being rich in P<sub>2</sub>O<sub>5</sub> and nitrogen and having high water relations" (Specht & Perry 1948); understorey of grass amongst patches of *Eucalyptus* litter. Samples from patches of litter under River Red Gums.

**Coastal Site.** Location: "Pinery", Grange Golf Course, near coast of Adelaide Plain, approx. 1.5 km from the sea; Australian Map Grid co-ordinates: 271310 m E/6137040 m N, map no. 6528-36-m, Dept. of Lands, Adelaide. Height above sea level: 0-30 m. Rainfall: approx. 43 cm/year. "greens" artificially watered. Temperature: January, 15°/28°C; July 6.5°/15°C. Terrain: inland relicts of coastal dunes formed in Pleistocene Period, modified to a golf course. Soil: Osborne Association; calcareous sand in which the soluble calcium bicarbonate has been leached to lower horizons. Vegetation: low woodland of Native Pines—*Callitris preissii* Miq.—with understorey of moss and sparse grass, on dune ridges, amongst artificial grass greens; "a 'degraded' climax plant community characteristic of infertile, non-calcareous, sandy soils" (Specht 1972). Samples from moss mats under Native Pines.

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## PEARSON ISLAND EXPEDITION 1969†-9. HYDROIDS

BY JEANETTE E. WATSON\*

### Summary

WATSON, JEANETTE E. (1973) . -Pearson Island Expedition 1969.-9. Hydroids. *Trans. R. Soc. S. Aust.* **97**(3), 153-200, 31 August 1973.

Intensive collecting of the sublittoral hydroid fauna of Pearson Island in the Great Australian Bight, in January, 1969, yielded 81 species (with 3 varieties in one species), of which 13 species are newly described. There are 18 new records for South Australia and 1 new record for Australia. The collection permits a fuller description of several hitherto poorly known southern Australian species. Collections were made using SCUBA at 3 localities representative of environmental extremes on the coastline—a rough-water site exposed to prevailing swell, a sheltered embayment, and a deep water situation in open ocean.

The deeper water fauna contained species already known from deep dredgings in the Great Australian Bight, but differed markedly from the collection from shallower water, with only 1 species common to both.

The Sertulariidae and Plumulariidae are represented by the greatest number of species, and are equally abundant in both epizoic and epiphytic habitats; the Haleciidae, Lafoeidae and Syntheciidae are epizoic, and Lineolariidae, with 1 species, epiphytic. The large plumose colonies of the Aglaopheniinae are epilithic. Hydroids are more abundant on the rough-water coastline, where red algae and the solitary ascidian, *Herdmania momus* (Savigny), are epiphytised by a large number of species. Delicate athecate species, and species of the Campanulariidae which may be expected to liberate medusae, are restricted to sheltered waters, or to depths below turbulence from surge in the rough-water locality.

The high percentage of hydroids now known to be common to the coasts of South Australia, Tasmania and Victoria, supports the view that the Flindersian province extends from Bass Strait into the Great Australian Bight.

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### Introduction

Hydroids have been reported from a number of expeditions around the southern and south-eastern Australian coastline—the voyage of the "Rattlesnake" (Busk 1852), the "Challenger" dredgings in Bass Strait (Allman 1883, 1884), the "Thetis" dredgings along the New South Wales coastline (Ritchie 1911), the "Endeavour" expeditions from New South Wales to Western Australia (Bale 1914, 1915), the Michaelson-Hartmeyer Expedition to Western Australia (Stechow 1924, 1925), and the McCoy Society Expeditions to Lady Julia Percy Island, Victoria (Blackburn 1937), and the Sir Joseph Banks Group, South Australia (Blackburn 1938). With the exception of the

last two expeditions, the hydroid collections were made over a wide geographical area, while the collections of the Michaelson-Hartmeyer Expedition and the McCoy Society Expeditions, although restricted in area, were gained mainly from drift, the eulittoral zone, and to a minor extent, from shallow subtidal dredgings. No intensive survey has however, been made of the subtidal hydroid fauna at any one locality in the Australian region.

The joint expedition of the Department of Fisheries and Fauna Conservation of South Australia and the Royal Society of South Australia to Pearson I., 6–15 January, 1969, provided an opportunity to undertake a comprehensive subtidal survey of the hydroid fauna of an offshore island.

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† Other accounts of the geomorphology and biology of the Pearson Islands are given in Volume 95, Part 3 (1971) of the Transactions, as well as in the present part.

The South Australian hydroid fauna is known from reports of the "Endeavour" dredgings in the Great Australian Bight along the 126° parallel of longitude, together with a small collection from the Isles of St. Francis in the Nuyts Archipelago. Blackburn (1938) recorded the shallow water fauna of the Sir Joseph Banks Group in Spencer Gulf, and Shepherd & Watson (1970) listed and discussed the associations of hydroids and algae at West I., Encounter Bay.

The survey yielded a total of 81 species (with 3 varieties in one species), of which 13 species are new; there are 18 new records for South Australia, including 1 new record for Australian waters. Only 2 athecate species were found, and 6 of the thecate hydroids could be identified only to genus.

Pearson I. (Fig. 1) is a granitic island situated at Lat. 33°57'S, Long. 134°15'E, about

64 km offshore on the continental shelf in the eastern region of the Great Australian Bight.

Weathering of the granite has produced a rugged topography of massive blocks, clefts and caverns, continuous to the seafloor at depths of 45 m immediately surrounding the island, with a rapid increase in depth offshore to 70 m. A more detailed account of the environmental conditions is given by Shepherd & Womersley (1971).

#### Methods

Collections were made by divers using SCUBA. As diving time was limited to a total of 30 hours underwater, two main sites were chosen for intensive collecting. One site was on the rough-water windward, southwesterly side of the island; the other was in the more sheltered north facing Eastern Cove (Fig. 1). The benthic flora and fauna at each site was systematically sampled (with particular attention to hydroids) from the upper sublittoral to the seafloor at 50 m depth. Two additional small collections were also made—one in seagrass meadows in the more sheltered part of Eastern Cove, and another, at 65 m depth, 4 km to the south, between Pearson I. and Dorothee (Station F). Because of the rugged nature and exposure of the coastline to surf, no collection of the intertidal fauna was made.

#### Collections

Holotype and paratype microslides, and other microslides and material are lodged in the National Museum of Victoria, Melbourne (NMV). Paratype microslides are also lodged in the South Australian Museum (SAM).

In most instances, the synonymy of Ralph (1958, 1961a,b, 1966) is adopted, and only pertinent references to species in Australian literature are given. The status of several species is reviewed to resolve confusion in the literature, and a number of rare and poorly known species are redescribed.

The site notation of Shepherd & Womersley (1971) is followed, "R" denoting material collected on the rough-water side of the island, and "S" denoting the sheltered side. Hydroids collected in deep water at Station F are noted separately. Depths at which each species was collected are given. These depths will, however, represent only part of the total range of each species. In most instances, the substrate upon which each species was found is also noted. As many hydroids are both seasonal and irregular in occurrence, it is likely that collections made at other parts of the island

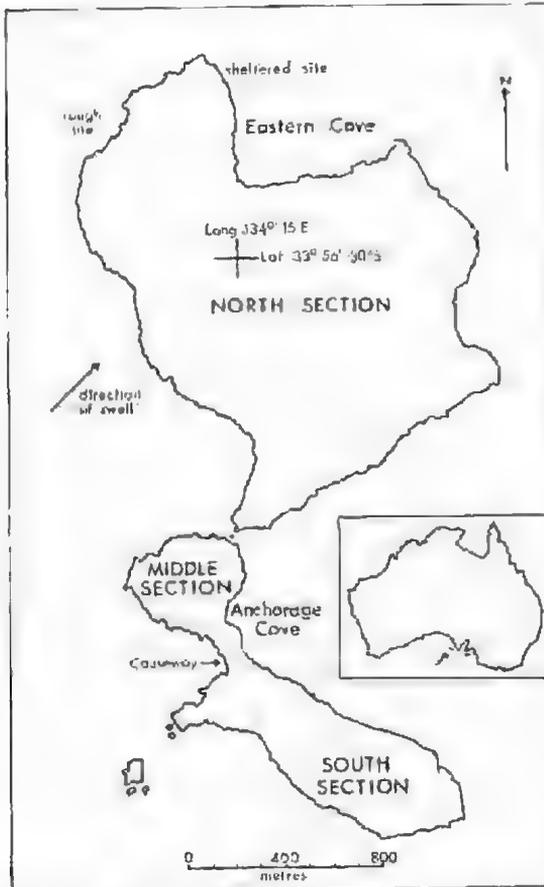


Fig. 1. Map of Pearson Island, showing study sites near the northern end. Inset shows the situation of Pearson Island in the Great Australian Bight. (After Shepherd & Womersley 1972).

or even at the same sites at other times, would yield a slightly different faunal list.

The algal ecology of these Pearson I. sites is described by Shepherd & Womersley (1971), who also list the algal species collected.

### Ecology

#### Occurrence of Hydroids

The collection yielded a large number of species, in spite of the apparent paucity of the hydroid fauna on first inspection of the locality. Many of the species are cryptic forms growing sparsely in small colonies among algae, where only accessible with SCUBA. Even those species (*Solanderia fusca*, *Thecocarpos divaricatus* var. *maccoyi*, *Halicornaria longirostris*, *H. prolifera*) which are known to form conspicuous colonies in other localities, were small and attenuated, suggesting that conditions for growth were not entirely favourable. This may be due to the strong surge conditions around the island preventing good growth of the colonies, or to the high light transmittance of these waters, which appears to inhibit hydroid growth (J. W. unpublished data).

The only athecate species, *Tubularia larynx* and *Solanterla fusca*, recorded from Pearson I., were found in relatively sheltered situations on the rough-water site. Only one colony of the former species, growing deep within a cavern, was recorded, whereas the latter species occurred as abundant small colonies in sheltered situations among the holdfasts of the brown kelp *Ecklonia radiata*.

The scarcity in rough ocean waters of athecate and other species which liberate medusae has already been noted at West I. (Shepherd & Watson 1970). Thus their absence from Pearson I. is not surprising, considering the exposure of the coastline to surf. *Campanularia australis*, a species likely to liberate medusae, but whose reproductive structures are still unknown, was however common on the rough-water site, but only at a depth of 34–50 m, well below the zone of maximum turbulence.

The collection from Station F, at 65 m depth, yielded a markedly different fauna from that of shallower water. The seafloor at this station was ripple-marked sand, with rare algae, a sparse epifauna of worm tubes, calcareous bryozoa, solitary ascidians, and old shell. The dominant hydroids here were *Symplectoscyphus subdichotomus*, *S. longithecus*, *Synthecium elegans* f. *subventricosum* and *Plumularia asymmetrica*. The only species of this group also ranging into shallower water

was *S. subdichotomus* but it was uncommon. *P. asymmetrica*, the most abundant species in the deeper water, has been recorded only three times previously, from adjacent waters of the Great Australian Bight.

#### Relationship between Hydroid and Substrate

Although little firm evidence of the association between hydroids and substrate can be gained on the basis of one series of collections, a number of broad relationships and possible obligatory associations are evident from the Pearson I. material.

Of the total of 81 species and 3 varieties, 27 are exclusively epiphytic, 30 are non-epiphytic, and 18 are both epiphytic and epizoic. The holdfast fauna, although strictly epiphytic, is listed with epizoic, epilithic and "icegrowing" species: (Table 3.)

#### A. Epiphytic Hydroids (Table 2).

The two major families present, the Sertulariidae and the Plumulariidae, are almost equally divided between epiphytic and epizoic species. The Lineolariidae, represented only by *Lineolaria spinulosa*, is epiphytic. Altogether, 47 species are associated with red algae, mostly on the rough-water site, 27 species are associated with brown algae, and 3 species with green algae. This is in accord with findings at West I. (Shepherd & Watson 1970) where red algae were also the most heavily epiphytised group. The most abundant and widely distributed species of algae had the greatest number of hydroid epiphytes. Brown algae, particularly *Sargassum*, although a substrate for fewer hydroids, were often heavily epiphytised by luxuriant colonies of some common species such as *Amphisbelia minima* var. *pumiloides*, *Plumularia epibracteolosa* and *Sertularella avrilia*.

Several hydroids showed a high degree of selectivity and were associated with only one algal substrate (Table 2); but as these species were not of common occurrence, it is uncertain whether an obligatory relationship actually exists. However, there are two instances of a commonly occurring hydroid associated with only one species of alga. *Sertularia acuta* was found only on the red alga *Stenocladia australis*, whereas at West I. it was abundantly associated with the red alga *Phacelocarpus labillardieri*. The factors influencing the preference of *S. acuta* for *Stenocladia australis*, to the exclusion of *Phacelocarpus labillardieri*, at Pearson I. are unknown.

The most conspicuous association was that of *Plumularia epibracteolosa* with the brown

alga *Sargassum bracteolosum*. The fronds of this alga were densely covered by the hydroid, in contrast to the stems which were exclusively epiphytised by *Amphisbetia minima* var. *pumiloides*. *S. bracteolosum* was also recorded at West I., but was epiphytised only by *A. minima* and *Campanularia australis*.

Two other species, *Lineolaria spinulosa* and *Plumularia australis*, were common epiphytes on the seagrass *Posidonia australis*, but were not associated with algae. Colonies of both hydroids were frequently intergrown on the same blade of seagrass.

The growth habit of *Plumularia flexuosa* with a species of the red algal genus *Mychodea* has not previously been reported. Usually hydroids avoid algae with a thallus of small diameter (Nishihira 1967). The frond of *Mychodea* sp., although somewhat larger than the hydroid stolon, is nevertheless rather narrow. The hydroid stolon passes length wise internally through the frond, giving off stems to the outer surface at regular intervals.

Of particular interest is the gradational epiphytism displayed by the *Amphisbetia minima-A. minuscula* group. Bale (1884) distinguished var. *pumiloides* from var. *intermedia* entirely upon the structures of the trophosome. Both these varieties, and the closely related species *A. minuscula*, are abundant in the present collection, and display a marked gradational preference for certain groups of algae—the robust var. *pumiloides* is found on large brown algae of the genus *Sargassum* (*S. varians*, *S. verruculosum*, *S. bracteolosum*) and on *Acrocarpia paniculata*; var. *intermedia*, a small form, is associated with the red algae *Rhodomythia australis*, *Metamastophora flabellata*, *Laurencia elata*, and *Carpopeltis phyllophora*. *A. minuscula* is both epiphytic and epizoic and is associated with the red alga *Laurencia elata*, the brown alga *Distromium flabellatum*, a species of the green alga *Caulerpa*, as well as being epizoic on *Herdmania momus* and *Halicornaria longirostris*.

#### B. Epizoic Hydroids

The Lafoeidae, Syntheciidae and Haleciidae (with one exception *Halecium* sp. 1) are entirely epizoic. Generally, epizoic associations are less well defined than epiphytic associations, most of the species involved being found on a wide variety of animal substrates. The substrates upon which hydroids were found were, in order of abundance, other hydroids (19 occurrences), calcareous bryozoa (15), sponges (14), the solitary ascidian *Herdmania*

*momus* (14), compound ascidians (3), and mucilaginous worm tubes (2). Of the animal substrates, only *H. momus* and other hydroids could be identified to species.

The two species of hydroids most commonly epizoitised by other hydroids are *Thecocarpus divaricatus* var. *cystifera* and *Halicornaria longirostris*, whose thick robust stems are suitable for colonisation by the small stoloniferous species such as *Symplectoscyphus epizoleus*, *Reticularia antarctica* and *R. annulata*.

*Herdmania momus*, one of the most abundant larger invertebrates at Pearson I., grows upon rock walls in open situations where there is moderate water movement. The leathery siphonal region of the ascidian is colonised by small species of red algae, bryozoans and hydroids, the most commonly occurring hydroids being *Sertularella robusta*, *Sertularella* sp. 1, and *Diphasia subcarinata*.

#### C. Epilithic Hydroids

Epilithic colonies are usually conspicuous plumose forms growing from small matted rootstocks on rock surfaces in open situations where they can take maximum advantage of water movement. This group, comprising *Thecocarpus divaricatus* var. *cystifera*, *Halicornaria prolifera*, *H. longirostris*, and *H. urea*, all belong to the Aglaopheniinae.

Closely allied in habit to the true epilithic species are the two "freegrowing" plumularian species, *Plumularia asymmetrica* and *Halopteris sulcata*. Both are large plumose colonies growing from a small rootstock attached to pebbles or shell fragments buried in the sea-floor.

#### D. Non-selective Hydroids

Species occurring in both epizoic and epiphytic habitats are often also associated with the most abundant animals and plants, and are thus among the most commonly occurring hydroids. The most frequent of these multi-preferential associations are:

Hydroid	Substrate
<i>Sertularella robusta</i>	<i>Ballia callitricha</i>
	<i>Herdmania momus</i>
<i>Sertularella</i> sp. 1.	<i>Laurencia elata</i>
	<i>Herdmania momus</i>
<i>Diphasia subcarinata</i>	<i>Amansia pinnatifida</i>
	<i>Herdmania momus</i>

Although many species (18) are both epizoic and epiphytic, only 2 species, *Thecocarpus divaricatus* and *Halicornaria longirostris* are epilithic as well. The largest of the 3 varieties of *T. divaricatus*, var. *cystifera*, is epilithic.

while of the 2 smaller varieties; var. *briggsi* is gradational between epiphytic and epizoaic, and var. *maccoyi* is epiphytic.

#### Distribution

All thecate families, with the exception of the Campanuliniidae, are represented in the collections. Campanulariidae are represented with 5 species, Sertulariidae with 31, Plumulariidae with 31, Haleciidae with 5, Lafoeidae with 4, Syntheciidae with 2, and Lincolariidae with 1 species.

With the exception of *Thecocarpus divaricatus* var. *briggsi* (previously recorded from New South Wales), *Reticularia antarctica* (Western Australia), and *Zygophylax antipathes* (Torres Strait), all other species newly recorded from South Australia are known from Victorian waters, mostly from the intensive collecting of Mulder & Trebilcock (1909-1916) along the central Victorian coastline, from Port Phillip Heads to Torquay.

The new record for Australia, *Synthecium dentigerum*, has been reported only twice previously, once from the Indian Ocean, and once from South Africa.

The genus *Lytocarpus*, well known from the Indo-Pacific region, is recorded for the first time (*L. mulderi*) from southern waters.

Only 14 of the 38 species listed by Blackburn (1938) from the Sir Joseph Banks Group were in the Pearson I. collections. The two groups of islands, however, are subject to different environmental conditions, the former group of islands being situated in sheltered water at the southern end of Spencer Gulf, in contrast to the extreme exposure to rough water of Pearson I. in the Great Australian Bight. Comparison of the faunal lists of the two island groups shows that the species common to both are mostly species epiphytic on algae, and on the seagrass *Posidonia australis*.

#### Zoogeography

Of the 83 species and 3 varieties recorded from Pearson I., 18 species are common to New Zealand waters, 15 have a northern Australian and western Indo-Pacific distribution, 10 species occur in South African waters, 6 are recorded from Japan, 2 from the Antarctic, and 2 are cosmopolitan. Thirty-nine (49%) of the species recorded (including the new species) are, as presently known, endemic to southern and south-eastern waters of Australia.

Blackburn (1942) estimated that 42% of the known hydroid fauna of South Australia ranged into New South Wales, and 18% into

Western Australia. The present collection (with 1 variety common to N.S.W. and 2 species common to W. Aust.) does not substantially alter these estimates. The basis of comparison between the 3 States is, however, poor, as both the deep and shallow water hydroid fauna of South Australia is now better known from SCUBA collections, whereas much of our knowledge of the hydroid fauna of New South Wales comes from deeper dredgings on the continental shelf, and that of Western Australia is from the reports of shallow water collections between Albany and Shark Bay (Stechow 1924, 1925).

The 18 new records from the present collection, combined with 18 from West I. (Shepherd & Watson 1970) brings the South Australian hydroid fauna, based on Blackburn's list, to 119 species.

Thus, the total number of species common to South Australia and Victoria is 81 (61%) of the known South Australian fauna. This figure does not differ greatly from Blackburn's earlier estimate of 65%.

Based on Hodgson (1950), the fauna common to both South Australia and Tasmania is 69% of the South Australian fauna. The species common to Victoria and Tasmania comprises 70% of the known Tasmanian fauna. This distribution pattern lends further support to the contention of Womersley & Edmonds (1958) that the Flindersian Province embraces much of the Maugean, and extends from the eastern Victorian coastline to at least the central coastline of South Australia.

#### Systematic Section

##### Order ATHECATA

##### Family TUBULARIIDAE

*Tubularia larynx* Ellis & Solander, 1786: 31, Bale, 1888: 748. Ralph, 1953: 68; 1966: 160.

*Records:* R. 24 m, on walls of cavern, sheltered from surge.

*Material:* One small cluster of stems to 2 cm high. Stems increasing gradually in diam, distally to 0.5 cm. Perisarc thick, smooth, with groups of 3-8 annulations; regrowth of broken stems beginning with a new series of annulations. *Hydranth* 1.2 mm long, 1.0 mm wide, but tentacles not fully extended. Proximal whorl of tentacles a little longer than distal. *Gonophores* small, spherical, sex indeterminate, clustered between whorls of tentacles. *Colour*—tentacles white, gonophores pink.

TABLE 1  
List of Species

Substrate notation: EZ — epizoid, Ep — epiphytic, El = epilithic, Fg — freegrowing, Hf — holdfast fauna.

Symbols are given in order of abundance of colonies on substrate.

\* denotes a new record for South Australia.

The number preceding names of the species in the following list is the key to the species in Tables 2 and 3.

ATHECATA

Family TUBULARIIDAE

1. \**Tubularia larynx* Ellis & Solander. El.

Family SOLANDERIIDAE

2. *Solanderia fusca* (Gray). Hf.

THECATA

Family CAMPANULARIIDAE

3. *Clytia* (?) *pearsonensis* n.sp. Ez.  
 4. *Campanularia ambiplica* Mulder & Trebilcock. Ep.  
 5. *Campanularia australis* Stechow. Ep, Ez.  
 6. \**Campanularia gaussica* Stechow. Fz.  
 7. *Campanularia* sp. Ep.

Family LAFOEIIDAE

8. \**Reticularia antarctica* (Hartlaub). Ez.  
 9. *Reticularia annulata* n.sp. Ez.  
 10. *Reticularia* sp. Ez.  
 11. \**Zygophylax antipathes* (Lamarck). Hf.

Family LINEOLARIIDAE

12. *Lineolaria spinulosa* Hincks. Ep.

Family HALECIIDAE

13. \**Ophiodissa australis* (Bale). Ep.  
 14. *Ophiodissa blackburni* n.sp. Ez.  
 15. *Phylactotheca armata* Stechow. Ez.  
 16. *Halecium delicatulum* Coughtrey. Ez.  
 17. *Halecium* sp. 1. Ez.  
 18. *Halecium* sp. 2. Ep.

Family SYNTHECIIDAE

19. *Synthecium elegans* forma *subventricosum* Bale. Ez.  
 20. \**Synthecium dentigerum* Jarvis. Ez.

Family SERTULARIIDAE

21. *Thyroscyphus marginatus* (Bale). Ep, Ez.  
 22. *Parascyphus simplex* (Lamouroux). Ez.  
 23. *Diphasia subcarinata* (Busk). Ep, Ez.  
 24. *Stereotheca elongata* (Lamouroux). Ep.  
 25. *Crateritheca acanthostoma* (Bale). Ep, Ez.  
 26. \**Crateritheca crenata* (Bale). Ep.  
 27. *Salacia obliquanoda* (Mulder & Trebilcock). Ep, Ez.  
 28. *Sertularella robusta* Coughtrey. Ep, Ez.  
 29. \**Sertularella simplex* (Hutton). Ez.  
 30. *Sertularella annulaventricosa* Mulder & Trebilcock. Ep, Ez.  
 31. *Sertularella avrilia* n.sp. Ep.  
 32. *Sertularella* sp. 1. Ez, Ep.  
 33. *Sertularella* sp. 2. ?  
 34. \**Symplectoscyphus longithecus* (Bale). ?  
 35. *Symplectoscyphus subdichotomus* (Kirchenpauer). Ez.  
 36. *Symplectoscyphus neglectus* (Thompson). Ep.  
 37. *Symplectoscyphus indivisus* (Bale). Ep.  
 38. *Symplectoscyphus pygmaeus* ? (Bale). Ez.  
 39. *Symplectoscyphus macrothecus* (Bale). Ep.  
 40. *Symplectoscyphus rostratus* n.sp. Ep, Ez.  
 41. *Symplectoscyphus epizoicus* n.sp. Ez.  
 42. *Sertularia macrocarpa* Bale. Hf.  
 43. *Sertularia unguiculata* Busk. Ez, Hf.  
 44. \**Sertularia bicuspidata* Lamarck. Ep.  
 45. *Sertularia maccallumi* Bartlett. Ep.  
 46. *Sertularia acuta* Stechow. Ep.  
 47. *Amphisbetia maplestonei* (Bale). Hf.  
 48. *Amphisbetia pulchella* (Thompson). Ep, Ez.  
 49. *Amphisbetia olseni* n.sp. Fz, Ep.

50. <i>Amphisbetia minima</i> var. <i>pumiloides</i> Bale.	Ep.
51. <i>Amphisbetia minima</i> var. <i>intermedia</i> Bale.	Ep. Ez.
52. <i>Amphisbetia minuscula</i> (Bale).	Ep. Ez.
Family PLUMULARIIDAE	
53. <i>Pyenotheca producta</i> (Bale).	Ep.
54. * <i>Antennella tubulosa</i> (Bale).	Ep.
55. * <i>Antennella campanuliformis</i> (Mulder & Trebilcock).	Ep.
56. * <i>Antennella secundaria</i> s.sp. <i>dubiaformis</i> (Mulder & Trebilcock).	Ep.
57. <i>Halopteris sulcata</i> (Lamarck).	Fg.
58. <i>Halopteris campanula</i> var. <i>campanula</i> (Busk).	El.
59. <i>Halopteris buski</i> (Bale).	Ez.
60. <i>Halopteris opposita</i> (Mulder & Trebilcock).	Ep.
61. * <i>Gattya halei</i> (Bartlett).	Ep.
62. <i>Gattya uglaopheniiformis</i> (Mulder & Trebilcock).	Ez. Ep.
63. <i>Gattya trebilcocki</i> n.sp.	Ep.
64. <i>Plumularia procumbens</i> Spencer.	Fl.
65. <i>Plumularia asymmetrica</i> Bale.	Fg.
66. <i>Plumularia flexuosa</i> Bale.	Ep.
67. <i>Plumularia spinulosa</i> Bale.	Ep. Ez.
68. * <i>Plumularia goldsteini</i> Bale.	Ep.
69. <i>Plumularia obliqua</i> (Johnston).	Ep.
70. <i>Plumularia australis</i> Kirchenpauer.	Ep.
71. <i>Plumularia epibracteolosa</i> n.sp.	Ep.
72. <i>Plumularia meretricia</i> n.sp.	Ez.
73. <i>Plumularia togata</i> n.sp.	Ep.
74. <i>Plumularia australiensis</i> n.sp.	Ez.
75. <i>Aglaophenia plumosa</i> Bale.	Ez. Ep.
76. <i>Thecocarpus divaricatus</i> var. <i>maccayi</i> Bale.	Fp.
77. * <i>Thecocarpus divaricatus</i> var. <i>briggsi</i> Bale.	Ep. Ez.
78. <i>Thecocarpus divaricatus</i> var. <i>cystifera</i> Bale.	Fl.
79. * <i>Lytocarpus mulderi</i> (Bartlett).	?
80. <i>Halicornopsis elegans</i> (Lamarck).	El.
81. <i>Halicornaria longirostris</i> (Kirchenpauer).	El. Ez. Ep.
82. * <i>Halicornaria prolifera</i> Bale.	El.
83. <i>Halicornaria aurea</i> n.sp.	El.

*Remarks:* This cosmopolitan species was doubtfully recorded for the first time from Australian waters by Ralph (1966) who reported a few infertile stems from Port Phillip Bay, Vic. This is the second record of the species in Australia, and a new record for S. Aust.

*Solanderia fusca* (Gray, 1868). Watson & Utinomi, 1971: 19, pl. 8.

*Ceratella fusca* (Gray), Spencer, 1891: 8.

*Records:* R, 14–33 m, among holdfasts of brown algae.

*Material:* Four very small infertile colonies broken off from the rootstock, the largest colony 55 mm high and 20 mm wide. Colonies compact, branching closely in one plane from a thick main stem. *Stem* of largest colony 3 mm wide at base, stem and branches flattened in plane of growth. *Hydrophores* are open shelf-like structures, prominent on younger branches, edged with 10–15 bluntly pointed terminal spines connected by a thick, shallowly scalloped chitinous web. *Trabeculate meshwork* of branches close and solid, with square to circular openings. *Spines* similar to those edging hydrophore developed at points of intersection of meshwork on older branches.

*Hydranths* poorly preserved. *Colour*—stems dark brown, shading to light brown on growing tips.

*Remarks:* The colonies of *S. fusca* from Pearson I., although dwarfed and infertile, are mature, occurring among algae on horizontal rock faces. This is in contrast to the known habitat of larger specimens from Victorian waters, which seem to favour vertical walls and the interior of caverns (J.W., unpublished). Bale (1888, p. 749) mentions that his small colonies from Sydney were from "Laminaria roots" (probably *Ecklonia radiata* holdfasts). Watson & Utinomi (1971) reported that the spinous trabeculae were not present in material examined by them from the Great Australian Bight, yet the Pearson I. specimens show these spines clearly. Unknown environmental and geographical factors may thus influence structural variations within the species.

#### Order THECATA

#### Family CAMPANULARIIDAE

*Clytia* (?) *pearsonensis* n.sp.

FIG. 2

TABLE 2  
Epiphytic Hydroids

The numbers refer to the species as given in the species list.

VC = very common, C = common, R = rare.

Algal Substrate	Hydroid
<b>CHLOROPHYTA</b>	
<i>Caulerpa brownii</i> (C.Ag.) Endlicher.	63(R)
<i>Caulerpa simplicioides</i> (Turner) J. Agardh.	77(R)
<i>Caulerpa</i> sp.	52(VC)
<b>PHAEOPHYTA</b>	
<i>Distromium flabellatum</i> Womersley.	52(VC), 53(R), 56(R)
<i>Distromium</i> sp.	37(C)
<i>Zonaria spiralis</i> J. Agardh.	76(VC)
<i>Scytothalia dorycarpa</i> (Turn.) Greville.	24(VC)
<i>Acrocarpia paniculata</i> (Turn.) Areschoug.	24(VC), 39(R), 50(VC), 76(VC)
<i>Cystophora brownii</i> (Turn.) J. Agardh.	5(C)
<i>Sargassum verruculosum</i> (Mert.) J. Agardh.	31(C), 40(C), 60(R)
<i>Sargassum bracteolosum</i> J. Agardh.	50(VC), 71(VC)
<i>Sargassum spinuligerum</i> Sonder.	37(C), 50(VC), 60(R)
<i>Sargassum varians</i> Sonder.	50(VC), 55(R)
<i>Sargassum</i> sp.	21(R), 30(C), 36(VC), 37(C), 54(R), 69(R)
<b>RHODOPHYTA</b>	
<i>Delisea pulchra</i> (Grev.) Montagne.	68(R)
<i>Pterocladia lucida</i> (R.Br.) J. Agardh.	5(C), 36(VC), 45(VC), 48(R), 55(C)
	61(C)
<i>Rhodopeltis australis</i> Harvey.	44(R)
<i>Metagoniolithon charoides</i> (Lamx.) W. v. Bosse.	27(VC), 36(VC), 73(VC)
<i>Metomastophora flabellata</i> (Sond.) Setchell.	44(R), 51(VC), 61(C), 69(R), 76(VC)
<i>Carpopeltis phyllophora</i> (H. & H.) Schmitz.	45(VC), 75(R)
<i>Collophyllis coccinea</i> Harvey.	62(R)
<i>Plocamium angustum</i> (J. Agardh) Hooker & Harvey.	67(C)
<i>Plocamium cartilagineum</i> (L.) Dixon.	76(VC)
<i>Phaeocarpus labillardieri</i> (Mert.) J. Agardh.	24(VC)
<i>Stenocladia australis</i> (Sond.) Silva.	24(VC), 46(VC)
<i>Mychodea</i> sp.	66(R)
<i>Rhodymenia australis</i> Sonder.	51(VC), 56(C)
<i>Ballia callitricha</i> (C.Ag.) Kuetzing.	28(C)
<i>Pterosiphonia?</i>	61(C)
<i>Anansia pinnatifida</i> Harvey.	23(VC)
<i>Laurencia elata</i> (C.Ag.) Harvey.	33(VC), 37(C), 51(VC), 52(VC), 55(C), 67(C)
Unidentified red algae.	4(R), 7(R), 25(R), 27(VC), 30(C), 36(VC), 40(R), 49(C), 53(R), 77(R), 81(VC)
<b>ANGIOSPERMAE</b>	
<i>Posidonia australis</i> Hook. f.	12(VC), 70(VC)

*Type Material and Records:* Holotype, NMV G1914, microslide—R, 22 m, on stem of *Thecocarpus divaricatus* var. *cystiferus*; paratype, G1915, microslide—R, 34 m, on bryozoa.

*Description from holotype and paratype:* Pedicels long, of variable diameter, irregularly wrinkled or smooth (holotype shows indistinct distal annulations), arising from a creeping stolon. *Hydrothecae* large, cylindrical, walls smooth, perisarc very thin and delicate, margin entire, everted into a thin lip. Thecal wall slightly thickened proximally, hydrotheca without floor, tapering into pedicel, a trace of a very thin diaphragm near base. *Hydranth* too poorly preserved for diagnosis, *Gonotheca* absent.

*Remarks:* Only 2 undamaged hydrothecae were found in the entire collection, although others, badly damaged, were noted. It is possible that the species has previously been overlooked because of the extremely delicate nature of the perisarc, which collapses immediately on removal from water.

*C. pearsonensis* is closely related to *Laomedea michael-sarsi* Léloup, 1935, reported from only two localities—the West Indies, and the west coast of North Africa. The hydrotheca of *L. michael-sarsi* are, however, shorter and less than half the diameter of *C. pearsonensis*. (Measurements are given for comparison).

Following Millard (1959, p. 248), the species may be referable to either *Campanu-*

TABLE 3

*Epizoic, Epilithic, Freegrowing and Holdfast Associations.*

Substrate	Hydroid
Epizoic Species	
Ascidian—	
<i>Herdmania momus</i> (Savigny)	14(C), 16(C), 19(R), 20(R), 21(R), 22(R), 23(V), 28(V), 29(R), 32(V), 38(C), 43(R), 49(C), 59(R)
Compound ascidians	15(R), 38(C), 75(R)
Sponge	5(C), 9(R), 13(R), 14(C), 15(R), 25(R), 27(C), 28(V), 38(C), 49(V), 56(C), 59(R), 74(C), 72(R)
Calcareous bryozoa	3(R), 6(R), 10(R), 14(C), 27(C), 28(V), 29(R), 30(C), 32(V), 35(R), 38(C), 40(R), 59(R), 75(R), 81(V)
Worm tubes	19(R), 59(R)
Other Hydroids—	
<i>Synthecium</i> sp.	16(C)
<i>Thyrosocyphus marginatus</i> (Bale).	67(C)
<i>Sertularia unguiculata</i> Busk.	20(R), 56(C)
<i>Symplectoscyphus subdichotomus</i> (Kirchenpauer).	77(R)
<i>Halopteris campanula</i> var. <i>campanula</i> (Busk).	32(C)
<i>Plumularia procumbens</i> Spencer.	16(C), 62(C)
<i>Thecocarpus divaricatus</i> var. <i>cystifera</i> Bale.	3(R), 8(V), 19(R), 22(R), 29(R), 38(C), 41(C)
<i>Halicornaria longirostris</i> (Kirchenpauer).	8(V), 17(R), 41(C), 52(V)
Epilithic Species	1(R), 58(R), 64(C), 78(C), 80(R), 81(V), 82(R), 83(C)
Freegrowing Species	57(C), 65(V)
Holdfast Species	2(C), 11(R), 42(C), 43(C), 47(C)

Dimension, mm	<i>C. pearsonensis</i>		<i>I. michael-sarsi</i>	
	holo type	para type	N. Africa	W. Indies
Stem length	1.80	1.32	—	1.00-1.50
diam.	0.07	0.17	—	0.10-0.15
Hydrotheca—				
width at margin	0.59	0.68	0.25	0.25-0.30
depth to diaphragm	0.78	0.69	0.63	0.40-0.50

*laria* or *Clytia*. The barely discernible diaphragm and very delicate thecal wall suggest it may belong to the latter genus, but its systematic position is indeterminate until fertile material is found.

***Campanularia ambiplica*** Mulder & Trebilcock, 1914: 11, figs. 2-4. Shepherd & Watson, 1970: 140.

*Paracalis ambiplica* (M. & T.). Stechow, 1925: 209, fig. E.

*Records*: S, 5-14 m, on red algae.

*Material*: Three infertile stems. *Stems* short, spirally annulated. *Hydrothecae* long, narrow, walls parallel, a very strong S-shaped fold about halfway along thecal wall. *Margin* with 6 teeth, each with several reduplications.

*Remarks*: Type material of *C. ambiplica* in the collection of the NMV shows more campanulate hydrothecae with blunter and less deeply excavated marginal teeth than the Pearson I.

specimens. Stechow's figures of specimens from Champion Bay, W. Aust. are intermediate in length between the two. Measurements are given for comparison.

Dimensions, mm	Pearson I.	Champion Bay	Victoria (M. & T.)
Stem diam.	0.06	0.06	0.06
Hydrotheca—			
length	0.52	0.42	0.34
width	0.17	0.18	0.17

***Campanularia australis*** Stechow, 1924: 61. Shepherd & Watson, 1970: 140.

*Orthopyxis australis* (Stechow). Hirohito, 1969: 10, fig. 9.

*Records*: R, 34 m, on the algae *Pterocladia lucida*, *Cystophora brownii*, and sponge.

*Material*: *Stems* variable, to 3 mm long, longer stems smooth, short stems annulated. *Hydrothecae* compressed, with a wide submarginal flange and 9-10 bluntly pointed teeth, in one instance showing reduplication. *Hydranth* with 16-20 tentacles. Colonies fertile.

*Remarks*: Although widely distributed at all depths and on a variety of substrates, the colonies were not luxuriant.

*Campanularia gaus­sica* Stechow, 1923: 102; 1924: 62.

FIG. 3

*Records:* S. 24 m, on calcareous bryozoa.

*Material:* Three infertile stems. *Stems* to 4 mm long, showing joints where breaks have regenerated. A spherule between stem and hydrotheca. *Hydrothecae* large, campanulate, 1.26–1.32 mm deep, expanding evenly from a narrow base to margin, an annular diaphragm in thecal cavity. Margin variable in diam., 0.78–1.2 mm, with 12 deep tongue-shaped teeth 0.015–0.018 mm wide at base, 0.013–0.015 mm long, the sinus between of same shape and size as tooth. *Hydranth* with approx. 16 tentacles surrounding a thick annular hypostome, similar to that of *Eudendrium*.

*Remarks:* The Pearson I. specimens are among the largest specimens of *Campanularia* recorded from Australian waters, the only other specimen of comparable size being "*Campanularia tineta* var. d" of Mulder & Trebilcock (1914a) from Breams Creek, Vic. (see discussion below). This is a new record for S. Aust.

*Remarks on the status of C. tineta* Hincks, 1861, *C. gaus­sica*, and *C. australis*.

Stechow (1925, p. 206) placed Mulder & Trebilcock's vars. "a", "b", "c" and "d" of *C. tineta* in tentative synonymy with *C. gaus­sica*. However, the dimensions of the hydrothecae calculated from Mulder & Trebilcock's figures are somewhat greater than those given by Stechow for his specimens. Moreover, his figure does not show the annular diaphragm figured by Mulder & Trebilcock, a feature also present in the Pearson I. specimens.

Earlier, Stechow (1924) stated that the gonosome of *C. gaus­sica* was unknown, yet included in his synonymy (1923, p. 102) a questionable reference to the *C. tineta* of Bale (1884, p. 57) from Portland, Victoria, for which the gonotheca was figured. He later referred Bale's species to *C. longitheca* without explanation. The Portland specimen in the collection of the NMV is undoubtedly *C. australis*, not *C. gaus­sica*.

I cannot agree with Rees & Thursfield (1965, p. 94) who referred *C. gaus­sica* to the synonymy of *C. tineta*. The latter is a very small and distinctive species; although they stated they had examined the type material of *C. tineta*, they failed to note the very considerable difference in size between the two.

The definition of the four species, *C. tineta*, *C. australis*, *C. gaus­sica* and *C. africana*, from

Australian waters is thus somewhat confused. Although *C. tineta* and *C. australis* are very similar, with bilaterally symmetrical hydrothecae, *C. australis* is considerably the larger of the two. *C. australis* shows a wide choice of substrate, being both epizoic and epiphytic, whereas *C. tineta* appears to be most frequently associated with the seagrass *Amphibolis antarctica* (J.W., unpublished).

Hirohito (1969, p. 10) transferred *C. australis* to *Orthopyxis* on the basis of the bilateral symmetry of the hydrotheca, but the true generic status of *C. australis* will remain indeterminate until the gonosome is found.

*C. africana* is a distinct species, and has been redescribed by Millard (1966, p. 474). The hydrotheca is of medium size and the gonosome is known. This species has been recorded from Queensland (Pennycook 1959, p. 169), from "rock pools and weed".

Until the collection of fertile material establishes the validity of *C. australis* and *C. gaus­sica*, those forms from Australian waters with very large campanulate hydrothecae and 10–14 tongue-shaped teeth are recognized as *C. gaus­sica*; those with large parallel-walled hydrothecae and bilateral symmetry are recognized as *C. australis*, and those similar to *C. australis* but much smaller in size, as *C. tineta*. In the case of *C. gaus­sica*, it is possible that more than one species may actually be involved.

*Campanularia* sp.

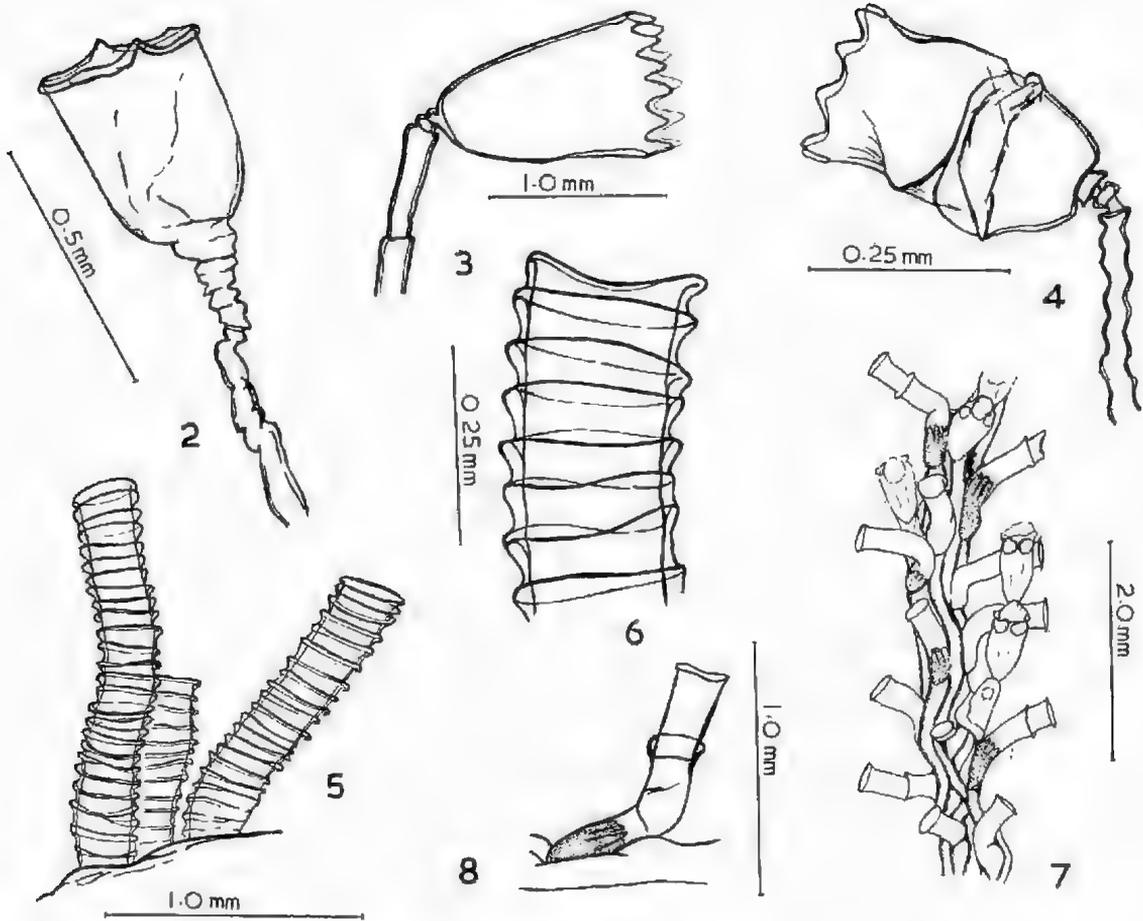
FIG. 4

*Records:* S, 17–20 m, on red algae.

*Material:* Three infertile stems. *Stems* 0.51–0.72 mm long, spirally annulated, annulations sometimes indistinct; maximum width of stem, 0.04 mm. *Hydrothecae* campanulate, length 0.39 mm, widest about one third distance up from base, this point being marked by a crumpled fold encircling thecal wall. Base of hydrotheca flat, with a slight concavity, a socket and spherule between hydrotheca and stem. *Margin* 0.22 mm in diam., with 8 broad tongue-shaped teeth 0.025 mm high; width between teeth, 0.06 mm.

*Remarks:* The hydrothecae are very delicate. Although the hydrothecae are somewhat collapsed in mounting, the fold around the proximal region of the thecal wall is clear in all specimens.

The specimens are undoubtedly referable to the *C. ambiplica-C. pulchratheca* group endemic to southern Australian waters, most resembling the latter species. However, *C.*



- Fig. 2. *Clytia* (?) *pearsonensis* n.sp. Hydrotheca, from holotype.  
 Fig. 3. *Campanularia gaussica* Stechow. Hydrotheca; stem with regenerated pedicel.  
 Fig. 4. *Campanularia* sp. Hydrotheca.  
 Figs. 5, 6. *Reticularia annulata* n.sp. Fig. 5.—Group of three hydrothecae Fig. 6.—Distal end of hydrotheca, enlarged. Drawn from holotype.  
 Figs. 7, 8. *Reticularia* sp. Fig. 7.—Part of colony, showing growth habit on bryozoan colony. Fig. 8.—Hydrotheca, enlarged, showing regenerated distal end.

*pulchratheca* has 14 sharply pointed teeth, the intrathecal fold is in the distal region, and does not encircle the thecal wall as in the present material. This may be a new species, but the material is inadequate for determination.

#### Family LAFOEIDAE

*Reticularia antarctica* (Hartlaub, 1904). Totton, 1930: 160, fig. 17, Briggs, 1938: 26.  
*Lafoea antarctica* Hartlaub, 1904: 11, pl. 2, fig. 2.  
*Filellum antarcticum* (Hartlaub). Stechow, 1925: 214.

**Records:** R, 18–33 m, on stem of *Thecocarpaceus divaricatus* var. *cystiferus*. S, 14 m, on stem of *Halicornaria longirostris*.

**Material:** Luxuriant infertile colonies. *Hydrothecae* delicate, of variable length, arising at various angles from hydrorhiza so thickly that it is difficult to determine the length of the adnate part, but it is usually not more than one quarter of the total length of the hydrotheca. *Margin* slightly everted, often with 2–3 reduplications; occasionally an earlier reduplication about halfway along hydrotheca coincides with a slight flexure of the thecal wall. Length of free part of hydrotheca, including reduplications, 1.0–1.18 mm; diam. at margin, 0.21 mm.

**Remarks:** It is very difficult to distinguish between *R. antarctica* and *R. serpens* in the

absence of coppiniae, and as the diameter of the thecal margin is greater than those measurements given by Stechow (1925, p. 214) for *R. serpens* (after Millard 1958, p. 175), the Pearson 1 specimens are referred to *R. antarctica*.

This is the first record of *R. antarctica* from S. Aust. waters. (Other locality—W. Aust.)

**Reticularia annulata** n.sp.

FIGS. 5, 6

*Type Material and Records:* Holotype NMV G1922, microslide: G2091, preserved material, remainder of holotype colony—S. 17 m, on a small calcareous bryozoa.

*Description from holotype:* Hydrothecae long, tubular, increasing slightly in diameter distally, adnate for a small part of length, free part 0.15–0.18 mm, curving out from hydrorhiza. Hydrothecae ringed throughout entire length with closely and evenly spaced annular ribs, average distance between ribs 0.05 mm, each rib with sharply everted rim; annulations on adcauline wall not as sharply defined as those on free wall. Margin circular, entire, same diam. as hydrotheca, 0.19–0.26 mm, occasionally sinuously curved, with everted rim. Gonotheca absent.

*Remarks:* *R. annulata* is closely related to both *R. antarctica* (Hartlaub, 1904) and *R. serpens* (Hassall, 1848) in shape and dimensions of the hydrotheca, but it is easily distinguished from these species by the close thecal rings. *R. serrata* (Clarke, 1879) is annulated, but the annulations are confined to the adnate part of the hydrotheca, and it is a much smaller species.

The rings in *R. annulata* are of uniform size, and the distance between them varies little along the entire length of the hydrotheca. They have developed by continuous apical reduplication during growth of the hydrotheca, the flange of each rib being a relict margin.

**Reticularia** sp.

FIGS. 7, 8

*Records:* R, 18 m, colony investing stalk of calcareous bryozoa.

*Material:* One infertile colony. Hydrothecae arising in groups, or singly at irregular intervals. Hydrothecae from the outer hydrorhizal tubes adnate for approximately half their length, free part standing out almost perpendicular to hydrorhiza. Length of free part 0.45–0.66 mm, only the orifice of those hydrothecae more deeply embedded in the stolonial complex visible. Hydrothecae tubular, 0.2 mm in diam.,

many with 2–3 regenerations after breakage, some with marginal reduplication. Colour—brown.

*Remarks:* The general appearance of the hydrothecae and the diameter of the margin are very similar to *R. antarctica* from Pearson 1, but the hydrothecae of the present specimens are much shorter; the thick woody fascicled hydrorhizal tubes further distinguish the present material.

The twiggy appearance of the colony, imparted by the shape of the host, strongly suggests the growth habit of *Cryptolaria*, but without the regularity of arrangement of the hydrothecae of that genus.

This may prove to be a new species

**Zygophylax antipathes** (Lamarck, 1816). Rees & Thursfield, 1965: 76.

*Sertularia antipathes* Lamarck, 1816: 115.  
*Campanularia rufa* Bale, 1884: 54, pl. 1, fig. 1.  
*Licorella antipathes* (Lamarck); Ritchie, 1911: 821.

*Zygophylax rufa* Bale, 1914c: 90.

FIG. 9

*Records:* R, 18–45 m; among holdfasts of brown algae on vertical walls and on the seafloor.

*Material:* Three infertile colonies, the largest 12 cm high, growing from a small rootstock. Stems woody, very brittle, main stem fascicled (2 mm thick in largest colony) the fasciculations decreasing distally along the branches. Branches given off randomly around main stem, some of younger branches monosiphonic. Hydrothecae alternate, 0.32–0.34 mm deep (margin to diaphragm) arising from an apophysis at 45° to stem, frequently a short segment (a broken and regenerated pedicel of an earlier hydrotheca) between hydrothecal pedicel and apophysis. Adcauline thecal wall convex, 0.30–0.37 mm long, usually smooth, sometimes a little undulated; abcauline wall straight or slightly concave, 0.30–0.36 mm long. Margin usually with a distinctly everted rim 0.17 mm in diam., occasionally with 1 reduplication. Diaphragm near base of hydrotheca transverse, occasionally oblique. Nematothecae rare, only 2 seen in mounted specimens, one given off from a hydrothecal apophysis, the other from a polysiphonic tube of the stem. Colour—deep reddish brown.

*Remarks:* The branches are overgrown with algae and compound ascidian.

Bale (1914c) maintained the distinction between *Z. rufa* and *Z. antipathes* on the following criteria:

- (i) the smaller colonies of *Z. rufa*, the lack of rigidity of the branches, and,  
 (ii) *L. antipathes*, following Billard, shows no distal narrowing of the hydrotheca, nor an everted margin.

Examination of a series of microslides of *Z. rufa* in the collection of the NMV, show Bale's material to have come from either a broken branch, or the distal end of a very young colony, and there are few hydrothecae which are not noticeably narrowed distally; some also lack an everted margin. One branch of the Pearson I. material has a series of hydrothecae with almost straight walls, no eversion of the margin, and a rather more delicate perisarc than usual.

Regenerated hydrothecal pedicels with an additional segment are common in the older regions of the stems, but are not present in the younger branches. They are a character developed with aging of the stem, and are thus not specifically diagnostic.

I have compared microslides of Ritchie's "Thetis" material of *Lictorella antipathes* with *Z. rufa* of Bale, and find them to be identical in all respects, except that the perisarc of *Z. rufa* is much more delicate than that of the "Thetis" specimens.

Ritchie did not comment on the presence of nematothecae (similar to those on the Pearson I. specimens) visible in his slides. These were apparently noted by Rees & Thursfield (1965) who transferred the species to *Zygophylax* without comment.

Since the present material has features which clearly bridge the gap between *Z. rufa* and *Z. antipathes*, the two are considered synonymous.

This is the first record of *Z. antipathes* in S. Aust. waters. (Other localities—Torres Strait, and off Port Jackson, N.S.W.)

#### Family LINEOLARIIDAE

*Lineolaria spinulosa* Hincks, 1861: 280, pl. 8.  
 Shepherd & Watson, 1970: 140.

*Record*: S, 15 m, on the seagrass *Posidonia australis*.

*Material*: Numerous infertile colonies overrunning the blades of the seagrass.

*Remarks*: *L. spinulosa* was not found on any other substrate at Pearson I.

#### Family HALECTIDAE

*Ophiodissa australis* (Bale, 1919).

*Ophiodessa australis* Bale, 1919: 336, pl. 16, fig. 1.

*Record*: R, 19 m, on black sponge.

*Material*: One colony of several infertile stems growing from a matted hydrothiza on the surface of the sponge. *Stems* to 2 cm long, fascicled, irregularly branched, with 2-3 supplementary tubes extending two thirds the distance up stem. *Hydrophore* with a few reduplications. *Nematothecae* rare. *Colour*—light greenish, with black patches scattered throughout hydrocaulus. (Under the microscope these patches are black granules concentrated on the hydranth and in the coenosarc.)

*Remarks*: The status of *Ophiodissa* has been briefly discussed by Watson (1969, p. 111). Bale (1919) described, but did not figure the gonophore of *O. australis*. Ralph (1958, p. 342) was uncertain whether *O. australis* is a synonym of *Hydrodendron caciniiformis* (Ritchie, 1907) but kept the two species separate because "the hydrothecae of *A. australis* Bale are shallower, measured from the margin to puncta line, than those of *H. caciniiformis*, and the gonothecae of the latter are unknown". Millard (1966b, p. 490) described the gonophore of *H. caciniiformis* from material from the Vema Seamount, off the west coast of South Africa.

There are two microslides of *O. australis* in the Bale collection in NMV, one from Green Point, N.S.W., and the other from Port Phillip Heads, Vic. The latter specimen is a lightly fascicled stem 2 cm long, with a group of 10 male gonophores growing from the hydrothiza, and is undoubtedly the slide from which Bale described the gonotheca of the species.

The gonothecae are smooth or very slightly annulated, with curved or straight pedicels, and several have a slight constriction just below the truncated distal end. The gonophores are nearly mature, the blastostyle almost filling the gonothecal cavity, and above the blastostyle there is a ring of black granules.

The gonothecae and gonophores of Bale's material are similar to those of *H. caciniiformis* figured by Millard, but the gonotheca of *O. australis* is much longer and more than twice the width of those of *H. caciniiformis*. Furthermore, the hydrophore of *H. caciniiformis* (from Millard's figure) is both wider and deeper than that of *O. australis* from Green Point. It seems that the two species, while very similar, are distinct.

Comparison of measurements (see below) of *H. caciniiformis* from New Zealand with Bale's *O. australis* shows that the New Zealand material falls near the dimensional range of *O. australis*, and may well be this species.

The finding of fertile material in New Zealand waters will settle this point.

Dimensions, mm	<i>O. australis</i>		<i>H. caciiformis</i>	
	Pearson I.	Green Pt.	N. Zealand	S. Africa
Hydrophore— diam. at puncta line	0.14	0.15	0.12	0.20
depth, margin to puncta line	0.025	0.035	0.04-0.06	0.10
Gonotheca length	—	1.44-1.50	—	0.90-1.20
width at aperture	—	0.94-1.00	—	0.40

The specimens from Pearson I. are identical in every respect with Bale's *O. australis*. This is the first record of *O. australis* from S. Aust.

#### *Ophiodissa blackburni* n.sp.

FIGS. 10-12

*Type Material and Records:* Holotype, NMV G1927, microslide; G2092, preserved material, remainder of holotype colony—S, 27 m, on *Herdmania momus*; Paratypes G1928, G1929, microslides; G2093, preserved material, remainder of paratype colony—S, 24-27 m, on bryozoa and sponge.

*Description from holotype and paratypes:* Hydrorhiza a winding tubular stolon 0.11-0.13 mm in diam., thick and strongly corrugated throughout entire length, becoming erect at intervals to form monosiphonic stems to 12 mm high. *Hydrophores* given off irregularly, either directly from the stolon or from stem. Pedicel of hydrophores of variable length, 0.19-0.27 mm, beginning with an annular constriction 0.07-0.10 mm in diam., followed by 1-2 annulations, then expanding evenly to margin. Perisarc thin. *Secondary* and tertiary hydrophores common, branching outwards just below the diaphragm of primary (or secondary) hydrophore, becoming ascending at annular constriction. *Hydrophores* reduplicated up to 4 times; reduplications of variable length, given off successively from the diaphragm of preceding hydrophore. *Diaphragm* 0.13-0.17 mm in diam., moderately deep, 0.04 mm from margin (best seen in preserved material). *Margin* flaring, with strongly everted lip, diam. 0.22-0.24 mm. *Nematothecae* sparse low tubular orifices 0.03 mm high, and 0.05 mm in diam. at base, situated on hydrorhiza or stem, opposite, or nearly opposite hydrothecal pedicel. *Hydranth* large, extensile, with approx. 30 stubby tentacles. *Colour*—yellow. *Gonotheca*—absent.

*Remarks:* The presence of nematothecae places the present material in *Ophiodissa* (Watson

1969, p. 111). Although in some instances the nematothecae may be mistaken for the broken base of a hydrothecal pedicel, their position opposite the pedicel, and their smaller size usually serves to distinguish them.

*O. blackburni* shows some resemblance to *O. corrugata* Fraser, 1936. However, neither branching nor reduplication of the margin is mentioned or figured by Fraser, and the tentacular organs of *O. corrugata* are described as being relatively large and flaring slightly at the margin (Fraser 1936, p. 113).

Blackburn (1938, p. 322) described a fragmentary *Halecium* sp. from the littoral zone of Reevesby I. in the Sir Joseph Banks Group, S. Aust., remarking that the material, too obscured by foreign matter for diagnosis, was probably a new species, similar to *H. corrugatum* Nutting, 1912. Although Blackburn's specimens are not available for comparison, it is certain that his material and the present specimens are the same species.

*Phylactotheca armata* Stechow, 1924: 59; 1925: 204, fig. C. Blackburn, 1942: 106.

*Ophiodissa fragilis* Blackburn, 1937a: 365, fig. 1.

*Records:* R, 33 m, on sponge and ascidian.

*Material:* A few infertile stems to 1 cm high.

*Remarks:* The Pearson I. material conforms to the description of the species given by Stechow and Blackburn.

There are no secondary hydrophores, nor any nematothecae developed in the present material. Blackburn's specimens from Balnarring, Vic., similarly showed no sign of nematothecae. Hence their presence or absence cannot be taken as a good diagnostic character for the genus.

*Halecium delicatulum* Coughtrey, 1876: 299. Ralph, 1958: 334, figs. 11, 12. (synonymy).

*Records:* R, 21-45 m, on *Plumularia procumbens* and *Synthecium* sp.; S, 24 m, on *Herdmania momus*, and bryozoa.

*Material:* Many small infertile stems to 2 cm high. *Stems* irregularly and sparsely branched; a few are lightly fascicled, with an extra polysiphonic tube running up the proximal part of the stem.

*Remarks:* One of the most abundant epizoaic species in the collection.

**Halecium** sp. 1.

FIG. 13

*Record:* R, 30 m. on lower stem of *Halicornaria longirostris*.

*Material:* A single infertile stem 1.2 mm high. Stem unfasciated, irregularly branched; stem and branch internodes of variable length, up to 0.22 mm, and 0.04 mm in diam., annulated proximally, but otherwise fairly smooth. Branches given off from distal end of internodes on lower part of stem. *Pedicle* of primary hydrophore of variable length, proximal node transverse, followed by 1-2 annulations, the remainder smooth, expanding evenly to diaphragm. *Hydrophore* small, shallow, with circular margin, 0.08-0.12 mm in diam., and strongly everted rim; up to 3 reduplications given off successively from mouth of preceding hydrophore. Diaphragm present, depth from margin to diaphragm, 0.02-0.03 mm. *Secondary* and tertiary branches common, arising from distal end of pedicel of primary (or secondary) hydrophore.

*Remarks:* This very small form resembles *H. tenellum* Hincks, 1861 in size and delicacy of the trophosome, but the dimensions are even smaller than those given by Millard (1957, p. 193) and Ralph (1958, p. 340) for this species.

In the present material, only the first internode can be described as a true stem, the branching being truly arborescent, all subsequent internodes being secondary branches given off the pedicels of the primary hydrophores. The presence or absence of punctae cannot be ascertained because of foreign matter. However, the Bale collection in the NMV contains a microslide labelled "*Halecium*, Griffiths Point, July, 1880" with one small infertile stem identical with the Pearson I, specimen, and the hydrophores of this stem show a very clear ring of punctae between the margin and diaphragm.

This is probably a new species, but due to its similarity to *H. tenellum* its identity is indeterminate until adequate fertile material is found.

**Halecium** sp. 2.

FIG. 14

*Record:* R, 35 m, on algae.

*Material:* Two very small infertile stems. *Hydrorhiza* tubular. Stems unbranched, 2 mm long, internodes of variable length, 0.28-0.66 mm; diam. 0.08-0.12 mm, perisarc thick; divided into segments by 2-3 deep, transverse

constrictions, the last segment expanding slightly to support base of hydrophore. *Hydrophore* very shallow, depth to diaphragm 0.03 mm. *Margin* circular, 0.14-0.17 mm in diam., slightly everted. Succeeding stem internodes arising just below hydrophore, standing out perpendicularly, giving stem a zig zag appearance. *Hydranth* too large to retract into hydrophore, body thick, about 24 stubby tentacles.

*Remarks:* All the hydrothecal margins are so damaged that it is impossible to determine if punctae are present. Although the dimensions fall well within the range of *H. lankesteri* (Bourne, 1890) (Millard 1968, p. 257) the internodes show no tendency to curve upward, nor is there any sign of the secondary hydrophores common in this species. For these reasons, the present specimens are not assigned to *H. lankesteri*.

## Family SYNTHECIIDAE

***Synthecium elegans* forma *subventricosum***  
Bale, 1914, Ralph, 1958: 347, fig. 16.

FIGS. 15, 16

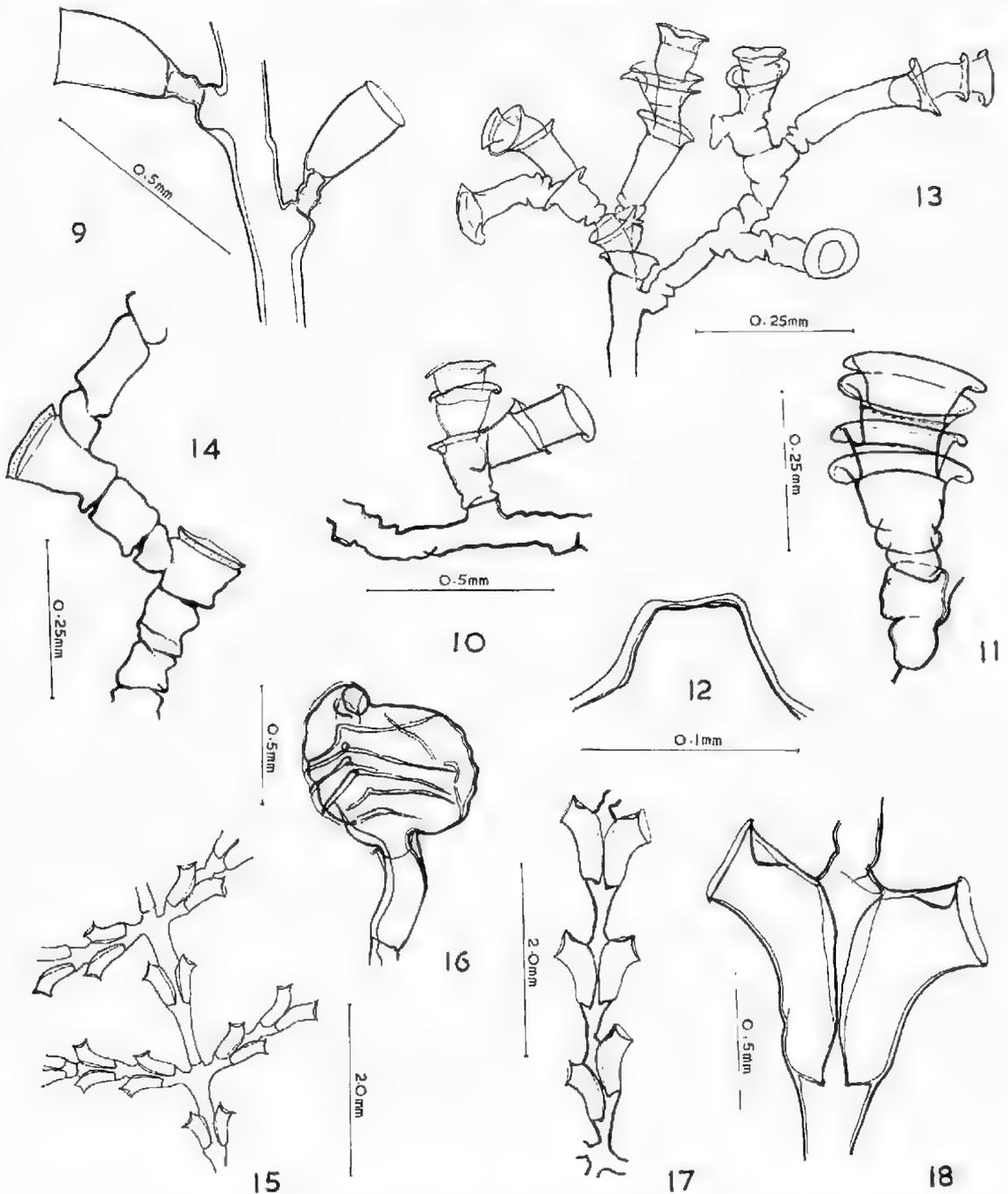
*Synthecium elegans* Allman, 1872: 229. Blackburn, 1942: 111.

*Synthecium subventricosum* Bale, 1914a: 5, pl. 1, figs. 3-5; 1915: 265.

*Records:* R, 34 m, on *Herdmania momus*; S, 18-25 m, on stem of *Theocarpus divaricatus* var. *cystifera*; Sta. F, 65 m, on worm tubes with *Diphasia subcarinata*

*Material:* Several immature colonies; one fertile stem. *Stems* monosiphonic, flexuous, to 2 cm long; no secondary branching, but a few tendrils given off distal ends of branches. Proximal stem internodes with 1-3 pairs of opposite hydrothecae; succeeding internodes 1.5-1.8 mm long, a pair of opposite hydrothecae in middle of internode, and a pair of opposite, distally situated hydrocladia. *Hydrothecae* of variable shape, generally tubular, three quarters of length adnate to internode, free adcauline wall 0.07-0.15 mm long, fixed wall 0.42-0.45 mm; abcauline wall 0.38-0.44 mm long. A delicate internal sheath clearly visible in many hydrothecae. *Margin* of hydrotheca sinuous, slightly everted, 0.18-0.19 mm in diam., a few marginal reduplications. *Gonotheca*—a single immature individual growing from the orifice of one of the second pair of hydrothecae on basal stem internode. *Colour*—white, with trace of purple.

*Remarks:* The single immature gonotheca identifies the Pearson I, material with *S. subventricosum* Bale, recognised by Ralph (1958) as a varietal form of *S. elegans* Allman.



- Fig. 9. *Zygophylax antipathes* (Lamarck). Portion of branch showing hydrothecae with everted margins and regenerated hydrothecal pedicels.
- Figs. 10-12. *Ophiodissa blackburni* n.sp. From holotype. Fig. 10.—Hydrotheca and stem with secondary hydrophores and reduplicated margins. Fig. 11.—Reduplicated hydrophores, enlarged. Fig. 12.—Nematothecae, enlarged.
- Fig. 13. *Halecium* sp. 1. Whole stem, showing growth habit.
- Fig. 14. *Halecium* sp. 2. Part of stem showing hydrophores and growth habit.
- Figs. 15, 16. *Synthecium elegans* forma *subventricosum* Bale. Fig. 15.—Part of stem. Fig. 16.—Immature gonotheca.
- Figs. 17, 18. *Synthecium dentigerum* Jarvis. Fig. 17.—Part of branch with subopposite to opposite hydrothecae. Fig. 18.—Hydrothecae enlarged, showing internal adcauline teeth.

Although there is considerable variation in shape of the hydrothecae among the specimens, most are tubular and closely adnate to the hydrocladium, not ventricose, as described by Bale for his specimens from the Great Australian Bight. Moreover, there is only one pair of opposite hydrothecae in the middle of each of the distal stem internodes, and a pair of opposite, distal hydrocladia, and the hydrothecal margins are decidedly sinuated, all features considered by Bale to be criteria distinguishing *S. patulum* Busk.

Thus, *S. elegans* forma *subventricosum* may eventually prove to be a synonym of *S. patulum*. However, in view of the lack of adequate fertile material, the fact that the type of *S. patulum* is not known to exist, and the possibility that sexual dimorphism may occur, it is best to keep the species separate at present.

*Synthecium dentigerum* Jarvis, 1922: 344, pl. 25, fig. 15. Totton, 1930: 172. Millard, 1964: 24, fig. 6.

FIGS. 17, 18

*Records:* S, 23 m. on stem of *Sertularia angulata* and *Herdmania momis*

*Material:* Five infertile stems, to 2 cm long. *Stems* monosiphonic, basal internodes long, 3.0–3.6 mm, with 5 pairs of opposite hydrothecae; each succeeding internode with 2–3 pairs of hydrothecae in mid region, followed by a pair of opposite hydrocladia. *Hydrocladia* arising perpendicular to stem from a distinct proximal joint; anastomoses, and some secondary branching occur. *Hydrothecae* almost tubular, adnate for two thirds their length, fixed adcauline wall 0.45–0.51 mm long, free wall 0.15–1.2 mm; abcauline wall 0.36–0.42 mm. *Margin* narrow, sinuated, with slightly everted rim, 0.21–0.27 mm in diam. Proximal hydrocladial hydrothecae subalternate, becoming opposite distally. (One stem has alternate hydrothecae with the abcauline wall bent sharply outwards.) Adcauline submarginal tooth present in most hydrothecae, variable from wedge-shaped to a mere thickening of the adcauline wall. No abcauline teeth or marginal reduplications.

*Remarks:* Three species of *Synthecium* with internal teeth have been described. *S. carinatum* Totton, 1930, *S. singulare* Billard, 1935, and *S. dentigerum* Jarvis, 1922. The Pearson I. specimens are larger than *S. carinatum* and smaller than *S. singulare*, but fall well within the range given by Millard (1964) for *S. dentigerum*. The specimens are distinguishable from *S. ele-*

*gans* forma *subventricosum* Bale, from Pearson I., only by the presence of the internal submarginal tooth, which is however not developed at all in some hydrothecae, the most prominent teeth being associated with those hydrothecae which have a flexure of the abcauline wall. Although the present material differs in some respects from descriptions of *S. dentigerum* in size of the colonies and arrangement of the stem hydrothecae, these are neither sufficiently constant nor important characters to warrant the erection of a new species.

This is the first record of *S. dentigerum* from Australian waters. It has been reported twice previously, from the Indian Ocean and South Africa.

#### Family SERTULARIIDAE

*Thyroscyphus marginatus* (Bale, 1884), Bale, 1915: 245; Stechow, 1925: 217. Blackburn, 1942: 112.

*Campanularia marginata* Bale, 1884: 154, pl. 1, fig. 2; 1888: 758; 1914: 91. Bartlett, 1907: 62.

*Records:* R, 14–30 m on algae and sponge; S, 22–30 m on *Sargassum varians*

*Material:* Four infertile colonies of a few stems each. *Hydrorhiza* a simple tube, loosely wound on substrate. *Stems* simple, to 1 cm long, smooth or slightly annulated, diam. increasing distally, a distinct transverse joint just above junction with hydrorhiza. *Pedicels* of hydrothecae 1.95–2.7 mm long, 0.25 mm in diam. distally. In one stem, 2 branches are given off side by side, 1 short, terminating in a hydrotheca, the other continuing normal growth, giving off a pedicel distally. *Hydrothecal margin* with 4 teeth, 4 valved operculum, and thickened submarginal ring. Depth of hydrotheca, 1.5 mm; diam. at margin, 0.75–1.21 mm.

*Remarks:* This agrees fairly well with descriptions of *T. marginatus* given by Bale.

*Parascyphus simplex* (Lamouroux, 1816). Blackburn, 1942: 112. Ralph, 1961a: 755, fig. 1. Stechow, 1925: 224.

*Laomedea simplex* Lamouroux, 1816: 206.

*Campanularia simplex* (Lamouroux), Bale, 1884: 58.

*Campanularia raridentata* Bale, 1894: 98, pl. 3, fig. 3.

*Thyroscyphus simplex* (Lamouroux), Hodgson, 1950: 10, fig. 22.

*Records:* R, 34 m, on sponge and *Herdmania momis* on vertical walls; S, 25 m, on *Thecocarpus divaricatus*.

*Material:* A few infertile colonies. *Stems* short, unbranched, to 5 mm long. *Hydrothecae*

swollen on proximal adcauline wall; some with a short pedicel. Stem apophyses pronounced, many with a constriction marking the site of growth regeneration after breakage.

*Remarks:* The stem apophyses figured by Hodgson (1950) and Ralph (1961) appear to merge into the base of the hydrothecae. Bale's (1894) figure shows a more pronounced apophysis, similar to those of the Pearson I. specimens.

**Diphasia subcarinata** (Busk, 1852). Bale, 1884: 102, pl. 4, fig. 1, pl. 19, fig. 18; 1914a: 7; 1915: 264. Ritchie, 1911: 850. Hodgson, 1950: 20, figs. 34, 35. Ralph, 1961a: 764, fig. 5. Shepherd & Watson, 1970: 140.

*Sertularia subcarinata* Busk, 1852: 390.

*Records:* R, 20–34 m on bryozoa; S, 25 m on *Amansia pinnatifida* and *Herdmania mannis*; Str. F, 65 m, on worm tube.

*Material:* Many infertile unbranched colonies 0.5–1 cm high. *Colour*—dark brown.

*Remarks:* The keel described by Bale (1884) in his Victorian material is present in the Pearson I. specimens only as an indistinct ridge passing between the lateral marginal tooth and the adcauline thecal wall. Ralph (1961) notes the presence of the ridge as a "prominent feature" on her New Zealand specimens, but Hodgson (1950) was unable to find the ridge in his Tasmanian material.

**Stereotheca elongata** (Lamouroux, 1816). Hodgson, 1950: 23, figs. 38, 39. Ralph, 1961: 762, fig. 4. Shepherd & Watson, 1970: 140.

*Sertularia elongata* Lamouroux, 1816: 189, pl. 5. Bale, 1884: 75, pl. 6, figs. 7, 8, pl. 19, fig. 7; 1915: 277. Mulder & Trebilcock, 1914a: 3, pl. 1, figs. 7–10.

*Records:* R, 30–45 m; S, 12 m, on *Stenocludia australis*, *Phacelocarpus labillardieri*, *Scytothalia dorycarpa* and *Aerocarpia pauciculata*.

*Material:* Luxuriant colonies, some fertile. *Stems* 4–5 cm long. *Gonothecae* with long horned processes.

*Remarks:* *S. elongata* is one of the commonest epiphytic hydroids of the southern Australian coastline. The Pearson I. specimens correspond to the "short stemmed ocean form" of Mulder & Trebilcock (1914a). *S. elongata* shows a wide choice of algal substrate and considerable tolerance of environmental conditions. The stems of the present specimens were free of the encrusting coralline alga usually associated with this species.

**Crateritheca acanthostoma** (Bale, 1882). Ralph, 1961a: 756, fig. 2. Shepherd & Watson, 1970: 140. Millard, 1964: 26, fig. 7.

*Sertularia acanthostoma* Bale, 1882: 23, pl. 12, fig. 4; 1884: 85, pl. 4, figs. 7, 8; 1913: 131. Bartlett, 1907: 44. Mulder & Trebilcock, 1914: 6.

*Stereotheca acanthostoma* (Bale), Stechow, 1919: 103. Blackburn, 1942: 172.

*Records:* R, 24–33 m, on sponge and red algae.

*Material:* Two colonies of a few stems each. *Stems* to 2 cm long.

*Remarks:* The specimens agree exactly with Bale's description of *S. acanthostoma*.

**Crateritheca crenata** (Bale, 1884). Ralph, 1961a: 757, fig. 2.

#### FIG. 19

*Sertularia crenata* Bale, 1884: 86, pl. 4, fig. 2.

*Record:* R, 33 m, on brown algae.

*Material:* Two fragmentary infertile stems. *Hydrothiza* tubular, winding. *Stem* fragments 2 cm long, with 4–6 deep proximal annulations, followed by a short athecate internode below first branch. *Internodes* 0.13–0.26 mm long, 0.04–0.06 mm in diam. at node.

*Remarks:* The Pearson I. specimens have a much less pronounced outward bend of the distal thecal wall than *C. crenata* figured by Bale (1884). However, a microslide of *C. crenata* from Snapper Point, Vic. in the Bale collection of the NMV, compares very closely with the Pearson I. material.

This is the second record of the species, and a new record for S. Aust. (Other locality—Port Phillip Bay, Vic.)

**Salacia obliquanoda** Mulder & Trebilcock, 1914).

#### FIG. 20

*Sertularia obliquanoda* Mulder & Trebilcock, 1913b: 41, pl. 5, fig. 1. Stechow, 1926: 106. Shepherd & Watson, 1970: 140.

*Records:* R, 18–46 m, on several species of red algae, including *Metamastophora flabellata*, bryozoa, and sponge.

*Material:* Luxuriant colonies. Epiphytic colonies fertile. *Hydrothiza* loose, tubular. *Stems* simple, to 3 mm high, some giving off distal tendrils which form new stolons. *Stem* internodes variable in length, 0.54–0.66 mm, width at base of hydrotheca, 0.18–0.24 mm, joints oblique, best developed on short internodes; indistinct or absent on long internodes. *Hydrothecae* similar to the description given

by Mulder & Trebilcock, but the hydrothecal aperture is oblique, not vertical, sloping diagonally back towards the stem in a line parallel with the abcauline wall. Length of free adcauline wall 0.12–0.18 mm, fixed adcauline wall, 0.24–0.27 mm, abcauline wall, 0.21–0.30 mm long. Margin with 2 sharp adcauline teeth, and a thickening of thecal wall in the base of the abcauline sinus; width of margin 0.06–0.15 mm. *Gonothecae* large, barrel-shaped, 1.53–1.6 mm long, 0.96–1.06 mm wide, with 6–8 deep annulations, a circle of hooked teeth below rim. Usually 1 gonotheca on a stem, borne below the proximal hydrotheca; male and female gonophores on the one colony.

*Remarks:* With the exception of the somewhat longer stem internodes and more oblique aperture, the Pearson I specimens compare closely with the type of *Sertularia obliquanoda* in the collection of the NMV.

Blackburn (1938, p. 319; 1942, p. 113) listed *Dynamena cornicina* McGrady, 1858, among the hydroids of the Sir Joseph Banks Group. *D. cornicina* (= *Sertularia complexa* Clarke, 1879) (see Bale 1888, p. 769; Billard 1925, p. 188) and *S. obliquanoda* are very similar, and are difficult to distinguish except in fresh fertile material. However, the hydrothecae of *D. cornicina* are larger, and the apertural teeth are more laterally situated. The abcauline opercular flap, easily visible in the present material, clearly distinguishes *S. obliquanoda* from *D. cornicina*.

The present specimens also resemble *Tridentata turbinata* (Lamouroux, 1816) (Stechow 1925, p. 223) particularly in the presence of the abcauline flap and the thickening of the abcauline wall. The status of this group needs further elucidation.

*S. obliquanoda* is one of the commonest species in the collection. This is the first definite record of *S. obliquanoda* for S. Aust. (Other localities—Torquay and Barwon Heads, Vic.)

*Sertularella robusta* Coughtrey, 1876: 300, fig. 22; Blackburn, 1942: 115; Hodgson, 1950: 33, fig. 58. Ralph, 1961a: 824, fig. 22; Shepherd & Watson, 1970: 140.

#### FIG. 21

*Records:* R, 24–33 m; S, 15–24 m, on *Ballia calliricha*, *Laurencia elata*, *Herdmania momus*, bryozoa, and sponge.

*Material:* Numerous infertile colonies. Stems simple, unbranched, to 1 cm long, arising from a tubular hydrorhiza. Stem internodes variable

in length, 0.42–1.14 mm, but fairly constant in maximum width, 0.15–0.18 mm, measured just below hydrotheca. *Hydrothecae* distal on long internodes, occupying most of the length of short internodes. Length of free adcauline wall 0.3 mm, fixed adcauline wall 0.24 mm; abcauline wall 0.42 mm; maximum width of hydrotheca, 0.24 mm. Thecal walls moderately to faintly annulated with 2–3 broad undulations passing around widest part of hydrotheca.

*Remarks:* Following Ralph (1961a), those stems with a fairly thick perisarc and annulated thecal walls, even though the annulations may be faint, are assigned to *S. robusta*.

*Sertularella simplex* (Hutton, 1873). Ralph, 1961a: 821, fig. 21.

#### FIG. 22

*Sertularia simplex* Hutton, 1873: 257.

*Sertularella peregrina* Hale, 1926: 19, fig. 4.

*Records:* R, 30 m, on the stem of *Thecopsis divaricatus* var. *cystifera*, *Herdmania momus*, and on bryozoa.

*Material:* Colonies of a few fertile stems. Stems to 1 cm long, occasionally branched, arising from a tubular hydrorhiza. Stems smooth, proximal internode atecate, with a few indefinite annulations; nodes distinct, sloping alternately right and left. Internodes fairly long, 0.39–0.60 mm, becoming progressively shorter distally, until hydrotheca occupies about two-thirds of internode. Width of internode below hydrotheca, 0.17–0.20 mm. *Branches*, when present, arising just below the hydrotheca, the first branch internode with 2–3 annulations. Tendrils present, growing from the distal ends of stems and from broken hydrothecae. *Hydrothecae* with 3 internal submarginal teeth—1 abcauline, 2 adcauline; thecal walls thin and smooth, length of free adcauline wall variable, 0.33–0.40 mm, fixed wall, 0.25–0.27 mm; abcauline wall, 0.52–0.54 mm; maximum width of hydrotheca, 0.22–0.27 mm. *Margin* showing occasional reduplications.

*Remarks:* The material from Pearson I., although variable, falls well within the range of variation of *S. simplex* defined by Ralph (1961a). The specimens assigned here to *S. simplex* are easily distinguished from *S. robusta* from Pearson I. by the generally larger and smoother walled hydrothecae.

Bale (1926) erected *Sertularella peregrina* to include hydroids from Bass Strait and Port Phillip formerly referred to *Sertularella polyzonias* and *S. gaudichaudi*. *S. peregrina* is indistinguishable from *S. simplex* as now defined;

accordingly *S. peregrina* is here referred to the synonymy of *S. simplex*.

A new record for *S. Aust.*

*Sertularella annulaventricosa* Mulder & Trebilcock, 1915: 54, pl. 7, fig. 1, pl. 8, fig. 4.

FIG. 23

*Sertularella undulata* Bale, 1915: 284, pl. 46, fig. 1. Hodgson, 1950: 34, fig. 59.

*Records:* R, 33 m, on *Sargassum* sp., on red algae, and bryozoa.

*Material:* Colonies moderately abundant, infertile. *Hydrorhiza* tubular. *Stems* simple, to 5 mm long, with 2-4 hydrothecae (exceptionally, 1 stem has 10 hydrothecae; another is branched) but many hydrothecae arising singly from hydrorhiza. *Stems* annulated proximally, annulations extending to base of first hydrotheca. *Internodes* 0.30-0.51 mm long, width below hydrotheca, 0.18 mm. *Hydrothecae* barrel-shaped, 0.27-0.36 mm in diam. at widest part. *Margin* 0.15-0.24 mm in diam., depth from margin to base, 0.30-0.36 mm.

*Remarks:* The holotype microslide of *S. annulaventricosa* in the collection of the NMV has longer stem internodes than the Pearson I. specimens, and is unbranched, although Mulder & Trebilcock note that "one specimen shows signs of having been slightly branched". The hydrothecal walls of the type are fairly smooth, with a ledge passing around the hydrotheca a little below the margin. The walls of the Pearson I. specimens are not as smooth as those of the type, and the submarginal ledge is replaced by 1-2 annular ridges, giving the hydrotheca a crumpled appearance. As in the type material, the aperture of the present material is somewhat variable in diam., ranging from a narrow orifice to almost the complete width of the hydrotheca.

This is the third record of the species, and a new record for *S. Aust.* (Other localities—central Victorian coastline, and Tasmania).

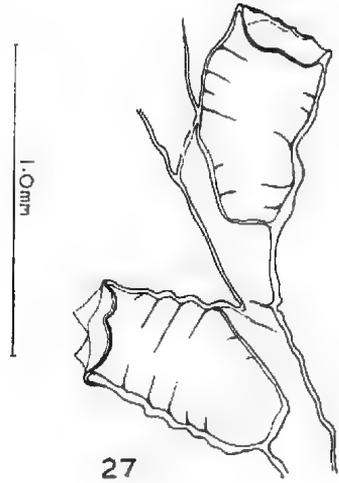
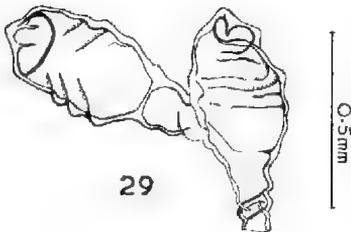
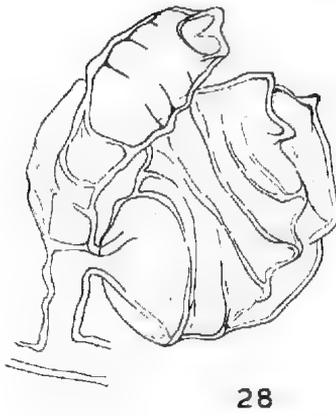
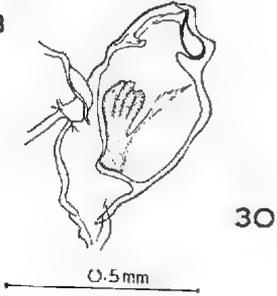
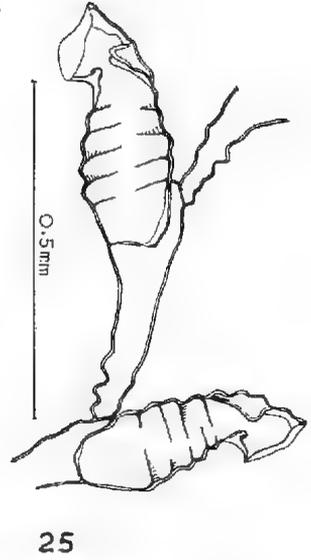
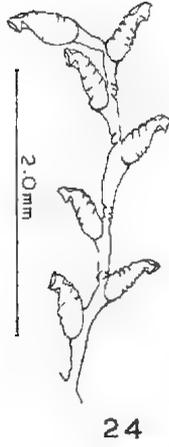
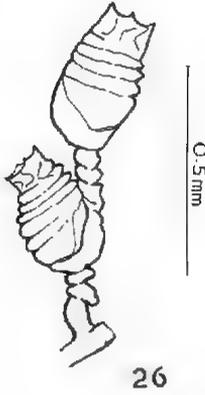
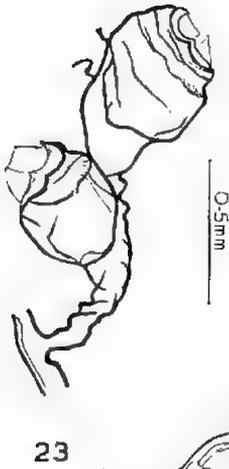
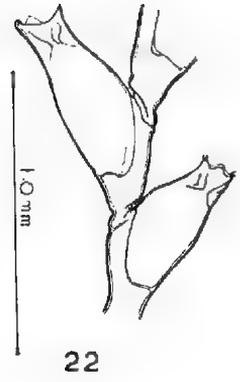
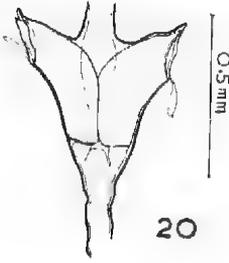
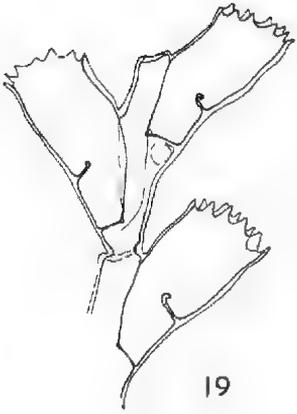
*Sertularella avrilia* n.sp.

FIGS. 24, 25

*Type Material and Records:* Holotype, NMV G1964, microslide; paratypes, G1965, G1966, G1967, microslides; SAM H35, microslide; holotype and paratypes from S, 13 m, on *Sargassum verruculosum*.

*Description from holotype and paratypes:* *Stems* simple, short, to 4 mm long, unbranched, arising from a thin tubular hydrorhiza. *First stem internodes* short, with 3 proximal annulations; succeeding internodes of variable length, 0.32-0.53 mm, widening from a narrow oblique proximal node, 0.04-0.08 mm in diam., to base of hydrotheca. *Nodes* sloping alternately left and right, with 1-2 oblique annulations, remainder of internode smooth. *Hydrothecae* distal on internode, alternate; a maximum of 8 on stem, each sloping outwards parallel with line of internode, giving stem a zig zag appearance. *Body of hydrotheca* long, almost cylindrical, slightly swollen at junction with internode, 0.16-0.19 mm in diam. *Adecauline wall* with 5-7 uniform, rounded annulations, most prominent across widest part of hydrotheca, but reduced to 4-6 on abcauline wall, fading out proximally. *Adecauline wall* arched outwards, abcauline wall inflexed into a long, narrow neck, 0.10-0.20 mm at narrowest diam., expanding again to margin. *Length of free adcauline wall*, 0.36-0.45 mm, *fixed adcauline wall*, 0.12-0.14 mm; *abcauline wall*, 0.32-0.37 mm. *Aperture* facing outwards and slightly down. *Margin*, 0.11-0.14 mm in diam., with 4 broad, low teeth, the adcauline tooth most prominent; 3 strongly developed internal submarginal teeth in thecal neck—2 identical dorso-lateral bract-like teeth, and 1 long peg-shaped abcauline tooth. *Hydranth* insufficiently preserved for description, but shows evidence of an abcauline caecum. *Gonotheca*—1 immature individual, arising from the base

- Fig. 19. *Crateritheca crenata* (Bale). Part of branch with three hydrothecae.  
 Fig. 20. *Salacia obliquanoda* (Mulder & Trebilcock). One stem internode showing hydrothecae with abcauline opercular flap.  
 Fig. 21. *Sertularella robusta* Coughtrey. Part of stem showing hydrothecae with shallowly annulated walls, and hydranth with abcauline caecum.  
 Fig. 22. *Sertularella simplex* (Hutton). Part of stem showing smooth-walled hydrothecae.  
 Fig. 23. *Sertularella annulaventricosa* Mulder & Trebilcock. Part of stem.  
 Figs. 24, 25. *Sertularella avrilia* n.sp. From holotype, Fig. 24.—Whole stem. Fig. 25.—Part of stem, enlarged, showing hydrothecae and internal submarginal teeth.  
 Fig. 26. *Sertularella* sp. 1. Whole stem with two hydrothecae.  
 Fig. 27. *Sertularella* sp. 2. Part of stem with two hydrothecae.  
 Figs. 28-30. *Symplectosecyphus rostratus* n.sp. Fig. 28.—Stem with one hydrotheca and gonotheca, from holotype colony. Fig. 29.—Stem with two hydrothecae; from paratype. Fig. 30.—Hydrotheca, lateral view, showing internal submarginal teeth, from paratype.



of a proximal hydrotheca; body strongly ribbed, with signs of the development of a slender terminal neck and 4 blunt spines.

*Remarks:* *S. avrilia* resembles both *S. robusta* (Coughrey, 1876) and *S. gilchristi* Millard, 1964. However, *S. avrilia* is smaller than *S. robusta*, the hydrothecae are more strongly annulated, and it is further distinguished by the long, curved thecal neck. Although *S. avrilia* shows some affinities with *S. gilchristi*, this South African species is a large, branching form, with fasciated stem, and a shorter, less conspicuously arched thecal neck.

**Sertularella** sp. 1.

FIG. 26

*Records:* R, 21–33 m, on *Laurencia elata*, *Herdmania momus*, *Halopteris campanula* var. *campanula*, and bryozoa.

*Material:* Numerous infertile colonies. Stems simple, monosiphonic, unbranched, straggling, arising from a tubular hydrorhiza 0.05 mm in diam. Stems to 3 mm long, first stem internode short, with 2–3 indefinite annulations, following internodes thecate, of variable length, 0.06–0.24 mm, irregularly annulated except just below hydrotheca. Nodes distinct, sloping alternately right and left, 0.04–0.06 mm in diam., measured just below hydrotheca. *Hydrothecae* distal on internode, a maximum of 4 on stem; body of hydrotheca barrel-shaped, one third to one half free of internode; length of fixed adcauline wall, 0.11–0.14 mm, free adcauline wall, 0.15–0.24 mm; abcauline wall, 0.25–0.34 mm; maximum width of hydrotheca at junction of adcauline wall with internode, 0.20 mm. hydrotheca gradually narrowing to margin. Thecal wall with 5–7 strong, entire annulations, most marked in mid-region, annulations fading out towards margin. *Margin* variable in diam., 0.08–0.13 mm, with 4 sharp, equidistant teeth. *Hydranth* with abcauline caecum. *Colour*—yellow-brown.

*Remarks:* The species resembles *S. angulosa* Bale, 1894 (= *S. robusta* Rulph, 1961) but is a smaller species, with much more deeply incised thecal ridges. It is further distinguished from *S. robusta* by its straggling growth habit and the large number of hydrothecae arising directly from the hydrorhiza.

Although displaying a wide choice of substrate, occurring on algae, ascidians, bryozoa, and other hydroids, this *Sertularella* was recorded only on the exposed site, where it was very abundant.

It seems likely that this is a new species, but is indeterminate until fertile material is found.

**Sertularella** sp. 2.

FIG. 27

*Record:* R, 18 m, no substrate recorded.

*Material:* Three fragmentary infertile stems detached from the hydrorhiza. *Stems* straight, unbranched, occasionally bent slightly at a node, perisarc very thick and brittle. Internodes of variable length, 0.48–0.96 mm, nodes oblique, sloping alternately left and right, angle of slope variable. Internode narrowest at node, 0.18–0.24 mm in diam., followed by 1–2 proximal annulations, widening to base of hydrotheca; width of internode at base of hydrotheca, 0.27–0.36 mm. *Hydrothecae* occupying distal half to two-thirds of internode, standing out at about 30° to axis, very large, variable in shape, either cylindrical, or with a slight distal narrowing behind margin, 5 distinct annulations passing completely around hydrotheca, the strongest in the mid-region of the abcauline wall, fading out proximally, annulations less distinct on older hydrothecae. Length of free adcauline wall, 0.39–0.48 mm, fixed adcauline wall 0.36–0.45 mm; abcauline wall 0.66–0.72 mm. *Margin* 0.33–0.51 mm in diam., thickened, with 4 low, blunt, slightly everted teeth. Operculum of 4 flaps. *Hydranth* not well preserved, but an abcauline caecum may be present.

*Remarks:* The hydrothecae are distinctive in shape, and are the largest recorded in Australian waters for *Sertularella*. This is almost certainly a new species, but confirmation must await the collection of adequate and fertile material.

**Symplectoscyphus longithecus** (Bale, 1888).

*Sertularella longitheca* Bale, 1888: 762, pl. 16, fig. 5, 6; 1894: 101, pl. 4, figs. 7–9.

*Record:* Sta. F, 65 m, no substrate recorded.

*Material:* A few straggling infertile branched stems to 9 cm long. *Stem* internodes straight, 0.54–0.75 mm long, nodes well defined, sloping alternately right and left. Branches given off from front of stem opposite base of hydrotheca. *Hydrothecae* long, tubular, narrowing distally towards margin; length of free adcauline wall, 0.24–0.36 mm. *Margin*, 0.15–0.18 mm in diam. One hydrotheca shows regeneration after breakage at base.

*Remarks:* The Pearson I. material compares well with Bale's (1888) specimens from Port Dennison and Port Phillip Bay, but they have

a shorter length of hydrotheca free of the internode than Ritchie's (1911) specimens from Wata Mooli, N.S.W.

This is only the fourth record of this apparently rare deeper water species, and a new record for S. Aust.

**Symplectoscyphus subdichotomus** (Kirchenpauer, 1884). Ralph, 1961a: 813, fig. 20.

*Sertularella subdichotoma* Kirchenpauer, 1884: 46, pl. 16, fig. 1. Bale, 1914a: 20 (discussion).

**Records:** R, 30 m, on bryozoa; Stn. F. 65 m, on bryozoa.

**Material:** Two colonies, each of a few infertile stems. Stems straggling, to 4 cm long; alternately, but irregularly branched. Nodes present on stem and branches, stem internodes indistinct, 1-3 annular constrictions at junction of branch with stem; several branches terminating in tangled anastomoses. *Hydrothecae* somewhat conical, with a slight concavity in middle of abcauline wall; a fine diagonal line running from the base of the adcauline wall to a small internal peg in the flexure of the abcauline wall.

**Remarks:** The Pearson I. specimens compare closely with microslides of *Sertularella divaricata* from the Great Australian Bight in the collection of the NMV (Bale 1914a, p. 20).

**Symplectoscyphus neglectus** (Thompson, 1879). Shepherd & Watson, 1970: 140.

*Sertularella neglecta* Thompson, 1879: 100, pl. 15, fig. 1. Bale, 1884: 110, pl. 3, fig. 3, pl. 19, fig. 22, 23; 1915: 287. Blackburn, 1942: 115.

*Symplectoscyphus* sp. Ralph, 1966: 163, figs. 1-4.

**Records:** R, 25-30 m, on *Delisea pulchra*, *Metagonolothon charoides*, and other red and brown algae.

**Material:** Luxuriant fertile colonies. Stems to 3 cm long, beginning with 2-3 oblique proximal twists, branches subalternate, no secondary branching, but occasionally a branch produced into a tendril. *Hydrothecae* triangular in section in young stems, with 3-4 distinct annular ridges, thecal walls of mature specimens much thickened and rounded, the annulations less distinct; marginal teeth of younger hydrothecae long and sharply pointed, blunt in older specimens. One-3 small internal submarginal teeth, sometimes not developed, but in mature hydrothecae may be thickened and projecting into centre of cell. *Gonothecae* abundant, male and female on separate stems. Female gonophores borne thickly on stem and proximal part of branches; male gonophores borne only on mid-

region and distal part of branches. Both sexes on a short pedicel arising beside a hydrotheca; body with 10-15 annulations and 2 hollow, conical distal processes. Female gonotheca stout, inflated, widest near middle, blastostyle spindle-shaped, supporting a cluster of ova. Male gonotheca long, narrow, widest near base, with a short distal obliquely inclined neck, blastostyle thin, rod-shaped, becoming indistinct distally.

**Remarks:** Bale (1884) in his redescription of *S. neglectus*, had only dried material before him, and inferred the transversely wrinkled, triangular hydrothecae to be artifacts of drying. However, much of the present material, particularly the younger stems, shows this to be a normal character of the species.

Bale's surmise that *S. neglectus* would show sexual dimorphism is demonstrated by the Pearson I. material. His figure "a" (Pl. XIX, fig. 23) with "two large conical hollow teeth, one more elevated than the other" is a female gonotheca, and gonotheca "h" (fig. 22) with "teeth smaller and about equally elevated" is male. In the Pearson I. material, the tooth-like conical processes of the female gonothecae are of approximately equal height, while those of the male are of unequal length and fairly short, but this is variable throughout the range of specimens. Ralph (1966) described and figured *Symplectoscyphus* sp. (from Port Phillip Heads) with smooth hydrothecae of triangular section and sharply erect marginal teeth. Although the hydrothecae are smoother than usual, the two latter characters clearly distinguish her material as young specimens of *S. neglectus*.

*S. neglectus* is a very common epiphytic hydroid in southern Australian waters, occurring on a variety of algae. It is easily recognised in the field by the incurved habit of the branches, the encrustation of pink coralline algae usually present, and the bright yellow gonothecae. The short marginal teeth seen on older hydrothecae are probably the result of constant abrasion against other stems and algae in the very turbulent conditions in which it is usually found.

**Symplectoscyphus indivisus** (Bale, 1882). Ralph, 1961a: 803, fig. 15. Shepherd & Watson, 1970: 140.

*Sertularella indivisa* Bale, 1882: 24, pl. 12, fig. 7; 1884: 105, pl. 3, fig. 5, pl. 19, fig. 27; 1915: 285. Blackburn, 1942: 115.

**Records:** R, 21-45 m, on *Laurencia elata* and *Sargassum spinuligerum*; S, 12-30 m.

on *Sargassum* spp., *Distrionium* sp., and *Polysiphonia* sp.

**Material:** Colonies abundant, 1 colony fertile, growing from a loosely wound hydrorhiza. *Stems* to 5 mm long; gonothecae clustered thickly at base of stems. *Colour*—bright yellow.

**Remarks:** The colonies fall within the known range of variation of *S. indivisus*, but are separable into 2 distinct morphological groups. The first group comprises stems with short, strongly undulated internodes, often completely occupied by the hydrotheca. The hydrothecae are inflated, irregularly undulated, with a short submarginal neck. The gonothecae are squat, deeply crumpled, with a very short pedicel. This group compares with Bale's (1888) *S. indivisa* from Portland, Vic. and figs. 5, 6, of *S. variabilis* from Port Jackson, N.S.W. The neck region of the Pearson I. specimens are however, more contracted than those figured by Bale.

The stem internodes of the second group are longer, and both internodes and hydrothecae are less inflated than those of the first group. The thecal wall is only occasionally faintly undulated, and the neck region is longer. The colonies are infertile.

There is thus a good correlation between stem morphology and environmental conditions, as the robust (fertile) stems were found only on the rough-water site, whereas the more flexuous (infertile) stems occurred only on the sheltered side of the island.

#### *Symplectoscyphus pygmaeus*? (Bale, 1882).

*Sertularella pygmaeus* Bale, 1882: 25, pl. 12, fig. 9; 1884: 108, pl. 3, fig. 8, pl. 19, fig. 19. Blackburn, 1942: 113, Hodgson, 1950: 36, figs. 63, 64.

*Symplectoscyphus pygmaeus* (Bale), Ralph, 1961a: 805, fig. 16.

**Records:** R, 18–30 m, on *Herdmania momus*, bryozoa and compound ascidians; S, 18–24 m, on stem of *Thecocarpus divaricatus* var. *cystifera*.

**Material:** Infertile colonies comprising a few stems to 4 mm long. *Colour*—bright yellow.

**Remarks:** It is difficult to distinguish between infertile material of *S. pygmaeus* and *S. rentoni* (Bartlett, 1907). Ralph (1961) distinguishes between the two species on the line of fine dots passing from the base of the adcauline wall to a point one third the distance up the abcauline wall in *S. pygmaeus*, and a lower diagonal in *S. rentoni*. However, examination of a series of microslides of *S. pygmaeus* in the collection of the NMV, shows that this is not

a reliable distinction; as the height of the diagonal varies considerably between different stems, and even among hydrothecae on the same stem.

Most of the hydrothecae of the Pearson I. material have a line of dots joining the abcauline wall about one quarter the distance up from the base, a distance greater than that given by Ralph as diagnostic for *S. pygmaeus*, the junction being marked by a thickened notch on the inside of the wall. As the Pearson I. specimens most closely resemble *S. pygmaeus*, especially one slide in the Bale collection (NMV) labelled "Queenscliff, 1881", the specimens are provisionally assigned to this species.

#### *Symplectoscyphus macrothecus* (Bale, 1882). Shepherd & Watson, 1970: 140.

*Sertularella macrotheca* Bale, 1882: 25, pl. 13, fig. 1; 1884: 107, pl. 3, fig. 4, pl. 19, fig. 24. Bartlett, 1907: 65, fig.

**Records:** R, 24 m, on *Acrocarpia paniculata*.

**Material:** One infertile colony of a few stems. *Hydrorhiza* a coarse undulating tube. *Stems* to 4 mm long, robust, athecate part very short, with a strong distal constriction. *Internodes* conspicuously inflated behind hydrotheca, nodes sharply twisted. *Hydrothecae* large, 2–6 on stem, completely occupying internode; fixed adcauline wall 0.18–0.20 mm, free adcauline wall 0.35–0.40 mm; abcauline wall 0.35–0.40 mm. Thecal wall smooth, with a notch on abcauline side below margin, opposite the submarginal tooth. *Margin* 0.15–0.20 mm in diam. lateral view. Three internal submarginal teeth, the abcauline tooth best developed.

**Remarks:** The present material agrees well with descriptions and figures by Bale of *S. macrotheca*.

#### *Symplectoscyphus rostratus* n.sp.

FIGS. 28–30

**Type material and Records:** Holotype, NMV G1981, microslide—R, 27–30 m, on *Sargassum verruculosum*; G2095, preserved material, remainder of holotype colony; paratypes, NMV G1982—R, 27–30 m, on *Sargassum verruculosum*; G1983—R, 33 m, on bryozoa; G1984—R, 27–30 m, on *Sargassum verruculosum*, microslides; SAM H36—S, 46 m, on red algae; microslide.

**Descriptions from holotype and paratypes:** *Hydrorhiza* tubular, loosely adherent to substrate. *Stems* short, to 2 mm long, unbranched, bearing 1–3 hydrothecae, perisarc thick and brittle. *Stem internodes* twisted, inflated behind

hydrotheca, proximal internode with 2-3 annulations; width of internode at base of hydrotheca 0.17-0.26 mm. *Hydrothecae* alternate, occupying most of internode, directed towards front of stem, each succeeding internode arising behind base of preceding hydrotheca, directed outwards, giving stem a zig-zag appearance. Hydrotheca barrel-shaped, narrowing to margin, with 2-3 shallow annular ridges passing completely around mid-region of thecal wall. Depth of hydrotheca (from base to margin) 0.42-0.50 mm; 0.27-0.30 mm in diam. at widest part. *Murgh* contracted, small, rim heavily thickened, with 3 teeth—1 blunt tooth in the central adcauline position, forming a raised beak-shaped crest; 2 blunt, low lateral teeth, flanking crest. Abcauline side of margin a shallow curve. Margin 0.12-0.16 mm in diam. (lateral view), 0.10-0.13 mm high (adcauline embayment to crest). Aperture facing obliquely outwards, depressed into the distal ridge of the abcauline wall. Four internal submarginal teeth—2 adcauline, long, flanking marginal crest, projecting downwards into cell; 1, low and ledge-like (not well seen in anterior view) just below margin in the centre of the abcauline embayment, and 1, similar in shape, but smaller, deep in the adcauline side of thecal neck, directly opposite the abcauline submarginal tooth, seen only in lateral view. *Hydranth* with abcauline caecum, connected by a delicate web to the abcauline wall below the internal tooth. *Gonothecae* large, ovate, 0.8 mm long; 0.6 mm wide, arising from a short pedicel below proximal hydrotheca, with 5 strong, crumpled annular ridges, and 3 low, fairly sharp apertural teeth.

*Remarks:* The material of *S. rostratus* from Pearson 1, included only 2 gonothecae, one of which was immature.

*S. rostratus* is in some respects transitional between the smaller forms of *S. indivisus* Bale, and *S. macrothecus* Bale, resembling the former in general aspect of the trophosome and gonosome, and the latter in the arrangement of the internal submarginal teeth. There is however, only 1 abcauline submarginal tooth in *S. rostratus*, compared to 3 in *S. macrothecus*. In *S. indivisus*, the 3 marginal teeth are alternate with the marginal teeth. The raised adcauline crest further distinguishes *S. rostratus*.

*Symplectoscyphus epiznicus* n.sp.

FIGS. 31-33

*Type Material and Records:* Holotype, NMV G1985, microslide—S. 20 m, on *Thecocarpius divaricatus* var. *cystifera*; G2096, pre-

served material, remainder of holotype colony; paratypes, G1986, G1987, G1988, microslides—R, 30 m, on *T. divaricatus* var. *cystifera*; SAM H33, microslide.

*Description from holotype and paratypes:*

*Hydrorhiza* tubular, of same diam. as stems. *Stems* simple, short, unbranched, to 3 mm long. Proximal stem internode short, atecate, with 4-5 annulations, width 0.13 mm; following internodes of variable length, 0.50-1.05 mm. *Hydrothecae* large, perisarc delicate, alternate, in one plane, a maximum of 4 on stem, not immersed in internode, distal on long internodes, occupying almost the whole length of short internodes, without definite floor, barrel-shaped, widest about middle, narrowing only slightly to margin. Length of fixed adcauline wall 0.22-0.28 mm, free adcauline wall 0.21-0.30 mm; abcauline wall 0.45-0.53 mm. *Margin* 0.28-0.31 mm in diam., thickened, with 3 equi-distant bluntly pointed teeth—1 adcauline, 2 lateral abcauline. *Operculum* of 3 delicate flaps. No internal submarginal teeth. *Hydranth* with approx. 24 tentacles, and an abcauline caecum. *Gonothecae* large, ovate, nearly 3 times length of hydrotheca, 1.11-1.35 mm long, widest at top, 0.87-1.02 mm, tapering to a short pedicel arising below proximal hydrotheca, walls faintly undulated proximally, the annulations more distinct about mid-region. Aperture small, circular, 0.13-0.15 mm in diam., depressed into the most distal annulation of the gonothecal wall; 4 very low rounded teeth. Gonophores female, mature, not filling gonothecal cavity, with 10-16 eggs. *Colour*—yellow.

*Remarks:* The colonies arise from a single stolon running up the main stem and branches of the host, the stems and occasional single hydrothecae given off at irregular intervals.

*S. epiznicus* resembles one of the larger forms of *S. indivisus* (Bale) (i.e. "*Sertularella variabilis*" Bale, 1888) in size and structure, and could easily be confused with this species in preserved material. However, *S. epiznicus* lacks the internal submarginal teeth which distinguishes *S. indivisus*.

*Sertularia macrocarpa* Bale, 1884: 80, pl. 5, fig. 2, pl. 19, fig. 11; 1914a: 14; 1915: 277. Mulder & Trebilcock, 1914b: 42. Hodgson, 1950: 27, fig. 47. Shepherd & Watson, 1970: 140.

*Records:* R, 28-34 m; S, 4-25, among holofasts of red algae.

**Material:** Colonies abundant, growing in thick tangled clusters. *Stems* to 12 cm long, infertile except for 1 gonotheca. **Colour**—dark brown. **Remarks:** This distinctive species is easily recognized by its dark colour, and large, tangled colonies which usually grow at the base of algae in semi-sheltered situations.

**Sertularia unguiculata** Busk, 1852: 394. Bale, 1884: 76, pl. 6, figs. 9–12; 1894: 100; 1914a: 16; 1915: 273. Blackburn, 1942: 113. Hodgson, 1950: 26, figs. 45, 46. Ralph, 1961a: 788, fig. 13.

**Records:** S, 25 m, on *Herdmania momus*, and among algal holdfasts.

**Material:** Several large infertile colonies. *Stems* short, to 3.5 cm, unbranched. Proximal branch internodes with 3 pairs of hydrothecae, each succeeding internode with 2 pairs of hydrothecae, nodes indistinct. *Hydrothecae* on branches adnate for two-thirds of length; cauline hydrothecae not immersed in stem. **Colour**—orange brown.

**Remarks:** Although shorter, the stems in the present collection conform to Bale's (1884) description of the thick stemmed, long internode form of *S. unguiculata*.

Although relatively common at Pearson I, *S. unguiculata* was restricted to sheltered water.

**Sertularia bicuspidata** Lamareck, 1816: 21. Blackburn, 1937: 367.

*Sertularia bicornis* Bale, 1882: 22, pl. 12, fig. 3; 1884: 83, pl. 5, fig. 9.

**Records:** R, 45 m, on *Rhodopeltis australis* and *Meiamastophora flabellata*.

**Material:** A few infertile stems. *Stems* stiffly erect, branched, to 1 cm long. **Colour**—dark brown.

**Remarks:** The distinctive paired finger-like processes flanking the margin distinguish this species from all other species of *Sertularia* in Australian waters.

This is the first undoubted record of *S. bicuspidata* from S. Aust. (Other localities—Queenscliff, and Lady Julia Percy I, Vic.)

**Sertularia maccallumi** Bartlett, 1907: 62, fig. 1–3. Mulder & Trebilcock, 1914a: 7, pl. 1, figs. 1–3. Bale, 1919: 340, pl. 16, figs. 3, 4. Shepherd & Watson, 1970: 143.

**Records:** R, 25–45 m, on *Carpopeltis phyllopora* and *Pterocladia lucida*.

**Material:** Luxuriant fertile colonies thickly over-running algae. *Stems* to 4 mm long.

**Colour**—hydrorhiza brown, hydrocaulus bright yellow.

**Remarks:** *S. maccallumi* is one of the commonest hydroids in the Pearson I. collection. Although both species of algae were also recorded at West I. (Shepherd & Watson 1970), *S. maccallumi* was never found on *P. lucida*, and only occasionally on *C. phyllopora* at that locality.

**Sertularia acuta** (Stechow, 1921), Millard, 1958: 192, fig. 8, Shepherd & Watson, 1970: 140.

*Sertularia loculosa* Bale, 1884: 91, pl. 4, figs. 5, 6; 1913: 121, pl. 12, figs. 7, 8; 1915: 272.

*Tridentata acuta* Stechow, 1921: 231.

*Sertularia halei* Briggs, 1922: 150.

**Records:** R, 45 m; S, 15 m, on *Stenocladia australis*.

**Material:** Abundant fertile colonies. *Stems* unbranched, to 5 mm long, internodes with an oblique proximal, and a transverse distal joint; exceptionally, a transverse joint is followed by 2 oblique joints. **Colour**—yellow. *Gonothecae* with 4–5 deep annulations.

**Remarks:** The Pearson I. specimens correspond closely to the short-celled form of "*S. loculosa*" Bale.

Millard (1958: p. 198) distinguishes *S. acuta* from *S. turbinata* (Lamouroux, 1816) in her South African material partly by the presence of transverse stem nodes in the former species, and oblique nodes in *S. turbinata*. The Pearson I. material has both transverse and oblique joints on the one stem, thus further reducing the difference between these two closely related species. *S. acuta* is a common epiphytic species in the collection and is associated with only one species of alga.

**Amphisbetia maplestonei** (Bale, 1884), Rees & Thursfield, 1965: 142. Shepherd & Watson, 1970: 140.

*Sertularia maplestonei* Bale, 1884: 70, pl. 6, fig. 4, pl. 19, fig. 2.

*Sertularia bidens* Bale, 1884: 70, pl. 6, fig. 6, pl. 19, fig. 1; 1914a: 16.

**Records:** R, 34 m; S, 25 m, among algal holdfasts.

**Material:** Luxuriant fertile colonies. *Stems* flexuous, 5–12 cm long.

**Remarks:** The distal conical processes of the gonothecae are moderately well developed, but many gonothecae have only 1 process on the abcauline side.

**Amphisbetia pulchella** (Thompson, 1879).  
Shepherd & Watson, 1970: 140.

*Serularia pulchella* Thompson, 1879: 109, pl. 18, figs. 3, 3a, Bale, 1884: 71, pl. 6, fig. 5, pl. 19, fig. 10.

*Serularia maplestonei* (Bale); Blackburn, 1942: 113.

*Records*: R, 45 m, on *Pterocladia lucida*; S, 14 m, on bryozoa epiphytic on algae.

*Material*: A few infertile stems to 1 cm long.

*Remarks*: Blackburn (1942) included *A. pulchella* in the synonymy of *A. maplestonei* although *A. pulchella* is a prior name. Although similar in microscopic details of the trophosome, the two species seem to be distinct, and are readily distinguished by the gonothecae and size of the stem. The stems of *A. maplestonei* are long and robust, while those of *A. pulchella* rarely exceed 2 cm. Both species are epiphytic: the larger species, *A. maplestonei*, is confined to the basal parts of algae, while the more delicate *A. pulchella* epiphytises the fronds. Possibly, further work may prove the two to be ecomorphs of the one species.

**Amphisbetia olseni** n.sp.

FIGS. 34-37

*Type Material and Records*: Holotype, NMV G2001, microslide—R, 33 m, on sponge; G2097, preserved material, remainder of holotype colony; paratypes, G2002, G2003, G2004, microslides—R, 33 m, on *Herdmania moinus*; G2005—S, 17-33 m, on brown algae, microslide; G2098, remainder of paratype colony G2005; G2006—R, 33 m, on red algae, microslide; SAM H34—R, 33 m, on sponge, microslide.

*Description from holotype and paratypes*: *Hydrorhiza* tubular, stems to 7 mm long, monosiphonic, stiffly erect, branched. Proximal stem internodes athecate, terminating in a strong V-shaped joint, succeeding internodes thecate, nodes indistinct, but if present, V-shaped, slender. Internodes 0.52 mm long, diam. at node, 0.06-0.09 mm; 3 hydrothecae on stem internodes, 1 axillar, 2 subopposite. *Branching* regularly alternate, up to 5 branches on stem, arising from a long proximal apophysis given off at 70° to stem. First branch internode very short, athecate, with a transverse proximal, and V-shaped distal joint; remainder of branch without internodes, but with up to 5 branches of hydrothecae. *Hydrothecae* on branches subopposite, in 1 plane, adnate approx. two-thirds of their length, saccate, widest near middle, narrowing to margin. Fixed adcauline wall 0.12-0.16 mm long, free ad-

cauline wall 0.05-0.08 mm, standing out horizontally, or at a slight upward angle from the internode. Abcauline wall 0.16-0.19 mm, a pronounced inflexure about one-third the distance up from the base, followed by a sharp outward bend, but this may be reduced to a mere concavity in the abcauline wall. Paired hydrothecae on younger parts of stem and branches in contact along fixed adcauline wall, but separated in older parts of stem; if in contact, the adcauline wall is straight, otherwise it is bent parallel to the inflexure of the abcauline wall. *Margin* with 2 long sharply pointed lateral teeth 0.07 mm long, separated by a deep, almost horizontal abcauline sinus; adcauline wall indented behind margin. Operculum of 2 flaps, abcauline component fixed. *Hydranth* with approx. 12 tentacles. *Gonothecae* arising from lower stem behind proximal pair of hydrothecae, large, ovate, flattened, 1.02-1.32 mm long. Perisarc thick, walls smooth, widening distally to a shoulder 0.84-1.02 mm width, produced into a pair of short, almost laterally directed spines. Aperture circular, 0.35 mm. in diam., with a slightly raised collar and a ring of minute internal denticles. Operculum a circular flap. Gonothecae empty. *Colour*—light straw colour.

*Remarks*: The branching in *A. olseni* is regularly alternate; where a branch fails to develop, the stem internode is longer, and has 1 axillar, and 2 pairs of subopposite hydrothecae, then branching resumes again. The branches are very brittle and break off easily at the slender proximal joint.

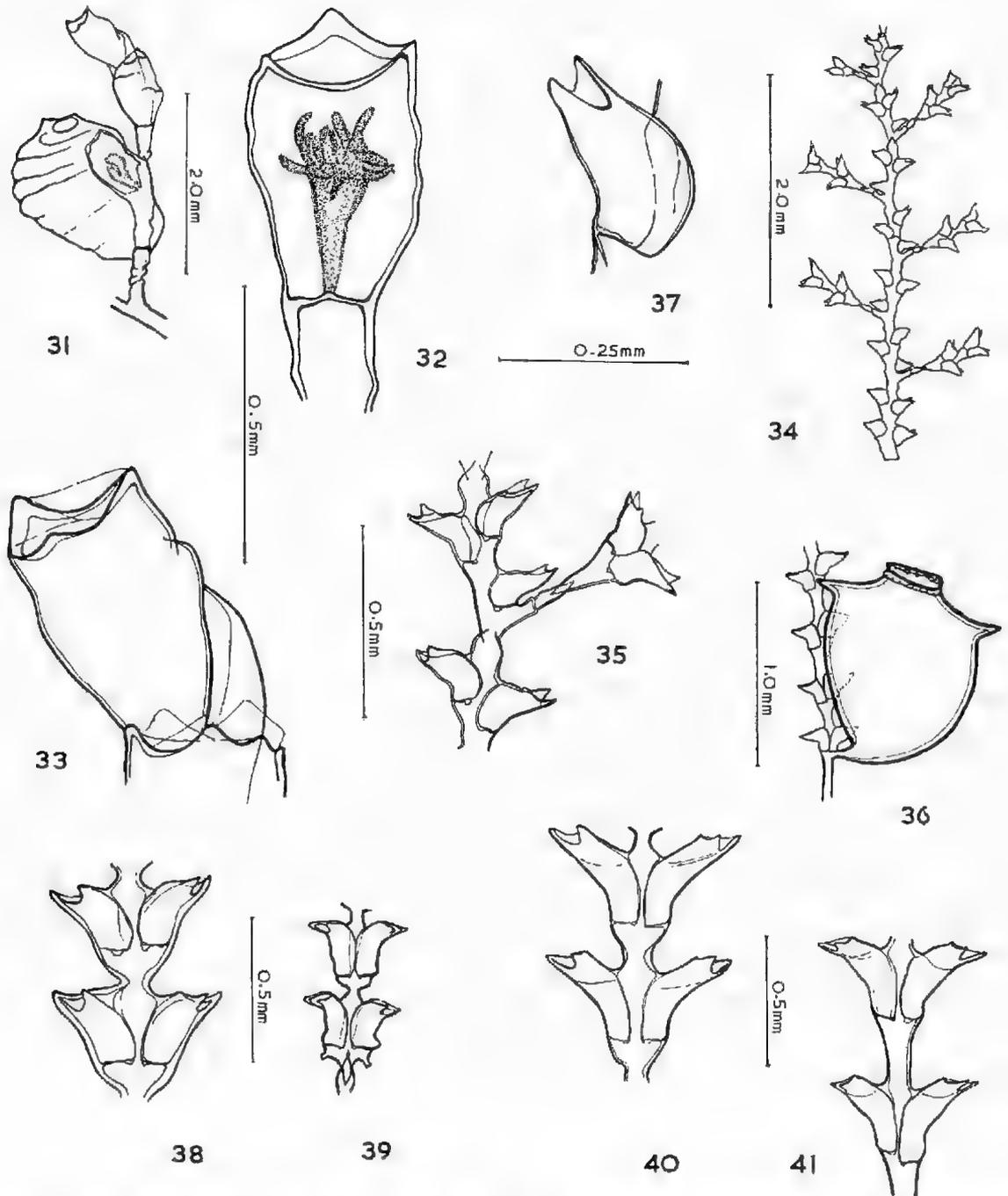
*A. olseni* is closely related to both *A. pulchella* (Thompson) and *A. bidens* (Bale) in structure of the trophosome and gonosome, but is distinguished from these species by the straighter, less flexuous stem, the pronounced concavity of the abcauline thecal wall, the less prominent marginal teeth, the greater proportion of the hydrotheca adnate to the internode, and the shape of the gonotheca.

With one exception (S, 17-33 m), the colonies were all found within the same area on the rough water site.

*A. olseni* is named after Mr. A. M. Olsen, whose interest and encouragement has done much to foster marine science in South Australia.

**Amphisbetia minima** (Thompson, 1879).  
Ralph, 1961a: 774, fig. 8. Shepherd & Watson, 1970: 140.

FIGS. 37, 38



- Figs. 31-33. *Symplectoscyphus epizoicus* n.sp. Fig. 31.—Whole stem with gonotheca. Fig. 32.—Hydrotheca enlarged, anterior view, with hydranth. Fig. 33.—Hydrotheca, lateral view. Drawn from holotype.
- Figs. 34-37. *Amphisbetia olseni* n.sp. Fig. 34.—Whole stem, from holotype. Fig. 35, part of stem and branch, enlarged. Fig. 36.—Part of stem and gonotheca, from paratype. Fig. 37.—Hydrotheca, enlarged.
- Fig. 38. *Amphisbetia minima* var. *pumiloides* Bale. Part of stem with two internodes.
- Fig. 39. *Amphisbetia minima* var. *intermedia* Bale. Part of stem with two internodes, Figs. 38 and 39 drawn at same scale for comparison.
- Fig. 40. *Amphisbetia minuscula* Bale. "Short internode" form.
- Fig. 41. *Amphisbetia minuscula* Bale. "Long internode" form.

*Sertularia minima* Thompson, 1879: 104, pl. 17, fig. 3, Balc, 1882: 21, 45, pl. 12, fig. 2; 1884: 89, pl. 4, figs. 9, 10, pl. 19, figs. 12, 13; 1915: 269; 1924: 248. Mulder & Trebilcock, 1914b: 39. Stechow, 1925: 231, fig. K, Blackburn, 1942: 114. Hodgson, 1950: 23, figs. 41, 42. Millard, 1957: 221.

*Records*: R, 12–50 m; S, 15–25 m, on algae (see Remarks).

*Material*: Luxuriant fertile colonies. *Stems* to 5 mm long. *Colour*—light brown.

*Remarks*: Bale recognized 3 varieties of *A. minima* in southern Australian waters, the largest, var. *pumiloides* Bale, 1884 (from Queenscliff, Vic.), a "typical" form from Port Phillip Bay and New Zealand waters, and var. *intermedia* Bale, 1915, from the Nuyts Archipelago in the Great Australian Bight. Ralph's (1951) figures and description show her New Zealand specimens to be closely allied to the Australian typical form, but there are nematothecae scattered throughout the hydrocaulus, a condition not normally encountered in the Australian material. *A. minima* is one of the most abundant hydroids in the Pearson I. collection, and the material examined falls with little intergradation into 2 of the varieties, var. *pumiloides* and var. *intermedia*. Although difficult to distinguish in preserved material, the varieties are easily separated in mounted preparations. These varieties have not previously been recorded together in the one locality.

The present material corresponding to var. *pumiloides* is a robust form, conforming to Bale's (1884) description. The hydrothecae are almost entirely adnate, and the typical wedge of perisarc between hydrotheca and internode is well developed. The gonothecae are variable in shape, round to elongate in lateral view; those with a raised apertural collar do not have a ring of internal submarginal denticles. The var. *intermedia*, not figured by Bale, is much smaller, with shorter internodes, and rectilinear hydrothecae. Nematothecae, varying from short cylindrical tubules to mere breaks in the perisarc, are present on all stems, but are confined to the infrathecal chamber of the proximal hydrothecae. Gonothecae are round to ovate. Dimensions of the 2 varieties from Pearson I. are given for comparison.

	var. <i>pumiloides</i>	var. <i>intermedia</i>
Dimensions: mm:		
Internode length	0.35–0.38	0.25–0.27
Dist. at node	0.05–0.08	0.03–0.04
Hydrotheca length	0.24–0.29	0.17–0.22

With few exceptions (Ritchie 1911), *A. minima* is recorded as an epiphytic species, and

at Pearson I. the 2 varieties show a strong selectivity towards certain species of algae. The var. *pumiloides* was found only on the robust brown algae *Sargassum bracteolosum*, *S. varians*, and *S. verruculosum*, as well as *Acrocarpia paniculata*; var. *intermedia* was associated with the more delicate red algae *Rhodymenia australis*, *Metamastophora flabellata*, *Laurencia elata*, and *Carpopeltis phyllophora*, with one record on the delicate brown alga, *Distromium flabellatum*. Shepherd & Watson (1970) noted that many commonly epiphytic hydroids show varying degrees of preference for particular species of algal substrate, but a differential selectivity by varieties of the same species has not previously been recognized.

Almost all the colonies have the pegged hydrothiza typical of *A. minima*. Bale (1915) and Mulder & Trebilcock (1914a) noted this fact; Ritchie (1911) suggested it may be a response to wave action, but Ralph (1961) could find "no constant relationship to environmental conditions" to account for the thickenings. In many of the colonies of both varieties of *A. minima* from Pearson I., the hydrothiza is often tubular and loosely winding when in contact with the curved and cylindrical surfaces of the lower stems of the alga, then flattening out and developing the transverse markings as the stolon passes onto the broader fronds. This change in cross section of the stolon may therefore be either a response to the greater movement of the algal frond in turbulent water, or it may be related to the nature of the algal surface.

The systematic status of the 3 so-called varieties of *A. minima*, and of the whole "*A. minima*" group, including *A. minuscula* Bale, *A. furcata* Trask, and *A. muelleri* Bale, needs further elucidation. It is possible that all may be ecologic variants of the one species, or several distinct, but closely related species.

#### *Amphisbetia minuscula* (Bale, 1919).

FIGS. 40, 41

*Sertularia minima* var. *tubotheca* Mulder & Trebilcock, 1914b: 40, pl. 4, fig. 1.

*Sertularia pusilla* Bale, 1915: 271, pl. 46, figs. 3–6.

*Sertularia minuscula* Bale, 1919: 340. Blackburn, 1942: 114.

*Records*: R, 30–40 m, on *Laurencia elata*, *Distromium flabellatum*, and *Herdmania manus*; S, 25–31 m, on the stem of *Caulerpa sp.*, and *Halicornaria longirostris*.

*Material*: Abundant colonies, some fertile. *Stems* simple, to 5 mm long, internodes variable. The stems are divisible into 2 groups—

long internode group, internodes 0.42–0.44 mm long, and a short internode group, internodes 0.30–0.34 mm long. Nodes of both stem groups 0.06 mm wide, indistinct, transverse, occasionally a V-shaped joint in distal region of stem. *Hydrothecae* similar to descriptions of authors, fixed adcauline wall 0.19–0.22 mm, free adcauline wall 0.07–0.11 mm; abcauline wall 0.19–0.26 mm; an indistinct downwardly curved ridge passing back from the embayment between the marginal teeth into the junction of the adcauline wall with the internode. *Gonothecae* 1.20–1.26 mm long, excluding pedicel, maximum width, 0.75–0.97 mm, present only on the "short internode" form.

**Remarks:** The hydrothecae of the "long internode" form of the Pearson I. material are larger than those of the "short internode" form, but both are smaller than measurements from microslides of *A. minuscula*, and the type of "*A. minima* var. *tubatheca*" in the collection of the NMV. The "long internode" form conforms with measurements of *A. pusilla* (Bale), while the "short internode" form is similar to the var. *tubatheca* of Mulder & Trebilcock. The nematothecae noted by Bale and Mulder & Trebilcock are present in only a few of the proximal stem internodes of the Pearson I. specimens; the intrathecal ridge, noted in the present material, is not present in the type. *A. minuscula* displays a wide choice of substrate. Some correlation evidently exists between stem type and environmental conditions, since the "long internode" form was abundant on the sheltered site, whereas the more robust "short internode" form was found only on the rough-water side of the island. This suggests that development of a thickened stem with short internodes is advantageous to withstand rough water conditions.

#### Family PLUMULARIIDAE

##### *Pycnotheca producta* (Bale, 1882).

*Plumularia producta* Bale, 1882: 39, pl. 15, fig. 3; 1884: 133, pl. 10, fig. 4; 1894: 111.  
*Kirchenpaueria producta* Bale, 1914a: 59, 1915: 302. Blackburn, 1942: 107.

**Records:** R, 24 m, on *Distromium flabellatum*; S, 24 m, on *Hymenena*?

**Material:** A few scattered infertile colonies. **Stems** to 9 mm long.

**Remarks:** The material conforms exactly to Bale's description of *P. producta*.

##### *Antennella tubulosa* (Bale, 1894).

#### FIG. 42

*Plumularia tubulosa* Bale, 1894: 114, pl. 5, figs. 2–5.

**Records:** R, 27–30 m, on bryozoa; S, 26–30 m, on *Sargassum* sp.

**Material:** Several colonies, each comprising a few infertile stems. **Stems** to 3 mm long, arising from a thick hydrorhiza. First internode with a proximal constriction, followed by an athecate internode with 1–2 nematothecae and an oblique distal node. Atecate internodes 0.11–0.16 mm long; thecate internodes as described by Bale; 0.27–0.37 mm long, with 1 median nematotheca and 2 scoop-shaped lateral nematothecae. *Hydrothecae* long, 5–6 on a stem, proximal part tubular, perisarc thick, adcauline wall 0.25–0.27 mm long; abcauline wall 0.22–0.30 mm long, distal part of adcauline wall more convex than abcauline side. **Margin** 0.13–0.15 mm in diam., deeply sinuated, curving up to meet produced adcauline wall. **Colour**—yellow.

**Remarks:** The Pearson I. material, although definitely referable to *A. tubulosa*, nevertheless shows considerable variability in thickness of perisarc, length, diam. of internode, and shape of hydrothecae. Bale (1894) considered that *A. tubulosa* may be a variant of *H. campanula*, or the "Antennella" form of an unknown Plumularian.

As the present material shows no sign of branching, *A. tubulosa* may therefore be considered a distinct species.

This is the second record of *A. tubulosa*, and a first record for S. Aust. (Other locality—Port Phillip Bay, Vic.)

##### *Antennella campanuliformis* (Mulder & Trebilcock, 1909).

#### FIGS. 43, 44

*Plumularia campanuliformis* Mulder & Trebilcock, 1909: 31, pl. 1, figs. 6, 9, 10; 1911: 115.

**Records:** R, 30–45 m, on *Sargassum* sp., *Laurencia elata* and *Pterocladia lucida*.

**Material:** Colonies common, fertile. The specimens conform to the type microslide of *Plumularia campanuliformis* in the collection of the NMV. The following description supplements that of Mulder & Trebilcock.

**Hydrorhiza** tubular. **Stems** to 1 cm long, first stem internode 0.5 mm long, athecate, with 1–2 nematothecae and 1–2 proximal annulations, distal node oblique, following internodes alternately thecate and athecate. Thecate internodes 0.39–0.45 mm long, almost entirely occupied by the hydrotheca, with an oblique proximal node, and a transverse distal node, 0.06–0.09 mm wide, often indistinct; athecate internode short, 0.28–0.31 mm (measured along base of hydro-

cladium). *Hydrothecae* cup-shaped, deep, base curved, abcauline wall 0.20–0.22 mm long, concave; adcauline wall 0.21–0.25 mm long, straight, or with a slight convexity below the margin, both walls thickened, the abcauline flange extending back to the median nematotheca. *Margin* circular, 0.21–0.23 mm in diam., slightly sinuated. *Nematothecae* large, bithalamic, 0.08–0.10 mm long, distal cup 0.05 mm in diam., 3 on the athecate internode—1 median, base stout, cup excavated on adcauline side, 2 laterals below hydrotheca on a very short apophysis of the hydrocladium, cups narrow, excavated on inner side, sides slightly inrolled; 1 on athecate internode, similar to others; 2 similar in shape, but larger than cauline nematothecae on the pedicel of female gonotheca, facing outwards, cups excavated on the side facing gonotheca; 1 nematotheca on male gonotheca above pedicel. *Gonothecae* of both sexes on the one stem, arising beside the median nematotheca on thecate internodes, male small, 0.22–0.27 mm long, ovate, 0.10–0.14 mm wide, only on proximal stem internodes; female large, 0.64–0.66 mm in diam., globular, only on distal internodes; female gonophore of 1 large egg surrounded by a top-shaped blastostyle.

*Remarks:* Although Mulder & Trebilcock describe and figure the hydrotheca of *A. campanuliformis* as campanulate, this is somewhat misleading, as the type specimens as well as the Pearson I. material have almost tubular hydrothecae.

This is the second record of *A. campanuliformis*, and a first record for S. Aust. (Other locality—Vic.)

*Antennella secundaria* (Gmelin) s. sp. *dubiaformis* (Mulder & Trebilcock, 1910).

FIGS. 45, 46

*Plumularia dubiaformis* Mulder & Trebilcock, 1910: 119, pl. 2, fig. 7.

*Antennella secundaria* (Gmelin); Billard, 1913: 8.

*Plumularia secundaria* (Gmelin), Blackburn, 1938: 361.

*Schizotricha secundaria* (Gmelin), Blackburn, 1942: 108.

*Records:* S., 17–27 m, on compound ascidian, *Rhodymenia australis*, *Distramium flabellatum*, *Sertularia unguiculata* and sponge.

*Material:* Abundant fertile colonies. *Hydrotheca* tubular. *Stems* to 6 mm long, perisarc delicate. First stem internode long, athecate, with 3 nematothecae and oblique distal joint, internode occasionally with 1 branch. Following internodes alternately thecate and athecate,

athecate internodes 0.3 mm long, with an indistinct transverse and a strong oblique distal joint; thecate internodes slightly longer, 0.30–0.35 mm long. *Hydrothecae* campanulate, 0.20–0.22 mm deep, set at an angle of 45° to hydrocladial axis; base flat, abcauline wall slightly thickened, adcauline wall almost entirely adnate, free part closely adpressed to internode. *Margin* entire, delicate, 0.26–0.30 mm in diam. *Nematothecae* as described for *A. secundaria*, 2 present on athecate internode. One small suprathecal nematotheca usually, but not always present in the sinus above the hydrotheca. *Gonothecae*—male and female on the same stem, arising beside the median subhydrothecal nematotheca, tapering to a short pedicel. Female globular, flattened, 0.52–0.58 mm long, widest near middle, 0.40–0.44 mm maximum width, closed by a thin operculum; 3 nematothecae similar to laterals, in basal region. Male gonotheca small, 0.15–0.20 mm long, 0.12–0.13 mm wide, with 1 proximal nematotheca.

*Remarks:* The present specimens are identical with 2 microslides of fragmentary infertile material of *Plumularia dubiaformis* Mulder & Trebilcock in the collection of the NMV. Mulder & Trebilcock, because of poor material, were unable to establish the presence or absence of the suprathecal nematothecae in *P. dubiaformis*. These nematothecae are clearly visible in the Pearson I. material.

I have also compared the present material with fertile material of *A. secundaria* from Mossel Bay, South Africa, provided by Dr. N. A. H. Millard, and with the exception of the 2 median nematothecae on the athecate internode in the Pearson I. specimens (1 in the South African material), the two are indistinguishable. As the number of nematothecae on the athecate internode is not a reliable specific criterion, I agree with Billard (1913) and Blackburn (1938) who suggested *P. dubiaformis* would prove to be a synonym of *A. secundaria*.

As the known South Australian material of *A. secundaria* always has 2 nematothecae on the athecate internode, compared to 1 in the typical form, and has now been recorded from two widely separated localities (Pearson I and Vic.), it is here recognized as a subspecies of *A. secundaria*.

*Halopteris sulcata* (Lamarck, 1816)

*Plumularia sulcata* Lamarck, 1816: 128. Briggs, 1915: 306, pl. 11, fig. 1. Bale, 1914b: 172, pl. 35, figs. 6, 7; 1915: 296.

*Plumularia aglaophenoides* Bale, 1884: 126, pl. 10, fig. 6.

*Records:* R. 30 m, on sandy floor of cavern.  
*Material:* Several large fertile colonies. *Stems* fasciated, branched, to 20 cm high, growing from a small fibrous rootstock. *Colour*—dark brown.

*Remarks:* This species is easily recognizable by its large, erect woody stem, colour, and brittle texture. At Pearson I., *H. sulcata* was found only on the floors of caverns sheltered from surge; it has however also been noted in open water to the east, in Investigator Strait (J.W., unpublished) at depths of 40 m.

***Halopteris campanula* var. *campanula*** (Busk, 1852), Ralph, 1961b:47.

*Plumularia campanula* Busk, 1852: 401. Bale, 1884: 124, pl. 10, fig. 5; 1888: 776; 1913: 133; 1915: 295. Hodgson, 1950: 40, fig. 69.

*Schizotricha campanula* (Busk), Blackburn, 1942: 107.

*Records:* R. 35 m, epilithic.

*Material:* One infertile colony growing from a common rootstock. *Stems* polysiphonic, branched, to 4.5 cm high; some secondary branching. *Colour*—yellow.

*Remarks:* The specimens agree with descriptions of *P. campanula*, and *H. campanula* var. *campanula* of Ralph (1961b).

***Halopteris buski*** (Bale, 1884).

*Plumularia buski* Bale, 1884: 125, pl. 10, fig. 3, pl. 19, figs. 34, 35; 1913a: 28; 1915: 296. Briggs, 1915: 304. Hodgson, 1950: 45, fig. 75. *Schizotricha buski* (Bale), Blackburn, 1942: 107.

*Records:* R. 30–33 m, on *Herdmania montus*, hryozoa and sponge; Stn. F. 65 m, on worm tube.

*Material:* Scattered colonies, each of a few stems to 2 cm long. One stem with immature male gonophores.

*Remarks:* The Pearson I. specimens do not differ significantly from descriptions of Bale and Briggs. With one exception (Stn. F) the colonies are all from the exposed side of the island. They are short and robust, with deeply incised stem joints; frequently an extra oblique septal internodal ridge is developed just below the adcauline hydrothecal wall. The stems from less turbulent deeper water (Stn. F) are more flexuous, with indistinct cauline nodes, and also lack the oblique hydrocladial septa present in the shallower water specimens. The deeper water stems were scarlet in colour, whereas the shallower water specimens varied from orange to yellow.

***Halopteris opposita*** (Mulder & Trebilcock, 1911).

FIG. 47

*Plumularia opposita* Mulder & Trebilcock, 1911: 120, pl. 2, fig. 5.

*Thevocaulis oppositus* (M. & T.), Blackburn, 1938: 316, fig. 2; 1942: 107.

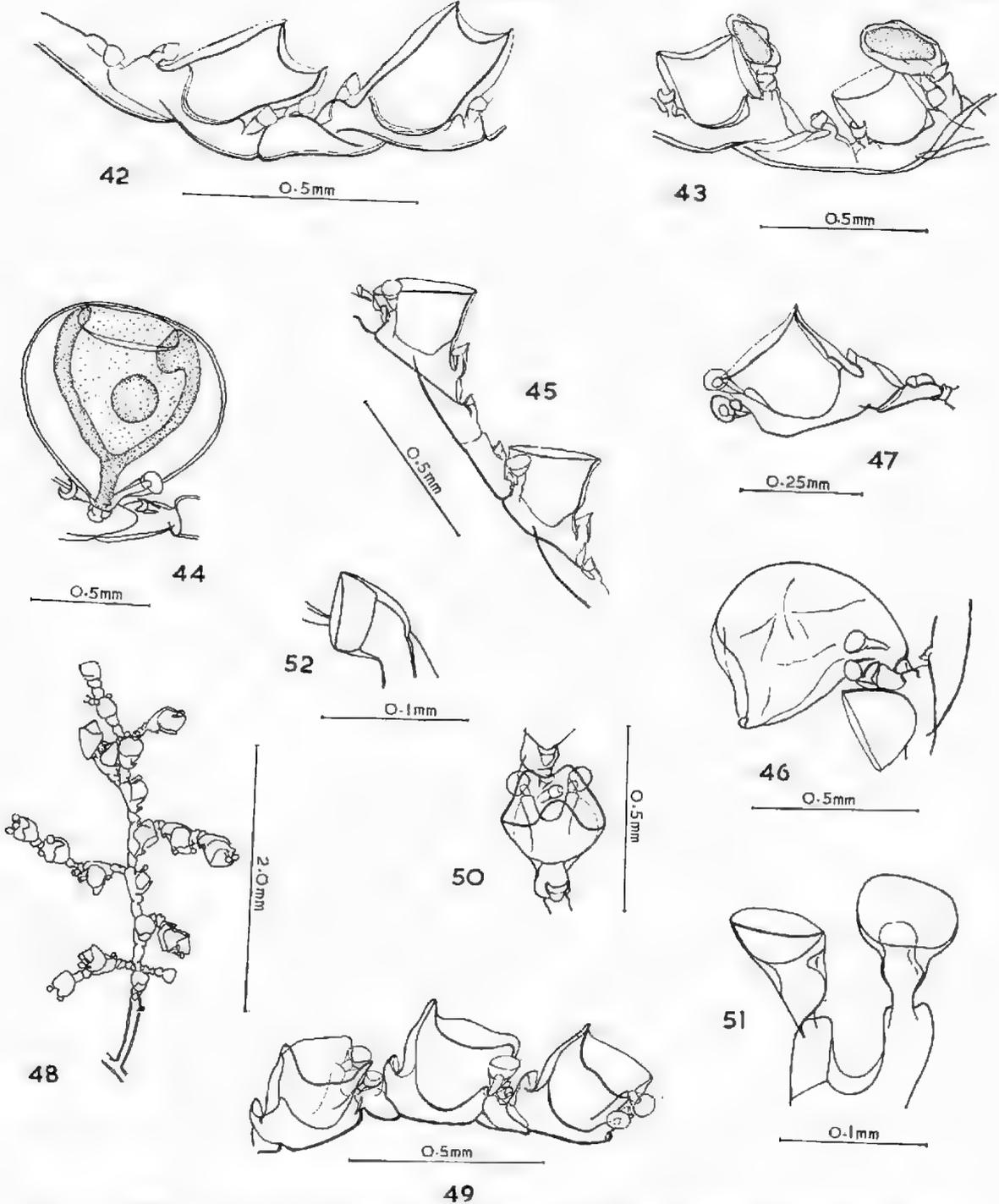
*Records:* S. 30 m, on *Sargassum spinuligerum* and *S. verruculosum*.

*Material:* Scattered infertile stems to 12 mm long. The specimens compare with the type microslide of *H. opposita* in the collection of the NMV, and allow a fuller description to supplement the previous brief description of Mulder & Trebilcock.

*Stems* with 2–3 indistinct proximal annulations, followed by a long athecate internode with 2–3 nematothecae, then alternate thecate and athecate internodes of approx. the same length, 0.27–0.39 mm; athecate internodes with a proximal transverse joint and strongly oblique distal hinge-joint, and 2–3 nematothecae; if 2, they are one above the other; the third, if present, is beside the distal nematotheca. *Hydrocladia* opposite, arising behind the cauline hydrothecae in middle of the internode, hydrocladia beginning with 2 short athecate internodes, the first internode the shorter, 0.05–0.07 mm long, the second 0.07–0.08 mm long, with a transverse proximal, and an oblique distal joint, and occasionally, 1 nematotheca. Thecate hydrocladial internodes similar to stem internode. *Hydrothecae* campanulate, 2–3 on hydrocladium, 0.15–0.18 mm deep, set at 45° to hydrocladial axis. *Margium* 0.19–0.21 mm diam., slightly sinuated, rim everted, with a peak on the abcauline side. Abcauline wall 0.12–0.15 mm long, in some hydrothecae a small transverse fold near base. *Nematothecae* 0.05–0.07 mm long, 2 suprathecal on stem internodes, 4 on thecate hydrocladial internodes—1 median, stout at base, distal cup cut away on adcauline side, closely adpressed to internode; 2 lateral suprathecal, with slender pedicels, on an apophysis of the internode, extending above hydrotheca, and 1 small nematotheca between laterals at base of hydrotheca. *Hydranth* with 10–16 tentacles, connected to internode by a small orifice in the upcurve of the abcauline wall.

*Remarks:* The stem of the type is thick and robust, and the athecate stem internodes are considerably shorter than the thecate internodes, with deeply constricted nodes.

The Pearson I. specimens have slender stems, and internodes of nearly equal length. Black-



- Fig. 42. *Antennella tubulosa* (Bale). Part of stem.  
 Figs. 43, 44. *Antennella campanuliformis* (Mulder & Trebilcock). Fig. 43.—Part of stem with male gonophores. Fig. 44.—Female gonophore.  
 Figs. 45, 46. *Antennella secundaria* s.sp. *dubiaformis* (Mulder & Trebilcock). Fig. 45.—Part of stem with two hydrothecae. Fig. 46.—Empty female gonotheca.  
 Fig. 47. *Halopteris opposita* (Mulder & Trebilcock). Hydrocladium with one hydrotheca.  
 Figs. 48–52. *Gattya trebilcocki* n.sp. From holotype. Fig. 48.—Whole stem. Fig. 49.—Hydrocladium with three hydrothecae. Fig. 50.—Hydrotheca, anterior view. Fig. 51.—Twin lateral nematothecae from distal end of hydrocladium, enlarged. Fig. 52.—Median nematotheca on thecate internode, enlarged.

burn (1938) also noted this feature in his material from the Sir Joseph Banks Group, and considered that it may "constitute a distinct variety". As the type microslide consists of a single stem fragment 3 mm long, it seems possible that the South Australian material may better represent the species than the type itself.

This is the third record of *H. opposita*. (Other localities—central Vic., Sir Joseph Banks Group, S. Aust.)

***Gattya agluopheniaformis* (Mulder & Trebilcock, 1909).**

*Plumularia agluopheniaformis* Mulder & Trebilcock, 1909: 32, pl. 1, fig. 7.

*Halopteris agluopheniaformis* (M. & T.), Shepherd & Watson, 1970: 140.

**Records:** R, 18–33, on *Plumularia procumbens* and *Callophyllis coccinea*.

**Material:** Several colonies of a few infertile stems each. *Hydrorhiza* tubular. Stems to 7 mm long, beginning with an athecate internode with 1–3 pairs of cauline nematothecae; thecate internodes with a proximal hydrotheca, and 2 pairs of suprathecal nematothecae. Hydrocladia arising from a small apophysis behind hydrotheca, the first pair opposite, first 2 hydrocladial internodes slender, short, athecate, 0.04–0.06 mm long, with transverse joints, distal internode longer, 0.07–0.09 mm, with 1 median nematotheca. *Hydrothecae* 0.17–0.20 mm deep (lateral view), with broadly lobed margin 0.13–0.18 mm in diam., the anterior and posterior lateral projections curving inwards over the aperture.

**Remarks:** The marginal projections of the Pearson I. specimens differ from those of *P. agluopheniaformis* figured by Mulder & Trebilcock. Furthermore, the cauline internodes are variable in length, some being barely long enough to accommodate the hydrotheca; those stems with longer internodes also have a thin perisarc, are more flexuous, and have a less deeply lobed hydrothecal margin than the type.

Following Millard (1962, p. 270), this and other species with a toothed thecal margin are referred to *Gattya*.

***Gattya halei* (Bartlett, 1907).**

*Plumularia halei* Bartlett, 1907: 65, Mulder & Trebilcock, 1909: 29, pl. 1, figs. 1–3. Hale, 1919: 344, pl. 17, fig. 6.

**Records:** R, 14–45 m on *Metamastophoru flabellata*, *Pterocladia lucida* and *Pterosiphonia?*

**Material:** Colonies common. A few fertile stems with female gonophores. Stems to 7 mm long.

**Colour**—yellow.

**Remarks:** This rare but distinctive species has not been recorded previously in S. Aust. (Other locality—central Vic.)

***Gattya trebilcocki* n.sp.**

FIGS. 48–52

**Type Material and Records:** Holotype, NMV G2029, microslide, G2099, preserved material, remainder of holotype colony—R, 10–33 m, on fragment of *Caulerpa brownii*; paratypes, G2030, G2031, G2032, G2033, G2034, G2035; SAM H39, microslides—R, 10–33 m, on *Caulerpa brownii*; G2100, preserved material, remainder of paratype colonies.

**Description from holotype and paratypes:** *Hydrorhiza* tubular, of same diam. as stem, embedded in the stem of the alga. Stems to 5 mm long, proximal stem internode 0.70–0.75 mm long, athecate, perisarc thick, with a few rough annular constrictions, and 1–2 distal nematothecae; distal hinge joint V-shaped. Following stem internodes alternately thecate and athecate, thecate internodes 0.25–0.45 mm long, athecate internodes 0.10–0.13 mm long, average diam. of internode 0.10 mm. *Hydrocladia* arising from a short apophysis of the stem above the hydrotheca on each cauline internode, first pair opposite, following hydrocladia alternate. Hydrocladium with 1–3 hydrothecae, thecate and athecate internodes alternate, crowded, identical to cauline internodes. Athebate internodes very short, 0.04–0.06 mm long, 2 between hydrocladial apophysis and first thecate internode, distal joint oblique, the second internode with oblique distal node, and 1 median nematotheca; following internodes alternately athecate and thecate, athecate internodes 0.07–0.08 mm long, thecate internodes 0.21–0.29 mm long, with oblique proximal and transverse distal nodes. Hydrothecae distal on internode, cup-shaped, 0.14–0.20 mm deep, perisarc delicate, base curved, set well down in hydrocladium; abcauline wall 0.15–0.20 mm long, convex, thickened to base of median nematotheca; adcauline wall shorter, 0.12–0.17 mm long (to end of lobes) not thickened, almost straight. **Margin** sinuated, 0.20–0.25 mm in diam., with 5 lobes of which 3 are well developed, tongue-shaped—1 anterior, peaked, rising over aperture, 2 posterior, paired, with a deep sinus between, and 2, paired, in middle of margin, broad and low in lateral view, but often obscure. **Nematothecae** binthalamie, of 3 types—1 median, on each athecate internode (except

first hydrocladial internode), base slender, distal cup deep and rather narrow; 4 nematothecae on thecate internodes—1 median, base very stout, 0.08–0.10 mm long; distal cup excavated on abcauline side, cup 0.04–0.06 mm in diam., margin vertical, closely adpressed to hydrocladium; 2 posterior laterals, longer than medians, 0.08–0.10 mm long, distal cup wide and shallow, 0.05–0.08 mm in diam., slightly flattened on abcauline side, overtopping marginal lobe of hydrotheca, base slender, on a pedicel 0.06–0.08 mm long; 1 small median suprathecal, similar to nematothecae on athecate internodes, but smaller, deeply set between the twin laterals at base of hydrotheca. *Hydranth* with approx. 16 tentacles. *Colour*—pale yellow. *Gonotheca* absent.

*Remarks:* *G. trebilcocki* shows close affinity with *G. aglaopheniaformis* Mulder & Trebilcock, but may be easily distinguished from this species by the shape of the posterior marginal lobes of the hydrotheca, which in *G. trebilcocki* are rounded. The cups of the lateral nematothecae are also much larger in *G. trebilcocki*.

Both species occur in the same locality and over a similar depth range, but *G. aglaopheniaformis* as presently known is an epizoic species, whereas *G. trebilcocki* has been found only on algal substrate. Both species are rare.

*Plumularia procumbens* Spencer, 1891: 130, pls. 21–23, figs. 17–25. Bale, 1894: 115, pl. 5, figs. 11, 12; 1914a: 29; 1915: 297, Briggs, 1915: 305, pl. 10, fig. 1.

*Records:* R, 33 m, epilithic on vertical rock faces.

*Material:* One infertile colony 7.5 cm high. *Stem* thick, fascicled, growing from a fibrous rootstock. Short hydrocladial internodes with nematothecae as described by Bale (1914a) and Briggs (1915).

*Remarks:* Although only 1 specimen was collected, several mature colonies of similar size and appearance were noted. The colonies are small in comparison with Briggs' Tasmanian material and Spencer's material from Port Phillip Bay, Vic. Bale (1914a, 1915) does not give dimensions of *P. procumbens* from the Great Australian Bight.

*Plumularia asymmetrica* Bale, 1914a: 29, pl. 4, figs. 2, 3; 1915: 279.

FIG. 53

*Records:* Stn. F, 65 m, freegrowing on sandy bottom.

*Material:* One infertile colony, 30 cm high.

*Stem* long, flexuous, branched, strongly fascicled near base. *Hydrocladia* with 12–15 hydrothecae, hydrocladial internodes with 5–7 strong septal ridges. *Hydrothecae* long, adnate, abcauline wall curving over distally towards hydrocladium; an indistinct intrathecal fold sometimes present about halfway along thecal wall. *Margin* with 2 broad bluntly pointed lateral lobes, usually of the same size and shape, occasionally 1 lobe much more prominent than the other.

*Remarks:* The Pearson I. material shows some variations compared with Bale's microslides of 'Endeavour' material from the Great Australian Bight in the collection of the NMV. The 'Endeavour' specimens show considerably more curvature of the distal hydrothecal abcauline wall than the Pearson I. material, have a distinct oblique intrathecal ridge, and a maximum of 4 septal ridges in the internode. The marginal lobes of the 'Endeavour' specimens seldom show the pronounced degree of asymmetry inferred from Bale's figures of *P. asymmetrica*. Furthermore, the margins of the lobes are rounded, rather than pointed, and each pair is usually the same shape; however, as the hydrothecal margin itself is slightly oblique to the hydrocladial axis, the lobes appear asymmetrical when viewed from above.

*P. asymmetrica* shows a strong resemblance to figures and description of *P. hertwigi* Stechow, 1909 from Japan (Bale 1914a, p. 31) and *P. habereri* var. *elongata* Billard, 1913 from the Indo-Pacific region. The latter is a small species 2–3 cm high, and the hydrocladial internodes and hydrothecae appear to be indistinguishable from *P. asymmetrica* from Pearson I. The less distinct intrathecal fold and more symmetrical marginal lobes of the Pearson I. specimens tends to bridge the gap between *P. asymmetrica* and *P. hertwigi*. Possibly all are geographical variants of the one species.

Although only 1 colony was collected, the species was a dominant member of the seafloor community of the deeper water. Many of the older colonies were almost completely invested by a growth of a pink coloured epizoic zoanthid, the weight of which bends the colonies over to touch the sand.

This is the fourth record of *P. asymmetrica*; other records are also from the Great Australian Bight.

*Plumularia flexuosa* Bale, 1894: 115, pl. 5, figs. 6–10. Mulder & Trebilcock, 1916: 78 (discussion), Stechow, 1925: 246. Black-

burn, 1938: 315. Shepherd & Watson, 1970: 140.

*Plumularia pulchella* (Bale). Totton, 1930: 221, fig. 58.

**Records:** R, 27–45 m, on *Mychoden carnosus*.  
**Material:** A few infertile stems. Stems to 3 mm long; internodes long, flexuous, nodes transverse, 3 cauline nematothecae on an internode—2 axillar, and 1 proximal, exactly as described and figured by Bale (1894) for *P. flexuosa*.

**Remarks:** I have examined a series of microslides of *P. pulchella* Bale, 1882, and *P. flexuosa* in the Bale collection of the NMV. The stems of *P. pulchella* are robust, with several transverse cauline internodal septa, but have no cauline nematothecae. Hydrocladia and hydrothecae are identical in both species.

The gonotheca of *P. pulchella* is globular, with an oblique aperture, and a row of large internal submarginal teeth. In *P. flexuosa*, the gonotheca is elongate, twice as long as wide, and there are no submarginal teeth.

Although Bale (1894) clearly distinguished between the two species, Totton (1930) united them in *P. pulchella* on the grounds that "*P. flexuosa* . . . appears to fall well within the range of variation of this species" (i.e. *P. pulchella*) as the stems of some of his material were "fine and flexuous, while others were stout and straight". His synonymy has since been followed by Ralph (1961b) and Millard (1957).

Stem thickness and the presence or absence of cauline nematothecae are frequently unreliable specific criteria among the Plumulariinae, but taking into account the difference between the gonothecae (unless sexual dimorphism can be demonstrated) it seems best, following Blackburn (1938), to regard the two as distinct species.

Although associated with a range of algal substrates in other localities (J.W. unpublished) *P. flexuosa* occurred only associated with a delicate species of the red algal genus *Mychodea* (usually placed under *M. carnosus* in herbaria). The growth habit of the hydroid is unusual and was first noticed by Dr. H. B. S. Womersley and G. T. Kraft who supplied the following description: "The hydroid infests the *Mychodea* fronds from a very early stage, with fronds less than 1 cm high showing abundant hydroid stolons. The stolons penetrate lengthwise through the outer medulla of the alga, branching occasionally laterally, and producing at regular intervals through the cortex the erect,

polyp-bearing axes. As the *Mychodea* plant develops, proliferation of the hydroid stolons in the lower axis breaks down the algal tissue until the *Mychodea* is attached to the substrate only by a dense web of hydroid. This may be 2–8 mm thick and a centimetre or more long, supporting a much branched *Mychodea* plant over 20 cm long and infested throughout with the hydroid."

**Plumularia spinulosa** Bale, 1882: 42, pl. 15, fig. 8; 1884: 139, pl. 12, figs. 11, 12; 1888: 783. Stechow, 1925: 246. Millard, 1962: 301.

FIGS. 54, 55

*Plumularia spinulosa* var. *spinulosa* Ralph, 1961: 37, fig. 4. Shepherd & Watson, 1970: 140.

**Records:** R, 18–30 m, on *Laurencia elata*, *Plocamilum angustum*, *Thyrosocyphus marginatus* and *Aglaophenia plumosa*.

**Material:** Abundant infertile colonies of a few stems each. *Hydrorhiza* wide and flat with transverse dark markings. Stems to 3 mm long, internodes of variable length, 0.17–0.21 mm, width at node 0.02–0.04 mm. *Hydrocladia* arising near middle of short internodes, distally on long internodes. *Hydrothecae* 0.16–0.18 mm deep, abcauline wall strongly convex. Terminal hydrocladial spines well developed, varying from long and sharply pointed to blunt and barely protruding past hydrothecal margin. *Nematothecae* identical with typical form, but pedicels of the median hydrocladial nematothecae show considerable variation in thickness.

**Remarks:** The Pearson I. material shows a wide variation in size of the stem internodes, position of the hydrocladial apophyses, width of the nematothecal pedicels and length of the terminal spine. Those hydrothecae with more pronounced terminal spines are always larger and more robust in appearance than those with the shorter spines. Because of the variability of length of the terminal spine, Millard (1961) no longer recognizes the distinction between the varieties of *P. spinulosa* (i.e. var. *typica* Stechow, 1923 — var. *spinulosa* Ralph, 1961b, and var. *obtusata* Stechow, 1923). The present material supports her view.

No correlation was evident between stem type, substrate, or environmental conditions.

**Plumularia goldsteini** Bale, 1882: 41, pl. 15, fig. 7; 1884: 137, pl. 11, fig. 9.

**Records:** R, 30 m, on *Delisea pulchra*.

**Material:** A few infertile stems to 3 mm long.  
**Remarks:** The specimens conform exactly to the description of *P. goldsteini* by Bale.

A new record for S. Aust. (Other locality—Vic.)

**Plumularia obliqua** (Johnston, 1847). Bale, 1884: 138, pl. 12, figs. 1–3, Blackburn, 1942: 108.

*Laomedea obliqua* Johnston, 1847: 106, pl. 28, fig. 1.

*Records:* R, 20 m, on *Metanastophora flabellata*; S, 30 m, on *Sargassum* sp.

*Material:* A few delicate infertile stems to 4 mm long.

*Remarks:* The material conforms to descriptions of *P. obliqua* by Bale.

**Plumularia australis** Kirchenpauer, 1876. Bale, 1884: 143, pl. 12, figs. 6, 7, pl. 19, figs. 43, 44.

*Plumularia obliqua* var. *australis* Kirchenpauer, 1876: 49, pl. 6, fig. 10.

*Records:* S, 14 m, on the seagrass *Posidonia australis*.

*Material:* Luxuriant infertile colonies. Stems to 4 mm long, arising from a broad flat hydro-rhiza with transverse dark markings.

*Remarks:* The Pearson I. material compares with Bale's (1884) description of *P. australis*. The median nematothecae are, however, not as deeply excavated on the adcauline side nor as closely adpressed to the hydrocladium as in his figures. The axillar monothalamic nematothecae are absent from many stems.

**Plumularia epibracteolosa** n.sp.

FIGS. 56–60

*Type Material and Records:* Holotype, NMV G2046, microslide; G2101 preserved material, remainder of holotype colony; paratypes, G2047, G2048, G2049, G2050, G2051; SAM H37, microslides; all material—R, 50 m, on *Sargassum bracteolosum*.

*Description from holotype and paratypes:* *Hydro-rhiza* flat, reticular, 0.25 mm wide, with pegged borders, radiating from a digitate stolonic plate. *Stems* monosiphonic, to 2 cm long, perisarc thick; proximal internodes roughly undulated, without hydrocladia, nodes indistinct, following internodes hydrocladate, 0.36–0.45 mm long, 0.14–0.15 mm in diam., proximal and distal nodes oblique, V-shaped. *Perisarc* smooth externally, internally ridged by 3–4 internodal septa—1 above, and 1 below node, 1–2 in middle of internode, ridges fewer in younger parts of stem; either absent or incipiently developed in younger stems. *Hydro-cladia* alternate, 1 on each stem internode, in 1 plane, arising from a short distal apophysis of

the stem. One or two hydrothecae on hydro-cladium: hydrocladium beginning with 1, occasionally 2, short proximal athecate internodes 0.09–0.12 mm long, proximal node transverse, distal node slightly oblique; thecate internode 0.23–0.27 mm long, socketted into the athecate internode by a slender joint; hydrocladia below internode straight, blunt end not projecting beyond thecal margin; 4–5 oblique internodal septa dividing internode into segments, 2 below median nematotheca, sloping opposite ways, and 2 below the hydrotheca. When 2 hydrothecae are present on hydrocladium, they are separated by 2 athecate internodes, the first short, 0.07–0.09 mm long, with transverse joints, the next 0.12–0.16 mm long, with a socketted proximal and an oblique distal joint and 1 median nematotheca; both internodes without septa. *Hydrothecae* wide, shallow, cup-shaped, 0.15–0.17 mm deep, with a flat base, set on the 3 strong convexities of the hydro-cladium; abcauline wall straight, 0.11–0.13 mm long, thickened by a continuous flange of perisarc extending the entire length of the thecate internode; adcauline wall 0.10–0.11 mm long, slightly convex, adnate to hydrocladium only near base, the remainder joined to the hydro-cladium by a wedge of perisarc. *Margin* 0.14–0.19 mm in diam. (lateral view), situated, with a thickened outwardly rolled rim, the line of the margin curved down to meet the hydro-cladium, but the aperture truncated by a delicate transverse sheet of perisarc extending across the cup 0.05 mm above adcauline wall. *Nematothecae* all of similar shape and size, 0.06–0.09 mm long, bithalamic, distal cups shallow, entire, 0.03–0.04 mm in diam.; 2 cauline with slender bases, 1 in middle of stem internode, often missing, and 1 axillar; 3 on thecate hydrocladial internodes—1, median, base stout, cup slightly excavated on adcauline side, 2 laterals below the hydrotheca, bases stout, cups narrow, standing upright on hydro-cladium but not reaching top of transverse perisarcular web. One minute manilliform pore present on the shoulder of the hydrocladial apophysis. *Hydranth* with approx. 24 tentacles. *Gonothecae* large, 1–2 on lower stem on a short pedicel arising from an old hydrocladial apophysis, elongate oval, 1.38–1.8 mm long (including pedicel) maximum diam. 0.72–1.02 mm (at two-thirds the distance up from pedicel) perisarc delicate, smooth, or slightly undulated, no operculum, top closed by a thin convex membrane. Gonophores male, mature, surrounded by a thin blastostyle. *Colour*—stems bright yellow, gonothecae orange.

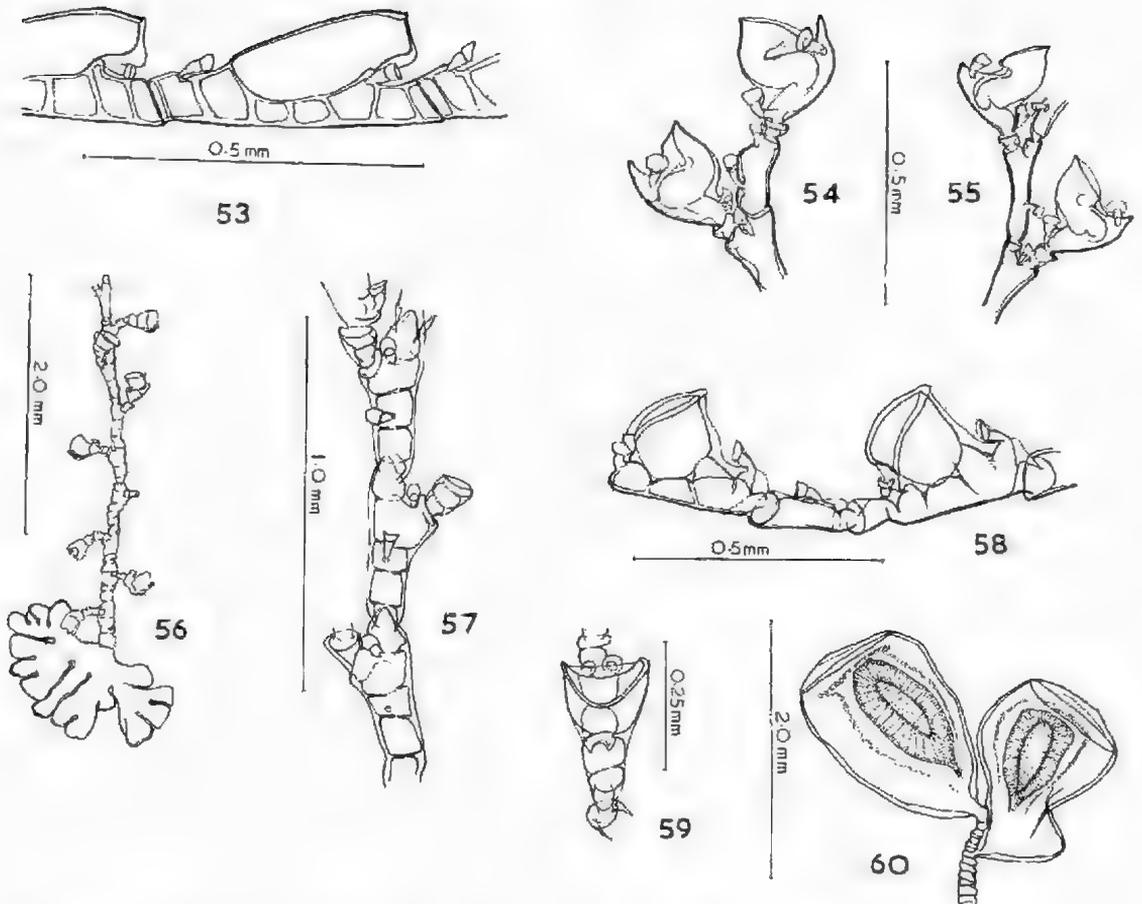


Fig. 53. *Plumularia asymmetrica* Bal. Part of hydrocladium with two hydrothecae.  
 Figs. 54, 55. *Plumularia spinulosa* Bale. Fig. 54.—Part of a stem with larger hydrothecae and prominent terminal spines. Fig. 55.—Stem with smaller hydrothecae and blunt spines.  
 Figs. 56–60. *Plumularia epibracteolosa* n.sp. Fig. 56.—Whole stem with stolonial plate, Fig. 57.—Part of stem showing internodal septa and cauline nematocyst. Fig. 58.—Hydrocladium with two hydrothecae. Fig. 59.—Hydrotheca, dorsal view. (Figs. 56–59 drawn from holotype). Fig. 60.—Group of two male gonophores, from paratype.

*Remarks:* *P. epibracteolosa* is closely allied to the *P. setaceoides* group endemic to Australia and New Zealand. It shows some affinities with *P. excavata* Mulder & Trebilcock, and with *P. corrugatissima* Mulder & Trebilcock, but is easily distinguished from both these species by the structure of the hydrotheca and from *P. corrugatissima* by its greater overall size. Stolonial reproduction, common among some species of the Plumulariinae, has been discussed by Billard (1904) and Gravier (1971) but has not previously been reported among the Australian members of the subfamily. Many stems of *P. epibracteolosa* show various stages of distal elongation into a tendril which flattens out laterally into an embryonic stolonial plate. This plate adheres to the edge of a nearby algal

frond, sending out hydrorhizal filaments to form a new colony, the parent stem finally breaking away. In one case (holotype microslide) a stem has re-attached itself by the distal end to the same stolonial plate, forming a closed loop.

*P. epibracteolosa* exhibits extreme variation in development of the cauline internodal septa. The older stems, distinguished by the thicker perisarc, are heavily internally ridged, while the younger stems have either none at all or show a gradational development between the two extremes. The presence of internodal septa has often been accepted as a diagnostic character within the Plumulariinae, but the variability of *P. epibracteolosa* demonstrates the unreliability of this criterion.

The fronds of the substrate alga *Sargassum bracteolosum* are seasonal, growing from September to February (Shepherd & Womersley 1970). *P. epibracteolosa* must therefore spread very rapidly in order to form fertile colonies within a very short period. This may account for the unusual propagation of the colonies by both normal growth and stolonial reproduction, the latter method ensuring spread of the colonies from one part of an alga to another.

Although the alga, *S. bracteolosum*, is also very common at West I. (Shepherd & Womersley 1970), *P. epibracteolosa* was never recorded from this locality. At Pearson I., the alga was restricted to a limestone seafloor in moderate surge at a depth of 50 m, at a distance of 400 m offshore. The colonies of *P. epibracteolosa* occur only on the fronds, whereas *Amphibesia minuta* var. *pumiloides* Bale exclusively epiphytises the harder stems of the alga.

***Plumularia meretricia* n.sp.**

FIGS. 61-64

*Type Material and Records:* Holotype, NMV G2053, microslide; G2102, preserved material, remainder of holotype colony—R, 27-30 m, on sponge on vertical walls; paratypes, G2054, G2055, G2056, G2057, G2058, G2059, SAM H38, microslides; G2103, G2104, preserved material, remainder of paratype colonies—S, 18 m, on sponge on rock walls.

*Description from holotype and paratypes:* *Hydrorhiza* tubular. Stems monosiphonic, erect, straight, to 15 mm long; stem internodes 0.42-0.51 mm long, smooth, the proximal internode beginning with a transverse joint near base of stem, following internodes with an oblique proximal joint, often indistinct, and a strong distal joint, 0.06-0.09 mm in diam. *Hydrocladia* alternate, 1 on each internode, widely spaced, arising from a distal apophysis 0.05 mm long, and 0.08 mm in diam. at extremity of internode, with 1, occasionally 2 hydrothecae, and rarely, a secondary branch given off behind the first hydrotheca. Hydrocladium with either 1 long smooth proximal athecate internode 0.14-0.19 mm long, and 0.07 mm in diam., or alternatively, 2-3 short athecate internodes 0.05-0.12 mm long, with internally ridged perisarc. These are followed by a long thecate internode 0.30 mm long, entirely occupied by hydrotheca and an infrathecal chamber 0.10 mm long, terminating behind hydrothecal margin. *Hydrothecae* campanulate, 0.15 mm deep, at 40° to hydrocladial axis; adcauline

wall rounded in lateral view, almost entirely adnate and immersed in internode, abcauline wall straight, expanding, contiguous with line of upper wall of hydrocladium, very slightly constricted behind margin. *Margin* everted, 0.18 mm in diam., slightly sinuated, curving down and back to adcauline wall. *Nematothecae* bithalamic with slender bases and shallow distal cups partially cut away on the abcauline side, occasionally 1-2 halfway up stem internode on opposite side to hydrocladium, and 1 axillar; 3 present on thecate internode—1 median, 0.04-0.06 mm long, adpressed to the infrathecal chamber, and 2 laterals below hydrotheca, 0.03-0.04 mm long, distal cup entire. One very prominent monothalamic mamilliform pore; with 1, sometimes 2 orifices on short tubular necks projecting from the top of the stem apophysis. *Gonotheca* absent.

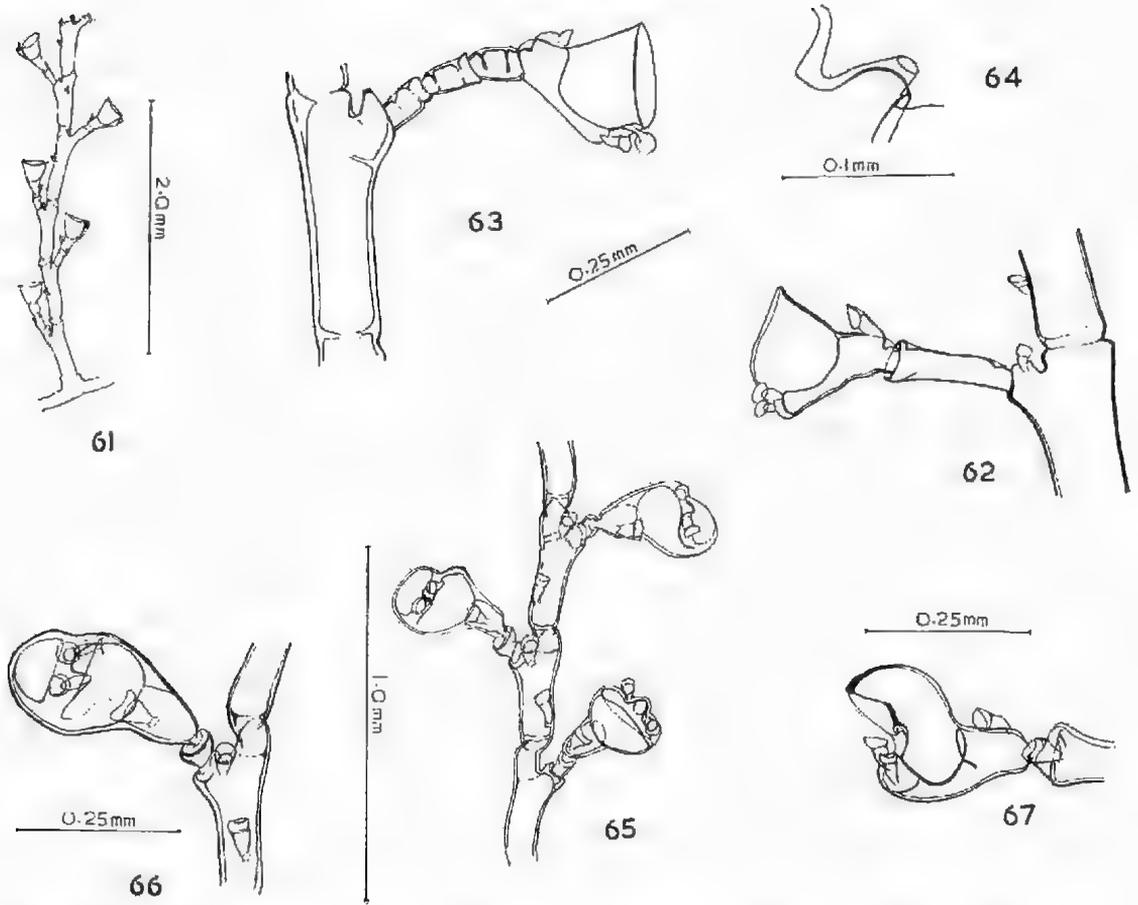
*Remarks:* *P. meretricia*, like *P. epibracteolosa*, shows considerable variability of features usually regarded as reliable specific criteria among the Plumulariinae. The younger stems have a smooth glassy appearance, with long stem and hydrocladial internodes, and also have cauline nematothecae. The stems seldom retain their cauline nematothecae after maturity, showing only scars where the nematothecae have dropped off. Since many of the younger stems show neither scars nor nematothecae, and in some cases, the axillar nematothecae have failed to develop as well, the presence or absence of these structures cannot be regarded as diagnostic of the species. The mamilliform pore is however, a constant feature of all the stems. The regenerated athecate hydrocladial internodes common in some stems, mark the site of repeated breakage and regrowth of the hydrocladium. In these cases, a short athecate internode is first added, followed by an embryonic hydrotheca and infrathecal chamber. Nematothecae bud off later as the hydrotheca nears maturity. The athecate internode at this stage is without internal perisarc ridges. These develop as the hydrocladium ages.

*P. meretricia* shows some relationship with *P. flexuosa* Bale and *P. hyalina* Bale, but it is much larger and more robust than either of these species.

***Plumularia togata* n.sp.**

FIGS 65-67

*Type Material and Records:* Holotype, NMV G2060, microslide—R, 33 m, on *Metagoniolithon charoides*; paratypes, G2061, G2062, G2063, G2064, G2065, G2066, SAM H40,



Figs. 61–64. *Plumularia meretricia* n.sp. From holotype. Fig. 61.—Whole stem. Fig. 62.—Part of stem with young hydrocladium and smooth athecate internode. Fig. 63.—Older hydrocladium with regenerated athecate internodes. Fig. 64.—Mamilliform axillar nematotheca, enlarged. Figs. 65–67. *Plumularia togata* n.sp. From holotype. Fig. 65.—Part of stem. Fig. 66.—Hydrocladium and hydrotheca, lateral view. Fig. 67.—Hydrotheca, anterior view, showing aperture.

microslides, G2105 preserved material; remainder of paratype colonies—S, 30 m, on *Metagoniolithon charoides*.

**Description.** *from holotype and paratypes:* *Hydrorhiza* broad and flat with transverse dark markings. *Stems* short, to 4 mm long, monosiphonic, flexuous; 1–3 short proximal internodes with transverse nodes, following internodes hydrocladial, longer, 0.03 mm long, 0.08 mm maximum diam., smooth, proximal node transverse, distal node V-shaped, a strong transverse septum above the node. *Hydrocladia* short, alternate, 1 on each internode, arising from a distal apophysis, with 1 very short proximal athecate internode 0.03–0.04 mm long, followed by a longer athecate internode 0.19–0.21 mm long, curving very slightly below

base of hydrotheca. *Hydrothecae* subglobular, 0.20–0.22 mm high from base to crest (lateral view), 0.16–0.18 mm wide (front view), abcauline wall rising perpendicular to hydrocladial axis, then curving over and back to thecal margin; adcauline wall rounded, set well into hydrocladium, free part rising in a sinuous curve to the margin. Infracal chamber 0.11–0.13 mm long, maximum width 0.10–0.12 mm, the proximal joint slenderly pointed and socketted into the athecate internode. *Nematothecae* bithalamic, with slender bases, terminal cups wide, a little cut away on adcauline side; 2 cauline—1 axillar, 0.07 mm long, and 1, same as axillar, one third distance up internode, on opposite side to hydrocladium; 3 hydrocladial nematothecae, 1 median, 0.05 mm long,

addressed to the infrathecal chamber, 2, slightly smaller, standing upright on a projection of the hydrocladium below hydrotheca, barely reaching thecal margin; and separated at the base by a rounded prominence of the hydrocladium. *Gonotheca* absent.

*Remarks:* *P. togata* is a very small species closely allied to *P. hyalina* Bale, from which it may be distinguished by its smaller size, the 2 cauline nematothecae, greater curvature of the abcauline hydrothecal wall and the distinctively hooded appearance of the margin.

***Plumularia australiensis* n.sp.**

FIGS. 68-71

*Type Material and Records:* Holotype, NMV G2067; microslide, G2106 preserved material, remainder of holotype colony—R. 20-25 m on sponge; paratypes, G2068, G2069, G2070, G2071, SAM H41, microslides—R. 20-25 m, on sponge.

*Description from holotype and paratypes:* *Hydrorhiza* tubular, embedded in surface of sponge. *Stem* monosiphonic, flexuous, to 15 mm long, perisarc thick, occasionally heavily thickened at point of regeneration of a new stem from the broken butt of an old stem. Internodes variable in length, 0.06-1.5 mm, nodes transverse, distinct, width at node 0.14-0.25 mm, proximal 2-4 internodes without hydrocladia. Internodes with 6-12 cauline nematothecae scattered in 2 vertical rows in the same plane as hydrocladia; axillar nematothecae absent, but 1 nematotheca usually present on internode just above hydrocladial apophysis; older internodes with fewer nematothecae. *Hydrocladia* to 2 mm long, alternate to subopposite (exceptionally, lower hydrocladia may be opposite) directed upwards in 1 plane from a short apophysis of the stem; 1-3 hydrocladia on internode, arising near top, middle, or base of internode, but this is variable; shorter internodes have fewer hydrocladia. Hydrocladial internodes alternately athecate and thecate, the proximal athecate internode with 1, occasionally 2 nematothecae; following athecate internodes 0.27-0.32 mm long (measured along base of hydrocladium) with a transverse proximal, and strongly oblique distal joint, and 2 nematothecae. Thecate internodes 0.18-0.20 mm long, 0.06-0.08 mm in diam. at transverse (distal) node, a maximum of 7 thecate internodes on a hydrocladium, and frequently, a transverse internodal septum below pedicel of lateral nematotheca. Thecate internode with 4 nematothecae—1

median, subhydrothecal, 2 lateral, and 1 suprathecal. *Hydrothecae* asymmetrical in lateral view, wider than deep, scoop-shaped, set at about 45° to the hydrocladial axis, abcauline wall straight or very slightly concave and a little thickened, 0.16-0.20 mm long; adcauline wall convex, 0.13-0.19 mm long, the shallow curve of the wall contiguous with the base of the hydrotheca. *Margin* 0.25-0.31 mm in diam., entire, delicate, at an angle of 30° to the hydrocladial axis. *Nematothecae* bithalamic, all of similar shape and size, the cauline nematothecae with moderately slender bases, cups shallow, adcauline wall excavated; 2 median nematothecae on athecate internode, similar to cauline nematothecae, 0.07-0.08 mm long, but with more robust bases, closely addressed to internode, the proximal nematothecae frequently somewhat smaller than the distal. Thecate internode with 1 median subhydrothecal nematotheca, cup deeply excavated, pressed close to base of thecal wall; 2 laterals with shallow open cups 0.05-0.06 mm in diam., slightly cut away on adcauline side, the edge of cup not reaching thecal margin, base slender, seated on a pedicel 0.05-0.06 mm long, arising at the junction of the adcauline wall with internode; 1 small leaf shaped monothalamic suprathecal nematotheca, set deep in sinus behind hydrotheca, the aperture facing inwards. *Gonothecae* present, male and female arising beside median subhydrothecal nematotheca, usually in proximal region of hydrocladium, sexes usually separate, occasionally both sexes present on same hydrocladium. Female gonotheca pear shaped, 0.18-0.25 mm long (excluding pedicel) 0.42-0.55 mm maximum width, with 1-2 nematothecae in the basal region similar to the laterals, but larger. Operculum a thin flap of same size as top of gonotheca. Male gonotheca smaller than female, slipper-shaped, 0.13-0.16 mm wide, with 1 proximal nematotheca, a little smaller than those on female gonotheca. No operculum. Pedicel a small round segment 0.07 mm in diam. in both sexes.

*Remarks:* *P. australiensis* is closely related to *P. hedoti* Billard from the Indo-pacific and *P. wasini* Jarvis from South and East Africa, but is distinguished from both these species by the shallow scoop-shaped hydrothecae. It also shows some affinities with some Indo-Pacific members of the genus *Halopteris*, e.g. *H. buski* (Bale) (a deeper water species common on the southern Australian coastline, also found at Pearson I.), and with *H. polymorpha* (Billard) in size and shape of the gonothecae and nema-

tothecae, general aspect of the colonies, and the tendency toward opposite branching in the basal stem region.

**Aglaophenia plumosa** Bale, 1882: 37, pl. 14, fig. 6; 1884: 153, pl. 14, fig. 5, pl. 17, fig. 12. Blackburn, 1942: 110. Stechow, 1925: 260. Ralph, 1961b: 65, fig. 9. Shepherd & Watson, 1970: 140.

*Records:* R, 24–33 m, on ascidians, hryozoa, and *Carpopeltis phyllophora*.

*Material:* Sparse infertile colonies. *Stems* to 1 cm long.

*Remarks:* The stems are short, with closely set hydrocladia and robust hydrothecae, features characteristic in this species, of an ocean environment.

**Thecocarpus divaricatus** (Busk) var. *maccoyi* (Bale, 1884: 162, pl. 15, fig. 7, pl. 17, fig. 7); 1915: 312, pl. 1.

*Aglaophenia maccoyi* Bale, 1882: 36, pl. 14, fig. 2. Blackburn, 1942: 110.

*Thecocarpus divaricatus* (Busk), Shepherd & Watson, 1970: 140.

*Records:* R, 23–45 m; S, 4–12 m, on *Metagoniolithon charoïdes*, *Plocamium carillaginum*, *Acrocarpia paniculata* and *Zonaria spiralis*.

*Material:* Luxuriant fertile colonies. *Stems* short, to 4 cm long, given off in groups from a winding hydrorhiza. Proximal region of stem without hydrocladia, lightly fascicled, some of the supplementary tubes running up the main stem for a short distance then branching off. *Hydrocladia* 4 mm long. *Hydrothecae* close-set at 45° to hydrocladial axis, marginal teeth deeply cut, the second anterior pair outwardly bent, the unpaired anterior tooth well developed, the hatchet shape becoming more pronounced distally along the branch. *Median nematotheca* variable in length, just overtopping margin in proximal region of hydrocladium, increasing to twice the height of hydrotheca distally, standing well out from the margin, the terminal aperture at the same time broadening out into 2 lobes. *Corbulae* immature, with 4–11 pairs of gonohydrocladia; immature gonophores in corbulae with more than 10 leaflets. *Colour*—variable, light to dark brown.

**Thecocarpus divaricatus** (Busk) var. *briggsi* Bale, 1926: 22, fig. 5.

*Aglaophenia divaricata* (Busk), Bale, 1884: 162, pl. 15, fig. 8, pl. 17, fig. 7.

*Aglaophenia divaricata* var. *neanthocarpa?* Bale, 1915: 312.

*Records:* R, 24–33; S, 18 m, on fragments of red algae and *Caulerpa simpliciuscula*; Stn. F, 65 m, on *Symplectoscyphus subdichotomus*.

*Material:* A few infertile stems in each colony. *Stems* to 1.5 cm long, unbranched, monosiphonic, given off singly from a winding hydrorhiza. Hydrocladia flexuous, distant, each internode with 2 distinct septa. *Hydrothecae* with 4 pairs of marginal teeth, similar in shape and size, the median anterior tooth not well developed. *Median nematotheca* slightly longer than hydrotheca, following curve of the abcauline wall, becoming erect just behind margin, terminal orifice round, in some cases broadening into lateral lobes; cauline nematothecae larger than laterals, bent around stem, orifice facing posteriorly. *Colour*—brown.

*Remarks:* This is the first record of the var. *briggsi* from S. Aust. (Other locality: Port Jackson, N.S.W.).

**Thecocarpus divaricatus** (Busk) var. *cystifera* Bale, 1915: 314.

FIG. 72

*Records:* R, 24–33 m, S, 24 m, epilithic on vertical rock faces.

*Material:* Abundant infertile colonies. Colonies of 1–3 stems to 10 cm high, growing from a small common fibrous rootstock. *Stems* thick, woody, brittle, lightly fascicled, the polysiphonic tubes running up the main stem and branching out alternately in one plane, giving the colony a distinct "front and back" aspect. Proximal region of stem bare, showing scars where branches and hydrocladia have dropped off. *Hydrocladia* to 13 mm long. *Hydrothecae* set at an angle of 45° to hydrocladial axis; marginal teeth of similar size, evenly spaced, the sinus between often wide and shallow. *Median nematotheca* following curve of the abcauline wall, terminating just below margin, terminal orifice round; cauline nematothecae large, egg-shaped. *Colour*—light brown.

*Remarks:* Bale (1915) described, but did not figure the variety *cystifera*, distinguishing it from other varieties of *T. divaricatus* only on the presence of the enlarged cauline nematothecae.

*Remarks on the varieties of T. divaricatus:*

It is of interest that the 3 varieties of this species, recognized by Bale, are recorded for the first time from one locality, *T. maccoyi*

has previously been reported from various localities along the Victorian coastline (Bale 1884) and from South Australia (Blackburn 1942, Shepherd & Watson 1970). *T. cystifera* has been recorded only from South Australia (Bale 1915) and *T. briggsi* only from New South Wales (Bale 1926). The only information hitherto available on the macrostructures of the hydrocaulus is given by Bale (1884) who described the typical form as having "numerous divergent branches and very dark colour" and the var. *maccoyi* as a "dwarf form". (The larger "typical" form, i.e. *A. divaricata* Busk, a very common and distinctive species of the south-eastern Australian coastline, was not found at Pearson I, despite careful search). The distinction between the varieties has therefore largely rested on microstructures alone.

Although some intergradation in structure does exist between the varieties, the material from Pearson I. now enables a clear distinction to be made in both micro- and macro-structures, as well as environmental preferences. *T. maccoyi* and *T. briggsi*, because of their similarity in size and overlap of substrate preferences, are difficult to distinguish in the field, but they are easily separated on micro-structures: *T. cystifera* although unmistakable in size and growth habit, has hydrothecae almost identical with those of *T. briggsi*. *T. maccoyi* was the only variety fertile at the time of collection. The gradation in micro- and macro-structures, habit, and apparent difference in fertile season of the varieties, suggests incipient speciation within the *T. divaricatus* group. Distinguishing features between the varieties from Pearson I. are tabulated below.

	<i>T. maccoyi</i>	<i>T. briggsi</i>	<i>T. cystifera</i>
Stem length	medium, 4 cm	small, 1.5 cm	large, 10 cm
Colony	lightly fasciated, branched	unfasciated, unbranched	fasciated, branched in 1 plane
Mesial nematotheca	twice length of hydrotheca, orifice lobed	to hydrothecal margin, orifice round to lobed	to hydrothecal margin, orifice round
Cauline nematotheca	normal size, shape	normal size, shape, facing posteriorly	large, ovate
Marginal teeth	sharp, deep	sharp, deep	wide, shallow
Habit	epiphytic	epiphytic-epizoic	epilithic

#### *Lyncarpus mulderi* (Bartlett, 1907).

FIG. 73

*Aglaophenia mulderi* Bartlett, 1907: 66. Mulder & Trebilcock, 1916: 73, pl. 10, fig. 3.

*Records:* Among algae; no other data recorded.

*Material:* A fragment 1 cm long, the distal end of a fertile stem. The specimen conforms to descriptions of Bartlett and Mulder & Trebilcock. *Gonosome* comprising 2 gonophores—1 male and 1 female, in an open corbula arising from a primary hydrocladium. Primary hydrocladium with thecate proximal internode, followed by a swollen internode bearing 3 nematocladia and gonophores. Nematocladia 0.75–0.84 mm long (but may be broken) each bearing a single row of nematothecae. Gonothecae round, laterally compressed; female, 1.35 mm in diam., slightly larger than male, packed with mature ova, blastostyle almost filling gonothecal cavity; male gonophore surrounded by a blastostyle of the same shape, but of smaller size than the female.

*Remarks:* This is the first record of a species referable to the genus *Lyncarpus* from southern Australian waters. As earlier descriptions were derived from fragmentary infertile material, it was assumed, in the absence of the gonosome, to belong to the closely related genus *Aglaophenia*, common in southern Australia. This is the third record of this rare but distinctive species, and the first record for S. Aust. (Other locality—Bream Creek, Vic.).

*Halicornopsis elegans* (Lamarck, 1816). Bale, 1914a: 56; 1915: 303. Briggs, 1914: 309, Blackburn, 1942: 107. Shepherd & Watson, 1970: 140.

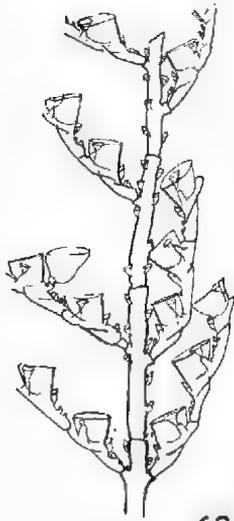
*Plumularia elegans* Lamarck, 1816: 129.

*Halicornopsis avicularis* Bale, 1882: 26, pl. 13, fig. 3; 1884: 185, pl. 10, figs. 1, 2, pl. 19, fig. 32.

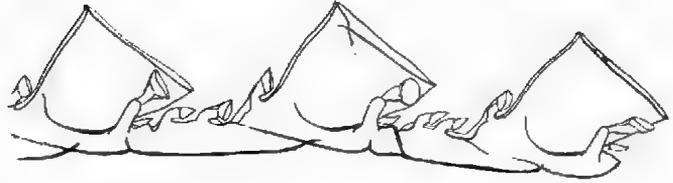
*Records:* R, 33 m, epilithic, and on bryozoa and red algae.

*Material:* One small infertile colony. *Stems* to 3 cm long, branched.

*Remarks:* The colonies were comparatively small and the individual stems short for the species.



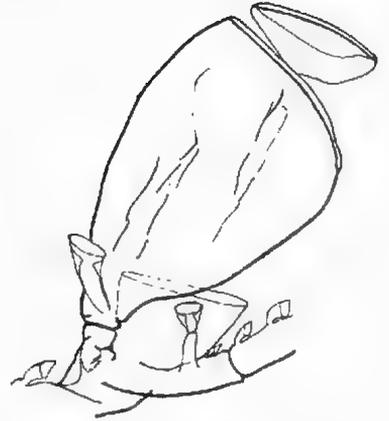
68



69



70

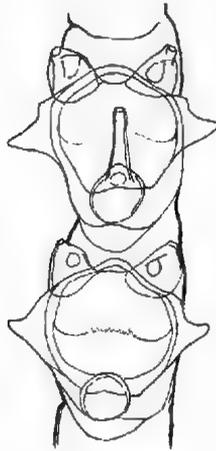


71



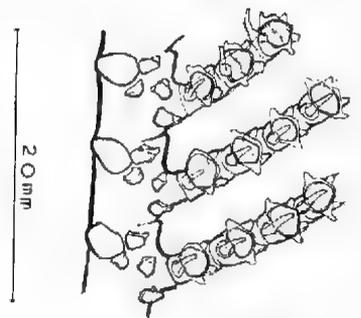
72

0.5mm

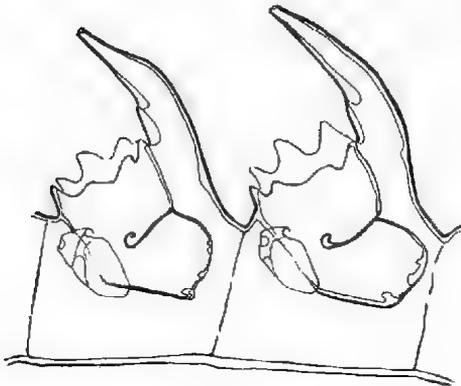


75

0.25mm

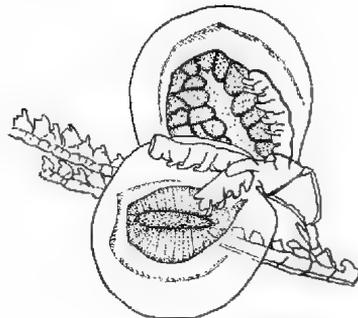


74



76

0.5mm



73

2.0mm

***Halicornaria longirostris*** (Kirchenpauer, 1872).

Bale, 1884: 181, pl. 13, fig. 7, pl. 16, fig. 3, pl. 19, fig. 30. Shepherd & Watson, 1970: 140.

*Aglaophenia longirostris* Kirchenpauer, 1872: 28, pl. 1, fig. 19, pl. 5, fig. 20.

*Records:* R, 18–33 m, epilithic on rock walls, on *Herdmania momus*, red algae, and bryozoa.

*Material:* Abundant infertile colonies. *Stems* to 7 cm long, with 1–2 proximal branches. *Colour*—pale straw colour.

*Remarks:* The colonies fall into 2 groups—those with long stems, and those with short stems. The larger colonies, comprising clusters of longer stems (up to 7 cm) were either epilithic or epizoid, whereas the shorter stems (up to 3 cm) growing singly, were epiphytic on algae. There is no difference in micro-structures between these two ecologically distinct stem types.

***Halicornaria prolifera*** Bale, 1882: 34, pl. 14, fig. 5; 1884: 183, pl. 14, fig. 1, pl. 16, fig. 10. Ritchie, 1911: 858, pl. 85, figs. 2, 3.

*Records:* R, 30 m, epilithic.

*Material:* One infertile unbranched colony. *Stem* 8 cm high. *Hydrocladia* 0.7 mm long, given off at an acute angle to the stem. Anterior and posterior cauline nematothecae with 3, sometimes 4 orifices; median hydrocladial nematotheca extending just below thecal margin. Marginal teeth shallowly scalloped, the middle pair slightly everted.

*Remarks:* The specimen agrees in most respects with Bale's description of *H. prolifera*, except that the median nematothecae are a little shorter than those described by Bale, and all the cauline nematothecae have 3 orifices. The hydrothecal margin is circular in anterior view, similar to Ritchie's (1911) specimens. This is the first record of *H. prolifera* from S. Aust. (Other localities—N.S.W. and Vic.)

***Halicornaria aurea*** n.sp.

FIGS. 74–76

*Type Material and Records:* Holotype, NMV G2088, microslide; G2107, preserved

material, remainder of holotype colony—R, 33 m, epilithic on rock walls; paratypes, G2089, microslide, G2108, preserved material, remainder of colony—R, 33 m, epilithic; G2090, microslide, G2109, preserved material, remainder of colony—R, 27–30 m, epilithic on rock walls; SAM microslide.

*Description from holotype:* Colony 6 cm high, growing from a small fibrous rootstock. *Stem* monosiphonic, lower stem 1 mm in diam., athercate, divided into internodes, nodes transverse, proximal internodes with circular pits where cauline nematothecae have dropped off. First branch 2 cm above base, all branching thereafter dichotomous, at an angle of about 40°, the branches becoming somewhat convergent distally, then rebranching. Branching repeated 6–7 times, always in the one plane. Branch internodes short, 0.60–0.69 mm, divided by indistinct transverse nodes, diam. at node, 0.66–0.84 mm. *Hydrocladia* to 5 mm long, alternate, 2 on an internode, given off after first branching of main stem, standing out stiffly at an acute angle from the branch, giving the colony a decidedly "front and back" aspect. Hydrocladial internodes 0.28–0.31 mm long, nodes almost perpendicular to the axis, indistinct, no internodal septa. *Hydrothecae* squat, set at an angle of 50° to hydrocladium, 0.23–0.26 mm deep, filling internode; adcauline wall straight, fixed part 0.12–0.14 mm long, free part 0.03–0.05 mm long; abcauline wall 0.17–0.19 mm long, divided in the middle by a long intrathecal ridge projecting slightly forward more than half way across thecal cavity; base of hydrotheca flat, with a small knot of denticles on the adcauline side marking the hydro-pore. Margin 0.17–0.29 mm in diam., with 8 teeth—3 pairs of prominent bluntly pointed teeth, the middle pair the longest, outwardly bent, the anterior pair erect, the posterior pair slightly everted; 1 low posterior tooth, often obsolete, and 1 small anterior tooth below the median nematotheca. *Median nematothecae* almost twice the height of the hydrotheca, 0.28–0.40 mm long, 0.05–0.07 mm wide at

Figs. 68–71. *Plumularia australiensis* n.sp. Fig. 68.—Part of stem. Fig. 69.—Part of hydrocladium, enlarged. Fig. 70.—Male gonotheca. (Figs. 68–70 from holotype). Fig. 71.—Female gonotheca, from paratype.

Fig. 72. *Thecocarpus divaricatus* var. *cystifera*. Bale. Part of branch with hydrocladia removed to show cauline nematothecae.

Fig. 73. *Lytocarpus mulderi* (Bartlett). Open corbula with male and female gonophores.

Figs. 74–76. *Halicornaria aurea* n.sp. From holotype. Fig. 74.—Part of stem with hydrocladia on one side removed to show cauline nematothecae. Fig. 75.—Hydrothecae, anterior view. Fig. 76.—Hydrothecae, lateral view.

base, tapering distally and inclined forward, terminal aperture small, circular, lateral aperture distinct. *Lateral nematothecae* small, 0.11–0.13 mm long, saccate, not reaching thecal margin, 1 small terminal aperture on a short outwardly turned neck, and 1 lateral aperture facing inward towards the hydrotheca. *Gonotheca* absent. *Colour*—amber.

*Remarks:* The marginal thecal teeth exhibit the variations in length and shape characteristic of *Halicornaria*. The teeth are normally long, the middle tooth being the longest of the 3 on each side. The median nematothecae are all of nearly equal size, and show little tendency towards increase in length in the distal region of the hydrocladium.

*H. aurea* resembles 2 other southern Australian species of *Halicornaria*—*H. superba* Bale, and *H. baileyi* Bale. It differs from the former in minor micro-structures, the marginal thecal teeth of *H. superba* being sharper and narrower than those of *H. aurea*, the median nematotheca of *H. superba* is larger, and the lateral nematothecae have 1 lateral and 2 terminal apertures. In *H. aurea* the laterals have only 2 apertures, 1 facing inward and the other outward; as they are very small they are sometimes difficult to distinguish. In macro-structures, however, *H. aurea* is easily distinguished from

*H. superba*, whose stems are long, gracefully plumose, and yellow-green in colour. In size, growth habit, and colour, the colonies of *H. aurea* are indistinguishable from *H. baileyi*. They are however, quite different in micro-structures.

*H. aurea* is an abundant species on rock faces exposed to surge.

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# PEARSON ISLAND EXPEDITION 1969†-10. OPISTHOBRANCHS

BY ROBERT BURNS\*

## Summary

BURN, R. (1973). -Pearson Island Expedition 1969.-10. Opisthobranchs. *Trans. R. Soc. S. Aust.* 97(3), 201-205, 31 August, 1973.

Three species of opisthobranch molluscs from Pearson I., *Notarchus indicus* (Schweigger), *Aporodoris merria* Burn n.sp. and *Goniodoris meracula* Burn, and one species from nearby Flinders I., *Sagaminopteron ornatum* Tokioka & Baba, are new records for South Australia. Additional distributional data are given for *G. meracula* and *S. ornatum*.

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### Introduction

The opisthobranch molluscan fauna of South Australia is relatively poorly known, especially with regard to the naked or "nudibranch" species of the western coastline of the State. Thus it is not unexpected that any collection from this area should contain new species and new records.

Three species described in this paper were collected during the 1969 Pearson Island Expedition, organized by the Royal Society of South Australia and the South Australian Department of Fisheries and Fauna Conservation. The Pearson Islands are the small southern part of the Investigator Group at the eastern end of the Great Australian Bight. The largest island, Pearson I., is about 162 hectares in extent, but the others are much smaller; they lie 64 km southwest of Elliston.

The fourth species in this paper was collected during a stop-over by the Expedition at Flinders I., a large island that forms the northern part of the Investigator Group.

The specimens have been deposited in the National Museum of Victoria, Melbourne (NMV).

Order CEPHALASPIDEA  
Superfamily PHILINACEA  
Family GASTROPTERIDAE

*Sagaminopteron ornatum* Tokioka & Baba, 1964: 218. Bennett, 1966: pls. 1, 120b. Baba, 1970: 47.

FIGS. 1-2

*Material:* Flinders I., Jan. 1969; 2 specimens from 10 m on *Cystophora* on vertical rock face in fair surge (NMV, F27399).

The living animals were reported as "bright blue under water, parapodia edged with bright yellow". They are now colourless and 12 and 9 mm long, 6 and 5 mm broad. When alive, the larger animal was almost 25 mm long.

The one major difference between the Japanese type specimens and Australian material (Fig. 1) is the presence of a relatively large strong shell in the mantle cavity beneath the posterior caudal lobe of the body. The shell of the larger Flinders I. specimen (Fig. 2) is 2 mm long by 1.4 mm wide, and is white with a yellowish transparent protoconch, the interior of which is open. The shell of a Lord Howe I. specimen is 2.4 x 1.7 mm, one from Cockburn Sound, Western Australia, is 2.1 x 1.6 mm, and another from Heron I., Queensland, is almost 4 mm long.

It must be assumed that the shells of the Japanese types dissolved during fixation and preservation.

Though hitherto unrecorded, *Sagaminopteron ornatum* is a fairly common species in eastern and southern Australia. Specimens examined by the writer are:

1. Lord Howe I.—Middle Beach, Jan. 1959, R. R. Blackwood, 1 specimen (NMV, F20717).
2. Queensland.—Heron I., Capricorn Group, Aug. 1965, I. Bennett, 1 specimen, Humpty

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† Other accounts of the geomorphology and biology of the Pearson Islands are given in Volume 95, Part 3 (1971) of the Transactions, as well as in the present Part.

1. Keppel Group, Sept. 1969, *N. Coleman*, 1 specimen.
3. New South Wales.—Angourie, Aug. 1966, *A. A. Cameron*, 1 specimen. Minnie Waters, Jan. 1963, *G. Biddle*, 1 specimen. Bawley Point, near Ulladulla, Dec. 1963, *I. Bennett*, 3 specimens.
4. Victoria.—Bear Gully, Waratah Bay, April 1970, *I. Marrow*, 6 specimens.
5. South Australia.—Port Noarlunga, Feb. 1966, *R. Balfour*, 1 specimen (SAM, 14888). Anxious Bay, Dec. 1968, *T. Castle*, 1 specimen.
6. Western Australia.—West of Carnac I., Cockburn Sound, Feb. 1971, *B. R. Wilson & N. Coleman*, 4 specimens (WAM, 474-71).

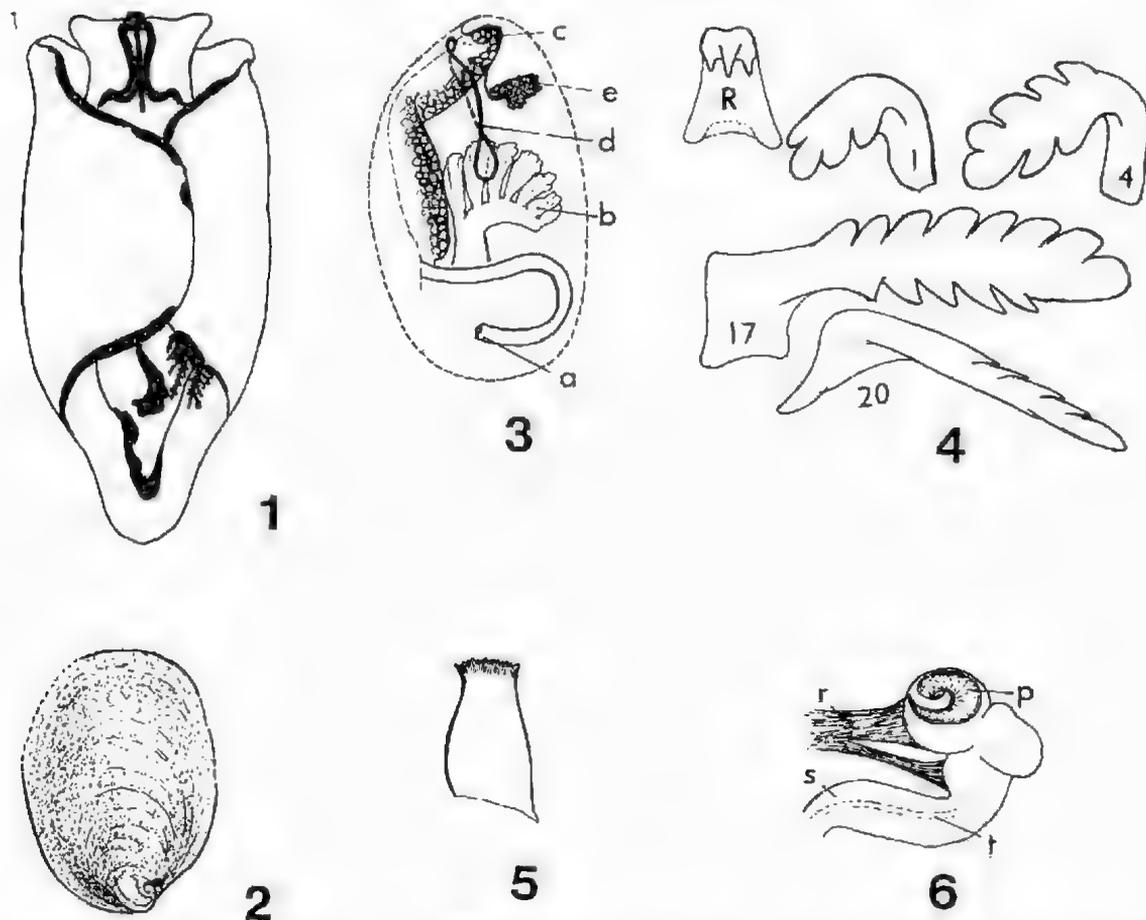
These specimens were collected from between the intertidal zone and 20 m depth, from beneath boulders, from brown algae, or from grey branching sponges. They have often been observed, in rock pools and deeper water, to swim with a rapid synchronous undulation of the parapodia.

Order ANASPIDEA  
Family APLYSIIDAE

*Notarchus indicus* Schweigger, 1820. Bergh, 1902: 349. Engel, 1936: 113. Eales, 1944: 12.

FIGS. 3-6

*Material:* Pearson I., Jan. 1969, 1 specimen from algae on horizontal faces at 26 m (NMV, F27401).



Figs. 1-2. *Sagaminopteron ornatum*. Fig. 1.—Dorsal view of a 20 mm long specimen from Port Noarlunga, S. Aust., from a sketch by Dr Helene M. Laws, Curator of Marine Invertebrates, South Australian Museum. Fig. 2.—Shell from larger Flinders I. specimen, dimensions 2 x 1.4 mm.

Figs. 3-6. *Notarchus indicus*. Fig. 3.—Diagram of mantle cavity and aperture (a—anus, b—gill, c—pigment gland, d—mantle aperture, e—opaline gland). Fig. 4.—Radular teeth. Fig. 5.—Jaw element. Fig. 6.—Male copulatory organ (p—penis, r—retractor muscles, s—sheath, t—seminal groove).

The colourless preserved specimen is 5 mm long, 3.5 mm wide and 3 mm high. The head and neck are invaginated into the smooth visceral hump. The 1 mm long mantle aperture (Fig. 3d), of the usual external shape, is placed well forward. The large mantle cavity, not yet pervious with the dorsal mantle aperture, contains a small lobulated gill (Fig. 3b), a long loop of the intestine terminating well behind the gill stem at the anus (Fig. 3a), a long curved granular pigment gland (Fig. 3c), and a small white opaline gland (Fig. 3e). No genital groove is apparent. Short stumpy rhinophores with deep lateral grooves project from the head, and a small rounded knob-like oral tentacle occurs either side of the mouth.

The jaw elements (Fig. 5) are narrowest just below the serrulate distal end. The hyaline radula (Fig. 4) is almost 2 mm long with 21 rows of 20.1.20 teeth. The rachidian tooth is slender with sharply pointed cusp and a short denticle each side. The lobulate first lateral tooth has one inner and two outer denticles, and the next six teeth have up to two inner and four outer denticles. The succeeding teeth have longer cusps with up to five inner and nine outer denticles at the third or fourth tooth from the margin. The marginal tooth has one inner denticle well back from the tip and about four incipient outer denticles.

The minute male copulatory organ (Fig. 6) agrees exactly with the figure for *Mauritius* specimens given by Engel (1936, p. 116, fig. 4) with the exception that the grooved smooth penis has not as many spiral turns.

*Discussion:* The descriptions by Bergh (1902) and Engel (1936) of specimens from Mauritius, plus that of a specimen from Zanzibar (Eales 1944), satisfactorily diagnose *Notarachus indicus*. The spiral unarmed penis justifies the identification of this very small Pearson I. specimen. The small number of lateral teeth (20), the marginals of which are not slender and smooth, does not agree with the above three descriptions where the lateral teeth number 43-45, 33 and 32 respectively and the marginals are long, slender and smooth. However, the Pearson I. specimen is probably a juvenile in which the radula has not attained the full complement of teeth nor the penis the full number of turns.

*Notarachus indicus* has a wide Indo-west Pacific tropical and subtropical distribution, and has been recorded from Sydney Harbour, New South Wales (Engel 1936, p. 119). It is a new record for South Australia.

Order DORIDACEA  
Tribe CRYPTOBRANCHIA  
Family DORIDIDAE

*Aporodoris merria* n.sp.

FIGS. 7-11

*Material:* Pearson I., Jan. 1969, 1 specimen (holotype) from red algae at 52 m (NMV, F27402).

The alcohol preserved specimen (Fig. 7) is dull orange-fawn in colour. It measures 8 mm long, 5 mm broad and 3.5 mm high. The notum is covered with various sized tubercles (Fig. 8b), the largest of which are somewhat flatly clavate and up to 0.6 mm in diam. All tubercles have projecting angles both laterally and dorsally. Bundles of spicules strengthen each angle. The rhinophoral cavities are protected by four tubercles; a large one at each side, a small one in front and a small one behind each cavity (Fig. 8a). The branchial cavity has nine or ten lappet-like tubercles of various sizes along the margin (Fig. 8c); these tubercles are up to 1 mm long and 0.8 mm wide and have small projecting angles or points on the outer or dorsal face only.

The thick fleshy hyponotum is narrower than the foot (Fig. 9), from which it is separated laterally by little more than the foot margin. The genital aperture opens in the middle width of the hyponotum. The lamellate rhinophores are completely withdrawn. There are five multipinnate gills. The head (Fig. 10) lies within a deep concavity of the anterior hyponotum, with a grooved ridge-like oral tentacle at each side of the mouth. The broad foot is anteriorly truncate with the upper lamina leading into the head cavity where it is notched. The tail is thin and broadly rounded.

The thick labial cuticle is smooth. The radula is 1.7 mm long and 1.4 mm wide. It has 40 rows of 61 teeth per half row. All teeth are hook-shaped and bear a single outer denticle beside the cusp, except for the two marginals which have 10 or more comb-like denticles (Fig. 11).

The brittle genital organs could not be examined satisfactorily. The whitish ampulla is long and winding. The yellow vas deferens is short and twisting, and terminates in an unarmed penial sheath without penial papilla.

*Discussion:* The angular, flattened, clavate tubercles of the notum and the single prominent outer denticle of the lateral radular teeth separate *A. merria* from other species of *Aporodoris* Ihering, 1886. The unarmed penis of the new species is similar to that of *Thor-*

*disa* Bergh, 1877, but in that genus the lateral teeth are smooth. The radula is also similar to that of *Taringa* Marcus, 1955, but the unarmed penis of *A. merria* contrasts with the cuticularized penial papilla and spines of the former genus.

The concavity of the head and the large lappet-like tubercles of the branchial margin are further distinguishing characters. The relatively flat underside of the specimen, with the head parts recessed, suggests that *A. merria* has unusual feeding preferences.

The specific name is derived from "merri", an Australian Aboriginal word meaning stones, in allusion to the notal tubercles.

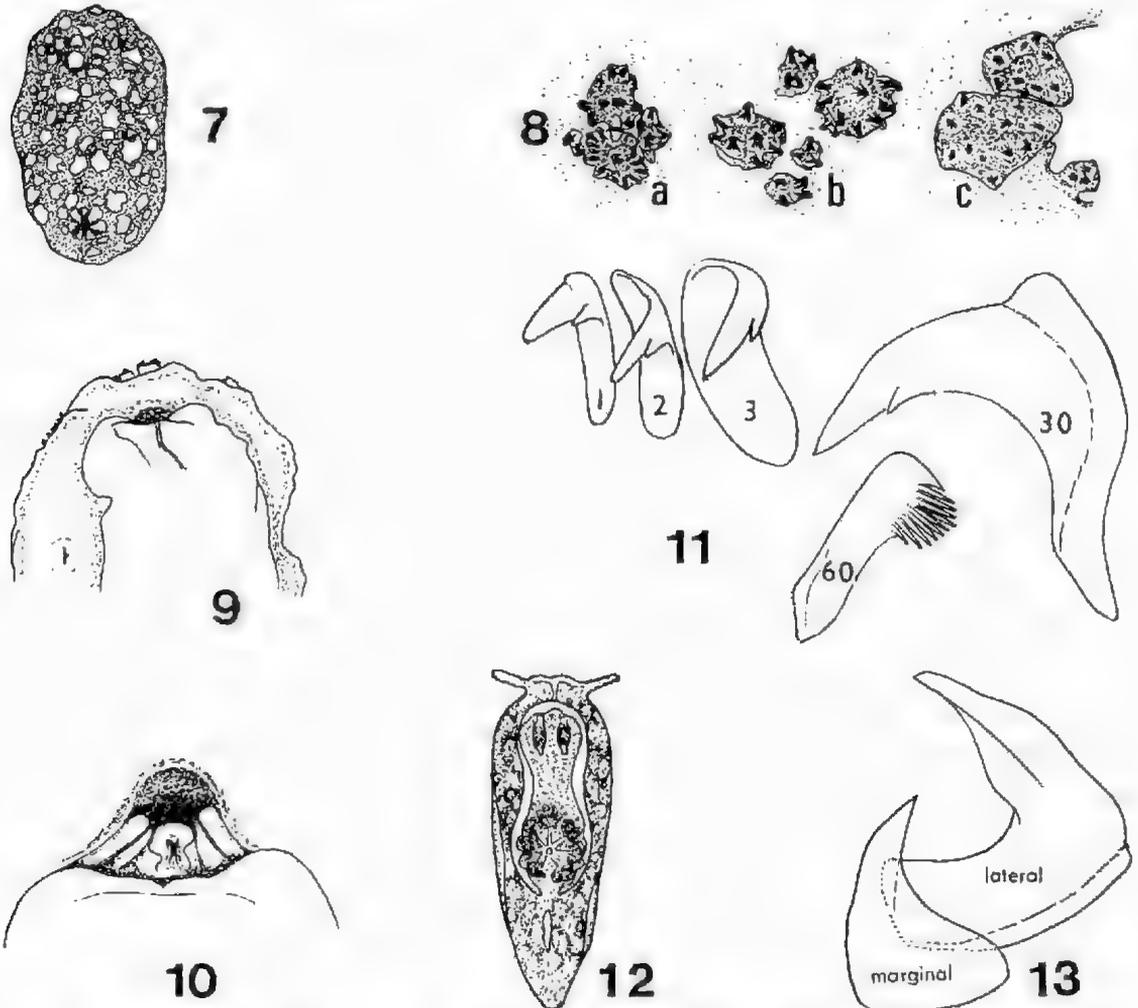
Tribe PHANEROBRANCHIA  
Superfamily SUCTORIA  
Family GONIODORIDIDAE

*Goniodoris meracula* Burnt, 1958: 27; 1966: 227.

FIGS. 12-13

*Material:* Off Dorothee, Jan. 1969, 1 specimen from algae at 65 m (NMV, F27400).

The colourless preserved specimen measures 7.5 mm long and 3.5 mm broad. Living specimens (Fig. 12) are usually yellowish with darker brown mottling. Important characters for the identification of this species are the smooth body, the high notal flange open be-



Figs. 7-11. *Aporodoris merria*. Fig. 7.—Dorsal view of preserved holotype. Fig. 8.—Notal tubercles from rhinophoral cavity (a), middle of the notum (b), and branchial margin (c). Fig. 9.—Anterior hyponotum. Fig. 10.—Detail of head with anterior foot folded down. Fig. 11.—Radular teeth.

Figs. 12-13. *Goniodoris meracula*. Fig. 12.—Dorsal view of an 8 mm long specimen from Point Danger, Torquay, Vic. Fig. 13.—Half row of radular teeth from Sydney Harbour specimen.

hind the gills, the short caudal crest, and the seven gills.

The species has been very rarely collected. The holotype was found eating into a yellowish compound ascidian beneath a stone at Point Danger, Torquay, Victoria (Burn 1958), and a second specimen was recorded from Portsea Pier, Port Phillip Bay (Burn 1966). A third specimen was taken by the writer at Point Danger, Torquay, Dec. 1963, where it was crawling on brown algae.

Three specimens (Australian Museum, C312), dredged in Sydney Harbour, New South Wales, on 11 June 1892, are a new record for that State and the only other specimens known to date. Each measures 10.5 mm

long by 5.5 mm wide. The radula (Fig. 13) of one specimen has the formula  $26 \times 1.1.0.1.1$ ; the lateral tooth is strongly hooked with smooth cusp, while the marginal tooth has much the same shape and is about half the size of the lateral tooth.

*Goniodoris meracula* is a new record for South Australia.

#### Acknowledgements

The writer is indebted to Mrs Jeanette E. Watson, Honorary Associate, National Museum of Victoria, Melbourne, for the collection of, and the field notes on, the Pearson I. opisthobranchs. This research has been aided by a grant from the Science and Industry Endowment Fund, C.S.I.R.O., Canberra.

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# PEARSON ISLAND EXPEDITION 1969†-11. CRUSTACEA: ISOPODA

BY W. F. SEED\*

## Summary

SEED, W. F., (1973) .-Pearson Island Expedition 1969.-11. Crustacea: Isopoda. *Trans. R. Soc. S. Aust.* 97(3), 207-212, 31 August, 1973.

Eleven species of isopods, all sphaeromatids, are represented in a small collection from Pearson I. Of these species, two are too immature for specific identification, but belong to the genera *Exosphaeroma* and *Cymodopsis*. One new species, *Cilicaeopsis floccosa*, is described and figured. The previously-known species are: *Cymodoce gaimardii*, *C. pubescens*, *C. unguiculata*, *Cilicaea latreillei*, *Cerceis acuticaudata*, *Haswellia anomala* and *H. cilicioides*.

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### Introduction

This paper discusses the isopod crustaceans collected during the Pearson I. expedition of 6-13 January, 1969, sponsored jointly by the Royal Society of South Australia and the Department of Fisheries and Fauna Conservation of South Australia. For discussion of collecting sites see Shepherd & Womersley (1971) and Watson (1973); R and S indicate rough-water and sheltered localities.

All specimens were recovered during the sorting of algal collections made by divers (S. A. Shepherd, J. E. Watson and J. Ottaway). This may account for the immaturity of much of the material, since larger, and presumably more vigorous, animals are often observed to escape the net during collection (S. A. Shepherd, pers. comm.). Nine species (including one new species) are identified, and two species are diagnosed to genus only.

The keys of Hale (1929), Hansen (1905) and Hurley (1961) were used to identify the genera; most of the species were determined from Hale's (1929) keys and species descriptions. Synonymies are not necessarily complete. I have followed Menzies (1962; see also Menzies & Frankenberg 1966) in giving only a brief diagnosis of the new species, supported by accurately drawn figures.

Use of the name Sphaeromatidae (rather than the more commonly-used Sphaeromidae) follows Schultz (1969) and Naylor (1972),

and anticipates a forthcoming paper by Hurley & Jansen (pers. comm.) in which the usage is discussed.

Specimens are deposited in the isopod collection of the National Museum of Victoria, Melbourne (NMV), but only the new species has been registered.

Tribe FLABELLIFERA  
Family SPHAEROMATIDAE  
Group HEMIBRANCHIATAE

Genus EXOSPHAEROMA Stebbing, 1900

*Exosphaeroma* sp.

*Locality*: Pearson I. (Station F at 65 m).

*Material*: One immature male, damaged (about 5 mm long). Penes are developing but appendix masculina is not yet distinct.

*Remarks*: More than thirty species have been placed in this genus, and the specimen differs from all of them in at least one point: the uropodal exopod is W-shaped at the distal end. Description of this species must await more suitable material.

Genus CYMODOCE Leach, 1813-14

*Cymodoce gaimardii* (Milne Edwards). Hansen, 1905: 121, Baker, 1926: 256, pl. 42, fig. 2. Hale, 1929: 286, fig. 284. Nierstrasz, 1931: 200. Naylor, 1966: 186, fig. 2.

*Sphaeroma gaimardii* Milne Edwards, 1840: 209.

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† Other accounts of the geomorphology and biology of the Pearson Islands are given in Volume 95, Part 3 (1971) of the Transactions, as well as the present Part.

## FIGS. 1-4

*Localities:* Australia (Milne Edwards 1840); Vic.: Port Phillip Bay (Baker 1926, Naylor 1966); Tas.: (Baker 1926); S. Aust.: Encounter Bay, Gulf St. Vincent (Baker 1926). *New record:* Pearson I. (Station F at 65 m).

*Material:* One female (11 mm long), immature, with no oostegites or eggs, and the mouthparts unmodified.

*Remarks:* The specimen agrees with the descriptions and figures of Baker (1926) and Naylor (1966), allowing for its being a juvenile. Comparison with these figures and with specimens collected from Western Port Bay reveals variation within the species in the sharpness of truncation of the uropodal endopods, in the shape of the joint between telsonic and pleonic tagmata, and in the shape and degree of exposure of the anterior suture on the pleon (Figs. 1-4).

*Cymodoce pubescens* (Milne Edwards). Hansen, 1905: 122. Stebbing, 1910: 104. Nierstrasz, 1931: 198. Naylor, 1966: 188, fig. 3.

*Sphaeroma pubescens* Milne Edwards, 1840: 209.

*Paracilicæa* (?) *pubescens* (Milne Edwards), Baker, 1926: 262, pl. 43, figs. 8-11; pl. 48, fig. 1, Hale, 1929: 290.

*Localities:* Australia (Milne Edwards 1840); N.S.W.: Port Jackson, Port Stephens (Haswell 1882); Vic.: Port Phillip Bay (Naylor 1966). Zanzibar: Wasini (Stebbing 1910). Indonesia: Sailus Besar, Paternoster I. (Nierstrasz 1931). *New record:* Pearson I. (Station F at 65 m).

*Material:* One male (8 mm long) and one female 7.5 mm long), both immature; the

appendix masculina of the male is not free; the female has no oostegites or eggs, and its mouthparts are unmodified.

*Remarks:* Specimens agree with published descriptions of this species. It should be noted that, although Hale (1929) has followed Baker in referring this species to *Paracilicæa* in the text, his key agrees with those of Hansen (1905) and Hurley (1961), the species keying out to *Cymodoce* in all three.

*Cymodoce unguiculata* Barnard, 1914: 394, pl. 34B. Baker, 1926: 259, Hale, 1929: 285.

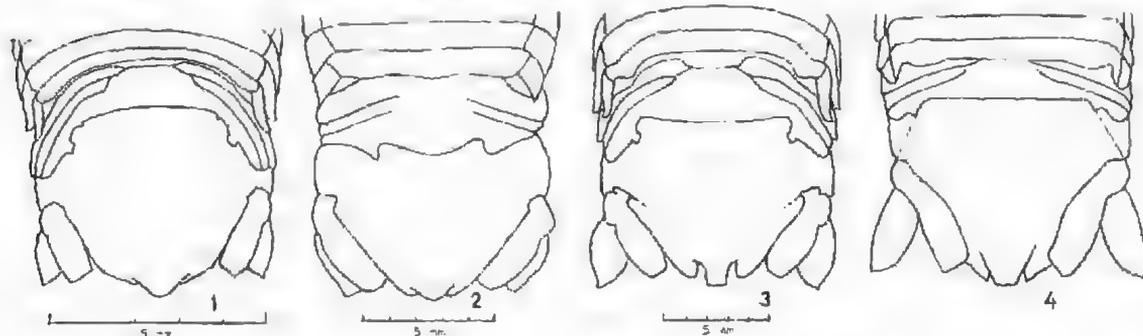
*Localities:* South Africa (Barnard 1914); S. Aust.: Beachport (Baker 1926). *New record:* Pearson I. (Station F at 65 m).

*Material:* Two females (6 and 9 mm long), both immature, without eggs or modification of the mouthparts, but with four pairs of oostegite buds in the larger specimen.

*Remarks:* The specimens lack the marginal fringe of setae referred to by both Hale and Barnard; the bosses on the telson are much less prominent than Barnard's figures indicate (by inference from his description, and directly from Hale's, they are the same size in adults of both sexes); and the hooked uropodal exopod differs slightly in both specimens from Barnard's figures. The uropodal endopod, however, is slightly excavate distally, as shown in Barnard's figure of the female, and in other respects the specimens agree well with descriptions of *C. unguiculata*.

## Genus CILICAEA Leach, 1818

*Cilicæa curtispina* Haswell, 1881b: 185, pl. 3, fig. 4. Stebbing, 1905: 36, Baker, 1908: 142, pl. 4, figs. 12-17, pl. 5, figs. 1-8; 1928: pl. 6, figs. 8-9. Hale, 1929: 280,



Figs. 1-4. *Cymodoce guimardii*, posterior region. Fig. 1.—Female (11 mm long) from Pearson I. Fig. 2.—Female (13.5 mm long) from Port Phillip (after Naylor). Fig. 3.—Male (24 mm long) from Western Port. Fig. 4.—After Baker: "Probably a young male"; locality and scale not indicated.

fig. 280. Nierstrasz, 1931: 205. Naylor, 1966: 189.

*Naesa antennalis* White, 1847: 105; *nomen nudum*.

*Cilicæa antennalis* White. Miers, 1884: 310.

*Cilicæa antennalis* Miers. Stebbing, 1905: 35. Nierstrasz, 1931: 205.

**Localities:** W. Aust.: Swan River (White 1847, Miers 1884) Vic.: Port Phillip (Haswell 1881b, 1882; Naylor 1966); "very common in shallow water around [southern Australian] coasts" (Hale 1929). *New record:* Pearson I. (R at 25 m).

**Material:** One adult male (14 mm long).

**Remarks:** The specimen agrees with Baker's (1908) and Hale's (1929) descriptions, except that the uropodal exopods are rounded apically, rather than slightly bifid. No description refers to the pads of short setae lining the incurved inner surface of the distal part of these exopods and of the median projection. This feature, together with the shape and arrangement of these three projections, seems to imply some definite function, such as clasping the female during mating, or clasping the anterior region when the animal is rolled.

*Cilicæa latreillei* Leach, 1818: 342. Miers, 1884: 308. Stebbing, 1905: 36, pl. 8. Hale, 1929: 282, fig. 282. Nierstrasz, 1931: 204, figs. 92-96. Naylor, 1966: 190, fig. 3.

*Naesca latreillei* Milne Edwards, 1840: 218.

*Cilicæa crassicaudata* Haswell, 1881a: 475, pl. 17, fig. 3.

**Localities:** There are numerous records from South Africa, Ceylon, East Indies, Australia and New Zealand (see Nierstrasz 1931, Naylor 1966). *New record:* Pearson I. (R at 20-25 m).

**Material:** One specimen, apparently female and very young (6 mm).

**Remarks:** The females of *Cymodoce pubescens* and *Cilicæa latreillei*, both of which have bifid uropodal exopods and are otherwise very similar, have caused much taxonomic confusion. The Pearson I. specimen lacks the characteristic scale-setae of *Cymodoce pubescens*, being fairly liberally covered with stiff, erect setae; it agrees well with Naylor's (1966) figure of a female of *Cilicæa latreillei*, although it has not the well-defined anterior boss of the Port Phillip (and Western Port) specimens, and the posterior tip of the uropodal exopod is forked.

These could well be juvenile features: comparison with a series of specimens from Western Port leaves little doubt that it is a very young female of *Cilicæa latreillei*.

It must be noted that the male figured by Nierstrasz, despite his statement that "Die Tiere (Figs. 92-96) stimmen gut mit den Beschreibungen von Miers [1884], Stebbing [1905], und Barnard [1914] überein", clearly belongs to another species, and what he has labelled as the female of *C. latreillei* is not a female of that species, although it could be a young male. Reliable figures will be found in the papers by Barnard, Naylor and Stebbing; they agree with all Victorian specimens available.

#### Genus *CILICÆOPSIS* Hansen, 1905

Hansen established this genus by designating *Cilicæa granulata* Whitelegge (1902) as the type, and his key to genera shows the diagnostic characters to be: "Abdominal notch semicircular, without any vestige of mesial lobe. Endp. of urp. rudimentary in the male". This seems to have been broadly interpreted as to both the semicircular nature of the abdominal notch and the rudimentary nature of the endopod. Some of the species included in this genus appear to necessitate a new generic diagnosis, but it will be best if modification of the diagnosis is left until this and the several closely-related genera are reviewed.

Taking a broad view of the meaning of semicircular, as Baker (1926) has done, the new species described below conforms with Hansen's diagnosis.

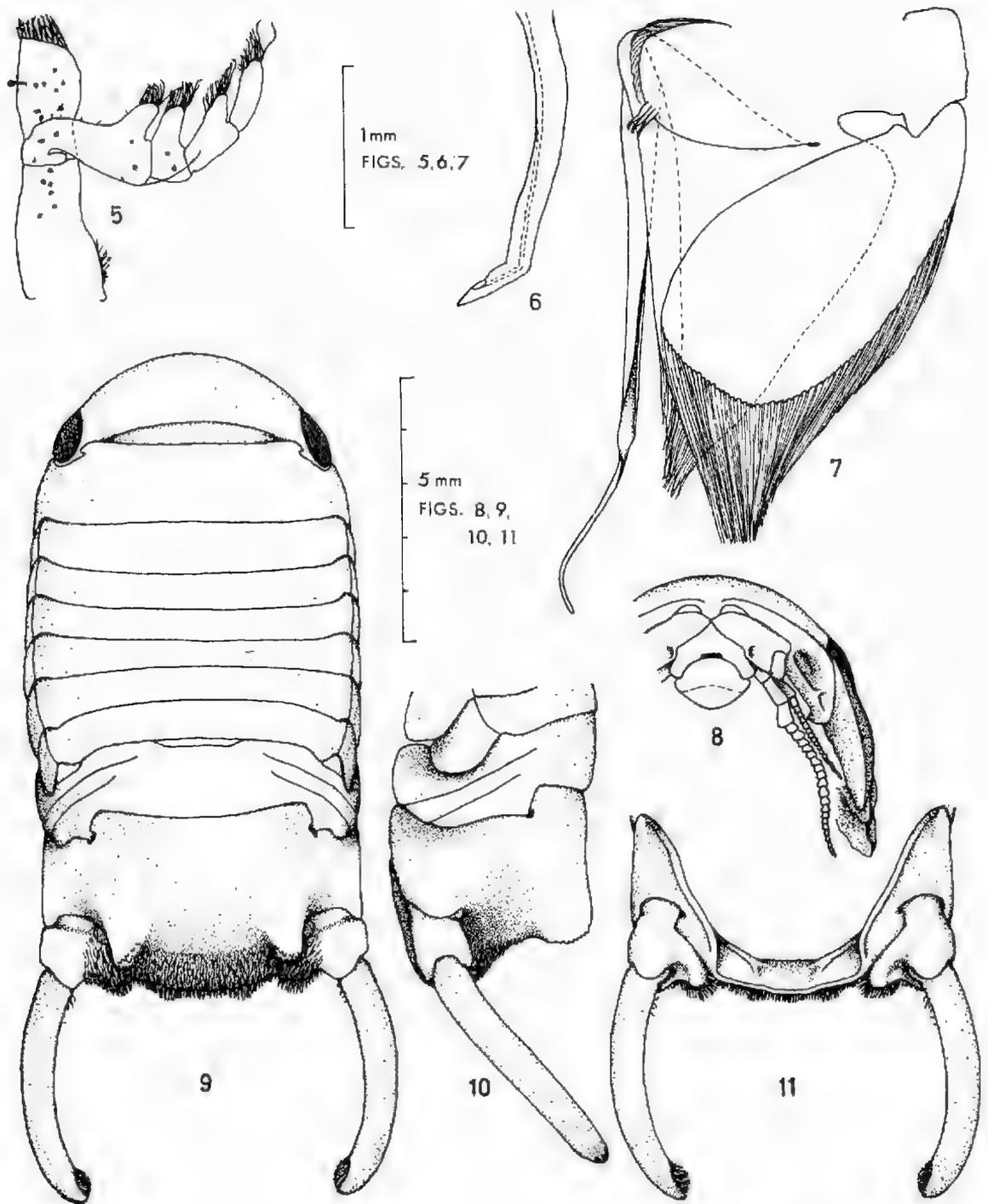
#### *Cilicæopsis floccosa* n.sp.

**Locality:** Pearson I. (R at 25 m: "From algae on horizontal face").

**Material:** One specimen, the holotype male (median length 12.5 mm, total length 16 mm, width 6.1 mm); apparently adult, *S. A. Shepherd*, 10.i.1969 (NMV, J-249).

FIGS. 5-11

**Diagnosis:** *Cilicæopsis* with slender, curved uropodal exopods bearing a furry tuft of setae on the median aspect of the distal end. Similar setae cover the dorsal surface of the endopods and of the pleotelson below and behind the two large tuberculate bosses; surface elsewhere glabrous. Appendix masculina long, with a curved narrow tip extending well beyond the setae of the second pleopod; inner edge of the endopod grooved behind to accommodate the upper part of the appendix. Penes long, tapering to a point, laterally compressed and kinked backward near the end. Abdominal



Figs. 5-11. *Cilicaeopsis floccosa*. All figures from the holotype male. Fig. 5.—Left maxillipede. Fig. 6.—Left penis, from the right side. Fig. 7.—Left second pleopod and appendix masculina. Fig. 8.—Head, ventral view. Fig. 9. Whole animal, dorsal view. Fig. 10.—Posterior region, from the left side. Fig. 11.—Pleotelson and uropods, ventral view.

notch wide and shallow, not visible from above. Epistome pointed, much shorter than broad.

Genus *CYMODOPSIS* Baker, 1926

*Cymodopsis* sp.

*Locality:* Pearson I. (R at 25 m, from algae on horizontal face).

*Material:* One immature male (8 mm long), with very rudimentary penes and appendix masculina not yet apparent.

*Remarks:* The specimen superficially resembles Baker's (1926) figure of *Cymodopsis crassa* in general form and in having two large conical projections on the pleotelson. In lateral view these are seen to be slightly undercut below, forming a postero-dorsal point on each, whereas the corresponding part of *C. crassa* appears, in Baker's figure, to be smoothly rounded and to run down to the telson as a straight ridge. Two other conspicuous differences are that the epistome is very much shorter than broad (and different from that of any described species), and that the uropodal exopod is relatively large, plate-like, and reaches to the end of the endopod in the closed position.

It seems clear that this is a new species, but no satisfactory description can be given in the absence of an adult male.

Group EURRANCHIATAE

Genus *CERCEIS* Milne Edwards, 1840

*Cerceis acuticaudata* (Haswell). Hansen, 1905: 127. Hale, 1929: 300. Nierstrasz, 1931: 216.

*Sphaeroma* (?) *acuticaudata* Haswell, 1881b: 191, pl. 3, Fig. 9.

*Localities:* Vic.: Griffith's Point, Port Phillip (Haswell 1881b); "This is a common species" (Hale 1929). *New record:* Pearson I. (R at 25 m, from algae on horizontal face, R at 20–25 m).

*Material:* Three females (8.5–9.3 mm long), all immature and without oostegites or eggs.

*Remarks:* Specimens agree with descriptions and figures of *Cerceis acuticaudata* except that they lack the spines on the uropods and the spine on the pleotelson is represented only by

a smooth median boss. Comparison with a series of specimens from Western Port shows that the growth of these spines is both allometric and variable.

Genus *HASWELLIA* Miers, 1884

*Haswellia anomala* (Haswell). Baker, 1926: 273, pl. 48, figs. 8–9. Naylor, 1966: 192. *Sphaeroma* (?) *anomala* Haswell, 1881a: 473, pl. 16, fig. 4.

*Zuzara emarginata* Haswell, 1881 b: 188, pl. 3, fig. 5.

*Haswellia emarginata* (Haswell). Hansen 1905: 127. Hale, 1929: 304, fig. 304.

*Localities:* N.S.W.: Port Jackson (Haswell 1881a); Vic.: Western Port (Haswell 1881b), Port Phillip (Naylor 1966); S. Aust.: St. Vincent Gulf (Hale 1929). *New record:* Pearson I. (R at 25 m).

*Material:* Seven females (5.8–8.6 mm long), all immature and without eggs, oostegites, or modification of the mouthparts.

*Remarks:* The females of this species are very similar to those of *Cerceis trispinosa*. The uropodal exopods provide a convenient diagnostic feature: in *C. trispinosa* females they are longer than the endopods, while in *H. anomala* they are both slightly shorter than the endopods, and conspicuously toothed on the distal edge. Comparison with a series of *H. anomala* from Western Port confirms the identity of the Pearson I. specimens. The largest of them have the hind margin of the seventh thoracic tergite produced in the centre (although not as far as in Haswell's figure of *Sphaeroma* (?) *anomala*), a feature which supports Naylor's view that *S. (?) anomala* was the female of this species and hence also supports his adoption of the specific epithet *anomala*.

*Haswellia cilicioides* Baker, 1908: 158, pl. 10, figs. 12–23. Hale, 1929: 304, fig. 305.

*Localities:* S. Aust.: St. Vincent Gulf (Baker 1908. Hale 1929). *New record:* Pearson I. (S at 30 m).

*Material:* One adult male (9 mm long).

*Remarks:* The specimen agrees with Baker's (1908) and Hale's (1929) descriptions and figures, except for slight differences in the shape of the uropodal endopods, and in the shape of the process of the last thoracic segment when viewed from above.

## Acknowledgements

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## Summary

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Kanmantoo Group rocks younger than the Middleton Sandstone are unknown in the Mt. Lofty Ranges. Because the formation is intruded by the Encounter Bay Granites, a thick cover must have been present at the time of intrusion and metamorphism.

Worm casts were the only fossils located in the study area and are suggestive of a marine environment of deposition.

The sequence mapped forms the eastern limb of a regional anticline overturned towards the NW. Two phases of folding are recognised.  $F_1$  folds plunge shallowly towards the SSW or NE. Eastwards from the core of the highly appressed and asymmetrical regional anticline,  $F_1$  folds in metasandstones become progressively more open, symmetrical and upright. Mesoscale  $F_2$  folds with E to SE plunges are confined to the eastern part of the type section. A weak crenulation of  $S_1$  is observable near Coolawang Creek, and becomes progressively stronger towards the east.

The Encounter Bay Granites were intruded and had crystallised prior to the main phase of  $F_1$  deformation because thin granite sheets, concordant with bedding, developed the  $S_1$  and  $S_2$  schistosity during the folding episodes.

Stability fields for the observed metamorphic mineral assemblages show that the metamorphism of the Kanmantoo Group was effected at moderate temperatures (below 540°C) and low pressures (below 3 kb). This is indicated also by the well preserved sedimentary structures found throughout this sequence of andalusite-staurolite grade rocks. Cordierite, restricted to the proximity of the granite, records the highest grade of metamorphism within the type section. Petrographic evidence suggests that cordierite crystallised during the pre- to early syn- $F_1$  phase, a conclusion in harmony with the suggested pre-tectonic emplacement of the Encounter Bay Granites. Petrographic evidence indicates that most of the andalusite formed during the late syn- $F_1$  phase of metamorphic crystallisation. In the post- $F_1$  and pre- $F_2$  static phase of metamorphic crystallisation, some andalusite, garnet, hornblende,

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scapolite and chlorite grew across the  $S_1$  schistosity. The  $S_2$  crenulation cleavage, where developed, deformed porphyroblasts of this age. Albitisation postdates the  $S_2$  schistosity.

A peculiar "striped" layering, post- $S_1$  and pre- $S_2$  in age, occurs within the Petrel Cove Formation west of Rosetta Head and resulted from alteration adjacent to tensional fractures.

Two distinct groups of basic dykes, post  $S_1$  and pre- $S_2$  in age, cut Kanmantoo Group metasediments.

### Introduction

A previous paper (Daily & Milnes 1971a) discussed the geology of the lower part of the type section of the Kanmantoo Group (Sprigg & Campana 1953) as found in the coastal cliffs of Fleurieu Peninsula between Campbell Creek and the western end of Tunkalilla Beach (Figs. 1 & 2). The present paper gives the results of our investigations of the geology for the remainder of the type section east to Rosetta Head near Victor Harbor. In addition, we have extended our traverse to include stratigraphically younger metasediments to the NE in the Port Elliot and Middleton areas.

The stratigraphic succession and geological structure over this 50 km of coastline (Figs. 3 & 4), differ significantly from that shown on the map given by Madigan (1925), on the *Jervis* (Campana & Wilson 1954) and *Encounter* (Crawford & Thomson 1959) 1:63,360

map sheets, on the BARKER 1:250,000 map sheet (Thomson & Horwitz 1962) and in the 'Handbook of South Australian Geology' (Thomson *in* Parkin 1969). In essence we have found that progressively younger formations occur to the east despite the advent of folds which repeat parts of the sequence. These folds are inclined to upright and plunge at relatively low angles towards the SSW, but as shown on the maps, some exceptions in plunge direction do occur, particularly in connection with parts of the Wattaberry Sub-group.

Our main aims in studying the geology of the type Kanmantoo Group have been to re-assess its stratigraphy and age limits and to try and determine the relative time of emplacement of the Encounter Bay Granites in contrast to the isotopic ages obtained by Dasch *et al.* (1971). In the presumed absence of diagnostic fossils within the type section, we have



Fig. 1. Locality map of geographic features exclusive of those shown on the geological maps in Figs. 2-4.

been forced to define the relative age of this emplacement in terms of the structural and metamorphic history of the Kanmantoo Group. Fortunately, sufficient rock samples were collected and enough structural observations were recorded during our traverse to enable us to suggest the emplacement of the granites prior to the culmination of the first phase of deformation.

We have not attempted a rigorous analysis of the structure and metamorphism of the Kanmantoo Group in its type section, and further work to this end is warranted. However, one of us (Milnes unpub.) has discussed 'The Encounter Bay Granites and their environment' in greater detail in a Ph.D. thesis, submitted to the University of Adelaide.

**Stratigraphy**

In presenting the geology of the upper part of the Kanmantoo Group we have revised the stratigraphic terminology previously applied in the type section (Daily & Milnes 1972a). This scheme is given in Table 1. As explained in the 1972 paper, we have discarded the term

Brukung Formation but have retained the geographic terms Inman Hill and Brown Hill to qualify sub-group names. This procedure retains the position of the boundary between the Inman Hill Formation and Brown Hill Beds as designated initially by Forbes (1957). Moreover, the base of the Brown Hill Sub-group, which is easily recognised, does not correspond to the base of the Nairne Pyrite Member at the base of the type Brukung Formation. The base of the Brown Hill Sub-group is estimated to be 3000-4000 m above that position in the Nairne region where the Brukung Formation was originally defined.

The following abbreviated account has been made from our field notes of the coastal sections and environs east of Tunkalilla Beach

**A. INMAN HILL SUB-GROUP (new rank)**

The Inman Hill Sub-group (Table 1) contains the Backstairs Passage Formation, Talisker Calc-siltstone and Tapanappa Formation. All three formations occur in superposition in their type sections. In addition, we have now located them on Dudley Peninsula, Kangaroo I. (Daily & Milnes 1971b) where they appear to be of identical facies. However, we have had difficulties in identifying the Tapanappa Formation in the northern sections of Fleurieu Peninsula, although Tapanappa Formation of comparable lithology to that exposed in the type section is well exposed along the Mount Barker Creek, near Callington, further to the north. So far we have not mapped any intertonguing relationships between typical Tapanappa Formation and other formations, nor have we recognised fault relationships that might account for its apparent absence in some sections. Nevertheless, we believe that such possibilities do occur and we have recently undertaken investigations in key areas to solve these problems.

**Tapanappa Formation**

Detailed observations on the lower part of the Kanmantoo Group (Daily & Milnes 1971a), did not extend beyond the western end of Tunkalilla Beach where the modern coastal cliffs abut upon the beach. However, there is an arcuate line of old coastal cliffs behind an alluvial bench backing that beach which permitted collection of data for the uppermost part of the Tapanappa Formation, despite the relatively poor outcrops in comparison with those in the modern coastal cliffline. The sequence consists of dark coloured, thick-bedded to laminated, generally fine- to coarse-grained metasandstones, although near the top of the

TABLE 1

*Stratigraphic scheme for the Kanmantoo Group in its type section between Campbell Creek and Rosetta Head. The table also includes stratigraphically younger metasediments in the Port Elliot-Middleton area and also shows the relationship of the Kanmantoo Group to older rocks (Precambrian and Cambrian) on Fleurieu Peninsula. The regional unconformity between Precambrian and Cambrian strata represents roughly the stratigraphic interval from the ABC Quartzite of the Flinders Ranges to the base of the transgressive Cambrian deposits.*

Cambrian System	Kanmantoo Group	Watershed Sub-group	Middleton Sandstone
			Parrel Cove Formation
		Inman Hill Sub-group	Balauhiddar Formation
			Tunkalilla Formation
		Lower Hill Sub-group	Tapanappa Formation
			Talisker Calc-siltstone
			Backstairs Passage Formation
	Cathkakalinga Head Foundation		Campana Creek Member
			Bluishwhite Creek Silstone Member
			Madigan Inlet Member
Nurmanville Group			
Regional Unconformity			
Marion Group (Late Precambrian)			

formation very fine-grained metasandstones predominate. The individual metasandstone beds, rarely more than 1 m thick, are split by poorly outcropping and frequently laminated metasilstones and phyllite interbeds which are generally much thinner than the metasandstones. These pelites range down to partings of a few millimetres. Poorly outcropping intervals, many in excess of 10 m stratigraphic thickness, are presumed metasilstones or phyllite beds. Bands and rods of calc-silicates occur sporadically in the metasandstones and even in some of the finer grained lithologies. Porphyroblasts of chlorite, muscovite and biotite are common in the finer grained lithologies, especially the phyllites, as well as some of the metasandstone bands. Outcrops of small-scale conglomerates occur as thin discontinuous bands in some of the coarser grained metasandstones but their presence in the sequence was generally indicated by float rather than outcrop.

#### B. BROWN HILL SUB-GROUP (new rank)

The base of the Brown Hill Sub-group and the Tunkalilla Formation is marked by a sequence of dark blue to black laminated phyllites about 15 m thick (not 10 m as in Daily & Milnes 1971a, p. 207), and outcrops on a small saddle behind the beach about 2.5 km west of Tunk Head. The Tunkalilla Formation together with the overlying Balquhider Formation constitute the Brown Hill Sub-group. The lithologies within the sub-group are not unlike those found in the Tapanappa Formation and indeed it is impossible to assign limited sequences to either unless the dark blue-black carbonaceous and sulphide-rich phyllites characteristic of the Brown Hill Sub-group are located within them. Fortunately, dark coloured phyllites of this type are unknown to us outside the sub-group within the type area. Geographically, they are quite extensive as they are known from Middle River (upstream from the dam site) on Kangaroo I.; north to at least the Callington area in the eastern Mt. Lofty Ranges.

#### *Tunkalilla Formation* (new name)

The dark coloured laminated phyllites marking the base of this formation conformably overlie the Tapanappa Formation metasediments. When weathered, the phyllites are characteristically stained yellow and brown by jarosite and goethite due to the oxidation of iron sulphides within the rock. Stratigraphically above this basal unit are about 30 m of poorly outcropping dark coloured medium- to coarse-grained metasandstones with interbedded meta-

siltstones and phyllites. Succeeding this there is a khaki to mid-grey coloured phyllite about 30 m thick overlain by a 20 m thick sequence of alternating 1 m thick bands of fine- to medium-grained metasandstones and khaki to mid-grey coloured phyllites. These are in turn overlain by a thick sequence (about 150 m) of predominantly well laminated metasilstones (Fig. 8) and phyllites with minor metasandstone interbeds cut-and-fill into the finer clastics. This interval occupies low ground and outcrops poorly. Elongate to ovoid porphyroblasts of micas and chlorite are common in the metasilstones. Several small quartz-feldspar-chlorite-muscovite pegmatites occur in silky phyllites near the mouth of Tunkalilla Creek. A well developed crenulation is present in the phyllites immediately adjacent to these 'sweat' pegmatites, but this is local and has not been observed elsewhere.

The topmost part of the formation is a well laminated phyllite-metasilstone to fine-grained metasandstone sequence capped by at least 3 m of blue-black laminated carbonaceous phyllites in which the alteration of sulphides has produced jarosite and goethite. Cubic-shaped voids after pyrite are readily apparent in the weathered phyllites. The best outcrops can be inspected high up on a mainly soil-covered west facing cliff about 100 m east of Tunkalilla Creek, after which the formation is named.

The position of the upper boundary of the Tunkalilla Formation is plotted on the geological map (Fig. 3). In the first creek west of Callawonga Creek, a 6 m thick band of black sulphide-rich finely laminated phyllites stained with jarosite and goethite marks the top of the formation. It is underlain by about 3 m of metasandstone. Below the metasandstone there is a much thicker poorly outcropping band of blue-black carbonaceous and sulphide-rich phyllites which, providing there are no structural complications, may have a thickness of 30 m. Paler coloured phyllites and metasilstones occur below this. We may have missed this approximately 30 m band of black phyllite in the type section due to thick soil cover at this stratigraphic level. In traverses east of Callawonga Creek however, we located only the upper of the two bands and therefore it is more likely that this thick band is a local development.

The only fossils found within the formation are abundant worm casts in outcrops of sand-blasted metasandstones at the back of Bolla-parudda Beach, adjacent to the western bank

of that creek. The worm casts (Figs. 9 & 10) are exceptionally well-preserved despite the tectonism and metamorphism. They are weathered out in full relief in an outcrop about 8 m long and their tubular and sinuous nature can be seen to perfection, particularly in sections normal to the bedding. The bioturbated interval, which is about 20 cm thick, forms the topmost bed in a large scour-channel (Fig. 14). The lower parts of the channel contain shale-chip conglomerates in which the now phyllite fragments are scattered in a metasandstone matrix.

Thus the Tunkalilla Formation in its type section at Tunkalilla Creek is a sequence (at least 250 m thick) of mainly fine-grained clastics whose base and top are marked by blue-black carbonaceous and sulphide-bearing laminated phyllites of a characteristic appearance. In the region to the north of Hindmarsh Valley mapped by Forbes (1957), a seemingly identical sequence can be found on Mr. J. Green's property just over 1 km SE of "Pambula" homestead (see *Milang* 1:63,000 map sheet, Horwitz & Thomson 1960, for the geographic position of "Pambula").

#### *Balquhiddy Formation* (new name)

This formation is named after the property known as "Balquhiddy" (see Fig. 3). Its type section spans the coastline from a point approximately 2 km west of Tunk Head east to a point about 0.7 km west of King Point, where the much finer grained metaclastics marking the base of the overlying Wattaberry Sub-group are first encountered. There is continuous outcrop over this approximately 30 km of coastline except for the two stretches occupied by Parsons Beach and Waipinga Beach. However, the sequence is repeated by folding across these two intervals so that our observations have covered most, if not all, stratigraphic levels within the formation. The oldest part of the formation occurs within a southerly-plunging broad synclinal structure whose axis lies immediately west of Tunk Head.

A sequence of medium- to coarse-grained metasandstones with metasilstone interbeds occurs at the base of the formation. These are conformable with the underlying Tunkalilla Formation. About 300 m stratigraphically above the base of the formation and west of Tunk Head, there is a 10 m thick sequence of black carbonaceous and sulphide-rich phyllites. Exposures are normally covered by sand on the coast between this outcrop and the base of the formation, but a sequence can be examined inland in the ancient coastal cliffs. The bulk of

the rocks are thick-bedded, medium- to coarse-grained metasandstones with thin interbeds of metasilstones or phyllites. However, there are intervals where the metasilstones (up to 3 m thick) are the dominant lithology and are interbedded with metasandstones up to 1 m thick. Some thin blue-black carbonaceous and pyritic phyllites were also noted. Porphyroblasts of chlorite and micas occur in many phyllite interbeds as well as in some fine-grained metasandstones.

The basal part of the formation is best seen in coastal exposures, for example in a traverse from Tunk Head east to Bollaparudda Beach. In these superior outcrops the sequence has a different character. For instance, many of the seemingly massive metasandstones are well laminated and cross-bedding becomes more apparent. Other notable features include phyllite-chip conglomerates (up to 0.5 m thick) which are associated with coarse-grained to granule-rich metasandstones in cut-and-fill structures, load casts and associated flame structures, and beds with climbing ripples (Figs. 11-13). Calc-silicate rods and bands are also apparent (Figs. 15 & 16).

Above the lowest blue-black carbonaceous and sulphide-rich phyllites within the Balquhiddy Formation on both limbs of the Tunk Head syncline, medium- to very coarse-grained massive and laminated metasandstones are dominant (Figs. 17-19). The beds are variable in thickness and generally less than 1 m thick, and where this is the case the sequence has a somewhat flaggy appearance (Fig. 20). However, there are intervals where metasandstones are up to 3 m thick. Nevertheless, the thickest bed recorded was a 15 m thick band of medium- to coarse-grained metasandstone occurring adjacent to a thin black carbonaceous and sulphide-rich phyllite within the uppermost beds of the syncline. Thin bands and lenses of small-scale pebble conglomerates and phyllite-chip bands occur sporadically through the sequence and are generally associated with the coarser sand intervals. Small-scale sedimentary structures are most frequently found in the metasilstones and laminated phyllitic intervals (Fig. 21). Calc-silicate bands and rods are again common.

The black carbonaceous and sulphide-rich phyllites are best seen on the eastern limb of the syncline just east of Tunk Head with the highest band visible in a gulch immediately west of the razor-edged ridge constituting that head. Sulphides concentrated into cross-cutting

veins within this unit at this locality were probably remobilized at or subsequent to the time of metamorphism (Fig. 22).

Between Callawonga and Bollaparudda Beaches, the basal part of the formation is similar to that described above, except that small-scale conglomerates are present in some of the cut-and-fill structures within thick metasandstones. Phyllite-chip conglomerates are again common associates.

On the point 0.4 km SE of Bollaparudda Beach, there are massive and well-bedded coarse-grained metasandstones, 15 cm to 1 m in thickness, alternating with phyllite and metasiltstone interbeds. Many sands are bioturbated. Higher in the sequence pebble bands (including gneiss pebbles up to 5 cm across) and lenses of small-scale conglomerates occur within laminated medium- to coarse-grained metasandstones (Fig. 23). Phyllite-chip conglomerates are associated with these conglomerates generally near the bottom of channels. Additional pebble bands in very massive looking metasandstones occur higher in the sequence. At first sight some thick bands appear to be structureless graded units with pebbles near the base and with grain size fining upwards. However, in all cases the sands were found in detail to be well bedded (Fig. 24).

The high incidence of conglomerates in the lower part of the formation east of Bollaparudda Beach contrasts with their relative paucity further west. The conglomerates are comparable with those found in the Tapanappa Formation. Similar conglomerates in rocks which we regard as being well down in the Balquhiddler Formation occur in the Cut Hill road-cutting on the Mt. Compass-Victor Harbor road. Therefore, it seems that conglomerates in this general stratigraphic position may be a widespread feature of the formation, thus reflecting the continuity of the Kangarooian Movements (Daily & Forbes 1969; Daily & Milnes 1971a) which were partly responsible for the deposition of the Kanmantoo Group.

A black carbonaceous and sulphide-rich phyllite occurs near the cape about 1 km east of Bollaparudda Beach and is overlain by a sequence of laminated to poorly-bedded metasandstone beds (up to 1 m thick) with thin phyllite and metasiltstone interbeds. From here to the mouth of Coolawang Creek the strike is almost parallel to the coast. A 3 m thick band of black carbonaceous and sulphide-rich phyllite overlain by thick poorly-bedded metasandstones and thin interbeds of metasiltstones and

khaki-coloured phyllites occurs at the mouth of Coolawang Creek. This may be the same sulphide band as seen on the cape alluded to above.

Between Coolawang Creek and Parsons Beach, a number of fold hinges and minor faults were located within the succession. Making due allowance for these, the sequence is seen to consist mainly of massive to well-laminated metasandstones in the lower part of the succession. Many of the channels cut within the sands are filled with coarse-grained to granule-sized clastics including lenses of small pebbles. Nodules and irregular shaped bands of calc-silicate lithology are developed in some parts of the sequence. About 1 km east of Coolawang Creek, porphyroblasts of scapolite occur in slumped and laminated metasandstones and phyllites. In some of the metasiltstones both scapolite and garnet may be found. In the same area pegmatites and feldspathized zones are common and are often associated with tensional features developed in massive metasandstone beds split by thin phyllites (Figs. 25 & 26). A little higher in the sequence some of the massive metasandstones (1–2 m thick and split by phyllites up to 1 m thick) are bioturbated towards their tops. A weak crenulation cleavage, noticed for the first time in our traverse, becomes much more apparent as one moves to the east, and provides evidence for a second phase of folding. The first-generation folds are open and asymmetric with steep westerly-dipping anticlinal limbs in contrast to the inclined folds further west possessing overturned easterly-dipping anticlinal limbs. The opening up of the fold hinges might be considered a function of distance away from the crystalline basement at the time of folding.

The remainder of the sequence east to Parsons Beach is made up of flaggy laminated metasandstones, generally less than 1 m thick, with interbedded thin laminated and sometimes rippled metasiltstones (Fig. 27) and crenulated phyllites up to 0.6 m thick. Some of the sands are bioturbated and some contain calc-silicate nodules. A feature of this part of the formation is the fashion in which the cleavage has destroyed or vastly modified the fine sedimentary structures within the top (and bottom) few centimetres of the sandier beds. Bedding surfaces, similar to that shown in Fig. 19, show an obvious lineation along the cleavage/bedding intersection due to the smearing out of the sedimentary structures. Another expression of the cleavage/bedding intersection is the pro-

nounced ridge-and-furrow lineation seen on the base of some metasandstones (Fig. 28). This simulates the cast of a glaciated pavement or sedimentary groove casts.

The readily accessible sequence forming the headland between Parsons Beach and Waitpinga Beach is on the eastern limb of a SW plunging syncline occupied by Parsons Beach. Massive and laminated coarse- to fine-grained metasandstones with interbedded metasiltsstones and phyllites again constitute the succession. In general, the metasandstone bands increase in thickness up the sequence and near Parsons Beach some beds are nearly 6 m thick. Sedimentary structures such as cross-bedding (occasional sets up to 0.65 m), planar-bedding, slumping, convolute-bedding (Fig. 29), load casts and associated flame structures, current ripples, simple and composite cut-and-fill structures (these are sometimes associated with thin small-scale conglomerates and phyllite-chip conglomerates), and bioturbated sandy intervals were recorded. There are several thick phyllite and metasiltsstone intervals, particularly towards the bottom of the exposed sequence. Some of these phyllites are crenulated and contain cordierite and other porphyroblasts. Calc-silicate bands and rods, some of which are at least 2 m long, are prominent through many of the metasandstone intervals. Segregations possessing the same mineralogy and encompassing parts of pebble beds were also recorded.

There is a total absence of Kanmantoo Group rocks across the 4 km wide sandy Waitpinga Beach. Cainozoic and Permian deposits (uncoloured in Figs. 3 & 4) blanket these rocks for many kilometres inland. However, the sequence is continued uninterrupted along the coastline from just west of Newland Head to the vicinity of Rosetta Head.

On the western side of Newland Head there are very thick (up to 10 m) medium- to coarse-grained metasandstones with pebble bands which are mainly associated with cut-and-fill structures. The sands are well laminated and cross-bedded within and away from the channel bottoms (Fig. 30). Pebbles are scattered through some of the bedded metasandstones and in one instance were seen to be present on the stoss side but absent on the lee side of mega-ripples. A band of crenulated andalusite schist was found about 200 m east from the commencement of outcrop. Above this and below a 2 m thick black carbonaceous and sulphide-rich phyllite is a thick metasandstone.

Stratigraphically higher is a very thick sequence of metasandstones (beds generally less than 2 m thick) which alternate with phyllites or metasiltsstones and an occasional much thicker metasandstone interval (Fig. 31). Two additional black carbonaceous and sulphide-bearing phyllites and two bands of andalusite schists were located in this latter sequence. Stratigraphically above and perhaps 300 m NE of Newland Head, another prominent blue-black carbonaceous and sulphide-rich phyllite is interbedded in the flaggy sequence (Fig. 32). This can be readily followed for about 1 km before it strikes inland and is lost from view. It is overlain by coarse metasandstones containing weak developments of small-scale conglomerates in an otherwise flaggy sequence. From this point onwards to within about 2 km west of King Point (Fig. 33), the strike of the beds parallels or is slightly oblique to the precipitous coastline, parts of which are totally inaccessible. Consequently, our traverse was made mainly along the top of the coastal cliffs. Another slightly younger blue-black phyllite occurs 2.4 km NE of Newland Head and below well-bedded, coarse-grained, impure metasandstones, split by thin phyllites.

About 1.5 km WSW of King Beach a 2 m thick band of a comparable blue-black sulphide-rich phyllite occurs above a regularly bedded medium- to coarse-grained metasandstone with thick laminated phyllite partings. It is either stratigraphically above or possibly on the same horizon as the blue-black phyllite mentioned above. Towards King Point laminated metasandstones, often with cut-and-fill structures, occur in beds varying from about 10 cm to 5 m in thickness. Banded metasiltsstones and finely crenulated phyllites (maximum thickness about 2 m) occur as interbeds and may contain porphyroblasts of mica or more rarely andalusite.

The uppermost part of the formation is marked by a sequence of relatively flaggy metasandstones and metasiltsstones, in which there are a number of interbeds of knotted andalusite schists, Cordierite porphyroblasts and quartz-rich aggregates co-exist with andalusite in some of the schists (Fig. 34). The cordierite porphyroblasts and quartz-rich aggregates are deformed in the plane of the prominent mica schistosity ( $S_2$ ) resulting in the development of small augen. In many pelitic units a prominent discontinuous layering occurs parallel to  $S_2$  defined by the alignment of these augen. Andalusite porphyroblasts, which are

seen in thin section to post-date the augen development, also help to define this layering.

Andalusite-rich pegmatites containing muscovite and corundum occur within this interval. Small-scale first- and second-generation folds are commonly present in the metasediments adjacent to the pegmatites, which are invariably strongly boudinaged.

#### C. WATTABERRI SUB-GROUP (new name)

A marked change in sedimentation took place after the deposition of the Balquhiddier Formation due to the influx of fine-grained clastics. These now constitute a sequence of essentially phyllites or schists, metasilstones and fine-grained metasandstones and are discussed below under the name of Petrel Cove Formation. The succeeding characteristically laminated and cross-bedded Middleton Sandstone is grouped with the Petrel Cove Formation as the Wattaberri Sub-group, named from the property called "Wattaberri", some 2.5 km north of Port Elliot.

#### *Petrel Cove Formation* (new name)

This formation is much less resistant to erosion than the Balquhiddier Formation and thus forms a more subdued topography. It occurs in low cliff lines between a point 0.75 km west of King Beach and Petrel Cove, after which the formation is named. Good outcrops can also be inspected at low tide in Rosetta Harbor on the NW side of Rosetta Head. All parts of the formation in this area are readily accessible. It can be regarded as one of the key areas in the State where so many aspects of the effects of metamorphism and tectonism of a sedimentary sequence can be demonstrated clearly. All efforts should be made to preserve this stretch of coastline as a geological monument. Various aspects of the geology of parts of the sequence have already been discussed by Browne (1920), Bowes (1954), Hobbs & Talbot (1966) and Talbot & Hobbs (1968 and 1969).

A sequence of folded porphyroblastic and andalusite-cordierite schists constitutes the base of the Petrel Cove Formation. These conformably overlie the topmost unit of the Balquhiddier Formation which is composed of a sequence of fine-grained metasandstones and metasilstones. The schists exhibit a well-developed augen layering ( $S_1$ ) axial plane to  $F_1$  folds, which are clearly outlined by the bedding ( $S_0$ ) as is seen in Figs. 35 and 36. In the same outcrops (see especially Fig. 35) very thin light-coloured layers pervade the schists and appear as a series of thin closely spaced

stripes ( $S_2$ ) at a low angle to the augen layering. These stripes define what is herein termed a "striped" layering (see also Talbot & Hobbs, 1968). We regard this "striped" layering as having developed by alteration along tensional fractures post-dating the  $F_1$  folds. Note also that in the same outcrop (Fig. 35) there are "pinch-and-swell" pegmatitic layers parallel to the "striped" layering and along which dislocation has taken place. In several areas more than one set of "striped" layering can be recognised.

A well laminated metasilstone sequence (Fig. 37), parts of which are strongly folded, occurs on the wave-cut platform above the basal andalusite-cordierite schists. Mica porphyroblasts, light-coloured augen in  $S_1$ , and an infrequent "striped" layering show up in parts of this succession. Dislocation of bedding parallel to the stripes is again evident in some outcrops. Stratigraphically above are porphyroblastic metasilstones and schists with intervals showing either isolated augen in  $S_1$  or with augen sufficiently concentrated to produce an augen layering in  $S_1$ . Very fine-grained metasandstones are interbedded with these. On King Point the beds are well laminated and exhibit small-scale sedimentary structures (Fig. 38). Near this locality some calc-silicate layers occur parallel to the bedding and show a cleavage/bedding intersection plunging towards the south. These beds strike across the bay towards Petrel Cove.

Along the coast between King Beach and the contact between the Petrel Cove Formation with the Encounter Bay Granites on Rosetta Head, the incompetent metasediments within the Petrel Cove Formation show numerous meso-scale folds of two generations. The folded sequence consists of very fine grained metasandstones with interbeds of metasilstones and crenulated schists. Numerous deformed sedimentary structures such as those in Figs. 39 and 40 are common. Similar sedimentary structures have been figured or discussed by Hobbs & Talbot (1966) and Talbot & Hobbs (1969).

The common occurrence of "striped" layering (Figs. 39-47) which, in a thick homogeneous rock type, could possibly be mistaken for bedding has been mentioned above. This layering is markedly refracted across the boundaries between the metasandstones and the andalusite-cordierite schists. The layering is not only discontinuous but may even show a feathering effect (Fig. 45), again a feature suggesting that it developed in response to tension. In addition, it formed after the  $F_1$  fold-

ing phase because faint stripes cut straight through structures on the top of beds deformed by that phase of folding (Fig. 39). In many andalusite-cordierite schist intervals, especially along the coastline immediately west of Petrel Cove, the "striped" layering has been folded on a small scale about an axial plane parallel to the crenulation cleavage (S<sub>1</sub>) (Figs. 43 and 46). Many of these andalusite-cordierite schists show either a preferred concentration or a depletion of andalusite porphyroblasts parallel to the "striped" layering (Fig. 47).

Cainozoic and Permian sediments (uncoloured in Fig. 4) blanket most of the region between Rosetta Head and the hills lying to the north of Port Elliot. Over this distance no rocks belonging to the Wattaberri Sub-group are known to outcrop on the coast. However, in a section between Brown Hill and Wattaberri we have inferred a boundary between the Balquhiddier Formation (containing some blue-black carbonaceous and pyritic phyllites) and an overlying dominantly phyllitic-metasilstone sequence identified as the Petrel Cove Formation (Fig. 48). Despite a prolonged search in the area, we have been unable to locate andalusite or other distinctive metamorphic minerals so characteristic of many parts of the formation in its type section between King Point and Rosetta Head. Stratigraphically above these rocks are metasandstones of a distinctive facies which we call the Middleton Sandstone. This formation is best examined in the Middleton quarry and on Middleton Beach. Metasandstones of an identical facies and stratigraphic position lie in contact with the Encounter Bay Granites on the eastern end of Kangaroo I.

We have been unable to locate a contact between the Petrel Cove Formation and the Middleton Sandstone due to imperfect outcrop. Nevertheless, a tentative boundary has been positioned as shown in Fig. 4. Rocks shown as Middleton Sandstone are characterised by the presence of epidote-rich bands.

#### *Middleton Sandstone (new name)*

The best section of Middleton Sandstone is seen on the wave-cut platform in the vicinity of Middleton (Fig. 4). These outcrops, which are totally isolated from other Kanmantoo Group rocks, consist largely of grey-coloured fine-grained metasandstones which are generally lighter in colour and more quartzose than the bulk of the metasandstones found in the Kanmantoo Group, with the exception of some of the Inman Hill Sub-group metasandstones,

for example those of the Backstairs Passage Formation. The metasandstones are typically very well-laminated and are commonly cross-bedded with sets up to 1.2 m thick (Fig. 49) and with an indicated current direction generally from the west throughout much of the sequence. In some of the higher parts of the outcropping sequence, more random current directions are indicated. Some slumping down the direction of the cross-bedding is evident. Breaking the monotony of this well-laminated sequence are intervals with minor sedimentary structures, mainly small-scale current ripples, which include some starved ripples involving material of somewhat different grain size. There are also rare metasandstone beds up to 0.5 m thick containing angular phyllitic clasts up to 30 cm long and 15 cm thick, though generally the clasts are platy and less than 5 cm across. They represent the tipping up of partly-indurated mudstones by strong currents and their subsequent deposition in scour-channels after very limited transport. The only other metasediments present are a few metasilstones, up to 10 m thick, containing chlorite and actinolite.

One of the most conspicuous features of the sequence is the prevalence of pale-green epidote-rich segregations which are developed consistently throughout the succession. Albitised bleached zones of alteration are also present. Most of the epidote-rich segregations occur either in bands or as lenticular patches and nodules parallel to the bedding (Figs. 50-52) but some epidote occurs in association with quartz-chlorite-feldspar pegmatites that are developed in fractures and hoodlined zones.

All beds in the sequence face north. Observations show that the frequent occurrence of overturned southerly dipping beds is due solely to warping locally developed along the strike. Fracture-cleavage/bedding intersections indicate that the beds belong to the southern limb of a syncline plunging shallowly towards the east. This syncline is a second-generation fold as shown by overprinting relationships in Middleton Sandstone in the Middleton quarry. The recognition of large second-generation folds in this area significantly adds to the small number of macroscopic F<sub>2</sub> folds reported from elsewhere within the Mt. Lofty Ranges by Officer & Fleming (1968).

No upper boundary to the Middleton Sandstone is known on the Fleurieu Peninsula, and consequently this formation comprises the youngest Kanmantoo Group rocks in the

eastern Mt. Lofty Ranges. Because the Encounter Bay Granites exposed at Port Elliot seem to have intruded rocks of this formation, a substantial sedimentary cover must have existed above the Middleton Sandstone at the time of granite emplacement and metamorphism. This cover is likely to have embraced rocks of Middle Cambrian to possibly Early Ordovician age, as rocks spanning this suggested time interval occur on Yorke Peninsula (Daily 1969) and in the Flinders Ranges (Daily & Forbes 1969).

#### D. INTRUSIVE BASIC DYKES

Two groups of basic dykes that have intruded the Kanmantoo Group within the type section are shown in Figs. 2-4. The dykes of the first group are transgressive fine- to medium-grained metadolerites. Similar rocks have intruded the Encounter Bay Granites at Rosetta Head and Port Elliot.

The second group consists of basic dykes extensively contaminated by meta-sedimentary rock material. One such dyke containing large feldspar megacrysts, intrudes Balquhilder Formation metasediments along the coast east of Tunk Head (Fig. 3). This dyke was described by Madigan (1925). A second contaminated basic dyke-rock occurs in the line of ancient coastal cliffs backing Tunkalilla Beach, but it is poorly exposed. Similar contaminated basic dykes have intruded the Middleton Sandstone along the south coast of Dudley Peninsula (Kangaroo I.), west of Cape Hart. The results of our investigations of these rock types will be presented in a subsequent communication.

### Structure

#### A. THE STRUCTURE OF THE META-SEDIMENTARY SEQUENCE

An interpretation of the geological structure of the Lower Cambrian rocks exposed along the south coast of Fleurieu Peninsula between Campbell Creek and Tunkalilla Beach has been given in Daily & Milnes (1971a). This sequence, involving the upper parts of the Normanville Group<sup>1</sup> and the lower parts of the Kanmantoo Group, is contained within a NE plunging regional anticlinal structure which is overturned to the NW (Fig. 2). On the normal eastern limb of this fold between Madigan In-

let and Tunkalilla Beach, all the mapped macroscale folds are believed to be first-generation ( $F_1$ ) structures. Generally they conform to the style of the regional fold, and indeed to the style of folds developed in the Late Precambrian Torrens Group rocks in the Houghton area described as  $B_1$  folds by Talbot (1964), and most of the folds described by Offler & Fleming (1968) as  $F_1$  folds within large areas of the Mt. Lofty Ranges. They are mainly inclined and asymmetric with eastern limbs of anticlines longer than western limbs and with axial plane cleavages which dip steeply to the SE. In many instances, dislocation of the overturned western limbs of anticlines has taken place along faults that tend to parallel the axial plane schistosity. All structural data for this section of coastline are summarized in Fig. 5 which shows the following:

- (a) poles to bedding ( $S_0$ ) indicate a fold axis estimated to plunge towards  $047^\circ$  at a low angle, although mesoscale  $F_1$  folds plunge at variable angles towards both the NE and the SW;
- (b) intersections of  $S_{11}$  with cleavage ( $S_1$ ), long axes ( $L_1$ ) of phosphatic nodules (in the Heatherdale Shale), and the elongation of boudins resulting from the deformation of calc-silicate bands within the overlying Kanmantoo Group are parallel to the axes of mesoscale  $F_1$  folds;
- (c)  $F_1$  fold axes and the long axes of phosphatic nodules and calc-silicate boudins define a great-circle distribution which may be the result either of refolding or of inhomogeneous strain;
- (d) a lineation defined by the elongation of calcite and mica crystals on  $S_1$  surfaces (not bedding surfaces as reported in Daily & Milnes 1971a, p. 207) in calcareous and pelitic intervals respectively, pitches up to  $20^\circ$  more steeply than  $L_1$ , and is now interpreted as a first-generation structure  $L_1'$  (not a second-generation structure as suggested by Daily & Milnes 1971a). The preferred orientation of hornblende poikiloblasts and chlorite porphyroblasts on  $S_1$  surfaces in calc-silicate boudins and pelitic intervals respectively is approximately parallel to  $L_1'$ , but its significance is not understood.

<sup>1</sup> This new name is defined herein to include all the Lower Cambrian sediments between the base of the Mount Terrible Formation and the base of the Carrickalinga Head Formation as mapped in the Sellick Hill-Normanville area by Abele & McGowran (1959) and revised by Daily (1963).

FOLD PHASE	PLANAR ELEMENT	LINEAR ELEMENT
First generation structures	$S_0$ = surface	
	$S_0$ = bedding	
$F_1$	$S_1$ = schistosity	$L_1$ = lineation or axis of fold in $S_0$ with $S_1$ as axial surface $L_1'$ = lateral plunging in $S_1$
Second generation structures	$S_2$ = crenulation cleavage. Axial surface to $F_2$ folds.	$L_2$ = lineation or axis of fold or crenulation in $S_0$ or $S_1$ with $S_2$ as axial surface
† represents estimated direction and plunge of fold axis		

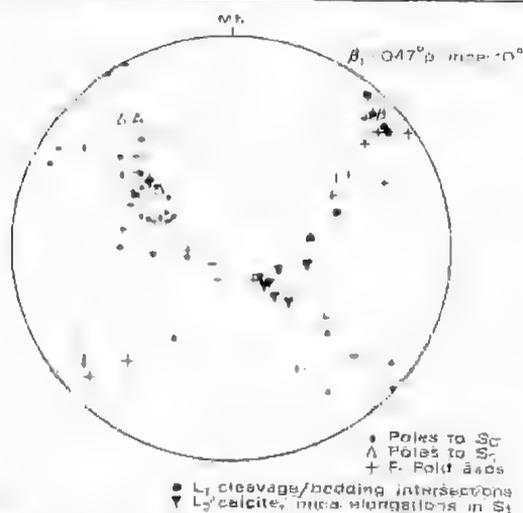


Fig. 5. (Above)—Table of structural elements and corresponding symbols utilised in the text. (Below)—Equal area projection of structural data for the section between Madigan Inlet and Tunkalilla Beach.

Structural data for the remainder of the type section and the region east to Middleton are as follows:

(i) *Tunkalilla Beach to Rosetta Head*

All the macroscale folds mapped and most of the mesoscale folds observed to the east of Tunkalilla Beach are interpreted as  $F_1$  structures. They contrast with the style of the regional fold to the west (mentioned above) in that the western anticlinal limbs are not overturned. The folds are however mainly asymmetric with western anticlinal limbs steeper and shorter than the eastern limbs although towards Rosetta Head the folds tend to be more upright, symmetrical and open (Fig. 36). In general, folds in metasediments are open

structures whereas folds in the metasiltsstones and schists, particularly within the Petrel Cove Formation, are smaller scale structures that tend to be moderately tight and upright. The transition from one style to another within the metasediments cannot be pin-pointed. Our observations suggest that it is gradual, and it seems significant that the highly appressed  $F_1$  folds are characteristic of the oldest parts of the stratigraphic sequence, whereas folds in progressively younger formations are more open and upright. The validity of this proposition is strengthened because on Dudley Peninsula, Kangaroo I., and along the Mount Barker Creek, comparable situations pertain on the eastern limb of the regional anticline.

The axial plane schistosity in  $F_1$  folds is defined by the preferred orientation of micas which commonly enclose small quartz-rich aggregates and, in some localities east of Newland Head, cordierite porphyroblasts. The resulting augen define a unique augen-layering parallel to  $S_1$  (Figs. 34 & 35; Talbot & Hobbs 1968). In the schists east of Newland Head there is a distinct but often discontinuous lineation due to the elongation of augen on  $S_1$  surfaces (Fig. 53). This lineation is decidedly different in orientation from that of the intersection of  $S_0$  and  $S_1$  surfaces and the axes of  $F_1$  folds.

A weak crenulation of  $S_1$  is apparent in phyllites near Coolawang Creek and becomes more distinct eastwards. This crenulation provides evidence for the overprinting of first-generation structures. In some areas there is a penetrative strain-slip cleavage ( $S_2$ ) which is axial plane to mesoscale second-generation ( $F_2$ ) folds. Such folds are most conspicuous adjacent to pre- $F_2$  metamorphic pegmatites (Fig. 54). They refold small-scale  $F_1$  folds (Figs. 54 & 55) and are responsible for the local variation in the plunge of  $F_1$  fold axes from NE to SW. It should be noted that in the Rosetta Head region, Talbot & Hobbs (1968, p. 584) have pointed out "that several sets of crenulation cleavage are developed locally". We have mapped only one crenulation cleavage ( $S_2$ ) in that area.

The distinctive "striped" layering ( $S_0$ ) referred to above is best developed just west of Petrel Cove. Talbot & Hobbs (1968) also reported its occurrence in the Kanmantoo Mine area in metasediments assigned by Daily & Milnes (1972a) to the Tapanappa Formation. The "striped" layers are zones of alteration and consist predominantly of quartz and plagioclase

with some muscovite. They are up to 3 cm wide, and are often bordered by thin biotite-rich zones. In addition they may show a median biotite- and/or quartz-filled fracture (Fig. 56). Although the "striped" layering cuts across  $S_2$ , a relict  $S_1$  schistosity, outlined by the preferred orientation of muscovite and rare biotite, can be seen within the "striped" layering. Structural relationships show that the layering is not only post- $F_1$  but clearly pre- $F_2$  (Figs. 43 & 46). Talbot & Hobbs (1968, p. 585) suggested that the "striped" layers are "non dilatational and represent some form of differentiation process in situ". In view of the presence of a central fracture within the "striped" layers, the refraction of layering across bedding, and feathering, we can only conclude that these structures are dilatational and are due to tension and subsequent alteration adjacent to the fractures.

All structural data collected between Tunkajilla Beach and Rosetta Head are given in Fig. 6 a-d. This shows the following: Poles to  $S_0$  show a great-circle spread and indicate a fold axis estimated to plunge at 25° towards 200° (Fig. 6a). This is supported by the attitudes of  $L_1$  lineations defined mainly by the intersection of  $S_1$  and  $S_0$  surfaces (Fig. 6b). However, axes of mesoscale  $F_1$  folds are distributed about two point maxima, indicating plunges towards the NE and the SW at shallow angles (Fig. 6c). This variation in plunge together with the significant spread of poles to  $S_1$  (Fig. 6c) may indicate refolding of the first-generation structures, or may be due to differential strain.  $L_2$  lineations (the axes of crenulations in  $S_1$ ) plot as a diffuse maximum giving an estimated plunge towards 165° at 65° (Fig. 6d)<sup>2</sup>.

### (ii) The Brown Hill Area

In the Brown Hill area, large scale NE plunging asymmetric  $F_1$  folds in Balquhider Formation metasediments occupy a narrow NE trending zone. The folds are upright, and have the open style typical of  $F_1$  folds in metasandstones in the eastern part of the type section. The axial plane schistosity is defined by the preferred orientation of micas. A lineation formed by the intersection of  $S_1$  and  $S_0$  surfaces is parallel to  $F_1$  fold axes.  $S_1$  surfaces in pelites contain a mineral lineation defined by the preferred orientation of micas. This lineation has a steep southerly pitch in  $S_1$  and is interpreted

as a first-generation structure ( $L_1'$ ). It is best seen in the Lincoln Park quarry, south of Brown Hill.

The structural elements measured in this area are plotted in Fig. 6e. Poles to  $S_0$  lie along a great circle, and indicate an  $F_1$  fold axis estimated to plunge at 35° towards 051°. This is supported by the attitudes of  $L_1'$  lineations. Two measured  $L_1'$  lineations plunge steeply towards the south.

### (iii) The Middleton Area

East of the Brown Hill area,  $F_1$  folds in metasediments assigned to the Petrel Cove Formation and the Middleton Sandstone have been overprinted by large- and small-scale  $F_2$  folds that plunge at shallow angles towards the SE. The relationships between  $F_1$  and  $F_2$  structures, both of which exhibit varying degrees of development in the area, are best examined in the Middleton quarry about 1.6 km NW of Middleton.

SE plunging  $F_2$  folds are the dominant structures in the Middleton quarry, and are moderately appressed, inclined folds in which the northern limbs of anticlines are longer than the southern limbs, and tend to be overturned (Fig. 57). The larger folds contain small-scale refolded  $F_1$  folds in pelitic units (Fig. 58).

A prominent set of fractures occurs in  $F_2$  folds in metasandstones and parallels the weakly developed axial plane schistosity of these folds (Fig. 57). The intersections of the fractures ( $S_2$ ) with the bedding define a ridge-and-furrow lineation which parallels the  $F_2$  fold axis and is referred to here as  $L_2$  (Fig. 59). These fractures have largely controlled albittisation and the emplacement of thin pegmatites. They have also been planes of post-alteration movement along which either thin coatings of fibrous hornblende or brecciated zones have developed.

Inspection of the metasediments in the Middleton area shows that three schistosities are present. A well expressed axial plane schistosity in some mesoscale folds in fine grained metasandstones can be seen in thin sections to crenulate a poorly developed older schistosity that is approximately parallel to bedding (Fig. 60). Moreover, an examination of the axial plane schistosity surfaces shows a conspicuous mica-streaking lineation that is not parallel to the fold hinges (Fig. 61). The presence of two schistosities in these folds

<sup>2</sup> Mesoscale  $F_2$  folds are uncommon but generally occur near the margins of pre- $F_2$  pegmatite dykes in the Petrel Cove Formation. No attempt was made to measure their attitudes in such localities.

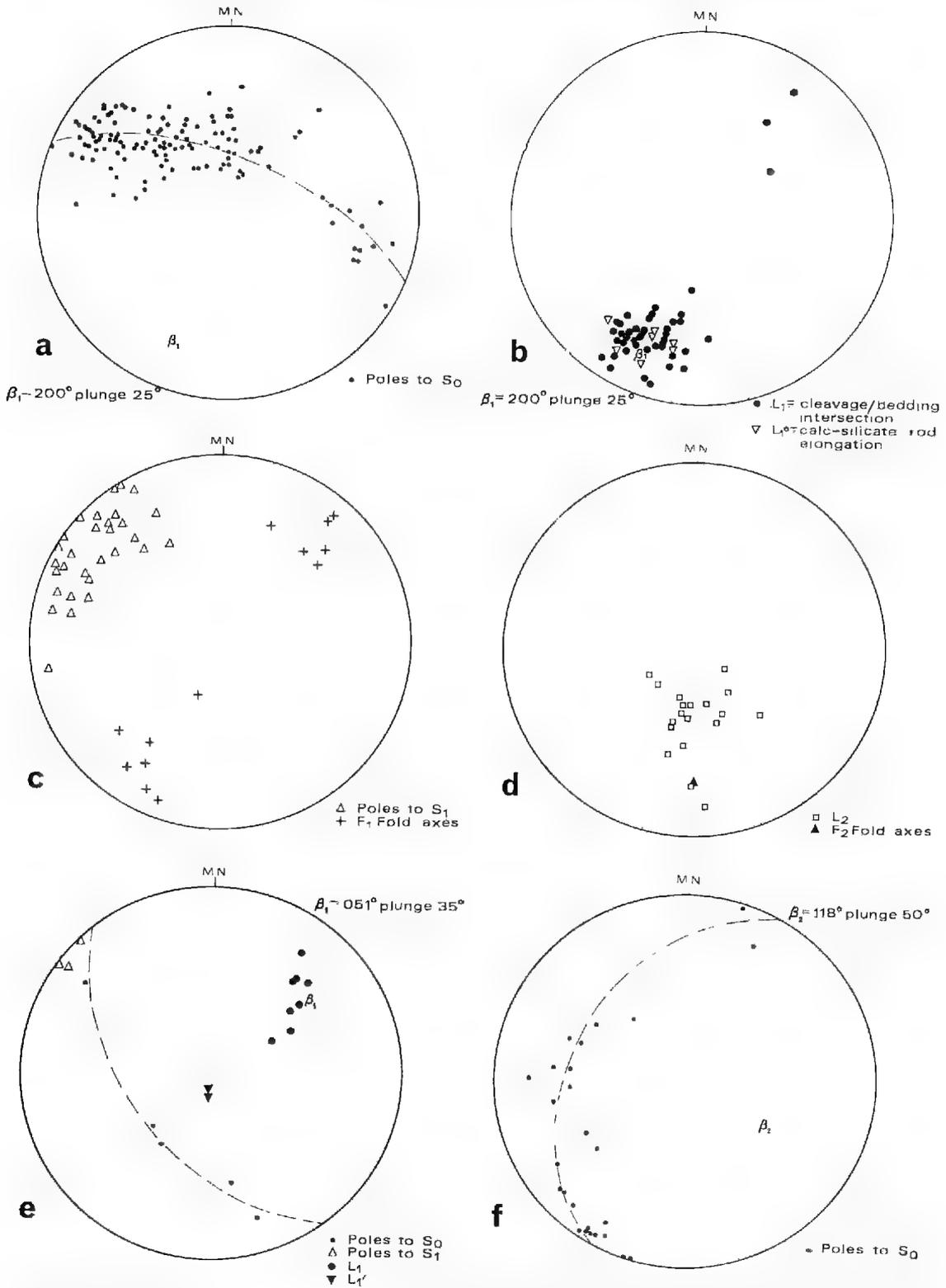


Fig. 6. Equal area projections of structural data. a-d, Tunkalilla Beach to Rosetta Head; e, Brown Hill area; f, Middleton quarry.

would normally identify the folds as second-generation structures. However, small scale  $F_2$  folds in the Middleton quarry are characterised by a *poorly-developed axial-plane schistosity* ( $S_2$ ) that overprints a moderately well-developed schistosity parallel to bedding. In these folds, it is the older schistosity that contains a prominent mica-streaking lineation which is similar in nature and orientation to the  $L_1'$  lineation recorded in metasediments in the coastal part of the type section and in the Brown Hill area. In the Middleton quarry, this mica-streaking lineation is readily seen on the surfaces of  $F_2$  folds, where it is oriented at a significant angle to the intersection between bedding and  $S_0$  (Fig. 62). In view of these observations, we presently interpret the meso-scale folds of uncertain affinities as first-generation structures that formed in metasediments containing a pre-tectonic bedding plane schistosity, and the accompanying prominent mica-streaking lineation as  $L_1'$ .

$F_2$  folds were not observed in the rather poor exposures outside the Middleton quarry, or in the small quarry exposures NW of Port Elliot. In these localities, folds also hesitantly interpreted as first-generation structures form the dominant structural elements. They are best seen in the exposures to the north of the Middleton quarry. They are inclined, and plunge at steep angles towards the SE. The axial plane schistosity is a pronounced mica-preferred orientation which again overprints a poorly preserved presumed pre-tectonic bedding-plane schistosity in some specimens. The intersection of bedding with the axial-plane schistosity is parallel to the axes of the folds. However, a prominent mica-streaking lineation on schistosity surfaces pitches up to 20° from the intersection between bedding and the axial-plane schistosity.

$S_1$  surfaces in phyllites of the Petrel Cove Formation exposed in the quarries NW of Port Elliot and in the cuttings along the Crow's Nest road exhibit a fine-scale crenulation. The crenulation appears to have a similar orientation to the conspicuous mica-streaking lineation (presumed  $L_1'$ ) on  $S_1$  surfaces in metasandstones in the Middleton area, but is interpreted as a second-generation structure.

The exposures of Middleton Sandstone along the coastline at Middleton are dominated by  $F_2$  structural elements. A prominent ridge-and-furrow lineation ( $L_2$ ) indicates a shallow easterly-plunging fold. This agrees with the

orientation of the fold axis of the only fold recorded along the beach.

The geometry of the structural elements for the Middleton area are given in Figs. 6f, 7a-c and show the following: Poles to  $S_0$  measured in the Middleton quarry (Fig. 6f) do not reflect the attitudes of first-generation folds, but define an  $F_2$  fold axis estimated to plunge towards 118° at 50°. This agrees with the attitudes of measured  $F_2$  fold axes and  $L_2$  ridge-and-furrow lineations (Fig. 7a). In addition, it is consistent with the distribution of poles to  $S_0$  fractures in metasandstones.

The distribution of measured mica-streaking lineations in the Middleton quarry indicates an estimated plunge towards 122° at 65°, whilst the attitude of the related schistosity indicates a steeply-plunging inclined style for folds herein interpreted as first-generation structures (Fig. 7b).

The structural elements  $S_0$  and  $L_2$  measured in the exposures at Middleton Beach define an  $F_2$  fold axis estimated to plunge at 28° towards 090°, and this is supported by the attitude of one mesoscale  $F_2$  fold axis (Fig. 7c).

In all other parts of the Middleton area, presumed first-generation structures are dominant. Poles to  $S_0$  define an  $F_1$  fold axis estimated to plunge at 60° towards 142° (Fig. 7d). The rather diffuse distribution of  $S_0$  poles on the western side of the diagram may reflect the influence of second-generation folds. The attitude of the  $F_1$  fold axis is confirmed by the distribution of mica-streaking lineations and the attitudes of poles to the axial-plane schistosity (Fig. 7e), and approximately coincides with the orientation of presumed first-generation structures recorded in the Middleton quarry.

## B. STRUCTURAL RELATIONSHIPS OF THE ENCOUNTER BAY GRANITES

The contact between the Kanmantoo Group metasediments (Petrel Cove Formation) and the Encounter Bay Granites is exposed on Rosetta Head and Wright I., but is best examined on Wright I. because of the excellent exposures there. Our observations of the relationships at this contact can be summarised as follows:

- (a) The marginal phase of the Encounter Bay Granites is a coarse-grained megacrystic granite. Megacrystic granite sheets of variable thickness and grain size form apophyses from the main granite mass, and are largely concordant with bedding in the Petrel Cove Formation metasedi-

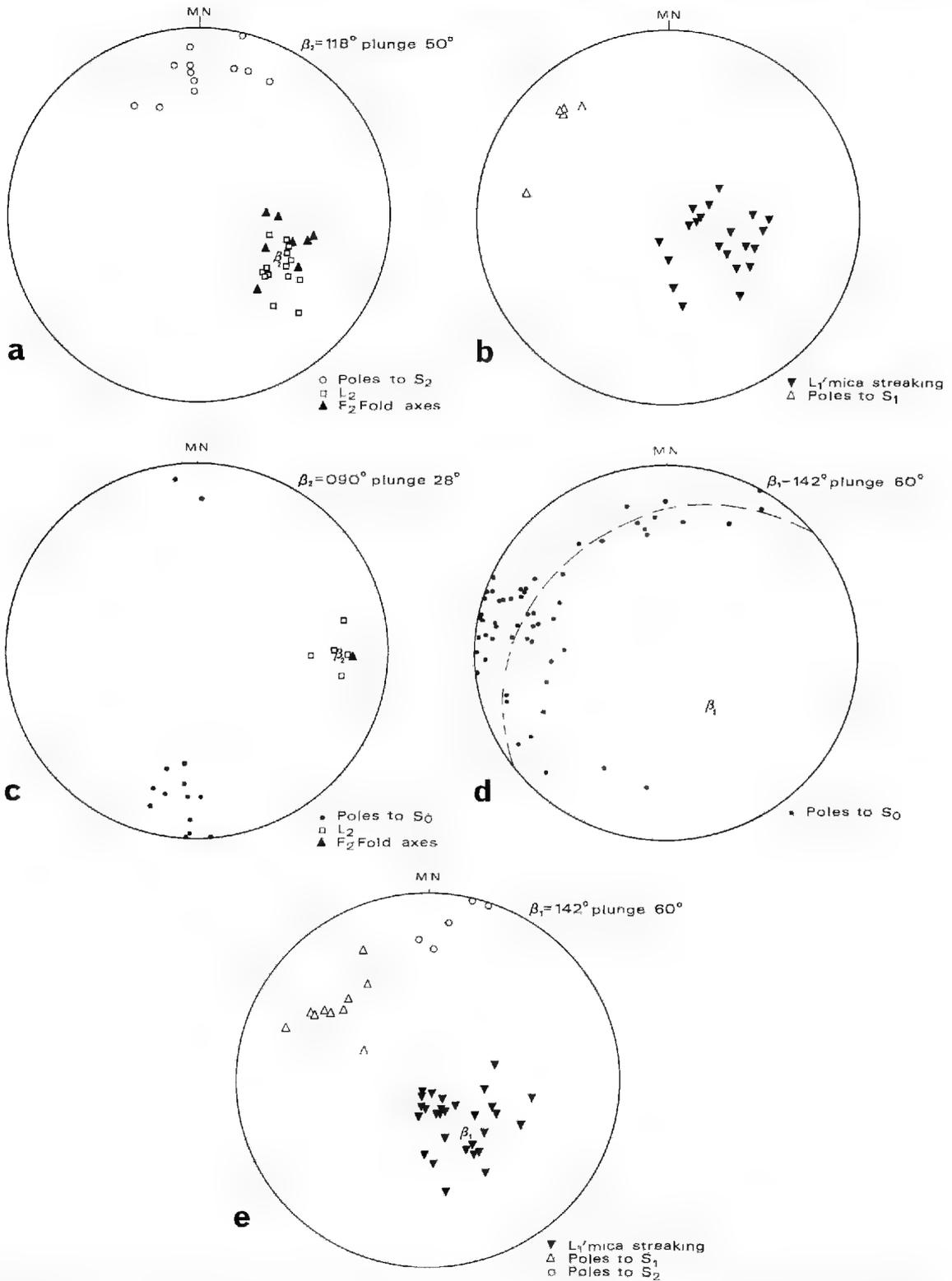


Fig. 7. Equal area projections of structural data. a-b, Middleton quarry; c, Middleton Beach; d-e, Middleton area excluding the Middleton quarry and Middleton Beach.

ments (Fig. 63). The granite sheets are markedly boudinaged in places.

- (b) Petrel Cove Formation metasediments in contact with the megacrystic granite, both on Wright I. and Rosetta Head, are laminated metasilstones. A paucity of porphyroblastic andalusite and cordierite schists adjacent to the contact compared with their abundance at lower stratigraphic levels within the formation further from the granite was noted.

- (c) A prominent schistosity ( $S_1$ ) occurs in the Petrel Cove Formation metasediments and a parallel schistosity occurs in the borders and constricted portions of the boudinaged megacrystic granite sheets (Fig. 64). The same schistosity is variably developed within the marginal metre of the main granite mass. Within the affected granite, the schistosity (Fig. 65) is defined by alternating laminae of recrystallised biotite and quartz, which enwrap large potash feldspar and plagioclase megacrysts. Although recrystallised along their margins, these megacrysts retain their original internal structures; some have been rotated.

The schistose granite may be regarded as a protomylonite using the terminology of Higgins (1971). However, we believe that the schistosity has been imposed during regional deformation at a moderately high temperature. The variable development of the schistosity in the granite along the contact, together with its absence from the internal parts of the pluton, are taken as evidence for the high yield strength of the granite at this time, and suggest that the pluton possessed rigid body properties during the regional deformation.

- (d) Metasedimentary-rock xenoliths within the megacrystic granite away from the contact are devoid of deformation structures and, with few exceptions, tectonically imposed mica-preferred orientations. Moreover, xenoliths containing andalusite or cordierite porphyroblasts have not been observed.
- (e) Structures younger than the  $S_1$  schistosity occur within the metasediments and granite sheets on Wright I., and include fine scale crenulations in the  $S_1$  schistosity. Broad scale kink-folding of bedding and thin granite sheets has also been noted. On the southern side of Wright I., a cataclastic zone crosses the contact and has deformed the  $S_1$  schistosity. Cataclastic

textures are conspicuous in the granite, and are strikingly different from textures in the schistose granite.

### C. SUMMARY

The observations and measurements of structural elements indicate two main phases of deformation of Kanmantoo Group metasediments in the type section. With the exception of parts of the Middleton area, first-generation structures are dominant. However, second-generation structures are moderately well developed in the Petrel Cove Formation between Rosetta Head and King Beach, and are dominant in Middleton Sandstone in the Middleton quarry and at Middleton Beach.

There are several structural observations that will only be adequately explained after the completion of a more comprehensive investigation of the structural geology of the Kanmantoo Group than was attempted here. Such observations include the variable development of structural elements in the type section, and the variability in style and orientation of first-generation folds. Notwithstanding, the data presented herein provide an adequate basis for an interpretation of the time of emplacement of the Encounter Bay Granites in relation to the structural deformations recorded in the contiguous Kanmantoo Group metasedimentary rocks. The following observations are considered most pertinent to this discussion;

- (a) The prominent schistosity that occurs within some parts of the megacrystic granite along its contact with the Kanmantoo Group metasediments, and in boudinaged granite sheets within metasediments adjacent to the contact, is parallel to the  $S_1$  schistosity in the metasediments; and
- (b) metasedimentary-rock xenoliths that occur within the megacrystic granite away from the contact are, with few exceptions, devoid of tectonically imposed mica-preferred orientations.

Thus the Encounter Bay Granites are considered to have been emplaced *prior to the main phase of first-generation deformation* and are, in this sense, *pre-tectonic*. The texture of the schistose granite indicates that the megacrystic granite had completely crystallised prior to the imposition of the  $S_1$  schistosity during the main deformation phase.

Although second-generation structures have overprinted the  $S_1$  schistosity in the metasediments and in the biotite-rich borders of the granite sheets on Wright I., their sporadic development has prevented an assessment of their

effect on the granites on a broad scale. On the other hand, second-generation structures provide an important reference point in a discussion of the relative ages of pegmatite and metadolerite dykes. For example, both pegmatites and metadolerites occur as transgressive dykes within the Petrel Cove Formation, and do not exhibit first-generation structural elements. However, they have been folded and boudinaged during the second phase of deformation. In fact, second-generation structures, including mesoscopic folds and an obvious crenulation cleavage, are commonly best developed immediately adjacent to these dykes. On the basis of these observations, the pegmatites and metadolerites appear to post-date the first-generation folding and pre-date the second. Similar rock-types intruding metasediments further west in the type section are probably of the same age, although this cannot be confirmed because of the apparent absence of second-generation structures in these areas.

### Metamorphism

Published studies on the metamorphic petrology of the type Kanmantoo Group have centred around the metasediments in the vicinity of Rosetta Head. From that area Browne (1920) first recorded the presence of andalusite and cordierite. Later, Bowes (1954) subdivided these metasediments into three groups, namely quartz-biotite schists, andalusite and cordierite schists, and albite and chlorite schists. Both Browne and Bowes regarded the metamorphic assemblages as a consequence of the emplacement of the Encounter Bay Granites. On the other hand, Offer & Fleming (1968, p. 259) recognised "snowball" internal fabrics in the andalusite and cordierite porphyroblasts in this area and suggested that "since the Victor Harbor Granite does not appear to have been emplaced forcefully, such fabrics could only have been produced during a deformation phase before the intrusion of the granites". As shown below cordierite is mainly pre- to early syn- $F_1$ , whilst andalusite is late syn- to post- $F_1$  and pre- $F_2$ .

For that part of the type Kanmantoo Group west of Tunkalilla Beach, Daily & Milnes (1971a) concluded that the metamorphic grade lay between the almandine and staurolite isograds as defined by Winkler (1970), and within the andalusite-staurolite zone of Offer &

Fleming (1968). Although our estimate of the grade still stands, we realize that our interpretation of the metamorphic history was oversimplified. In the present context we have attempted to link the various mineral assemblages to readily identifiable structural elements in the rocks and thus deduce the relative time relations between crystal growth and deformation in the fashion of Zwart (1963), Spry (1963) and Offer & Fleming (1968). However, this method cannot give a measure of the time between the various structural and concomitant metamorphic phases, nor can it allow one to assess the time taken for the essential metamorphic reactions to produce the mineral assemblages seen today. It is most likely that the various recognisable metamorphic phases discussed below are but part of a continuum.

It should be noted that all the following observations and the conclusions drawn from them pertain only to rocks in the type section of the Kanmantoo Group as specified by Sprigg & Campana (1953) and in our extension of the type section into the region between Brown Hill and Middleton Beach, which we regard as belonging to the uppermost part of the Kanmantoo Group in the eastern Mt. Lofty Ranges.

Within the Kanmantoo Group conspicuous metamorphic mineral assemblages are uncommon, and are confined mainly to thin calc-silicate bands and lenses and to some pelitic intervals. All metasediments except the phyllites retain aspects of their original detrital nature despite the deformation and metamorphism.

The following assemblages of minerals<sup>3</sup> seem to be representative of the various rock types within this region:

- (a) metasandstones and metasiltstones—  
quartz + plagioclase + biotite + muscovite ± calcite ± chlorite + garnet ± scapolite ± epidote;
- (b) phyllites—  
quartz ± plagioclase + biotite + muscovite ± chlorite ± garnet ± andalusite ± cordierite;
- (c) carbonaceous and sulphide-rich phyllites—  
quartz + plagioclase + muscovite + pyrrhotite + graphite;
- (d) calc-silicates—  
quartz + plagioclase + hornblende ± garnet ± chlorite ± calcite ± biotite ± muscovite ± pyrrhotite ± epidote.

<sup>3</sup> Offer & Fleming (1968) have reported fibrolite in many schists within the Mt. Lofty Ranges. We had not seen this mineral in our thin sections until Dr. R. Offer located an isolated patch in a thin section of metasandstone collected 200 m east of Bollaparudda Beach.

As a result of a petrographic study of the Kanmantoo Group rocks collected during our traverses, the following scheme of progressive metamorphic crystallisation is envisaged:

#### A. Pre- to Syn- $F_1$ Metamorphic Crystallisation

Metamorphic elements attributed to this phase of crystallisation include small quartz-rich aggregates; groundmass biotite and muscovite, porphyroblasts of biotite, andalusite and rare chlorite, and cordierite augen, the latter commonly altered to a brownish-yellow clay mineral determined by electron probe analysis as kaolinite.

Biotite porphyroblasts occur with groundmass micas throughout the region, but the quartz-rich aggregates seem to be restricted to the region between Tankahilla Beach and Encounter Bay. Cordierite is more severely restricted, being found only in some phyllite bands in the upper part of the Balquhadder Formation, and in the Petrel Cove Formation near Rosetta Head.

Metamorphic elements of pre- $F_1$  age are uncommon but include many small quartz-rich aggregates containing feldspar, opaques and micas (Figs. 66 & 67). Their grain size is always finer than that of the same minerals in the groundmass. They form augen which generally contain a random internal mica fabric and are enwrapped by the well developed mica schistosity. However, some quartz-rich augen that have been observed with a poorly-oriented mica fabric may be partly syntectonic. Some cordierite augen in the Petrel Cove Formation exhibit a random inclusion fabric and represent pre- $F_1$  crystallisation.

Metamorphic elements formed during the first phase of deformation include the minerals that define the  $S_1$  schistosity, namely biotite and muscovite. For the most part, syn- $F_1$  biotite and muscovite are fine grained. Medium-grained biotite and chlorite porphyroblasts of this age have been noted.  $S_1$  is also commonly marked by a preferred orientation of opaque mineral laths, for example Fig. 66. Many cordierite augen which are enwrapped by  $S_1$  show oriented inclusion fabrics, that are either planar and inclined at a significant angle to  $S_1$ , or are S shaped (Figs. 67-70). Such fabrics are continuous with the  $S_1$  schistosity in the enclosing rock. Moreover, as inclusions within the porphyroblasts are finer than the same minerals in the groundmass, we conclude that cordierite crystallised and was rotated during the early stages of formation of  $S_1$ .

Andalusite commonly occurs as S-shaped poikiloblasts containing S-shaped inclusion-trails that are continuous with the external  $S_1$  schistosity (Fig. 71). Such poikiloblasts are the result of late syn- $S_1$  crystallisation and rotation. In some cases the outer margins of poikiloblasts cut across this schistosity and must therefore represent post- $S_1$  crystallisation (Fig. 72)

#### B. Post- $F_1$ Metamorphic Crystallisation

The major porphyroblastic crystallisation appears to have occurred during the post- $F_1$  and pre- $F_2$  static phase when andalusite, garnet, hornblende, biotite, chlorite, muscovite, scapolite and epidote crystallised in rocks of appropriate lithology. These minerals cut across the groundmass  $S_1$  schistosity, but are deformed by the  $S_2$  crenulation cleavage in rocks in which this structure is developed. The following conspicuous minerals and mineral assemblages are characteristic of this metamorphic episode:

- (a) calc-silicates—  
hornblende + plagioclase  $\pm$  garnet  $\pm$  chlorite  $\pm$  epidote;
- (b) metasediments and metasilstones —  
muscovite  $\pm$  garnet  $\pm$  chlorite  $\pm$  epidote;
- (c) phyllites—  
 $\pm$  andalusite  $\pm$  chlorite  $\pm$  muscovite  $\pm$  garnet  $\pm$  scapolite  $\pm$  biotite.

In addition, there are several minor components such as tourmaline, some opaque minerals and sphene which appear to have crystallised across the groundmass  $S_1$  schistosity, and are similarly attributed to this metamorphic episode.

Post- $S_1$  andalusite occurs both as overgrowths on syn- $S_1$  poikiloblasts (Fig. 72), and as poikiloblasts that have overgrown the groundmass  $S_1$  schistosity and have retained relicts of this in the form of oriented opaque laths and quartz grains (Figs. 73 & 74). In addition, post- $S_1$  chlorite (Figs. 75 & 76) and less commonly muscovite occur in phyllites and metasilstones throughout the type section as poikiloblasts that have grown across  $S_1$ . Scapolite occurs as small porphyroblastic clots that appear to have grown across  $S_1$  within metasilstones, 1 km east of Coolawang Creek.

Porphyroblastic zoned garnets (Fig. 77) may occur with minor muscovite, chlorite, epidote and tourmaline in metasilstones and metasediments throughout the type section. These have grown across the  $S_1$  schistosity. Such garnets are conspicuous in the heavy mineral sand suites along the southern coastline.

Although an interpretation of the textural relationships in most rocks suggest that the crystallisation of cordierite preceded that of andalusite, co-existing post- $F_1$  cordierite poikiloblasts and andalusite euhedra occur in pelites within 1 m of a metadolerite dyke about half way between King Beach and Rosetta Head. As structural evidence indicates that the metadolerite intrusions are post- $F_1$  but pre- $F_2$ , the cordierite-andalusite assemblage is interpreted as being the result of a local increase in temperature along the dyke margins.

Post- $F_1$  calc-silicate segregations occur throughout much of the region and possess a weakly defined relict  $S_1$  schistosity that contrasts with the better defined schistosity of the enclosing metasediments. Hornblende poikiloblasts (erroneously identified optically as actinolite by Daily & Milnes 1971a) occur in the calc-silicates and, at best, exhibit only a moderate degree of preferred orientation parallel to the relict  $S_1$  schistosity. Some hornblendes transverse to  $S_1$  contain undeflected remnants of that schistosity, especially opaque laths. Zoned garnets occur in the calc-silicates as subhedral poikiloblasts that cut across  $S_1$  but these also have inherited the  $S_1$  schistosity.

Post- $F_1$  metamorphic minerals that occur in pelites in the eastern part of the type section, where the  $S_2$  crenulation cleavage is best developed, are deformed by  $S_2$ . The dislocation of chlorite and andalusite poikiloblasts along zones commonly defined by trains of opaque minerals grains (Fig. 78), are especially evident in pelites in the Petrel Cove Formation in which  $S_2$  assumes the characteristics of a strain-slip cleavage.

Many pegmatites within the type section are composed of minerals that characterise the post- $F_1$  mineral assemblages in the host rocks. On structural evidence, such pegmatites are post- $F_1$  and pre- $F_2$  and represent the "sweat" products concentrated in regions of low pressure gradient (Rivalenti & Sighinolfi 1971). Wall-rock alteration has been noted adjacent to some of these pegmatites.

### C. Conditions of Metamorphic Crystallisation

A petrographic examination of Kanmantoo Group metasediments in the type section seems to indicate a relatively simple sequence of metamorphic crystallisation. This sequence began with the formation of quartz-rich aggregates and the crystallisation of cordierite during the pre- to early syn- $F_1$  phase of deformation, was followed by the late syn- $F_1$  crystallisation of andalusite and chlorite and ended with the

post- $F_1$  crystallisation of andalusite, chlorite, garnet, hornblende, muscovite and seapolite.

Offler & Fleming (1968) regarded the metamorphic mineral assemblages throughout much of the Mount Lofty Ranges as characteristic of low pressure, intermediate-type metamorphism. With reference to the aluminosilicate data of Newton (1966), they suggested that metamorphism in the areas of highest grade occurred at pressures ( $P_{total} - P_{fluid}$ ) between 3 and 4 kb and at temperatures in the vicinity of 650°C. The metamorphic minerals in the Kanmantoo Group metasediments in the type section are certainly consistent with conditions of low pressure, intermediate-type metamorphism, but are representative of lower temperatures and pressures than the assemblages upon which Offler & Fleming based their estimate.

The crystallisation of pre- to syn- $F_1$  cordierite and late syn- to post- $F_1$  andalusite in metasediments in the type section suggests that the conditions of metamorphism at this time were consistent with the andalusite-cordierite-muscovite subfacies of the amphibolite facies (Winkler 1965). Of several possible parageneses involving the crystallisation of cordierite, the reaction—chlorite + andalusite + quartz = cordierite + vapour (Siefert & Schreyer 1970) seems to be consistent with the observed mineral assemblages. Based on the experimental P-T conditions for this reaction, and for the aluminosilicate stability as determined by Holdaway (1971), the crystallisation of cordierite and andalusite in metasediments in the type section probably occurred at pressures below about 3 kb and at temperatures estimated to be less than 540°C (Milnes unpub. Ph.D. thesis).

## Discussions and Conclusions

As a result of our studies on the upper part of the type Kanmantoo Group, several facts emerge from which a number of conclusions can be drawn additional to those given in Daily & Milnes (1971a).

### A. Stratigraphic Relationships

In no instance throughout the whole of the coastal sections have we been unable to ascertain bedding. Transposition as described by Talbot & Hobbs (1968) is confined to the vicinity of Petrel Cove. Most outcrops retain their gross sedimentary features despite the tectonism and metamorphism. This is readily discernible from the accompanying figures.

There appears to be conformity between all the formations making up the Kanmantoo Group as set out in Table 1. The validity of this stratigraphic scheme is enhanced by the occurrence of a virtually identical sequence on Dudley Peninsula, Kangaroo I. (Daily & Milnes 1971b, 1972b). As our investigations on this island are as yet incomplete there is still room for an upward continuation of the sequence beyond the Middleton Sandstone. The latter constitutes the youngest part of the Kanmantoo Group in the Mt. Lofty Ranges. It is worth noting that in the original definition of the Kanmantoo Group, Sprigg & Campana (1953, p. 14) stated that "the upper boundary of the Kanmantoo Group remains undefined".

#### B. *The Kangarooian Movements and Kanmantoo Group Sedimentation*

All the original sediments making up the Brown Hill and Wattaberrri Sub-groups in the type section were clastics which ranged in grain size from clay to pebbles at least 5 cm in diameter. Limestones were absent. Indeed, carbonate shows up only as pebbles in conglomerates or pebbly sandstones. However, its former presence as an accessory is probably indicated by epidote-rich bands in the Middleton Sandstone and as the thin calc-silicate segregations and bands in all the other stratigraphic units within both sub-groups.

Metasandstone is by far the dominant lithology throughout most of the Kanmantoo Group. The sands were essentially immature and contained varying amounts of clay and silt (mud) as matrix. Quartz and subordinate feldspar were the dominant sand-sized particles and were derived mainly from the older Precambrian crystalline basement.

The rapidity of deposition may be gauged not only by the immaturity of the sands but also from the dominance of parallel lamination within the metasandstones. We interpret this type of bedding as a consequence of the high flow regime that prevailed through much of the depositional history of the group. Intervals with cross-bedding and especially current-ripple lamination are common and represent deposition at lower flow power as has been established by Simons *et al.* (1965), Guy *et al.* (1966) and Williams (1967). Allen (1970a, Figs. 4 & 6), using some of these experimental data, has shown the possible alternative sequences of sedimentary structures that may form for varying grain size with decreasing flow power at the time of deposition.

The sands were laid down by currents, which

over long periods of time were largely unidirectional. Measured current directions from sediments infilling low amplitude scour-channels within the Brown Hill Sub-group indicate distribution of sediment by currents flowing generally from the NW quadrant. This is similar to current directions established for the underlying Inman Hill Sub-group. We have been unable to detect a decrease in pebble size towards the east for conglomerates in the Brown Hill Sub-group, though such a variation is discernible in the underlying Inman Hill Sub-group. For instance, conglomerates in an overturned sequence of metasandstones at Penne-shaw, Kangaroo I., contain clasts up to 30 cm in diameter. In correlative conglomerates in the uppermost parts of the Tapanappa Formation near Tunkalilla Beach, the maximum pebble size is 7 cm. The greater distance of transport for these pebbles is also reflected in the lower proportion of carbonate clasts relative to other clast types.

The persistence of lenticular conglomerates and pebble bands into the upper levels of the Balquhiddier Formation indicates that the nearby tectonic lands, elevated in response to the Kangarooian Movements, periodically contributed gravels to the basin (for discussion on these movements see Daily & Milnes 1971a, p. 209). Evidence, mainly from Kangaroo I. and Yorke Peninsula, indicates that the pebble suites were derived from the erosion of a stratigraphic sequence involving crystalline basement and its unconformable cover of Lower Cambrian sediments, mainly carbonates. Within the Balquhiddier Formation the bases of the sands are sharp. No flute casts, tool marks or groove casts were located. The tops of sands tend to be similarly abrupt.

In contrast to the sandstones of the Brown Hill Sub-group, the sandstones constituting the Middleton Sandstone are much cleaner and in this regard are similar to those of the Backstairs Passage Formation. They are very well laminated and the abundant medium-scale cross-bedded sets indicate current directions almost invariably from the west, although some reversed directions are known. Slumping is common and always down the fore-set direction. We do not interpret the slumping as a consequence of the slope of the basal floor at the time of deposition. More likely, it has resulted from the mass movement of the highly unstable water-laden (thixotropic) fore-sets, perhaps due to current drag. The Middleton Sandstone on Dudley Peninsula, Kangaroo I.,

also consistently shows fore-sets and slumps directed towards the east.

Load casts on the bases of metasediments are common. Occasionally, where soft sediment formation was more intense, pseudo-nodules (Macar & Antun 1950) were formed and in extreme cases isolation from the overlying parent sand was effected, thus permitting the balled-up sand to sink into the underlying muds. Examples of all these structures can be seen in the Rosetta Head area and were figured by Talbot & Hobbs (1969).

The Kanmantoo Group pelites above the Tapanappa Formation frequently show good sedimentary structures, mainly lamination or rippled features. The latter range from starved ripples, indicating insufficient silt to fine sand in the transported fraction to form a continuous bed, to sets of climbing ripples. "where sediment deposition occurs simultaneously with continuing transport in suspension and as bed-load" (Allen 1970, p. 6) in the lower flow regime. The latter structures are indicative of very high rates of deposition.

Convolute lamination is not common but where it occurs it can often be traced along strike for the full length of outcrop, thus indicating the widespread nature of the events which led to its formation.

According to Sprigg & Campana (1953, p. 12) the dominant facies of the Kanmantoo Group "are comparable with the Alpine Flysch". Daily (1956, p. 139) stated "It is believed that shoreline conglomerates, sandstones and shales as seen in the Kangaroo Island Group grade seawards into the 'flysch-like' Kanmantoo sediments which were deposited in areas of rapid subsidence". There is no doubt that the characteristic alternation of metasediments and pelites as seen in the Balquhider Formation is "flysch-like". However, in no respects can we regard this as a turbidite facies. For instance, nowhere have we seen the five-fold division of internal sedimentary structures which characterise the "complete" turbidite of Bouma (1962). In fact, prolonged search has failed to find the truly graded and structureless basal interval which features so prominently in Bouma's "turbidite facies model". The fact that some grading may occur within the well-laminated and ripple-bedded intervals is no criterion of deposition by turbidity currents because comparable grading occurs in sequences deposited in a number of environments, marine and non-marine. In his critical review of the turbidite problem Van

der Lingen (1969, p. 10) also used the term "flysch-like" to cover "alternating sequences reaching thicknesses of geosynclinal magnitude, but lacking typical turbidite characteristics".

In our opinion it is wrong to equate "flysch-like" sequences with turbidites, be they either proximal or distal (Walker 1967, Table II, p. 32), or fluxoturbidites, (Dzulinski *et al.* 1959). What must be proved of course is that the sequences concerned are the products of turbidity currents before they can be called turbidites. In addition, the terms *flysch* and *turbidites* conjure up in many people's minds the notion of deep water environments. Already there are many instances where such ideas are incompatible with the evidence, for example the discovery of the footprints of birds in some areas of flysch (Mangin 1962).

The interpretation of the depositional environment of a sedimentary sequence may be deduced only after critical examination of all the available evidence. Even then no finality need be reached. In the present context we visualise the following:

- (a) Because of the great thickness of Kanmantoo Group metasediments, subsidence must have been extremely rapid. Basin development was probably controlled by faulting to account for this.
- (b) The nature of most of the rocks shows that sedimentation was rapid. Possibly deposition kept pace with subsidence. There is no evidence of temporary emergence, such as mud-cracks. However, these would be hard to locate in this metamorphic terrain.
- (c) Within the Balquhider Formation, low amplitude scour-channels are common in the thicker sand intervals. The associated low angle cross-bedded sets (generally less than 1 m thick) are typical of deposition in an aqueous environment. A marine environment is suggested by the prevalence of the bioturbated tops of some of the sandier bands. Severe restriction giving rise to unfavourable environmental conditions could be invoked to explain the presumed absence of a benthonic shelly fauna in the sands. However, such a restriction may be more apparent than real, for in view of the rapid rate of deposition, the basinal waters would have contained abundant fines in suspension which may have been deleterious to the presence of a Cambrian shelly fauna. Assuming a marine environment, the lack of reworking of the sediments indicates that either subsidence

was rapid enough to prevent reworking or that sedimentation took place at a depth below effective wave base. This could have been quite shallow (McCave 1971).

- (d) The high incidence of medium scale cross-bedding and the greater maturity of the sands of the Middleton Sandstone seem to indicate that it was deposited in a shallower environment than the Balquhiddler Formation. It is almost certainly a shallow water deposit.

In the absence of autochthonous fossil assemblages it is impossible to give any objective depth indicators purely on the basis of the known sedimentary structures. All we can suggest here is that the Middleton Sandstone is a shallow water deposit, which because of rapid subsidence escaped reworking. Rocks of the Balquhiddler Formation were probably deposited in somewhat deeper water but there is no guarantee of this. We certainly do not envisage a deep water origin for it, because unmetamorphosed sediments of similar facies and of shallow water origin occur on the northern coast of Kangaroo I. Possibly the deepest water is indicated by the finely laminated blue-black carbonaceous and sulphide-rich phyllites indicating stagnant bottom conditions. However, even here a very shallow environment of deposition is possible. All that is needed to produce sediments of this type is a fall off in the deposition of coarser elastics, a restriction of circulation, and a supply of abundant organic matter to produce the carbon and sulphides under strongly anoxidising conditions.

### C. Relationship of Metamorphism and Structure to the Emplacement of the Encounter Bay Granites

Our observations suggest that the Encounter Bay Granites in the Encounter Bay area were emplaced prior to the main phase of first-generation deformation. Moreover, metamorphism in this area began with the pre- to early syn- $F_1$  crystallisation of cordierite and quartz-rich aggregates in metasediments of appropriate composition, continued with the late syn- $F_1$  crystallisation of andalusite and chlorite, and ended in the post- $F_1$  structurally static phase during which the crystallisation of andalusite, chlorite, garnet, muscovite, hornblende and scapolite occurred in metasediments of appropriate composition.

Cordierite is restricted to some pelites in the upper part of the Balquhiddler Formation and in the Petrel Cove Formation along the coastal section between Encounter Bay and

Parsons Beach and its crystallisation records the highest grade of metamorphism in the region. It occurs as altered augen in phyllite bands that crop out in the headland at the eastern end of Parsons Beach; it has not been recognised in rocks to the west of this locality, nor in rocks in the Brown Hill to Middleton area. Andalusite occurs mainly in some pelites in the upper part of the Balquhiddler Formation and in the Petrel Cove Formation along the coastline east of Newland Head in association with cordierite. However, rare altered post- $F_1$  poikiloblasts that occur further west along the coastline, for example in Tapanappa Formation metasediments near the western end of Tunkalilla Beach and at Tunk Head, are considered to have been composed of andalusite. Their occurrence is consistent with the presence of andalusite poikiloblasts in Tapanappa Formation metasediments that crop out along the northern coast of Dudley Peninsula, just east of Penneshaw (Daily & Milnes, unpublished observations). Minerals such as hornblende and garnet, which are characteristic of calc-silicate lithologies, occur throughout the type section. Scapolite however, is confined to certain pelites that occur 1 km east of Coolawang Creek.

We have mapped a magnificent development of syn- to post- $F_1$  metamorphic minerals such as andalusite, hornblende, scapolite and garnet in Adelaide Supergroup metasediments which occur within a thrust fault block along the north coast of Dudley Peninsula, approximately 12 km from the Encounter Bay Granites at Cape Willoughby (Daily & Milnes 1971b, 1972h). However, there is a conspicuous paucity of these minerals in Kanmantoo Group metasediments closer to the granites. Thus, Kanmantoo Group metasediments in this area appear, on the whole, to be of such composition (for example deficient in alumina and lime) that they fail to contain metamorphic assemblages that are indicators of metamorphic grade.

The entire type section of the Kanmantoo Group, as well as the section on Dudley Peninsula, occurs within the regional andalusite-staurolite zone of metamorphism according to Offler & Fleming (1968). The presence of plagioclase of oligoclase-andesine composition in the metasediments we have examined is consistent with this grade of metamorphism. Thus, the paucity of andalusite in all but parts of the Balquhiddler Formation and Petrel Cove Formation west of Petrel Cove is best interpreted

as due to a scarcity of metasediments of appropriate bulk composition. The restricted occurrence also of cordierite may be due to the limited presence of metasediments of suitable composition. However, the conspicuous development of large post- $F_1$  cordierite porphyroblasts near a post- $F_1$  metadolerite dyke intruding metasediments on the coast about half-way between Petrel Cove and King Point suggests that varied proximity to a heat source, such as the Encounter Bay Granites, may also have influenced its development. The absence of cordierite and andalusite and other porphyroblastic minerals in Balquhider Formation and Petrel Cove Formation metasediments in the Brown Hill to Middleton area, compared with their abundance in metasediments in the same stratigraphic position along the coastline west of Encounter Bay, is particularly difficult to account for. It may be the result either of inappropriate bulk compositions of metasediments in the Brown Hill to Middleton area, perhaps due to facies changes along strike from the coastal section, or the effect of conditions of significantly lower metamorphic grade. In view of the occurrence of plagioclase of oligoclase-andesine composition in the metasediments in the Brown Hill to Middleton area, the former suggestion is favoured.

Thus, the relationships between structural deformation, metamorphism and the emplacement of the Encounter Bay Granites in the Encounter Bay area, as deduced from field and petrographic evidence, can be envisaged as follows:

- (a) Regional folding was initiated, probably with the development of broad-scale folds and the development of an incipient  $S_1$  schistosity.
- (b) The Encounter Bay Granites were emplaced, and simultaneously incorporated abundant metasediment xenoliths, the majority of which do not display an imposed mica-schistosity. Cordierite and quartz-rich augen crystallised in metasediments of appropriate composition adjacent to the granites, in response to locally elevated temperatures.
- (c) The main phase of  $F_1$  folding, a regional event, deformed the marginal granite phases which had already completely crystallised, and brought to completion the development of the penetrative  $S_1$  fabric in the Kanmantoo Group metasediments. Andalusite and chlorite porphyroblasts

crystallised in these metasediments on a regional scale as a result of suitable P-T conditions.

- (d) Significant porphyroblastic growth of metamorphic minerals occurred during the post- $F_1$  static phase. Post- $S_1$  andalusite crystallised as overgrowths on syn- $S_1$  porphyroblasts, and as poikiloblasts adjacent to the post- $S_1$  striped layering ( $S_2$ ). Pegmatite and metadolerite dykes were emplaced.
- (e) A second phase of folding ( $F_2$ ) deformed pre-existing structures, including  $S_1$  and the post- $S_1$  "striped" layering, and was responsible for the development of a crenulation cleavage and a strain-slip cleavage  $S_2$ . The main development of  $F_2$  structures occurs in the eastern part of the type section. Evidence for metamorphic crystallisation during or post-dating the second phase of deformation has not been observed. However, albitisation and the crystallisation of fibrous hornblende has occurred along the  $S_2$  fracture cleavage. This is believed to be associated with the widespread late stage albitisation (Dasch *et al.* 1971) affecting the Encounter Bay Granites. As well, we have observed tourmaline filled fractures with orientation similar to that of  $S_2$ .

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- Fig. 8. Well laminated metasiltstones within the Tunkalilla Formation, south side of Tunkalilla Creek. Scale in mm (total length 7.5 cm).
- Figs. 9, 10. Worm casts etched out by sand blasting of metasandstones, Bollaparudda Beach.
- Fig. 11. Well laminated metasandstones occupying a cut-and-fill channel in Balquhiddy Formation, eastern side of Tunk Head. Hammer length 28 cm.
- Fig. 12. Tectonically deformed load casts and associated flame structures, in the base of a metasandstone, about 0.2 km east of Tunk Head.
- Fig. 13. Climbing ripple-trains developed in metasandstones interbedded with metasiltstones. Same locality as for Fig. 12.
- Fig. 14. An erosional channel cut into well laminated metasandstones, same locality as for Figs. 9 & 10. Channel was filled with shale chips and sands. The hammer is lying against the bioturbated metasandstones shown in Figs. 9 & 10.
- Fig. 15. Calc-silicate rods developed in metasandstones and plunging parallel to the fold axis; same locality as for Figs. 12 & 13.
- Fig. 16. Thin planar- and irregular-shaped segregations of calc-silicates developed roughly parallel to the bedding in metasandstones; same locality as for Fig. 15.
- Fig. 17. Well bedded and cleaved metasandstones in the trough of the Tunk Head syncline about 0.6 km west of Tunk Head. Note the well developed sigmoidal cleavage (outlined). The cavernous weathering of the rocks is a common feature along the coast of Fleurieu Peninsula and on Kangaroo I.
- Fig. 18. Thick hands of well-banded metasandstones interbedded with thin laminated phyllites, trough of Tunk Head syncline. Note the cross-cutting pegmatitic veins to the right of the figure, 1.8 m tall.
- Fig. 19. View of top surface of a coarse-grained metasandstone bed showing smeared out sedimentary structures. Lineation (hammer handle parallels it) is due to a cleavage/bedding intersection; same bedding surface as that shown in the bottom left corner of Fig. 18. Sedimentary structures within the central parts of the bed are relatively undistorted by the cleavage. Only in the uppermost few centimetres of the bed is the cleavage sharply refracted thus producing marked distortion or tectonic smearing of the sedimentary structures.
- Fig. 20. Beds of metasandstones alternating with thinner intervals of less resistant phyllites and metasiltstones; centre of Tunk Head syncline.
- Fig. 21. Tectonically deformed current-bedded (rippled) and laminated metasiltstones interbedded with phyllites about 30 m west of Tunk Head. Note the abundance of thin pygmaic pegmatitic veins.
- Fig. 22. Sulphide segregations and veinlets within a 2 m thick blue-black phyllite/metasandstone interval; narrow gulch immediately west of Tunk Head.
- Fig. 23. Fallen block of Balquhiddy Formation metasandstone displaying a thin band of small-scale conglomerate about 0.4 km east of Bollaparudda Beach. Hammer head lying in plane of bedding.
- Fig. 24. Well-bedded coarse-grained metasandstones within the Balquhiddy Formation. Note small granules and pebbles recurring up through the sequence. Locality about 0.5 km east of Bollaparudda Beach. Width of hammer head 17 cm.
- Fig. 25. Bright orange-red coloured zones of feldspathization developed along closely-spaced fractures within metasandstone beds, 1.1 km east of Bollaparudda Beach. Note paucity of tensional fractures within the phyllite interbed compared with their greater abundance in the overlying and underlying metasandstones. However, feldspathised zones do occur along some of the fractures cutting the phyllites. Feldspathised zones also occur to the west of Bollaparudda Beach.

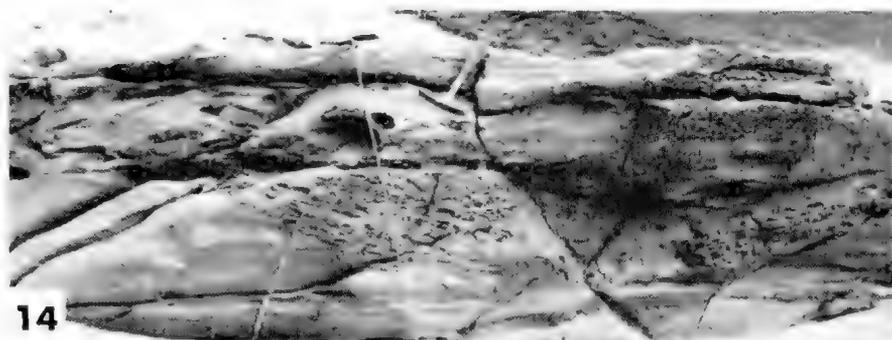
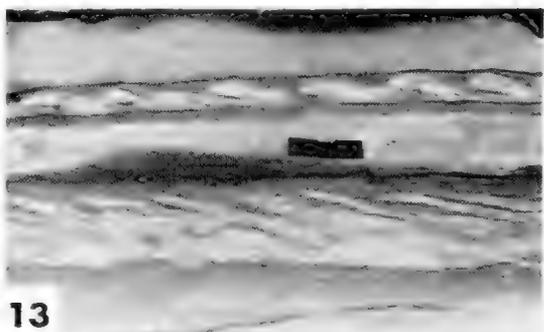
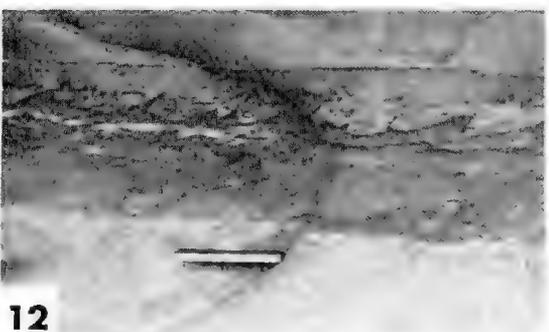
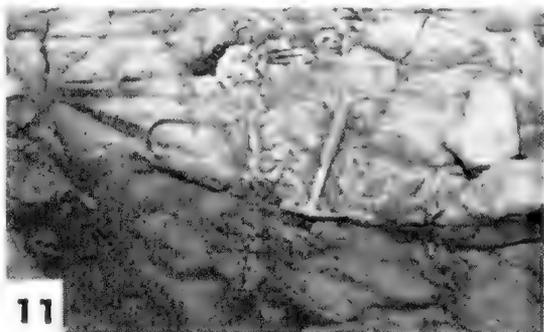
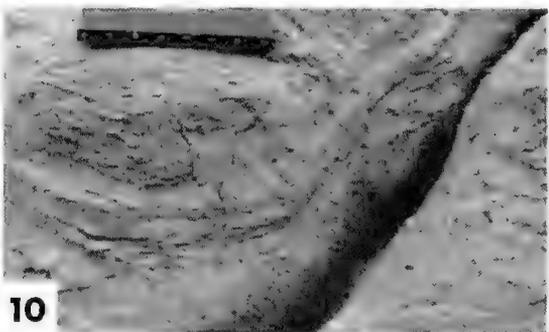
- Fig. 26. Pegmatites infilling tensional fractures in metasandstones of the Balquhider Formation 0.7 km east of Coolawang Creek. Note the warping and feathering of the fracture infills.
- Fig. 27. Well-laminated metasilstones overlain by current-bedded sets of ripple trains 1.2 km east of Coolawang Creek, Hammer handle 15 cm long.
- Fig. 28. A prominent rib-and-furrow lineation on the sole of a thick metasandstone bed 0.7 km west of Parsons Beach. Boot for scale.
- Fig. 29. Convolute lamination in metasilstones west side of Parsons Beach. Coin 2.3 cm in diameter.
- Fig. 30. Small channel cut into a pebbly metasandstone and filled with cross-bedded and laminated metasandstones. Adjacent to beach on western side of Newland Head.
- Fig. 31. Flaggy outcrops of metasandstones with thin phyllite partings on the western side of Newland Head. A more massive band of metasandstone is visible on top of the exposed sequence.
- Fig. 32. View looking SW along strike towards Newland Head. Sequence consists of steeply-dipping metasandstones and interbedded thin phyllites. Included also is a blue-black carbonaceous and sulphide-rich phyllite.
- Fig. 33. View looking towards Rosetta Head showing the high cliffline cut in the Balquhider Formation. Note the lower cliffline cut in Petrel Cove Formation between King Point (extreme right) and Rosetta Head.
- Fig. 34. Pen (14 cm long) is parallel to bedding in metasilstone bands interbedded in knotted porphyroblastic schists just below top of Balquhider Formation, about 0.6 km west of King Point. Note the pale coloured strain shadows around the augen aligned in the cleavage which dips away to the left.
- Fig. 35. Relationships of various layerings in porphyroblastic andalusite schists occurring near the base of the Petrel Cove Formation. ( $S_0$ ) is bedding, ( $S_1$ ) is an augen layering in the cleavage, ( $S_2$ ) [referred to as ( $S_3$ ) in text] is a pale coloured "striped" layering. Note also the "pinch-and-swell" quartz-feldspar-mica pegmatitic layers developed parallel to the "striped" layering and along which dislocation has occurred. Pen for scale.
- Fig. 36. A small synclinal fold in andalusite schists plunging towards  $210^\circ$  at  $25^\circ$ . The bedding, well expressed by the folded darker layers, is also partly expressed by some andalusite-rich layers. Some steeply dipping fine "striped" layers can be seen cutting the bedding in the left of the photo. Tip of pen for scale.
- Fig. 37. Extremely well-laminated metasilstones in the lower part of the Petrel Cove Formation about 0.2 km west of King Point.
- Fig. 38. Current-bedded ripples and other sedimentary structures in well-bedded metasilstones, Petrel Cove Formation, King Point.
- Fig. 39. Deformed load casts, their attendant flame structures, and ripple-trains in metasandstones in the Petrel Cove Formation, 0.75 km SW of Rosetta Head wharf. Note thin "striped" layers cutting the deformed sedimentary structures. Two pale coloured ribs of coarser sand are elongated towards  $210^\circ$  in the direction of the  $F_1$  fold axis. The "striped" layering is post  $F_1$  as it cuts deformed sedimentary structures. Pen is 14 cm long.
- Fig. 40. Deformed load casts 10 m SW of Fig. 39. Bedding dips shallowly to right. Note that the bedding has been slightly offset by shearing parallel to the cleavage. Note also the broad stripe, right of the coin (diameter 2.3 cm), dips at a slightly lower angle than the cleavage. The stripe has a thin central dark biotite layer margined by broad pale coloured stripes in turn margined by selvages of biotite.
- Fig. 41. View looking SW at outcrop of shallowly-dipping, well-bedded, fine-grained metasandstone interbedded with softer and darker coloured andalusite schists. 0.75 km SW of Rosetta Head wharf. All beds are cut by a white "striped" layering.

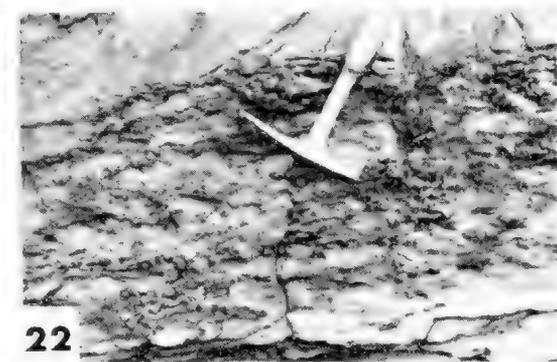
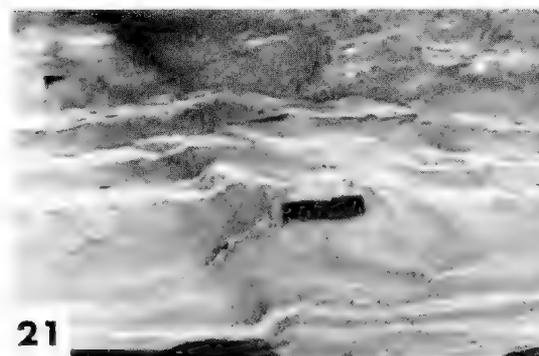
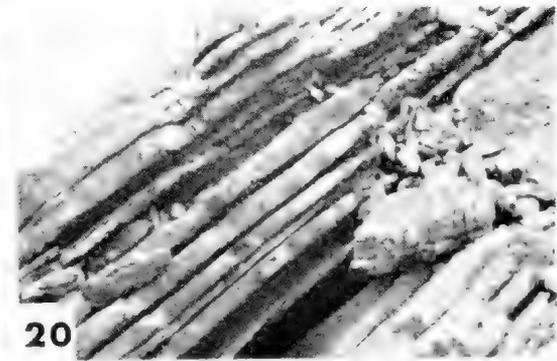
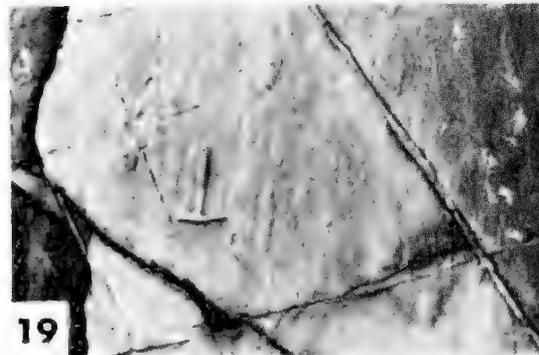
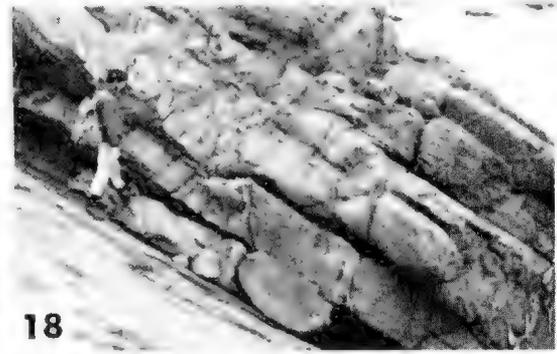
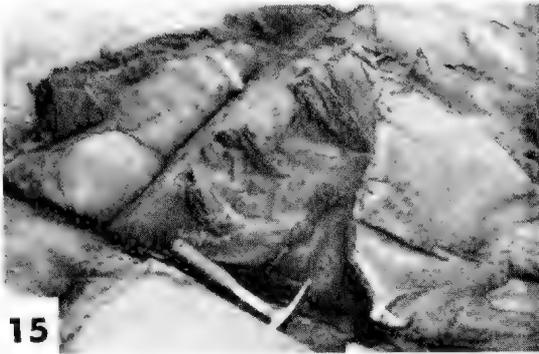
- Fig. 42. Note refraction of discontinuous white "striped" layering in schists, steeper in metasandstones. Same locality as Fig. 41.
- Fig. 43. Refracted "striped" layering (partly discontinuous) sloping to left and crenulation cleavage (almost vertical) in andalusite schist. Same outcrop as for Figs. 41 & 42. Note that the "striped" layers are slightly folded in some of the andalusite schist layers. The crenulation cleavage ( $S_2$ ) is axial plane to these folds. No obvious folds occur in the overlying fine-grained metasandstone which dips to left at a shallower angle than the "striped" layering.
- Fig. 44. Same outcrop as in Fig. 41. Note the refraction of the "striped" layering as it crosses the andalusite-deficient bands. There they are thickened.
- Fig. 45. Feathering of "striped" layers in metasandstones of Petrel Cove Formation just west of Petrel Cove.
- Fig. 46. "Striped" layering markedly refracted in passing from metasandstones into interbedded andalusite schists. Bedding dips steeply to right and occurs on the limb of a fold plunging towards  $205^\circ$  at  $25^\circ$ . Note that there is a crenulation cleavage axial-plane to small-scale  $F_2$  folds confined to the "striped" layering within the andalusite schists. Locality on western side of Petrel Cove.
- Fig. 47. Andalusites preferentially developed along some of the "striped" layers west of Petrel Cove. Lens cap 7 cm in diameter.
- Fig. 48. View from 1.3 km SW of Brown Hill looking towards Rosetta Head. Note metasandstones of Balquhider Formation in foreground sloping down towards lower ground on the extreme left which is underlain by phyllites of the Petrel Cove Formation. This is comparable with the geomorphology to the right of Rosetta Head just below horizon.
- Fig. 49. Cross-bedded and well-laminated metasandstones of the Middleton Sandstone near western extremity of outcrop, Middleton Beach. Scale 11 cm long.
- Fig. 50. Pale coloured epidote-rich bands in well-bedded fine-grained Middleton Sandstone near western extremity of outcrop, Middleton Beach.
- Fig. 51. Epidote-rich segregations or nodules occurring parallel to bedding in the fine-grained Middleton Sandstone, near western extremity of outcrop, Middleton Beach.
- Fig. 52. Pale coloured epidote-rich layers outlining a markedly cross-bedded metasandstone unit (30 cm thick) in the Middleton Sandstone, Middleton quarry. Sequence is part of the steeper limb of the  $F_2$  fold illustrated in Fig. 57.
- Fig. 53. View of  $S_1$  surface in Petrel Cove Formation andalusite-cordierite schist showing the intersection between  $S_1$  and bedding ( $L_1$ ) and a lineation ( $L_2$ ) defined by the elongation of andalusite and cordierite augen. Length of ( $L_1$ ) arrow 14 cm.
- Fig. 54.  $F_2$  fold in bedding and in a thin metamorphic pegmatite, Petrel Cove Formation, along coast between Petrel Cove and King Beach. Note refolded  $F_1$  folds. Coin 2.1 cm in diameter.
- Fig. 55. Small-scale  $F_1$  folds in bedding in Petrel Cove Formation metasiltstone refolded by  $F_2$  fold. Schistosity, oriented approximately EW in photograph, is  $S_2$ . Same locality as Fig. 54. Coin 2.1 cm in diameter.
- Fig. 56. "Striped" layering in laminated metasiltstone in Petrel Cove Formation metasiltstone, same locality as in Fig. 41. Note median biotite- and/or quartz-filled fractures, and biotite-rich margins of stripes. Coin 2.3 cm in diameter.
- Fig. 57. Large-scale, SE plunging  $F_2$  fold in Middleton Sandstone, Middleton quarry. Light coloured layers parallel to bedding are epidote-rich. Prominent fracture cleavage axial plane to fold has controlled albitisation (light coloured cross-cutting zones). Figure (arrowed) 1.3 m tall.
- Fig. 58. Tight small-scale  $F_1$  fold in laminated metasandstones on limb of large-scale  $F_2$  fold in Middleton quarry. Scale on right 7.5 cm. long.

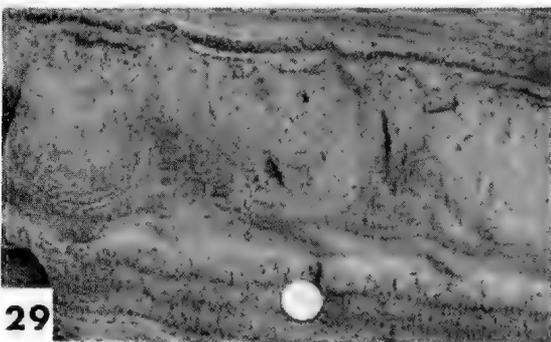
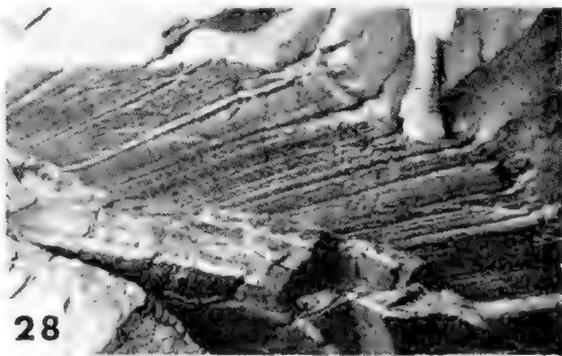
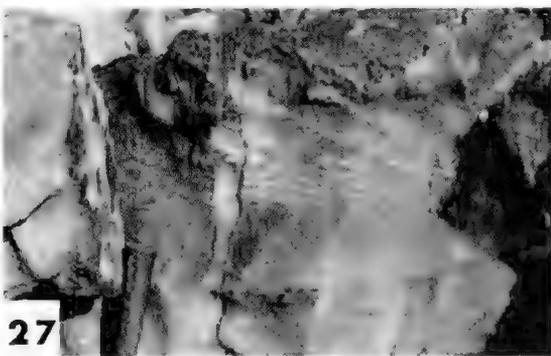
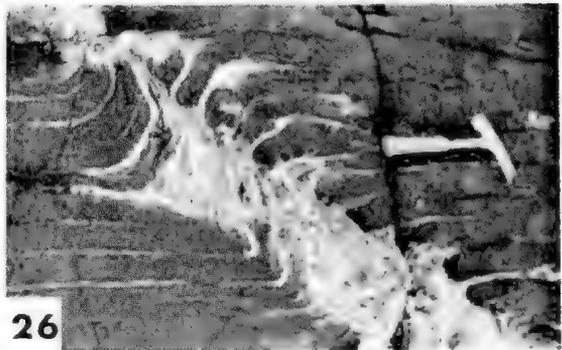
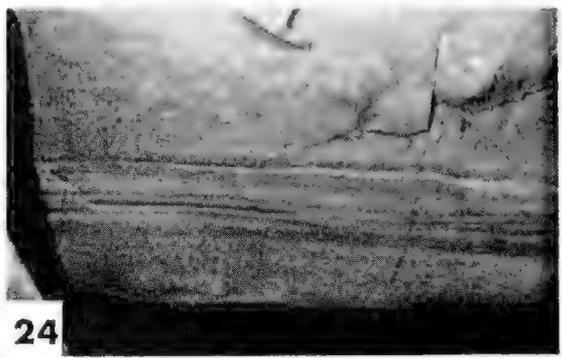
- Fig. 59. Ridge-and-furrow lineation ( $L_2$ ) defined by the intersection of bedding and fracture cleavage axial plane to  $F_2$  folds, Middleton quarry. Scale provided by 5 cm wide compass.
- Fig. 60. A large thin-section of mesoscale folds in which a well-developed flaring axial-plane schistosity (S-fold) overprints a poorly developed schistosity (S) parallel to bedding; Middleton quarry. Scale cm graph paper.
- Fig. 61. A specimen of mesoscale folds in bedding from which the section in Fig. 60 was cut. Note fold hinges (J-fold), and conspicuous mica-streaking lineation ( $L_1$ ) developed on schistosity axial plane to folds (S-fold); Middleton quarry. Bar scale represents 4 cm.
- Fig. 62. Small-scale  $F_2$  fold showing ridge-and-furrow lineation ( $L_2$ ), which is defined by the intersection between bedding and the fracture cleavage axial plane to the fold. Note the mica-streaking lineation ( $L_1$ ) that occurs on the moderately well-developed,  $S_1$  schistosity approximately parallel to bedding; Middleton quarry. Bar scale represents 1 cm.
- Fig. 63. Thin concordant granite sheet intruding laminated metasilstones of the Petrel Cove Formation, Wright I. Pen 14 cm long.
- Fig. 64. Boudinaged concordant granite sheet in Petrel Cove Formation metasilstones, Wright I. Note well-developed schistosity in margins and constricted portions of sheet. White spots on rock surfaces are small marine gastropods, Hammer length 28 cm.
- Fig. 65. Surface of slab of schistose megacrystic granite. Schistosity, defined by alternating biotite and quartz-rich laminae, enwraps feldspar megacrysts (light coloured megacrysts are plagioclase, darker coloured megacrysts are potash feldspar). Quartz megacrysts did not survive the deformation. Specimen collected from main granite mass on NE side of Wright I. within 1 m of contact with Petrel Cove Formation metasilstone. Scale in mm.
- Fig. 66. Pre- $S_1$  quartz-rich augen enwrapped by  $S_1$  schistosity in thin section of Balquhiderder Formation porphyroblastic schist SC97\*, 200 m beyond eastern end of Waitpinga Beach. Note the preferred orientation of abundant opaque laths in  $S_1$ . Transmitted plane polarised light. Bar scale represents 0.10 mm.
- Fig. 67. Pre- $S_1$  cordierite augen, now altered to kaolinite, enwrapped by groundmass  $S_1$  schistosity. Thin section of Petrel Cove Formation porphyroblastic schist T130A. Transmitted plane polarised light. Bar scale represents 0.50 mm.
- Fig. 68. Field in Fig. 67. Crossed polars. Note fine-grained size of quartz inclusions within altered cordierite augen compared with grain size of quartz in groundmass. Bar scale represents 0.50 mm.
- Fig. 69. Syn- $S_1$  cordierite poikiloblasts, now altered to kaolinite. Thin section of Petrel Cove Formation cordierite schist SC106A. The poikiloblasts exhibit an oriented internal fabric which is continuous with the external  $S_1$  mica schistosity, and have been rotated relative to it. Note post- $S_1$  muscovite lath (M). Transmitted plane polarised light. Bar scale represents 0.50 mm.
- Fig. 70. Field in Fig. 69. Crossed polars. Note fine grain size of quartz inclusions in altered cordierite augen compared with grain size of quartz in groundmass. This suggests that cordierite crystallised during early syn- $S_1$  phase. Absence of curved internal fabric suggests cordierite porphyroblasts were rotated homily with respect to external  $S_1$  schistosity after crystallisation was completed. Note post- $S_1$  muscovite lath (M). Bar scale represents 0.50 mm.
- Fig. 71. Syn- $S_1$ , S-shaped andalusite poikiloblast (A), with S-shaped internal fabric. Internal fabric continuous with external groundmass  $S_1$  schistosity. Note post- $S_1$  overgrowth on bottom right of poikiloblast just left of post- $S_1$  chlorite lath (c). Thin section of Petrel Cove Formation andalusite-cordierite schist T108. Transmitted plane polarised light. Bar scale represents 0.50 mm.

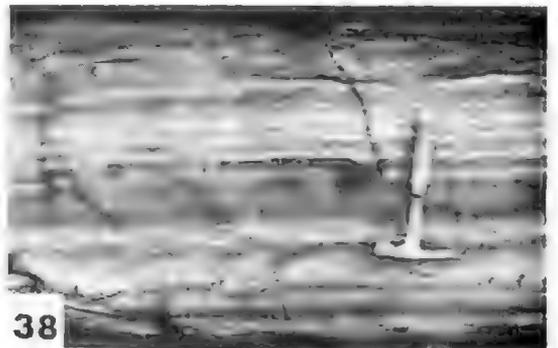
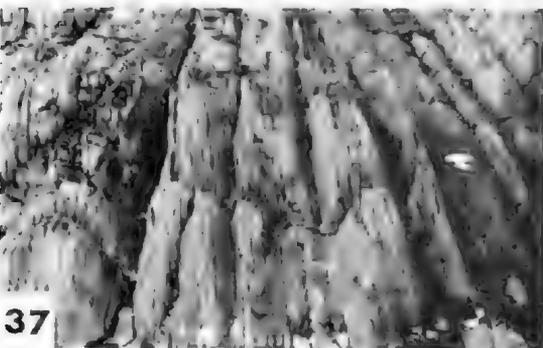
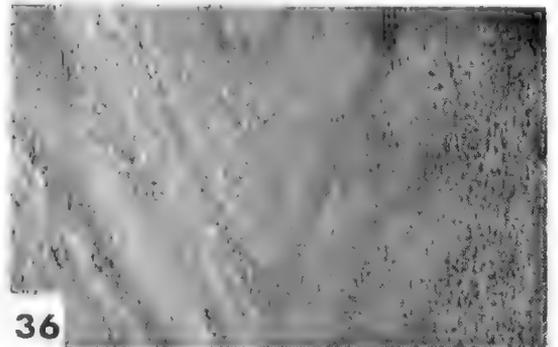
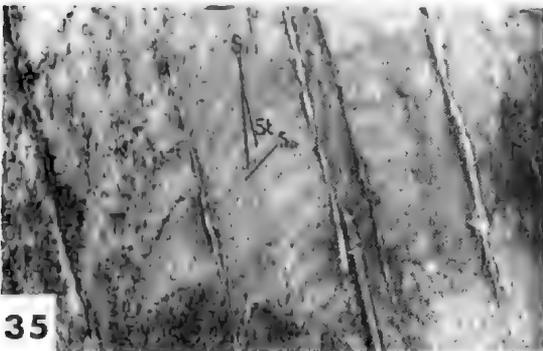
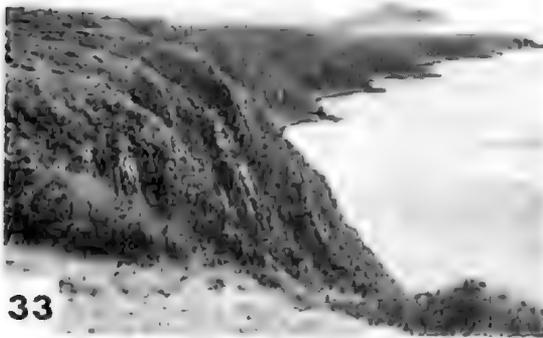
\* Numbers prefixed by SC refer to rock sample numbers collected by us. Numbers prefixed by T refer to rocks collected by Professor J. L. Talbot.

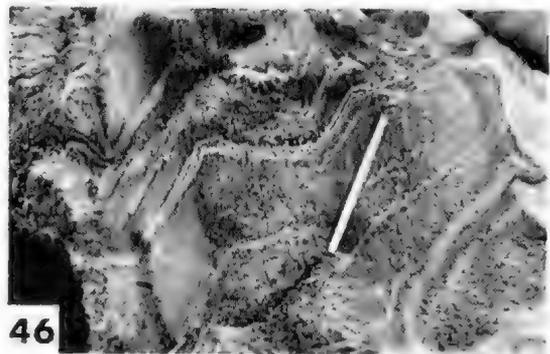
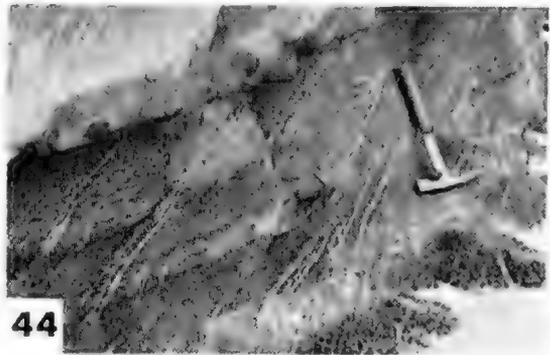
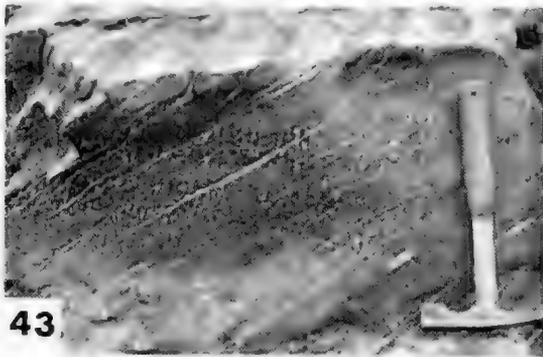
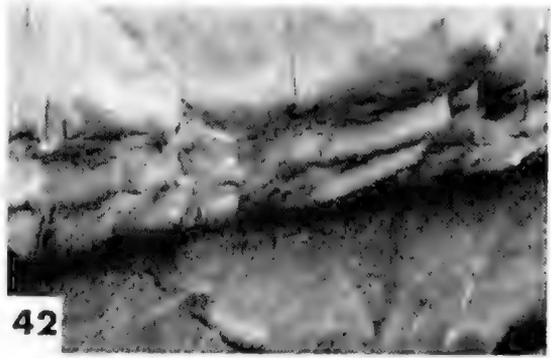
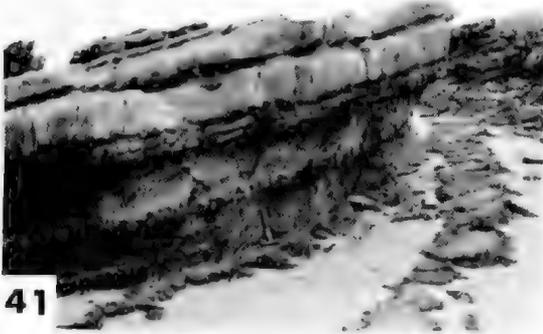
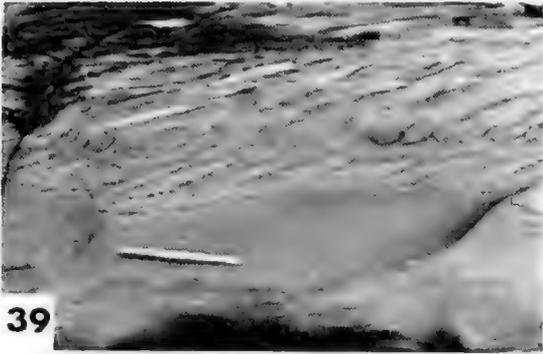
- Fig. 72. Post- $S_1$  andalusite (A) as overgrowths on syn- $S_1$  andalusite poikiloblast. Groundmass  $S_1$  schistosity is defined both by micas and by opaque mineral laths. Note sharp contacts between andalusite "fingers" and groundmass micas. Thin section of Petrel Cove Formation andalusite schist SC102. Transmitted plane polarised light. Bar scale represents 0.10 mm.
- Fig. 73. Post- $S_1$  andalusite poikiloblast (A) which has crystallised around altered cordierite augen (C). Thin section of Petrel Cove Formation andalusite-cordierite schist T135A. Transmitted plane polarised light. Bar scale represents 0.50 mm.
- Fig. 74. Field in Fig. 73. Crossed polars.
- Fig. 75. Post- $S_1$  chlorite poikiloblasts (c) which have crystallised across  $S_1$  and inherited the  $S_1$  fabric, indicated by elongate quartz and opaque mineral inclusions. Thin section of Tapanappa Formation porphyroblastic phyllite SC50, from ancient cliffline, western end of Tunkalilla Beach. Transmitted plane polarised light. Bar scale represents 0.10 mm.
- Fig. 76. Post- $S_1$  chlorite poikiloblasts (c) which have crystallised across  $S_1$  and inherited the  $S_1$  fabric, indicated by opaque mineral laths. Thin section of Petrel Cove Formation andalusite schist SC102. Transmitted plane polarised light. Bar scale represents 0.50 mm.
- Fig. 77. Post- $S_1$  euhedral garnet (g) and chlorite (c) porphyroblasts adjacent to pre- $S_1$  quartz-rich augen (Q) in thin section of Tunkalilla Formation porphyroblastic phyllite SC58A, eastern side of Tunkalilla Creek. Transmitted plane polarised light. Bar scale represents 0.10 mm.
- Fig. 78. Thin section of Petrel Cove Formation andalusite schist SC103 showing the development of  $S_2$  strain-slip zones, outlined by opaques. The strain-slip zones cut across post- $S_1$  chlorite porphyroblasts (c). Note andalusite porphyroblast (A). Transmitted plane polarised light. Bar scale represents 0.50 mm.

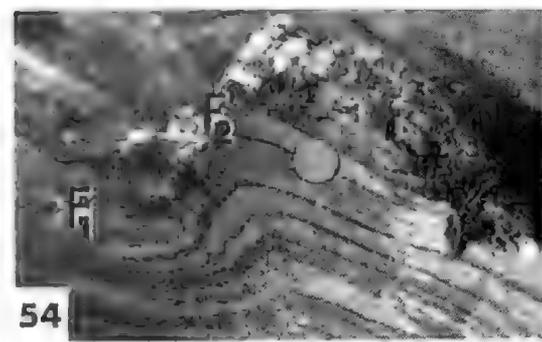
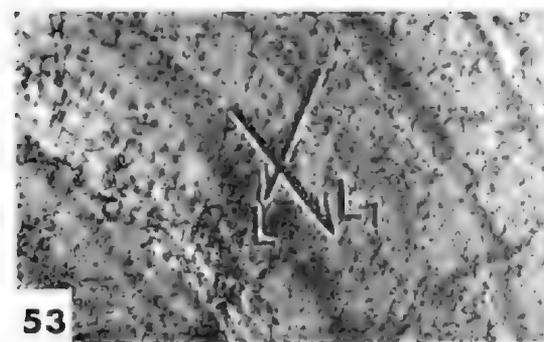
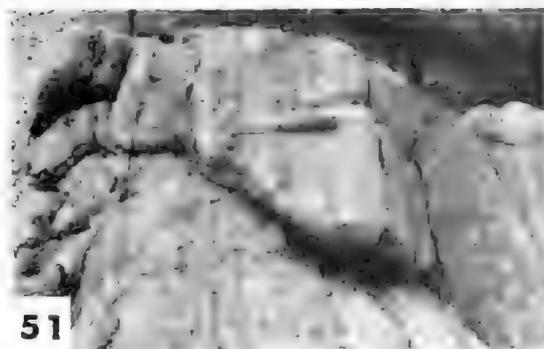
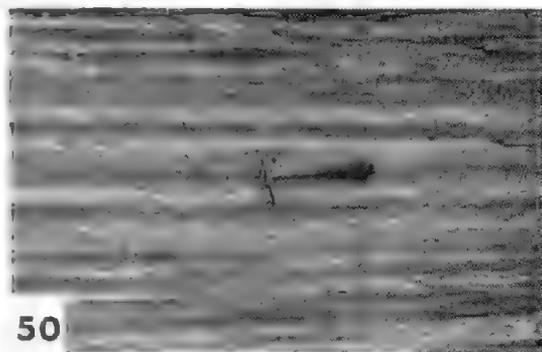
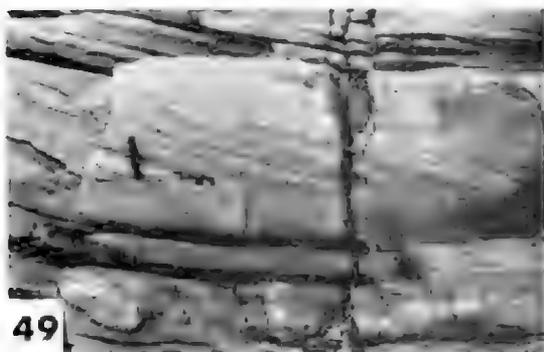
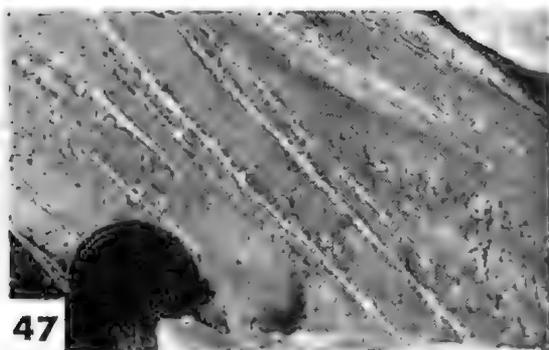


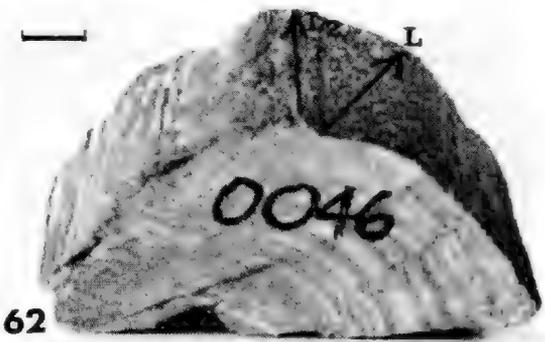
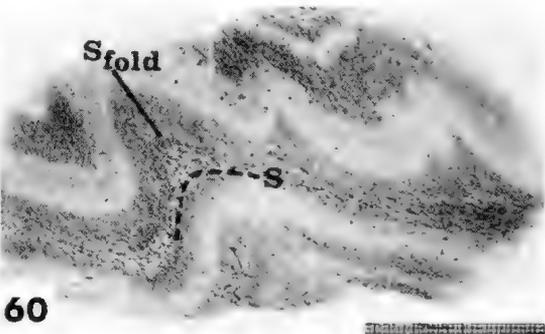
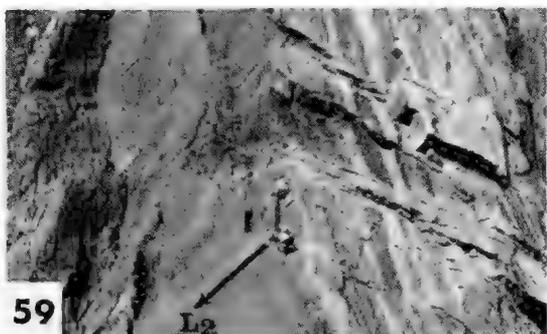
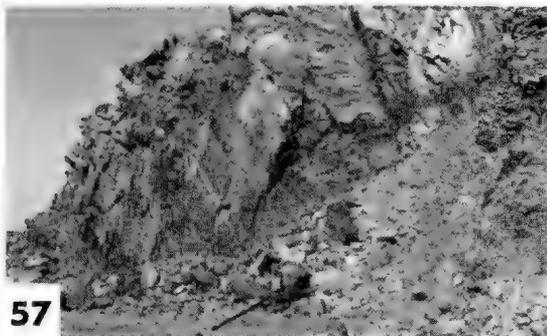
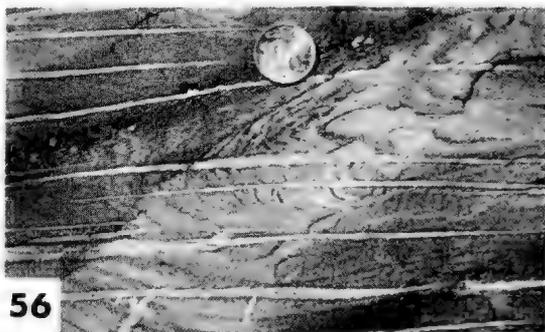
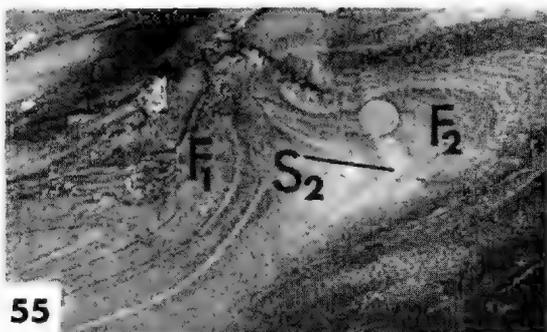


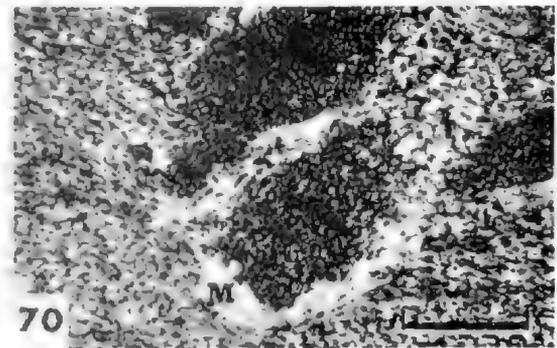
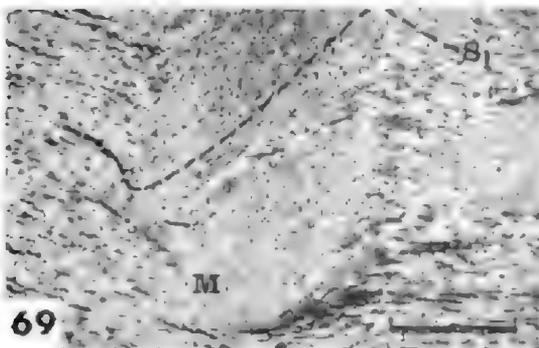
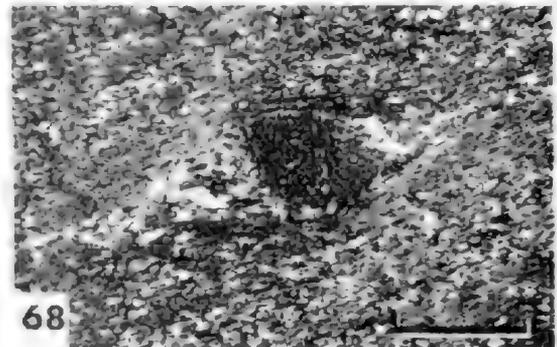
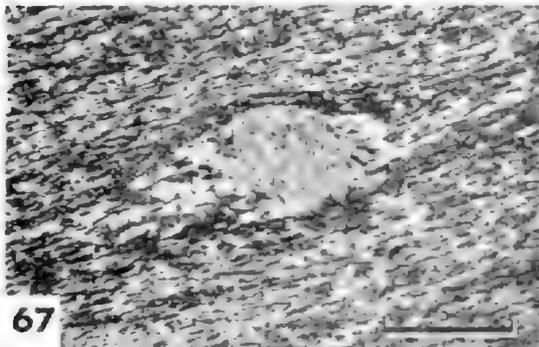
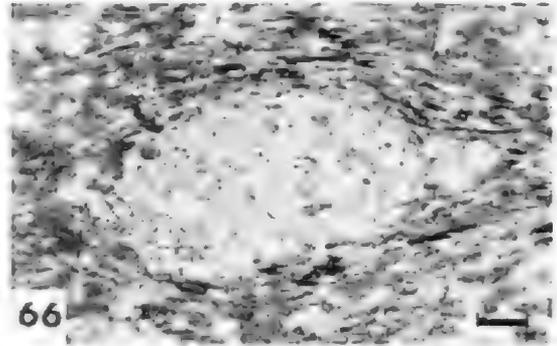
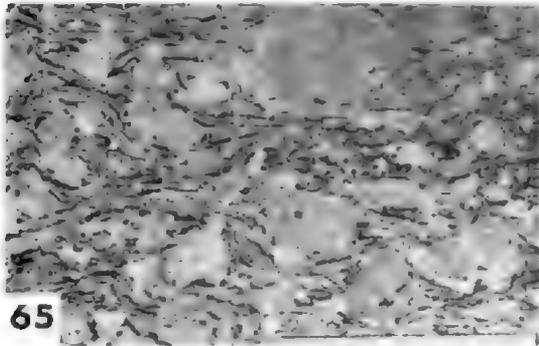
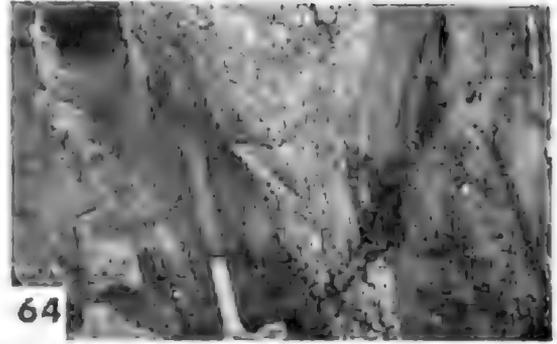


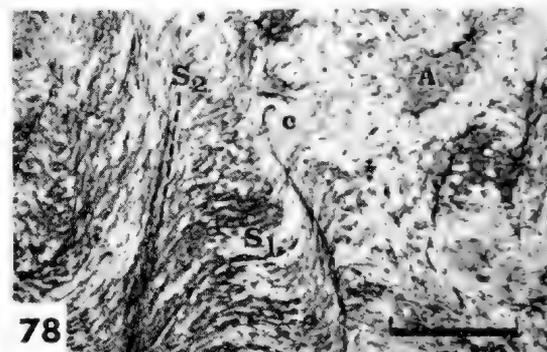
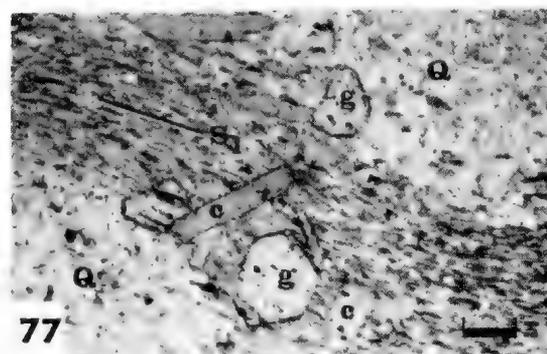
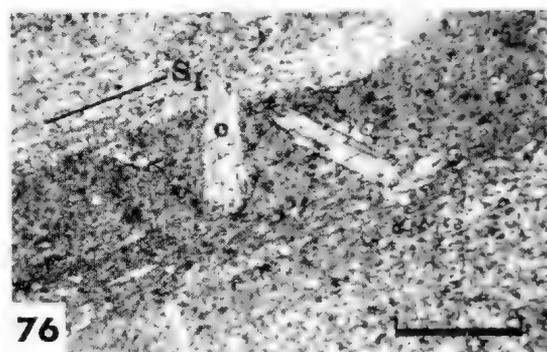
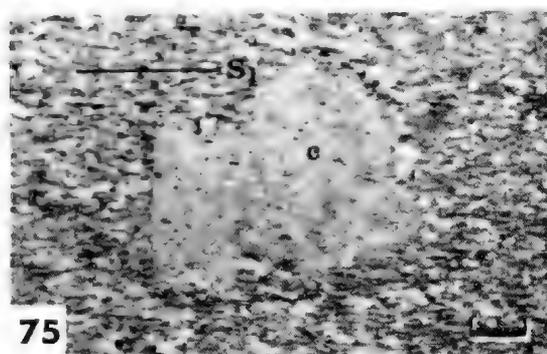
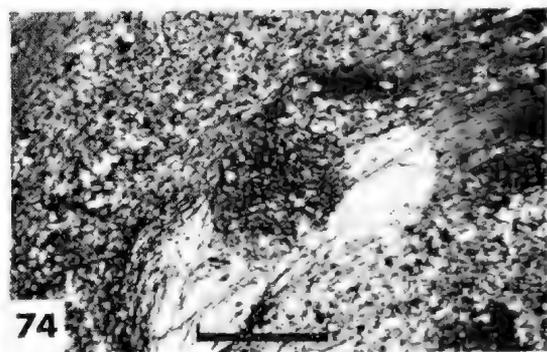
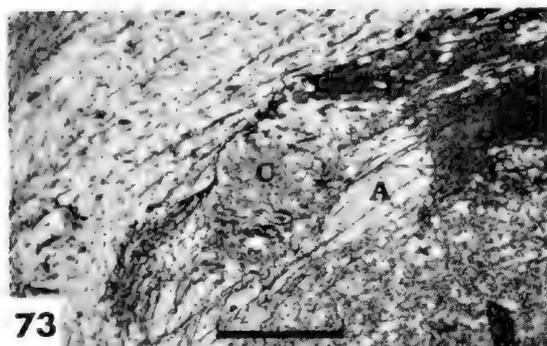
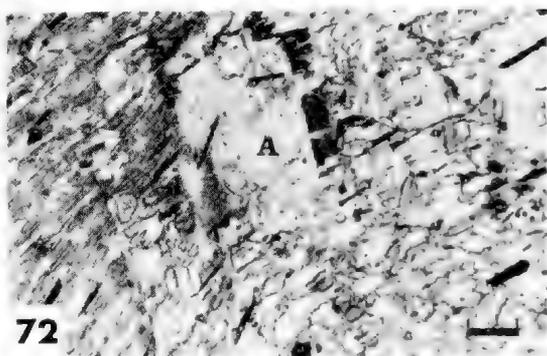
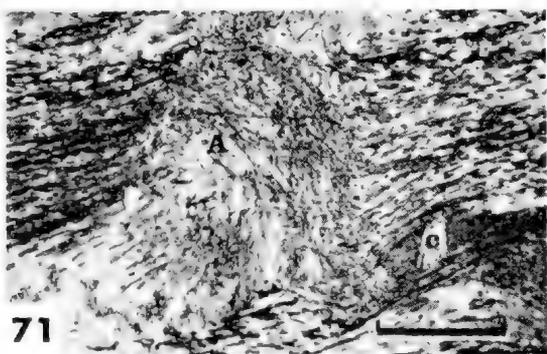












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# FURTHER STUDIES ON AUSTRALIAN KALLYMENIACEAE (RHODOPHYTA)

BY H. B. S. WOMERSLEY\*

## Summary

WOMERSLEY, H. B. S. (1973). -Further studies on Australian Kallymeniaceae (Rhodophyta).  
*Trans. R. Soc. S. Aust.* 97(4), 253-256, 30 November, 1973.

Further collections since the monograph of Womersley & Norris (1971) extend the range of *Kallymenia cribrogloea* into N.S.W., clarify the structure and relationships of *K. rosea* and *K. polycoelioides*, and show that *Cirrulicarpus australis* and *Meredithia nana* are one species now known as *Cirrulicarpus nana* (J.Ag.) comb. nov. *Callophyllis coccinea* is now referred to as *C. rangiferinus* (Turner) comb. nov.

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### Introduction

Since the monograph of Womersley & Norris (1971) on Australian Kallymeniaceae, further SCUBA collections by S. A. Shepherd from New South Wales and Tasmania have provided material permitting clarification of some doubtful species, and an earlier name for *Callophyllis coccinea* is evident.

#### 1. *Kallymenia cribrogloea* Womersley & Norris 1971: 7, figs. 6-12, 78-80.

The range of this species was previously given as from Waldegrave I., Eyre Peninsula, S. Aust. to Port Phillip Heads, Vic. and Bruny I., Tas. Well developed, typical specimens have been found in Jervis Bay, N.S.W., 18 m deep in the southern end of the bay (Shepherd, 15.viii.1972; ADU, A42614). This extends the range considerably, and SCUBA collections from deep water may show that this is not an uncommon species, though rarely found in the drift because of its delicate nature.

#### 2. *Kallymenia rosea* Womersley & Norris 1971: 9, figs. 13-18, 81, 82.

This species was described largely on numerous specimens of Lucas from N.S.W. (mainly in NSW and MEL), collected before 1912; the only other record was one specimen from Port Stephens, N.S.W., in ADU.

The range of *K. rosea* can now be extended to Jervis Bay in southern N.S.W. where it was found 18 m deep in the southern end of the

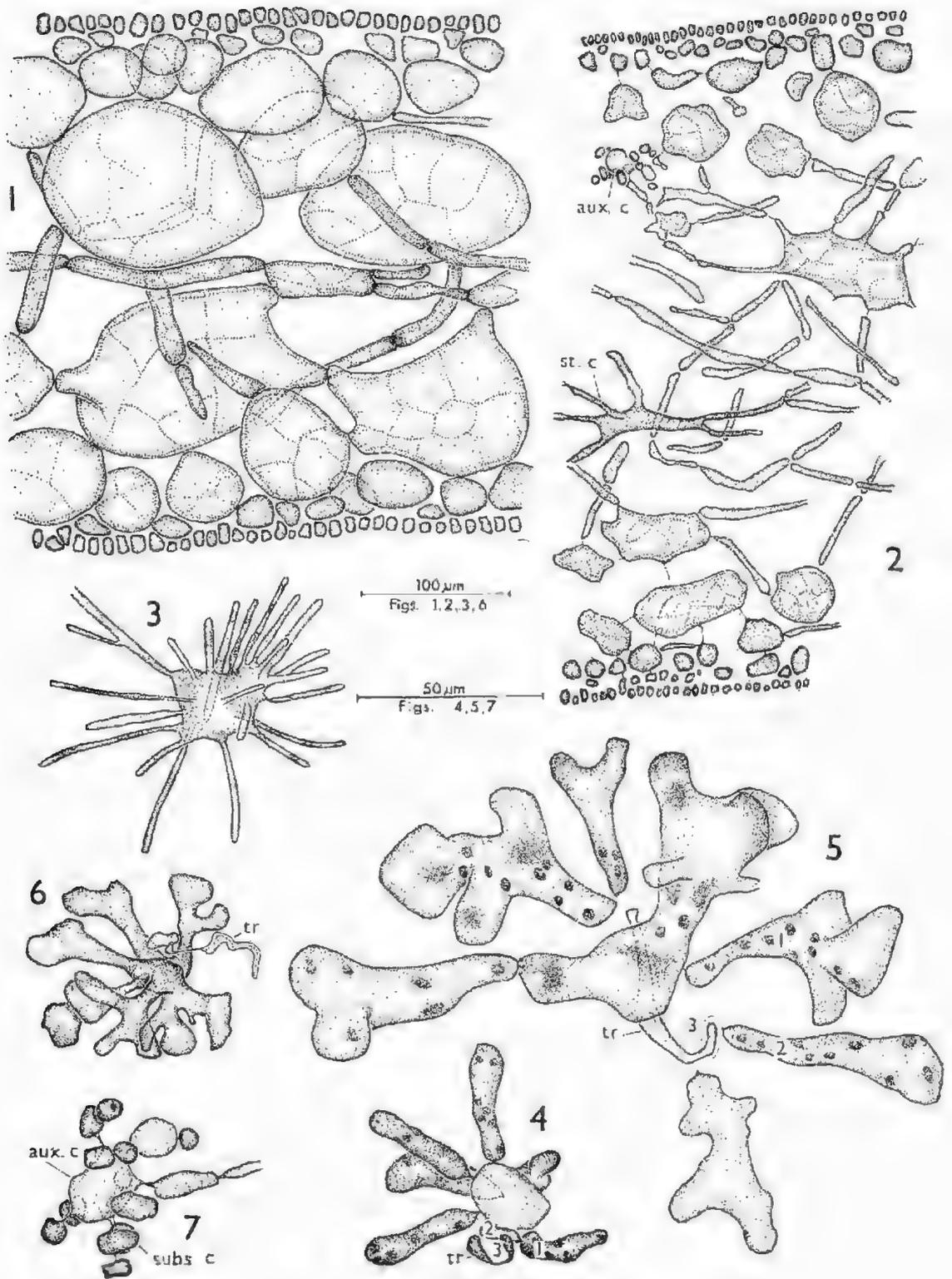
bay, in sheltered situations (Shepherd, 15.viii.1972; ADU, A42615).

This material (4 specimens) agrees well in form with the Lucas plants but is without surface proliferations and is medium red in colour. It is slightly rubbery when fresh and fairly thin. The thallus of liquid preserved specimens is (150-) 250-300  $\mu$ m thick (rather more than previously estimated from dried material) and has an epidermis of fairly compact cells grading rapidly to large, thin walled, ovoid, inner cells with large intercellular spaces (especially in the centre of the thallus); fairly loose, moderately coarse, filaments are produced from the larger cells (Fig. 1). Some of the large cells become stellate, as previously figured (Womersley & Norris 1971, fig. 14).

Carpogonial branch systems are polycarpogonial with 8-16 carpogonial branches, the first cell of which is clavate to lobed, and the second cell smaller and clongate; auxiliary cell systems are as previously described and figured, but the large, ovoid, cell recorded as associated with the carpogonial branch systems was not apparent in the Jervis Bay material. Apparently this cell is only a vegetative cell appearing somewhat distinctive in the Lucas specimens. Apart from young fusion cells, stages of carposporophyte development were not present in the Jervis Bay material.

*K. rosea* is probably a fairly deep water species and is distinct from other Australian species of *Kallymenia* in its form, and from

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other similar foliose species in the presence of polycarpogonial reproductive systems.

3. *Kallymenia polycoelioides* J. Agardh 1876: 687.

*Meredithia polycoelioides* (J. Ag.) J. Agardh 1892: 76; Womersley & Norris 1971: 42, fig. 108.

Thallus complanate, foliose-subdichotomous, to 12 cm high, arising from a short stipe 1–4 mm long with a discoid holdfast 1–3 mm across; thallus cuneately to broadly expanded to 1–4 cm across at a few cm above the stipe, developing subdichotomous branches 1–1½ cm broad, and 1–2 cm between dichotomies, with broad, rounded apices or lobes 3–6 mm across; in some plants new subdichotomous lobes arise proliferously from older basal parts. Colour deep red to brownish-red, substance fairly soft, adhering closely to paper on drying.

Thallus 400–600 µm thick (Fig. 2), with a cortex 5–7 cells thick and a broad medulla of fairly loosely arranged filaments mostly 7–15 µm in diam.; outer cortical cells fairly compact, 2–4 µm across and isodiametric in surface view, inner cortical cells large; medulla with stellate cells (Fig. 3) often with numerous arms and slightly to moderately staining.

Carpogonial branch systems (Figs. 4, 5) monocarpogonial, the supporting cell lobed and bearing usually 4 lobed subsidiary cells and a 3 celled carpogonial branch, the first cell of which is lobed and the second elongate. Fusion cell lobed (Fig. 6). Auxiliary cell systems (Fig. 7) relatively small, 25–50 µm across, consisting of an auxiliary cell bearing about 8 subspherical subsidiary cells each of which often bears one further cell. Cystocarps scattered, about 2 mm in diam. (in the type).

Male and tetrasporangial thalli unknown.

*Type Locality*.—Orford, Tas. (*Meredith*).

*Type*.—Herb. Agardh, LD (24843).

*Distribution*.—South-eastern Tasmania. As well as the type, two further Tasmanian collections are known—Fluted Cape, Bruny I, 23 m (*Shepherd*, 12.ii.1972; ADU, A41925), and Great Taylor Bay, Bruny I, 2.5 m (*Shepherd*, 14.ii.1972; ADU, A42131).

Previously this species was considered of uncertain status (Womersley & Norris 1971, p. 42) but two collections by S.A. Shepherd from near the type locality, and agreeing very well in form with the type, show typical kallymeniaceous female reproductive systems.

*K. polycoelioides* differs from other Australian species of the genus (see Womersley & Norris 1971, p. 4) in its subdichotomous habit, and is most closely related to *K. rubra* Womersley & Norris in its structure and reproduction.

*K. polycoelioides* agrees well with *Kallymenia* in thallus structure and in reproduction, but differs from most other species in being broadly subdichotomous (as in the holotype illustrated by Womersley & Norris 1971, fig. 108) rather than foliose or foliose-lobed. However, Codomier (1971) has referred two Mediterranean species, which show a branched habit, to *Kallymenia*, though without knowledge of the reproduction of either; *K. patens* (J. Ag.) Codomier becomes subdichotomous several times, while *K. spathulata* (J. Ag.) Codomier is broadly furcate and lobed above.

*K. polycoelioides* has a fairly soft thallus, drying thin and closely adherent to paper, and not cartilaginous. The texture, structure and reproduction agree so well with other species of *Kallymenia* that *K. polycoelioides* cannot be separated generically simply on the basis of its habit.

Placement of *K. polycoelioides* in *Kallymenia* involves consideration of the difference between *Kallymenia* and *Cirrullacarpus*. The latter is usually distinguished by its branched thallus. Both the type species of *Cirrullacarpus* [*C. gmelini* (Grunow) Tokida & Masaki] from Japan, and *C. australis* Womersley & Norris (see below) from southern Australia, have thalli with several subdi- to polychotomous branchings. While *K. polycoelioides* and *Cirrullacarpus* both have a branched habit, the thallus texture of the former is soft and not cartilaginous (as is typical of most species of *Kallymenia*), in contrast to the thallus of *Cirrullacarpus* which is cartilaginous, not or only slightly adherent to paper. A possible distinction also lies in the cystocarps which Norris

Fig. 1. *Kallymenia rosea*. Cross section of thallus.

Figs. 2–7. *Kallymenia polycoelioides*. Fig. 2.—Cross sections of thallus with a stellate cell and auxiliary cell system. Fig. 3.—Stellate cell. Fig. 4.—Young carpogonial branch system. Fig. 5.—Mature carpogonial branch system. Fig. 6.—Fusion cell. Fig. 7.—Auxiliary cell system.

Abbreviations used: aux.c, auxiliary cell; st.c, stellate cell; subs.c, subsidiary cell; tr, trichogync. 1, 2, 3 refer to the first cell, second cell, and carpogonium of the carpogonial branch respectively.

*et al.* (1960) report as being compound or confluent in *C. gmelini*, and which are grouped in *C. australis*. For the present *Cirrucarpus* is best maintained as a distinct genus, but further studies of distinctions between it and *Kallymenia* are needed.

#### 4. *Cirrucarpus australis* and *Meredithia nana*.

Womersley & Norris (1971, p. 42) regarded *Meredithia nana* J. Agardh as of doubtful affinity, commenting that the thallus structure is kallymenioid but reproductive systems were not seen adequately in the type. It was considered that it might not be a member of the Kallymeniaceae.

Further study of plants of *Cirrucarpus australis* Womersley & Norris, especially of small thalli, show that the type specimen of *Meredithia nana* is almost certainly a young plant of *C. australis*. Their form is comparable taking regard of the state of development, the structure in cross sectional view is identical, and the type locality of *M. nana* (Port Phillip, Vic.) is similar to that of *C. australis* (Port Phillip Heads).

The species should therefore be known as *Cirrucarpus nana* (J. Agardh) comb. nov. (Basionym *Meredithia nana* J. Agardh 1892, p. 76), with *C. australis* Womersley & Norris (1971, p. 19, figs. 39-43, 90) as a synonym.

#### 5. An earlier name for *Callophyllis coccinea* Harvey.

Since the publication of Womersley & Norris (1971), the type specimen of *Fucus rangiferinus* Turner has been examined. This specimen in the British Museum, from Kents Islands, Bass Strait, was collected by R. Brown (No. 256) in 1803-4, and is a tetrasporangial specimen 4-6 cm high, much branched with slender ultimate branches typical of *Callophyllis coccinea* Harvey.

The correct name is thus *Callophyllis rangiferinus* (Turner) comb. nov. (Basionym *Fucus rangiferinus* Turner 1811, p. 114, pl. 183).

Following the original description of Turner, *F. rangiferinus* was placed under *Chondria* by C. Agardh (1823, p. 359) and under *Hypnea*? by Greville (1830, p. lix) and Kuetzing (1849, p. 761). J. Agardh (1852, p. 636) referred it to *Lecithites*, but later (1876, p. 572) referred his 1851 description to *Mychodea hamata* Harvey, excluding the previous synonyms. De Toni (1897, p. 264) followed J. Agardh.

#### Acknowledgments

Loan of the type of *F. rangiferinus* from the Department of Botany of the British Museum is gratefully acknowledged. Technical assistance is acknowledged under a grant from the Australian Research Grants Committee. I am grateful to Professor R. E. Norris for comments on the manuscript.

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# AMIDOSTOMATINAE (NEMATODA: TRICHOSTRONGYLOIDEA) FROM AUSTRALIAN MARSUPIALS AND MONOTREMES

BY PATRICIA M. MAWSON\*

## Summary

MAWSON, PATRICIA. M. (1973). -Amidostomatinae (Nematoda: Trichostrongyloidea) from Australian marsupials and monotremes. *Trans. R. Soc. S. Aust.* 97(4), 257-279, 30 November, 1973. This work is a revision of the genera *Austrostrongylus* Chandler and *Nicollina* Baylis. Two new genera are proposed, *Paraustrostrongylus* and *Woolleya*; these four genera, with *Patricialina* Inglis, belong to the Amidostomatinae. *Filarinema* Mönnig is transferred to the subfamily Mackerrostrongylinae. *Austrostrongylus* and *Paraustrostrongylus* spp. are recorded from a phalanger and from macropod marsupials, *Nicollina* from monotremes and the numbat (a dasyurid), and *Woolleya* from dasyurids and a native eutherian, the water rat.

New species described are *Austrostrongylus hypsiprymnodontis* from *Hypsiprymnodon moschatus*; *A. paratypicus* from *Macropus rufogriseus*; *A. chandleri* from *Macropus bicolor* and *M. rufogriseus*; *Paraustrostrongylus bettongia* from *Bettongia cuniculus*; *P. trichosuri* from *Trichosurus vulpecula*; *Nicollina calabyi* and *N. inglisi* from *Myrmecobius fasciatus*; *Woolleya sprenti* from *Dasyurus viverrinus*, *Antechinus stuartii*, *Dasyurops maculatus* and *Thylacinus cynocephalus*; *W. hickmani* and *W. monodelphis* from *Antechinus stuartii*; *W. martini* from *Antechinomys spenceri*.

Species redescribed in whole or in part are *Austrostrongylus macropodis* Chandler, *A. wallabiae* Johnston & Mawson, *A. aggregatus* Johnston & Mawson, *A. minutus* Johnston & Mawson, *A. thylogale* Johnson & Mawson, *Paraustrostrongylus potoroo* (Johnston & Mawson) (syn. *A. potoroo*), and *Nicollina echidnae* Baylis.

Other new combinations are *Woolleya sarcophili* (Cameron), *W. cathiae* (Inglis), *W. iota* (Mawson), *W. acinocerus* (Mawson), all transferred from *Nicollina*, and *W. hydromyos* (Mawson), transferred from *Austrostrongylus*.

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### Introduction

The trichostrongyloid nematodes from Australian vertebrates were discussed by Inglis (1966) who considered that all belong to the family Amidostomatidae. In the subfamily Amidostomatinae he included (from marsupials) the general *Filarinema* Mönnig, *Patricialina* Inglis, *Austrostrongylus* Chandler and *Nicollina* Baylis. *Filarinema*, however, differs markedly from all other genera of the subfamily in the virtual absence of a buccal capsule—the teeth occur in an enlargement of the anterior end of the oesophagus, so this genus should be referred to the subfamily Mackerrostrongylinae Inglis, in which a buccal capsule is absent. Of the three genera from monotremes and marsupials remaining in Amidostomatinae, no *Patricialina* sp. has been found during the present study.

Up to the present, most of the species from marsupials have been identified as belonging to either *Austrostrongylus* (type species *A. macropodis* Chandler, 1924) or *Nicollina* Baylis, 1931 (type species *N. tachyglossae* Baylis, 1930). Proposing the genus *Nicollia* (which he changed to *Nicollina* in 1931) Baylis stated that this genus differs from *Austrostrongylus* in the presence of a shallower buccal capsule, the symmetrical bursa, the absence of ventral teeth, and in the shape of the tail of the female. More species were later attributed to each genus, and Mawson (1960, p. 264) pointed out that among species with ventral teeth, the female tail in some is conical and in others bears a terminal spine, and it was suggested that the best character on which to separate the genera would be the shape of the spicules, which in *Austrostrongylus* spp. are

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entire and in *Nicollina* spp. are bifid or trifid distally. Inglis (1968, p. 336) agreed with this and gave an amended list of species belonging to each genus.

In the present study, 13 new species of amidostomes have been identified from monotremes and from a variety of Australian marsupials, including dasyurids, from which only one species had previously been described (*N. calthiae* Inglis, 1968). The identification of these has entailed the re-examination of all available paratype or holotype specimens of existing species, and a re-evaluation of the generic characters.

### Discussion

Two new genera are proposed, *Paraustrostrongylus* and *Woolleya*. Both *Paraustrostrongylus* spp. and *Austrostrongylus* spp. are characterised by wide and thick lateral alae and single-tipped spicules, and these features distinguish them from *Nicollina* spp. and *Woolleya* spp. in which lateral alae if present are small and thin and the spicule tips are divided. Distinct differences in the form of the buccal capsule and dorsal tooth distinguish *Nicollina* spp. from *Woolleya* spp. These four genera are found in different hosts, *Austrostrongylus* spp. and *Paraustrostrongylus* spp. being recorded from macropods and phalangers (herbivores), *Nicollina* spp. from the echidna and the numbat (termite and ant-eaters) and the platypus (which eats worms, etc.) and *Woolleya* spp. from dasyurids, bandicoots, and a eutherian, the water rat (all carnivores).

However, there are some species which are not satisfactorily accounted for. The spicules of *N. cameroni* (Mawson), *W. sarcophili* (Cameron) and *W. acinacetus* (Mawson) are not divided, but the body lacks the lateral alae and the characteristic bursa of *Austrostrongylus* and *Paraustrostrongylus*. In *Woolleya mundelphii* n.sp. and *W. hydromyos* (Mawson) the spicules are divided and the longitudinal crests are like those of *Woolleya* spp., but the tail of the female is pointed and lacks a spine. The position of these species will be discussed under *Woolleya* n.g.

The characters of the four genera will be described in detail below, but some general remarks are made here about the cuticular swellings and crests commonly found in species of all these genera. Cuticular ridges and cuticular inflations in the Heligmosomatidae have been studied in detail by Durette-Desset (1964, 1966) in species from the Old and New Worlds. According to this author almost all the

heligmosomes are rolled into a sinistral spiral. Some live coiled around villi (with the anterior end towards the base of the villus) and maintain their position by a combination of pinching with the internal (best developed) crests and the apposition of lateral crests and alae. Others, in which different areas of the body bear the best-developed crests, also form a sinistral coil, but not around a villus, and these move through the mucus between the villi with a corkscrew action, so that the outside of the coil (the dorsal body surface) which bears the best-developed crests, comes in contact with the villi.

Although they belong to a different group from the Heligmosomatidae, the Australian amidostomes may be compared with them in some respects. If they are coiled, it is in a sinistral spiral. In some genera (*Austrostrongylus* and *Paraustrostrongylus*) the lateral alae are very well developed, not only out from the body in a lateral direction, but they are almost as thick, dorsoventrally, as the body (Figs. 7, 13, 26). The cuticle over these enlarged alae bears one or more longitudinal ridges, and there are also one or more crests on the ventral surface of the body proper. These alae differ from those described by Durette-Desset as enlarged crests, because the enlargement is caused by subcuticular swelling, the crests themselves being of normal size (as indicated by their cuticular "skeleton") and merely borne on the inflated cuticle. In other genera, *Nicollina* and *Woolleya*, lateral alae are less distinct, and the longitudinal crests are variously distributed. In all cases males and females of the same species show similar peculiarities of structure and distribution of the crests. In some species, but by no means in all, there is a gradient around the body in the size of the crests. In many Australian species, crests are absent on the dorsal surface. An attempt has been made to classify the various species according to alae and crests. Those with two, wide, thick lateral alae form a natural group (also distinguished by other characters) which is further differentiated into the two genera *Austrostrongylus* and *Paraustrostrongylus*. Among the remaining species, in which lateral alae if present are of a different type, longitudinal crests are variously arranged—they may be many (8–20 or more) and distributed all round the body, or they may be few (2–4) and restricted to the ventral surface. However, neither of these types is associated with any one of the types of spicule tips, dorsal ray or female

tail, so that further classification on the type of crests is impracticable.

Most of the specimens examined were not seen *in situ* in the host, although a few were found coiled round torn off villi.

Unless otherwise indicated, all the transverse sections figured were taken about the midbody of the worm.

Measurements of new material are given in Tables 1, 2, 3, or 4, as indicated in each case under the species heading. Types of new species will be deposited in the South Australian Museum, Adelaide.

#### Key to genera

1. Lateral alae wide and thick; dorsal lobe of bursa markedly thickened ..... 2
1. Lateral alae, if present, thin; dorsal lobe of bursa not thickened ..... 3
2. Genital cone well developed, chitinised  
*Paraastrostrongylus*
2. Genital cone not well developed, not chitinised ..... *Astrostrongylus*
3. Buccal capsule a shallow ring; dorsal tooth blunt, protrusible ..... *Nicollina*
3. Buccal capsule domed anteriorly; dorsal tooth pointed ..... *Woolleya*

#### AUSTROSTRONGYLUS Chandler

Amidostomatidae: Small usually coiled worms with thick and wide lateral alae; longitudinal cuticular crests on alae and on body proper; cephalic cuticle inflated; buccal capsule well developed, with one dorsal and sometimes two smaller subventral oesophageal teeth. Male: bursa more or less symmetrical, lateral lobes long, dorsal short and thick; dorsal ray usually dividing into three pairs of branches; externo-dorsal ray arising separately, other rays from same root, separating at tips; genital cone not distinct, spicules slender with simple points, sometimes united by small alae. Female: tail tapering to long point; vulva near posterior end of body, ovejectors divergent. Parasites of small intestine of macropod marsupials.

Type species: *A. macropodis* Chandler, 1924: 160.

Other species: *A. aggregatus* Johnston & Mawson, 1940b: 472; *A. minus* Johnston & Mawson, 1938: 195; *A. thylogale* Johnston & Mawson, 1939: 534; *A. paratypicus* n.sp.; *A. chandleri* n.sp.; *A. hypsiprymnodon* n.sp.

In some species of *Astrostrongylus*, perhaps in all, there is a strong tendency to the deposition of a dark reticular and granular material under the cuticle. Durette-Dussel (1966, pp. 457, 461) notes a similar condition in some heligmosomes and, by staining, concluded that

it is a chitinoid substance. This occurs especially in the lateral alae and in the bursa, and sometimes in the cephalic inflation, but may also appear in the older female between vulva and anus, all round the body. The distribution in the bursa appears to vary with the species; in many cases it obscures the dorsal ray, especially in long-stored specimens: it is resistant to clearing in lactophenol, but less so in cresote or Berlese's Fluid.

In all species of *Astrostrongylus* the dorsal lobe of the bursa, whether containing granular material or not, is much thickened, so much so that the lobe is in fact almost spherical, the inner or ventral face of the lobe extending to the cloaca. A genital cone, as such, is absent. Because of the shape of the bursa, the dorsal ray must be considered in three dimensions rather than two.

The characteristic bursa, and the striking strap-like form given to the body by the wide thick alae, appear to be important diagnostic features of the genus, although they have not previously been mentioned. Both characters are present in the type species of the genus, which is partially redescribed below.

*Astrostrongylus macropodis* Chandler, 1924: 160. From Bennett's Kangaroo, *Macropus rufogriseus* var. *bennetti*.

#### FIGS. 1, 2

The type and paratype material of *A. macropodis* has been examined. The holotype male and cotype female (U.S.N.M. Helm. Coll. 26124) are on slides and impossible to examine thoroughly. What is assumed to be the paratype material is in the collection of the Department of Biology, Rice University. This material (H.N. 23049) is labelled 'from Bennett's Kangaroo' and was worked on by Dr. Chandler. The specimens agree closely in most particulars with Chandler's description of *A. macropodis*. They have the wide lateral alae and the swollen dorsal lobe of the bursa which have been seen in all other species of the genus. Unfortunately the darkening of the dorsal lobe obscures the final branching of the dorsal ray. It is clear, however, that the dark part of the dorsal lobe extends nearly to its posterior border, and that in Chandler's Fig. 3 the clear part of the lobe is its swollen inner surface, which is unpigmented, and which in some positions of the bursa appears to be its posterior border. Thus the dorsal ray extends nearly to the posterior edge of the bursa, and the dorsal lobe is shorter than indicated by Chandler. There may be two or three pairs of

branches of the dorsal ray, but the tips of the inner branches shown here in Fig. 1 are not clear. If there are only two pairs, this is the only species of the genus in which this is so. The tips of the spicules are enlarged by alae, as figured by Chandler.

The bodies of these specimens are so much contracted that a good transverse section could not be drawn. Allowing for some distortion, the sections made show alae and crests similar to those shown in Figs. 14 and 18, but with an extra crest on the dorsal aspect of the right side.

#### Key to species of *Austrostrongylus*

1. Female monodelphous *A. hypsiprymmodontis*
1. Female didelphous ..... 2
  2. Vagina long, more or less equal to distance from vulva to anus ..... *A. aggregatus*
  2. Vagina short ..... 3
3. Spicules with relatively wide alae round tips 4
3. Spicules with small or no alae at tips ..... 5
  4. Male 4.5-5 mm long, spicules 375-500  $\mu$ m ..... *A. macropodis*
  4. Male 3.8-4.7 mm long, spicules 520-700  $\mu$ m ..... *A. paratypicus*
5. Dorsal ray gives off first pair of branches, then bifurcates ..... *A. minutus*
5. Dorsal ray gives off two pairs of branches, then bifurcates ..... 6
  6. Tips of spicules united in small ala ..... 7
  6. Tips of spicules not united in ala ..... *A. wallabiae*
7. Three crests on each lateral ala; branches of dorsal ray elongate ..... *A. thylagale*
7. One crest on each lateral ala; branches of dorsal ray short, stout ..... *A. chandleri*

***Austrostrongylus wallabiae*** Johnston & Mawson, 1939: 534, from *Macropus rufogriseus* (syn. *M. ruficollis*).

#### FIGS. 3-6; TABLE 1

Host and locality: *Macropus rufogriseus* from Logan Village, Qld.

New specimens as well as the type material have been examined and the original description can now be amended. As was stated, the type specimens are darkened by masses of granular material deposited under the cuticle in the wide, thick, lateral alae, in the bursa, especially in the dorsal lobe, and in the female at the posterior end of the body—in a few of the older specimens this region is so distended as to overhang the anus. In the newer specimens from Queensland there are similar dark masses but these are neither so thick nor so dark.

On the broad lateral alae there are longitudinal crests, three on one side, two on the other; there are also two large and one small ventral crests. There are no dorsal crests except those on the dorsal side of the alae (Fig. 1).

In the female the lateral alae terminate at about the level of the vulva, in the male the left ala reaches nearly to the bursa, and the right is rather shorter.

The buccal capsule is well developed with two small ventral, and one large dorsal, teeth.

The spicules are very slender, with simple acicular tips not enclosed in alae. The bursa is thick-walled, especially the dorsal lobe, and is more or less symmetrical—in some specimens the right lobe is rather longer and narrower than the left. The dorsal ray, seen more clearly in the new material, has one more pair of branches than originally described (Fig. 4).

The vulva in the original material is 500-600  $\mu$ m from the posterior end of the worm (not 1,500  $\mu$ m). The cuticle just in front of the vulva is more or less inflated (Fig. 2).

Although the species is similar to *A. macropodis*, there are distinct differences in the bursal rays, and there appears to be less granular material deposited in various parts of the body.

***Austrostrongylus aggregatus*** Johnston & Mawson, 1940: 472, from *Wallabia bicolor* (syn. *Macropus wallabatus*).

#### FIGS. 7-10; TABLE 1

Host and locality: *Wallabia bicolor* from Logan Village, Qld.

The type male and female and the paratype material of this species have been re-examined and compared with the new material. Measurements of the new material are given in Table 1.

Two asymmetrical lateral alae are present, as well as three ventral longitudinal crests. The oesophagus widens gradually in its posterior third.

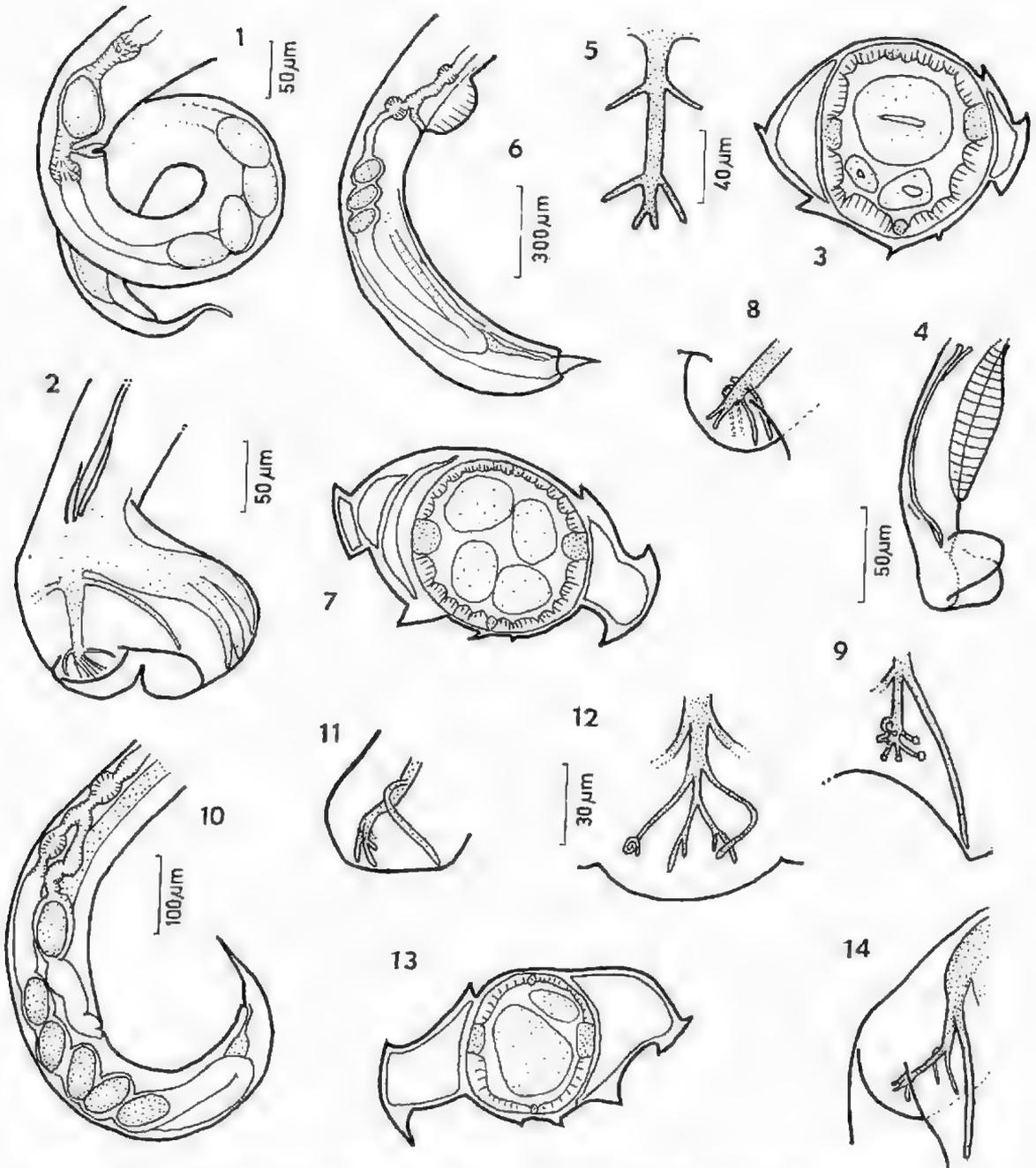
The vagina is unusually long, reaching a distance anterior to the vulva about equal to that of the vulva from the posterior end of the body.

The bursa is thick, particularly the dorsal lobe, and darkened with a granular deposit. In one male this deposit is almost absent, and the branches of the dorsal ray quite clear (Figs. 8, 9). The spicules are long and very slender, both ending in one ala. The gubernaculum is a thin plate.

***Austrostrongylus minutus*** Johnston & Mawson, 1938: 195, from *Macropus dorsalis*.

#### FIGS. 11-12

The paratype material of this species has been examined; the lateral alae and the dorsal lobe of the bursa agree with the revised definition of these structures in *Austrostrongylus*. However, the few specimens have been greatly



Figs. 1-2. *Austrostrongylus macropodis*. Fig. 1.—Posterior end of female, Fig. 2.—Posterior end of male.  
 Figs. 3-6. *Austrostrongylus wallabiae*. Fig. 3.—Transverse section of body of female. Fig. 4.—Posterior end of male. Fig. 5.—Dorsal ray. Fig. 6.—Posterior end of female.  
 Figs. 7-10. *Austrostrongylus aggregatus*. Fig. 7.—Transverse section of body of male. Figs. 8 and 9.—Lateral and ventral views of dorsal ray. Fig. 10.—Posterior end of female.  
 Figs. 11-12. *Austrostrongylus minutus*. Fig. 11.—Lateral view of dorsal lobe and dorsal ray. Fig. 12.—Ventral view of dorsal ray.  
 Figs. 13, 14. *Austrostrongylus thylogale*. Fig. 13.—Transverse section of the body. Fig. 14.—Lateral view of dorsal lobe, with dorsal and one externa-dorsal rays.  
 Figs. 3, 6, 7, 8, 11 and 13 to scale beside 6; Figs. 9, 12 and 14 to scale beside 12.

flattened and a useful transverse section cannot be given. There appears to be only one ventral body crest; apart from those on the alae. The lateral alae extend beyond the vulva in the female, and in the male the left ala is a little longer than the right. The right side of the bursa is rather longer than the left, but the rays are similar on the two sides. The dorsal lobe is so swollen as to be almost spherical, and the three pairs of branches of the dorsal ray (not two pairs) lie almost at right angles to its main axis.

***Austrostrongylus thylogale*** Johnston & Mawson, 1940a: 99, from *Macropus eugenii* (syn. *Thylogale eugenii*), from Kangaroo I., S. Aust.; Mawson, 1959: 155, from *Setonix brachyura*, from Rottneest I., W. Aust.; Inglis, 1968: 336, from *S. brachyura*, W. Aust.

FIGS. 13-14

Specimens from the Kangaroo I. wallaby have been studied and compared with those of other species of *Austrostrongylus*. The lateral alae are broad and wide, asymmetrical in section, with three asymmetrical crests on the alae and two ventral crests on the body.

*A. thylogale* appears to be free from the granular deposits which obscure, or partially obscure, the bursa of some other species of the genus. The swollen dorsal lobe of the bursa is clear, and in it can be seen the three pairs of branches of the dorsal ray, penetrating the lobe in three planes (Fig. 14). In the female the lateral alae extend to just behind the vulva; in the male the left continues nearly to the bursa, the right ends shortly anterior to this. The spicule tips are united in a very small ala.

***Austrostrongylus paratypicus*** n.sp.

FIGS. 15-18; TABLE 1

Host and locality: *Macropus rufogriseus* from the Bathurst district, N.S.W.

In the same host animal as specimens of *Austrostrongylus wallabiae*, there were about 20 specimens of a smaller and apparently new *Austrostrongylus* sp. The body form is similar to that of *A. wallabiae*, more or less tightly coiled. The lateral alae are very wide, with one crest on the left side and two on the right, and there are in addition two ventral crests. Towards the posterior end of the male the left ala terminates but the right, in most specimens dark with granular material, continues nearly to the bursa. In the female, the lateral alae extend to or a little beyond the vulva.

The buccal capsule is well developed, the dorsal tooth large and the two sub-ventral teeth

small. The nerve ring surrounds the oesophagus towards the end of the second third of its length. The excretory pore is close to, or behind, the base of the oesophagus in the male, rather more anterior in the female.

The tail of the female tapers to a long cylindrical process. Both ovejectors are well developed. A uterine egg near the ovejector is 90 x 45  $\mu$ m.

The bursa is thickened with granular material, especially in the dorsal lobe, where it often obscures the detail of the dorsal ray. The lateral lobes are asymmetrical, the left wider than the right. The three lateral and two ventral rays are closer together in the right lobe, diverging only near their tips. The external lateral ray of the left side is distinctly larger than that of the right. The dorsal ray gives off two branches before its final bifurcation, not all in the same plane (Fig. 18).

The spicules widen near their distal ends; the tips are alate, the alae are folded around the tips when lying in the body and when dissected out; in no case were the spicules extruded naturally. The gubernaculum is very small and thin.

The species is distinguished from *A. wallabiae* by the more posterior position of the vulva, the shape of the spicule tips, and the asymmetrical bursa. It seems to be close to *A. macropodis* (from the Tasmanian sub-species of *Macropus rufogriseus*). However, the spicules are longer. Because of this and the apparent difference in the branching of the dorsal ray, and also because the hosts come from widely different localities, the two species are regarded as separate.

***Austrostrongylus chandleri*** n.sp.

FIGS. 19-24; TABLE 1

Hosts and localities: *Macropus rufogriseus* (type host) from *Wallabia bicolor* from Logan Village, Qld.

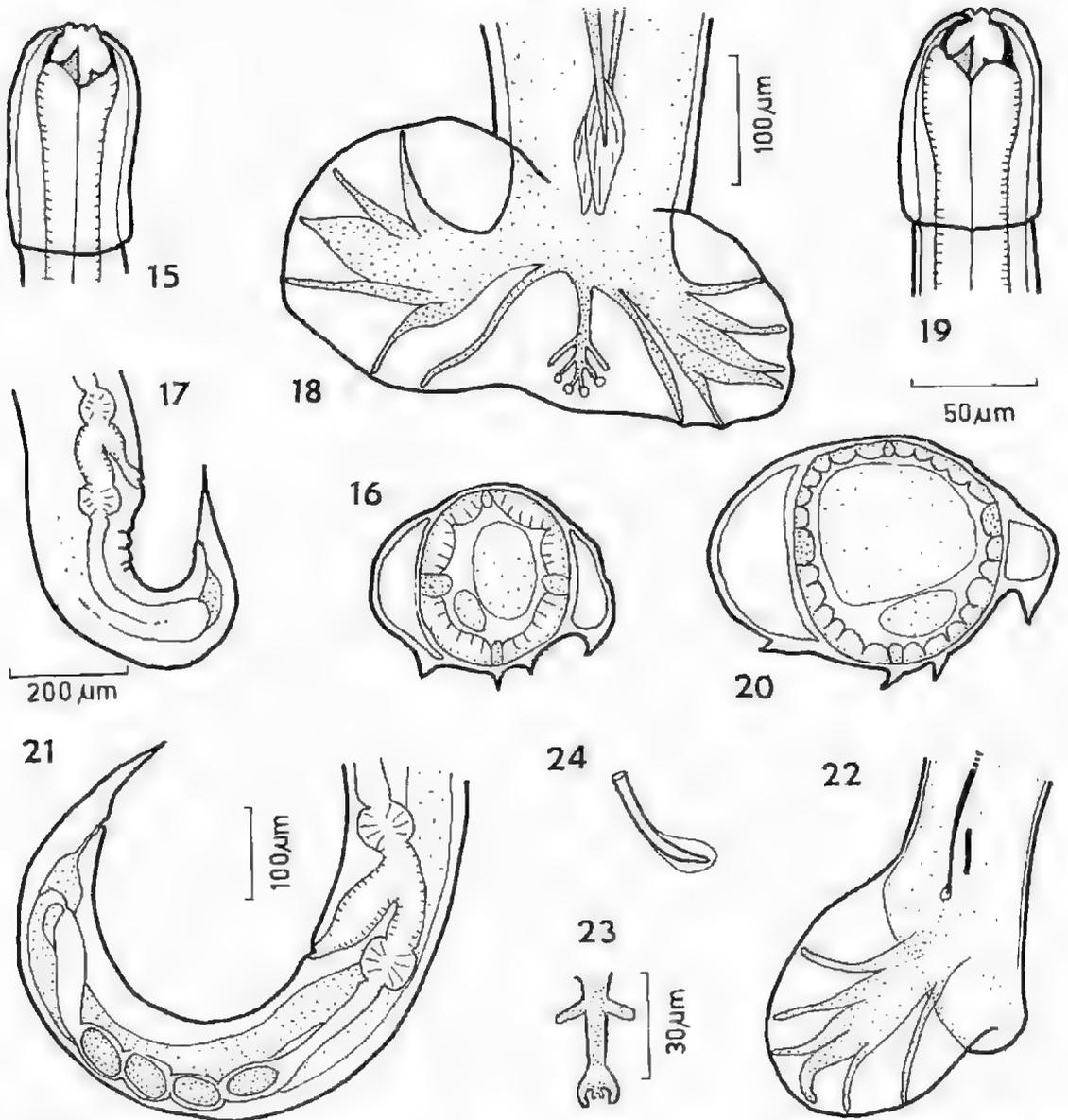
The body is loosely coiled. The lateral asymmetrical alae are well developed, each with one crest; in addition, two ventral crests are present. The buccal capsule is well developed, the dorsal tooth about half the depth of the capsule and the two sub-ventral teeth small.

The tail of the female tapers, ending in a thin finger-like piece. The vulva, well in front of the anus, leads to a short vagina; the ovejectors are about equal in size. The eggs are 75-85 x 45-50  $\mu$ m.

The spicules are long, slender throughout their length, and end in blunt tips slightly curved ventrally and enclosed in a single small

TABLE 1  
*Measurements of Austrostrongylus spp., taken from material newly recorded in this paper. Unless otherwise stated, measurements are in  $\mu\text{m}$ .*

Species	<i>A. wallabiae</i>	<i>A. aggregatus</i>	<i>A. chandleri</i> (type host)	<i>A. paratypticus</i>	<i>A. hypsiprymmodontis</i>
Male:					
Length (mm)	5.1-6.3	4.0-4.5	4.9-6.2	3.8-4.7	4.3-4.5
Oesophagus	420-550	330-420	400-480	330-450	280-310
Length/Oesophagus	9.3-13.9	9.7-12.1	10.4-14.1	10.2-14.2	14.5-15.3
Ceph. inflation	85-90	65-75	80-90	88-92	60-70
Antr. end—nerve ring	not clear	210 (1x)	220-245		140-145
—excr. pore	300-400	290-360	310-370		280-390
Spicules	600-730	840-1005	520-600	520-700	600-670
Length/spicule L.	8.2-9.0	4.3-4.7	8.8-10.5	6.5-8.2	6.4-7.2
Female:					
Length (mm)	7.8 (2x)	4.1-4.6	6.1-8.1	5.6-6.1	4.2-4.6
Oesophagus	500-670	300-400	420-490	410-460	315-370
Length/Oesophagus	11.5-15.6	11.5-13.7	13.2-16.6	13.2-14.1	11.9-14.4
Ceph. inflation	100 (2x)	70-80	75-85		63-75
Antr. end—nerve ring		200-220	220-270	230-250	165-210
—excr. pore	100-140	240-310	320-350	320-380	350-420
Tail		90-100	90-110	100-130	90-95
Postr. end—vulva	1100-1300	390-550	600-1100	600-800	190-200
Length/P—vulva	6.0-7.2	8.2-11.5	6.6-10.3	7.3-9.1	23.0-23.2
P—vulva/tail	9.3-11.0	4.3-5.5	6.7-10.6	6.0-6.4	2.0-2.2



Figs. 15-18, *Austrostrongylus paratypicus*. Fig. 15.—Head. Fig. 16.—Transverse section of body of male. Fig. 17.—Posterior end of female. Fig. 18.—Bursa of male.  
 Figs. 19-24, *Austrostrongylus chandleri*. Fig. 19.—Head. Fig. 20.—Transverse section of body of male. Fig. 21.—Posterior end of female. Fig. 22.—Lateral view of bursa. Fig. 23.—Ventral view of dorsal ray. Fig. 24.—Tip of one spicule.  
 Figs. 15, 19 and 20 to scale beside 18; Figs. 23 and 24 to scale beside 23.

oval ala. The gubernaculum is small and inconspicuous.

The bursa is more or less symmetrical, the dorsal lobe thick, the genital cone absent as such. The granular thickening of the bursa is strongly developed, darkening much of it, including the dorsal lobe and the area posterior and dorsal to the externo-dorsal rays.

The species resembles *A. wallabiae* in the arrangement of the bursal rays (Figs. 22, 23). It differs however in the distribution of the granular material in the bursa, in the absence of a lateral ala extending nearly to the bursa, and in the shape of the tips of the spicules. The form of the bursa and shape of the spicule tips are close to those of *A. thylogale*, but in

this species the bursa is without granular inclusions, the spicules are shorter, and the shape of the dorsal ray is different.

It will be seen from the measurements given in Table 1 that the specimens from *W. bicolor* are smaller than those from the type host. There is also some difference in the position of the longitudinal crests on the lateral alae in specimens from the two hosts, although this is similar in males and females for the same host, and in collections from the same host species. The value of this difference is uncertain; no other morphological difference can be seen between the specimens.

***Austrostrongylus hypsiprymmodontis* n.sp.**

FIGS. 25-29; TABLE 1

Host and locality: *Hypsiprymnodon moschatius* from Qld.

This is a small coiled worm, with very well developed lateral alae, of which the right is wider than the left. There are five longitudinal crests, two on each lateral ala and one on the ventral surface of the body. In the female the right ala is a little shorter than the left, which widens considerably before ending at about the level of the vulva. In the male the two alae extend from just behind the cephalic inflation nearly to the bursa, where they end abruptly at the same level.

The buccal capsule is well developed. The dorsal tooth is about half the length of the capsule. The excretory pore lies well behind the oesophagus.

The bursa is symmetrical, the dorsal lobe short and swollen and with a vesiculate structure internally, which rather obscures the dorsal ray. The arrangement of the rays is shown in Figs. 28, 29. The spicules are long and slender and end in a point. The presence of terminal alae could not be determined. A small gubernaculum is present.

The tail of the female is about half the distance from vulva to posterior end of the body. Only one, the anterior, uterus and ovejector is present. Eggs are 63-65 x 35-37  $\mu$ m.

This species has been referred to *Austrostrongylus* because of the inconspicuous genital cone, the origin of the externo-dorsal ray, and the way the lateral alae in the male end at the same level just in front of the bursa. In these features it differs from *Paraustrostrongylus* spp. It is distinguished from other species of the genus by the monodelphous condition of the female and the posterior position of the vulva. The cuticular swelling around the vulva is of

the irregular form seen in other species of *Austrostrongylus* rather than the definite ventral outgrowth seen in *Paraustrostrongylus* spp.

**PARAUSTROSTRONGYLUS n.g.**

Amidostomatidae: Small, usually coiled, worms with thick, wide lateral alae; longitudinal crests present on alae and on rest of body; cephalic inflation present; ventral cuticle at posterior end of body inflated, forming prebursal, or pre-vulvar, swellings usually of distinctive shape. Buccal capsule small, with dorsal oesophageal tooth. Ventral teeth present or absent. Male: bursa of two lateral and one small dorsal lobes, thickened dorsally and usually ventrally; externo-dorsal ray arising from base of dorsal, dorsal dividing into three pairs of branches, ventro-ventral ray diverging markedly at its base from latero-ventral and lateral rays; genital cone strongly chitinised, spicules long and slender, ending together in one or two alae; gubernaculum small, plate-like; Female: tail tapering to long point; monodelphous, only anterior ovejector, uterus, and ovary developed. Parasites of the intestine of macropod marsupials.

Type species: *P. potoroo*, syn. *Austrostrongylus potoroo* Johnston & Mawson, 1949.

This genus is close to *Austrostrongylus* in the form of the lateral alae, the swollen dorsal lobe of the bursa, and the tapering tail of the female. It is distinguished from it by the presence of a well developed genital cone, divergent ventro-ventral rays in the bursa, and a prebursal cuticular inflation in the male, and by the absence of the posterior part of the reproductive system of the female.

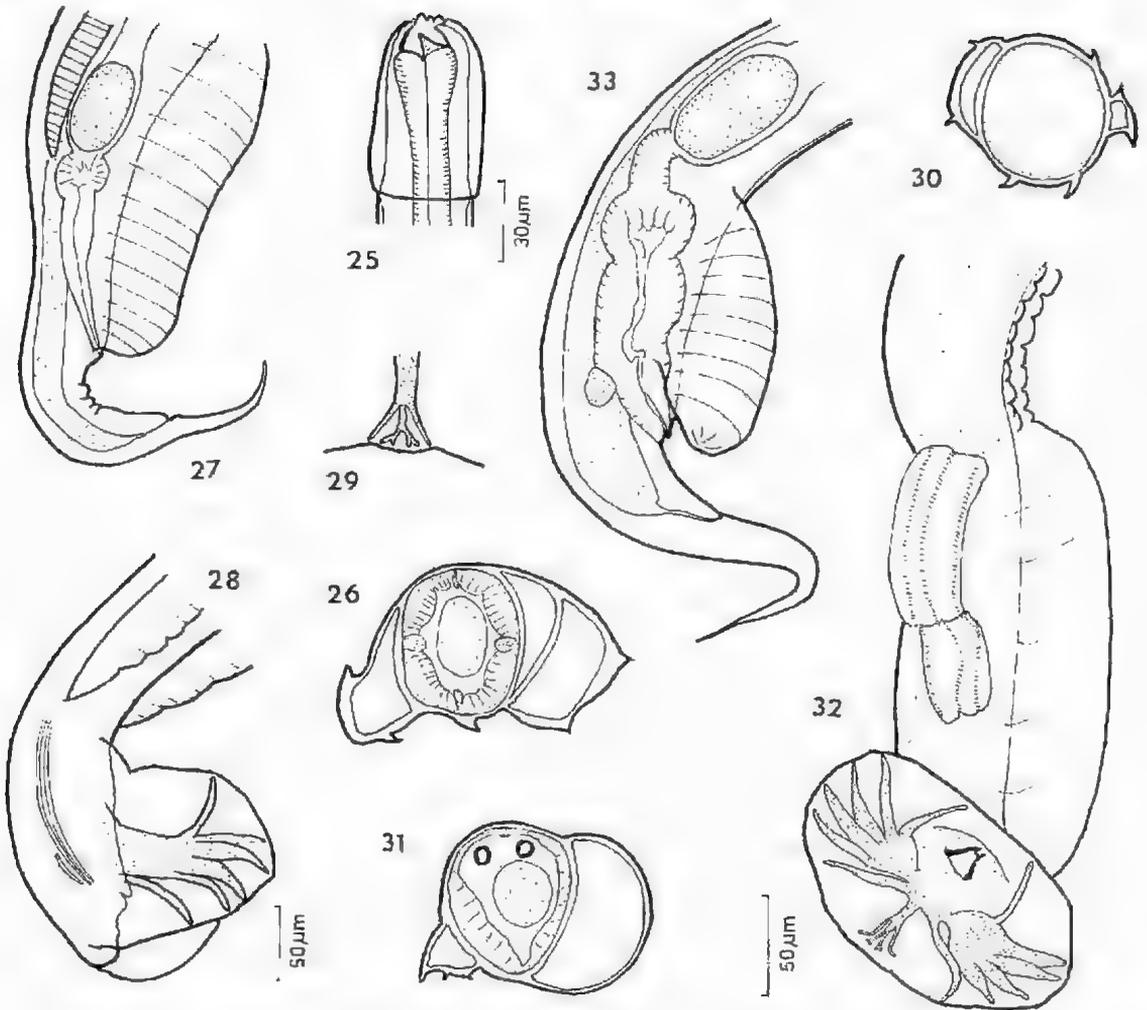
***Paraustrostrongylus potoroo* (Johnston & Mawson, 1969: 64).** from *Potorous tridactylus*.

FIGS. 30-33; TABLE 2

Host and locality: *Potorous tridactylus* from Hobart, Tas.

The type material of this species, as well as fresh material from the same host species, has been examined and a fuller description is now given.

The left lateral ala is thicker than the right; each bears two crests, and in addition there are two ventral cuticular crests and one dorso-lateral on the right side. These crests commence in the oesophageal region and continue to about the level of the vulva in the female and nearly to the bursa in the male. In the male the left ala becomes greatly inflated just an-



Figs. 25-29. *Austrostrongylus hypsiprymnodontis*. Fig. 25.—Head of female. Fig. 26.—Transverse section of body of male. Fig. 27.—Posterior end of female. Fig. 28.—Posterior end of male. Fig. 29.—Dorsal ray.  
 Figs. 30-33. *Paraustrostrongylus potoroo*. Fig. 30.—Transverse section of body of male. Fig. 31.—Transverse section of male shortly in front of bursa. Fig. 32.—Posterior end of male. Fig. 33.—Posterior end of female.  
 Figs. 26, 27 and 28 to scale beside 28; Figs. 29, 30, 31, 32 and 33 to scale beside 32.

terior to the bursa; the right ala ends a little anterior to this inflation. The subventral cuticle on the right side anterior to the bursa is raised into an elongate "blister" on which there are three obliquely longitudinal crests (Fig. 31).

The buccal capsule is small and the dorsal tooth relatively large. The ventral teeth are very small. The nerve ring lies just behind the mid-length of the oesophagus and the excretory pore is near its base.

The tail of the female tapers to a long point. The cuticle anterior to the vulva is greatly enlarged, forming a rounded mass overhanging

the vulva. The shape of this mass is similar on all new specimens examined, from two hosts, but in the older specimens it is flattened. Only the anterior part of the female reproductive system is present.

The bursa is slightly asymmetrical, with the left side, and its rays, a little larger than the right. The thickening of the dorsal lobe is not very marked. The arrangement of the bursal rays is shown in Fig. 32. The spicules are simple, undivided at the tips. A small gubernaculum is present. The genital cone is strongly chitinised, and probably acts as an accessory guide for the spicule.

TABLE 2

Measurements of *Paraastrostrongylus* spp. Unless otherwise indicated, measurements are in  $\mu\text{m}$ .

	<i>P. potoroo</i>	<i>P. bettongia</i>	<i>P. trichosuri</i>
<b>Male:</b>			
Length (mm)	2.4-2.6	4.0-4.4	4.3-5.3
Oesophagus	240-275	340-380	350-420
Ceph. inflation	40-48	70-80	90-100
Antr. end—nerve ring	120-150	218-230	250-270
—excr. pore	210-230	330-400	460-510
Spicules	250-260	380-400	380-450
Gubernaculum	40-45	45-50	35-40
<b>Female:</b>			
Length (mm)	2.7-3.0	5.7-6.0	5.0-6.7
Oesophagus	250-290	340-410	400-435
Ceph. inflation	45-50	80-85	80-100
Antr. end—nerve ring	130-140	200-220	230-260
—excr. pore	200-250	280-340	440-510
Tail	90-120	105-140	120-150
Postr. end—vulva	150-200	310-370	250-330

***Paraastrostrongylus bettongia* n.sp.**

FIGS. 34-41; TABLE 2

Host and locality: *Bettongia gaimardi* from Tas.

These are relatively large worms lying in tight or loose coils. There are two longitudinal crests on each lateral ala and two additional ventral crests. Each of these ends a little in front of the vulva in the female. Shortly in front of the bursa of the male, the right ala disappears but the left is much enlarged. Between the termination of the right ala and the bursa there is an elongate subventral inflation bearing 3 to 4 oblique-longitudinal crests (Fig. 38).

In nearly every specimen the anterior end is curved back against the rest of the body. The cephalic inflation is about a fifth of the length of the oesophagus. The buccal capsule is shallow, the dorsal tooth short. The nerve ring is at about the middle, and the excretory pore near the posterior end of the oesophagus.

All three lobes of the bursa are thickened. Ventral to the chitinised genital cone there is a cuticular thickening, which merges at each side with the ventral part of the bursa, and which is penetrated by the ventro-ventral ray. The arrangement of the bursal rays is shown in Figs. 39-41. Because of the thickening of the dorsal lobe, the branches of the dorsal ray are not all in the same plane. The spicules end in alae, folded around the tips. The short gubernaculum is finely bossed.

The vulva is about three tail lengths from the posterior end of the body. Anterior to the vulva the ventral cuticle is greatly inflated, and hangs over the vulva in an elongate sausage

shaped mass. The shape of this mass is similar in all specimens from the two host animals. No vestige was seen of the posterior part of the female reproductive system. Eggs are 54-55 x 32-33  $\mu\text{m}$ .

The species is distinguished from *P. potoroo* by the form of the bursa, which is not asymmetrical and is thicker-walled, by the size of the ventral tooth, the distance of the vulva from the anus, and the shape of the vulvar flap.

***Paraastrostrongylus trichosuri* n.sp.**

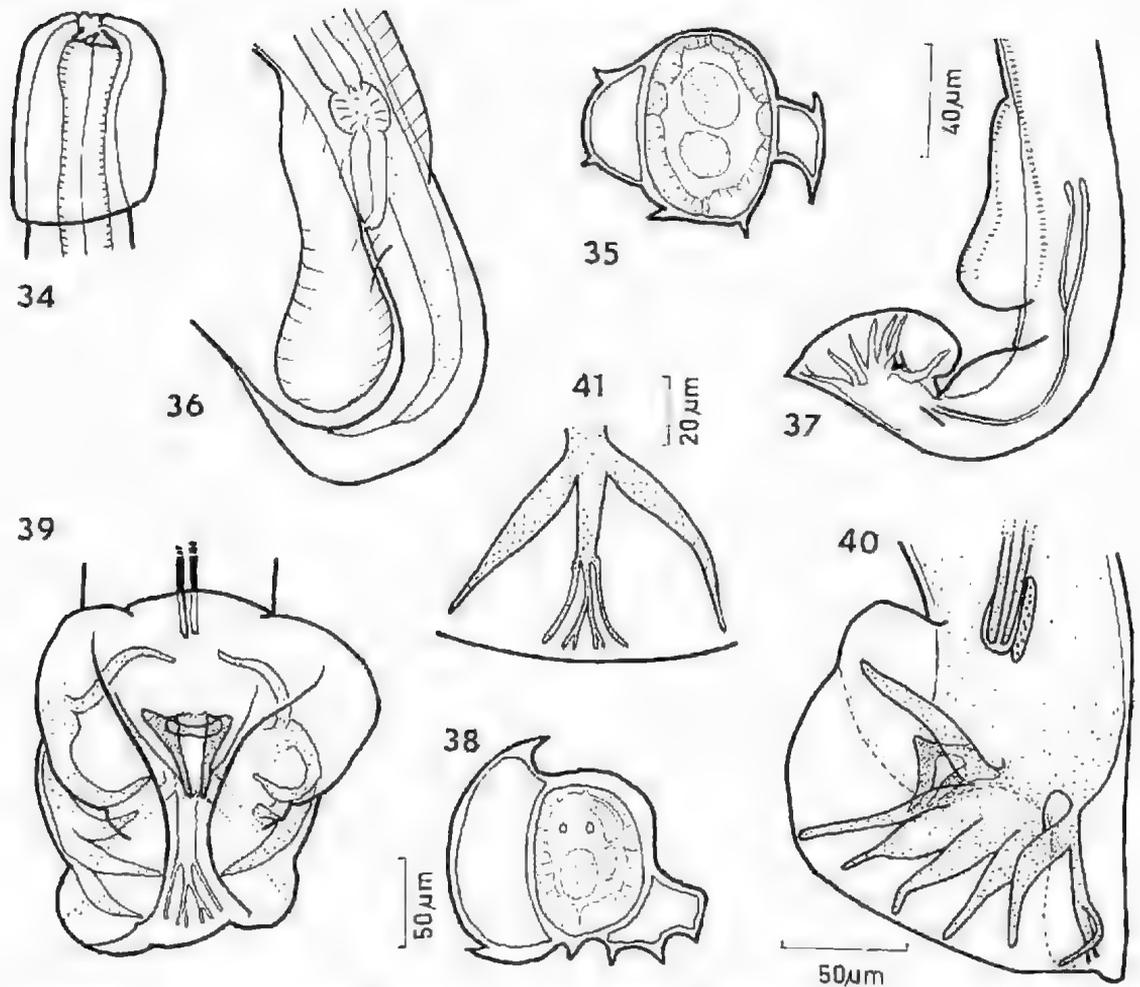
FIGS. 42-47; TABLE 2

Host and locality: *Trichosurus vulpecula* from D'Aiguillax and Camp Mt., Qld.

These worms are coiled into a fairly tight spiral from which the anterior and posterior ends protrude. The lateral alae are well developed, the right with three longitudinal crests and the left with two, and there are also three ventral longitudinal crests. In the male the crests and right ala disappear a short distance in front of the bursa and are replaced by a sub-ventral inflation. The left ala is wider in this region and terminates close to the bursa. In the female the alae and crests are discontinued just in front of the vulva and there is a separate small ventral inflation just anterior to the vulva.

The cephalic inflation is about a fifth of the length of the oesophagus. The buccal capsule is shallow, and the dorsal tooth small; sub-ventral teeth are apparently absent.

In the female the tail tapers to a fine point; the vulva is about a tail length in front of the anus. Eggs are about 70 x 45  $\mu\text{m}$ .



Figs. 34-41. *Paraastrostrongylus hettongia*. Fig. 34.—Head of female. Fig. 35.—Transverse section of body of male. Fig. 36.—Posterior end of female. Fig. 37.—Posterior end of male. Fig. 38.—Transverse section of body through prebursal inflation. Fig. 39.—Ventral view of bursa, without coverslip. Fig. 40.—Lateral view of bursa. Fig. 41.—Dorsal and externo-dorsal rays.

Figs. 34, 35, 39, and 40 to scale beside 40; Figs. 36 and 37 to scale beside 37.

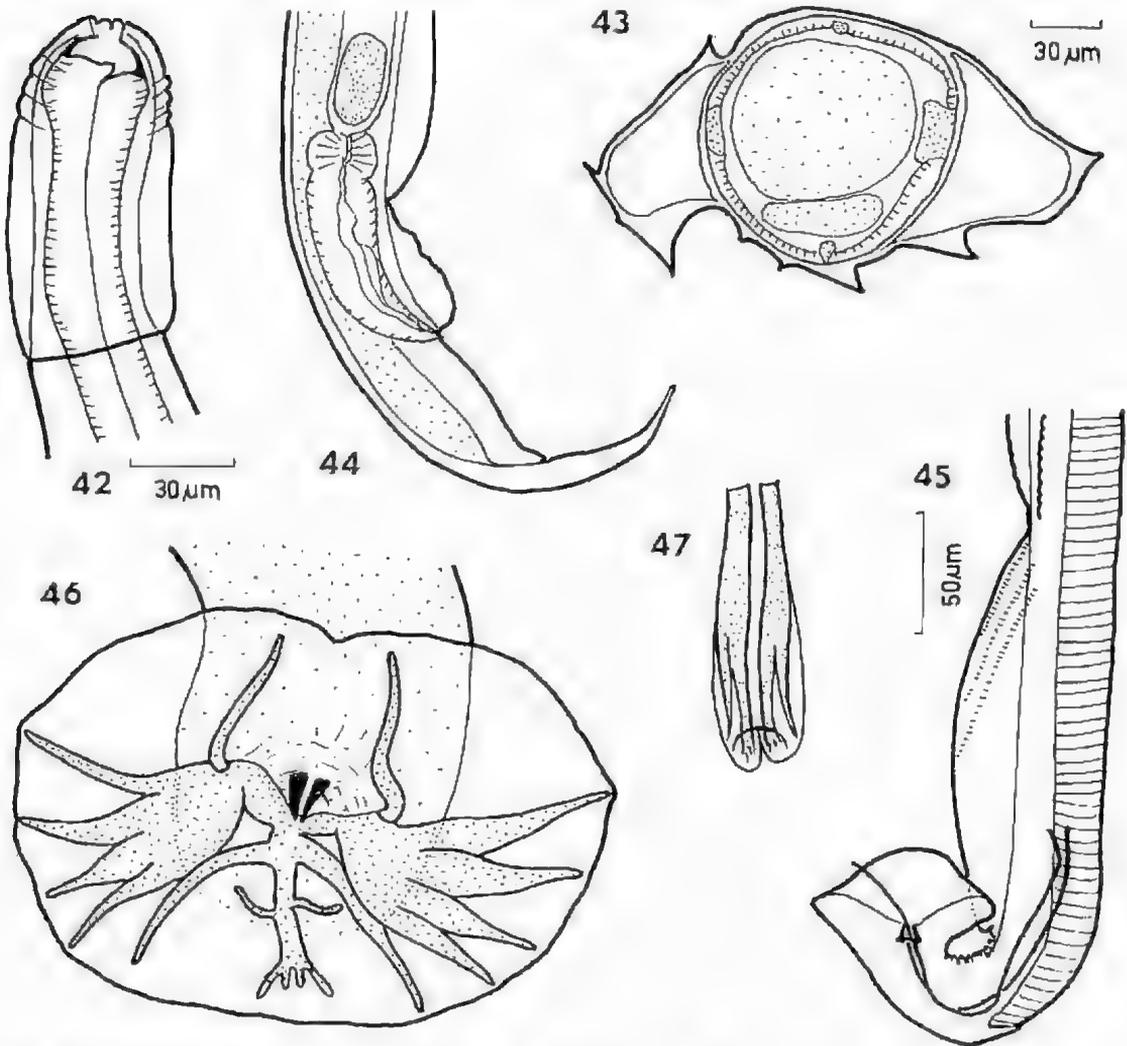
The margin of the bursa is entire, and the dorsal and ventral parts are swollen. The genital cone is strongly cuticularised. The arrangement of the rays is shown in Fig. 46. The dorsal ray however is partially obscured in all specimens examined by refractive inclusions in the bursal wall close to the mid-dorsal line; the ray is small, as it must be restricted to the region of the inclusions.

The species differs from both *P. putoron* and *P. bettongia* in the greater development of lateral alae in comparison with the body diameter, as well as in the dorsal ray and the smaller prevulvar swelling. The bursa itself is less swollen than that of *P. bettongia* and more so than that of *P. putoron*.

#### NICOLLINA Baylis

*Nicollina Baylis*, 1930: 550, syn. *Nicollia* Baylis, 1930, nec Nuttal, 1908, nec Kritschewsky, 1922.

Amidostomatinae: body with longitudinal crests and sometimes with one or two lateral alae; anterior end with inflated cuticle; buccal capsule shallow, stoutly built, containing a blunt dorsal oesophageal tooth. Bursa more or less symmetrical, dorsal lobe absent or poorly developed; dorsal ray dividing into four branches; externo-dorsal ray arising separately or from base of dorsal ray; lateral and ventral rays somewhat divergent. Spicules usually bifurcate or trifurcate; gubernaculum present. Fe-



Figs. 42-47. *Parauostrostrongylus trichosuri*. Fig. 42.—Head of male. Fig. 43.—Transverse section of body of female. Fig. 44.—Posterior end of female. Fig. 45.—Posterior end of male. Fig. 46.—Bursa spread out, inside view. Fig. 47.—Tips of spicules. Figs. 43 and 46 to same scale, 44 and 45 to same scale, 42 and 47 to same scale.

male didelphous, vulva towards posterior end of body; tail of female with dorsal terminal spike and two short subventral terminal lobes. Parasites of monotremes and Australian marsupials.

Type species: *N. tachyglossae* (Baylis).

Other species: *N. echidnae* (Baylis, 1930); *N. ridei* Inglis, 1969; *N. cameroni* Mawson, 1959; *N. calabyi* n.sp.; *N. inglisi* n.sp.; *N. baylisi* n.sp.; *N. mundayi* n.sp.

Through the courtesy of Dr. W. G. Inglis and the British Museum (Natural History) it has been possible to examine the type specimens of *N. tachyglossae* and *N. echidnae*. In

comparing these with other species attributed to *Nicollina*, it appears that not enough consideration has been given to the shape of the buccal capsule and the dorsal tooth. In *N. tachyglossae* (Fig. 48) and *N. echidnae* the buccal capsule is shallow, ring-like, and stoutly built, and the dorsal tooth is blunt and apparently readily protruded through the mouth (Fig. 49). In some other species (*N. cathiae* Inglis and *N. sarcophili* Cameron) the buccal capsule is thinner, deeper, and somewhat domed, and the dorsal tooth is erect and pointed and does not seem ever to be protruded through the oral opening. Moreover, in *N. tachyglossae* and *N. echidnae* the tail of the

female ends in a dorsal spine and two sub-ventral processes. In species with a deeper buccal capsule this type of tail has not been seen.

It is concluded that species having these characteristics in common should be grouped in a genus for which the name *Nicollina* is available. For the other species formerly included in *Nicollina* a new genus, *Woolleya*, is proposed.

#### Key to species of *Nicollina*

- |  |                        |
|--|------------------------|
| 1. Worms more or less coiled                 | 2                      |
| 1. Worms not coiled                          | 5                      |
| 2. Dorsal ray with three pairs of branches   | 3                      |
| 2. Dorsal ray with two pairs of branches     | 4                      |
| 3. Buccal ring thick, lobed anteriorly       | <i>N. calabyi</i>      |
| 3. Buccal ring not lobed, thinner and deeper | <i>N. ingllsi</i>      |
| 4. Spicules bifid                            | <i>N. ridei</i>        |
| 4. Spicules simple                           | <i>N. cameroni</i>     |
| 5. Spicules trifid                           | 6                      |
| 5. Spicules bifid                            | 7                      |
| 6. One lateral ala present                   | <i>N. echidnae</i>     |
| 6. Lateral alae absent                       | <i>N. tachyglossae</i> |
| 7. Lateral alae present                      | <i>N. mundayi</i>      |
| 7. Lateral alae absent                       | <i>N. baylisi</i>      |

#### *Nicollina echidnae* Baylis

FIG. 50

*Nicollina echidnae* (Baylis) Baylis, 1931; Mawson, 1959: 154; syn. *Nicollina echidnae* Baylis, 1930: 14. From *Tachyglossus aculeatus*.

The material examined in 1959 from an echidna from Kangaroo I. has now been compared with the type material of the species, and the identification confirmed. A transverse section of the Kangaroo I. specimen is given. In this species, and in *N. tachyglossae*, the excretory pore, not mentioned by Baylis, is post-oesophageal.

*Nicollina cameroni* Thomas, 1959: 154, from the Echidna, *Tachyglossus aculeatus*.

FIGS. 51-52

The paratype material of this species has been re-examined. The body was described as having two lateral alae and "some appearance of longitudinal banding". Transverse sections show a very slight widening of the cuticle laterally and in addition about 16 crests, most of them lateral or ventral. The tooth is blunt, and lies for the most part in the oesophageal funnel.

This species differs from others of the genus in that the spicules are not divided distally, but in view of the similarity of other characters it has been retained in the genus. It differs very markedly from species of *Austrostrongylus* and

*Paraustrorstrongylus*, in which the spicules are single, in characters of the lateral alae, buccal capsule, dorsal tooth, and bursa.

#### *Nicollina haylisi* n.sp.

FIGS. 53-59; TABLE 3

Host and locality: *Tachyglossus aculeatus*, Tas.

These are straight worms, with a cephalic inflation, followed by numerous very low longitudinal crests. Lateral alae are absent. The buccal capsule is very shallow. The oesophagus is more or less cylindrical in its anterior two-thirds then widens to an elongate bulb at the posterior end. The nerve ring surrounds it just behind its midlength and the excretory pore and cervical papillae are at about the same level near its posterior end.

The lateral lobes of the bursa are very long and are folded over each other. The externo-dorsal ray arises from the dorsal and diverges widely from it. The dorsal ray divides into two bifid branches near its distal end. The spicules are bifid for about half their length. The outer branch of each ends in a barb and bears about 10 well-marked transverse ridges in the middle third of its length. The end of each branch is surrounded by an ala, that on the smaller branch much wider than that on the larger. The gubernaculum is stout, pitted on the surface, and rather more than half the spicule in length.

The tail of the female is rounded and bears a subterminal spike and two small lobes. The vulva, a transverse slit in a depression of the body wall, lies at a little less than a sixth of the body length, or 20-27 tail lengths, from the posterior end of the body. Uteri are opposed. The eggs are 79-80 x 43-45  $\mu$ m.

The species is in many ways very like *N. tachyglossae*, a straight worm with 8-10 longitudinal crests and with somewhat similar, but trifid, spicules. The two species differ however in body length, position of the vulva, and size of the gubernaculum.

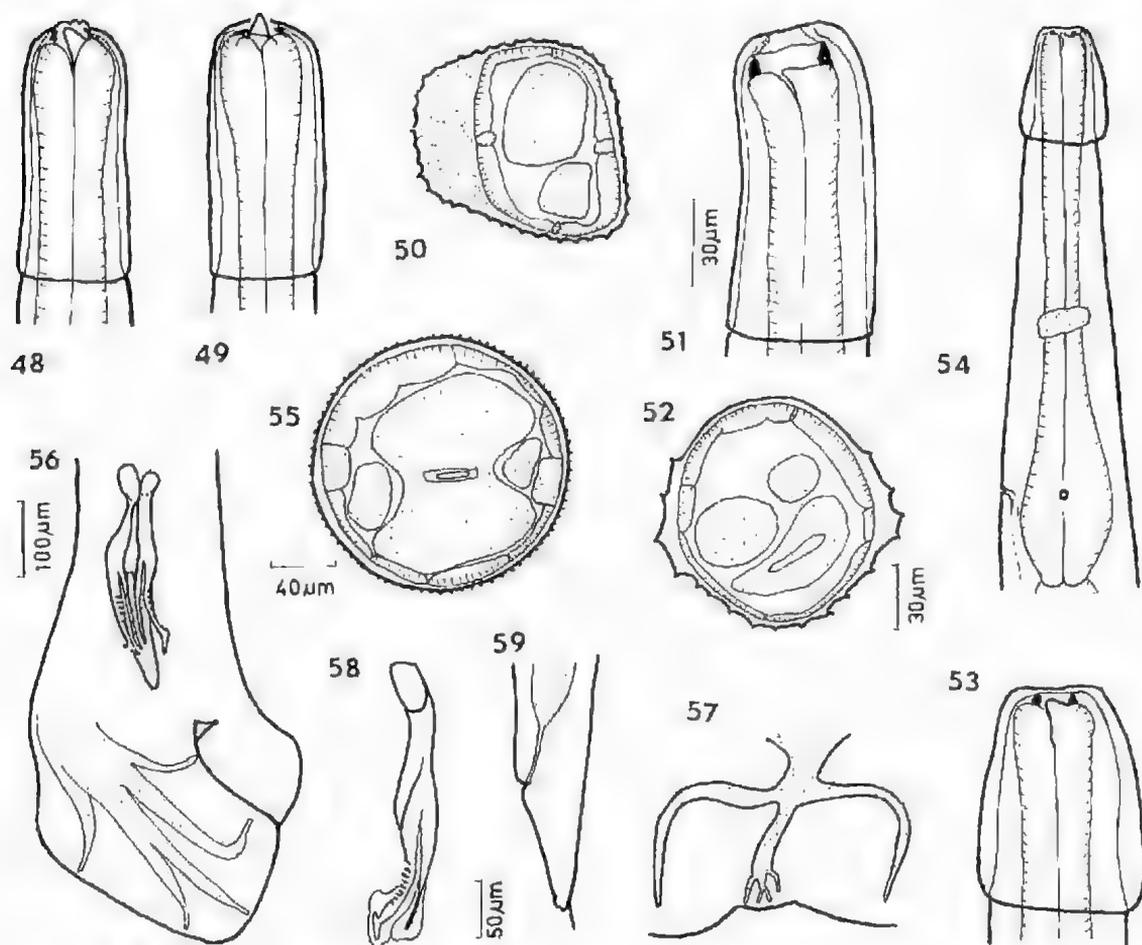
#### *Nicollina mundayi* n.sp.

FIGS. 60-66; TABLE 3

Host and locality: *Tachyglossus aculeatus* and *Ornithorhynchus anatinus* from Tas.

This is a short straight worm very similar in some respects to *N. echidnae*. There are two lateral alae and about 20-22 longitudinal cuticular crests, more or less evenly distributed around the body circumference for most of its length, but fewer towards the extremities.

The buccal capsule is short, ring-shaped; the dorsal tooth is blunt and, at rest, hardly pro-



Figs. 48, 49. *Nicollina tachyglossae*, lateral and dorsal views of anterior end.  
 Fig. 50. *Nicollina echidnae*, transverse section of body.  
 Figs. 51, 52. *Nicollina cameroni*. Fig. 51.—Head. Fig. 52.—Transverse section of body.  
 Figs. 53–59. *Nicollina baylisi*. Fig. 53.—Oesophageal region. Fig. 54.—Lateral view of head. Fig. 55.—Transverse section of body just posterior to oesophagus. Fig. 56.—Posterior end of male. Fig. 57.—Dorsal ray. Fig. 58.—One spicule. Fig. 59.—Tail of female.  
 Figs. 48, 49, and 51 to scale beside 51; Figs. 52 and 53 to same scale; Figs. 54, 57, 58, and 59 to scale beside 59.

jects into the buccal cavity. The oesophagus is cylindrical for most of its length, ending in a bulb. The nerve ring lies at about half, and the excretory pore and the small but distinct cervical papillae at three-quarters the length of the oesophagus.

The end of the tail of the female bears a terminal spike and two small subterminal lobes. The vulva, at about 8–11 tail lengths in front of the anus, lies between two rounded expansions of the lateral alae. Eggs are about  $75 \times 40 \mu\text{m}$ .

The spicules are bifid, the outer branch of each is longer and stouter than the other and ends in a barbed point, the inner branch ending

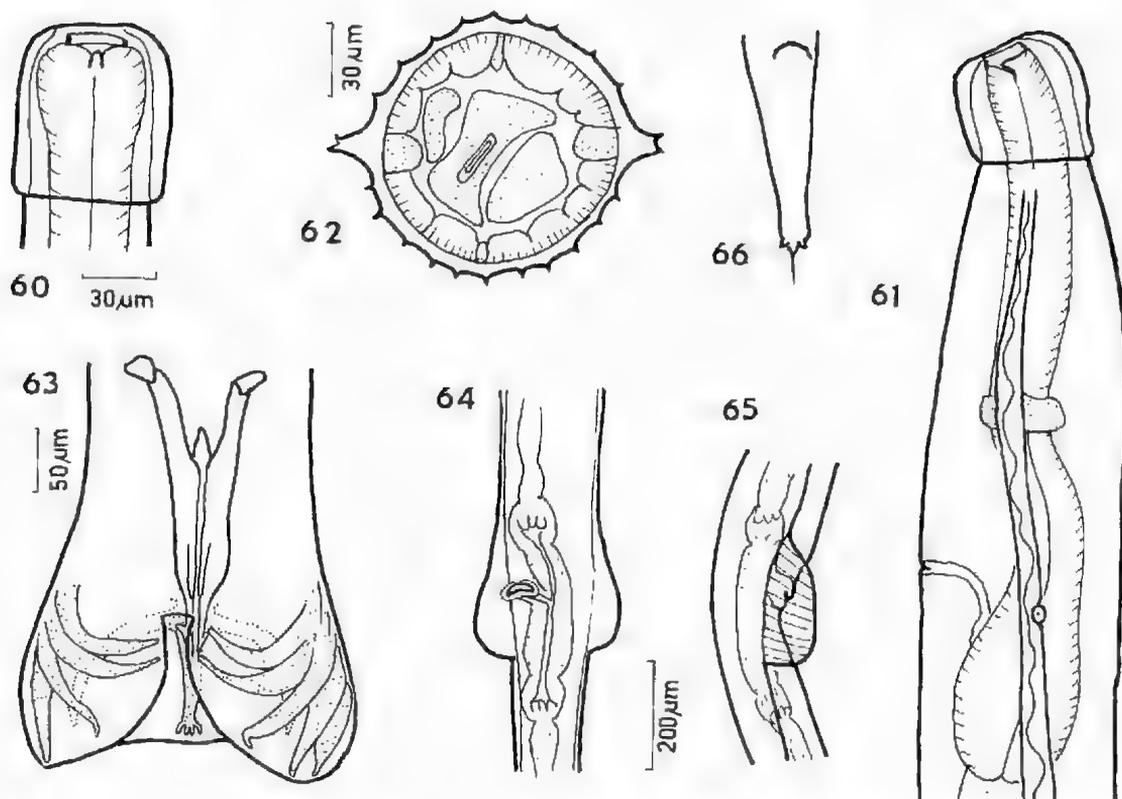
simply. As only two male worms are present, the spicules were not dissected out. Their appearance is very similar to those of *N. baylisi*, on which the terminal alae were not visible until the spicules were out of the body. The gubernaculum, at least two-thirds the length of the spicules, is strongly built and its surface pitted. The lateral lobes of the bursa are not particularly long. The rays are shown in Fig 63.

The species closely resembles *N. baylisi*, but is distinguished by being distinctly shorter, with lateral alae and with fewer and more prominent cuticular crests, as well as by the shape of the bursa, the absence of ridges on the spicules,

TABLE 3

Measurements of *Nicollina baylisi*, *N. mundayi*, *N. calabyi*, and *N. inglisi*. Unless otherwise indicated, measurements are in  $\mu\text{m}$ .

Species	<i>N. baylisi</i>	<i>N. mundayi</i>	<i>N. calabyi</i>	<i>N. inglisi</i>	
Host	echidna	echidna	platypus	numbat	
Male:					
Length (mm)	12.8-14.1	5.2, 5.3	4.6-5.7	2.4-3.4	2.1-3.4
Oesophagus	500-525	445, 500	400-450	330-360	210-250
Ceph. inflation	80 (3x)	75, 75	70-100	50-70	60-65
Antr. end—nerve ring	210-220	215, 220	220-230	120-170	100-120
—excr. pore	360-400	275, 315	370-390	160-260	150-180
Spicule	240-275	270, 295	250-270	600-700	400-440
Gubernaculum	145-165	140, 152	140-160	80-110	70-80
Female:					
Length (mm)	24.3, 25.3	6.5-8.1	7.7-8.0	2.5-4.2	2.3-3.4
Oesophagus	600, 520	480-510	450-500	260-400	270-335
Ceph. inflation	100, 110	75-80	80-110	60-80	55-70
Antr. end—nerve ring	300, 270	210-240	230-240	120-200	100-115
—excr. pore	500, 550	230-305	380-400	150-345	140-220
Tail	190, 150	120-140	140-165	70-130	60-90
Postr. end—vulva	3800, 4100	1250-1400	1500-1600	350-460	200-300



Figs. 60-66. *Nicollina mundayi*. Fig. 60.—Head. Fig. 61.—Oesophageal region. Fig. 62.—Transverse section of body. Fig. 63.—Posterior end of male, ventral view. Figs. 64 and 65.—Ventral and lateral views of region of vulva. Fig. 66.—Tail of female.  
Figs. 61-66 to same scale; Figs. 64 and 65 to same scale.

and the presence of cuticular flaps beside the vulva. The measurements are similar to those of *N. echidnae*, but the two species are distinguished by the shape and size of the spicules and of the dorsal and externo-dorsal rays, and by the presence of the well-developed left lateral ala in *N. echidnae*.

*Nicollina calabyi* n.sp.

FIGS. 67-72, TABLE 3

Host and locality: *Myrmecobius fasciatus* from W. Aust.

The body forms a loose coil. The length of the anterior cuticular inflation is about one and a half times the body width just behind the inflation, and about a fifth to a sixth the length of the oesophagus. The cuticle of the rest of the body is raised into 8-9 lateral and ventral longitudinal crests, of which the lateral are the best-developed.

The mouth is surrounded by six small cuticular lips. The buccal capsule is stoutly built, its anterior edge six-lobed, each lobe formed by a thickening of the wall on the outer side of the capsule. The dorsal tooth is rounded at the apex, and reaches to about half the depth of the buccal capsule. The oesophagus is wider in the second half of its length and is surrounded by the nerve ring at the end of its first quarter; the excretory pore lies at about the end of the third quarter.

The tail of the female is rounded at the tip, with a subterminal spine of low ventral prominence. The vulva is a transverse slit, three to four tail lengths in front of the anus. At the level of the vulva the cuticle is raised into three longitudinal crests, one, bilobed, to the left of the vulva, a frilled narrow one to the right of the vulva, and a longer wider one to the right of this again (Fig. 72). The sizes and arrangement of these crests are similar in all the specimens available. The eggs are thin-shelled, 65-70 x 35-40  $\mu$ m.

The spicules of the male are bifid for the terminal 80-100  $\mu$ m, the shorter of the two ends pointed, the longer truncated and slightly barbed. The gubernaculum is elongate, rounded at the ends, and thicker in the central parts. The bursa has a short dorsal lobe, slightly separated from the large latero-ventral lobes. The rays are arranged as shown in Fig. 69.

The species is placed in the genus *Nicollina* because of the form of the buccal capsule and tooth. It differs from the species from monotremes in the form of the dorsal ray, as well as

in the presence of 3 cuticular crests near the vulva.

*Nicollina inglisi* n.sp.

FIGS. 73-76; TABLE 3

Host and locality: *Myrmecobius fasciatus* from W. Aust.

This is a rather slender loosely coiled worm. The length of the inflated cephalic cuticle is about twice the width of the body just behind it. There are 8-10 longitudinal crests on the body, two dorsal and two lateral, and the rest ventral. The buccal cavity contains a large blunt tooth. The oesophagus widens in its posterior third and the nerve ring surrounds it at about the end of the first third. The excretory pore is at the end of the second third.

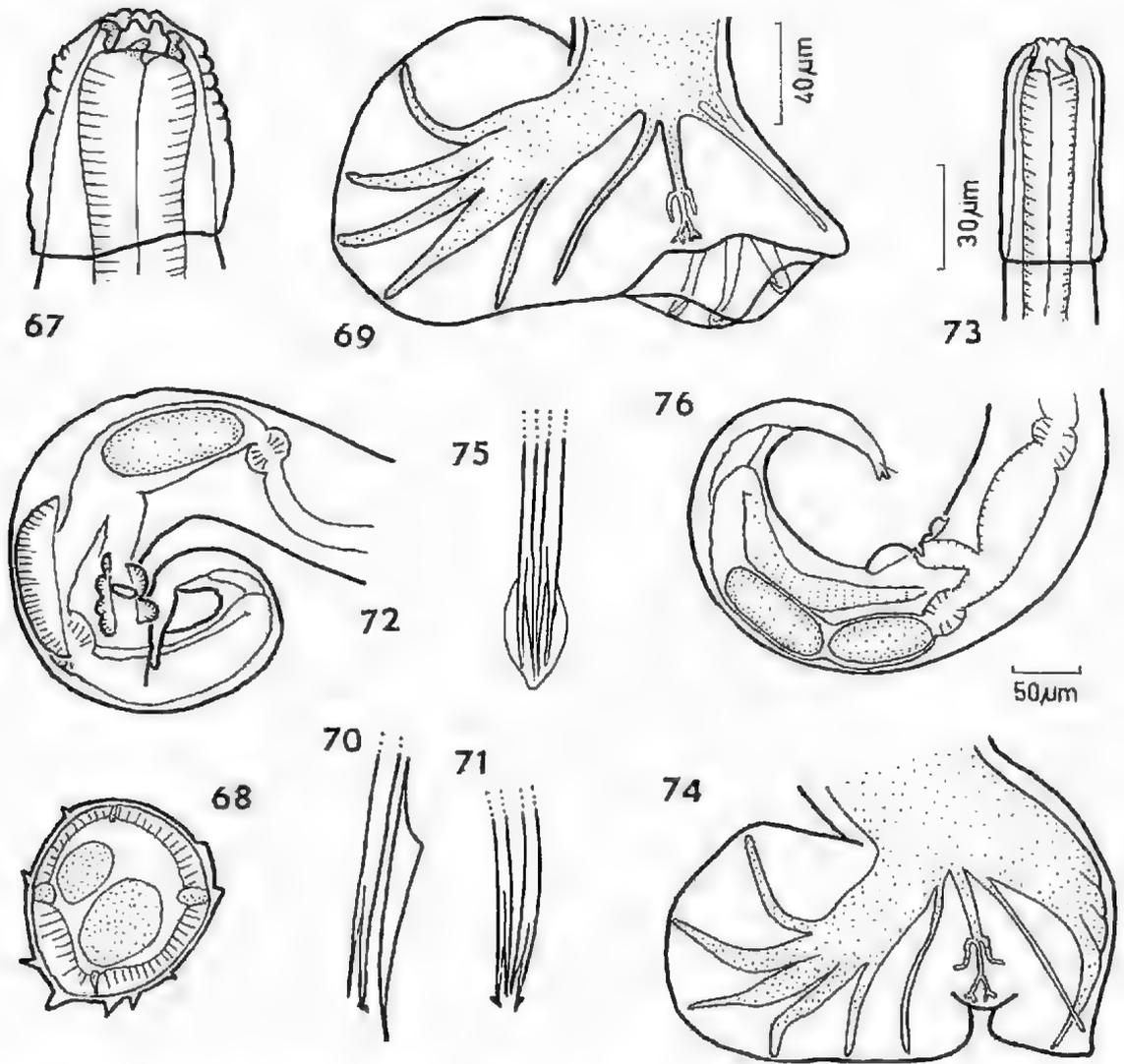
The tail of the female tapers to a bi-lobed tip, with a spike arising subterminally. The vulva is a transverse slit situated about three to four times the tail length in front of the anus. The cuticle just anterior and posterior to the vulva is slightly inflated and strongly striated. Amphidelphous, posterior uterus short, but containing developing eggs. Eggs are up to 100 x 50  $\mu$ m.

In the male, one side of the bursa is slightly longer than the other, but the rays are similarly disposed. The dorsal lobe is short and the dorsal ray thin (Fig. 74). The spicules are bifid, with one branch shorter than the other, and the four tips, two from each spicule, appear to be enclosed in one terminal ala.

The species is close to *N. calabyi*, which was found in the same collections. It is distinguished by the more slender build of the body, the relatively longer cephalic inflation, the slightly thinner-walled and deeper buccal capsule, without anterior thickening; in addition, the gubernaculum is longer, and there is a small but consistent difference in the dorsal rays.

WOOLLEYA n.g.

Amidostomatinae: Small, more or less coiled worms with inflated cephalic cuticle and longitudinal cuticular crests behind this; buccal capsule well developed, with pointed dorsal tooth. Male: bursa more or less symmetrical, dorsal lobe small, dorsal ray dividing into two or three branches, externo-dorsal ray arising from dorsal ray or separately; lateral and ventral rays arising together, diverging from mid-lengths; genital cone not strongly developed. Spicules single or divided at tips; gubernaculum well developed. Female: tip of tail rounded with thin spike, or tapering to a point; vulva



Figs. 67-72. *Nicollina calabyi*. Fig. 67.—Head. Fig. 68. Transverse section of body. Fig. 69.—Bursa. Fig. 70. Gubernaculum and tips of one spicule, lateral view. Fig. 71.—Tips of both spicules, ventral view. Fig. 72.—Posterior end of female.  
 Figs. 73-76. *Nicollina inglisi*. Fig. 73.—Anterior end. Fig. 74.—Bursa. Fig. 75.—Tips of spicules. Fig. 76.—Posterior end of female.  
 Figs 67, 70, 71, 73, and 75 to scale beside 73; Figs. 68, 69 and 74 to scale beside 69; Figs. 72 and 76 to scale beside 76.

towards posterior end of worm; mono- or didelphous. Parasites of intestine of Australian mammals, mainly of marsupials.

Type species: *W. sprengi* n.sp.

Other species: *W. cathiae* (Inglis), syn. *Nicollina cathiae*; *W. sarcophili* (Cameron), syn. *Nicollina sarcophili*; *W. iota* (Mawson), syn. *Nicollina iota*; *W. acinocercus* (Mawson), syn. *Austrostrongylus acinocercus*; *W. hydromyos* (Thomas), syn. *A. hydromyos*;

*W. hickmani* n.sp.; *W. martini* n.sp., *W. monodelphis* n.sp.

The genus is named in recognition of the help given by Dr. Patricia Woolley in collecting specimens from dasyurids.

*Woolleya* species are distinguished from *Nicollina* spp. chiefly by the shape of the buccal capsule which is cup-like with relatively thin walls, and by the shape of the sharply pointed dorsal tooth, originating from the anterior end

of the oesophagus rather than, as in *Nicollina* spp., from the anterior end of the wall of the lumen of the oesophagus.

Figures are given of transverse sections of *W. acinocercus* and *W. hydromyos*, which have been re-examined but are not redescribed here (Figs. 71, 78).

#### Key to species of *Woolleya*

1. Tail of female tapering to a point . . . . . 2
1. Tail of female rounded at tip, with spike . . . . . 4
2. Spicules not divided, or tritid<sup>1</sup> . . . . . *W. sarcophil*
2. Spicules bifid . . . . . 3
3. Female didelphous . . . . . *W. hydromyos*
3. Female monodelphous . . . . . *W. anodelphi*
4. Spicules not divided . . . . . *W. acinocercus*
4. Spicules bifid . . . . . 5
5. Longitudinal crests more or less evenly distributed around body . . . . . 6
5. Longitudinal crests only on ventral surface . . . . . 8
6. Tip of longer branch of each spicule enlarged . . . . . *W. lata*
6. Neither tip of spicules enlarged . . . . . 7
7. Dorsal ray ends in three pairs of branches . . . . . *W. martini*
7. Dorsal ray ends in two pairs of branches . . . . . *W. hickmani*
8. Narrow lateral alae present . . . . . *W. cothiac*
8. Lateral alae absent . . . . . *W. sprenti*

#### *Woolleya sprenti* n.sp.

FIGS. 79-85; TABLE 4

Host and localities: *Dasyurus viverrinus* from Iccna, Tas. (type host and locality); *Antechinus stuartii* from Mt. Tibbinbilla, A.C.T.; *Dasyurops maculatus* from N.S.W.; *Thylacinus cynocephalus* from Tas.

These are relatively long, slender worms, some coiled loosely, some in a tight spiral. The inflated cephalic cuticle, about a quarter the length of the oesophagus, is lightly striated transversely, the cuticle on the rest of the body is more heavily striated and thrown into three longitudinal crests extending most of the body length on the ventral side.

The buccal capsule is large with a dorsal tooth just over half the depth of the capsule. Ventral teeth were not seen. The nerve ring is just behind the mid-oesophagus and the excretory pore near the posterior end of the oesophagus.

The posterior end of the female narrows abruptly just in front of the anus and the tail is digitiform with a rounded tip bearing a terminal spine. The vulva is about five to eight tail-lengths in front of the anus. Two ovejectors

and uteri are present, the posterior much the shorter.

The bursa is symmetrical, its dorsal lobe short but quite distinct. The arrangement of the bursal rays is shown in Figs. 82 and 83. Each spicule bifurcates at about a fifth its length; one branch is slightly longer and stouter than the other, and is curved inwards at the tip. The gubernaculum is long and wide, the central part more heavily chitinised.

The specimens (two females) from *Thylacinus cynocephalus* agree in all particulars with the types. In view of the different host, it is possible that they may belong to a different species, distinguishable only by characters of the male. As the host species is now virtually extinct it is unlikely that a male will be found, unless in some museum. The specimens described here were found in a museum specimen of the host, through the enterprise of Professor J. F. A. Sprent.

This species most closely resembles *N. hydromyos* Thomas in the shape of the spicules and the arrangement of the dorsal ray. The two species differ however in the lengths of spicules and gubernaculum and in the shape of the female tail.

#### *Woolleya martini* n.sp.

FIGS. 86-89; TABLE 4

Host and locality: *Antechinomys spenceri* from Sandringham, Qld.

This is a relatively small species, with 10 longitudinal cuticular crests. The cephalic inflation of the cuticle is about twice as long as its diameter, and between a third and a quarter the length of the oesophagus. The cuticle around the mouth forms six distinct lips. The dorsal tooth is about half the length of the buccal capsule. The excretory pore lies at or just behind the base of the oesophagus.

The spicules are bifid in their distal quarter: both branches are slender, one a little more curved and slightly longer than the other. The arrangement of the bursal rays is shown in Fig. 88.

The body of the female narrows just in front of the anus and ends in a digitiform tail, rounded at the tip and bearing a terminal spine. Only two, sub-ventral, crests continue posterior to the vulva.

This species is distinguished from *W. sprenti* chiefly by the number of cuticular crests, and by the origin and shape of the externo-dorsal ray.

<sup>1</sup> The number of terminations of each spicule is not stated in the description of this species.

TABLE 4  
 Measurements of *Woolleya* spp. described in this paper. Unless otherwise indicated, measurements are in  $\mu\text{m}$ .

Species	<i>Woolleya sprenti</i>		<i>Thylacinus cynocephalus</i>	<i>W. martinii</i>		<i>W. monodelphis</i>
	<i>Dasyurus viverrinus</i>	<i>Antechinus stuarti</i>		<i>Antechinomys spencei</i>	<i>W. hickmani</i>	
Host						
Male:						
Length (mm)	3.6-5.5	2.0-4.3	—	2.2-2.9	2.4-6.4	1.1-1.4
Oesophagus	360	250-280	—	220-270	330-370	(160+)
Ceph. inflation	100	65-70	—	70-100	70-90	50-55
Antr. end—nerve ring	190	110	—	130-190	195	—
—excr. pore	310	200	—	200-250	350	—
Spicules	350-400	300-320	—	180-220	260-340	115-125
Gubernaculum	90-100	70-80	—	55-65	50-55	30-40
Female:						
Length (mm)	5.3-7.8	5.2-5.5	5.5, 5.8	2.9-3.4	5.3-6.2	1.2-1.4
Oesophagus	360-430	280	360, 370	310-320	280-320	150-170
Ceph. inflation	90-100	70	80, 90	75-95	65-80	50-55
Antr. end—nerve ring	180-230	155	175, 185	170-185	—	—
—excr. pore	270-350	240-260	350, 355	270-310	—	—
Tail	100-110	70	75, 80	70-80	50-65	60-90
Postr. end—vulva	710-1000	380-430	800, 800	600-800	340-610	100-140

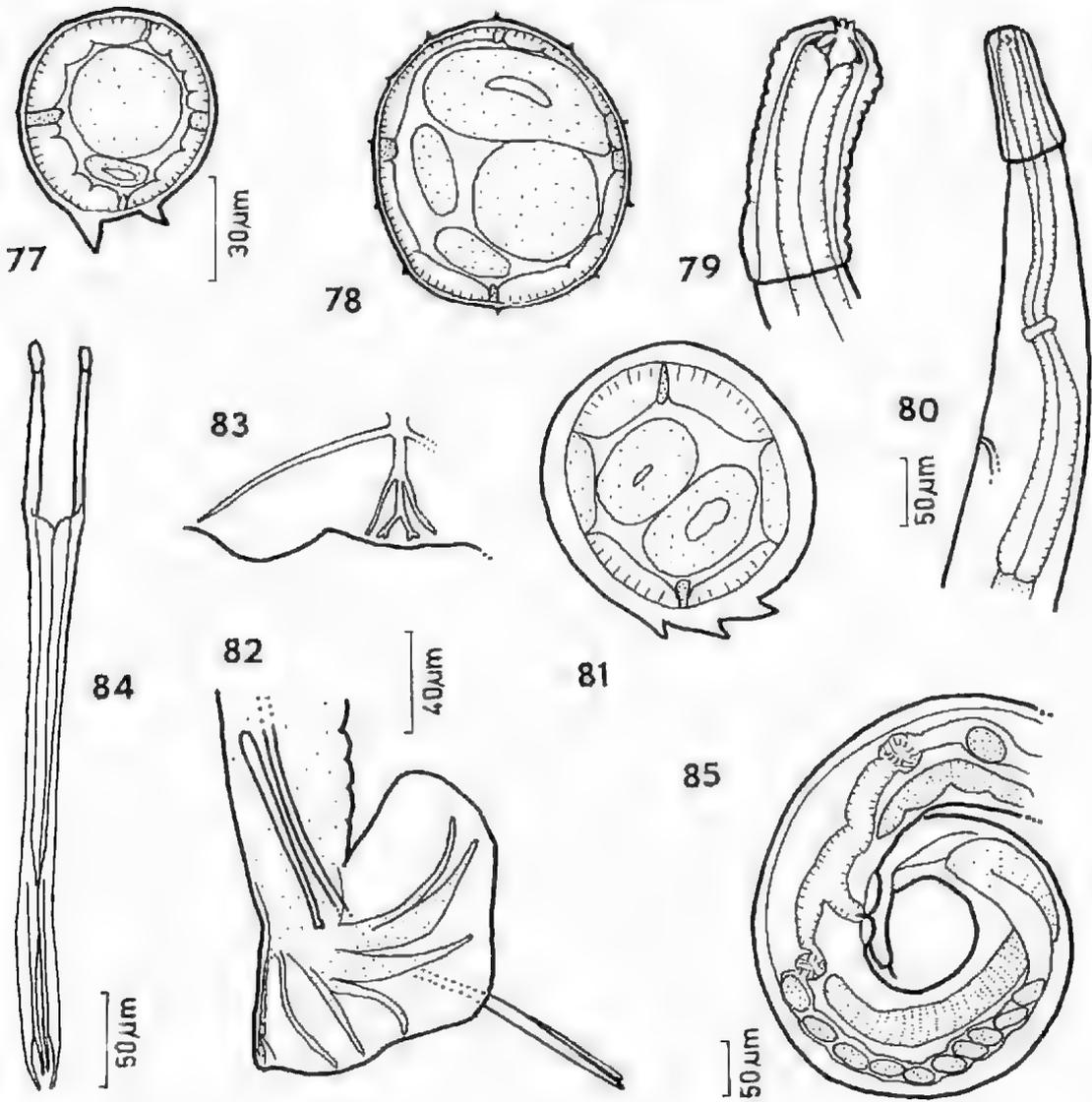


Fig. 77. *Woolleya hydromyos*, transverse section of body.  
 Fig. 78. *Woolleya acinocercus*, transverse section of body.  
 Figs. 79-85. *Woolleya sprenti*. Fig. 79.—Anterior end. Fig. 80.—Oesophageal region. Fig. 81.—Transverse section of body. Fig. 82.—Posterior end of male. Fig. 83.—Dorsal and one externodorsal rays. Fig. 84.—Spicules. Fig. 85.—Posterior end of female.  
 Figs. 77, 79, and 83 to scale beside 77; Figs. 78 and 84 to scale beside 84; Figs. 81 and 82 to scale beside 82.

***Woolleya bickmani* n.sp.**

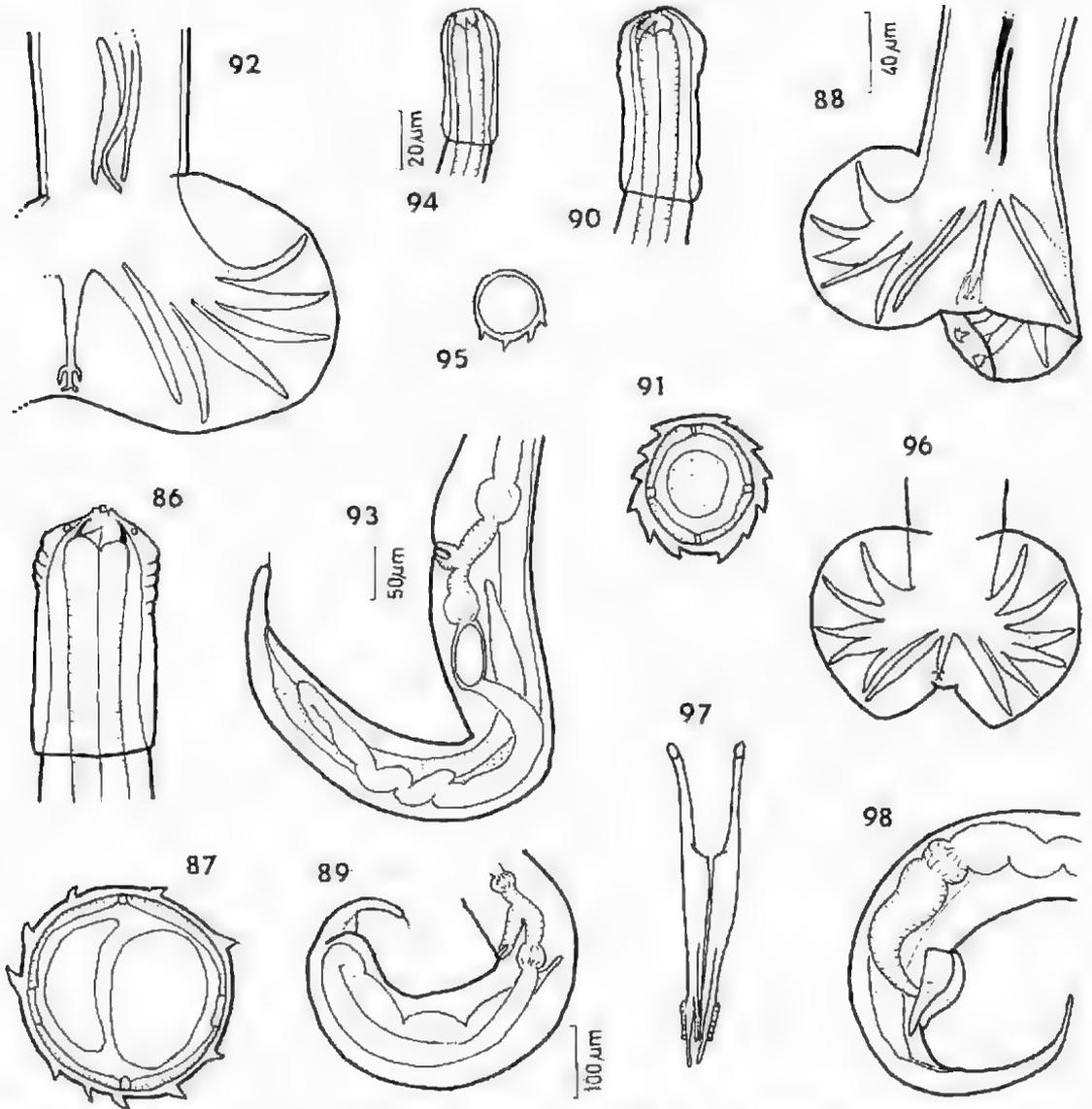
**FIGS. 90-93; TABLE 4**

Host and locality: *Antechinus stuartii* from Condor Creek and Mt. Tidbinbilla, A.C.T.

These are longish coiled worms. The cuticle is raised into ten or twelve longitudinal crests, extending for most of the body length, and more or less evenly distributed around the

body, the widest gap being on the dorsal side (Fig. 91). The buccal capsule is shallow and the dorsal tooth short.

The bursa is more or less symmetrical, the dorsal lobe not separated from laterals. The arrangement of the rays is shown in Fig. 92. The spicules bifurcate at about 3/4 or 4/5 their length; each branch ends in a blunt point,



Figs. 86-89. *Woolleya martini*. Fig. 86.—Anterior end. Fig. 87.—Transverse section of body. Fig. 88.—Part of bursa. Fig. 89.—Posterior end of female.  
 Figs. 90-93. *Woolleya hickmani*. Fig. 90.—Anterior end. Fig. 91.—Transverse section of body behind oesophagus. Fig. 92.—Bursa. Fig. 93.—Posterior end of female.  
 Figs. 94-98. *Woolleya monodelphis*. Fig. 94.—Anterior end. Fig. 95.—Transverse section of body. Fig. 96.—Bursa. Fig. 97.—Spicules. Fig. 98.—Posterior end of female.  
 Figs. 86, 91, 94, and 97 to scale beside 94; Figs. 87, 88, 90, 92, 96, and 98 to scale beside 88.

the longer one rather more curved at the tip. A thin plate-like gubernaculum is present.

The posterior end of the body of the female is slightly swollen; the tail tapers somewhat and is rounded at the end, with a terminal spike. Two ojectors are well-developed. Eggs are about  $60 \times 30 \mu\text{m}$ .

This species differs from *W. martini* in the distribution of the cuticular crests and in the branching of the dorsal ray (see Figs. 88, 92).

***Woolleyi monodelphis* n.sp.**

**FIGS. 94-98; TABLE 4**

Host and locality: *Antechinus stuartii* from Condor Creek, A.C.T.

This is a very small species; the anterior end of the body ends in a more or less tight spiral: the posterior is curved, and in the female distinctly swollen in the region of the vulva. There are four longitudinal ventral crests, on the anterior two-thirds or more of the body. The

cephalic inflation is about two-thirds the length of the oesophagus. The buccal capsule is large, the dorsal tooth very small. The posterior end of the oesophagus was seen clearly in only one specimen, and the nerve ring and excretory pore were not seen in any.

The arrangement of the bursal rays is shown in Fig. 96. The dorsal ray is unusually stout, and arises separately. The branches of the dorsal ray are very small, and it is possible that the final branch shown in Fig. 96 is divided. The spicules are bifid for about one third of their length, one branch of each being thicker and slightly longer than the other. A slender gubernaculum is present.

The tail of the female is relatively long and tapers to a fine point. The vulva lies about one tail length in front of the anus, between two short and wide sub-ventral crests or flaps. There is only one ovejector and uterus, the anterior. No eggs were seen.

This species differs from all others referred to *Woolleya* in being monodelphous, in the wide externo-dorsal rays, and in the very small

size, and from most of the species in the shape of the tail of the female.

#### Acknowledgements

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# THE STRUCTURAL GEOLOGY OF THE WARREN NATIONAL PARK AND THE WESTERN PORTION OF THE MOUNT CRAWFORD STATE FOREST, SOUTH AUSTRALIA

BY *K. J. MILLS\**

## Summary

MILLS, K. J. (1973) .-The Structural Geology of the Warren National Park and the Western Portion of the Mount Crawford State Forest, South Australia. *Trans. R. Soc. S. Aust.* 97(4), 28 1-3 15, 30 November, 1973.

A structural study of coarse-grained sillimanite-bearing mica schists and gneisses exposed on the southern shores of the Warren Reservoir, south-east of Williamstown, has revealed evidence for three successive phases of strong compressive deformation, each characterised by the introduction of new structural elements. These rocks stratigraphically overlie a thick crossbedded schistose metasandstone unit which closely resembles the Aldgate Sandstone of the Adelaide Supergroup. This metasandstone unit also displays evidence for three superimposed fold episodes. Coarse grained sillimanite-bearing mica schists and gneisses underlying the metasandstone have a similar lithological and compositional range to those above the metasandstone, but are more complexly deformed and show indications of earlier compressive deformation events. Careful mapping of the contact between these older schists and the metasandstone has revealed an angular unconformity in several localities, thus re-establishing an exposure of pre-Adelaidean basement, herein named the Warren Inlier. Rocks within the inlier have been reconstituted at high temperatures along with the Adelaidean sequence and have structural characteristics quite unlike those of the previously described basement inliers within the lower temperature metamorphic environments of the Mount Lofty Ranges. Detailed mapping has established that a period of major thrust movements took effect during and after the second compressive deformation in the Adelaidean sequence, and that these thrusts were later folded during the third compressive deformation. The final significant tectonic event is recorded by the Williamstown-Meadows Fault, which brought the amphibolite facies schists and gneisses into conjunction with biotite zone phyllites.

The fortunate combination of thrusting and updoming in subsequent folding, with later uplift on the Williamstown-Meadows Fault in this part of the central Mount Lofty Ranges, has enabled erosion to unveil a tectonic window, herein named the Williamstown Window, through which may be read the structural history of the lowermost tectonic and stratigraphic levels of the Upper Proterozoic sedimentary pile and the underlying basement gneisses.

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## Introduction

This paper is concerned with the elucidation of the structural history of a key area of approximately 40 km<sup>2</sup> in the central Mount Lofty Ranges. The area is located south-east of Williamstown and extends south and west of the Warren Reservoir. Much of the area is virgin scrubland, parts of which have been recently acquired by the National Parks Commission (Warren and Hale National Parks), or are under the control of the Engineering and Water Supply Department, or form part of the Mount Crawford State Forest. There are a few small grazing properties in Dead Horse Gully (Watts Gully) and south of the reservoir. Lookout Tower Hill (over 525 m) forms

the highest peak in the area and from its central location one can view the rugged gullied scarp country of the Warren National Park falling off to the west, and the gorge of the South Para River and the Warren Reservoir to the north. Outcrops are frequent and fresh on these youthfully eroded slopes. To the south-east and south a much more mature topography, containing remnants of laterised erosion surfaces, exhibits only scattered bedrock exposures, most of which are deeply weathered.

The area was the scene of a goldrush in 1885, and this led to the appearance of one of the earliest geological maps to be published in this state (Brown & Woodward 1886). In

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describing the bedrock around Watts Gully (see Fig. 1). Brown & Woodward clearly recognised two metamorphic sequences—micaceous and chloritic and clay slates with beds of quartzite and schistose sandstones; and highly metamorphosed rocks consisting of mica schist, quartzites, sandstones and gneissic rocks. The goldfields were situated in the highly metamorphosed sequence.

Howchin (1906, pp. 254-256), referring to the ridge between Williamstown and the South Para River, recognised and described the "basal grits" of the "Adelaide Series", although here they have been strongly metamorphosed and intruded by pegmatites. An older basement of highly foliated mica schists, penetrated with pegmatites, was observed to underlie the basal grits in the gorge of the South Para River, and to be separated from them by a grass covered, but nevertheless "abrupt and strongly defined" junction.

Howchin (1926) presented the results of more extensive observations in this area, including a 13 km section extending ENE from the "Houghtonian" schists in the South Para gorge near the Warren Reservoir Weir, through the basal grits into a sequence of rocks, comprising the Barossa Ranges, which he equated with the lower portion of the "Adelaide Series". Although clearly recognising the existence of an older basement in this area, Howchin included within his basement some coarsely crystalline schists, such as Brown & Woodward's highly metamorphosed rocks of the Gumeracha Goldfields, and the host rocks of the rutile deposits near the reservoir, which are now known to overlie the "basal grits".

Hossfeld (1935) refuted many of Howchin's views and, although accepting the "basal grits" south of Williamstown, regarded the rocks east of Williamstown as an older sequence (Woolnough's Barossian) which underlay the grits. Miles (1950) published a map incorporating the north-western part of the area under present consideration and showed that highly metamorphosed Adelaide System rocks overlay the haematitic schistose sandstones, and were faulted against low grade Adelaide System rocks belonging to a much higher stratigraphic level.

Alderman (1942) regarded the high-grade aluminous schists and gneisses, and their contained sillimanite, kyanite and clay deposits, north of the reservoir as products of an extensive metasomatic alteration of original country

rocks of regional biotite grade. This concept of extensive metasomatic activity in the area was further advanced by Campana (1953) and Campana *et al.* (1955) in the interpretation of the Gawler Geological Sheet. Schists which Howchin saw as an underlying basement to the basal grits were interpreted by Campana as a metasomatic facies of the basal beds. Hence these rocks were shown as the "Aluminous metasomatic zone of South Warren Reservoir" on the Gawler Geological Sheet. Campana accepted Howchin's view that the sequence east of this zone could be correlated with rocks of the Adelaide System.

Previously (Mills 1963), I outlined the petrology of the various rock units in the area south of the Warren Reservoir and considered that the schists were the products of normal amphibolite facies metamorphism of rocks of appropriate composition, doubting the need for extensive metasomatic activity. The schists and gneisses south-west of the reservoir were observed to underlie Howchin's "basal grits", but at that stage a convincing unconformity had not been identified. The schistose metasandstone unit became more micaceous towards its base and was thought to pass conformably downwards into micaceous schists and gneisses.

Whilst studying the mesoscopic geometry of structures in these high-grade schists in the summer of 1967, I discovered that schists below the metasandstone unit were much more complexly deformed than those above, despite similarities in lithological character, and this led to the discovery of several outcrops displaying a distinct stratigraphic unconformity between the metasandstone and the underlying schists, in a section which has become the southern portion of the Warren National Park. Through personal communication with Messrs. O'fler and Fleming, this rediscovered basement inlier appeared in their published synthesis of the structural and metamorphic history of the Mount Lofty Ranges (O'fler & Fleming 1968, pp. 248, 252). Since that time I have engaged in several summer field excursions to the area, mapping in further detail, and the following account presents the results.

The area has been mapped using aerial photographs and a base map constructed from an uncontrolled mosaic. There may, therefore, be slight distortions from true orthographic projection in parts of the map, but it has been found that the grid used on the *Adelaide*

and *Gawler* 1:63,360 Military Sheets may be satisfactorily imposed. It is important to realise that the maps, as reproduced here, present interpreted boundaries and faults. Reasons governing these interpretations will be outlined below. The reader may be disappointed to discover, particularly in the south-eastern portion of the area, that lines on the map may seem to have no readily apparent meaning in the field. They are, however, based on the close inspection and interpretation and careful plotting of all available field exposures over the whole area covered by the map.

### Stratigraphic and Metamorphic Relationships Between Mapped Lithological Units

#### PRELIMINARY COMMENTS

The presence of an older Precambrian basement inlier, here referred to as the Warren Inlier, has now been firmly established on the basis of observed unconformable relationships and on structural grounds. Overlying this basement is a mantle of Adelaidean sediments, beginning with a thick schistose metasandstone of Aldgate Sandstone type, and passing upwards into a varied sequence of pelitic, arenaceous and calcareous beds. The Adelaidean mantle has suffered three strong compressive deformations and coarse recrystallisation in amphibolite facies metamorphism. Strong thrusting from the east accompanied or followed the second deformation and resulted in several strike faults with extensive aggregate movement. The largest of these faults has brought a kyanite-andalusite facies sequence of simple structural character into conjunction with a complexly deformed sillimanite-muscovite facies sequence. The thrust slices were folded in a third deformation, which also updomed the basement inlier. Following this deformation, the whole area was uplifted by a very large displacement on the Williamstown-Meadows Fault, bringing amphibolite facies rocks into conjunction with a biotite grade sequence, marking the western boundary of the area. Figure 1. shows the subdivision and distribution of lithological units.

#### THE BASEMENT (WARREN INLIER)

The pre-Adelaidean basement schists and gneisses are exposed over an area of approximate 6.5 km<sup>2</sup>. These rocks clearly underlie the cross-bedded schistose metasandstone of the Adelaidean sequence and are separated

from that metasandstone unit by an angular unconformity. It is proposed that the name Warren Inlier be applied to this basement exposure. The South Para River, downstream from the Warren Reservoir, has cut a rugged gorge through this inlier, and the spillway of the reservoir, like that of the South Para Reservoir further downstream, has been constructed on the older Precambrian basement. There are also large exposures of the basement rocks north and south of the South Para gorge, and in particular at the southern end of the Warren National Park.

The fresh artificial exposures on the overflow race at the southern end of the Warren Weir provide a conveniently accessible location for examining the general nature and structural complexity of these rocks. The predominant rock here is a coarse-grained schistose quartz-felspar-mica gneiss with prominent lenticular quartzofelspathic and micaceous compositional layers developed on all visible scales and displaying various intricate fold structures. A typical specimen is composed of 60% plagioclase (An 14) as unzoned rarely twinned 0.5-1 mm granoblasts; 10% quartz; 20% biotite as plates up to 3 mm in diameter, interleaved with some muscovite and altering to chlorite; 10% fibrolitic sillimanite, which has undergone almost complete sericitisation and recrystallisation to new decussate muscovite flakes, distributed in lenticular layers; and the minor accessories rutile, zircon and apatite. The coarse crystals in this rock are observed to be mimetic after crenulations in the gneissosity, although there are also pronounced late strain features, such as bent mica flakes and deformation lamellae and strain bands in quartz. The size of the quartz inclusions in the plagioclase grains and of accessory zircons indicate a likely pelitic parentage. There are rare layers of very coarse biotite rich schist, and one of these grades into a biotite amphibolite with accessory rutile. This rock is composed of about 80% of poorly oriented interlocking hornblende poikiloblasts 1-2 mm in diameter, containing about 5% of small quartz, biotite, epidote, carbonate and opaque inclusions. The amphibole is pleochroic from pale lemon to blue-green and is characterised by strong rutile exsolution. Thick biotite flakes (5%) altering to chlorite are scattered throughout. The leucocratic fraction is composed of equal amounts of quartz and plagioclase (An 45-50) granoblasts. Rutile, apatite, epidote and opaque grains are accessories. The textures



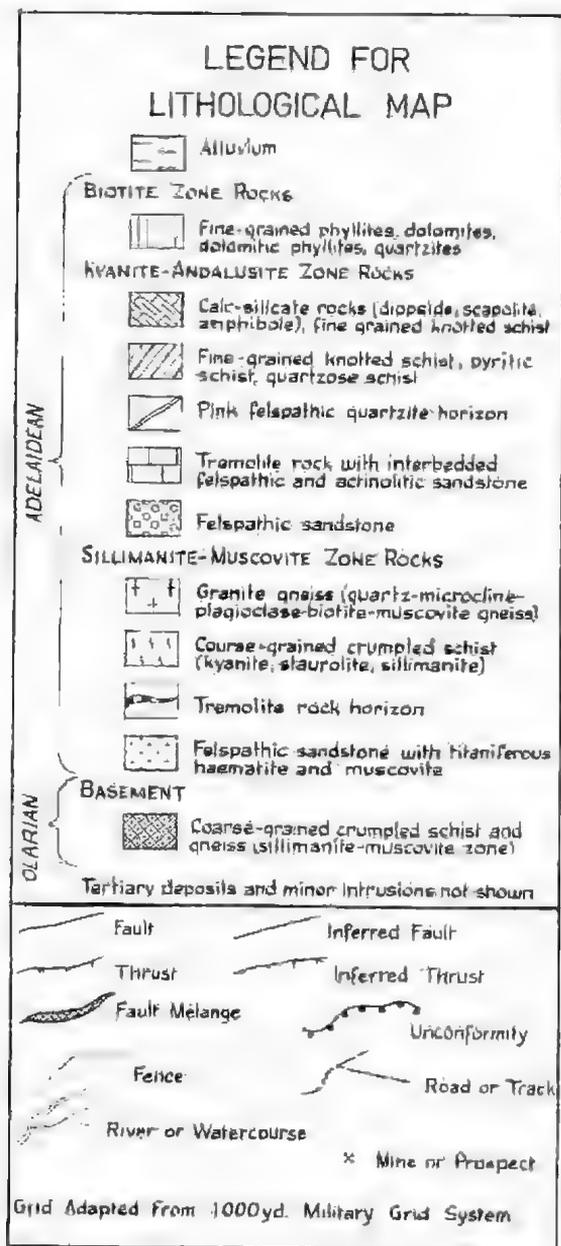


Fig. 1. (Opposite). Lithological map showing the distribution of the principal divisions of rock types in the region around the Warren Reservoir.

and the composition of this rock suggest an original marl. Pods and lenses of quartz and segregation pegmatites are also common in the outcrop.

No attempt has been made to map lithological variations across the remainder of the inlier, although exposure is sufficiently good for this to be a promising line of attack. Reconnaissance observations have not revealed a great deal of lithological variation. Almost all rocks appear to have had a pelitic or psammopelitic ancestry, although there are some more quartzofelspathic varieties in the South Para downstream from the weir. The biotite-rich schists and amphibolites noted at the weir are to be found elsewhere as small isolated occurrences, but are apparently quite sparse. No rocks of the "Houghton diorite" type (Benson 1909) have been found in this inlier. The only rocks with an intrusive character are scattered quartz pods and dykes and abundant pegmatoidal rocks, mostly of a segregation type but with rarer crosscutting varieties containing sparse beryl and tourmaline.

Amongst the pelitic and psammopelitic gneisses compositional variations range from sillimanite (sericite)-rich gneisses (e.g. grid refs. 909082 and 916106), through varieties with less sillimanite, similar to the weir gneisses described above, to quartzofelspathic gneisses lacking sillimanite. Some of the latter may contain abundant well-twinned microcline, or pass into rocks consisting almost entirely of muscovite and quartz, such as the coarse-grained crenulated schist immediately underlying the metasandstone on the shore of the reservoir north of the weir. Within each compositional group are a number of structural variants, such as folded, crenulated, lineated, banded, striped or granulose gneisses, depending on the local structural history of each rock.

A study of the metamorphic minerals and textures of the basement rocks has indicated that they were brought to a metamorphic temperature peak late in their structural history. This metamorphic peak was apparently uniform over the whole inlier and reached the stage where sillimanite was stable in the presence of muscovite in aluminous schists. No evidence has been found for any extensive breakdown of muscovite and potash feldspar (microcline) is confined to the non-aluminous varieties. Of other index minerals, garnet and kyanite have been rarely recognised and anda-

ltsite and staurolite have not so far been identified. It seems that the basement rocks have an apparently similar metamorphic history to the Adelaidean schists and gneisses immediately overlying the metasandstone unit, and it is believed that the metamorphic peak indicated in the basement rocks was identical to that which may be deduced from rocks of the Adelaidean mantle. It seems clear that the pre-Adelaidean metamorphism of the basement rocks involved lower grade conditions than those reached in the early Palaeozoic orogeny which affected both basement and mantle.

Spry (1951) reported a fall in grade from south to north, involving sillimanite, garnet and biotite zones, for the early pre-Adelaidean metamorphism of the nearby Houghton Inlier, which could be construed to fit the above conclusion, but Talbot (1962)<sup>1</sup> has disputed this grade variation. Talbot (1963) has shown that the Houghton Inlier has suffered three metamorphisms. Two pre-Adelaidean episodes, the earlier involving upper amphibolite facies conditions, and the later involving pervasive greenschist facies retrogression accompanying strong phyllonitisation, were overprinted by a greenschist facies (biotite zone) episode accompanying the Palaeozoic metamorphism of the Adelaidean mantle. A tentative Rb-Sr date of  $867 \pm 32$  m.y. has been suggested for the upper amphibolite facies metamorphism (Couper & Compston 1971), while the Palaeozoic metamorphism has been dated at  $490 \pm 15$  m.y. (White, Compston & Kleeman 1967).

In the Warren Inlier the Palaeozoic metamorphism has obscured all evidence of pre-Adelaidean metamorphic grade in the basement rocks. It is conceivable that rocks of the Warren Inlier have passed through a phyllonitic stage similar to the Houghton Inlier, but there is so far no evidence of it or of any earlier higher grade metamorphic episodes.

The late metamorphic history of the Warren Inlier rocks and the overlying Adelaidean schists is also similar, involving pervasive retrogression of sillimanite to sericite and muscovite and of biotite to chlorite, and the appearance of late strain features such as bent and kinked micas, lamellar twinning in plagioclase and deformation bands and lamellae in quartz.

#### THE UNCONFORMITY

The actual surface of unconformity is only clearly exposed in two localities; on private land south of the reservoir (grid ref. 925108), and in the southern part of the Warren National Park (grid refs. 909088-912090). The Warren National Park exposures are the most instructive and will be described first.

Several large exposures in the southern portion of the Warren National Park display a fingernail sharp unconformity surface. There is a large angular discordance between the gently south dipping quartzofelspathic banding in the basement gneisses and the near vertical bedding of the overlying metasandstone (Fig. 3f). The basement gneisses here are coarse-grained, mica-rich and schistose. The prominent quartzofelspathic bands may be related to original bedding, but are probably transposed and lack stratigraphic significance. The basal units of the overlying metasandstone are rich in muscovite and strongly schistose. These units become quite friable on weathering, resulting in a negative relief against the more massive basement gneisses. A basal conglomerate is developed locally at grid ref. 911088. The pebbles range up to 30 cm in length, are moderately angular and are locally derived from the quartzofelspathic bands of the underlying basement. The bed is up to half a metre thick and is observed to be welded onto the basement. In adjacent outcrops the conglomerate is absent and a muscovite-rich schistose metasandstone, characterised by an unusual abundance of haematite and a few scattered rounded quartz or quartzite pebbles to a few centimetres in diameter, is welded directly on to the basement with a sharply defined contact. A strong metamorphic and structural convergence of the basement and the overlying Adelaidean beds has obscured this contact in some exposures. Where the contact is clear the unconformity surface is seen to be quite irregular in detail, with harder bands in the basement protruding into the basal beds. A metre or so above the unconformity the bedding in the metasandstone is unaffected by these irregularities.

Following the inlier boundary to the southwest from the above localities, no actual exposures of the unconformity were seen, although a boundary between the basement

<sup>1</sup> Talbot J. L. (1962)—A study of the structural and metamorphic relationships between older and younger Precambrian rocks in the Mt. Lofty Range—Olary Arc, South Australia. Univ. Adelaide. Ph.D. Thesis.

gneisses and the metasandstone can be mapped, the basal metasandstone exposures being again enriched in haematite. In the south-west corner of the inlier the boundary begins to turn eastwards and disappears beneath alluvium. Apart from one small exposure of cross-bedded haematite-rich metasandstone overlying the basement a little further eastwards, no other exposures of the contact are seen, the southern and eastern sides of the inlier being delineated by a major thrust fault.

Following the inlier boundary to the north-east from the Warren National Park exposures, the basal metasandstone beds are haematite and muscovite-rich, but no actual unconformity surface was observed. The actual contact lies near the base of a steep escarpment of basement gneisses. This escarpment is related to the friability of the basal beds of the Adelaidean sequence and the erosional resistance of the basement gneisses. Rainfall run-off from the basement gneiss exposures engenders a thick undergrowth near the contact.

On a track extending north-west of Lookout Tower Hill (grid ref. 918105) a haematite-rich quartz-muscovite rock is seen close to the inlier contact as the lowest bed in the metasandstone sequence. This rock is composed of 65% quartz as large granoblasts to 3 mm, 25% muscovite, 10% haematite, and 5% barite as evenly distributed interstitial grains. Much post-crystalline strain is evident in the quartz and muscovite.

Following the inlier boundary westwards around several folds, no actual exposures of the unconformity surface were found. The basal beds of the Adelaidean are muscovite-rich metasandstones, usually bearing notable haematite or a trace of biotite. Bedding is outlined by quartz-rich bands, and occasional rounded quartz or quartzite pebbles to 5 cm in diameter are scattered along some bedding planes. The adjacent basement is mostly a mica-rich schist. No unconformity surface was observed along the long meridional western contact of the inlier although the boundary can be closely mapped. Again muscovite-rich schistose metasandstones are characteristic of the basal beds. On the Engineering and Water Supply access road (grid ref. 902125) a two metre gap of soil and grass separates what appears to be the basal bed, a coarse haematite-rich quartz-muscovite metasandstone with a few small pebbles, from strongly folded

coarse-grained quartz-felspar-biotite-muscovite gneisses of the basement. This haematite-rich bed can be seen at several points further north near the inlier contact, but nearer the northern tip of the inlier this basal bed has apparently lensed out and beds of muscovite-rich metasandstone from slightly higher in the sequence come to rest on the basement. From the northern tip of the inlier (Hale National Park) to the reservoir the inlier contact was not easily mapped. The unconformity exposure described by Hossfeld (1935, p. 37) could not be found, although both basement and metasandstone rocks are sufficiently well exposed near the E. & W.S. access road north of the weir to place the inlier contact on the map with confidence.

South-east of the weir the inlier boundary becomes involved in several tight folds—in part interpreted previously as a cross-fault (Mills 1963). On the ridge west of Wirrianda homestead some good exposures of the unconformity surface may again be seen. Here a coarse-grained muscovite and haematite-rich schistose metasandstone overlies a closely folded muscovite-rich gneiss containing quartzofelspathic layers and some haematite. The unconformity surface is again seen to be irregular in detail. Scattered pebble-like quartz pods to 10 cm in diameter occur in both the basement and metasandstone and are apparently of segregation origin. Immediately south of the homestead the haematite-rich basal beds of the metasandstone run into the Wirrianda Thrust which marks the eastern boundary of the inlier.

In conclusion, an unconformity between rocks of the Warren Inlier and the overlying Adelaidean sequence is well established. The inlier boundary can be mapped along most of its length with confidence, and details of the actual unconformity surface can be observed at two localities. The lowest beds of the Adelaidean sequence are composed of schistose muscovite-bearing metasandstones and the basal beds are usually enriched in haematite, although not as enriched as in the ML Bessemer sequence on the eastern side of the nearby Houghton Inlier (Miles 1950). A basal conglomerate of the local derivation has been found at only one locality.

#### THE ADELAIDEAN SEQUENCE

##### *The sillimanite-muscovite zone*

The lowermost units of the Adelaidean sequence overlying the basement of the Warren Inlier have reached the grade of meta-

morphism where sillimanite and muscovite are in stable equilibrium in rocks of appropriate composition. The basal formation is a thick cross-bedded schistose felspathic metasandstone, which is overlain by a thick aluminous pelitic formation. The top of this pelitic formation has been cut out by major faults which have brought the sillimanite-muscovite zone rocks into conjunction with lower grade sequences. Three distinct phases of strong compressive deformation have affected rocks in the sillimanite-muscovite zone and no reliable estimates of stratigraphic thicknesses can be made.

The lithological character of the basal metasandstone formation in this area has been carefully described by Howchin (1906, p. 255; 1926, p. 5) who noted its close similarity to the Aldgate Sandstone. The metasandstone supports rather sparse vegetation and usually forms large leucocratic outcrops. The friable nature of this rock preserves the freestone character of the Aldgate Sandstone despite high grade metamorphism. Bedding, cross-bedding and festoon-bedding, outlined by laminae of titaniferous haematite, are beautifully preserved although considerably appressed by subsequent tectonic deformation. The haematite laminae are normally about one millimetre in thickness, but rare layers up to 10 cm in thickness have been observed. Miles (1950) presents the results of a chemical analysis of the titaniferous haematite from a specimen collected in the north-west corner of this area. In some outcrops (e.g. grid ref. 908070) the metasandstone is strongly magnetic; magnetite presumably replacing the haematite as the principal opaque accessory. It is not known whether this magnetic property is confined to certain beds.

As described in the previous section, the lowest beds against the unconformity are normally enriched in haematite, this component being scattered evenly throughout. These haematite-rich beds are not more than a few metres in thickness and in many places they thin out and disappear entirely. The next 30-50 metres of section consists of a muscovite-enriched metasandstone, perhaps best described as a quartz-muscovite schist. The remainder of the section, perhaps amounting to 500 metres, consists of felspathic metasandstone, characterised by titaniferous haematite laminae outlining the bedding surfaces, with intermittent muscovite-enriched layers. The base of this more quartzofelspathic section

was taken as the base of the psammitic formation on my earlier map (Mills 1963). As described by Howchin, rounded pebbles up to 30 cm in diameter, mostly of quartz or fine-grained quartzite, are distributed throughout the sequence, although more commonly encountered at certain horizons. True conglomeratic beds are rarely observed, the pebbles being mostly scattered unevenly on bedding surfaces throughout the outcrop. In some exposures the pebbles are seen to have suffered a strong flattening and some elongation resulting from tectonism. Stratigraphic bedding can usually be identified and opportunities for facing observations based on cross-bedding are numerous. Some slicing and transposition of bedding has been noticed in the muscovite-enriched section near the base of the sequence in the South Para Gorge. Occasional pegmatite and milky quartz veins carrying accessory ilmenite plates intrude the metasandstone throughout the area.

Sixteen specimens covering the composition range of the psammites were examined microscopically. Quartz, ranging from 25-75%, occurs in some rocks as large strained clasts up to 3 mm, while other samples, particularly the more micaceous ones, demonstrate all stages in the recrystallisation of original strained clasts to new metamorphic granoblasts. This recrystallisation is closely associated with the axial surface schistosity of the second compressive deformation. In some samples the new quartz grains preserve a pronounced preferred orientation of their c-axes, apparently related to the second deformation. Some quartz clasts are sagenitic. Potash feldspar (0-30%) is the sole feldspar component. It usually occurs as strained tarran-twinning clasts up to 2 mm. In some specimens the clasts are apparently untwinned but have partially recrystallised to small well-twinning granoblasts near their margins. Muscovite (5-50%) is present in all specimens, usually as large flakes up to 2 mm, commonly showing late strain effects. It appears to be wholly of metamorphic origin and is responsible for the preservation of many of the tectonically imposed features of these rocks. Biotite is present in many samples up to 5% and is usually pleochroic olive brown to pale lemon. Opaque grains (1-10%) are invariably present. Apatite, zircon, monazite and tourmaline, pleochroic pale pink to olive green, are accessories. Considering the coarse-grained micaceous gneisses above and below the schistose sandstones, the

preservation of quartz and feldspar clasts at this metamorphic grade is quite remarkable and the weakly metamorphosed appearance of the more quartzofeldspathic varieties of this metasandstone must be partly attributable to the preservation of these clastic features.

The upper contact of the metasandstone against the overlying sillimanite bearing pelitic schists is sharply defined. In the south a thin intermittent tremolite rock bed, normally expressed at the surface as an opaline replacement rock, marks the contact, while in the east some pelitic schist is inserted between this bed and the metasandstone. In the north-west a sliver of coarse-grained sillimanite bearing pelitic schist is observed to rest directly on the schistose sandstone. The true nature of the tremolite marker bed can be observed in detail from a shaft sunk on the ridge north of Sailors Gully where the rock below the weathered profile is composed of interlocking pale-green tremolite-actinolite prisms. Elsewhere the surface expression is an opaline chalcedony showing tremolite casts and some talc.

The thick pelitic formation above this tremolite bed has been previously described in some detail (Mills 1963, p. 171). These rocks have suffered intense folding and compression and true bedding cannot be recognised with certainty. Although apparently quite thick, no estimates of stratigraphic thickness can be made. The rocks are coarse-grained micaceous schists and gneisses, usually displaying aluminosilicate knots, cross-cutting crenulations and small folds in their schistosity, leading to the field name "crumpled schists" (c.g. Miles 1950). The major primary constituents are quartz, plagioclase (An 0-15), biotite and muscovite with variable amounts of sillimanite and kyanite and rarer staurolite and garnet. Assemblages of these minerals developed in rocks of appropriate pelitic composition and approached equilibrium in a sillimanite-muscovite grade metamorphic peak during the second deformation. As with the basement gneisses, no metasomatism is considered to be necessary for their formation. A pervasive retrogression, which took place in the interkinematic period between the second and third compressive events, has resulted in the extensive alteration of aluminosilicate minerals and biotite to sericite and chlorite. This retrogression is more pronounced in some zones where shearing associated with thrust movements is believed to have been important.

Some introduction of  $H_2O$  may have accompanied this retrogression.

In the east, part of the pelitic formation has been replaced by a body of granite gneiss, as previously described in greater detail (Mills 1963). Although the chemical processes which led to the formation of this granite gneiss are not yet understood, extensive chemical migrations are not envisaged in its formation. This granite gneiss and its immediate envelope of schists have escaped retrogression. It is envisaged that the granite gneiss body behaved as a solid impermeable block during the retrogressive episode which affected the adjacent schists.

In conclusion, the basal metasandstones and the overlying pelitic schists have been subjected to a metamorphic peak in the middle amphibolite facies under temperature conditions where sillimanite was in equilibrium with muscovite. Some clastic textures have been preserved in the more quartzofeldspathic metasandstone beds but in the pelitic schists extensive recrystallisation took place. Sillimanite, kyanite, staurolite and garnet were crystallised during this metamorphism and granitisation occurred locally. At a later stage under greenschist facies conditions, extensive retrogression took place in the pelitic schists.

#### *The kyanite-andalusite zone*

A sequence of Adelaidean rocks belonging to the lower amphibolite facies have been faulted against rocks of the sillimanite-muscovite zone in the south, east and north-west. North of the Warren Reservoir, Alderman (1942) placed these rocks in the biotite zone, a reasonable supposition considering the abundance of biotite-quartz-feldspar schists which occur in this sequence. Aluminous beds containing andalusite or kyanite knots are rare and these knots are usually severely retrogressed to sericite. Calc-silicate beds in the sequence carry diopside, scapolite, amphibole, epidote and oligoclase-andesine, confirming their amphibolite facies character. This sequence of rocks is characterised in the field by the fine to medium grain-size of the pelitic and psammopelitic units and their simple structural character dominated by a single schistosity, which in most outcrops is parallel or nearly parallel to well-defined bedding planes and bedding laminations. Crenulations in this schistosity are rarely found, and if present are weakly developed. The sequence east of

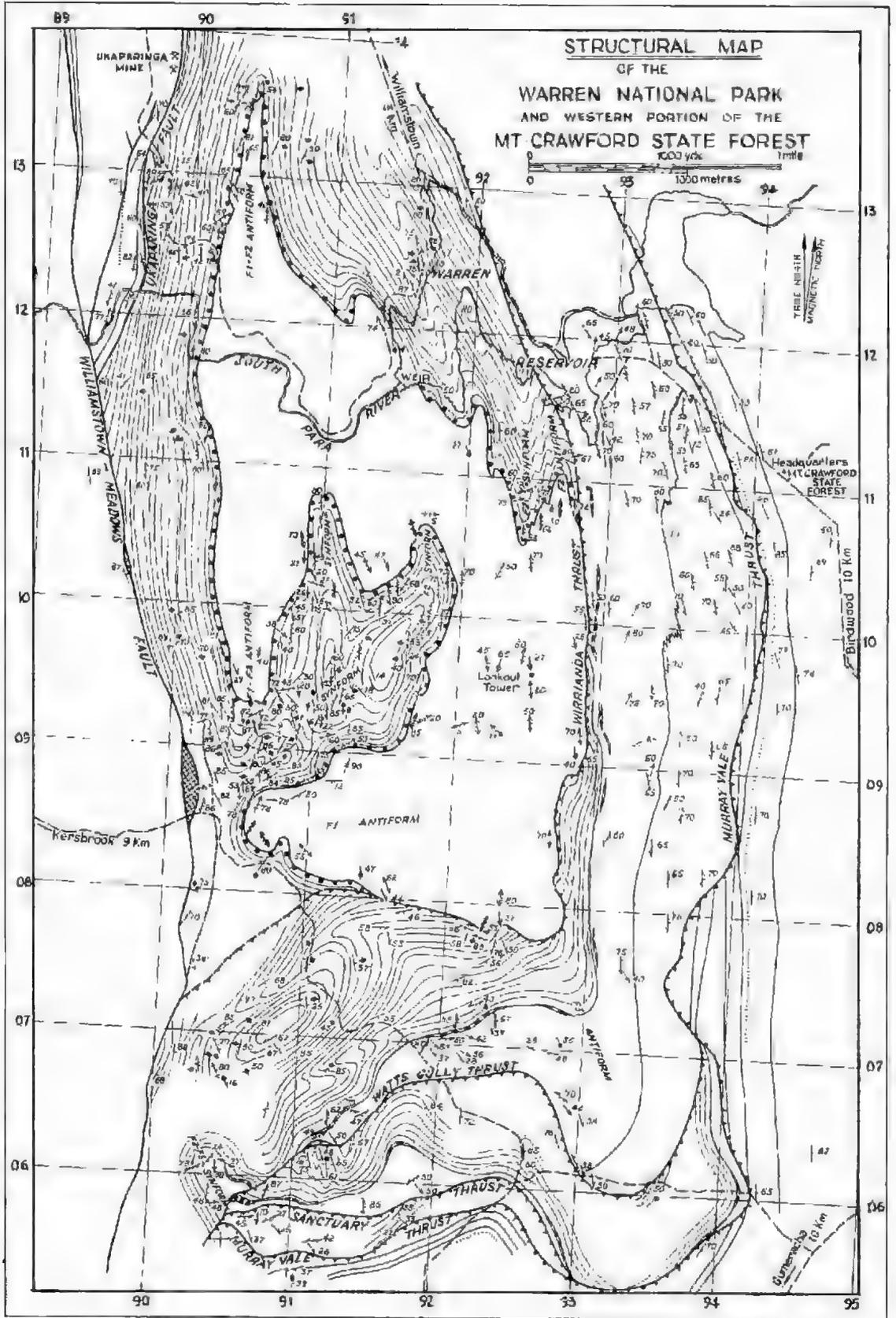


Fig. 2.

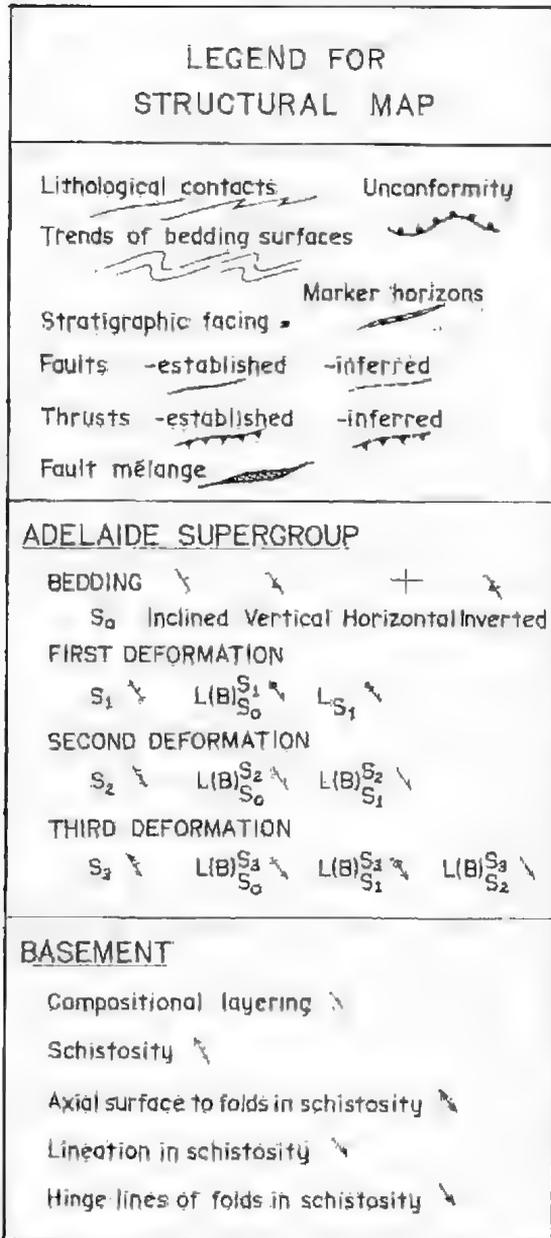


Fig. 2. (Opposite). Structural map showing the principal structural features in the region around the Warren Reservoir.

the granite gneiss has been briefly described (Mills 1963, p. 171).

Exposure of this sequence is very poor in the south and south-east but it seems that the lowest unit is a pink meta-arkose containing some haematite laminac, but no mica, and preserving good clastic characters. South of Watts Gully this meta-arkose is overlain by a sequence of fine to medium-grained quartz-felspar-biotite schists containing some pink microcline-rich meta-arkose beds with accessory pyrite. Then follows a tremolite rock marker unit, expressed at the surface as a ten metre width of opaline replacement rock. This unit has been traced intermittently, using exposures of opaline replacement rock or talc, around to the eastern side of the granite gneiss where it forms a thick and useful marker horizon. At the surface it is usually expressed as opaline chalcedony, but fresh samples from below the weathering profile consist of coarse interlocking tremolite prisms. North of the present area this same horizon is apparently represented as a tremolite marble and has been traced from well north of Williamstown to the proximity of the Warren Reservoir (Howchin 1926, pp. 7-8; Hossfeld 1935).

East of the granite gneiss the tremolitic marker unit is overlain by a mica schist group consisting of fine to medium-grained quartz-felspar-biotite-muscovite schists with thin interbedded meta-arkoses. Most of these meta-arkoses are fine-grained, pyritic, graphitic and very enriched in microcline. A useful pink felspathic quartzite marker horizon crops out persistently a little above the tremolitic marker unit. Some mica schist beds contain small knots which have altered to fine sericite. Rare kyanite relics have been found in these knots. The uppermost part of the sequence examined is a calc-silicate group consisting of interbedded fine to coarse calc-silicate rocks and knotted fine-grained mica schists.

A wedge of rocks belonging to the kyanite-andalusite zone has been mapped west of the Ukapinga Copper Mine, in the north-west corner of the area. The lowest bed here is a thick medium-grained dolomitic marble, which may be equivalent to the tremolitic marker bed east of the granite gneiss. Specimens of this rock consist largely of dolomite with variable amounts of tremolite, talc, muscovite and primary chlorite. Calcite is rare or absent. Two analyses of this marble are presented by Miles (1950). This marble is overlain by a mica schist sequence, containing fine-grained

pyritic meta-arkose beds, very similar to that east of the granite gneiss. Higher in the sequence some mica schists have sericite knots containing andalusite relics. The calc-silicate group has not been recognised here, although a second marble unit crops out high in the sequence against the Williamstown-Meadows fault.

#### *Biotite zone*

No attempt has been made to map beds in the low grade sequence exposed west of the Williamstown-Meadows fault. Near the fault the main rock types are fine-grained grey dolomites, grey-brown dolomitic phyllites, phyllites and fine-grained quartzofelspathic pyritic metasilstones. Rocks of the biotite zone are usually extremely fine-grained (0.01-0.03 mm). A pale mustard-brown weakly pleochroic biotite is characteristic of the phyllitic rocks. Dolomite seems to dominate over calcite in the carbonate rocks. A thick sequence of grey impure dolomites (20% quartz, plagioclase, muscovite and opaque impurities) is exposed south of the South Para River

#### CONCLUSIONS

The basement rocks of the Warren Inlier are unconformably overlain by the Adelaidean rocks. The Adelaidean sequence is divided into three portions belonging to different metamorphic and structural levels by several major fault surfaces. The basal sillimanite-muscovite zone rocks and the kyanite-andalusite zone rocks of the Adelaidean sequence are separated in this area by faults which are surfaces of marked metamorphic and structural discontinuity. It therefore seems likely that there is a large stratigraphic gap between the sequences represented within these metamorphic zones. Further detailed mapping, particularly to the north of the present area, may help to determine how much of the stratigraphic sequence has been removed. Until this problem is solved it seems unwise to attempt correlations of individual beds or parts of the sequence with other beds or sequences in the Mt. Lofty Ranges. The Williamstown-Meadows fault brings biotite zone rocks in the west against sillimanite-muscovite zone rocks. As suggested by Miles (1950) the biotite zone rocks probably belong to a much higher

stratigraphic and metamorphic level in the Adelaidean sequence and displacement on this fault must be very large.

### Structural Relationships between Mapped Lithological Units

#### PRELIMINARY COMMENTS

Three successive compressive deformation events,  $F_1$ ,  $F_2$  and  $F_3$ , have affected the Adelaidean sequence in the vicinity of the Warren Reservoir and the structural features produced in these deformative phases will now be described more fully. Metamorphism of the Adelaidean sequence began before or during  $F_1$  and reached a peak temperature in the amphibolite facies early in the  $F_2$  episode. A series of east to west thrust movements occurred late in the  $F_2$  event and extensive retrogression under greenschist facies conditions accompanied or followed these movements. The thrust sheets were folded during a rather brittle low temperature  $F_3$  event. After  $F_3$  and late in the cooling history the Williamstown-Meadows fault developed its maximum displacement.

In describing the structural features and events in the Adelaidean sequence it is convenient to introduce the following shorthand notation<sup>2</sup> (see also map legend, Fig. 2)—

- $S_0$  — surface of compositional layering relating to primary bedding.
- $F_1, F_2, F_3$  — the three successive compressive events.
- $S_1, S_2, S_3$  — axial surfaces to folds produced in the  $F_1, F_2, F_3$  events respectively.
- $B(S_0-S_2)$  etc. — folds in bedding with  $S_2$  as axial surface etc.
- $L(S_0-S_2)$  etc. — lineations resulting from  $S_0-S_2$  intersections etc.
- $L(S_1)$  etc. — strain elongation axis in  $S_1$  etc.

Orientation measurements are recorded in relation to true north-point azimuth. Figures 2 and 8 illustrate the principal structural features

#### THE BASEMENT (WARREN INLIER)

At the type locality of the basement rocks at the Warren Reservoir Weir a partial history of tectonic events may be determined. As in all exposures of the basement rocks, bedding

<sup>2</sup> Owing to printing difficulties this form of notation is adopted in the text rather than the more conventional form shown on the map legend.

with stratigraphic significance cannot be proved, although quartzofelspathic bands and layered lithological variations may reflect a primary bedding precursor. Lithological layers and schistosity in the exposures near the weir are strongly folded on all scales and at first sight the folding appears to be rather regular with a prominent schistosity, defined by coarse mica plates, crenulated and folded about shallow plunging axes (Mills 1963). This schistosity is observed in detail to be a highly evolved crenulation cleavage, and is therefore an axial surface schistosity belonging to at least a second deformation event. In parts of this exposure this schistosity has been folded into recumbent Z-shaped folds with near horizontal hinge surfaces, and these folds have been overprinted in turn by a widespread later folding with a moderately west-dipping axial surface, producing crenulations in the earlier schistosity with a wavelength of 0.5-3 cm. Thus, at least four overprinted fold events can be distinguished in this exposure, and there are yet other folds present which may represent a fifth deformation. The earlier folds in the weir exposure tend to have a plygmatic style in which the fold hinge lines have a more regular orientation than the hinge surfaces. Nevertheless, the hinge lines remain curvilinear on all scales and the folds are never strictly cylindrical. The later folds are also irregular and often of polyclinal style, this being partially induced by the presence of many large intrusions of pegmatite and blocks and lenses of quartzofelspathic gneiss which have acted as buffers inducing inhomogeneous strain during the later fold movements (Fig. 3b, c, e). Due to these irregularities, reliable field measurements of the orientation of structural elements are difficult to make, even in the most favourable exposures.

Elsewhere in the inlier most exposures show signs of complex folding and overprinted deformation structures, justifying field names such as crenulated or crumpled schists. Bedding cannot be verified and any lithological layering present is strongly lenticular and suggestive of transposition processes. Some exposures are very irregularly deformed and no orientation measurements can be made, but some of the more micaceous schists display fairly regular folding of their schistosity, approaching local cylindricality. There is much variation in the style of small folds from concentric to sharp chevron folded forms (Fig. 3a, d, h). Most pegmatite intrusions have also been folded

along with the host rock schistosity. Examination of exposures in the vicinity of Lookout Tower Hill again suggests multiple deformation involving at least four compressive events, the latest phase involving ubiquitous tight to open chevron style folds in the earlier schistosity of the more micaceous rocks.

Microscopically the basement rocks are coarse-grained, with a prominent schistosity defined by oriented mica flakes, which are often segregated into lensoidal gneissic layers with signs of evolution through an earlier crenulation cleavage stage. In parts of the inlier a strong mineral lineation, defined by sillimanite fibres in aluminous schists or mica plate dimensions, is observed within the schistosity. Folds and crenulations in the schistosity are ubiquitous and are mostly pre- or synmetamorphic. Some of these folds seem to be closely related to the  $F_2$  deformation in the overlying metasediments. Weak late metamorphic strain features, undulose extinction and deformation lamellae in quartz and kinking and bending of mica plates, are observed in most specimens.

Although some structural measurements have been made in the basement rocks (Fig. 6, sub-area A), these have little or no meaning in terms of the complex structural history to which these rocks have been subjected, and a more complete understanding of their structural history may only evolve through a more detailed structural analysis of the whole inlier.

#### THE ADELAIDEAN SEQUENCE

##### *The sillimanite-muscovite zone*

The basal unit of the Adelaidean sequence is a schistose metasandstone in which quartzofelspathic and mica-rich layers and titaniferous haematite laminae clearly outline primary bedding ( $S_0$ ), and well preserved cross-bedding structures provide evidence for stratigraphic facing as described previously. Plates of white mica, presumably crystallised from a former clay/felspar fraction in the sandstone, are present in almost all beds of this unit but become more abundant towards the base. These platy crystals have enabled various tectonic structures to be preserved in the metasandstone, and from a study of the mica plate orientations a tectonic history can be erected. Like the overlying pelitic sequence the basal metasediments have been affected by three major deformative events  $F_1$ ,  $F_2$  and  $F_3$  (Fig. 6). The  $F_1$  and  $F_2$  events caused tight

folding of the metasandstone throughout most of the area considered here. The  $F_2$  event involved strong compressive deformation near the peak temperature of metamorphism and this combination has tended to obscure the effects of the  $F_1$  event in most exposures. During the  $F_2$  event a strong  $S_2$  schistosity evolved through the crenulation and transposition of an earlier  $S_1$  schistosity. The effects of the  $F_3$  event are rather weak and are responsible for some post-crystalline crenulations in earlier schistosity in the centre of the area and macroscopic folding of earlier structures in the south-east (Fig. 6, sub-areas M, N, O, P, Q).

Most exposures of the metasandstone display a schistosity defined by oriented mica plates. In the less micaceous rocks some difficulty is experienced in differentiating this schistosity as  $S_1$  or  $S_2$ . In some of the more micaceous rocks  $S_1$  and  $S_2$  are both present and can be clearly distinguished on the basis of overprinting relationships. Where  $S_1$  is most clearly preserved it is seen to be defined by well-oriented mica plates. The mica crystals are grouped into anastomosing clusters of nearly parallel plates separated by a single layer of quartz and feldspar grains. The clusters are evenly distributed rather than forming the segregated trains of mica plates more charac-

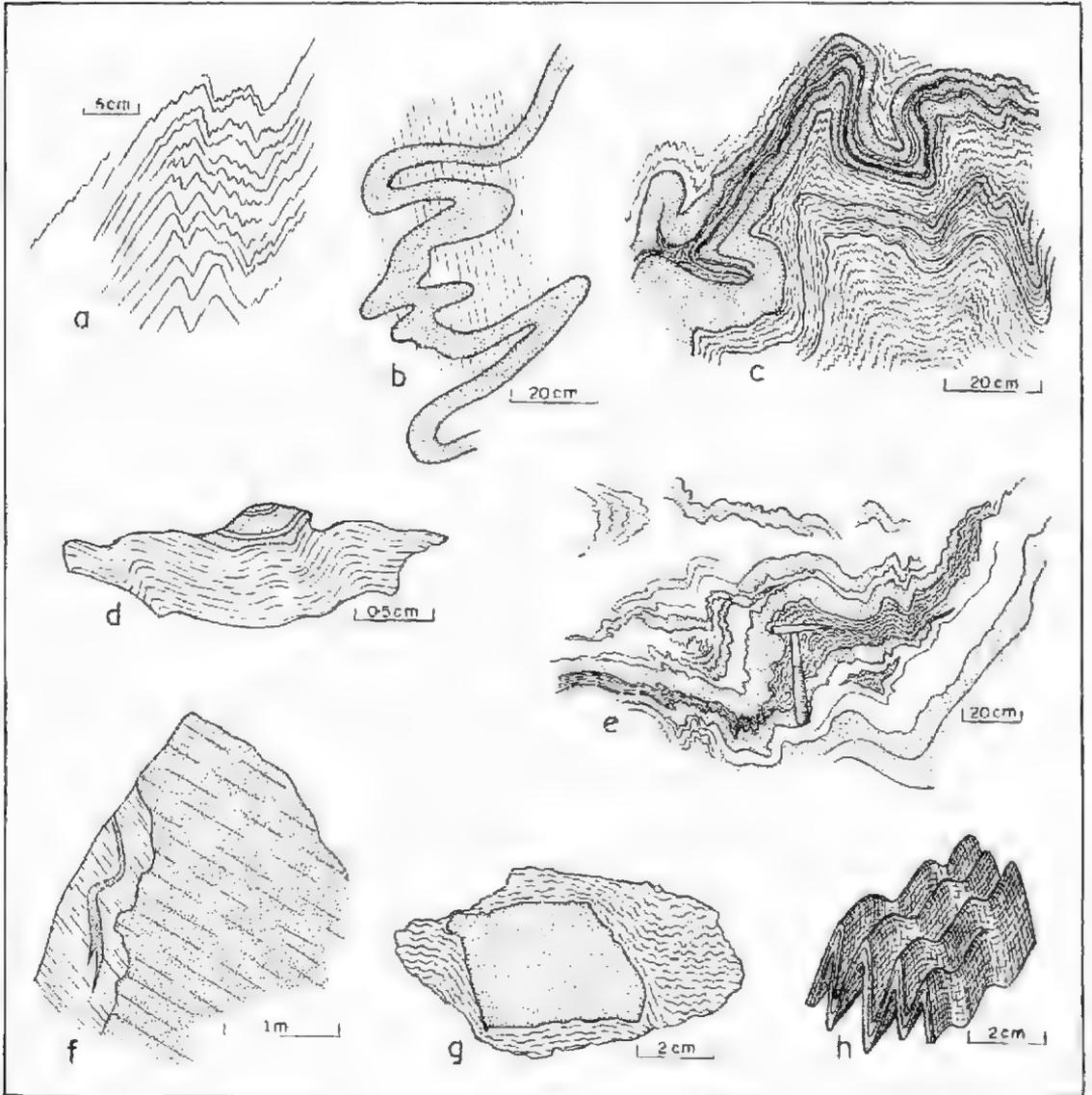


Fig. 3.

teristic of the  $S_2$  microstructure. The grain size of the mica plates does not seem to be a consistent feature for the distinction of  $S_1$  and  $S_2$ . In situations where the  $S_1$  surface lies at a distinct angle to  $S_0$  and in cross-bedded micaceous metasediments,  $S_1$  can be shown to be an imposed tectonic feature and not a "bedding foliation". However, in most outcrops  $S_1$  is sensibly parallel to  $S_0$ , suggesting a position on the limbs of very appressed  $F_1$  folds.

Owing to the strong overprinting effects of the  $F_2$  event, macroscopic  $F_1$  folds cannot be readily mapped out, but the shape of the basement exposure suggests the position of some macroscopic  $F_1$  folds. A stereographic plot of poles to bedding surfaces measured over the large synclinal structure straddling the centre of the inlier results in a broad girdle pattern, the pole of which, plunging at  $20^\circ$  towards  $202^\circ$ , may be taken to represent the mean macroscopic  $B(S_0, S_1)$  fold axis for this structure (Fig. 6, sub-area L). The orthographic block diagram of Fig. 8, showing the general form of the structure, has been derived using this calculated  $F_1$  axis and the local orientation data on the overprinted  $F_2$  and  $F_3$  structures. In the north-west of the area, for example along the Engineering and Water Supply track crossing the metasediment on the western side of the inlier, some mesoscopic  $F_1$  folds show tight appression with the  $S_1$  axial surface structure striking  $002^\circ$  and dipping steeply eastwards. Insufficient observa-

tions have been made to discuss strain in the  $F_1$  deformation.

All stages in the development of the  $S_2$  structure can be observed in the metasediment, from faint, open crenulations in the earlier  $S_1$  schistosity, to appressed crenulations in which the mica plates have become concentrated in the limb regions, leaving the hinge areas enriched in quartz and feldspar with only a few diversely oriented mica plates; to a new gneissose schistosity in which the mica plates are largely segregated into trains parallel to  $S_2$ , leaving little sign of the previous  $S_1$  structure in the rock. In the more quartzofeldspathic beds both the quartz and feldspar grains have discoidal shapes with long axes lying in the  $S_2$  surface. The mica plates defining the crenulations of the new  $S_2$  schistosity characteristically lack pronounced strain features and evidently underwent recrystallisation during and after the  $F_2$  event, that is syntectonic and post-tectonic crystallisation, and this feature serves to distinguish  $F_2$  crenulations from  $F_3$  crenulations over most of the area. However, in the south-western portion of the Warren National Park deformation in the  $F_2$  event outlasted recrystallisation. Here mica plates have been strongly kinked and intragranular movements outlasted strain relieving processes. Relict quartz clasts show strong undulose extinction with deformation bands parallel to  $S_2$  and newly crystallised quartz grains have developed a pronounced c-axis fabric during the  $F_2$  event. This fabric

- Fig. 3. Structures in basement rocks of the Warren Inlier and at the base of the Adelaidean succession.
- a.*—Profile of folds in coarse-grained quartz-mica gneiss, Warren Inlier. A well developed gneissic schistosity has been thrown into regular chevron folds in a deformation which may be correlated with  $F_2$  in the overlying Adelaidean succession. Traced from photograph. Location 928098.
- b.*—Profile of folds in basement rocks, Warren Reservoir weir. Quartzofeldspathic layer in mica gneiss showing polyclinal folds. A crenulation cleavage cross-cuts the folds (shading) and crenulates an earlier axial plane schistosity in the mica gneiss. Freehand sketch. Location 916116.
- c* and *e.*—Disharmonic folding of quartzofeldspathic layers in coarse-grained mica gneiss, Warren Reservoir weir. Small folds associated with the crenulation of an earlier schistosity show a polyclinal style. Traced from photographs. Location 916116.
- d.*—Profile of open folds in coarse-grained mica gneiss containing thin quartzofeldspathic layers, Warren Inlier. Traced from photomicrograph. Location 928098.
- f.* Sketch of unconformity between basement rocks of Warren Inlier and basal metasediment of Adelaidean succession. Drawn looking eastwards. The quartzofeldspathic basement (stippled) has thin micaceous layers dipping at a low angle to the south. The unconformity is steeply dipping, but has an irregular detailed topography. A haematite-rich micaceous metasediment showing traces of bedding in the form of haematite-rich seams (fine stipple) is welded onto the basement and has a strong  $S_1$  schistosity, defined by the orientation of mica plates, dipping to the south (shading). Freehand field sketch. Location 912091, Warren National Park.
- g.*—An angular quartz pebble immersed in coarse-grained muscovite-rich metasediment near the base of the Adelaidean succession. Note the  $F_2$  crenulations in the earlier  $S_1$  schistosity. Traced from photomicrograph. Location 903107.
- h.*—An example of the overprinting of early folds in schistosity of a quartz-muscovite gneiss by later folds, Warren Inlier. Sketched from hand specimen. Location 917106.

has not yet been investigated in detail, but appears to involve a girdle or crossed girdle pattern in which the *c*-axes tend to be symmetrically disposed to the  $S_2$  surface and to the strong  $L(S_1-S_2)$  lineation lying within it.

A lineation,  $L(S_1-S_2)$ , is seen to lie in the  $S_2$  surface in most exposures throughout the area. Where  $S_2$  is developed only as a crenulation cleavage this lineation is the crenulation axis and is the geometrical result of the intersection of the  $S_1$  and  $S_2$  surfaces. Where  $S_2$  is more strongly developed into a new schistosity the lineation may take the form of a mineral streaking effect on the  $S_2$  surface. Microscopically this mineral streaking is seen to be the visible effect of elongate mica plates, with variable dimensions but averaging 14.5:10, which are inotazonally arranged about the lineation axis with their longest dimensions parallel to the lineation. Some quartz and feldspar grains are also elongate parallel to the lineation. Quartzose pebbles are often discoid within  $S_2$  and slightly elongate parallel to the lineation. However, whether this lineation, which has been mapped as an  $S_1-S_2$  intersection lineation in the field, is also a principal axis of strain has not yet been determined.

Most of the mapped macroscopic folds within the metasandstone and involving the unconformable contact between the metasandstone and the basement rocks have proved to be  $F_2$  folds. Mesoscopic  $F_2$  folds in both bedding and  $S_1$  surfaces are not uncommon. Two small  $B(S_1-S_2)$  folds from north of the weir, illustrated in Figs. 4a and 4b, were analysed using the technique suggested by Ramsay (1962; 1967, p. 413) for unravelling flattened flexural slip folds. In both cases the western limbs proved to be more "flattened" than the eastern limbs, and a more micaceous layer had both limbs "flattened more than 100%". These results are unrealistic and indicate that other mechanisms besides flexural slip and flattening were involved. The greater "flattening" of the western limbs could be explained by a component of simple slip or shearing motion, involving intergranular movements, which would be consistent with the east to west thrusting movement characteristic of the later stages of the  $F_2$  event. In the incompetent micaceous layer mass movement of material from limbs to nose could explain the anomalous "flattening" in these layers. However, a more generalized mechanism may have been responsible for these folds (Hobbs 1971).

In the vicinity of 906093, crenulations with a wavelength of  $\frac{1}{2}$ -1 cm are seen to have hinge surfaces parallel to those of larger folds. These hinge surfaces strike at  $335^\circ$  and dip steep westerly and are interpreted as belonging to  $F_3$  folds. In some specimens  $L(S_1-S_2)$  lineations are seen to be folded over these crenulations. Thin sections show that all crystals have preserved intense strain features related to this deformation. In the south-east, in the vicinity of the Gumeracha Goldfields, structures in the metasandstone have been folded over a large south-easterly plunging  $F_1$  antiform.

In this section, specimens of the metasandstone from throughout the area show some strain in the quartz and mica crystals, but it is not known whether this is related to the  $F_2$  deformation event outlasting recrystallisation, the  $F_3$  event, or some other later mild phase of deformation.

Rocks of the thick pelitic sequence overlying the basal metasandstones are characterised by a coarse grain size, a pronounced schistosity defined by mica plates, and an abundance of mesoscopic lineations and fold structures. Like the basement gneisses, there is much variation in the textural and structural features of each rock depending on the original composition and the local tectonic history. Figures 6 and 7 summarize the mesoscopic orientation data measured in the Adelaidean sequence. Similarities in the orientation data measured in the metasandstones and overlying schists and gneisses may be noted (e.g. compare sub-areas R and H with sub-area J).

The most attractive structures within the pelitic schists are the open to moderately tight mesoscopic folds belonging to the  $F_3$  event. These folds show varying degrees of development in different outcrops and are apparently absent in some parts. The style of the  $F_3$  folds and their patchy distribution suggests that they were produced in a rather mild late tectonic event when compared with the intensely compressed nature of the earlier structures. The main schistosity in these rocks can be observed to be an axial surface structure to very appressed, almost isoclinal, folds and to be a highly evolved crenulation cleavage belonging to the  $F_2$  event. No mesoscopic  $F_1$  folds have been identified in these schists, although relics of an earlier schistosity testify to the presence of a possible axial surface structure, equiva-

lent to slaty cleavage, for this earliest tectonic event.

No bedding with stratigraphic significance has been proved within these schists. Lenticular compositional layering, labelled  $S_{11}$ , is observed within the larger exposures, but even the thickest layers are not traceable as bedded units. Attempts to map out lithological units on a larger scale, using compositional and textural variations, have failed. This could be partly due to lack of sufficient continuous exposure. Relics of an early schistosity,  $S_1$ , presumed to be an axial surface structure for the  $F_1$  event, are to be found in many exposures. These relics take the form of an early schistosity acting as the folded surface in some isoclinal  $F_2$  folds, which are usually best preserved in rocks of more quartzose composition, and relics of an early crenulated schistosity in microlithons within the  $F_2$  microstructure in rocks of more micaceous composition. The observation of disc-shaped quartz-sillimanite and staurolite knots lying within the  $S_1$  surface forming the folded surface of  $F_2$  folds suggests that these minerals grew during or after the  $F_1$  event and before the imposition of the  $F_2$  event. No  $B(S_{11}-S_1)$  folds have been identified in the schists. From the scant evidence available it seems that  $S_{11}$  and  $S_1$  were nearly parallel in these rocks, and this could be attributable to a situation on the limb of a large appressed  $F_1$  fold.

The main schistosity in these rocks,  $S_2$ , forms the axial surface structure to tight folds produced in the  $F_2$  event. In some exposures relics of appressed crenulations in  $S_1$  with sharply attenuated hinges are observed within the  $S_1$  microstructure, but transposition of the earlier schistosity has been so great that only rarely are these crenulation hinges preserved. The more fully evolved  $S_2$  microstructure is characterised by a coarse-grained gneissic texture in which quartz and feldspar granoblasts are segregated into thin lenticular plates interleaved with trains of coarse-grained mica flakes. Mica plates comprising the mica trains commonly show a consistent imbricate or echelon stacking arrangement indicative of an evolution of the  $S_2$  microstructure through the concentration and metamorphic segregation of a pre-existing  $S_1$  mica preferred orientation (Fig. 4g). Isolated mica plates within the quartzofeldspathic lenses tend to show a diversity of orientation. Where unaffected by the  $F_3$  event the  $S_2$  surfaces in

rocks south of the reservoir have a mean strike of  $350^\circ$  and dip  $75^\circ$  east.

Folds in compositional layering and  $S_{11}$ , with  $S_2$  as axial surface, are not uncommonly met with, but are less obvious than the later steep plunging  $F_3$  folds. These  $F_2$  folds are tightly appressed and almost isoclinal with thickened hinge regions (Figs. 4c, d, e, f). They are overturned to the west and their hinge lines plunge at variable angles within  $S_2$ . The strong  $S_2$  axial surface structure tends to obliterate the folded  $S_1$  surfaces, especially in rocks containing coarse porphyroblastic knots. A strong lineation  $L(S_1-S_2)$  results from the intersection of the  $S_1$  and  $S_2$  surfaces. This lineation takes the form of a mineral streaking or rodding defined by ellipsoidal shaped granoblasts and mica plates, or is more rarely seen as crenulation hinge lines. The lineation is usually parallel to the axes of  $F_2$  folds in  $S_{11}$  or  $S_1$ , but examples are known where the lineation is more steeply plunging than  $B(S_{11}-S_2)$  fold axes, suggesting that  $S_{11}$  and  $S_1$  were not strictly parallel before the  $F_2$  deformation event. Near the old reservoir road bridge the  $L(S_1-S_2)$  lineation has a shallow north or steep easterly plunge, but further south and west a moderate south-easterly plunge becomes predominant. Cross joints have been developed perpendicular to this lineation. It is not known to what extent this lineation is also a principal axis of strain.

A mild  $F_3$  event occurred late in the metamorphic history producing patchily developed open to tight  $F_3$  folds. These folds are mostly  $B(S_2-S_3)$  folds, but locally  $B(S_{11}-S_3)$  and  $B(S_1-S_3)$  folds may be found. Several examples of the overprinting of  $F_3$  folds on  $F_2$  folds have been observed. The  $F_3$  folds usually have open concentric, boxlike or V-shaped styles, which pass into regular or polyclinal chevron folds in the more strongly deformed exposures (Fig. 5). Mesoscopic folds near the reservoir have wavelengths up to 6 metres, but much larger macroscopic folds, such as the Gumeracha Goldfields antiform, occur in the south. A mapped macroscopic fold in the south-west has a curious irregular form in which  $S_2$  has been folded about an axis plunging  $20^\circ$  to  $153^\circ$ , but the  $F_3$  structures show various anomalous orientations.  $B(S_2-S_3)$  folds plunge steeply north-east to south-east near the reservoir (Fig. 7) and moderately south-east in the Watts Gully region (Fig. 6). Rotation of earlier  $L(S_1-S_2)$  lineations in conical surfaces suggests a

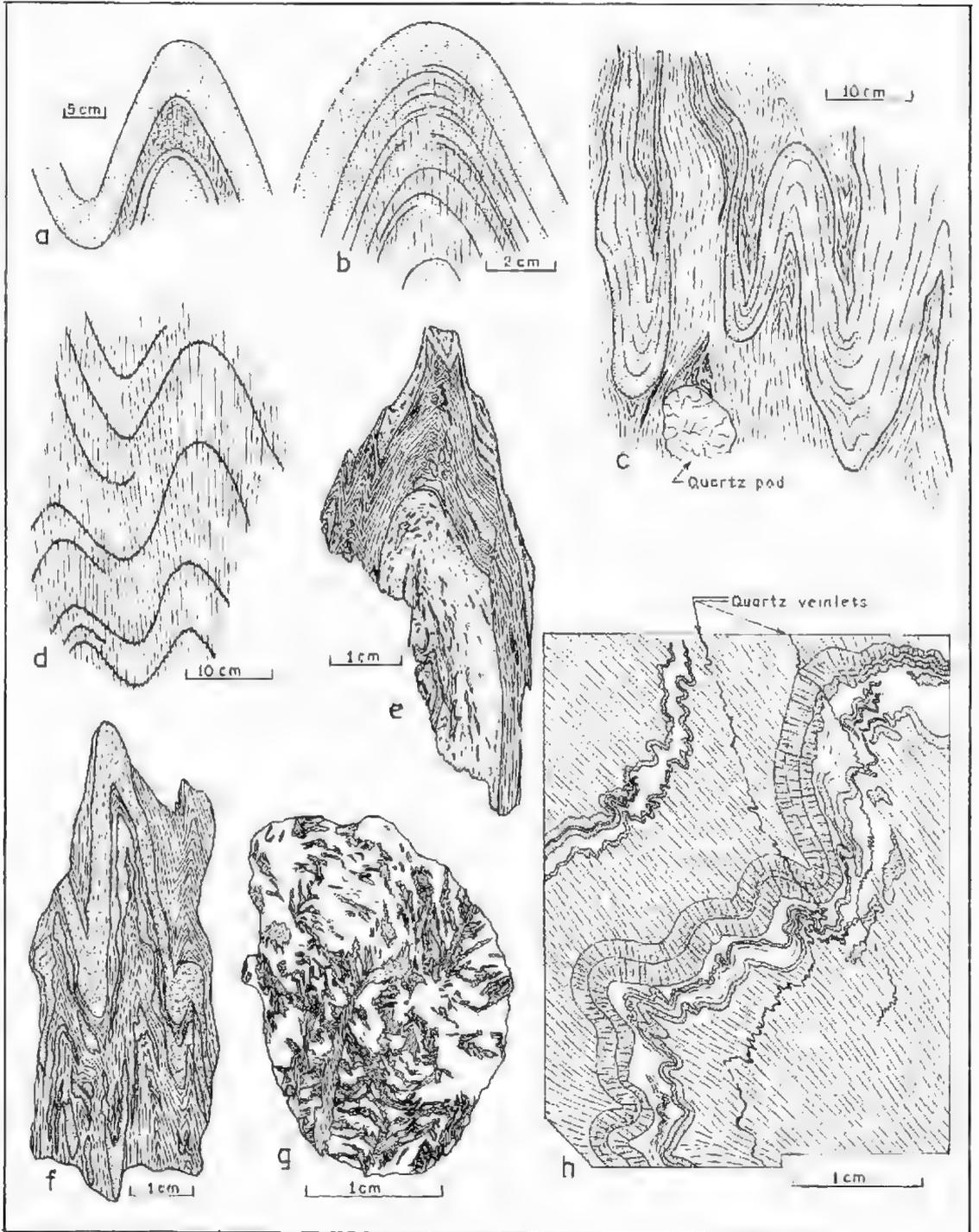


Fig. 4.

flexural slip mechanism. The  $F_2$  folds tend to split along their hinge surfaces on exposure and this is often the only expression of an  $S_2$  axial surface structure. However, in the tightest  $F_3$  folds an  $S_3$  crenulation cleavage has begun to appear.  $F_3$  folds tend to have a polyclinal style with considerable variation in the orientation of their axial surfaces. Near the reservoir the  $F_3$  folds have a left-handed vergence and  $S_3$  axial surfaces vary in strike from NE-SW for open fold styles, to N-S for appressed styles where the  $S_3$  crenulation cleavage has begun to appear (Fig. 7). In the Walls Gully region the folds have a right-handed vergence, the  $S_3$  axial surfaces in the open folds having a NW-SE strike swinging to N-S as the folds become tighter (Fig. 6, sub-areas M, N, O, P, Q). Under the microscope the  $F_3$  folds near the reservoir seem to show a greater degree of healing of both quartz and mica in their hinge regions than do  $F_3$  folds in the west and south-west of the area. This may suggest a slightly higher temperature during the  $F_3$  event in the vicinity of the Mount Crawford granite gneiss. There are a few exposures in which measurements made on late fold structures suggests anomalous orientations, for example, the irregular synform in the south-west. These anomalies may be related to a conjugate  $F_3'$  or an  $F_4$  event.

The Mount Crawford granite gneiss replacing the eastern part of the pelitic sequence contains a pronounced schistosity with the

characteristic gneissic  $S_2$  microstructure of the pelitic schists including the characteristic imbricate stacking arrangement of individual mica plates within the mica trains. A strong lineation, considered to be  $L(S_1-S_2)$ , lies within the schistosity and is defined by elongate mica plates and quartz and feldspar grains. The schistosity has a mean strike of  $349^\circ$  and a dip of  $56^\circ$  east and the lineation plunges  $33^\circ$  to  $149^\circ$  (see Fig. 6, sub-area G). The uniform orientation of the  $L(S_1-S_2)$  lineation is related to the uniform initial orientation of  $S_1$  and  $S_2$  and the fact that the granite gneiss has largely escaped the  $F_3$  deformation event. The granite gneiss would appear to have behaved as a solid block after the main metamorphic peak was reached early in the  $F_2$  event. As a consequence it has escaped the late or post- $F_2$  retrogressive event and the effects of the  $F_3$  deformation. Skialiths of pelitic schists within the granite gneiss have been affected by the  $F_1$  and  $F_2$  events, but not the  $F_3$  event.

Numerous amphibolite dykes of basaltic or doleritic parentage have been mapped in this area (Mills 1963). They are confined to the coarse-grained schist sequence east of the Warren Inlier and also penetrate the granite gneiss. They have a distinctive microstructure made up of a schistosity and strong lineation defined by hornblende prisms. Within dykes cutting the granite gneiss these structures are concordant with the  $S_2$ - $L(S_1-S_2)$  microstructure of the gneiss. Within the pelitic schist sequence both  $F_2$  and  $F_3$  folds have been observed

Fig. 4. Profiles of  $F_2$  folds in Adelaidean succession.

- a.* and *b.*—Moderately tight  $F_2$  folds in metasediments. Note  $S_2$  crenulation cleavage deforming earlier  $S_1$  schistosity in mica-rich layer in *a.* and weak  $S_2$  axial plane structure defined by flattened quartz grains and oriented mica plates in *b.* Traced from photographs. Location 917126.
- c.*—Tight  $F_2$  folds in quartzofeldspathic layers (stippled) in micaceous gneiss of the thick pelitic sequence. Note that an early schistosity ( $S_1$ ) preserved in the quartzofeldspathic layers parallel to the layering is folded in the  $F_2$  deformation. In the micaceous gneiss the  $S_2$  crenulation cleavage has been largely transposed into a new schistosity. Traced from photograph. Location 928116.
- d.*— $F_2$  folds in quartz-feldspar-sillimanite-mica gneiss of the thick pelitic sequence. An early  $S_1$  schistosity, apparently parallel to the primary compositional layering, is almost obliterated by the imposition of the  $S_2$  cleavage axial plane to the folds. Traced from photograph. Location 928117.
- e.* and *f.*—Tight  $F_2$  folds in coarse-grained mica schist containing quartzofeldspathic layers (quartz stippled, mica shaded). An earlier schistosity ( $S_1$ ), outlined by mica plates, is well preserved in both mica-rich and quartz-rich layers ( $S_2$ ). Traced from photomicrographs. Location 934094.
- g.*—Tracing from photomicrograph showing early stage in the development of  $S_2$  mica-rich layers during the process of crenulation of earlier schistosity ( $S_1$ ) in a quartz-biotite-sillimanite schist enclave in the granite gneiss. In the granite gneiss the  $S_1$  structure is largely destroyed but the  $S_2$  gneissosity commonly preserves the characteristic echelon or imbricate arrangement of mica plates. Location 939102.
- h.*— $F_2$  folds in fine-grained quartzofeldspathic bedding laminations (stippled) in dolomitic phyllite. The axial surface structure in the phyllite is a very fine crenulation cleavage (shaded). Note the cross-cutting quartz veinlets which were pygmatically folded in the  $F_2$  deformation. Biotite zone-phyllites west of Williamstown-Meadows Fault. Traced from photomicrograph. Location 890120.

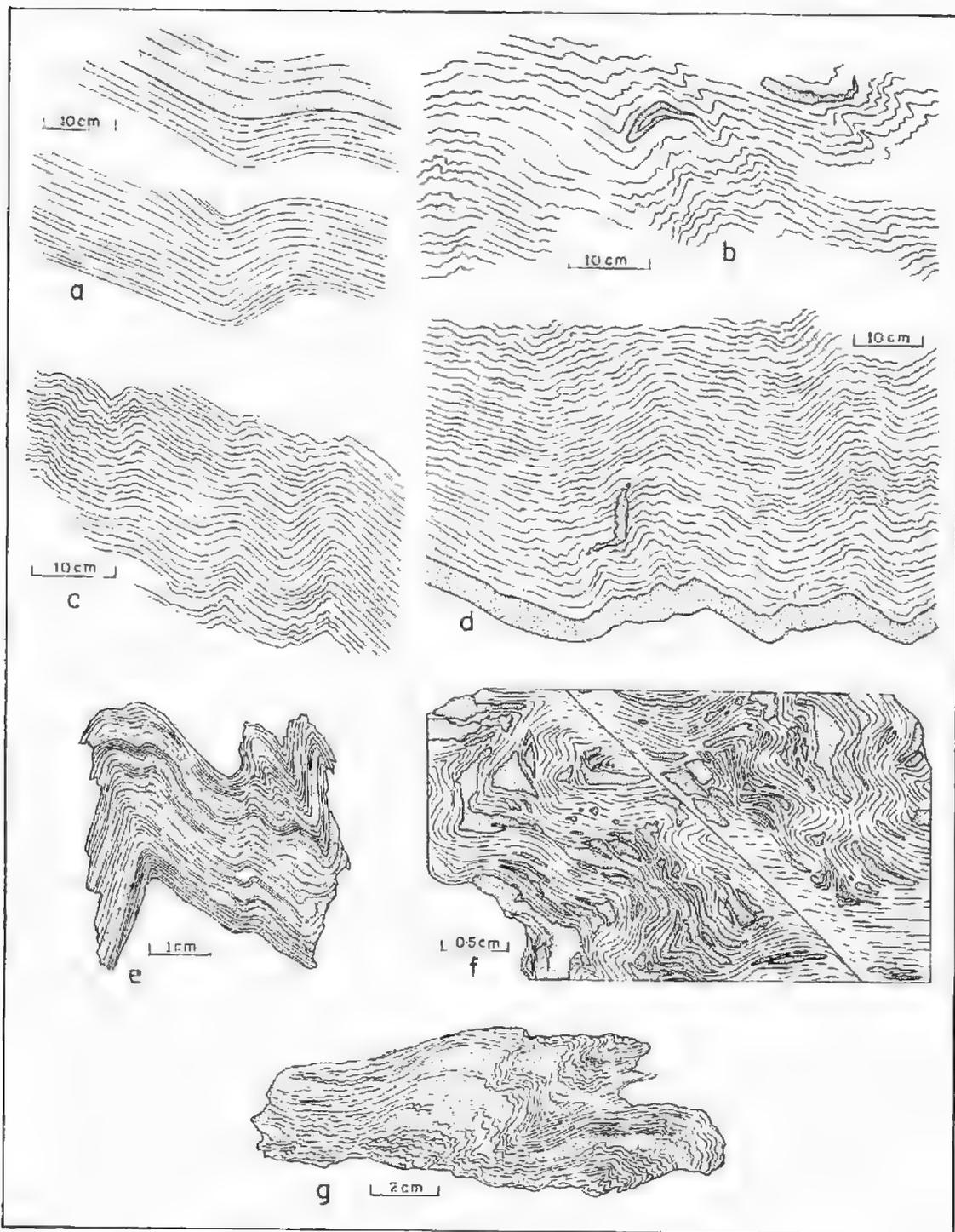


Fig. 5.

within the amphibolite dykes. Some  $F_2$  folds involving amphibolites have been recently exposed on the south side of the reservoir in the cutting for the road leading to the new bridge. The amphibolites were apparently intruded during or prior to the  $F_1$  event.

Veins and pods of pegmatite and quartz are intruded extensively through the pelitic sequence. Some of these were strongly sheared prior to the  $F_2$  event and were subsequently folded in the  $F_3$  and  $F_4$  events, but most of the coarse-grained massive varieties appear to have been intruded after the  $F_2$  event. Some of the smaller pegmatite veins were folded during the  $F_3$  event. Some large tourmaline porphyroblasts were observed to have grown across  $F_3$  structures.

#### *The kyanite-andalusite zone*

Medium-grained biotite-quartz-felspar schists, marbles and calc-silicate rocks belonging to this zone are exposed east and south of the Murray Vale Thrust and between the Ukaparinga and Williamstown-Meadows faults in the north-west. The schists in this sequence are characterised by a simple planar schistosity,  $S_1$ , made up of oriented mica plates which are usually evenly dispersed through the rock. This schistosity is almost parallel to bedding laminations in most exposures and no mesoscopic or macroscopic  $F_1$  folds have been found.<sup>3</sup> Deformation structures related to the  $F_2$  and  $F_3$  events are rarely observed and are only weakly developed. A notable coarsening of grain size, especially of mica plates in mica rich laminae, and the growth of post-tectonic muscovite porphyroblasts occurs low in the

sequence adjacent to the higher grade block and near pegmatite intrusions. This could be due to some late contact heating after thrust sheet emplacement. Pegmatite intrusions of a massive or zoned type are rare and are confined to a few veins running parallel to  $S_1$  immediately east of the Murray Vale Thrust. No amphibolite intrusions are known to cut rocks of this zone.

Bedding, defined by compositional variation, is well preserved on all scales in this sequence and where the exposure is sufficient the beds are found to have great lateral continuity. Stratigraphic facing indicators are rarely observed, but the sequence is considered to dip east and to face east in the east and to dip west and face west in the north-west block, the two areas of exposure representing the limbs of a very large  $F_1$  anticlinal structure. The schistosity  $S_1$ , assumed to be axial surface to the macroscopic  $F_1$  structure, is observed to lie at a small angle to  $S_0$ , usually less than  $10^\circ$  in the more micaceous rocks. This tends to promote splitting along the bedding surfaces of the quartz-felspar-biotite schists to yield slabby blocks which were apparently favoured for building purposes in the early days of settlement. Microscopically the  $S_1$  surface in the schists is defined by the orientation arrangement of biotite plates, which tend to have an even spatial distribution except in strongly knotted schists, where cusped concentrations of biotite plates have grown at the margins of porphyroblasts. These porphyroblasts are mostly retrogressed to fine sericite but contain rare relics of andalusite and kyanite. The size of inclusions in the

Fig. 5. Profiles of  $F_n$  folds in the thick pelitic sequence of the Adelaidean succession.

- a.—Open  $F_3$  folds in mica schist. The main schistosity ( $S_1$ ) is apparently parallel to the compositional layering. Sketch from photograph. Location 928117.
- b.—Polycylindrical  $F_3$  folds in mica schist. Main schistosity is  $S_2$ .  $F_3$  fold outlined by quartz lens has been folded in the  $F_4$  deformation. Traced from photograph. Location 926116.
- c.—Open  $F_3$  folds in micaceous metasandstone. Main foliation is  $S_2$ . Traced from photograph. Location 923109.
- d.—Open  $F_2$  folds in mica schist. Main schistosity is  $S_2$  which appears to be parallel to the quartz-felspathic layer at the base of the diagram (stippled). Note cross-cutting quartz lens. Traced from photograph. Location 926117.
- e.—Tight  $F_2$  folds in quartz-felspar-mica gneiss. Main schistosity is  $S_2$ . Traced from photomicrograph. Location 929119.
- f.—Disharmonic  $F_4$  folds in mica-quartz gneiss (quartz stippled, mica shaded). Main schistosity is  $S_2$ . Note late cross-cutting fault. Traced from photomicrograph. Location 918060.
- g.—Tight  $F_3$  folds in quartz-muscovite gneiss showing incipient development of  $S_3$  crenulation cleavage (quartz stippled, mica shaded). Main schistosity is  $S_2$ . Traced from photomicrograph. Location 933118.

<sup>3</sup> Owing to differences in the structural development in the high and low-grade sequences the correlation of mesoscopic structures is a matter of conjecture. The author has adopted the simplest correlation compatible with his present knowledge of the area.

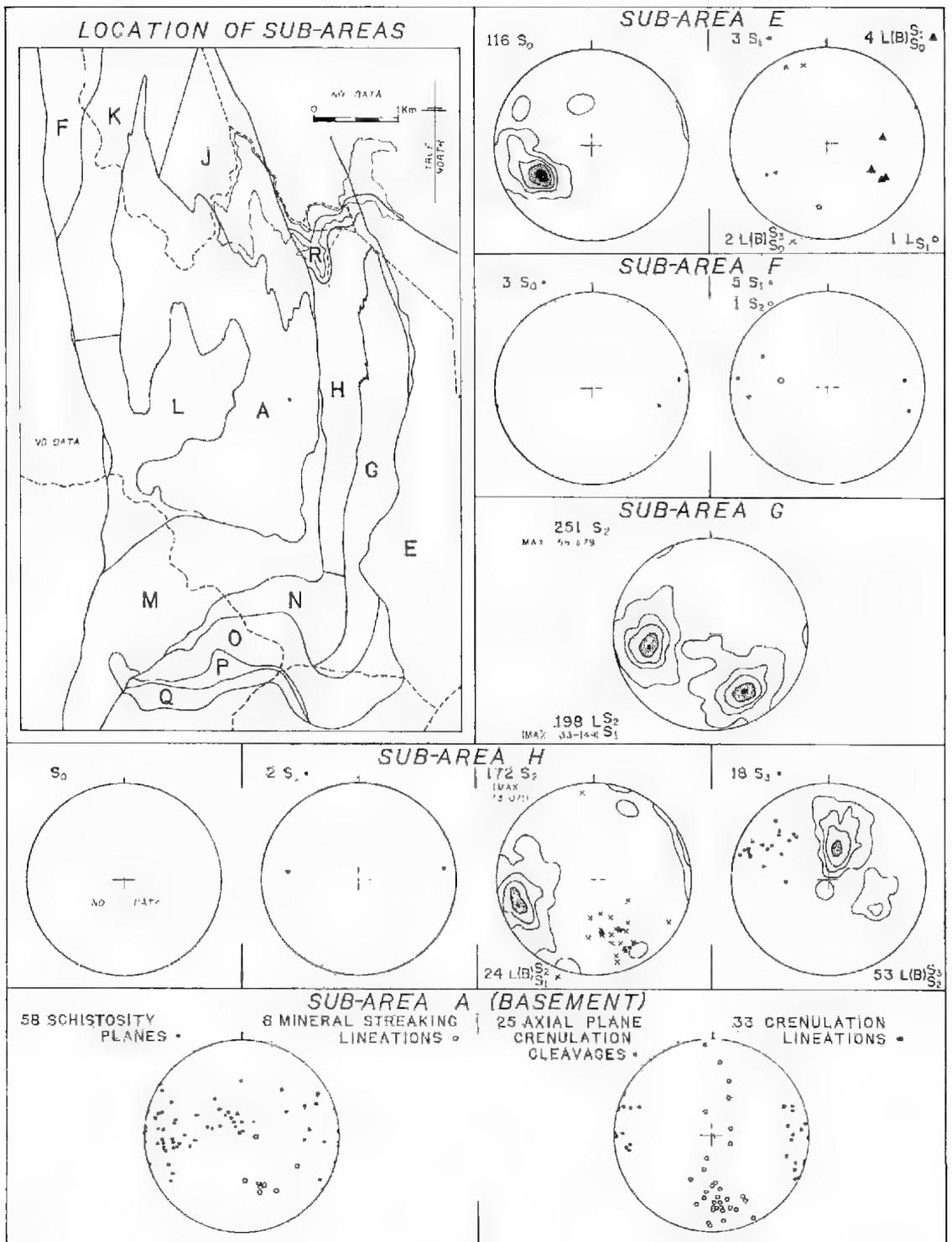


Fig. 6.

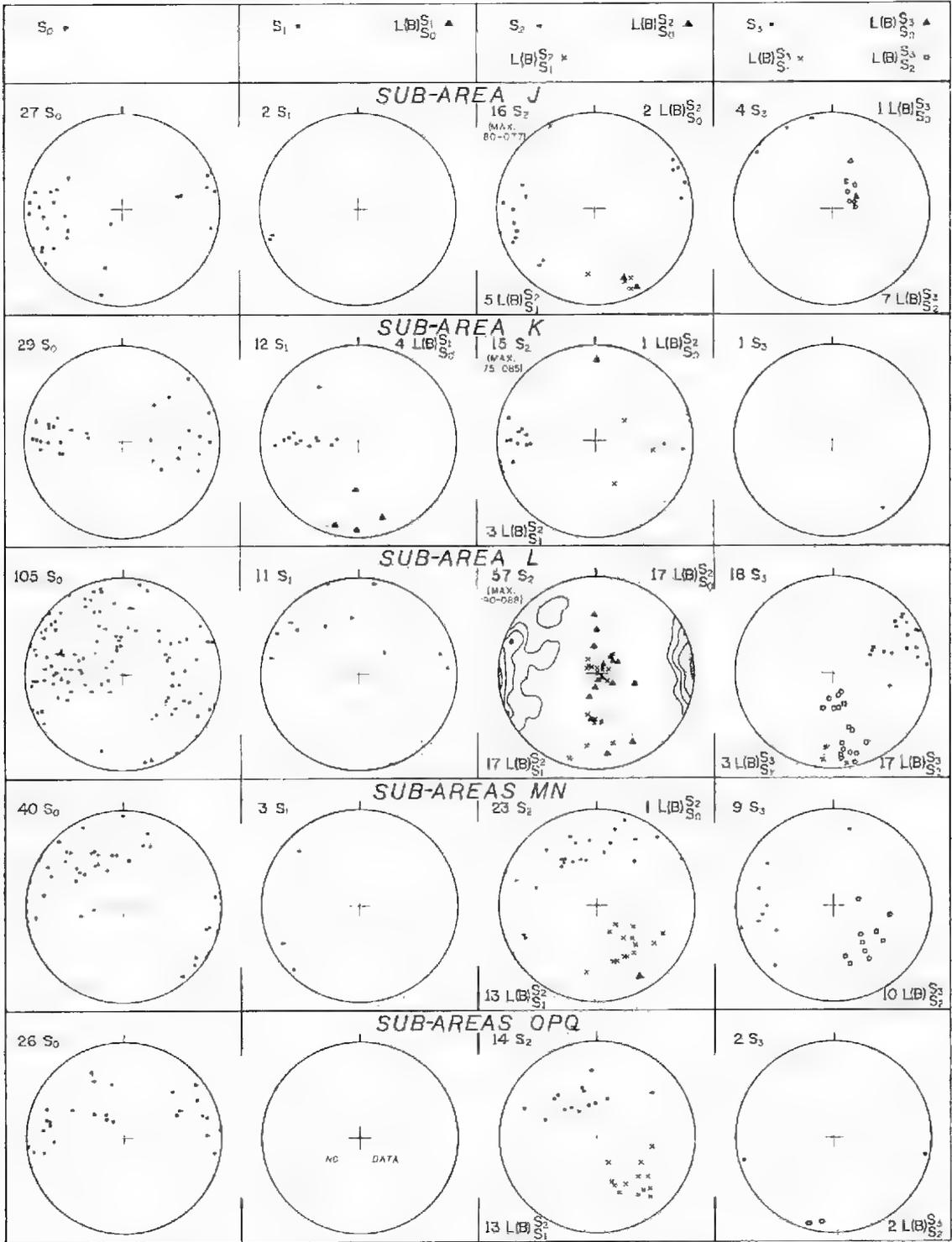


Fig. 6. Lower hemisphere equal area projections of structural elements measured in all sub-areas shown in the inset figure except sub-area R. True north at top of diagrams. Contours at 0.5, 5, 10, 20, 30% per 1% area.

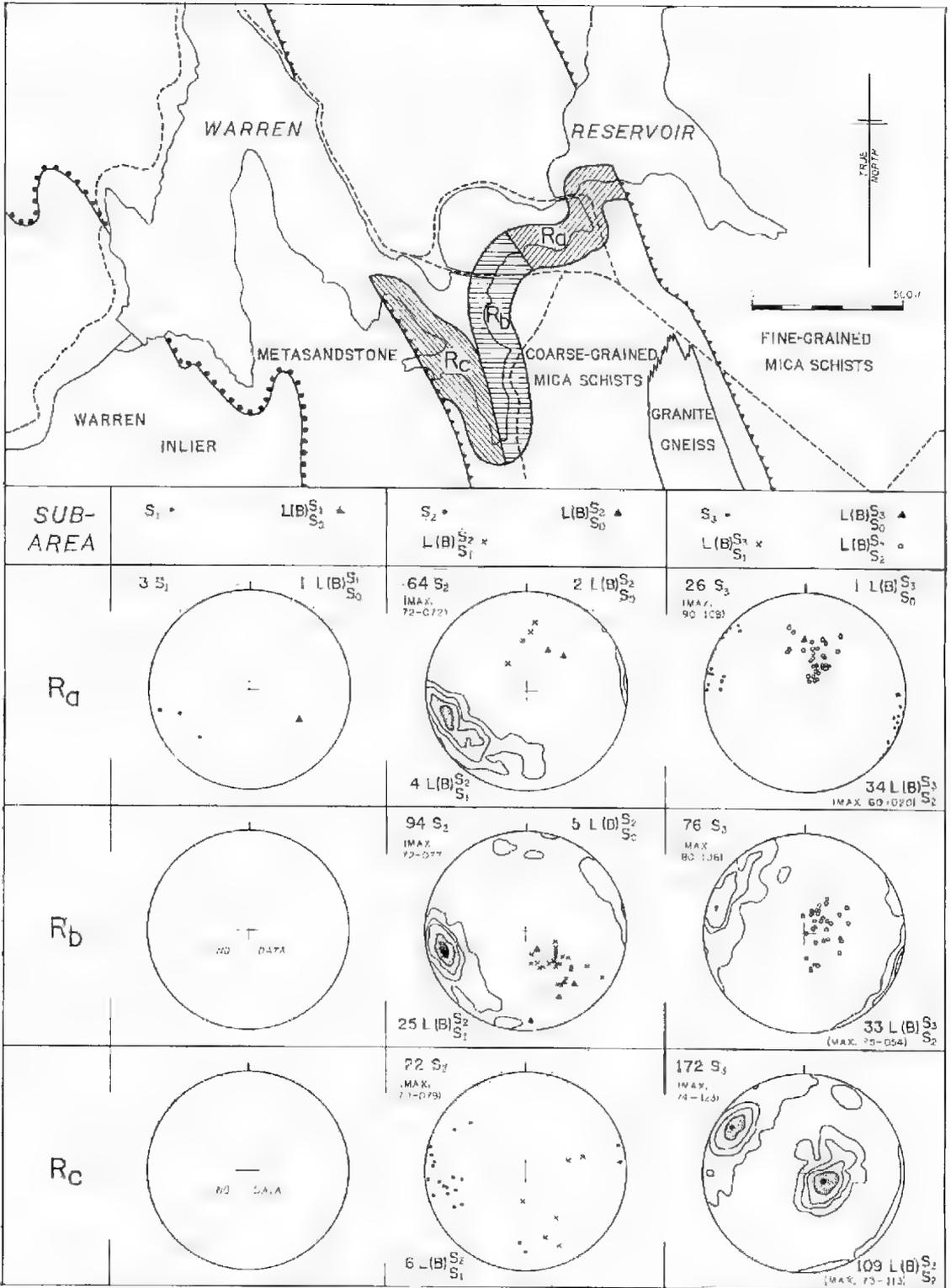


Fig. 7. Lower hemisphere equal area projections of structural elements measured in coarse-grained Adelaidean schists of sub-area R. True north at top of diagrams. Contours at 0.5, 5, 10, 20, 30% per 1% area.

porphyroblasts in relation to matrix grain size indicates growth during and after the  $F_1$  deformation event. In other rocks ellipsoidal quartz, feldspar and carbonate crystals, and the long axes of amphibole prisms, may define  $S_1$ . A moderate quartz c-axis fabric has been noted in some specimens of quartzofeldspathic schist and an early quartz veinlet cutting the  $S_1$  surface of a quartz-feldspar rich schist in the north-west block was observed to be recrystallised and to have a strong quartz fabric in which most c-axes were aligned within the  $S_1$  surface.

A faint to strong mineral streaking lineation is notable within the  $S_1$  surfaces of some exposures. This lineation is defined by elongate mica plates and porphyroblastic knots in schists and by amphibole prisms in calcareous rocks. A set of cross joints is commonly seen to lie perpendicular to this lineation. In the mica schists the lineation is defined by a combination of two effects. Firstly the mica plates are up to twice as wide parallel to (001) in the direction of the lineation than they are across it, the biotite plates being considerably more stumpy in form than associated muscovite plates. Secondly the mica plates are much more diversely oriented in sections cut perpendicular to the lineation than they are in sections cut parallel to it; that is, the mica plates are tautozonally arranged about the lineation axis. In the absence of suitable strain markers in the present area it is not possible to determine whether this lineation is due to the mimetic growth of crystals in lines of bedding-cleavage intersection,  $L(S_0-S_1)$ , or is a tectonic strain lineation,  $L(S_1)$ , developed during metamorphic mineral growth. The penetrative nature of this lineation in many rocks, and strain shadow effects around syntectonic porphyroblasts, favours the latter.

No mesoscopic  $B(S_0-S_1)$  folds have been observed. In some schists in the north-west block a mild crenulation in the  $S_1$  surface, showing syntectonic crystallisation of the mica plates in the crenulation hinges, suggests effects of the  $F_2$  event. Some mesoscopic  $F_2$  folds of hand specimen size have been found as float in the north-west block, but they are apparently quite rare. These folds show  $S_1$  parallel to  $S_2$  folded into V-shaped styles with planar limbs, well defined hinge regions and thickened noses.

Likewise the effects of the  $F_3$  event are weakly developed in this sequence. The

Gumeracha Goldfields antiform in the south-east has macroscopically flexed the  $S_{11}$  and  $S_1$  surfaces, but otherwise, only occasional box-like post-crystalline crenulations, showing strong strain effects in the minerals of their hinge regions, are considered to belong to the  $F_3$  event.

#### *Biotite zone*

West of the Williamstown-Meadows fault line fine-grained impure dolomites, dolomitic phyllites, phyllites and phyllitic slates belonging to the biotite zone are also characterised by multiple deformation. Evidence for three overprinted deformation phases can be recognised in some exposures and provisionally equated with the  $F_1$ ,  $F_2$  and  $F_3$  events. These rocks have a very fine grain size, quartz and micas averaging 0.01-0.015 mm, and invariably have a strong  $S_1$  slaty cleavage fabric defined by the shapes of carbonate grains and the parallel orientation of muscovite and biotite plates. "Strain shadows" are present around some opaque minerals. The c-axes of quartz grains possess a strong orientation in the  $S_1$  fabric of some phyllites, with most c-axes tending to lie in the  $S_1$  surface.  $S_1$  is seen to lie at large angles to  $S_0$  in some exposures and broad hinge regions of  $B(S_0-S_1)$  folds are present.  $S_0$  is usually well defined by compositional layering or lamination.

At 890120 well developed finely spaced strain-slip or crenulation cleavage,  $S_2$ , was observed in phyllite. Microlithons between the crenulation cleavage planes are about 0.3 mm in width. The  $S_1$  cleavage within the microlithons is bent into the  $S_2$  crenulation cleavage surfaces and this process is accompanied by an increase in mica content within the  $S_2$  surfaces. Apparent displacement on the  $S_0$  surfaces crossing the phyllite is not represented as displacement in cross-cutting quartz veinlets, but as sharp monoclinical folds with attenuated limbs crossing the  $S_2$  surface. Where  $S_2$  is developed, mesoscopic  $B(S_0-S_2)$  folds are observed in the bedding (Fig. 4h). Quartzose layers are buckle folded, white carbonate-rich laminated phyllite layers are strain slipped. The folds are disharmonic on all scales, but the  $S_0$  surfaces tend to have a constant orientation. Thin quartz stringers were seen to have been pygmadically folded on a microscopic scale in the  $F_2$  event. Later more brittle kink folds are rarely observed and might be attributable to a weak  $F_3$  event.

## FAULT STRUCTURES

### *Thrust faults*

Several thrust sheets have been mapped in the present area on the basis of metamorphic and structural discontinuities. These thrust sheets were emplaced during or after the  $F_2$  event and were subsequently folded in the  $F_3$  event. Four principal thrusts are named. The Wirrianda Thrust, passing near "Wirrianda" homestead situated on the southern shore of the reservoir; the Watts Gully Thrust, passing close to the site of the richest gold discoveries in the Gumeracha Goldfields; the Sanctuary Thrust, largely confined to the flora and fauna sanctuary in the south-west; and the Murray Vale Thrust, named after the pastoral property south-east of the headquarters of the Mount Crawford State Forest. The last three named faults appear to be hinged near the southern margin of the mapped area. The opalised tremolitic rock bed at the contact of the metasandstone and the coarse-grained schist sequence has proved to be a useful marker horizon in the identification of sequence repetition in the thrust sheets. There are no proven natural exposures of the thrust fault surfaces in the area, and critical thrust sheet interplay, particularly in the south-west, is obscured by alluvium and poor outcrop. There is some evidence from the study of the mesoscopic orientation data that the higher sheets rotated clockwise over the lower sheets in the south-west corner of the area. This may be the result of rotation during the thrusting movements or differential rotation of the sheets in the subsequent  $F_3$  event. Numerous exposures of sheared and mylonitic gneisses in the thick pelitic sequence are thought to have been developed during the thrusting movements.

On the northern slopes of the reservoir the Wirrianda Thrust is marked by a sharp contact between metasandstone and coarse-grained micaceous gneisses. South of the reservoir the sandstone cuts out and the basement gneisses are brought into contact with the schists and gneisses of the Adelaidean sequence. Although exposure is fairly good here, similarities between rock types and the overprinting of mesoscopic  $F_2$  folds from the Adelaidean schists into the basement rocks have obscured the actual fault surface. Further south the upper section of the metasandstone unit reappears but the fault zone is everywhere obscured by soil cover. North of Watts Gully the fault line follows the bottom of a steep V-shaped valley and its actual path across the

metasandstone further to the south-west has not been identified, but it is assumed to eventually run into the Williamstown-Meadows Fault.

Structural evidence in support of the Watts Gully Thrust is obtained from an area of moderate exposure near the centre of the patch of virgin scrubland of the flora and fauna reserve south-west of Dead Horse Gully. Here considerable discordance exists between structures on either side of the mapped fault trace, and a narrow splinter of pebbly micaceous metasandstone appears to lie within the fault zone. The Watts Gully Thrust is also responsible for a repetition of the stratigraphic sequence. Near Watts Gully the fault trace can be followed as a junction between schists and metasandstone and is marked in places by a distinctive white albite rich rock, which may carry talc or actinolite crystals. Under the microscope this rock is largely composed of well-crystallised untwinned plagioclase with a composition near pure albite, carrying occasional rutile inclusions. Some interstitial quartz grains with slightly undulose extinction are dispersed through the albite. Scattered muscovite plates, preserving a microstructure like that of  $S_2$  in the pelitic schists, are strongly bent and are encased or adjoined by the unstrained post-tectonic albite.

The Sanctuary Thrust is of limited extent and is defined on the basis of a repetition of a belt of metasandstone above pelitic schists. The fault trace is also marked in a few places by a peculiar white albite rich rock similar to that described above.

Movements on the Murray Vale Thrust were of greater magnitude than those on the underlying thrusts and resulted in the conjoining of rocks of markedly differing metamorphic and structural character, as described in previous sections. Exposures of rocks near the thrust surface are very rare, and for most of its length the thrust line is marked by a conspicuous strip of soil cover. In the field the position of the thrust has been placed on the basis of the readily mapped distinction between the coarsely crystalline rocks of the sillimanite-muscovite zone and the medium to fine-grained schists of the andalusite-kyanite zone. Much of the eastern margin of the granite gneiss has been reinterpreted as the thrust surface. The banks of a road cutting on the improved section of the main road south of the reservoir, about half a kilometre north of the headquarters of the Mt Crawford

State Forest, expose rocks on either side of the Murray Vale Thrust. Fine-grained schists and the thick opalised tremolite rock bed lie in conjunction with weathered amphibolite and coarse-grained mica schists with intrusions of pegmatite. The faulted contact is marked by a narrow zone of green clay-like pug.

The Murray Vale fault line has been superficially traced north of the reservoir where it is marked in a few places by a sugary white albite rock containing green actinolitic spots. After passing through a left-handed displacement, probably a large  $F_2$  fold, it traverses the centre of the large quarry excavated for clay and sillimanite. Near the base of the quarry the fault zone is seen to be less than half a metre in width and filled with pale greenish clay-like pug. The fault surface dips easterly at about  $70^\circ$  with some irregularities caused by open  $F_2$  folds. On either side of the fault extensive shearing, especially in the higher grade rocks to the west, has resulted in the formation of the unique Williamstown damourite schists containing kyanite and corundum, massive sillimanite pods and clay deposits. The clay deposits seem to be related to late stage alteration within the fault zone. West of the fault are a variety of high grade gneisses showing less alteration to clay away from the fault surface. Fine-grained lower grade schists are exposed east of the fault. Some are very fine-grained pyritic schists which are extensively altered to clay near the fault, although still preserving fresh pyrite cubes near the base of the quarry. Some open folds, presumably of the  $F_2$  event, are visible in the lower grade rocks. North of the quarry the Murray Vale Thrust probably passes through another large  $F_2$  fold resulting in the appearance of fine-grained quartz-felspar-biotite schists displaying open shallow north-plunging  $F_2$  folds in small quarries north of the forked junction of the roads leading to "Springfield" and the Australian Industrial Minerals quarry.

#### *The Ukaparinga Fault*

The Ukaparinga copper prospect in the north-west corner of the area is situated within the brecciated zone of a major metamorphic and structural discordance, herein named the Ukaparinga Fault. Displacement on this structure must be at least as great as that on the Murray Vale Thrust, but it is uncertain as to whether this fault should be grouped with the pre- $F_2$  thrusts or is a branch of the

nearby post- $F_2$  Williamstown-Meadows Fault, which it joins a little south of the South Para River. A little to the west of the Ukaparinga Fault, a parallel fault line has been traced on the ground in an area of moderate exposure of the schists of the kyanite-andalusite zone sequence, but its importance as a fault structure has not been determined.

#### *The Williamstown-Meadows Fault*

An important fault line, separating fine-grained biotite zone rocks from coarse-grained amphibolite facies rocks, can be traced in a north-south direction on the western side of the area. In earlier literature this fault has been referred to as the Kitchener Fault, but as it appears that this name is based on a misconception, and since the author has been able to follow the path of this fault as a continuous line from well north of Williamstown to well south of Meadows, the name Williamstown-Meadows Fault is preferred.

Within the present area the actual fault zone, along most of its length, appears to be very narrow and sharply defined, although some exposures of tectonically emplaced foreign blocks lying within the fault zone have been shown on the map as fault melange. Where the fault line crosses deeply incised valleys, a steep easterly dip of about  $60-70^\circ$  has been estimated for the fault surface at several points. This would suggest that the fault is of the steep reverse type, but unlike the thrusts described earlier, movement occurred after the  $F_2$  folding episode.

A narrow zone of brecciated phyllite marks the fault zone at one exposure north of the South Para River. South of the river fine-grained dolomites are brought against the fault surface in several places and close to the fault these rocks have been recrystallised to medium-grained white dolomitic marbles containing large plates of muscovite and talc and minor amounts of quartz and felspar granoblasts and an opaque accessory. The equigranular hornfelsic texture and the partially dissolved nature of twin relics within the carbonates suggests that these marbles were affected by some form of contact metamorphism. It seems that the higher grade hanging wall block was still sufficiently warm during and after the fault displacement to contact metamorphose the impure dolomites near the immediate contact with the fault surface.

In the south-western corner of the Warren National Park float and outcrop of felspathic

and micaceous schists and gneisses of foreign textural appearance, opalised tremolitic marbles and metasandstones testify to the presence of a melange lens within the fault zone. A further lens containing peculiar mica-rich schists defines the fault zone separating metasandstones from dolomitic phyllites almost half way between this locality and the South Para River. The microstructural features of the schist blocks within the fault zone can be provisionally correlated with the  $S_0$ ,  $S_1$  and  $S_2$  structures of the area. The metamorphic grade of these schists seems to be that of the upper greenschist or lower amphibolite facies. A small staurolite crystal was found in a specimen of biotite-rich schist. Apart from some kinking and bending of mica plates and quartz grains and the introduction of thin stringers of potash feldspar, the fault movements appear to have had little effect on the structure of these schists, and the faulting appears to have occurred when the metamorphic temperatures were too low to permit any significant recrystallisation.

The amount of displacement on this fault must be very large judging from the metamorphic differences between rocks on either side of the fault surface. Miles (1950) suggested a minimum displacement of 5,000' with a probable displacement of about 10,000'. Displacement of the order of 3 to 5 thousand metres does not seem incongruous, but a better estimate of the amount of displacement must await a more detailed study of the stratigraphic and metamorphic relationships along most of its length.

Earlier workers (Miles 1950; Sprigg 1945) have considered the possibility of Tertiary to Recent movements on this fault, the evidence for this being based on the marked fault scarp expression and the occurrence of erosional surfaces and gravel beds of supposed Tertiary age west of the fault line near Williamstown. However, hills composed of Adelaidean bedrock in the south-west of the present area are at the same height on either side of the fault line, and there is no evidence of recent rejuvenation on the fault surface. The fault scarp is believed to be due to the erosive power of the South Para River and its tributaries removing the more readily disintegrated biotite zone phyllites and dolomites west of the fault, after crossing the resistant Warren Inlier and its mantle of metasandstones and schists. This erosional scarp was probably in existence during the formation of the Tertiary

gravels and lateritic surfaces near Williamstown, with the Warren Inlier and its surrounding mantles of high-grade rocks protruding above the Tertiary erosion levels.

## CONCLUSIONS

### (1) Basement-Adelaidean relationships

Howchin (1906, 1926) clearly recognised the existence of basement rocks in the gorge of the South Para River, south of Williamstown, and claimed that an unconformity separated the basement from the underlying metasandstones of Aldgate Sandstone type. Hossfeld (1935) claimed to have recognised an actual exposure of the unconformity near the Warren Reservoir weir, but this could not be confirmed in the present study. Later workers (Campana 1953; Mills 1963) failed to recognise a basement inlier. Campana apparently regarded the lowest schists as metasomatic alteration products of the Aldgate Sandstone equivalent and Mills interpreted the schists below the metasandstone as an early Adelaidean pelitic sequence. The present study has confirmed Howchin's claim for the existence of a basement inlier. Marked structural discontinuity across the observed unconformity surface discounts the possibility of an early Adelaidean pelitic sequence. The coarse-grained schists and gneisses above the metasandstone unit lithologically resemble the basement gneisses, but they contain mesoscopic structures which may be correlated with analogous structures in the metasandstone unit and not with structures in the basement gneisses.

In the nearby well-established Houghton Inlier, Spry (1951) showed that schistosity in the basement and in the Adelaidean mantle were generally parallel. The schistosity in the basement was interpreted as a retrograde schistosity which was associated with the Palaeozoic folding of the Adelaidean succession and updoming of the basement, although there was some evidence (Spry 1951, p. 120) for shearing of the basement prior to Adelaidean sedimentation. Campana (1955) suggested that movements in the basement of the Adelaide region were responsible for the folding of the Adelaidean sedimentary mantle, the lower beds of which were consequently adjusted into tight folds characterised by sharply overturned anticlines, with attenuated limbs grading into overthrusts and broad corrugated synclines. Talbot (1962)<sup>1</sup> carried out an extensive study of the southern part of

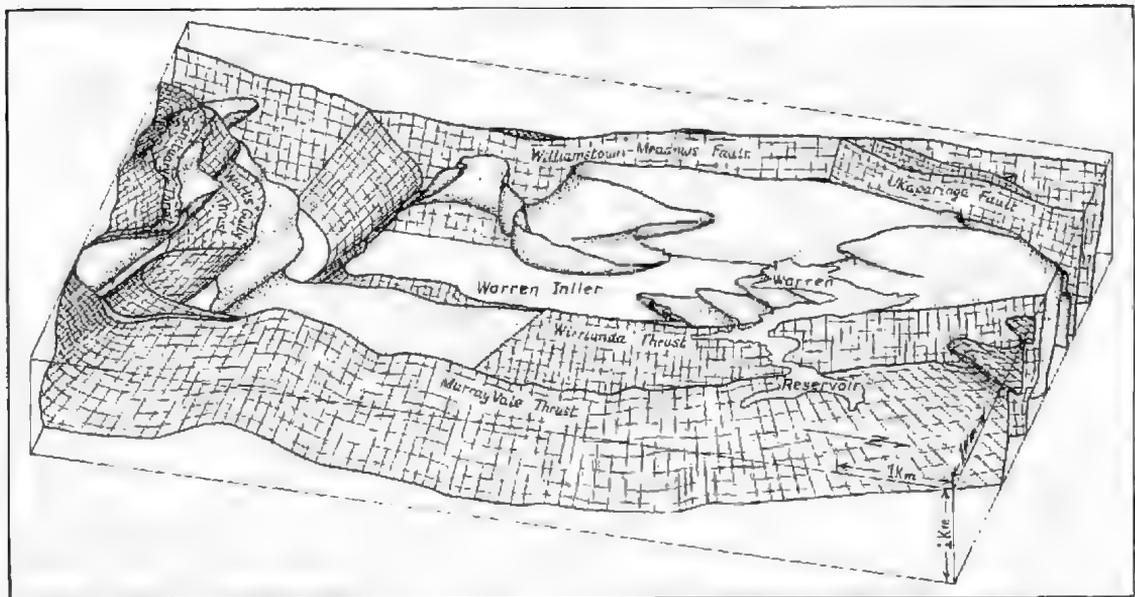


Fig. 8. Block diagram constructed to scale in orthographic projection on a line of sight plunging  $35^\circ$  towards  $253^\circ$  showing the forms of the principal structural surfaces in the vicinity of the Warren Reservoir. The structural surfaces shown are the thrusts and faults (cross-hatched), unconformity between the basement rocks of the Warren Inlier and the Adelaidean sequence and the top of the Aldgare Sandstone equivalent (stippled). The surface of the block corresponds to the high water level in the Warren Reservoir but detailed adjustment to the map pattern to allow for topographic variations have not been made. The  $F_1$  synform outlined by the unconformity in the centre of the diagram is overprinted by macroscopic  $F_2$  folds, and other  $F_2$  folds are seen near the Warren Reservoir. The structural surfaces are folded by large  $F_3$  folds in the southern part of the diagram and lesser  $F_3$  folds are interpreted to deform the Murray Vale Thrust to the north of the reservoir.

the Houghton Inlier and its Adelaidean mantle and considered that the chlorite grade basement "acted as a simple core structure and adjusted to the folding of the overlying Torrens Group" by passive movement along foliation planes produced in a pre-Adelaidean retrogressive phase.

The present study has established that the lower portion of the Adelaidean succession is welded onto the basement rocks of the Warren Inlier and that the basement rocks were rejuvenated during the deformation events and the extensive metamorphic recrystallisation which affected the overlying Adelaidean sediments during the lower Palaeozoic Delamerian orogeny. The surface of unconformity has been infolded into the basement gneisses and there is little evidence of any differential movement at the boundary between the basement rocks and the overlying sedimentary mantle. The basement rocks of the Warren Inlier have undergone a partial tectonic reconstitution in which the lower Palaeozoic folds were imposed on the older pre-Adelaidean structures.

## (2) Folding of the Adelaidean succession

Regional studies in the Mt. Lofty-Olary orogenic arc have indicated that the upper Proterozoic (Adelaidean) and lower Palaeozoic successions were affected by only a few gentle epirogenic episodes (Sturtian tectonism, Duttonian folding, Cassinian and Waitpingan movements) prior to a major orogenic revolution (the Delamerian Orogeny) in lower Ordovician time (Thomson, in Parkin 1969). This orogenic cycle brought about extensive fold deformation, created a belt of low to intermediate pressure metamorphism and granite intrusion, and brought an end to geosynclinal sedimentation in the Mt. Lofty Range region. The syntectonic Palmer granite, intruded into the core of the metamorphic belt in the eastern Mt. Lofty Ranges, has been isotopically dated at 490 million years (White, Compston & Kleeman 1967).

Detailed structural studies in several key areas in the Mt. Lofty Ranges has established that three important episodes of fold deformation took place at various stages during the

metamorphism. Offler & Fleming (1968) synthesized previously published and unpublished work relating to the deformational and metamorphic history of the Mt. Lofty Ranges and assumed that each of the three folding episodes ( $F_1$ ,  $F_2$  and  $F_3$ ) were synchronously developed across the whole deformed belt, but it seems that more key areas will need to be analysed before this premise can be verified and a satisfactory unravelling of the deformational history is achieved.

The present structural study of the upper Proterozoic rocks around the Warren Inlier has established that three distinct tectonic episodes involving fold deformation have occurred in succession in relation to metamorphic recrystallisation.

#### *F<sub>1</sub> deformation*

Bedding surfaces ( $S_0$ ) of the Adelaidean succession were deformed into large regional folds during recrystallisation of the sediments under conditions of rising metamorphic temperatures and mica plates and other metamorphic minerals, grown or deformed syntectonically, developed a strong axial surface schistosity fabric ( $S_1$ ) containing an inter-related axis of elongation,  $L(S_1)$ , which is expressed as a mineral streaking lineation in some exposures. The commonly observed near parallelism of  $S_0$  and  $S_1$  suggests that these early folds possessed an isoclinal style with extensive near planar limb areas. Mesoscopic  $F_1$  folds are apparently rare and difficult to identify, and little can be deduced from the initial geometry of the  $F_1$  deformation within the confines of the small area studied. Structural analysis of the bedding attitudes in the basal metasandstone suggested that the hinge lines of macroscopic  $F_1$  folds were gently plunging or subhorizontal and it can be assumed from regional studies elsewhere in the ranges that the hinge surfaces of the  $F_1$  folds were dipping steeply east and striking north-south parallel to the trend of the orogenic belt (Offler & Fleming 1968). The regional structure which Campaña *et al.* (1955) named The Lookout Tower overturned anticline can be considered to refer to the domal structure comprising the culmination of the Warren Inlier, although this culmination is the combined resultant of the  $F_1$ ,  $F_2$  and  $F_3$  folding events.

Textural-mineralogical evidence suggests that metamorphic temperatures had reached a peak by the end of the  $F_1$  deformation, or during

the interkinematic period between the  $F_1$  and  $F_2$  events and the marked metamorphic zonation observed in this area was impressed at this time. In the higher grade schists the mica and quartz grains defining the plano-linear  $S_1$ - $L(S_1)$  fabric had developed a coarse grain-size and sillimanite fibres and prisms had grown within the  $S_1$  surfaces prior to the commencement of the  $F_2$  deformation. Despite high-grade metamorphism sedimentary clasts and textures are still preserved in most specimens of the coarser arenites, even in specimens exhibiting a strong  $S_1$ - $L(S_1)$  fabric. In those metasediments assumed from their composition to have initiated as pelites and semi-pelites recrystallisation and grain growth has obliterated all signs of sedimentary structures in the coarser grained rocks of the sillimanite-muscovite zone, but thin bedding laminations are preserved in the finer grained schists of the kyanite-andalusite and biotite zones.

#### *F<sub>2</sub> deformation*

This deformation episode commenced at or near the peak of metamorphic temperature, allowing recrystallisation and grain growth processes to become dominant over strain preservation in some rocks, and allowing the  $F_2$  strain effects to outlast grain growth in others. The results of the  $F_2$  deformation are expressed in two principal forms:

- (1) The development of intensely appressed folds in the earlier  $S_0$  and  $S_1$  surfaces and the imposition of a strong crenulation cleavage-schistosity ( $S_2$ ) with a north-south strike and a steep easterly dip, and
- (2) the development of major late-metamorphic thrusts which now divide the area up into several distinct structural-metamorphic zones.

The penetrative effects of the  $F_2$  deformation are most pronounced in the coarse mica-rich schists and gneisses of the sillimanite-muscovite zone where intensely deformed isoclinal folds in lithological layering have a well-developed crenulation cleavage ( $S_2$ ) (crenulation of the  $S_1$  schistosity) grading into a new coarse-grained schistosity as an axial surface structure. In many exposures the  $S_2$  schistosity has become the dominant penetrative structure and traces of the former  $S_1$  schistosity are preserved only in the form of a strong mineral streaking lineation  $L(S_1-S_2)$ . The Mount Crawford granite gneiss formed during the  $F_2$  deformation and preserves a well-developed  $S_2$  schistosity and a constantly oriented mineral lineation interpreted as the

$L(S_1-S_2)$  intersection lineation. Basic dykes, intruded before or during the  $F_1$  event, recrystallised to schistose amphibolites preserving a strong amphibole prism lineation, which is interpreted as the result of mimetic growth of hornblende prisms parallel to the  $L(S_1-S_2)$  intersection lineation.

The effects of the  $F_2$  deformation are less pronounced in the metasediments, and, although  $F_2$  crenulations are well developed in the more mica-rich varieties, intergranular movements were probably dominant. Mesoscopic  $F_2$  folds in the metasediments show strong appression and flattening of the quartz grains into the  $S_2$  surface. In some areas some of the plastic strain induced in the arenites during the  $F_2$  deformation outlasted recrystallisation and strain relief, leading to the development of well-orientated quartz  $c$ -axis fabrics.

In the lower grade kyanite-andalusite and biotite zone blocks the  $F_2$  deformation is not so apparent and the  $S_2$  crenulation cleavage is only locally evident, although some local  $F_2$  mesoscopic folds are to be found and show a similar tight appression.

The  $F_2$  deformation culminated in the appearance of several steep thrusts and mylonitic zones involving considerable, but as yet unknown, amounts of displacement.

Following the  $F_2$  deformation, a second static interkinematic period is envisaged in which the strain preservation from the  $F_2$  deformation became relieved under greenschist facies conditions resulting in the extensive retrogression of higher grade minerals to quartz, albite, chlorite, sericite and rutile. The sericite has undergone patchy regrowth to larger randomly orientated muscovite crystals. The growth fabrics of these late stage minerals tend to be isotropic except where they were mimetically controlled.

#### *F<sub>3</sub> deformation*

Most parts of the area covered in the present survey were affected by a rather more brittle deformation late in the metamorphic history resulting in macroscopic and mesoscopic folds in earlier structural surfaces. The  $F_3$  deformation is more pronounced in certain zones.  $F_3$  folds are rounded to angular and

show varying degrees of appression, ranging from open warps with east-west hinge surface trends to tight folds with north-south hinge surface trends and a weakly developed crenulation cleavage ( $S_3$ ). Both the hinge surfaces and the hinge lines show considerable variation in attitude. Minerals grown during the earlier retrogressive metamorphism became deformed during  $F_3$  folding and show signs of both plastic and brittle strain. The preservation of such fine  $F_3$  strain features as quartz deformation lamellae suggests that very little crystal recovery took place after the  $F_3$  event.

The fold deformational history outlined above is in general accord with the conclusions of other structural studies carried out in the Mt. Lofty Ranges (Offler & Fleming 1968). At this stage it seems valid to correlate the present results with those from the Pewsey Vale area 10 km north-east of the Warren Reservoir where Offler (1966)<sup>1</sup> found three deformational events in the Adelaidean succession which appear analogous to those described here. In the Pewsey Vale area  $F_1$  folds were rare and  $S_1$  was almost parallel to  $S_0$ , some mesoscopic  $F_2$  folds were developed and open macroscopic  $F_3$  folds dominated the regional structure. Metamorphism had reached its peak late in  $F_1$  or during  $F_2$  and was waning during the  $F_3$  event. Strong crossed girdle quartz  $c$ -axis patterns developed within quartzites after the  $F_1$  phase but prior to the  $F_3$  event. In the adjacent Kanmantoo Group sediments at Pewsey Vale, Offler recorded two deformational events which he interpreted as  $F_1$  and  $F_3$  with metamorphism outlasting the  $F_2$  event. In the Cambrai-Springton region Mills (1964)<sup>2</sup> found that the Kanmantoo Group metasediments were tightly folded in a dominant early deformational event with local overprinting by a second fold event with the metamorphic peak being reached during and following the second event.

#### (3) Faulting

Two varieties of faults have been distinguished in the present survey; firstly, faults and mylonite zones considered to be of a high angle thrust type, which developed late in the  $F_2$  deformational event and were subsequently folded in the  $F_3$  event; secondly, a high angle

<sup>1</sup> Offler, R. (1966)—The structure and metamorphism of the Pewsey Vale area, north-east of Williams-town, South Australia. Univ. Adelaide, Ph.D. Thesis.

<sup>2</sup> Mills, K. J. (1964)—The structural petrology of an area east of Springton, South Australia. Univ. Adelaide. Ph.D. Thesis.

reverse fault, the Williamstown-Meadows fault, which developed after the  $F_1$  event and has a regional significance within the orogenic belt.

The late  $F_2$  thrusts developed soon after the peak metamorphic temperatures had been reached and movements continued during waning temperatures. Some strongly schistose retrograde rocks have formed within the thrust zones, including the interesting Williamstown damonrite-kyanite  $\pm$  corundum schists. Displacements on some of these thrusts were large, and in the case of the Murray Vale thrust, blocks with considerably different structural and metamorphic character have been brought into conjunction.

Thrust faults (strike faults, overthrusts) have been described from various parts of the Mt. Lofty Ranges, but as yet few have been adequately mapped. Howchin (1906) recognised an overthrust belt in the foothills of the Mt. Lofty Ranges near Adelaide and envisaged an east to west movement. Sprigg (1946) described this belt in greater detail and concluded that the amount of over-riding was small. Thrusts and strike faults are also well established on the western side of the Houghton Inlier (Benson 1909, p. 105; Spry 1951; Campana *et al.* 1955). Freytag (1957)<sup>11</sup> recognised and mapped several strike faults north of Williamstown and his Enterprise Fault may eventually prove to be a continuation of the Murray Vale Thrust of the present survey.

A portion of the Williamstown-Meadows Fault has been closely mapped in the present survey. The outcrop trace of the fault surface provides evidence of a steep easterly dip and the fault may be classed as a steep reverse type (see also Thomson, in Parkin 1969, p. 108). The actual displacement directions and the amounts of displacement are unknown, but a dip-slip component of 3-5,000 metres does not seem incongruous with the observed metamorphic grade differences across this portion of the fault surface. Recrystallisation of dolomitic marbles in the lower grade block adjacent to the fault surface suggests heat derived from fault movement or from a still warm uplifted higher grade eastern block. Erratic schistose blocks carried within the fault zone carry a metamorphic mineral assemblage suggestive of lower amphibolite facies

conditions. It is suggested that movement on this fault occurred during waning metamorphism in lower Palaeozoic time. There is no evidence of any more recent rejuvenation of movement on this fault and the present fault scarp is a geomorphological erosional feature. Further investigation will be necessary to establish whether the economically important Ukapinga Fault is a branch of the Williamstown-Meadows Fault or a steep thrust of the post- $F_2$  type.

#### (4) Williamstown Window

A great deal of confusion seems to have arisen in the previous literature regarding the interpretation and significance of the coarse-grained schists and gneisses in the Williamstown-Warren Reservoir region. These rocks were initially regarded as basement rocks by Howchin (1906, 1926), but later workers (e.g. Alderman 1942; Campana 1953; Campana *et al.* 1955) considered them to be of metasomatic origin. Campana (1953) mapped them as the "Aluminous metasomatic zone of South Warren Reservoir" on the Gawler 1-mile Geological Sheet.

The present study has established that these gneisses are in part basement gneisses of the Warren Inlier and in part metamorphic equivalents of the lower portion of the Adelaidean succession. The present author inclines to the view that the schists and gneisses may be the result of an isochemical reconstitution of initially aluminous pelites of not unusual composition under high grade metamorphic conditions within the sillimanite-muscovite zone of the amphibolite facies. Their striking texture and coarse grain-size is a result of syntectonic crystallisation near the peak temperature of metamorphism within a zone of locally intense  $F_2$  deformation. Adjacent meta-sandstones, although showing remarkably well-preserved cross-bedding, and even some clastic grain textures, have, in fact, been subjected to similar metamorphic conditions. Later  $F_2$  up-thrusting of the Warren Inlier and its surrounding mantle of high grade Adelaidean metasediments, principally on the Murray Vale Thrust, and later updoming in the  $F_1$  phase and subsequent erosion has exposed a unique kind of tectonic window within which we can examine the metamorphic and structural reconstitution of the pre-Adelaidean basement

<sup>11</sup> Freytag, I. B. (1957)—The Victoria Creek Marble, with observations of the geology of an area north-east of Williamstown, South Australia. Univ. Adelaide. Honours B.Sc. Thesis.

and the lower levels of the Adelaidean succession in the core of the orogenic belt.

It is proposed to call this structure the Williamstown Window. Rock units within the window comprise the basement of the Warren Inlier, the basal metasediments in the Williamstown region, and the overlying coarse-grained Adelaidean schists and gneisses belonging to Campana's "Aluminous metasomatic zone of South Warren Reservoir".

#### (5) Economic Considerations

It seems apposite to present here a few comments on the structural control of some of the economic mineral concentrations within the area surveyed.

The Ukapinga (Unapinga) Copper Mine, located in the north-west corner of the mapped area, was worked in 1850 as the Wheel Friendship Mine (Brown 1908, p. 137; Cornelius 1940) although apparently little ore was won. There has been some renewed interest in this deposit as a low-grade copper prospect in recent years (Blissett 1965). This deposit is located within the Ukapinga Fault zone which has been traced south of the mine property. From Blissett's description of the mineralized zone within the mine the fault zone would appear to be dipping 65-70° east, and this fault is a steep reverse type with a very large component of displacement. A point of some interest is that the thick tremolitic marble bed mapped in the South Paragorge, south of the mine, can be predicted to occur within the footwall block beneath the mine, and this might portend a more richly mineralized zone at depth. It is not yet known whether the Ukapinga Fault is a branch of the Williamstown-Meadows Fault or is a late  $F_2$  thrust fault. Several other copper prospects are located within similar fault zones north of Williamstown.

The short-lived Gumeracha and Mount Crawford Goldfields, located around Watts Gully in the Mount Crawford State Forest, were discovered in 1884 and developed as an alluvial field. Numerous shafts were sunk in an attempt to locate the source of the gold, but the gold was apparently confined to quartz leaders of small size which proved unpayable (Brown & Woodward 1886). The known gold distribution in this field is confined to the hinge region of a large  $F_3$  antiform, the Gumeracha Goldfields Antiform, and it seems likely that the auriferous quartz leaders were localised within fractures associated with this brittle late metamorphic fold structure. This struc-

tural control may prove to be of some interest in the interpretation of the distribution of other goldfields in the Mt. Lofty Ranges.

The Williamstown clay deposits have been worked in the vicinity of the Warren Reservoir since early this century. Several older disused mines are located south of the reservoir within the mapped area, especially within north-south zones of highly altered rocks running immediately east of the Wirrianda homestead and east of the road immediately south of the old road bridge, but the main quarry currently operated is that in section 950, Hundred of Barossa, just outside the north-east edge of the mapped area. Many reports have been written on these deposits but hitherto no important structural control has been recognised. Jack (1926) suggested that the kaolinisation and hydromica development was greater than would be expected by weathering alone and suggested some form of introduction. Cornelius (1932) indicated that the deposit in section 950 dipped steeply east and had a southerly pitch. Alderman (1942, 1950) concluded that the clay deposits had largely originated through the hydration of an original body of massive decussately textured sillimanite rock and erected an elaborate metasomatic scheme to explain the various phases present and the sudden changes from low grade to high grade rocks. Alderman (1942, p. 8) states that "there does not seem to be any major structural feature separating the aluminous rocks from the low grade rocks". Later workers (Gaskin & Sampson 1951, p. 60; Betheras 1953; Cochrane 1954, p. 54; Cochrane 1955, p. 85) generally accepted Alderman's views, and although there are references to various damourite shears and small faults, these are considered to be of minor importance, and perhaps due to volume changes during metasomatism. The clay deposits appear to be irregular in distribution and this was related to the fortuitousness of metasomatism.

The clay deposits north of the reservoir were not studied by the author, but preliminary observations have indicated that the Murray Vale Thrust passes through the centre of the large quarry on section 950 and separates the highly altered sillimanite-kyanite bearing rocks to the west from the low-grade "clay-slates" to the east. In the vicinity of the quarry the Murray Vale Thrust is apparently involved in several tight  $F_3$  folds.

In terms of the structural history determined for the schists occurring south of the

reservoir, the following series of events is envisaged as controlling factors in the formation of the clay deposits. The original massive sillimanite-rutile rocks are thought to have crystallised within the sillimanite-muscovite zone schists and gneisses at the peak of metamorphism under static conditions during the interkinematic period between the  $F_1$  and  $F_2$  deformation events. The origin of the sillimanite remains obscure, but presumably some form of metasomatic transfer was involved. During the  $F_2$  event, whilst the country rocks were being intensely deformed and reconstituted, a number of damourite-kyanite  $\pm$  corundum shear zones developed within the tectonically resistant sillimanite pods and late in the  $F_2$  event several strong thrust zones appeared, and the subsequent passage of hot aqueous solutions within the thrust zones altered the sillimanite deposits to clay. It is considered that the sillimanite and damourite-kyanite deposits may be structurally controlled within early incipient zones of  $F_2$  thrusting, but this will need further investigation. The subsequent development of clay within some of the sillimanite bodies may have required the presence of open channelways along zones of later movement and could be enhanced by the development of strong  $F_3$  folds in the vicinity of section 950.

#### (6) Summary

The following list of events summarises the proposed geological history for the Warren Reservoir region:—

(a) Deposition of pre-Adelaidean sediments of the Warren Inlier. These sediments were largely pelitic and homogeneous with some quartzofelspathic units and minor marls.

(b) Deformation of the pre-Adelaidean sediments of the Warren Inlier. Several phases of folding, as yet unravelled, accompanied this deformation, with metamorphism to upper greenschist or lower amphibolite facies at most. There are no intrusive rocks, apart from pegmatites, no volcanics, no rocks of "Houghton diorite" type; and no evidence for a phase of pre-Adelaidean retrogression and phyllonitisation.

(c) Erosion to a peneplain surface.

(d) Deposition of the Adelaidean sequence, consisting of a basal cross-bedded felspathic

sandstone followed by a pelitic sequence grading upwards into more calcareous or dolomitic sequences.

(e) Deformation and metamorphism of the Adelaidean succession in the lower Ordovician Delamerian orogeny. Three compressive events accompanied this orogeny and metamorphism locally reached the sillimanite-muscovite zone of the amphibolite facies within and adjacent to the Warren Inlier. A locally important phase of thrusting from the east accompanied and followed the second compressive event under conditions of waning metamorphic temperatures. The third compressive event, of more brittle character, occurred during low metamorphic temperatures and played an important role in the development of various mineral deposits.

(f) Formation of the Williamstown-Meadows Fault as a major plane of discontinuity extending along most of the length of the central Mount Lofty Ranges. This fault is responsible for bringing the higher grade metamorphic zones of the eastern Mount Lofty Ranges into conjunction with the lower grade zones of the western Mount Lofty Ranges. Displacement on this fault occurred in the early Palaeozoic and there is no evidence of subsequent rejuvenation of movements.

(g) Extensive denudation and peneplanation and development of a marked fault scarp erosional feature along the Williamstown-Meadows Fault in the Williamstown region through the differential erosion of the lower grade phyllites by the South Para River.

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**OBITUARY: THEODORE GEORGE BENTLEY OSBORN,  
D.SC., M.A., F.L.S.**

**Summary**



THEODORE GEORGE BENTLEY OSBORN  
D.SC., M.A., F.L.S.

## OBITUARY

### THEODORE GEORGE BENTLEY OSBORN, D.Sc., M.A., F.L.S.

2.x.1887 - 3.vi.1973

Theodore George Bentley Osborn was born in England and educated at Burnley Grammar School and the University of Manchester. He spent just over half of a long and energetic life in Australia, occupying Chairs of Botany at Adelaide and Sydney Universities and later the Sherardian Chair at Oxford University. On retirement he chose to return to Adelaide.

Osborn's research during the period 1908-1912 was on the fungi, when he was a lecturer in Economic Botany in the University of Manchester. In 1911 he was awarded the M.Sc. degree, and in 1920 the D.Sc. degree, from the same University.

In 1912, Osborn was invited to become Professor of Botany, Vegetable Pathology and Parasitology in the University of Adelaide, combined with the office of Consulting Botanist to the Government of South Australia, and his publications over the next nine years strongly reflect the nature of this appointment.

Shortly before coming to Australia, he married Edith Muy Kershaw, M.Sc., Assistant Lecturer in Botany in the University of Manchester. They had three sons, Peter, Andrew, and Richard, all of whom served in World War II; Andrew, an R.A.F. pilot, was killed in action in 1942.

When he established the Department of Botany in Adelaide in 1912, Osborn was only 25 years old and youthful in appearance. He was fond of the story of how he went into the examination hall, which was being supervised by a middle-aged woman who had not met him, and asked for the Botany I paper. She brought him the paper and when he said "and while I'm here I'll have a look at the Agricultural Botany paper too" she replied, "You'll do nothing of the sort, young man, you'll just sit down there and get on with your Botany I."

Osborn developed the first degree courses in Botany at Adelaide University, though Botany

courses had been given earlier under Professor Ralph Tate. He took most of the teaching until 1916 when a demonstrator was appointed, followed in 1922 by a Lecturer in Plant Pathology. The latter appointment, and the establishment of the Waite Agricultural Research Institute in 1925, relieved Osborn from much of his time-consuming advisory work. However, in 1926 he was asked by the executive of the recently formed Commonwealth Council for Scientific and Industrial Research to review botanical work in progress in Australia, and further to report on plant problems in Australia. In 1927 he was appointed adviser to the Council and was offered the directorship of their Division of Plant Industry. However, at about this time he applied for the Chair of Botany at the University of Sydney, to which he was appointed in 1928.

During the early years of his residence in Adelaide, Osborn developed interests in plant ecology, studying areas near Adelaide as well as distant ones, such as Franklin Island and the Pearson Islands, off the west coast of Eyre Peninsula. During a visit by Professor R. S. Adamson (University of Cape Town), joint studies were made of the ecology of the Ooldea district and of *Eucalyptus* forests of the Mount Lofty Ranges. These studies were published in the Transactions of the Royal Society of South Australia. Osborn also published on two primitive lycophytes, (*Isoetes* and *Phylloglossum*), found for the first time in South Australia.

These ecological studies led to Osborn's great interest in the vast arid region of South Australia. He made numerous visits to the saltbush areas and developed cordial relationships with pastoralists. This culminated in the generous gift of Messrs. Hamilton, Wilcox Ltd., in 1925, of the Koonamore Vegetation Reserve, which is now the oldest biological station, with continuous records, in Australia. The reserve,

located 385 km NNE of Adelaide, was renamed the "T. G. B. Osborn Vegetation Reserve at Koonamore" in 1972. The first important work on grazing and regeneration of natural vegetation in these arid regions resulted from the collaborative work of Osborn and his two colleagues, J. G. Wood and T. B. Paltridge. The reserve and nearby areas are still used extensively by staff and students of the Adelaide Botany Department.

In 1928 Osborn became Professor of Botany at the University of Sydney and he set about reorganising the undergraduate courses there. He took the first year lectures and those in plant physiology, as well as in ecology. At first he continued to clear up his arid zone research, retaining direction of the Koonamore work until 1931, but increasingly he became interested in the vegetation of coastal New South Wales. In 1930 he gave the Livingstone Lectures entitled "Plant Life in the Sydney District", with an ecological approach. He was interested in the xerophytic properties of the plants characteristic of this relatively high rainfall area. In 1932, his Presidential Address to the Linnean Society of New South Wales was on "The Plant in Relation to Water", with special reference to the properties of xerophytes in being able to withstand drought. Later, Osborn's work in ecology stimulated the interest of his students in descriptive ecological accounts of other parts of New South Wales, including one on the ecology of the Myall Lakes vegetation, jointly with R. N. Robertson.

During his time in Australia, Osborn was an active member of scientific societies. He was a strong supporter of the Royal Society of South Australia, contributing several papers and being a Fellow since 1913 and Honorary Fellow since 1955. He was a Council Member 1915-20, 1922-24, Vice-President 1924-25, 1926-27, and President 1925-26. He played an active part in the establishment of Flinders Chase on Kangaroo Island, being a member of the board from 1919 to 1927, and Honorary Secretary and Treasurer 1921-25. Osborn was also a member of the Linnean Society of New South Wales from 1928 and President in 1932, and President of Section M (Botany) of A.N.Z.A.A.S. in 1928, and a Vice-President from 1924-25. The Royal Society of New South Wales awarded him the Clarke Medal in 1958.

Osborn became Sherardian Professor of Botany and a Fellow of Magdalen College, Oxford, in 1937. The Oxford Department was

very poorly housed in cramped surroundings in an antiquated building in the Oxford Botanic Garden. This Botanic Garden, founded in 1621, had been somewhat neglected, but Osborn stimulated collaborative work with the Garden, which continued strongly after the Department moved into the new laboratories planned by him and constructed shortly before his retirement in 1953.

Osborn's achievements at Oxford have been summarised in his obituary in *The Times* for 6 June 1973—"There can be no doubt that under him the study of botany in Oxford achieved an eminence which it had not before reached even under more famous Sherardian Professors. Not only was the production of original work in botany greater in quantity and quality than ever before but of the undergraduates, demonstrators and research men present in Oxford during his tenure of the chair, eleven or more are or have been Professors and heads of departments, and several more Readers in biological departments of Universities in Britain and elsewhere."

In 1953, Osborn retired from the Chair at Oxford and returned to Australia. After a period of residence in Adelaide, in 1957 the Osborns moved to Melbourne where Mrs. Osborn died a year later. Following this, Osborn returned to Adelaide to live. During 1959 he was Acting Master of St. Mark's College, of which he had been one of the founders in the early 1920's. In 1962, when the Botany Department celebrated its 50th anniversary, he was appointed Professor Emeritus of the University of Adelaide, having been given a similar title at Oxford University on his retirement in 1953.

Osborn left Oxford well known, among other things, for his course on Gymnosperms, and in Adelaide he was invited by Professor J. G. Wood to give a course on this group of plants to third year students. This he continued to do for five or six years, and in 1960 published his last paper, on the embryology and life history of *Podocarpus salicatus*. Osborn had long intended writing a book on the Gymnosperms, but unfortunately this never came to fruition.

Osborn made his home at St. Mark's College during 1959, where he was associated with the very capable secretary Marjorie Sabine, whom he married in England in 1960. Both Professor and Mrs. Osborn took an active part in the life of the Botany Department from then on, and Osborn attended the weekly seminars until shortly before his death.

Osborn was a good lecturer and teacher who attracted students of quality. His influence was passed on to several of the present leaders in Australian plant ecology, and among his many Australian students were: J. G. Wood (formerly Professor of Botany, University of Adelaide), G. Samuel (formerly Deputy Chief Scientific Officer of the Agricultural Research Council, U.K.), G. J. Rodger (formerly Director-General of Forestry, Canberra), B. H. Bednall (formerly Conservator of Forests, South Australia), T. B. Paltridge (formerly Chief Scientific Liaison Officer, C.S.I.R.O.), N. A. Burges (formerly Professor of Botany, University of Sydney, and Vice-Chancellor, University of Northern Ireland), M. R. Jacobs (formerly Director-General of Forestry, Canberra), D. Martin (Officer-in-Charge, Tasmanian Regional Laboratory, C.S.I.R.O.), H. K. C. Mair (formerly Director and Chief Botanist, National Herbarium, New South Wales), R. N. Robertson (Director, Research School of Biological Sciences, Australian Na-

tional University), Lilian Fraser (formerly Chief Biologist, Division of Science Services, N.S.W. Department of Agriculture), Joyce Vickery (formerly Senior Botanist, N.S.W. Department of Agriculture), N. C. W. Beadle (formerly Professor of Botany, University of New England), Gwenda Davis (formerly Associate Professor of Botany, University of New England), N. H. White (formerly Professor of Plant Pathology, University of Sydney), and Irma Brewer (née Pidgeon, School of Biological Sciences, University of Sydney).

Osborn died after a short illness on 3 June 1973. He will be long remembered in Australia for the influence he had on Botany in Adelaide and Sydney, and particularly for his qualities of leadership and inspiration of younger people. He always had the happy knack, even in his later years, of being able to talk with students, to be interested in what they were doing, and to catch their interest in his experiences.

—R. N. Robertson and C. M. Eardley.

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