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*BY H. WOPFNER**

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The post-Eocene history of the central Great Artesian Basin is characterised by long periods of aerial exposure interspersed with comparatively short-lived depositional events. Products of deep chemical weathering on long exposed land-surfaces therefore gain major stratigraphic importance, equal to that of actually deposited rock-units.

To arrive at a meaningful and workable stratigraphy; a scheme is proposed which combines conventional rock-units with morphological units of stratigraphic significance.

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To arrive at a meaningful and workable stratigraphy, a scheme is proposed which combines conventional rock-units with morphological units of stratigraphic significance.

The sequence of events considered here commences with the CORDILLO SURFACE, an aggradational plain which existed in the late Eocene to early Oligocene. On this plain formed a "surface-quartzite", the SILCRETE OF THE CORDILLO SURFACE. The post-Cordillo diastrophism deformed the Cordillo Surface and shaped broad fold structures. In the synclines of these structures the DOONBARA FORMATION, consisting mainly of ferruginous sands and pisolites, formed. This formation is overlain conformably by the CADELGA LIMESTONE, a chemical deposit of middle to late Miocene age.

Introduction

The depositional record of the Tertiary period in the central and western region of the Great Artesian Basin comprises two comparatively thin sequences of fluviatile and lacustrine sediments. The two depositional events were separated by a period of exposure and non deposition which was initiated by widespread epeirogenetic movements. These movements not only formed the principal structural pattern of broad anticlines and synclines as it exists today (Jack 1925, 1930; Wopfner 1960; Wopfner & Twidale 1967), but also strongly influenced distribution and thickness of the Tertiary deposits.

The first depositional event which commenced in the Paleocene and was terminated in the middle to late Eocene, comprises a dominantly fluviatile and paludal sequence of mature sandstones with interbeds of fine-clastics and lignites. This stratigraphic unit which is now termed EYRE FORMATION (Wopfner, Callen & Harris 1974), was laid down as an almost continuous sediment-blanket, disconformably covering the underlying Cretaceous strata of the central, southern and western Great Artesian Basin.

Sediments of the second depositional phase were first recognised in the vicinity of Lake Eyre and termed ETADUNNA FORMATION by Stirton *et al.* (1961). This formation consists mainly of primary dolomites with interbeds of dolomitic shales and mudstones. Subsequent results of drilling on Lake Eyre and from Poonarunna No. 1, northeast of the Lake, has demonstrated an extensive distribution of this formation at shallow depth (Johns & Ludbrook 1963; Wopfner & Twidale 1961). Stirton *et al.* (1961) suggested an Oligocene age for the Etadunna Formation, but palynological data obtained recently by W. K. Harris of the Geological Survey of South Australia from very similar dolomite sequences in the Frome Embayment are indicative of a Miocene age (Wopfner *et al.* 1974).

The distribution of the Etadunna Formation and its equivalents is much less ubiquitous than that of the Eyre Formation, being restricted to the large downwarped areas of the Lake Eyre region, the Strzelecki Desert and the Frome Embayment.

The purpose of this present paper is to discuss the events which followed the deposition of the Eyre Formation in northeastern-most

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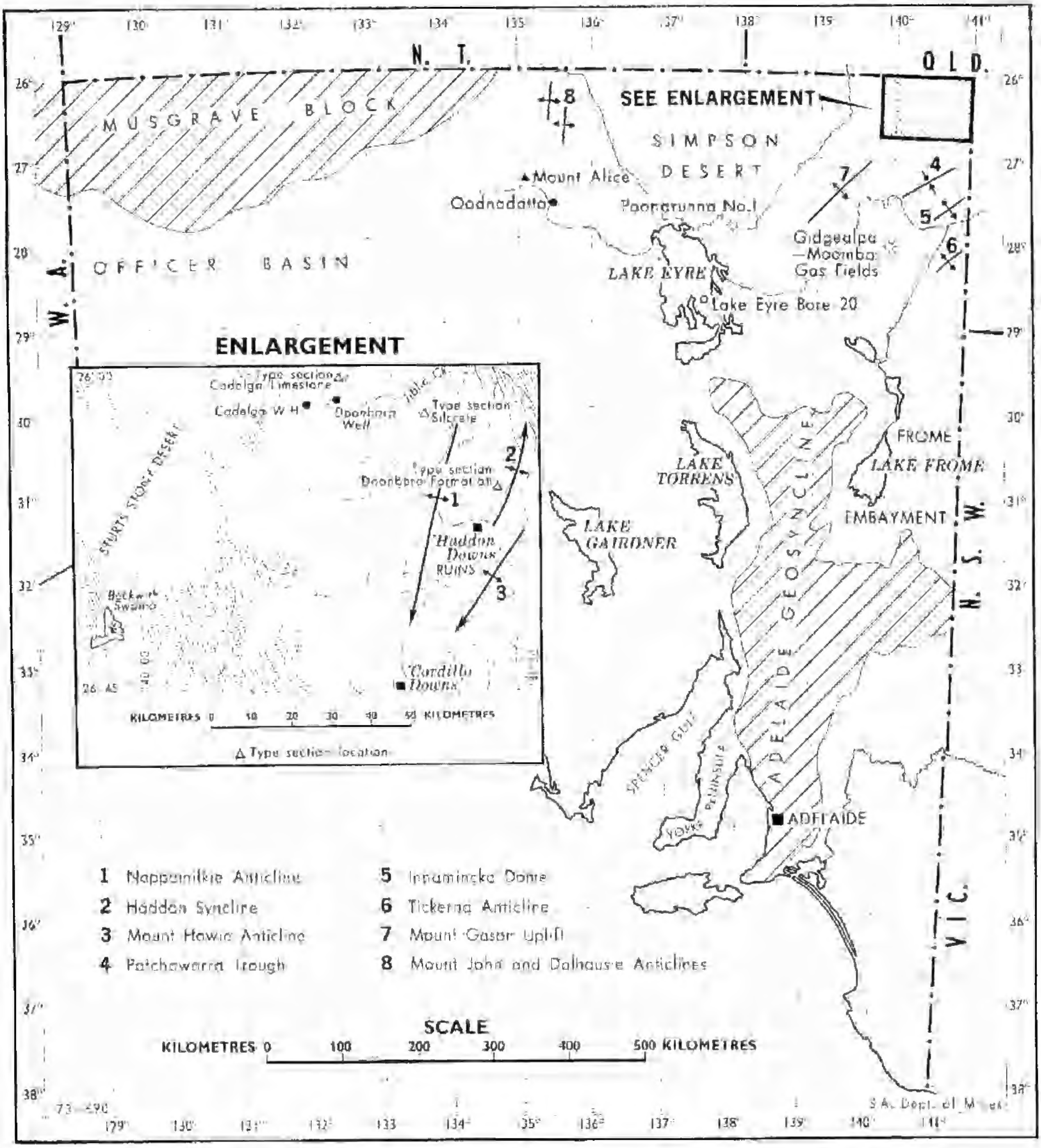

Fig. 1: Locality map showing major anticlinal structures in north-eastern South Australia.

South Australia. This region is characterised by its large and often complex anticlinal structures and thus contrasts markedly with the large, downwarped areas. This contrast is not only evident in the different sedimentological record but also in the development of alteration products, resulting from chemical weathering processes on long-exposed land surfaces.

Such palaeosurfaces have therefore no less stratigraphic importance than actually deposited sediments and are treated here as morphological units of stratigraphic significance.

Type localities and places and structures mentioned in the text are indicated on Fig. 1.

Cordillo Surface

GENERAL DESCRIPTION

This new name is introduced to identify that land surface which existed in the early Tertiary shortly before and after the termination of the deposition of the Eyre Formation. This land-surface developed over the whole central and western region of the Great Artesian Basin but it also extended westward well beyond the basin margins (Wopfner 1967).

Termination of the deposition of the Eyre Formation, and consequently the development of the Cordillo Surface, was however not a spontaneous event. Within the central Great Artesian Basin deposition ceased first in those regions where, due to epeirogenetic instability, anticlinal structures began to form. This structural growth which followed a pre-existing pattern of fold structures already established in the Permian (Wopfner 1966; Martin 1967; Kapel 1973), is demonstrated by the overall thinning and lensing out of the Eyre Formation across the crests of those anticlines (Wopfer *et al.* 1974). This left some of the anticlinal crests "bald-headed", exposing Winton Formation to the processes of weathering. The rivers which were responsible for the deposition of the Eyre Formation were thus deviated into the synclinal areas where sedimentation continued on vast flood plains and in intermittent lakes and swamps. Depositional regression gradually reduced the area of this early Tertiary phase of sedimentation to such an extent that most of the region remained as a stable and, to all intents and purposes, flat land-surface.

This stable surface of the late Eocene and early Oligocene is here termed CORDILLO SURFACE.

SILCRETE OF THE CORDILLO SURFACE

On the flat and stable Cordillo Surface, lateral run off was at a minimum. Coupled with a high ground-water table caused by the depositional regression, conditions existed which led to deep chemical weathering and the development of a leached soil-profile. Apparently within the B-horizon of this profile silica began to accumulate in irregular nodules which then agglutinated into rod shaped aggregates, 2 to 4 cm thick and 15 to 30 cm long. As the profile matured, silica concentration increased further to form centripetally oriented columns or polygonal prisms of a dense and brittle silcrete. The silcrete, which may be up to 3 m thick, grades downward into a zone of angular, broken-up parent rock and this is underlain by leached and kaolinised, but otherwise undisturbed parent rock (Wopfner 1964; Wopfner & Twidale 1967).

It is proposed that this Silcrete be referred to as SILCRETE OF THE CORDILLO SURFACE.

The Silcrete of the Cordillo Surface is composed entirely of quartz, whereby detrital quartz grains and pebbles of the original rock are still retained in their original shapes, encased in a microcrystalline quartz-matrix. This contrasts with younger silcretes, like red and white silicified breccias, silicified carbonates and opaline layers, in which tridimitic-cristobalitic silica predominates.

The Silcrete of the Cordillo Surface is usually best developed near the crests and on the flanks of the surface anticlines. Along the lower flanks of the anticlines where the Eyre Formation occurs in an off-lap position, several layers of immature silcrete may be intercalated in the sediment-sequence, whereas a mature silcrete usually caps the section. This may indicate temporary "instability" of the surface when the formation of a silcrete-profile was terminated by the deposition of new sediment on top of it.

From the limbs of the anticlines the silcrete commonly can be traced below the present surface where its presence can cause great difficulties during drilling operations and is therefore invariably recorded by the driller. In the deeper synclinal parts of the basin however, the silcrete is often absent or its development is so rudimentary that it can be overlooked very easily.

It would appear therefore that the formation of the silcrete of the Cordillo Surface commenced in the crestal region of the embryonic anticlines whence its development progressed outwards as larger areas became excluded from sedimentation. Thus the silcrete was last but usually also least developed in those areas where sedimentation persisted longest.

TYPE AREA AND SECTION

The type area for the Cordillo Surface is the Cordillo and Innamincka region where this surface was first recognised. For obvious reasons no type section can be established, but Figs. 2 & 3 show typical expressions of this surface.

The type section for the silcrete of the Cordillo Surface and the associated deep weathering profile is situated on the headwaters of the central tributary of Jiblie Creek where a complete, monogenetic profile is exposed on the east face of a tall mesa, standing isolated in front of the Nappamilkie escarpment. Other sections more readily accessible

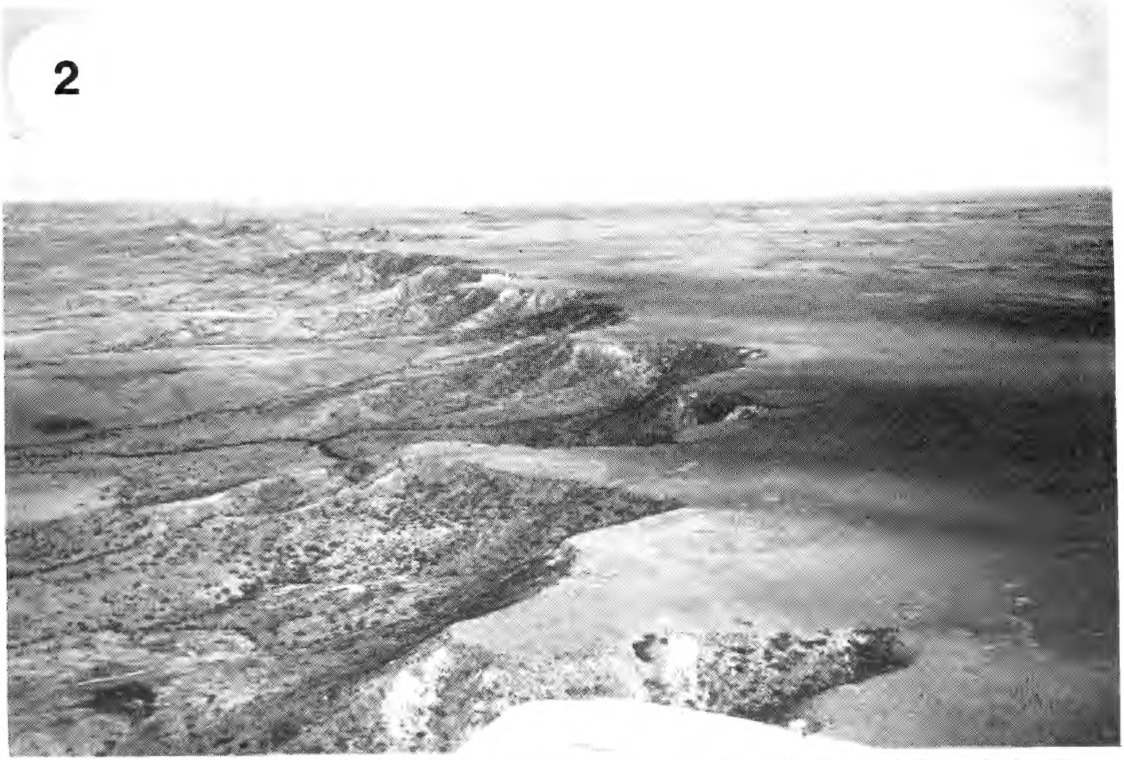

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Fig. 2: Typical expression of silcrete-capped Cordillo Surface on north limb of Innamincka Dome. The silcrete capping forms the sharp edge at the top of the escarpment and is characterized by an even, almost textureless pattern on aerial photographs. Scarp-foot erosion from the south (left) has cut deeply into the northern limb of the dome, whereas a consequent drainage still prevails on the north-dipping Cordillo Surface. View is to the WSW from a point near the South Australian-Queensland border.

exist in the vicinity of Needle Hill and on Innamincka Dome (Fig. 2).

The name is derived from Cordillo Downs station which occupies the northeast corner of South Australia. Cordillo Downs homestead is built on the south-dipping, silcrete-covered Cordillo Surface.

Distribution and Lateral Developments

The Cordillo Surface can be recognised in all structurally positive areas where it forms the dip slopes of anticlinal structures (Figs. 2 & 3). It extends over the whole northeastern corner of South Australia and the adjacent structural uplands in southwestern Queensland (Wopfner 1960). From the Cordillo anticlinal complex it can be traced westward through Sturt's Stony Desert to the region of the Birdsville Track where the surface gains prominence again in the Mt. Gason Dome.

It is also prominently developed on the Innamincka Dome (Fig. 2) and on the Tickerna Structure.

It cannot be traced with confidence beneath Lake Eyre but equivalents of the Cordillo Surface exist in the Oodnadatta and Dalhousie region, where in parts it may be developed on Lower Cretaceous strata. From here on westwards, the surface progressively transsects older rocks (Wopfner 1964), including Lower Palaeozoic sediments and granites, exposed along the margin of the Great Artesian Basin.

From these relationships it is apparent that the Cordillo Surface and its equivalents may be regarded as a depositional plain within the area of the Great Artesian Basin, but as a peneplain near the basin margin and beyond.

The geomorphic form of this surface indicates that the system was exorheic, and open to the sea in a southwesterly direction—a situation similar to that proposed for the drainage pattern during the deposition of the Eyre Formation (Wopfner *et al.* 1974). An exorheic system may be indicated also by the fact that remnants of silcreted surfaces can be traced all the way to the shores of Spencers Gulf on

Fig. 3: West limb of Haddon Syncline, showing marked east-dip of silcrete-covered Cordillo Surface. Flat-lying Doonbara Formation (in background behind and to the left of tree) unconformably laps onto the folded Cordillo Surface. Some columnar silcrete is exposed in right foreground. The type section of the Doonbara Formation is about 1 km to the south of this location.

Yorke Peninsula. The map of silcrete distribution produced by Stephens (1971) also suggests an open system. However, it should be noted that the age suggested by Stephens for the silcrete formation is demonstrably too young.

Mid-Tertiary (Post Cordillo) Diastrophism

Epeirogenetic movements which had made their presence felt during the deposition of the Eyre Formation became active again in the middle of the Tertiary. The exact time of this event cannot be ascertained as yet. The information available at this stage indicates an interval with a lower limit in the early Oligocene and an upper limit in the early Miocene, during which these movements could have taken place.

The movements resulted in further folding and warping in the deeper parts of the basin and in normal faulting along the basin-margins. The deforming forces acted in the same sense as those which had been active during the early Tertiary, thus reactivating structural growth along pre-existing patterns. This led to the development of large, commonly closed anticlines with structural reliefs of 90 m to 200 m (Wopfner 1960).

Within the deeper parts of the basin, these diastrophic forces appear to have acted rather uniformly, resulting in slow but continuous fold-movements. Along the basin margins however, the same diastrophism was expressed by a sequence of pulses which, depending on the local stress-accumulation, occurred as short-lived events in different parts of the basin at different times. This is indicated by the considerable variations in the maturity of those silcretes of the Cordillo Surface which were tilted or otherwise deformed by faulting along the basin margin. Good examples may be observed along the Mt. Harvey and Mt. Margaret Faults south of Oodnadatta and the Waratta Fault southwest of Tibooburra. As such strong deformation of these silcretes disrupted the balanced morphological and groundwater conditions required for the formation of these silcretes, their stage of maturity also gives the relative time of their deformation (Wopfner & Twidale 1967).

There can be little doubt, if any, that the Cordillo Surface was actually deformed by folding. It can be shown in many places that the planar contact between the late Cretaceous Winton Formation and the early Tertiary Eyre Formation strikes and dips in sympathy with the Cordillo Surface, although the dip on the latter may be one or two degrees less than that observed at the base of the Tertiary. This indicates quite clearly the common deformation of both planes. Excellent examples of this were described from the Innamincka Dome[1], the Haddon Syncline and the Morney Dome (Wopfner 1960). The Cordillo Surface was also used as the structural datum for the aerial mapping of the central Great Artesian Basin by the author and Dr. R. O. Brunnschweiler in 1957. Using the altimeter of the aircraft to measure the elevations of the folded Cordillo Surface, a structure-contour map was produced of all the major surface structures between the Grey Range in western Queensland and the Simpson Desert in South Australia (see Sprigg 1958). Extensive seismic and geological surveys carried out over that area since then have proved this map essentially correct, thus confirming the basic morpho-stratigraphic concept outlined above.

The post-Cordillo diastrophism completely reshaped the morphology of the central and western Great Artesian Basin. This changed morphology, which is still the basis for the distribution of the major land-forms of today, also had a pronounced effect on the drainage and thereby on the sediment distribution. The once vast and monotonous plains now became sub-divided into distinctive morphological and structural units. Apart from the various fold-structures mentioned before, two large areas of deposition commenced to take shape: one formed in the region of Lake Eyre and the southern Simpson Desert, and a second one developed in the area of Lake Blanche and the Strzelecki Desert. The two negative areas were separated by a chain of anticlines which formed along the region now traversed by the Birdsville Track. It would appear therefore, that this period of mid-Tertiary diastrophism also formed the mould out of which developed the present endorheic drainage system of Lake Eyre and Lake Frome.

Doonbara Formation

General Description

As the anticlines rose above their surroundings, initial erosion gouged shallow, consequent drainage systems into the flanks of the structures. The eroded material was deposited in the neighbouring synclines, the sand-fraction close to its place of origin and the finer grains in the more distal regions. Reworked silcrete of the Cordillo Surface, ranging in particle-size from coarse sand to cobbles, was frequently incorporated, particularly near the base of the sequence.

The formation of broad and shallow drainage channels rather than deep erosional incisions suggests that the area as a whole was not elevated much above base-level. The lowering by erosion of the headwater regions, coupled with the gradual filling up of the depositional areas, resulted in a further and progressive reduction of dynamic intensity. Erosional gradients were thus reduced to such a degree, that the landforms became quasi-stabilised. This allowed for the commencement of ferralitisation, a process which was particularly effective within the synclinal regions, where high groundwater levels were likely to have existed. Ferralitisation however should be envisaged as a continuous, almost syn-depositional event which adjusted to new levels whenever new erosional detritus was added onto an existing surface.

The result of this combination of deposition and soil-process led to the formation of ferruginous pisolites, pisolitic sandstones and in places to ferruginous oolites. It is proposed here to term this sequence the DOONBARA FORMATION. The base of the Doonbara Formation is defined by its unconformable or disconformable contact with the silcrete of the Cordillo Surface or older rocks (Fig. 4), whereas the top is placed below the first carbonate-bed of the overlying rock-unit.

Lithology

The Doonbara Formation is substantially a brick-red, medium-grained, ferruginous sandstone, large parts of which show pronounced and well developed pisolitic texture. The clastic components consist almost entirely of quartz grains which are generally rounded to subrounded and polished. Sorting is usually good and it is suspected that a large proportion

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[1] Wopfner, H., (1958).—The Geology of the Innamincka Dome. Report for SANTOS Ltd *in* S. Aust. Dept. Mines Envel. 74. Unpublished.

Fig. 4: Typical flat cake of ferruginous pisolite of basal Doonbara Formation, resting on reworked and fragmented silcrete of Cordillo Surface. Silcrete-clasts are cemented with ferruginous material derived from the Doonbara Formation. Locality is at Nilpie Nilpie Creek, about 50 km east of Cordillo homestead.

of the quartz grains have been derived by reworking from the underlying Eyre Formation. In those parts of the section which have not been affected by the formation of pisolites, current bedding is often discernible. It is usually a shallow trough-bedding with individual sets averaging 15 to 25 cm thickness. Near the base of the formation the grain size increases to coarse sand. Granules and rounded cobbles of silcrete are also common. An off-white pebble conglomerate in coarse sand-matrix may be present at the base of the formation.

The pisolitic portions of the Doonbara Formation occur either in thick, flaggy banks or in the shape of round, flat cakes with diameters ranging between 40 and 90 cm (Fig. 4). The usual colour is again brick-red, although medium brown and dark yellow are also common. Marked colour-differences are often observed within the cake-shaped portions of the formation, where the cake is often dark red and the surrounding pisolitic material of a much lighter, often bleached appearance.

The individual pisoliths vary between 0.5 and 2 cm in diameter. They are generally massive, although concentric structures are present in some areas. In cross-section the pisoliths show a ferruginous, largely goethitic matrix, enclosing fine to medium grained quartz. There is normally very little clay within the pisoliths. Frequently the inside colour of the pisoliths is much darker than the surrounding "matrix". Cementation between the pisoliths is poor, giving the formation a very high porosity and permeability.

The quartz-content of the sandy portions of the Doonbara Formation is about 80 percent but it may be less than 60 percent in the iron-rich pisolitic portions. The average contents of iron and alumina also vary over a wide range. A number of analyses of pisolites from the Doonbara Formation (then referred to as "ferruginous pisolite"), were presented by Wopfner & Twidale (1967). These analyses show that despite the wide range of the individual values, the ratio between Fe_2O_3 and Al_2O_3 remains fairly constant at about 0.3.

Immediately beneath the base of the Doonbara Formation one observes a kind of regolith, where the underlying, older rocks have been broken up and disintegrated into angular fragments. The interstices between the rock fragments are cemented with red, ferruginous material derived from the overlying Doonbara Formation. Still further below the contact, a pronounced red and white mottling in the pre-Doonbara material is developed. In many instances the base of the Doonbara Formation can be seen trans-secting from silcrete onto sediments of the Eyre Formation or even older rocks, clearly demonstrating the erosional and disconformable relationship between the Doonbara Formation and the underlying stratigraphic units.

TYPE AREA AND SECTION

The type area for the Doonbara Formation is the northeastern-most portion of South Australia, in particular the immediate surroundings of the Cordillo Structures, the Innamincka Dome and their extensions into Queensland.

The type section is situated on the CORDILLO 1:250 000 map-area, about 70 km north of Cordillo Downs homestead, where about 8 m of dark red sandstone and pisolite are exposed on the western limb of the Haddon Syncline (Fig. 3). The locality is almost due west of Narratella waterhole. Additional information on the sequence was obtained from seismic shot holes, drilled across the Haddon Syncline (Wopfner 1960).

An excellent section also exists at Candradecka waterhole on the northwest limb of the Innamincka Dome (INNAMINCKA 1:250 000 map-area). This section which was described in some detail recently is selected as a reference section[2].

The name of the formation derives from Doonbara Well, situated on the west limb of the Nappamilkie Anticline (Wopfner 1960), and some 60 km north of Cordillo Downs homestead. The well obtains its water from the Doonbara Formation (Wopfner 1961).

DISTRIBUTION AND AGE

The Doonbara Formation is ubiquitous along the flanks of all the major surface anticlines, whence it extends into the subsurface (Wopfner 1960, 1961). It is generally present within the synclinal structures where it is usually covered by younger deposits. The average thickness observed in outcrop is about 7 to 15 m, but in some areas it may be considerably thicker. The maximum thickness recorded so far is 40 m in the core of the Haddon Syncline (Wopfner 1960).

Locally the Doonbara Formation provides the reservoir for the run-off from occasional precipitation and forms an aquifer on the slopes and peripheries of the anticlinal structures. In proximity to local intake areas the water is of excellent quality (Wopfner 1961).

From the surface structures in northeasternmost South Australia and western Queensland, the Doonbara Formation can be traced westward under Sturt's Stony Desert. Occasionally the formation is exposed on the surface as for instance north of Beckwith Swamp and on the eastern slopes of the Mt. Gason Uplift. Ferruginous pisolites and oolites at the base of the Etadunna Formation in the Lake Eyre bores (Johns & Ludbrook 1963) are regarded by the present author as equivalents of the Doonbara Formation (see Wopfner & Twidale 1967).

The value of aluminous laterites as stratigraphic marker horizons was pointed out most recently by Valeton (1972). Since ferralitisation also requires rather specialised climatic and morphological conditions, it would appear reasonable to use this criterion as a basis for correlation.

To the northwest of Lake Eyre, lithologically identical sequences are again exposed along synclinal areas between Oodnadatta and the Northern Territory border. Extensive remnants also occur on the Ueatanna plateau (OODNADATTA 1:250 000 map-area) and on the Emmery Range (DALHOUSIE 1:250 000 map-area).

No fossils have been found in the Doonbara Formation so far and its age is not known with certainty. However, if the correlation with the ferruginous oolites at the base of the Etadunna Formation is correct, an approximate age can be deduced. Recent palynological work by Harris (see Wopfner *et al.* 1974) indicates a Miocene age for the Etadunna Formation. From this a late Oligocene or early Miocene age seems to be most likely for the Doonbara Formation.

Cadelga Limestone

GENERAL DESCRIPTION

A thin sequence of carbonates overlies the Doonbara Formation in many places. The

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[2] THORNTON, R. C., (1973).—Measured Sections from the Innamincka 1:250 000 area. Geol. Surv. S. Aust. Rept. 73/26. Unpublished.

typical lithology of this carbonate sequence, comprising pale coloured, cherty limestones and dolomitic limestones, remains remarkably uniform over large areas of the central and western Great Artesian Basin. It is proposed here to name this carbonate sequence the CADELGA LIMESTONE. The lower boundary of this unit is defined by its contact with the underlying Doonbara Formation whereas the upper limit is usually formed by an erosional surface.

The contact between the Doonbara Formation and the Cadelga Limestone generally appears to be conformable, although in a number of exposures a disconformable relationship is suggested by marked erosional features at the base of the carbonate deposits. Erosion must be expected at this boundary which marks the change from the subaereal deposition and ferralitisation under which the Doonbara Formation was formed and the subaqueous environment in which the Cadelga Limestone was laid down.

Where the water came from which provided the medium for the deposition of the Cadelga Limestone is still highly speculative. From the widespread distribution of this limestone and its equivalents, extending from western Queensland to Western Australia, one would be justified in accepting either permanent or tidal inundation by sea-water as suggested by Lloyd (1968), provided a satisfactory explanation can be found for the almost complete absence of marine fossils (see below). It was mentioned earlier that the landscape which existed at the time of deposition of the Doonbara Formation was not much elevated above base level. If this base level was sea level, even a small fluctuation of the latter would have inundated large areas, in particular the synclinal regions, to form chains of shallow pans and lagoons. The paucity of clastic material together with the abundance of dolomite, chert and algal structures is indicative of a mildly evaporitic environment, and hypersalinity would thus account for the near absence of marine fossils. Alternatively, only slight variations would be required to adjust the above model to an endorheic system of similar or identical morphology which was never or only rarely connected with the sea. In this case the occasional foraminifera could have been brought in by birds, whereas larger animals could have gained access via temporary interconnecting channels.

LITHOLOGY

It is very difficult to find a surface exposure of the Cadelga Limestone which is not reduced by erosion. However, the dominant lithologies constituting this stratigraphic unit are so characteristic that they can be recognised and readily identified in widely separated localities.

In the type section about 5 m of Cadelga Limestone are exposed. The lower part of the section consists of fawn to pink, chalky limestone, containing a great abundance of reworked fragments of the underlying Doonbara Formation. This reworked material ranges in size from individual, goethite-coated quartz-grains to fragments and aggregates of pisolites about 2 to 3 cm in diameter. These limestones are interbedded with olive green, silty shale, calcareous shale and thin carbonate-bands. Lenses of red, sandy limestone are also present.

Outside the type section one observes at this level also banded limestones, consisting of alternating cream and maroon or purple bands, several centimetres thick. This rock-type was also reworked and is then found, forming angular fragments up to 2 cm thick and 5 cm long, in slightly higher portions of the sequence. Vuggy limestones are also common in this lower part of the succession. On the southern flank of the Cordillo Dome, in the lower reaches of Nilpie Nilpie Creek, some round and fibrous structures, about 1 to 2 cm in diameter, up to 25 cm long and irregularly curved, are observed on the bedding planes. These structures are thought to be calcified algal colonies.

The middle and upper parts of the sequence consist of thickly-bedded to flaggy limestones, usually of light grey to beige colour. These are hard, brittle and dense carbonates, ranging in composition from slightly dolomitic limestones to dolomites. All of these contain lenses, wisps and irregularly shaped bodies of white, grey and black chert. Some of the cherts are banded and show depositional features indicative of primary cherts whilst others appear to have replaced the original carbonate during diagenesis. This latter occurrence may best be explained as a nucleation effect. Usually the cherts are amorphous, consisting of tridimitic and cristobalitic silica, but recrystallisation is reasonably common in some parts. When exposed to weathering the carbonate dissolves, leaving the cherts to form rough and rugged remnants on the surface of the rock (Fig 5). In some instances where the carbonate has been removed completely, the ground

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Fig. 5: Exposure of Cadelga Limestone at the type section, about 7 km northeast of Cadelga waterhole and just south of the border fence between South Australia and Queensland. The dark portions on the otherwise light coloured rock in the left and central foreground are stringers and irregular patches of chert. Hammer handle measures about 25 cm.

surface is covered with residual chert fragments as the sole indication of the once present Cadelga Limestone.

The carbonates are generally micritic, but dolo-siltites and calcarenites are also observed. Dark grey to almost black, bituminous limestone occurs near Horseshoe Well, on the southern limb of the Cordillo Dome. Apart from the possible algal structures mentioned above, some gastropods and (?)diatoms were observed in thin sections, made from material from the CORDILLO 1:250 000 map-area.

Based on the lithological and textural characteristics outlined above, it is suggested that the Cadelga Limestone is largely a chemical deposit which was laid down in large, shallow pans. The dolomitic nature and the abundance of chert indicate a mildly evaporitic depositional environment.

Type Area and Section

The type area for the Cadelga Limestone is the region around the Cordillo and Innamincka structures and Sturt's Stony Desert. The type section is situated on the area of the CORDILLO 1:250 000 map-sheet, about 13 km north of Doonbara Well and on the western limb of the Nappamilkie Structure (Fig. 5).

The name of the formation is derived from Cadelga waterhole, situated approximately 7 km southwest of the type section. Cadelga Limestone occurs in the immediate vicinity of the waterhole and grey and white cobbles and pebbles of chert with a typical smooth, lustrous ("greasy") surface appearance were concentrated by selective erosion along the northern bank of the waterhole. According to aboriginal legend, these chert-pebbles are the fat which was splattered by the ancestral goanna when he went hurriedly underground to escape the chase by the kangaroo man. The hole which formed where he went down is now Cadelga waterhole. The cherts associated with the Cadelga Limestone were of considerable importance to the aboriginal inhabitants of that region, who valued them as an excellent raw material for the manufacture of stone implements.

DISTRIBUTION AND AGE

Cadelga Limestone is exposed intermittently along the western and southern limbs of the Cordillo structure, in the Haddon Syncline and the northern part of Sturt's Stony Desert. It occurs also on the north limb of the Innamincka Dome and in the Patchawarra Trough, where it is covered by younger sediments. From here it may extend below the surface into the area of the Gidgealpa and Moomba gas fields, where chalky limestones and cherty dolomites are found above the clastic sequence of the Eyre Formation. These carbonates are thought to be, at least in parts, equivalents of the Cadelga Limestone. From there to the south-west, the same carbonates are then correlated with the Etadunna Formation of Stirton *et al.* (1961) and with Miocene carbonates in the Frome Embayment (Wopfner *et al.* 1974).

Chalcedonic limestones of identical lithology to the Cadelga Limestone are exposed on the west shore of Lake Eyre, near the mouth of the Neales River, an occurrence which, through its proximity to the Etadunna Formation beneath Lake Eyre (Johns & Ludbrook 1963), strengthens a lithological correlation between the Cadelga Limestone and the Etadunna Formation.

Litho-equivalents of the Cadelga Limestone are widespread also between the Simpson Desert and the western margin of the Great Artesian Basin. In the Oodnadatta region they are referred to as Alberga Limestone (Freytag *et al.* 1967). Unquestionable tests of foraminifera were found by the present author in thin sections of Alberga Limestone from a locality near Mt. Alice.

As mentioned above, the only fossils recorded from the Cadelga Limestone so far are some gastropods, (?)diatoms and algal structures. None of these are sufficiently diagnostic to establish the age of the sediment. Based on the correlation with the Etadunna Formation, a middle to late Miocene age is suggested for the Cadelga Limestone.

Conclusions

Recognition and definition of post-Eocene sedimentary and morphological units allows the reconstruction of the geological history of the northeastern portion of South Australia and adjoining parts in Queensland. This history is characterised by a topography of low amplitudes, thin sedimentary sequences and a pronounced presence of alteration products. Throughout the period under consideration, the region experienced tectonic stability, except for the period of epeirogenetic movements (post Cordillo diastrophism) in (?)late Oligocene to early Miocene time.

The depositional periods described here followed the diastrophic movements and major depositional areas were established in the synclinal and synecliform depressions formed by these movements. Such dependence of sedimentation on structural events as indicated by the reciprocal thicknesses of the carbonates (Cadelga Limestone, Etadunna Formation and equivalents) and the Doonbara Formation can be interpreted as due to longer exposure to aerial conditions, and thereby later inundation of the regions proximal to structurally positive areas.

If the total Tertiary sequence, inclusive of the Eyre Formation is considered, one notices a remarkable similarity with other Tertiary successions in South Australia. When comparing the much more complete and largely marine sections of the coastal basins with those sketchy sections from the very margin of deposition, one must not overlook the fact that only basic trends will remain to be compared, and that long periods of time may be represented by only a few metres of sediment or just a palaeosol.

Of interest is the climatic history of the region as indicated by the sequence of sediments and palaeosols described in this paper. A moist to seasonally wet and warm-temperate climate is indicated in the early Tertiary during the deposition of the Eyre Formation (Wopfner *et al.* 1974), and very much the same climate, perhaps with more pronounced seasonal aridity, can be predicted for the silcrete formation. The ferralitisation during the period in which the Doonbara Formation was formed is indicative of a warmer, probably hot climate with high rainfall, whereas increased aridity and warm to hot conditions prevailed during the deposition of the Cadelga Limestone.

Thus a temperature maximum is indicated in the Miocene, with lower preceding temperatures in the early Tertiary and a gradual decline in the post-Miocene. This mid-Tertiary temperature peak observed in Australia contrasts with the palaeo-climatic curves for the Tertiary of Europe and North America. There the temperature decreased steadily from the Eocene onwards, until the minimum of the Pleistocene glacial periods was reached. This was pointed out by Schwarzbach (1966), who suggested drifting of the Australian continent to account for this discrepancy in the palaeoclimatic history of the Australian Tertiary. Such a hypothesis, invoking a north drift of the Australian continental mass in the early to mid-Tertiary is also in close agreement with latest geological data obtained from Cretaceous-Tertiary basins along the southern coast of Australia, and with palaeomagnetic results from Australian Tertiary volcanics and the floor of the Southern Ocean.

At the beginning of the Tertiary the distribution of land-forms in northeastern South Australia was considerably different to that observed today. The basic distribution of morphological units as it exists at present was introduced by the post-Cordillo diastrophism in the early mid-Tertiary. Since the deposition of the Cadelga Limestone, modifications occurred only by degree and the changes so apparent in the late Cainozoic history of the region can be ascribed exclusively to variations of the climate coupled with some minor epeirogenetic re-adjustments.

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THE ORIGIN OF COTTONS BRECCIA, KING ISLAND, TASMANIA

BY J. B. JAGO

Summary

JAGO, J. B. (1974).-The Origin of Cottons Breccia, King Island, Tasmania. *Trans.* R. *Soc.* S. *Aust.* **98**(1), 13-28, 28 February, 1974.

Cottons Breccia is the southernmost and most isolated of the proven and possible Late Precambrian glaciogenic sediments of Australia. It outcrops over a distance of 8 km along the southeast coast of King Island; it varies in thickness from 40 to 100 m. The lithology varies considerably, both laterally and vertically over quite short distances. Cottons Breccia is a very poorly sorted, crudely stratified rock with angular clasts set in a carbonate or limonite cement. Thin siltstone and sandstone lenses are reasonably common. The great majority of clasts show some rounding although some clasts show no sign of rounding. The largest clasts in any particular horizon are generally 30-50 cm or less across. However, at one locality there is a 15 m interval of very large carbonate clasts with the largest one being over 3.3 m long. The larger clasts tend to be quartzite and the smallest clasts a variety of metasiltstones. However, on the whole, various types of carbonates dominate the clast assemblage. Very rare basic lava clasts are known; no acid igneous or high grade metamorphic rock clasts have been found.

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Features such as drop-stones, thin sandstone lenses within the breccia, and the possibility of varved sediments, suggest a glaciogenic origin for Cottons Breccia. The presence of graded bedding, the crudely stratified nature of the breccia and the fact that almost all the clasts are sedimentary suggest a density flow origin. It is possible that Cottons Breccia originated in a tectonically active area by a combination of glacial action and submarine mass transport.

Introduction

Dunn *et al.* (1971) have proposed to use the Late Precambrian glaciation of Australia as the basis of a continent-wide chronostratigraphic unit. The southernmost and most isolated of the glaciogenic sediments noted by Dunn *et al.* (1971) is a tillite-like rock from King Island (Fig. 1). The regional geology of King Island is shown in Fig. 2.

This rock, defined below as Cottons Breccia, was first noted from City of Melbourne Bay by Waterhouse (1916) who considered it to be a Permo-Carboniferous glacial till. Carey (1947), while supporting a glacial origin for the rock, suggested a Cambrian age and correlation "with the Adelaide series glacial horizon, and also with the Daspoort and Griquatown tillites of South Africa". Carey also suggested that the overlying laminated dolomite may be a varved sediment. Hills & Carey (1949, p. 23) included the King Island rocks within the "Zeehan Glacials" then considered to be of Cambrian age but now known to be Permian (Spry 1958; Blissett 1962). Hills & Carey (1949) stated: "this formation includes a true tillite rich in striated pebbles associated with varved shales". However, it was not specifically stated that striated pebbles came from King Island although Hills & Carey noted striated pebbles from the Zeehan-Dundas area.

David & Browne (1950, p. 77) called the rocks under discussion the King Island Beds and assigned them to the Late Precambrian. Banks (1956, 1962) and Spry (1962) agreed with Carey (1947) and considered the King Island rocks to be a tillite; Spry (1962) suggested correlation with the Sturt Tillite of South Australia.

Edwards *et al.* (1956, p. 75) noted the presence of irregular ovoid patches or "pods" in the hanging wall of what they termed the Top Orebody Bed of the King Island Scheelite Open Cut. They further suggested (p. 77) that these pod-bearing beds are the metamorphosed equivalent of Cottons Breccia.

Bartlett (1962) called the rock a conglomerate without reference to its origin. A map by Bartlett (p. 8 *in* Smith & Williams 1965) of the southeast coast of King Island notes the presence of tillite and dolomite

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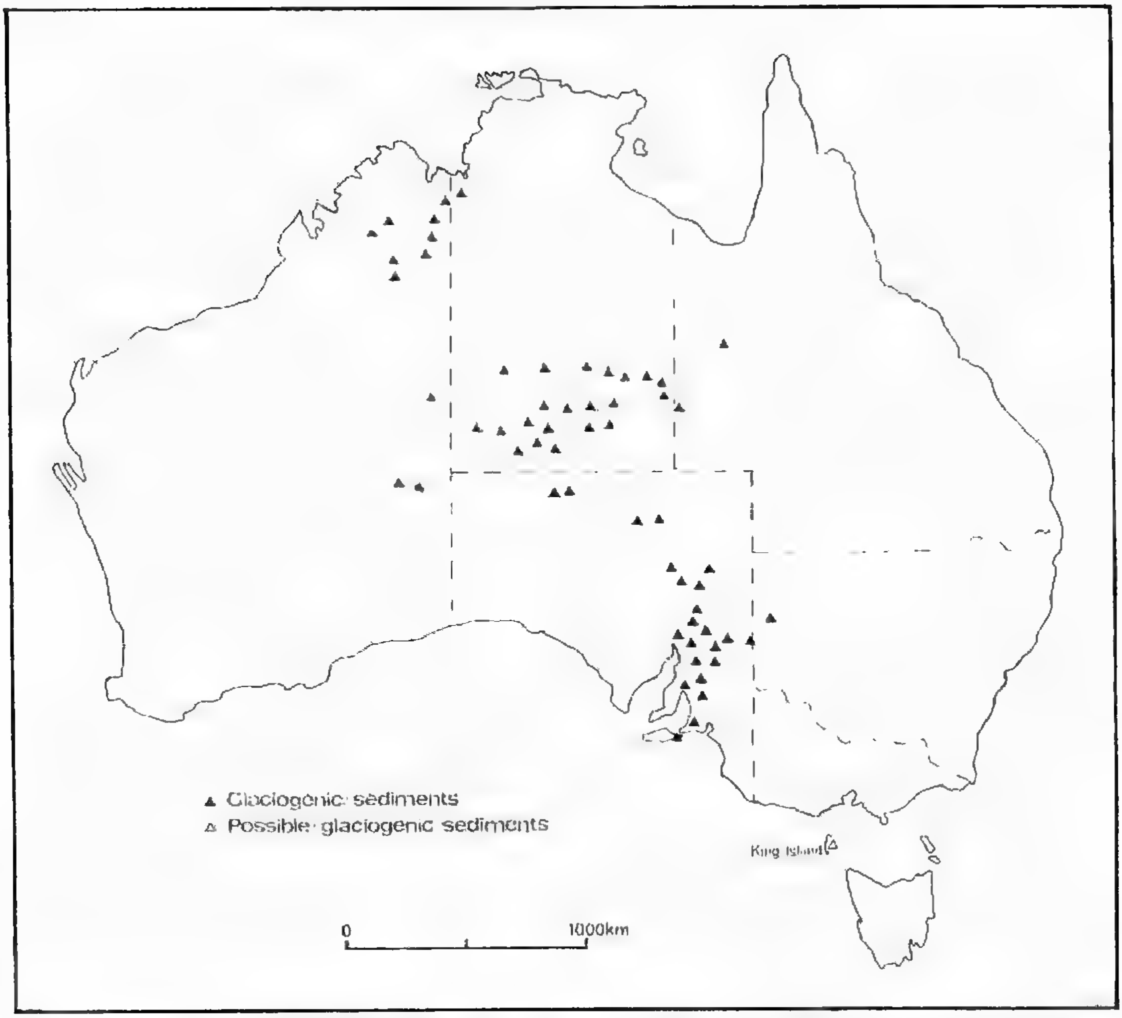

Fig. 1. Distribution of proven and possible glaciogenic sediments in Australia (modified after Dunn *et al.* 1971).

breccia. Schwarzbach (1965) noted the uncertain stratigraphic position of Cottons Breccia which he regarded as being of possible Late Precambrian age. In reviewing the possibility of a world-wide Late Precambrian glaciation, Harland (1964, 1965) included Cottons Breccia in the Late Precambrian tillites.

Solomon & Bartlett (*in* Solomon 1969) produced a generalized stratigraphic succession of the southeast coast of King Island. They noted the presence of striated pebbles and mapped the unit concerned as a Lower Cambrian or Upper Proterozoic tillite. Large (1971) used the term tilloid to describe the rocks under discussion which he included in the Grassy Group. However, the Grassy Group was named by Knight & Nye (1953, p. 1,222) as "the contact metamorphosed sediments of the mine and environs". One of the problems of the geology of the south-east of King Island has been the difficulty in trying to correlate from the City of Melbourne Bay area to the mine area. No satisfactory correlation is available, and hence the term "Grassy Group" should not be used for rocks outside the mine area.

The terminology of sediments of possible glacial origin has been discussed by various workers (Schermerhorn & Stanton 1963, Schwarzbach 1965, Schermerhorn 1966, Harland *et al.* 1966, Cooper 1971, Kröner & Rankama 1972, Rankama 1973). The terms till and tillite have been used for a considerable time for unlithified and lithified glacial sediments respectively (Harland *et al.* 1966). Numerous workers (e.g. Schermerhorn &

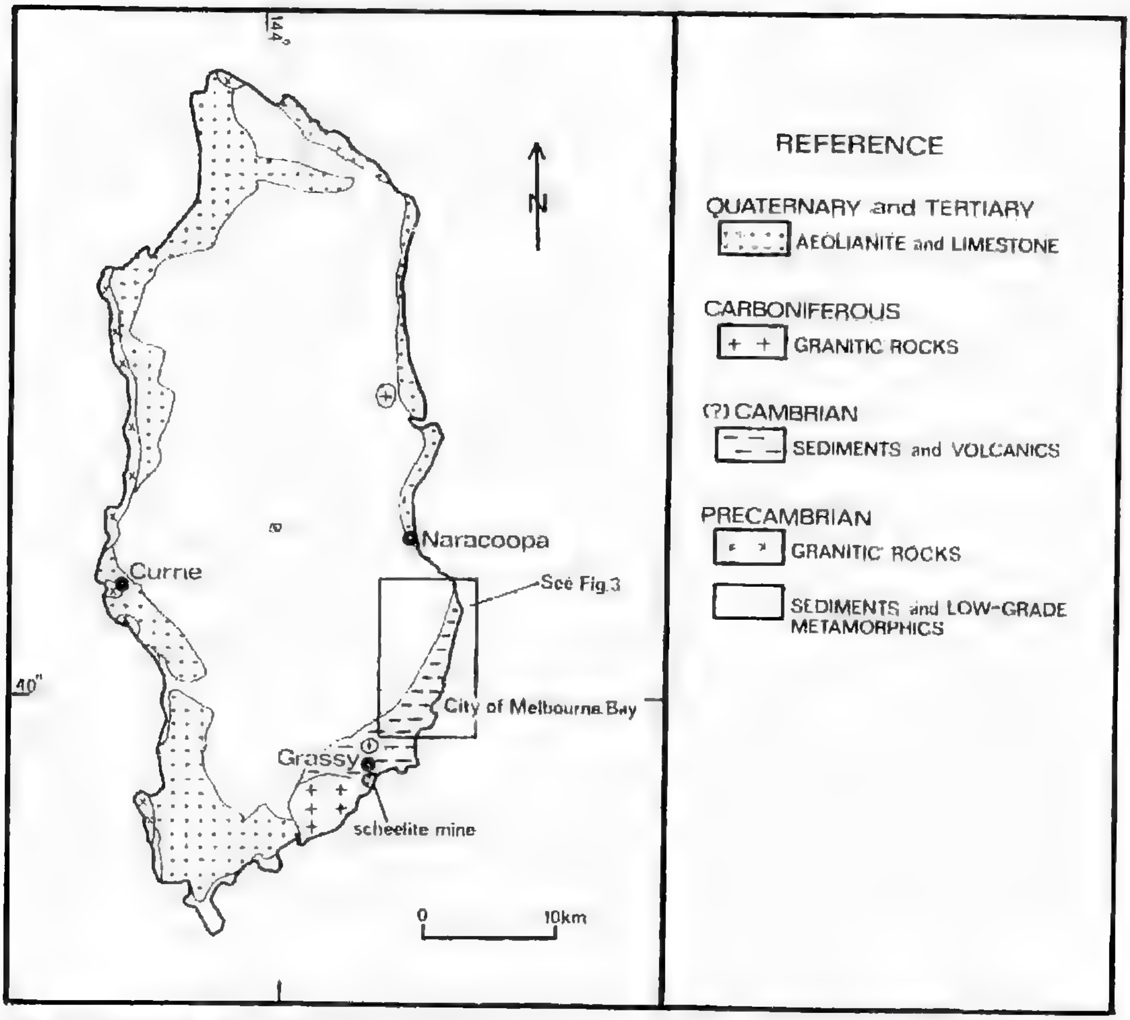

Fig. 2. Geology of King Island (modified after Tasmanian Department of Mines map, 1961 edition).

Stanton 1963, Kröner & Rankama 1972) suggest that the term tillite should be applied only to rocks of undoubted glacial origin. Such terms as tilloid, pseudotillite, diamictite and mixtite have been used to describe tillite-like sediments of doubtful or non-glacial origin. There is no general agreement as to which term, if any, should be used. In the following definition and discussion the term breccia is used because (a) it does not prejudge the origin of the rocks of southeast King Island and (b) it is a suitable descriptive term for these sediments.

Definition

Cottons Breccia is herein defined as that poorly sorted, crudely stratified rock, with angular clasts set in a carbonate or hematite cement, which outcrops over a distance of about 8 km along and near the southeast coast of King Island between Lancaster Creek (lat. 39°57.2'S; long. 144°08.2'E) and Cottons Flat (lat. 40°01.5'S; long. 144°06.9'E). The most common clasts are various carbonates, quartzite and metasiltstones. They range up to 3.3 m across. Cottons Breccia is overlain either conformably by a siltstone or disconformably by a dolomite or dolomitic siltstone. It overlies a metasiltstone with apparent conformity. The formation varies in thickness from about 40 m in the Robbins Creek/Cumberland Creek area to about 100 m in the City of Melbourne Bay area. The lithology varies considerably, both laterally and vertically, over quite short distances. Hence, no type section is designated. The unit is unknown away from the southeast coast of King Island. The age of the formation is either Late Precambrian or Cambrian. Cot-

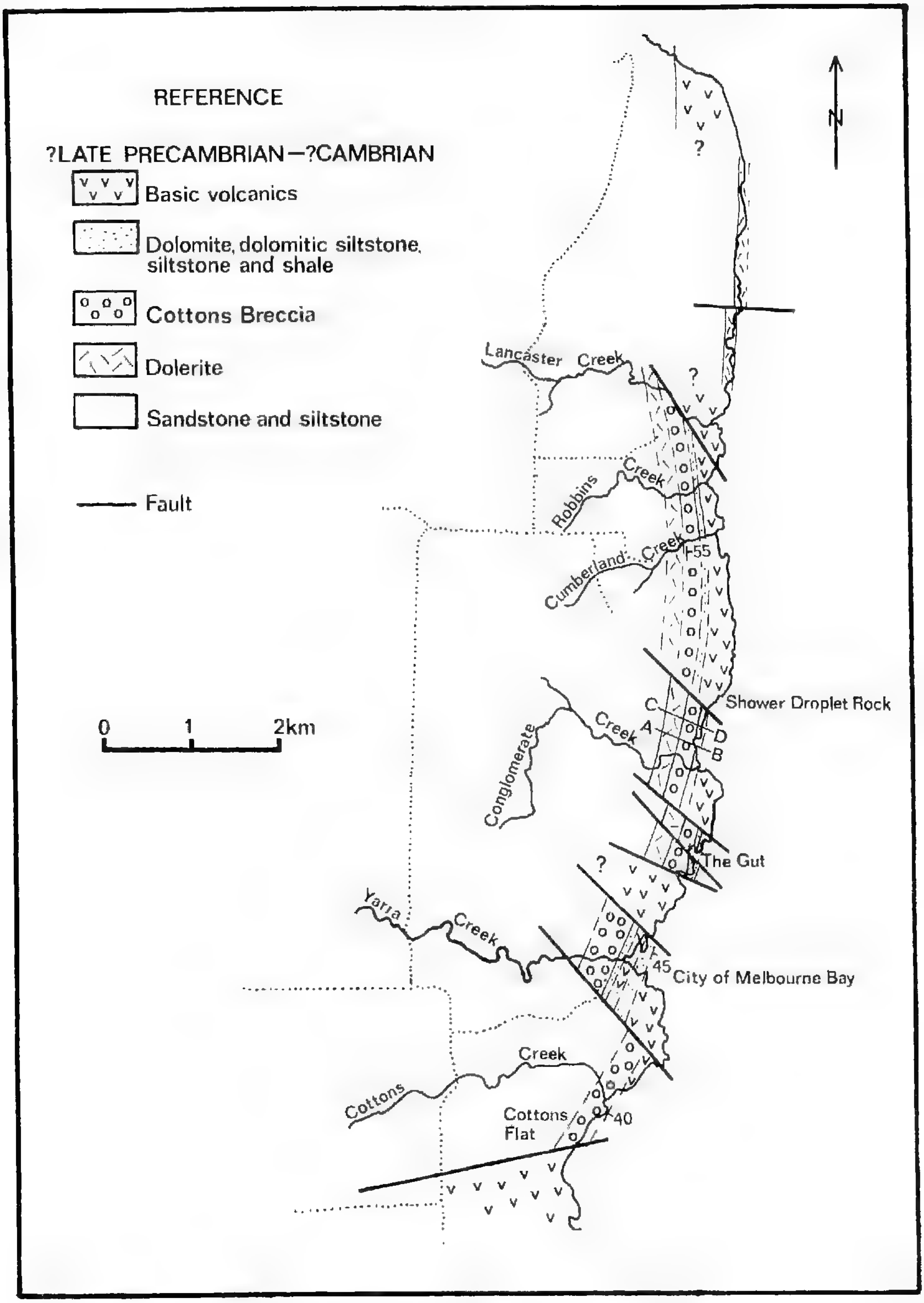

Fig. 3. Geology of part of south-east coast of King Island.

tons Breccia is named after Cottons Creek which enters the sea at lat. 40°01.4'S; long. 144°07.4'E.

Age of Rocks

By comparison with similar volcanics from western and northwestern Tasmania, the volcanics associated with the breccia suggest a Cambrian age (Carey 1947, Scott 1951, Solomon 1969). However, the age of the base of the essentially Cambrian volcanics in Tasmania is unknown; it could be as old as the Late Precambrian.

There is also the reverse argument, i.e. if the breccia is indeed one of the Late Precambrian tillites and that these tillites represent a chronostratigraphic unit as suggested by Dunn *et al.* (1971), then the essentially Cambrian volcanism of Tasmania would have started in the Late Precambrian. The volcanics from King Island have not been dated radiometrically. I conducted an unsuccessful search for fossils in the sediments overlying the breccia.

The only rocks dated radiometrically on King Island are those reported by McDougall & Leggo (1965). These workers concluded that the granitic rocks of the west coast of King Island were most probably emplaced about 750 m.a. If the sedimentary rocks intruded by granite on the west coast are conformably overlain by the sequence containing the breccia on the east coast, then this would suggest a Precambrian age for the breccia. An alternative explanation is that there is an unconformity between the sequences exposed on the west and east coasts of the island (Gresham 1972; Geopeko Ltd., unpublished report). However, over most of King Island away from the coasts, a thin veneer of Quaternary sediments obscures the underlying rocks.

Thus, at present there is no direct evidence for the age of the breccia.

Present Investigation

In order to attempt to determine the origin of Cottons Breccia, 9 days were spent on King Island between December 28, 1972, and January 5, 1973. The geology of the area under discussion is shown in Fig. 3. The breccia is exposed along the south-east coastline between Cottons Flat and Lancaster Creek over a distance of about 8 km. The relationship between the geology of the area shown in Fig. 3 and that of the mine area (immediately south of Fig. 3) is unknown. The breccia appears to be cut off at both the north and south by faults.

Stratigraphic sections were measured across the breccia at various points (Fig. 4). Where possible the sections were measured from the base of the overlying massive volcanics, down through the siltstones and breccia to the underlying dolerite intrusion or sedimentary rock. However, at many localities even the top of the breccia was inaccessible due to the sea. Once away from the shore platform, outcrop is very poor except in the gorges of Cumberland and Robbins Creeks. In the southernmost outcrops in the Cottons Flat area, neither the top nor the bottom of the breccia could be located, although general stratigraphic considerations suggested that the base of the outcrops in this area were close to the base of the breccia. In most sections the breccia appears to conformably overlie a fine quartzite or metasiltstone. However, in Robbins Creek it directly overlies dolerite. In most sections a dolerite intrusion is found only a little way below the base of the breccia.

In some localities (e.g. The Gut) the breccia is overlain with apparent conformity by a fine red hematitic sandstone (Figs. 6 & 7), a laminated red siltstone or a fine green siltstone. However, at one locality about 100 m south of Shower Droplet Rock the laminated dolomite directly overlies the breccia with clear evidence of disconformity between the breccia and the dolomite (Figs. 8 & 9). In both Figs. 8 and 9 the basal part of the dolomite is clearly conglomeratic (particularly Fig. 9).

In the two northern sections (Cumberland Creek, Robbins Creek) the situation is different. In both sections the main body of breccia is overlain by about 3.5 m of a hard, green laminated dolomitic siltstone which in Robbins Creek contains a few pebbles 1 to 2 cm across. This siltstone is in turn overlain by about 1.5 m of fine breccia. In Cumberland Creek this "upper" breccia is overlain by about 3 m of pebbly sandstone before passing up into at least 8 m of well-bedded, purplish siltstone and dolomite. In Cumberland Creek there is no more than 43 m of section between the top of the breccia and the base of the overlying massive volcanics.

In the other sections where the sediments above the breccia and overlying thin siltstone are exposed, there are between 5 and 12 m of laminated dolomite which in places is pyritic. This is followed by between 20 and 35 m of laminated grey, green, and black siltstones and shales, some of which are dolomitic or pyritic. At some localities there are volcanic horizons (tuffs and lavas) within these siltstones. Basic dykes cut the breccia and overlying sediments in numerous localities.

Lithology of Cottons Breccia

The breccia is generally a very poorly sorted, crudely stratified rock with angular clasts set in a carbonate, or a limonite, cement (Figs. 10, 11 and 12).

The breccia varies in thickness from about 40 m in the Robbins Creek/Cumberland Creek area to about 100 m in the City of Melbourne Bay area. However, in the City of Melbourne Bay area the out-crop is poor and the figure of 100 m may be excessive. In the Conglomerate Creek area between the mouth of Conglomerate Creek and Shower Droplet Rock the thickness is about 80 m although outcrop is poor (Figs. 4 and 5) so that the exact thickness is difficult to obtain. However, the presence of scattered float in the parts of the sections shown in Figs. 4 and 5 as "No outcrop" suggests that 80 m is the approximate thickness of Cottons Breccia in the Conglomerate Creek/Shower Droplet Rock area. Thus, there appears a definite thinning to the north. As noted above, neither the top nor the bottom of the breccia is exposed in the Cottons Flat area south of City of Melbourne Bay.

The breccia shows great lithological variation, both lateral and vertical, over extremely short distances. Fig. 5 shows the distribution of clast sizes within the breccia from various sections. The fine breccia in Fig. 5 is where few or no clasts are over 10 cm across; medium breccia is considered to be where there are a substantial number of clasts between 10 and 20 cm across, but few above 20 cm across; coarse breccia is considered to be where there are a substantial number of clasts more than 20 cm across. Admittedly, this is an arbitrary subdivision, but it was found to be a convenient one in the field; hence I feel that it is of some value. As shown in Fig. 5, there is no correlation on the basis of clast size even in closely spaced sections. However, in the Conglomerate Creek/The Gut area there is an apparently continuous, very coarse horizon (1 to 4 m thick) just below the top of the breccia (Figs. 6, 7, 13 and 14). The breccia in Robbins Creek, the northernmost section measured, showed less variation in average clast size than did the breccia further south.

Thin (up to 30 cm across and 10 m long), comparatively well-sorted siltstone and sandstone lenses are reasonably common within the breccia (Figs. 10 and 15). Most horizons show some signs of crude stratification with larger clasts tending to line up with their long axes roughly parallel to the stratification (Figs. 11 and 15). Between Cottons Flat and The Gut there is an apparently continuous horizon of tuff which in thin section shows shards.

The great majority of the clasts show some rounding (Figs. 11 and 13) although some show no rounding at all (Figs. 16 and 17). The largest clasts at any level are usually 30-50 cm across although at many horizons they are less than 10 cm across (Fig. 25). However, at The Gut there is a 15 m interval of very large cream carbonate clasts with the largest clast being over 3.3 m long. This large boulder is itself a conglomerate with light grey carbonate and chert clasts set in a cream carbonate (Figs. 18 and 19). No similar very large clasts were seen away from The Gut.

The clast types include various carbonates, quartzite, pyritic quartzite, chert, metasiltstones, sandstones, red jasper and basic lavas. The various carbonates dominate the clast assemblage with cream and grey dolomites being the most common (Fig. 12), except in the Cottons Flat area where quartzite clasts tend to be as common as the carbonate clasts. A very dark limestone is found occasionally near the top of the breccia (Fig. 13); a few oolitic limestone clasts are known throughout the sections.

Quartzite clasts tend to make up the majority of clasts over 20 cm across. The pyritic quartzite clasts were seen only in the Cottons Flat area. The smallest clasts (less than 3 cm) tend to contain a predominance of black, green and grey, sometimes laminated, metasiltstones. Rare cross-bedded siltstone clasts are known. The red jasper clasts are quite rare, although they are up to 40 cm across.

In any one section, a particular cream dolomite or a black metasiltstone may predominate at a certain level. However, when plotted over the whole area, it was found that the common clast types occur throughout the breccia and that no particular clast type can be said to be characteristic of any particular level within the breccia, with the probable exception of the rare very dark limestone mentioned above.

Very rare clasts of basic lavas are known. No acid igneous rocks or high grade metamor-

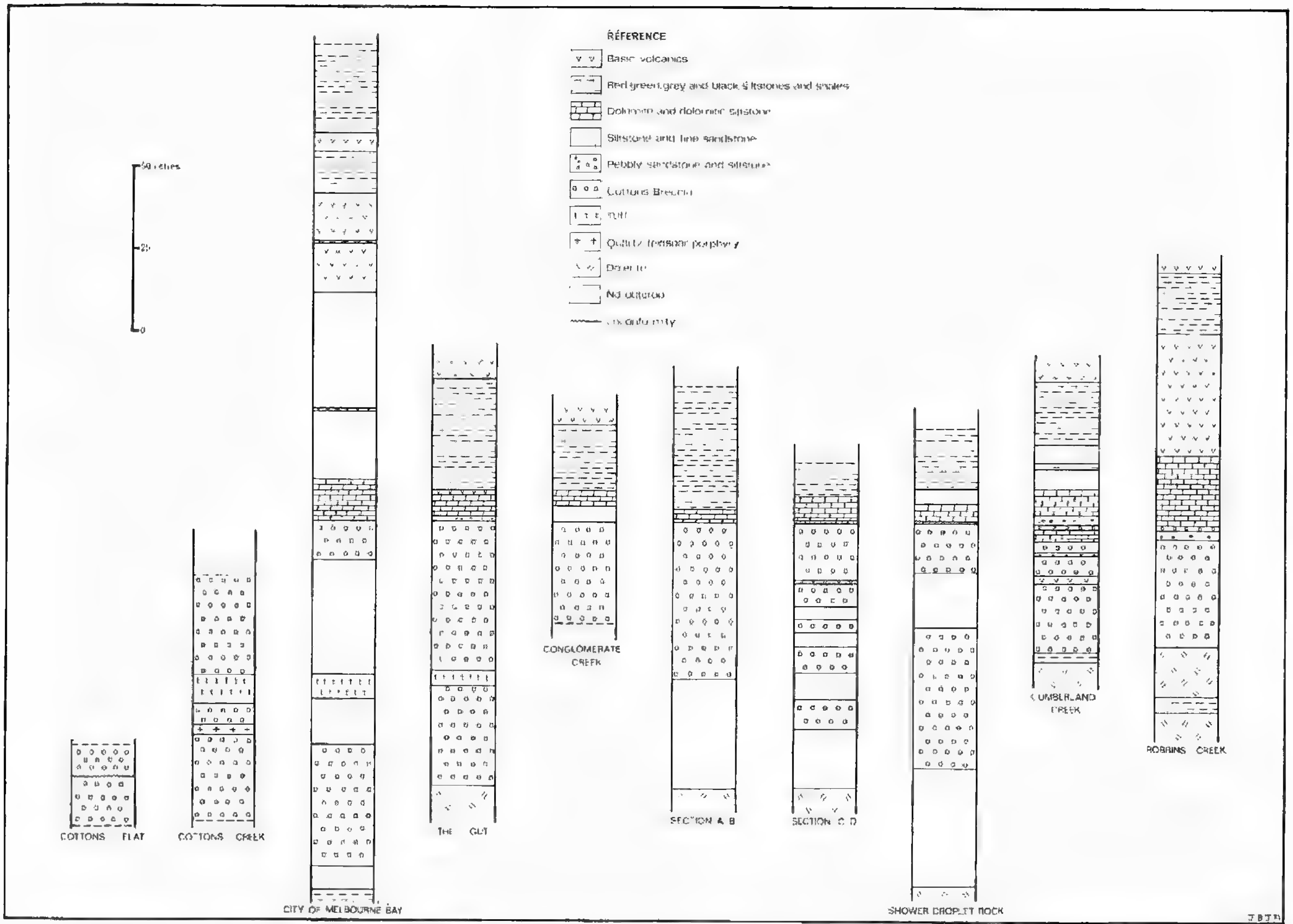

Fig. 4. Stratigraphic sections through Cottons Breccia and adjacent rocks from Robbins Creek to Cottons Flat. The locations of sections A-B and C-D are shown in Fig. 3.

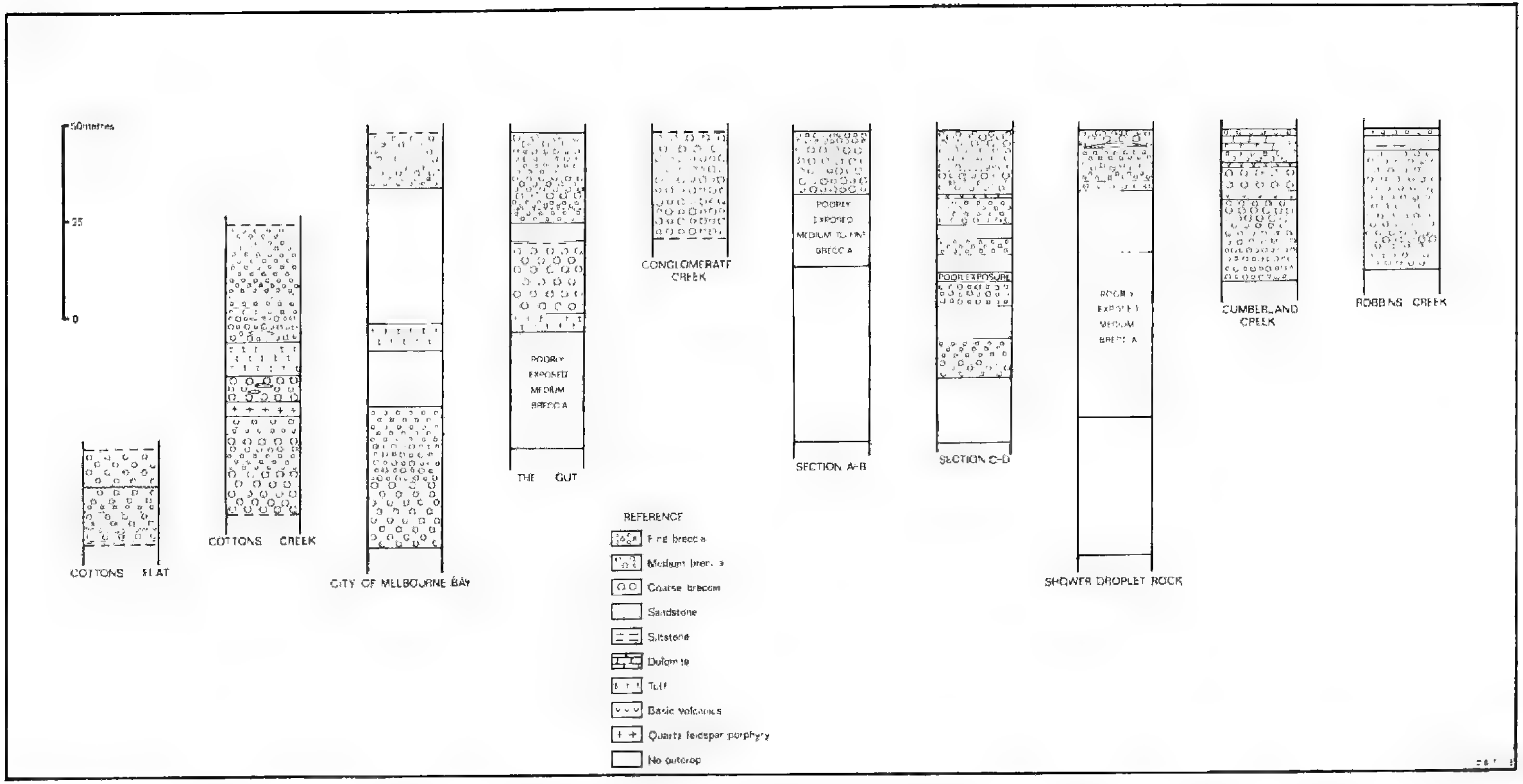

Fig. 5. Distribution of clast sizes within Cottons Breccia. Fine breccia is where few or no clasts are over 10 cm across; medium breccia is considered to be where there are a substantial number of clasts between 10 and 25 cm across, but few above 20 cm across; coarse breccia is considered to be where there are a substantial number of clasts more than 20 cm across.

phic rocks are known from the clast assemblage.

Since the source of the clasts is unknown, a classification into intrabasinal and extrabasinal types in the manner of Schermerhorn & Stanton (1963) is inapplicable.

Sedimentary Structures within the Breccia

In the Cottons Flat area, graded bedding is quite common. There are two scales of graded bedding. The finer scale of graded bedding is exposed towards the base of the outcrops in a fine green sandstone and siltstone with pyrite pseudomorphs. Each graded layer is between 2 and 3 cm across. The best exposures of the coarser scale of graded bedding are just south of Cottons Creek where each graded layer is up to 30 cm across (Fig. 20). One possible example of reversed grading is seen in the Cottons Flat area. Graded bedding is not seen away from the southern outcrops.

There is at least one well marked local disconformity within the breccia at the southernmost outcrop at Cottons Flat. There appear to be disconformities within the breccia at other localities, e.g. at The Gut just above the biggest clast (Fig. 21). However, the generally very poorly bedded nature of the breccia makes disconformities within it difficult to pick out.

There are a few examples of wet sediment movement within the breccia. At one location in the Cottons Flat area convoluted bedding indicates a west to east movement of the sediment. In the vicinity of The Gut there are rare clasts of sandstone which show clear evidence of being transported to the site of deposition before being properly consolidated (Fig. 22).

Striated pebbles have been reported by Solomon (1969), but the writer did not observe any such pebbles. There are several examples of what may be drop-stones (Figs. 23 and 24). These figures show possible drop-stones in the Cottons Flat area. Figure 24 is of particular interest in that the surrounding sediment is reasonably fine grained. About 5 cm below it there is a 6 cm thick set of laminae of graded fine sandstones and siltstones which could be interpreted as varves.

Origin of Cottons Breccia

The criteria used for the recognition of glacial sediments have been discussed or listed by several workers (Flint 1961, 1971; Harland 1964, 1965; Schwarzbach 1964; Heezen & Hollister 1964; Harland *et al.* 1966; Hamilton & Krinsley 1967; Kröner & Rankama 1972).

Harland *et al.* (1966) comprehensively reviewed the criteria for distinguishing tillites from other rocks. They concluded that there is only one criterion which can be considered to be unequivocally in favour of a sediment having a glacial origin, i.e. the presence of numerous large boulders penetrating and deforming a series of host strata. However, as noted by Harland *et al.* (1966) the shape, surface, size and composition of the clasts within the sediment under consideration may be used in favour of a glacial origin if the features are of sufficient quantity and quality.

Harland *et al.* (1966) also note that the presence of extensive grooved and striated pavements also clearly indicates glacial abrasion, e.g. the Late Precambrian pavements of the Kimberly Region of Western Australia described and figured by Dow (1965), Dow & Gemuts (1969) and Perry & Roberts (1968). However, problems arise when there are only limited exposures of pavements or possible pavements (e.g. Daily *et al.* 1973). One of the most commonly used criteria for evidence of glaciation is the presence of striated clasts. However, striations can be formed by other means (Harland *et al.* 1966). Despite this, some workers (e.g. Bruckner & Anderson 1971) continue to use the presence of striated clasts as unequivocal evidence of a glacial origin for the enclosing sediment.

If a tillite-like sediment is not of glaciogenic origin, the most commonly postulated alternative explanation is a mudflow or density flow origin (e.g. Schermerhorn & Stanton 1963; Winterer 1964; Schermerhorn 1964). Schermerhorn & Stanton (1963) listed 22 points as evidence in determining whether a breccia from the West Congo Geosyncline should be considered to be of glacial origin or of density flow origin. Kilburn *et al.* (1965, p. 358) dispute the validity of all but three of these criteria and suggest that the criteria which favour a density flow origin are (1) the presence of graded bedding, (2) the presence of the largest boulders in the thickest tillite-like beds and (3) the occurrence of tillite-like sediments at the beginning of sedimentary cycles accompanied by sharp epeirogenic downwarping of the basin. Flint (1971, Table 7-B) tabulated the characteristics of tills and tillites as compared with tillite-like sediments of non-glaciogenic origin. Heezen & Hollister (1964) stated that turbidity current deposits are frequently associated with glaciation but they need not be. An example of this is the Late Palaeozoic glacial sequences of the Falkland Islands which in part are the result of submarine mass movement (Frakes & Crowell 1967) although a similar case from the Late Precambrian of northern Norway described by Siedlecka & Roberts (1972) has been strongly disputed by Bjorlykke (1973). Heezen & Hollister (1964, Table 1) suggested that although turbidity current deposits are clearly different from glaciogenic sediments, tillites and sediments of mudflow origin are very difficult to distinguish. Kilburn *et al.* (1965) and Spencer (1971) have suggested that the presence of discontinuous horizons of sorted sediment (mudstone and sandstone) within a structureless breccia are difficult to explain by a mudflow hypothesis and that such horizons indicate a glacial origin for the breccia. Dott (1963), Fisher (1971) and Cook *et al.* (1972) have discussed various aspects of sediments derived from submarine gravity transport.

The points in favour of Cottons Breccia being of glaciogenic origin are

1. the angular nature of most clasts;
2. the possibility of drop-stones being present;
3. the presence of some fine graded sediments within the breccia in the Cottons Flat area which could be interpreted as varves;
4. the presence of undeformed and comparatively well sorted sandstone and siltstone lenses up to 10 m long within the breccia.

The main features of the rock suggesting that the rock is not of glaciogenic origin are:

1. The presence of a considerable amount of coarse graded bedding in the Cottons Flat area. Although the fine scale grading noted above could be considered as varves, the coarse grading shown in Fig. 20 is unlikely to have been deposited by glacial action.
2. The "conglomerate in conglomerate" nature of the largest boulder at The Gut indicating that there are at least two similar depositional cycles involved in the deposition of this boulder.
3. The only non-sedimentary clast types are rare basic lavas which are almost certainly of local origin. In other well known glacial sequences, e.g. the Permian rocks of Tasmania and the Late Precambrian Sturt Tillite of South Australia, metamorphic and igneous clasts are very prominent where there are abundant clasts. This suggests a non-glacial origin for Cottons Breccia, although such evidence is clearly far from conclusive, because the clast types in glacial sequences depend on the terrain over which a glacier has passed.

No formation similar to Cottons Breccia is known in the Late Precambrian or Cambrian sequences of Tasmania. If such a formation was found in a similar stratigraphic position then the aerial extent of the rock would probably indicate a glacial origin.

Dolomite, or a dolomitic siltstone, is closely associated with many of the confirmed Australian Late Precambrian tillites (Dunn *et al.* 1971). Spencer (1971) and Spencer & Spencer (1972) have noted the association of proven tillites and dolomites in Late Precambrian sequences. The presence of dolomite and dolomitic siltstones just above Cottons Breccia may indicate glacial or at least cold conditions. Spencer & Spencer (1972) have noted the apparent contradiction of the high temperature origin (>22°C or 35–55°C) usually proposed for primary dolomite in relation to the associated cold temperature tillites.

Fisher (1971) has suggested that coarse-grained deposits, formed by high concentration debris flows, will be poorly sorted, will have an unsupported framework, may include elongate fragments aligned roughly parallel with the bedding and may show inverse grading. These features are present in Cottons Breccia except that the grading in Cottons Breccia is normal. However, as noted above, sediments formed by submarine mass movement are quite likely to be found in a glacial environment.

The presence of volcanics within Cottons Breccia indicates that, at the time of deposition, the King Island area may have been tectonically active. Intermittent earthquakes could have given rise to a series of debris flows. Against this is the presence of the comparatively well sorted thin lenses of sandstone and siltstone within the breccia. Such bodies are difficult to explain if a gravity slide mechanism is invoked for the origin of the breccia (Kilburn *et al.* 1965; Spencer 1971).

Conclusions

The evidence discussed above does not provide an unequivocal answer to the problem of the origin of Cottons Breccia. Features such as drop-stones, the thin sandstone lenses within the breccia and the associated dolomite favour a glacial origin. The presence of graded bedding, the crudely stratified nature of the breccia and the fact that almost all the clasts are of sedimentary origin tend to favour a density flow formation. It is possible that Cottons Breccia originated in a tectonically active area by a combination of glacial action and submarine mass transport, i.e. it may represent a density flow deposit derived from an area affected by glaciation. The area in which the breccia was deposited was intermittently affected by volcanism and may have had icebergs floating on the overlying sea, releasing debris which dropped into the underlying sediment.

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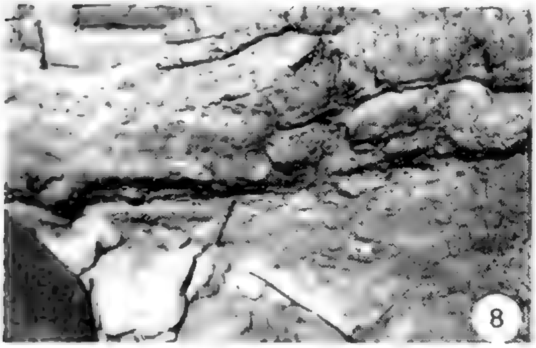
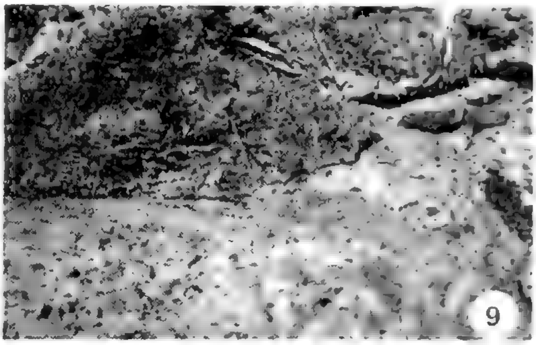
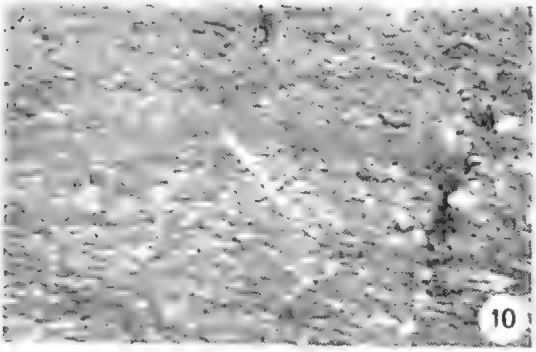
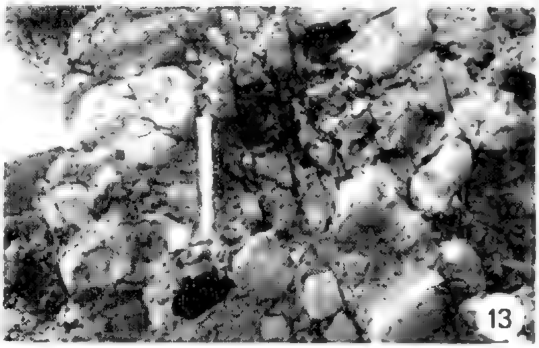








Figs. 6-13

Figs 6, 7. Conformable contact between Cottons Breccia and the overlying laminated haematitic sandstone and siltstone. In Fig. 6 note the laminated nature of the overlying haematitic sandstone and siltstone. Locality, immediately north of The Gut. Hammer length is 32.5 cm.

Fig. 8 Disconformable contact between Cottons Breccia and the overlying dolomitic siltstone. Pencil points to the contact. Note the pebbly nature of the base of the dolomitic siltstone and its more laminated nature higher in the section. Locality, about 100 m south of Shower Droplet Rock. Hammer length, 32.5 cm.

Fig. 9. Disconformable contact between Cottons Breccia and the overlying dolomitic siltstone. Pencil points to the contact. Note the very pebbly nature of the base of the dolomitic siltstone. Locality, close to that of Fig. 8. Pencil length, 15 cm.

Fig. 10. Sandstone lens within Cottons Breccia. Locality, about 40 m south of the mouth of Cottons Creek. Hammer length, 32.5 cm.

Fig. 11. Long axes of clasts aligned roughly parallel to the stratification. Locality near Shower Droplet rock. The largest pebble is about 15 cm long.

Fig. 12. Fine breccia showing pockmarked nature of rock due to carbonate pebbles being eroded out. Locality, The Gut. Hammer length, 32.5 cm.

Fig. 13. Very coarse breccia near top of Cottons Breccia. Note the slightly rounded nature of almost all clasts. The four large very dark clasts, including the one immediately below the hammer head, are composed of a dark limestone which is found only near the top of the formation. Most of the larger pebbles are quartzite. Locality, The Gut. Hammer Length, 32.5 cm.

Fig. 14. Very coarse horizon near top of Cottons Breccia. Note the overlying quite fine horizon. Locality, Section AB about 100 m north of Conglomerate Creek. Hammer length, 32.5 cm.

Fig. 15 Siltstone lens within Cottons Breccia. Note the alignment with bedding of the large carbonate boulder to the right of the hammer. Locality, The Gut. Hammer length, 32.5 cm.

Fig. 16 Large flat clast (quartzite) showing no sign of rounding. Locality, section C-D. Hammer length, 32.5 cm.

Fig. 17 Large angular clast (quartzite). Locality, Cottons Flat. Hammer length, 32.5 cm.

Fig. 18 Very large carbonate clast (total length is at least 3.3 m). Note the conglomeratic nature of the clast which contains light grey carbonate and chert clasts up to 12 cm across. Locality, The Gut. Hammer length, 32.5 cm.

Fig. 19. Same clast as in Fig. 18. The top and bottom of this large clast are roughly parallel with the bedding which trends from the top left to the bottom right of the photograph. Hammer length, 32.5 cm.

Fig. 20 Coarse graded bedding on broken slab of breccia. Locality, 30 m south of mouth of Cottons Creek. Hammer length 32.5 cm.

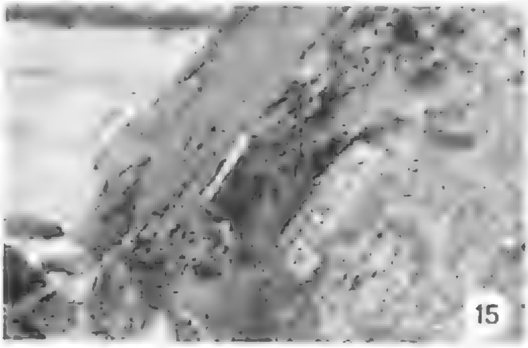
Fig. 21 Possible disconformity (tip of pencil) within Cottons Breccia. Largest clast (see Figs. 18 and 19) is immediately below the field of view. Locality, The Gut. Hammer length, 32.5 cm.

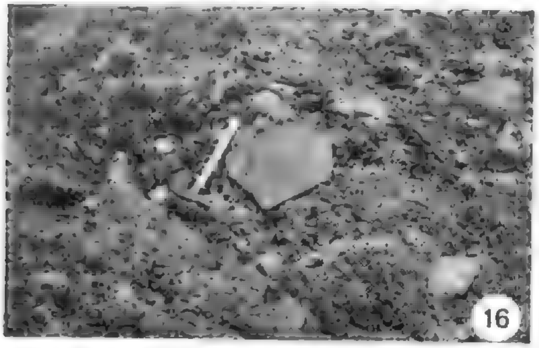
Fig. 22 Sandstone clast showing disturbed bedding indicating that it was transported to the site of deposition before it was properly consolidated. Locality, The Gut. Hammer length, 32.5 cm

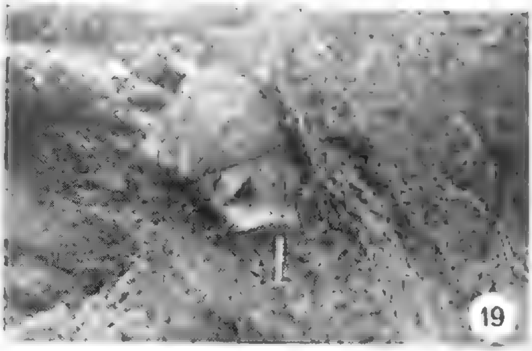
Fig. 23 Possible drop-stone. Locality, Cottons Flat. Pencil length, 15 cm.

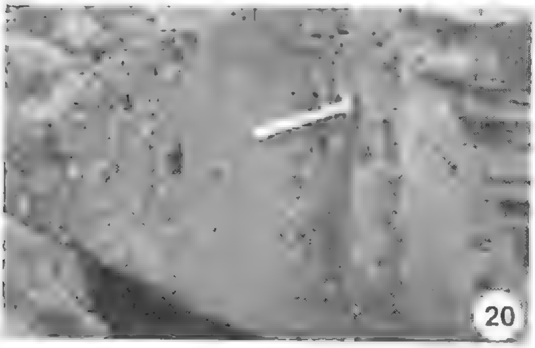
Fig. 24. Possible drop-stone. Note the laminated and graded nature of the fine sandstone and siltstone a short distance below the (?) drop-stone. These could be interpreted as varves. Locality, Cottons Flat. Pencil length, 15 cm.

Fig. 25 Fine breccia. Locality, about half way between the mouth of the Conglomerate Creek and Shower Droplet Rock. Pencil length, 15 cm.









Figs. 14-21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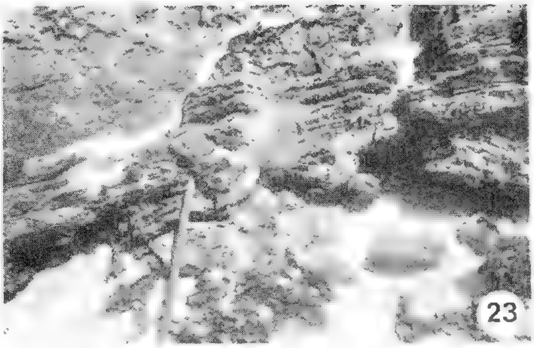
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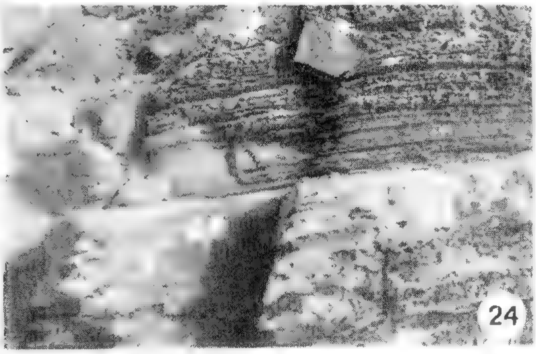
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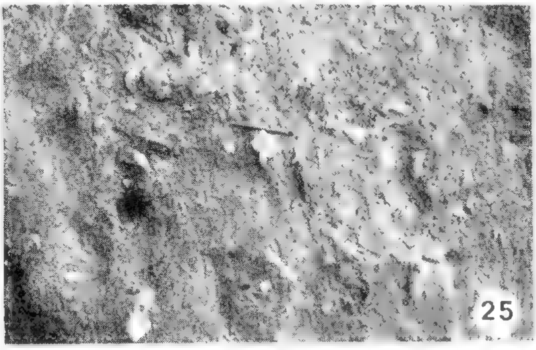
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Figs. 22-25

STRATIGRAPHY AND PALYNOLOGY OF THE PERMIAN AT WATERLOO BAY, YORKE PENINSULA, SOUTH AUSTRALIA

*BY C. B. FOSTER**

Summary

FOSTER, C. B. (1 974) .-Stratigraphy and palynology of the Permian at Waterloo Bay, Yorke Peninsula, South Australia. *Trans.* R. *Soc.* S. *Aust.* **98**(1), 29-42, 28 February, 1974.

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Introduction

Palynostratigraphic correlations with other Permian deposits of Australia have resulted from the recovery of Permian, and reworked Devonian, miospores from sediments of the Waterloo Bay area (Fig. 2). The sediments of the Troubridge Basin are regarded as glacigene deposits (Ludbrook 1969a). Field observations and a biofacies analysis presented in this paper support this and the consequent overall palaeogeographic setting.

The first record of a Permian microflora within the Troubridge Basin (Fig. 1) was given by Cookson (1955, p. 57) when she reported reworked palynomorphs in a deposit of "probable Eocene age". More recently, Harris & McGowran (1971) recorded for the first time *in situ* Permian miospores. One sample collected from the Waterloo Bay area yielded a particularly well preserved assemblage. The purpose of this study was to re-examine the section containing this assemblage. This involved detailed mapping and precise stratigraphic sampling. Samples collected yielded palynomorphs and Foraminifera; no other fossil groups were found. Subsurface material from the Peesey Swamp bore, PDH No. 1, provided moderately well preserved assemblages allowing an intrabasinal correlation. This was in contrast to the subsurface material examined by Harris & McGowran which was poorly preserved. Bore locations are shown in Fig. 1.

Methods

Cliff sections were measured using a Jacob staff with a sighting attachment (Kottlowski 1965). Working from the water's edge, it was possible using Tide Tables (S.A. Dept. Marine & Harbours 1972) to calculate the height of the base of the cliff sections above mean sea level. This provided the "datum" shown in Fig. 2. Section locations were plotted on a base map prepared from air photographs (S.A. Dept. Lands, Svy.962; 2549, 2535) and section heights checked with the Edithburgh Topographic Map (Sheet 828; S.A. Dept. Lands). A 7 cm diameter "post hole digger" was used for field sampling to obtain less weathered samples at depth (max. 1.2 m).

Palynological samples were prepared by treatment with hydrofluoric acid to remove silicates. Excess organic material was then removed using warm Schulze solution followed by alkali. The use of heavy liquid density separations ($ZnBr_2$; S.G. 1.98–1.6) and ultrasonic cleaning improved the yield. Samples

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examined for Foraminifera were processed using standard techniques (Glaessner 1945).

Palynological residues and strew slides deposited in the South Australian Geological Survey Palynological Collection are prefixed "S". Slide coordinates given are from a Leitz Laborlux microscope No. 579756 housed at the Survey.

Locality

The study area, 16 km SW of Edithburgh, occurs as upthrown fault blocks (Wopfner 1970) and forms the southwestern part of the

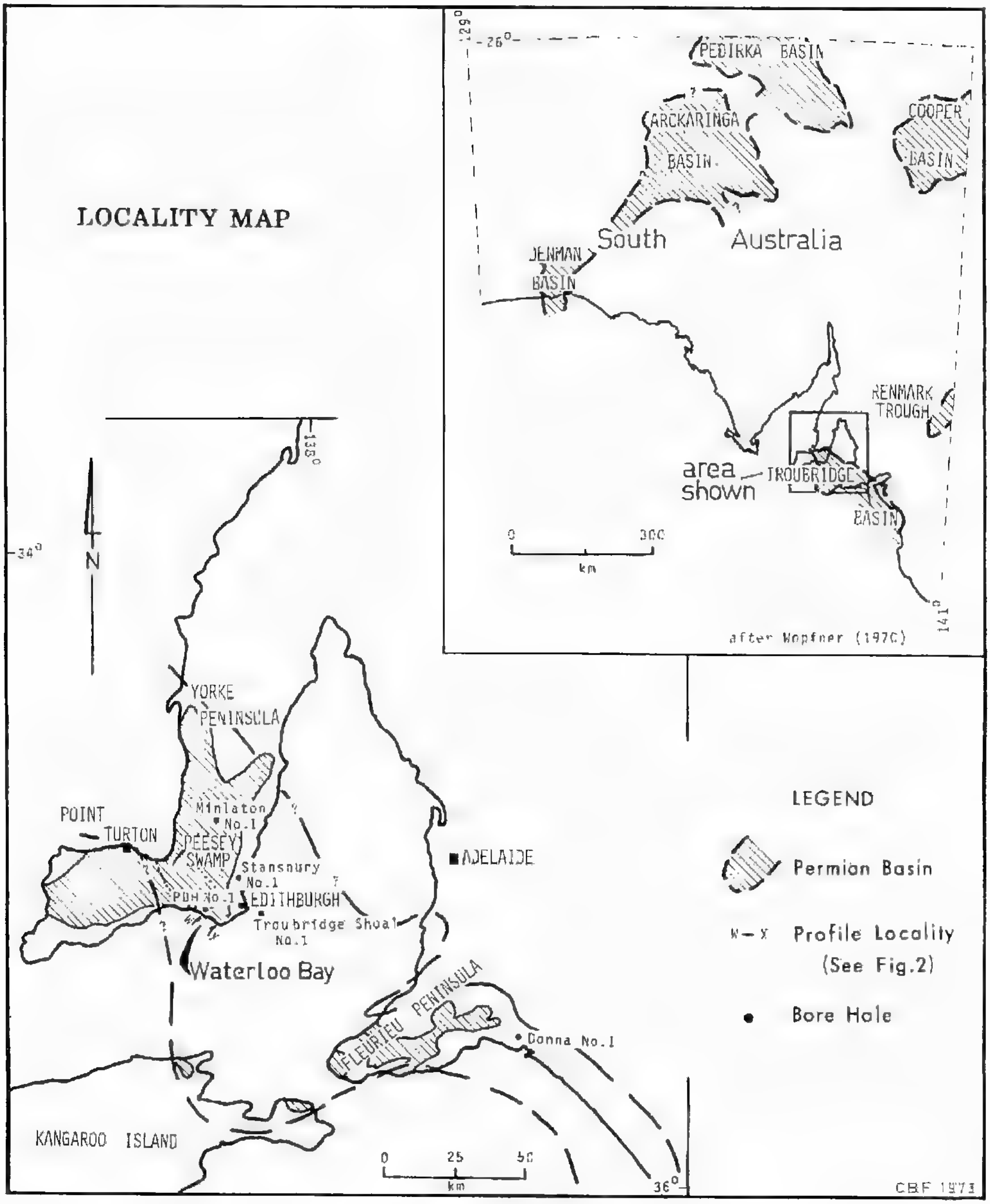


Fig. 1. Locality map.

Troubridge Basin, as defined by Wopfner (1969). It is gently undulating with salt lakes occupying many of the low lying areas. The existence of these lakes, many with scattered erratics about their margins (Howchin 1900), infers the ubiquity of the underlying Permian clays. A thick calcrete capping obscures the geology of the area except in coastal sections where maximum thicknesses of 31 m are exposed. Large erratics and boulder trains litter much of the beach area. Pink garnetiferous sands, which have been associated with glacigene deposits (Coats 1962), occur in high concentrations along parts of the beach.

Stratigraphy

Columnar stratigraphic sections and the coastal profile of Waterloo Bay are shown in Fig. 2.

Permian

The lowermost outcrop, a brown gritty siltstone containing erratics, occurs at beach level and is poorly exposed. Small-scale slump structures were observed, although elsewhere there is no evidence of bedding. Samples collected from this level were barren.

Overlying this, and forming the base of the cliff sections, are black to blue-grey, sandy, micaceous clays. They are carbonaceous in part and on weathering appear grey-white. The sand fraction is poorly sorted and ranges from clear, angular to frosted, well rounded grains. Maximum thickness of the unit is 12 m. Small erratics ($3\ cm^2$) of granitic, gneissic and quartzose composition are scattered throughout. These are smaller than the erratics on the beach, which have been reworked to form modern lag deposits. The sediments are moderately indurated, but lack the fissility typical of shales and the compactness of mudstones; consequently they are referred to as claystones (Pettijohn 1957). Samples yielded a well preserved microflora and a few arenaceous Foraminifera.

Interbedded within the claystones are discontinuous sand lenses, which include fine grained light blue to white and coarse red sands. The origin of these sands is not known, although R. P. Harris (1971, unpublished B.Sc. Honours Thesis, University of Adelaide) has suggested that they are wind blown. Samples collected from these lenses for foraminiferal analysis were barren. Many of the lenses exhibit prominent ferruginous concretionary structures, up to 1 m in diameter; these are most probably weathering features. Generally the contact between the claystones and the sand is sharp; at one locality (Section 8, Fig. 2), the lens overlies a cobble bed (40 cm thick) but it is not traceable for more than 2 m. The bed could represent Permian reworked sediments forming a channel deposit. Similar lag deposits were seen at Point Turton (Fig. 1).

Much of the unit is severely ironstained which gives the outcrop a grey/orange mottled appearance. This apparent lateritization (Crawford 1965) could be a post-Permian surface feature. Ludbrook (1965), however, records iron-staining in subsurface material. Reynolds & Johnson (1972) have reported chemical weathering (lateritization) in a recent subglacial environment, and so the possibility of this being a Permian feature cannot be discounted.

A comparison of the outcrop with the lithologies logged from the Stansbury No. 1 and Minlaton No. 1 Stratigraphic bores (Ludbrook 1965) places the claystones high within the local Permian section and includes them within the Cape Jervis Beds (see also Ludbrook 1969b).

?Permian Clays and Sandstones

Clays, which are mottled reddish green, occur mainly as slope cover. The heavily weathered nature of the unit obscures its boundary contacts (max. thickness 5 m).

Sandstones, which consist of grey white, ill-sorted, poorly indurated clayey sand with small erratics. Where it is not in direct contact with the sea (e.g. Section 8), it weathers to form peculiar columnar structures. These appear to be the result of two sets of "jointing"; the earlier horizontal set could be following bedding planes with the latter set perpendicular to the first. Maximum thickness 4 m.

Samples collected from these units were barren and considering the possibility of post-Permian reworking their exact age is not known. An essentially similar outcrop to that of Section 8 was found at Port Moorowie (Sections 2 and 3) and has been mapped as "Permian" by Crawford (1965).

Tertiary

These are horizontally bedded, buff to pink, polyzoal limestones (Section 10) that have been sporadically calcreted. They form resistant headlands for 2 km along the coast to Troubridge Hill. Underlying the calcrete the pinkish limestone is strongly recrystallised and shows numerous irregular solution cavities. Below this level the unit becomes less recrystallised and contains distinctive buff coloured "sub-units". Angular quartz gravel bands grading upwards to coarse brown iron-stained sands occur at several intervals throughout the unit. Maximum thickness 24 m.

Foraminifera from samples of these less indurated sub-units indicate a Late Eocene age and suggest correlation with Rogue Formation and basal Port Willunga Beds (J. M. Lindsay, 1972, S.A. Department of Mines, unpublished report, RB 72/190).

The Pliocene Hallet Cove Limestone, which Crawford (1965) has shown to occur at Point Gilbert, was not found at this locality.

Ardrossan Clays and Sandrock (Crawford 1965)

The maximum thickness of the unit at this locality is 1.7 m. This includes the mottled green-brown sandy clays containing grit bands and deeply weathered erratics and the unconformably overlying red-brown clays with their distinctive "alunite and/or kaolinite" bands (Crawford 1965, pp. 40-41).

X-ray diffractometer (X.R.D.) analysis of samples collected from these bands indicated mainly illite (R. J. Love, personal communication). A similar lithology was sampled at the Tertiary/Permian contact (Section 10) and X.R.D. analysis showed a similar clay mineralogy to that from the Quaternary sequence. Therefore, it is most likely that these bands are a post-depositional feature.

Quaternary Aeolianite and Calcrete

Aeolianite, the maximum exposure of this grey-white poorly indurated calcarenite (8 m), occurs where it forms a prominent headland and an associated wave-cut platform (Section 5, Fig. 2). This is the only section which exhibits large scale cross-bedding. Elsewhere in the profile the unit is horizontally bedded but is easily identified by its distinctive "swallow hole" weathering pattern. Planktonic and benthonic Foraminifera recovered by Lindsay (1972, cited above) from a well bedded buff calcarenite (1 m thick) contained within the aeolianite sequence (Section 5) were considered by Lindsay to indicate a Late Cainozoic age and identification as Bridgewater Formation (Firman 1969).

Calcrete, of varying thickness (up to 8 m), and in part underlying the aeolianite, forms a blanketing surface seen in all sections. In places it was possible to identify up to five distinctive "beds" which were of limited lateral extent. One such "bed" (0.8 m, Section 8) consisting of black, rounded to angular fragments within a light green calcareous matrix, could be traced for 10 m before becoming "absorbed" into the more massive featureless calcrete to the east and faulted out to the west. The unit is sandy and friable at the base becoming more nodular to massive at the top.

Taxonomic List of Permian Microflora

Forty-six species, from thirty genera, of Permian palynomorphs were identified from ten samples. Sample locations *not* shown on Fig. 2 occur away from the sections illustrated. Precise locations of all samples accompany the slides deposited at the Geological Survey. Fifty-two strew slides were examined; selected species are figured. The miospore genera are arranged alphabetically within the classificatory scheme proposed by Potonié (1956 and subsequent publications) and its emendations, especially those of Dettmann (1963).

Where necessary, brief notes on taxa have been included; the descriptive terminology used is in keeping with Kremp (1965). Disaccate measurements are in accord with Segroves (1969, Fig. 1, p. 176).

Quantitative microfloral data and the chronostratigraphic significance of the Waterloo Bay Assemblage are discussed later in the paper.

Anteturma SPORITES H. Potonié 1893

Turma MONOLETES Ibrahim 1933

Suprasubturma ACAVATOMONOLETES Dettmann 1963

Subturma **AZONOMONOLETES** Luber 1935

Laevigatosporites flexus Segroves 1970 (Fig. 14)

Laevigatosporites sp.

Tuberculatosporites modicus Balme & Hennelly 1956

Turma TRILETES Reinsch, emend. Dettmann 1963

Suprasubturma ACAVATITRILETES Dettmann 1963

Subturma **AZONOTRILETES** Luber, emend. Dettmann 1963

Acanthotriletes teretiangulatus Balme & Hennelly 1956

Apiculatisporis levis (Balme & Hennelly) Segroves 1970

Apiculatisporis sp. (Fig. 8)

Trilete, laesurae extending to equator and sometimes bifurcating at termini. Lips developed 0.5μm wide and unsculptured. Amb round to oval, boundary uneven. Sparsely spaced broad coni (1–2 μm wide) are arranged concentrically on the distal face. Diameter (10 specimens) 18–37 μm.

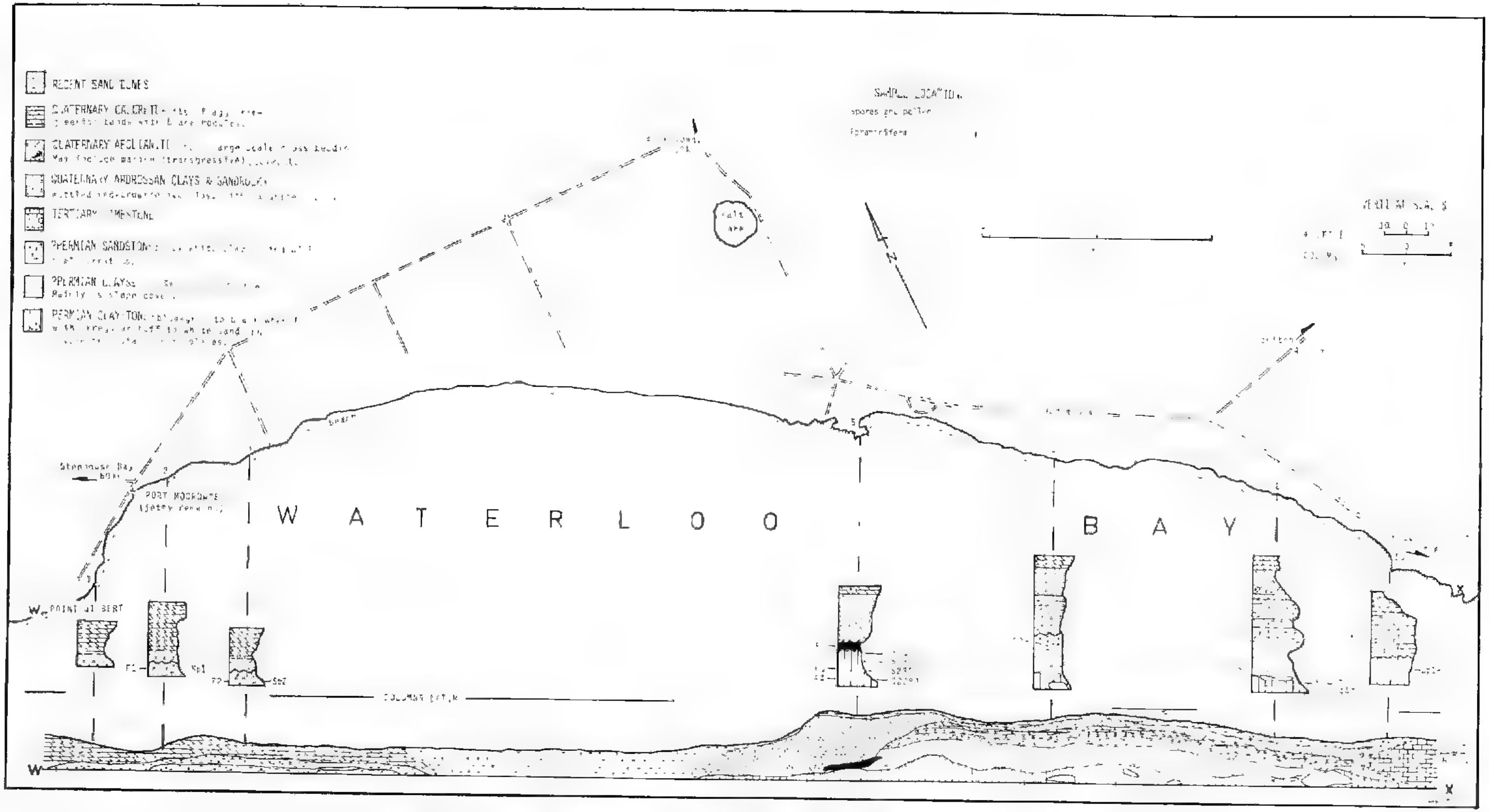


Fig. 2. Columnar stratigraphic sections and coastal profile, Waterloo Bay.

Baculatisporites sp.

Calamospora diversiformis Balme & Hennelly 1956

Calamospora sp. cf. *C. microrugosa* Schopf, Wilson & Bentall 1944

Deltoidospora directa (Balme & Hennelly) Norris 1965

Densoisporites solidus Segroves 1970

Granulatisporites sp. cf. *G. trisinus* Balme & Hennelly 1956

Granulatisporites trisinus Balme & Hennelly 1956

Horriditriletes ramosus (Balme & Hennelly) Bharadwaj & Salujha 1964

Krauselisporites sp.

Leschikisporis vestus Segroves 1970

Lophotriletes sp. (Fig. 11)

Trilete, triangular amb with strongly developed concave sides, paralleling the laesurae. Raised lips (1 μm) slightly thickened. Exine 1 μm thick supporting on the distal surface and at the equator small blunt cones (2 μm high, 1 μm apart) and spines 2-4 μm, 1.5 μm apart. Ornament lacking on proximal face. Diameter 35μm. Differs from cf. *L. rarus* Bharadwaj & Salujha 1964 by the strong concavity of the amb and the increased ornament, but lacks the thickened interradial areas of *L. novicus* Singh 1964.

Microbaculispora tentula Tiwari 1965

Punctatisporites gretensis Balme & Hennelly 1956

Punctatisporites sp. cf. *P. gretensis* (Fig. 7)

In all regards this form resembles *P. gretensis*, except in size. Av. diameter 20 μm cf. 118 μm of the latter. The exine, 2 μm, is thicker than that of *P. minimus* de Jersey 1960.

Verrucosisporites sp.

Anteturma POLLENITES R. Potonié 1931

Turma PLICATES Naumova 1939

Subturma **MONOCOLPATES** Iversen & Troels-Smith 1950

Cycadopites cymbatus (Balme & Hennelly) Segroves 1970

Marsupipollenites triradiatus forma *triradiatus* Balme & Hennelly 1956

Turma SACCITES Erdtman 1947

Subturma **MONOSACCITES** Chitaley emend. Potonié & Kremp 1954

Parasaccites gondwanensis (Balme & Hennelly) Segroves 1969 (Fig. 16)

Parasaccites sp. A (Fig. 17)

Monosaccate, trilete scar ruptured on several specimens. Distal saccus attachment overlaps 1/3 of corpus diameter. Amb triangular, with undulant margin. Corpus rounded triangular in shape. Sacci brochi elongate, 0.5–1 μm in diameter. Dimensions (3 specimens): T.D. 60 μm, C.D. 30 μm. This species differs from *V. triangularis* (Mehta) Lele 1964 in that the corpus is roundly triangular and not circular.

Parasaccites sp.

Parasaccites sp. cf. *V. Mehtae* Lele 1964

Parasaccites diffusus Tiwari 1965

Potonieisporites balmei (Hart) Segroves 1969 (Fig. 9)

?Hoffmeisterites sp. (Fig. 19)

Monosaccate. Amb oval, corpus sub-circular with marginal folds. Trilete mark not seen. Saccus attachment is equatorial and subequatorial. Dimensions: longitudinal axis 160 μm; transverse axis 100 μm; corpus diameter 75 μm.

Subturma **DISACCITES** Cookson 1947

Alisporites gracilis Segroves 1969

Limitisporites moersensis (Grebe) Klaus 1963 (Fig. 13)

Limitisporites sp. cf. *L. rectus* Leschik 1956 (Fig. 21)

Differs from *L. rectus* being somewhat larger; total breadth 76 μm, breadth of corpus 42 μm; saccus length 38 μm, corpus length 46 μm; cappa width 26 μm.

Protohaploxypinus rugatus Segroves 1969

Striatoabietites multistriatus (Balme & Hennelly) Hart 1965 (Fig. 5)

Sulcatisporites sp.

Sulcatisporites sp. cf. *S. splendens* Leschik 1956 (Fig. 18)

Vittatina sp.

Incertae Sedis

Group ACRITARCHA Evitt 1963

Subgroup **ACANTHOMORPHITAE** Downie *et al.* 1963

?Baltisphaeridium sp. (Fig. 12)

Micrhystridium spp.

Subgroup **POLYGONOMORPHITAE** Downie *et al.* 1963

Veryhachium spp. (Fig. 10)

Subgroup **NETROMORPHITAE** Downie *et al.* 1963

Leiofusa spp. (Fig. 15)

Algae

Botryococcus braunii Kützing 1849 (Fig. 6)

Composition of Palynological Assemblage

No significant quantitative changes in miospore composition were recorded from any of the samples (see Fig. 3). Unfortunately, spores from the upper samples in Peesey Swamp No. 1 (10.6 m–45 m) were too poorly

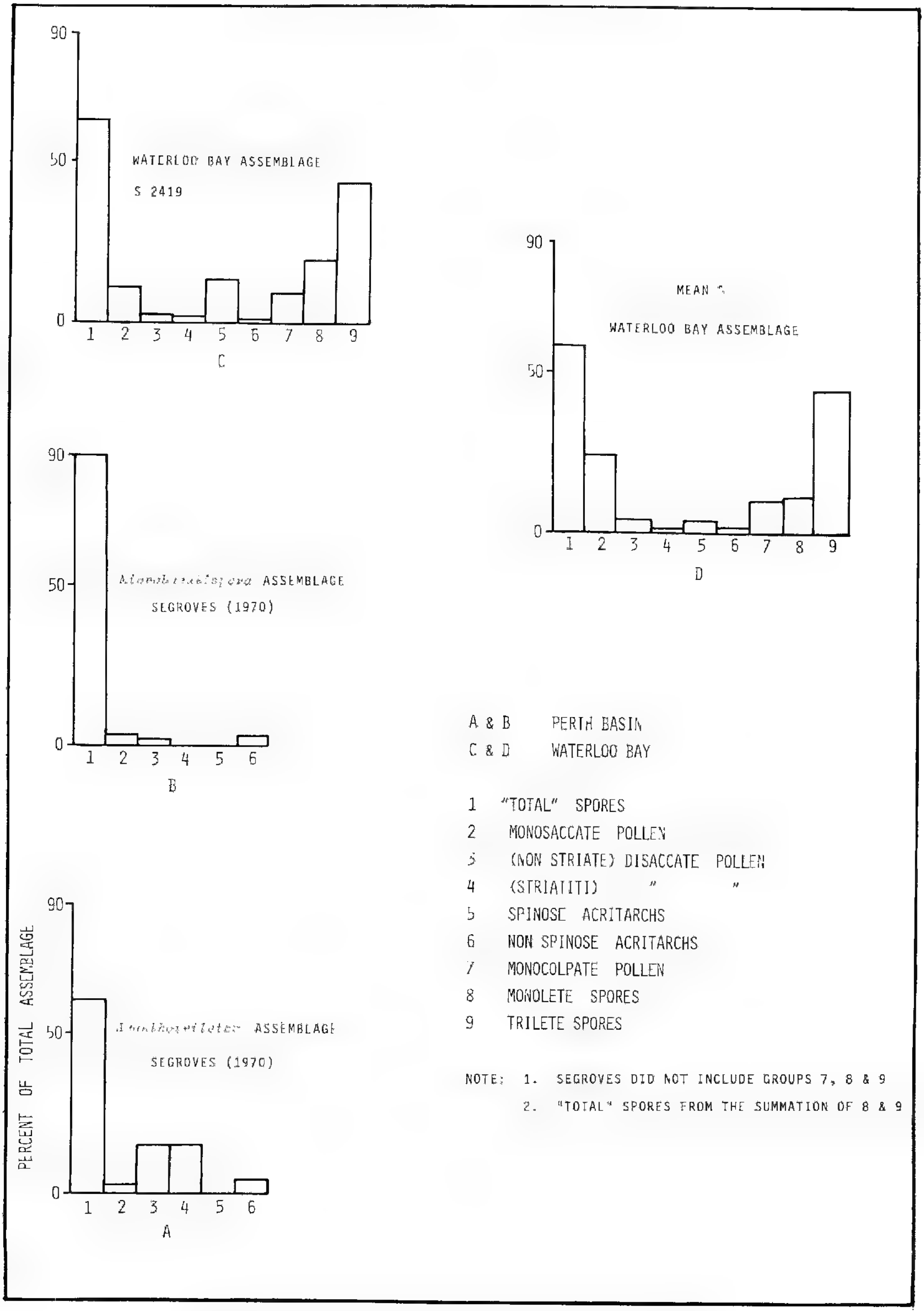


Fig. 3. Quantitative comparison of microfloral assemblages.

preserved to allow any firmer conclusions other than that the assemblage is of Permian age. Consequently, only one microfloral assemblage is considered to be present.

This well preserved, moderately diverse assemblage is dominated by monosaccate pollen including *Potonieisporites balmei* and *Parasaccites* spp. (av. 20%, max. 30%). Monocolpate pollen, *Cycadopites cymbatus*, is also abundant (5–10%) as is the trilete spore *Microbaculispora tentula* (12%). Non-striate bisaccates form a minor element of the assemblage (3%) and striate bisaccates are rare (<1%). Four genera of spinose acritarchs are present (up to 13%) and include *Verybachium*, *Micrhystridium*, and *Leiofusa*. Percentages are based on a total count of 1,600 specimens.

Apart from these elements, a well preserved reworked Middle to Late Devonian microflora (up to 2%) is present, including *Geminospora lemurata* Balme, *Convolutispora fromensis* Balme & Hassell, and *Ancyrospora* sp. Fungal spores, algae, *Botryococcus braunii*, and wood fragments form a minor background element. No megaspores were found.

Biostratigraphy and Age

The Australian Permian microfloral sequence has been subdivided into various palynostratigraphic zones. Evans (1969), working in southern and eastern Australia, erected a five-fold subdivision ("Stages" 1–5) which he considered ranged from Late Carboniferous through to Late Permian (Stages 2–5). He related these Stages to the early work by Balme (1964) in Western Australia. Paten (1969) re-subdivided Stages 4–5 into six sub-stages on material from the Cooper Basin (South Australia). More recently Segroves (1970) produced five assemblage zones within the Permian sequence of the Perth Basin. The relationship between these schemes is shown in Fig. 4. Although the late Early to Late Permian subdivisions do not apply to this study, they have been included for completeness.

Recognition of these subdivisions is based upon the first appearances of key species and the quantitative composition of the assemblage (in particular Segroves 1970; this study). Problems exist using this approach because of facies variations (Balme 1969; see later), and in many cases the precise stratigraphic ranges of the key species are not known. Negative evidence such as the absence of a particular Stage indicator within a well preserved assemblage is often used to preclude it from being younger than that Stage. This approach may not be desirable and it reflects the need for further study of the Australian Permian. The writer is currently engaged in research into these problems in the Bowen Basin, central Queensland.

Correlation

The Waterloo Bay Assemblage may be compared with Evans' (1969) assemblages ("Stages") and with those of Segroves (1970). The correlation using both works is shown separately and the differences are discussed.

Two species, *Deltoidospora directa* and *Marsupipollenites triradiatus* forma *triradiatus*, which Evans (1969, Fig. 4) has shown do not occur in assemblages older than his Stage 2, were found in the Waterloo Bay Assemblage. In addition the presence of striate bisaccate forms, e.g. *Protohaploxypinus rugatus*, exclude the assemblage from Stage 1. The absence of *Verrucosisporites pseudoreticulatus*, a Stage 3 index form, within this well-preserved assemblage, is taken to indicate that the microflora is not younger than Stage 2. Consequently, using these criteria the Waterloo Bay Assemblage is equated with Stage 2.

In terms of Segroves' units (1970, text. fig. 2) the Waterloo Bay Assemblage compares closely with that of the "*Microbaculispora* Assemblage" (Stage 2, Evans' units). A quantitative comparison is given in Fig. 3. The slightly higher percentage of striate bisaccate pollen at Waterloo Bay suggests that its microflora is younger than the Perth Basin assemblage, and is therefore correlated with the upper Nangetty Formation, Perth Basin.

However, using the *range chart* (Segroves 1970, fig. 4) the Waterloo Bay Assemblage appears to correlate with the "*Acanthotriletes* Assemblage" (Stage 3 plus lower Stage 4; Evans' units). The species whose ranges indicate this are *Granulatisporites trisinus*, *Tuberculatosporites modicus* and *Laevigatosporites flexus*; and are included with several other species (viz. *C. diversiformis*, *A. teretiangulatus*, *A. levis*) of the ten considered diagnostic of that assemblage (Segroves 1970, p. 514). To check this discrepancy the two microfloras were compared quantitatively (Fig. 3). The Waterloo Bay Assemblage was found to differ from the "*Acanthotriletes* Assemblage" as follows:

(i) The greater abundance of monosaccate pollen.

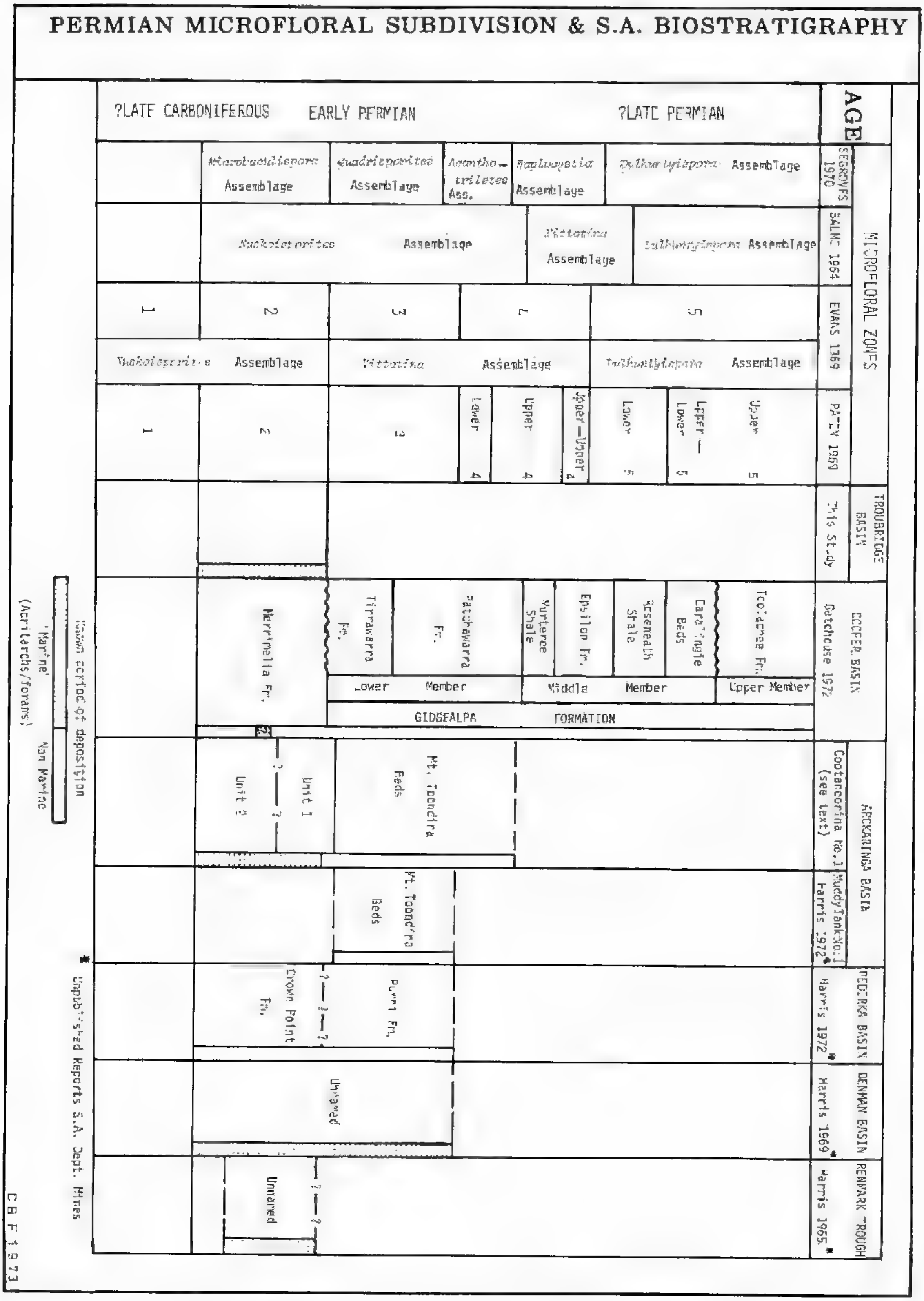


Fig. 4. Permian microfloral subdivision, South Australian biostratigraphy.

(ii) The greater abundance of spinose acritarchs.
(iii) The lower frequency of bisaccate pollen.

The first two can be explained by facies variations, the acritarchs indicating saline conditions, while the monosaccate pollen indicate proximity to the floral source, as their dispersal is effected by wind and water currents (Muller 1959). However, the low frequency of bisaccates cannot be explained by the same reasoning, and is considered significant as they reflect the progression of floral evolution (Balme 1962). Consequently the apparent correlation (i.e. with the "*Acanthotriletes* Assemblage") is rejected. Because of this, the stratigraphic ranges of these three species, mentioned above, presumably extend into earlier Permian strata.

Age

Marine shelly fossils from the Nangetty Formation, Perth Basin, and the Upper Lochinvar Formation, Sydney Basin, both Stage 2 microfloral localities, have been correlated with those from the type Sakmarian (Dickins 1963, 1968a, b) and are accordingly of Early Permian age. The Waterloo Bay Assemblage correlated herein with the Stage 2 microflora is, therefore, of Early Permian age. Moreover the gross microfloral composition of this assemblage, in particular the low percentage taeniate bisaccate pollen, is considered indicative of middle Sakmarian age (Balme 1962; Segroves 1969; Hart 1971).

Although problems in correlating the Australian Permian with the standard Russian sections exist (see Waterhouse 1970), the Standard Stage names are used in this paper to allow rapid comparisons with earlier published works. However, should the recent conclusions of Balme (1973) regarding the position of the Carboniferous/Permian boundary be accepted, the Waterloo Bay Assemblage will be of Late Carboniferous age.

Local Implications

Correlations with other Permian sediments within South Australia are shown in Fig. 4. Such information is useful in palaeogeographic and environmental interpretations. Within the Troubridge Basin the outcrop at Waterloo Bay has been correlated with at least 35 m of Permian sediments intersected (45–80.5 m) in Peesey Swamp No. 1.

The high frequency of reworked, excellently preserved Devonian spores suggests a local origin (Harris & McGowran 1971). Long distance transport along ice movement pathways from areas of proven Devonian sedimentation (e.g. Antarctica, Helby & McElroy 1969) would destroy the palynomorphs, particularly those with delicate appendages such as *Ancryospora*. This is further evidence of Devonian deposition within the State (see Harris & McGowran 1973).

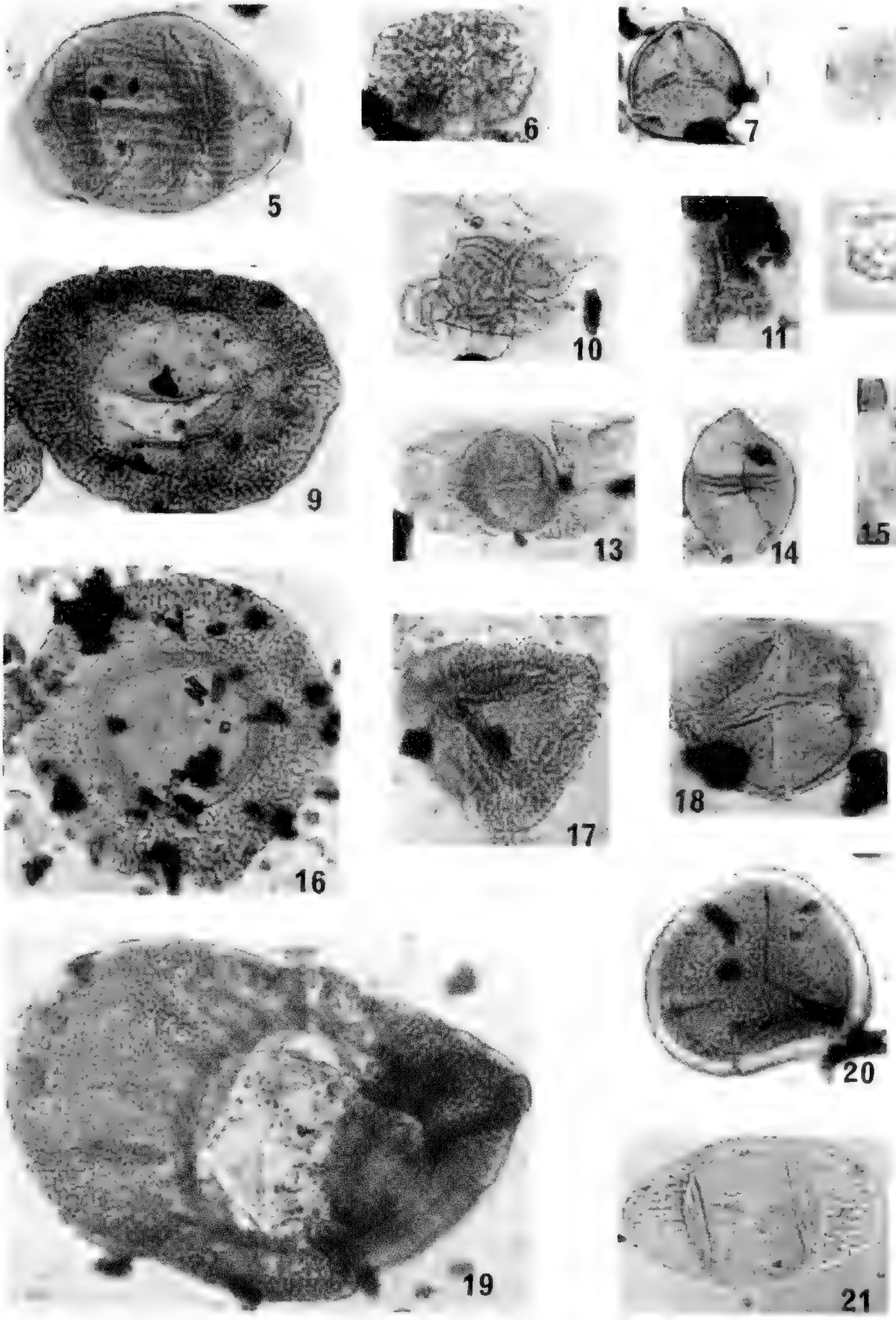
Environment

The following environmental inferences are made from a consideration of the preserved associations of microfossil groups in the Waterloo Bay sediments.

Spinose acritarchs have in general been regarded as indicators of marine conditions or marine influences (Downie, Evitt & Sarjeant 1963). Smith & Saunders (1970, p. 324) demonstrated that acritarchs of the same genera (viz. *Veryhachium*, *Baltisphaeridium*; also see Staplin 1961) as those from Permian sequences are "confined to areas continuously or intermittently open to marine waters and

FIGS. 5-21
All figures x 400.

Fig. 5. *Striatoabietites multistriatus* (Balme & Hennelly) Hart, S 2267/3, 23.8:114.1.
Fig. 6. *Botryococcus ?braunii* Kützing, S 2267/1, 25.5:113.0.
Fig. 7. *Punctatisporites* sp. cf. *P. gretensis* Balme & Hennelly, S 2267/4, 40.8:111.9.
Fig. 8. *Apiculatisporis* sp., S 2441/2, 27.8:110.1.
Fig. 9. *Potonieisporites balmei* (Hart) Segroves, S 2390/1, 32.3:99.8.
Fig. 10. *Veryhachium* sp. (cluster), S 2267/4, 27.0:100.4.
Fig. 11. *Lophotriletes* sp., S 2388/1, 48.0:104.7.
Fig. 12. *?Baltisphaeridium* sp., S 2389/1, 39.0:95.0. (Nomarski Interference.)
Fig. 13. *Limitisporites moersensis* (Grebe) Klaus, S 2267/4, 25.5:110.8.
Fig. 14. *Laevigatosporites flexus* Segroves, S 2267/4, 25.8:110.3.
Fig. 15. *Leiofusa* sp., S 2389/1, 33.0:93.3.
Fig. 16. *Parasaccites gondwanensis* (Balme & Hennelly) Segroves, S 2267/2, 36.8:109.2.
Fig. 17. *Parasaccites* sp. A, S 2419/1, 41.1:112.4.
Fig. 18. *Sulcatisporites* sp. cf. *S. splendens* Leschik, S 2390/5, 30.0:109.1.
Fig. 19. *?Hoffmeisterites* sp., S 2390/5, 39.6:109.6.
Fig. 20. *Geminospora lemurata* Balme (reworked Devonian example), S 2267/4, 99.6:39.4.
Fig. 21. *Limitisporites* sp. cf. *L. rectus* Leschik, S 2388/3, 32.6:92.8.



FIGS. 5-21

do not occur in fluvial deposits". Data from S.A.G. Cootanoorina No. 1 (Arckaringa Basin, Harris & McGowran 1973) are in keeping with this conclusion and suggest a threshold salinity is required for their appearance.

Within the Permian sequence at Waterloo Bay the association of spinose acritarchs and arenaceous Foraminifera is taken to indicate unequivocally marine conditions. Furthermore, a *low salinity* marine environment is inferred from the following:

(1) The presence of *Botryococcus braunii* within the assemblage. This is generally regarded as a fresh water species (Blackburn 1936; Dulhunty 1944) although Cookson (1953) has recorded *B. braunii* from Recent brackish water environments.

(2) The meagre foraminiferal assemblage consisting of only a few specimens (18) of apparently only a single species, *Hemidiscus balmei* Ludbrook 1967, which is a primitive form, for which a low salinity environment seems likely (Harris & McGowran 1971).

(3) The excellent preservation of the miospores, in particular the reworked Devonian forms. Tschudy (1969) has shown that such preservation would best be achieved under low pH, negative Eh conditions where bacterial activity is minor. Such conditions are commonly developed on lake bottoms and in closed basins; i.e. not normal marine situations.

Accordingly it is believed that the Permian sequence at Waterloo Bay was deposited in a low salinity marine or quasimarine environment.

Evidence of Permian glacial activity within the Troubridge Basin, particularly on Fleurieu Peninsula (Fig. 1), has been well documented (see Ludbrook 1969a). At Waterloo Bay glacial influence is indicated by erratics and rare faceted pebbles which occur within the sequence. Accordingly cold climatic conditions are inferred. This view is also maintained by Ludbrook (1967, 1969a) and Harris & McGowran (1971) who have stated that the arenaceous foraminiferal assemblages are also consistent with cold water conditions (see above). Moreover troughs or fiords have been postulated as the sites of deposition of the microfaunas (Ludbrook 1969a).

The diversity of the microfloral assemblage at Waterloo Bay suggests, however, that conditions were not fully glacial and that the climate was becoming warmer. In a comparative study of microfloral assemblages (Stage 2) from Antarctica, South America and Pakistan, Kemp (1973, p. 38) concluded it was likely that the sediments examined "represent a late stage in the glacial history of the areas studied".

An active tectonic environment covering all of southern Australia has been proposed by Wopfner (1970) and McGowran (1973). Both workers have postulated that initial rifting between Australia and Antarctica occurred during this time. Although there is little other evidence from the present study, it is most likely that the sediments were deposited in graben structures formed by syngenetic faulting (see Wopfner 1970). The immediate environment of deposition using this model is the same as that proposed by Ludbrook (1969a), although "Alpine type" glacial features as proposed by Campana & Wilson (1955) would not be present.

Synthesis

From the microfloral evidence it is postulated that the period of glaciation was ending. Syndepositional movement, in particular uplift during deglaciation, rejuvenated erosion and increased sedimentation rates. Rapid rates of sedimentation are supported by the presence of unaltered biotite, which forms a significant part of the micaceous element of claystones (see Wopfner 1970), and the excellent preservation of the reworked Devonian miospores. Such preservation demands rapid recycling within a reducing environment.

There is clear evidence that during this period a marine ingression occurred. It is suggested that inflowing glacial meltwaters appreciably lowered the salinity of the ingressing sea and consequently restricted faunas to arenaceous Foraminifera.

This model, consistent with known sedimentological and palaeontological data, equates the sediments of Waterloo Bay with the second marine shale unit of Wopfner's (1969) three-part lithological sequence for the Permian of South Australia. The youngest unit, generally a fresh water deposit, has not been recorded within the Troubridge Basin.

Conclusions

From the results of a taxonomic study given in this paper, the Waterloo Bay Assemblage is correlated with Evans' (1969) "Stage" 2 microflora (lower Dalwood Group, Sydney Basin) and equated with the "*Microbaculispora* Assemblage" (Nangetty Formation, Perth

Basin). This and the gross quantitative microfloral data indicate a probable Sakmarian (Early Permian) age.

The stratigraphic sequence described is of local importance and includes two Cainozoic discoveries; the dating of the Tertiary limestones at Late Eocene, and a further record of planktonic Foraminifera within the Quaternary aeolianitic sequence.

From a consideration of the palynomorphs and associated arenaceous Foraminifera, a low salinity environment of deposition was concluded. It is thought to have resulted from glacial meltwaters lowering the salinity of an ingressing sea.

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STUDIES ON SEASONAL ANAEMIA IN THE ROTTNEST ISLAND QUOKKA, *SETONIX BRACHYURUS* (QUOY & GAIMARD) (MARSUPIALIA; MACROPODIDAE)

*BY S. BARKER**

Summary

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Introduction

Rottnest Island, lying west of Fremantle, Western Australia, was named by de Vlamingh in 1696 after the small wallaby that was abundant there at that time and which he mistook for a rodent. This wallaby, the quokka *Setonix brachyurus* (Quoy & Gaimard), is still abundant on the island (Hodgkin & Sheard 1959). The total area of Rottnest is 1900 ha, of which 200 ha is covered by salt lakes. Fresh-water seepages occur on the shores of several of these and are important as water sources for the quokkas during the summer.

The island is 9.7 km long and 4.8 km wide at the maximum width and the long axis is orientated roughly east-west. At 6.4 km from the eastern end, the island is constricted to a narrow neck of land some 180 m wide and further west the island broadens out to a maximum width of 0.7 km. The part of the island west of the narrow neck is known by the general name of West End. All of the salt lakes, seepages and the few fresh-water soaks are confined to the middle and eastern end of the island and none are known further west than near the main lighthouse, situated on the highest hill which is in the middle of the island.

Weather conditions on Rottnest I. are similar to those on the nearby mainland, except that annual rainfall (734 mm) is 150 mm less and maximum and minimum temperatures are less extreme. The overall pattern is one of winter rainfall and summer drought. During summer, maximum daily temperatures can be in excess of 38°C and temperatures above this figure have been recorded during November-March. Mean rainfall during the same period is 14 mm per month in November and March, 10 mm in December and February, and 6 mm in January. No free surface water is available to West End quokkas in the summer except after occasional thunderstorms when surface pools may form but quickly disappear. The season usually breaks in April when general winter rains commence. Maximum monthly rainfall occurs in June.

When Europeans first settled in Western Australia, the predominant trees on Rottnest I. (Somerville 1954) were the Rottnest pine, *Callitris preissi* Miq., ti-tree, *Melaleuca pubescens* Schau., and coastal wattle, *Acacia rostellifera* Benth. Since the establishment of a prison on the island in 1838, changes occurred in the vegetation caused by clearing, fires and overgrazing by quokkas (Storr 1963). At the present time pines have almost disappeared, wattle now occupies only a small area and ti-trees occur sporadically. The predominant

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plant association which has increased in area since settlement is a heath of *Acanthocarpus preissii* Lehm.-*Stipa variabilis* Hughes (Storr *et al.* 1959). The samphires, *Arthrocnemum arbuscula* (R. Br.) Moq., *A. halocnemoides* Nees, and *Salicornia australis* Banks et Sol., grow around the salt lakes and soaks, some of which are fringed by swordgrass, *Gahnia trifida* Labill., and the sedge, *Scirpus nodosus* Rottb., both forming a dense cover heavily utilised by quokkas. A flora list has been published by Storr (1962).

The quokka is one of the small members of the family Macropodidae. Adult females weigh from 2.5-3.0 kg and adult males from 3.5-4.5 kg. Its relationships with the rest of the group have been discussed by Sharman (1954) and Ride (1957). Moir *et al.* (1954, 1956) described ruminant-like digestion in the quokka, which has a well developed bacterial population in the fore-stomach and pre-gastric fermentation. Blood glucose and plasma volatile fatty acid concentrations are intermediate between those of ruminants and rabbits (J. Barker 1961).

Quokkas occur all over Rottnest I. but during summer those living in the central part of the island congregate in the vicinity of fresh-water seepages on the edges of the salt lakes and near the fresh-water soaks. They graze the mat of salt-water couch, *Sporobolus virginicus*, (L.) Kunth., so close that it becomes a typical 'marsupial lawn', similar to those seen in Tasmania (Ridpath 1964) and other areas of Australia. They live in high density on the eastern end of the island, under the houses used for tourist accommodation, and they are addicted garbage feeders. The smallest population probably occurs between the main lighthouse and West End. There seems to be a fairly constant population (Niven 1970)[1] living on West End, which shows local feeding movements during summer (Nicholls 1971). They do not migrate from West End to fresh-water sources during the height of summer or indeed at any time of the year (Dunnet 1962).

Work on the ecology of the quokka population on Rottnest I. commenced with a tagging programme in November 1953. The summer of 1953/54 was hot and dry and by March 1954 many quokkas were emaciated and some were dying. Research was commenced to find out why animals were dying and what factors were controlling population numbers (Waring 1956). The progress made on these problems is the main subject of this paper.

Seasonal Anaemia

In 1954 it was found that haemoglobin concentrations of quokkas caught in the centre of the island in summer were much less than those of quokkas kept in the yards of the Zoology Department, University of Western Australia, at the same time of the year (Waring 1956). The first possibility considered was the occurrence of a seasonal deficiency of copper, cobalt or both. It was known at that time that the quokka had ruminant-like digestion (Moir *et al.* 1954, 1956), that sheep quickly die on Rottnest from copper and cobalt deficiency, and that deficiencies of both copper and cobalt in ruminants result in anaemia. By analogy, the same deficiencies might have been affecting the quokkas. Barker (unpublished) collected serum samples from animals captured at West End and at Lake Bagdad over an 18 month period. The samples were assayed for vitamin B_{12} (by the Haematology Department, Royal Perth Hospital) using *Euglena* as the test organism. Mean serum vitamin B_{12} concentration of animals caught near Lake Bagdad was very much greater than that of animals caught at West End at all times of the year (means varying between 2,000-4,500 pg/ml as against a mean of around 1,000 pg/ml). The West End animals showed a slight annual fluctuation with the lowest mean serum vitamin B_{12} concentration in the spring and the highest in summer. None of these animals had concentrations low enough to indicate cobalt deficiency when compared to the concentrations measured in animals that had been fed very low cobalt intakes for several months (Barker unpublished).

Blood copper analyses of Lake Bagdad quokkas showed a positive correlation with haemoglobin concentration but this relationship was not found in West End quokkas. It was considered that only in the Lake Bagdad population was copper deficiency likely to exert any effect on blood parameters and then it was only likely to be one factor associated

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[1] Niven presented a computer study with numbers calculated from data for the West End quokka population between 1955-63, based on Holdsworth, W.N. (1964).—Marsupial behaviour with special reference to population homeostasis in the quokkas on the West End of Rottnest Island. Ph.D. thesis. University of Western Australia (unpublished).

with the development of seasonal anaemia (Barker 1961).

Shield (1959) found that haematological counts fluctuated with season and were correlated with changes in body weight. Adult quokkas from West End and from around Lake Bagdad were in peak condition in the spring. Their body weight was maximal and their blood counts were normal. By the end of summer there was a mean decline of up to 25% in body weight and there was a similar reduction in red cell parameters. There were differences between quokkas caught in the two areas in that West End animals showed higher maxima in spring and lower minima in autumn than those from Lake Bagdad.

The possibility of disease causing the anaemia was discounted, as white cell counts were lower in the summer than in the winter, whereas it would be expected that white cell numbers would increase if disease occurred in the summer. Dehydration was not thought to be a contributing factor to the decline in condition of West End animals, as Shield (1959) had found that quokkas kept for 6 months without access to drinking water, lost weight but had increased plasma protein concentration. However, it is unlikely that West End quokkas would experience such severe dehydration. Storr (1964a) calculated that they had a daily water intake of about 130 ml gained from water contained in their plant food. Shield (1959) found that in West End quokkas, haematocrit and plasma protein concentration declined during the summer period. In a later study (Shield 1971) he found that plasma volume of field animals was unchanged throughout the year. Clearly, the field animals were not experiencing the acute dehydration seen in the yard animals that did not have access to drinking water. However, the possibility that a lesser or more chronic degree of dehydration is occurring in the field cannot be excluded and this could aggravate the quokkas' condition. As a result of his studies, Shield (1959) (Main *et al.* 1959) suggested that the quokkas were affected annually by 'severe semi-starvation', which Main (1968, p. 99) interpreted as protein deficiency.

In a study of the plants eaten by the quokka, Storr (1964a) made calculations of the nitrogen and water intakes of quokkas from different localities on the island at different times of the year. The figures he used for nitrogen requirements of male quokkas were those of Brown (1964)[2] from one adult male quokka used in two series of nitrogen balance trials. Extrapolating from this data, Storr (1964a) stated that an adult male quokka requires 0.6 g N/day to remain in positive nitrogen balance. He calculated mean nitrogen intake at different localities on the island at different times of the year and concluded that quokkas at Cape Vlamingh had a large surplus of nitrogen in winter and a varying deficit in late summer. There is no doubt that Storr's use of the data of Brown (1964) is an oversimplification: for example 3 of the 4 adult male quokkas used in a feeding trial by Calaby (1958) were in negative nitrogen balance, although their daily nitrogen intake ranged from 1.3-1.6 g N/day. The diets used by Calaby were not comparable to that used by Brown (1964).

Barker *et al.* (1974) collected blood samples from one sub-population of quokkas living on West End in spring and at the end of summer (1970/71). The weight differences between the animals in spring and autumn were marked, yet mean plasma urea concentrations were similar. The field plasma urea concentrations found by Barker *et al.* (1974) were significantly less than plasma urea concentrations found in a group of male quokkas fed on high-protein food for 3 months prior to feeding them a low-protein diet. In this experiment it was found that quokkas with a low nitrogen intake (< 0.3 g N/day) and given water *ad lib.* had plasma urea concentration reduced to 20 mg/100 ml within four weeks. Thereafter plasma urea concentrations of most animals rose. Plasma urea concentrations of quokkas fed the same diet but with a restricted water intake, fell to 40 mg/100 ml and then remained at this concentration.

This pattern has not been found in the Kangaroo Island wallaby in a similar type of experiment (Barker *et al.* 1970). Wallabies fed on a low nitrogen diet showed a progressive fall in plasma urea concentration over a two-month period. In a group fed a similar diet but with restricted water intake, plasma urea concentrations also fell but remained higher than in the control group throughout the experiment. It seems most probable that in both the experiments with the quokka and

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[2] BROWN, G. D. (1964).—The nitrogen requirements of macropod marsupials. Ph.D. thesis, University of Western Australia (unpublished).

Kangaroo Island wallaby, the higher plasma urea concentration in water restricted animals is a reflection of a lowered and inadequate energy intake. Water restriction below the *ad lib.* intake results in an immediate decline in appetite and thus in dry matter intake. The actual reduction in dry matter intake appears to be correlated with the severity of water restriction compared with the *ad lib.* intake. This seems to be constant *in* individual animals though it fluctuates widely *between* individual animals.

Two isolated short-term studies have also been carried out on Rottnest I. quokkas. Herrick (1961) measured adrenal ascorbic acid concentration of Rottnest I. and experimental animals to determine changes in adrenal function during summer stress, but his results were inconclusive. Packer (1968) counted eosinophil numbers in blood samples taken from quokkas on Rottnest I. at different times of the year to determine whether changing population density caused changes in circulating eosinophils. He found no consistent trend that suggested changes at different times of the year.

Nature of the Summer Stress

So far the only evidence of disease affecting the quokkas on Rottnest I. has come from the work of Gibb *et al.* (1966) who described the occurrence of Toxoplasmosis on Rottnest I. but only from animals captured in the vicinity of the settlement on the eastern end of the island. It is expected that other infective agents will eventually be described after a diligent search has been made for them, but very little research effort has been made in this important direction.

The key to summer survival for the quokkas on West End is probably their success or otherwise in obtaining water from their food plants. No permanent source of fresh-water is known to occur further west than the main lighthouse during the summer. However, on the night of March 22nd, 1957, the writer and Dr. E. P. Hodgkin of the Department of Zoology, observed about 20 quokkas on a narrow beach in Green Island Bay, beneath a low cliff. The animals were lined up at the water's edge and were apparently drinking sea water. From close observation it was seen that the animals were digging holes in the sand, near to the water's edge, before drinking. Water samples were taken from some of these holes and from the sea some 12 inches from where the quokkas were drinking. Analysis of the samples showed that the water sampled from the hole in the sand was much fresher than sea-water (Cl 0.51%) while that taken from the sea (Cl 1.61%) was slightly less salty than normal sea water (Cl 1.9%). Casual observation without collecting water samples would have led us to the conclusion that the quokkas were drinking sea water. As Bentley (1955) found that the quokka can maintain water balance under laboratory conditions drinking 2.5% NaCl (but not sea water) it seems reasonable to assume that animals drinking seepage water were able to maintain a positive water balance.

Although water is essential for the maintenance of fluid space, excretion and temperature regulation, one of the first manifestations of water shortage is depression of appetite. To an animal that may have to forage for suitable food over long distances and survive the stress period on a marginal diet, from an energy point of view, this could lead to a slowly worsening starvation state. The animal would gradually lose weight, become weak, and unless there was relief from a change in the season, it could eventually succumb. Storr (1964a) indicated that although quokkas which feed on *Carpobrotus* at Cape Vlamingh may get sufficient water from this plant to meet their needs, their nitrogen intake would certainly be reduced below a reasonable intake for maintenance purposes and such animals could fit into the scheme outlined above.

Water is also an essential requirement for those animals living close to freshwater sources, particularly during summer and this fact has been exploited for the capture of large numbers of quokkas (Dunnet 1956). Access to water alone, however, is not sufficient for the maintenance of constant blood parameters. Both Shield (1959) and Barker (1961) showed that in animals with access to drinking water haemoglobin concentrations fell during the summer though not as dramatically as in animals captured on West End.

Despite a great deal of work and speculation on this problem, there is still no clear-cut answer to the question of the nature of the stress experienced by quokkas during the summer and early winter. It is probable that some animals surviving summer stress, but debilitated by it, are killed off when the season breaks and they are faced with cold and wet conditions. Barker *et al.* (1974) found that 8 out of 11 quokkas that had survived for 8 weeks on a low nitrogen intake, died in 10 days when night and early morning temperatures fell over a short period.

There is a strong possibility that the population at West End faces a more severe stress than those in the central parts of the island. At West End, quokkas almost certainly face a less than adequate water intake, except for those feeding on *Carpobrotus* at Cape Vlamingh (Storr 1964a), as well as nutritional stress. Quokkas living in the centre of the island face a nutritional stress only, water being available. A water shortage at West End would result in quokkas having a decreased dry matter intake causing a lowered nutritional status leading to anaemia. If nitrogen intake of quokkas in the Lakes area becomes inadequate in summer, dry matter intake would be depressed also leading to anaemia. The nature of the anaemia developed at each area would be similar despite a different origin (Barker *et al.* 1974).

Inadequate water intake does not necessarily lead to haemo-concentration (Barker *et al.* 1974). Shield's (1959) conclusion that water intake is not limited on West End in summer was based on the results of his experiment where no water whatever was provided for the experimental animals. This situation never occurs on West End as although moisture content of food plants is reduced during summer (Storr 1964a), the reduction in water intake is not likely to be much greater than half of the *ad lib.* requirement. Shield (1971) showed that a decrease in blood volume does occur in West End animals during the autumn relative to blood volumes of West End animals measured in the spring. However, the difference was due to a reduction in red cell mass, not in plasma volume, a finding not incompatible with the thesis of a restricted water intake exerting a nutritional effect through loss of appetite.

Although the figures for nitrogen requirement of the quokka given by Storr (1964a) are too limited to be conclusive, it seems from his data that nitrogen intake at West End could be less than the maintenance requirement. However, the possibility that nitrogen shortage alone causes the debility seems remote in a complex situation, where nitrogen is likely to be only one of several components of the diet which are seasonally deficient.

Future of the Rottnest Quokka

Despite the obviously deteriorating environment on Rottnest I., caused mainly by human activities but also affected by natural erosion, the quokka population is surviving. Some of the differences between the Rottnest I. environment and that of one area where the quokka still occurs on the adjacent mainland, have been outlined by Storr (1964b). In one way, Rottnest is totally unlike the mainland situation in that no predators are present. If they were, the population would be reduced as those animals weakened by seasonal influences would fall easy prey to a predator.

The quokka has a considerable and unique value as a natural resource and it is to be hoped that it has a guaranteed future on Rottnest I. The value of the island as a training ground for scientists has been stressed by Main (1959, 1967) and this is largely because of the occurrence there of the quokka. However, the greatest value of the quokka lies in its asset as a tourist attraction. It is to be hoped that the Western Australian Government Tourist Bureau, which controls the island, does not underrate this asset and takes positive steps towards ensuring the permanent survival of the quokka on Rottnest I.

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*BY T. F. HOUSTON**

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Introduction

The species-complex dealt with here includes the Tawny Dragon, *Amphibolurus decresii*, the Peninsula Dragon, *A. fionni*, and several forms hitherto undescribed. The lizards inhabit an area of South Australia bounded by Ceduna in the west, Marree in the north and Kangaroo I. in the south, and which extends east to Mootwingee in western New South Wales (Fig. 1).

Much confusion has arisen around the complex and the need for a taxonomic revision has long been felt. A wide array of colour patterns occurs amongst adult males from different areas with little or no corresponding morphological diversity and without comparable colour variation in females and juvenile males. Thus, while the geographical origin of an adult male may be determined from its colour pattern, this is seldom possible with females or juvenile males. Unfortunately, the name *A. fionni* was based only on the female sex and no accurate indication of the type locality was given. The description fitted females from most areas and the applicability of the name to a particular male colour form was left in doubt. The status and nomenclature of the different male colour forms were variously interpreted with resulting confusion in collections.

The present study included examination of over 300 specimens in the collection of the South Australian Museum and field observations in many parts of South Australia. It has become clear, however, that a full understanding of the complex cannot be obtained without detailed behavioural and ecological studies. This paper is intended to clarify nomenclature as far as presently possible, to facilitate such studies now being undertaken elsewhere.

All specimens listed in this paper are in the South Australian Museum and, unless otherwise indicated, all localities mentioned are in South Australia.

Diagnosis of A. decresii complex

Lizards of moderately to strongly depressed form, up to 25 cm long (snout-vent length ⩽ 96 mm); nostril below a sharp canthus rostralis; a weak nuchal crest but no vertebral crest (at most, a line of perfectly aligned keels or a raised fold of skin); dorsal body scales mostly homogeneous, smooth to obtusely keeled and subtubercular; skin around tympani, nape and sides of neck with few to many spines, occurring singly or clustered on folds of skin; ventral scales smooth; 32-50 femoral and preanal pores, closely arranged along a more or less straight line extending full length of thighs but interrupted medially; each pore situated between several scales; lower jaw with dark irregular reticulations or longitudinal lines (often obscured by bright colour washes in males); chest of subadult and adult males with a grey to black patch tapering posteriorly,

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* South Australian Museum, North Terrace, Adelaide, S. Aust. 5000.

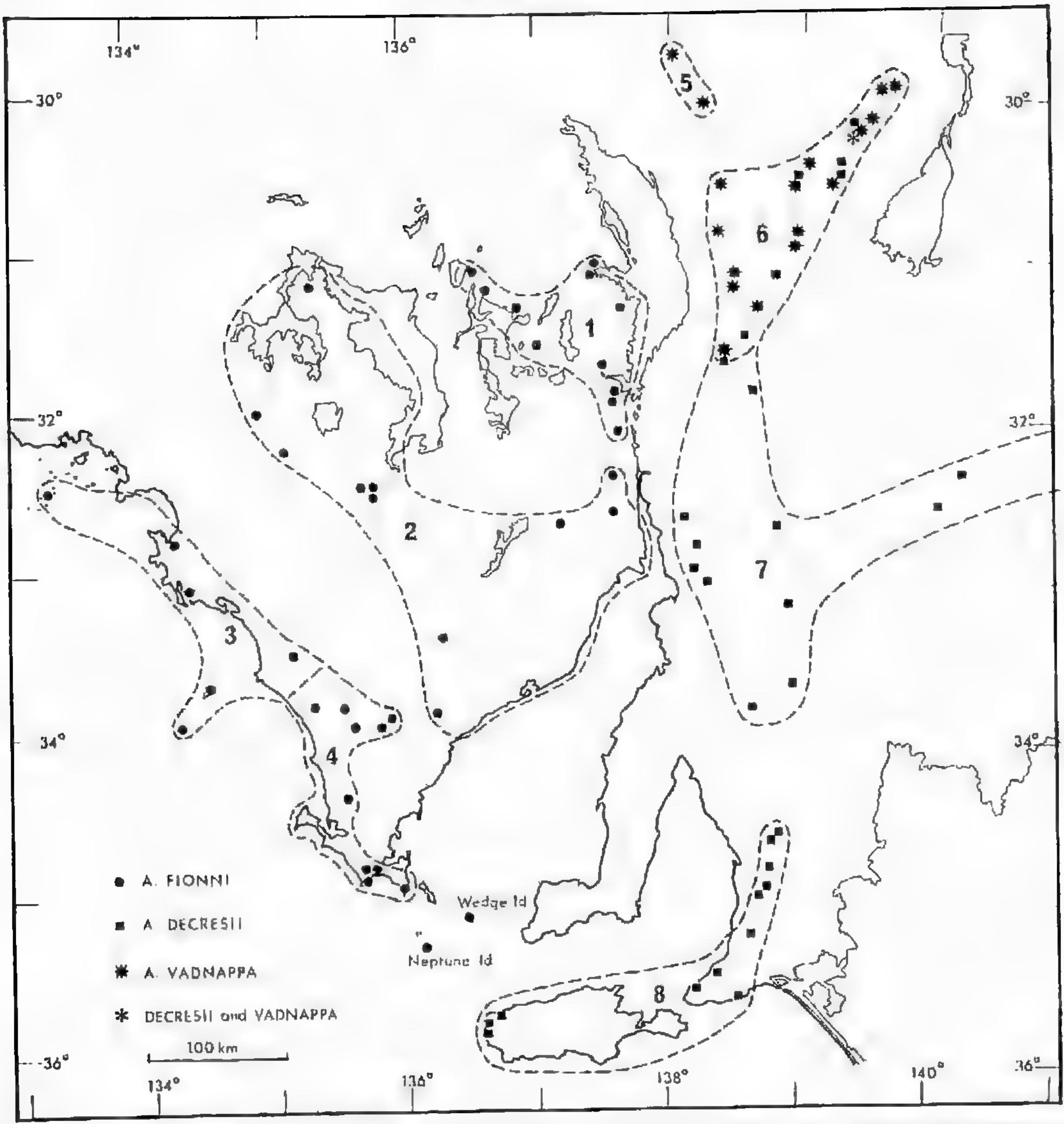

Fig. 1. Distribution of *Amphibolurus decresii* complex in S. Aust. Broken lines enclose the ranges of individual races. The numbers are referred to in the text.

sometimes closely approaching vent; males (except early juveniles) usually with bright yellow, orange, red, pink or blue patches or washes; females and early juvenile males usually dull grey, brown or reddish brown with black stippling and mottling; tail length 1.4–2.3 times snout-vent length; hind limb 0.7–1.0 times snout-vent length.

Examination of all available material suggests the existence of three major taxa (each composed of two to several minor taxa) which I am treating as species. These taxa are distinguishable mainly on colour differences but there are also some minor structural features separating them. The name *A. decresii* (Duméril & Bibron) applies to one taxon (inhabiting areas 6–8, Fig. 1) and the name *A. fionni* Procter to another (inhabiting areas 1–4, Fig. 1, and Neptune and Wedge Is.). In view of the very close similarity of these two taxa, they may not be reproductively isolated, but until this is clearly demonstrated nomenclatorial changes are unwarranted. The third major taxon (inhabiting areas 5 and 6, Fig. 1) is the most distinctive of the three and is partially sympatric with *A. decresii*. In the absence of known intermediates, it is accorded species status and named here as *A. vadnappa.*

It is not a simple matter to clearly define the three forms because of intraspecific variation, but the following key should facilitate recognition of them.

Key to species of the A. decresii complex

1. Dorsal head scales between and in front of eyes usually coarsely wrinkled (Fig. 2), not simply keeled; mid-dorsal row of scales with longitudinally aligned keels extending at least partway along back (more prominent in males which are able to raise a fold of skin along vertebral line); adult males with orange or reddish spots on sides of body tending to coalesce to form vertical bars and with a broad immaculate vertebral stripe from nape to base of tail (Figs. 12, 13); mottling on sides of females often suggestive of barring . . . . . *A. vadnappa*

1. Dorsal head scales between and in front of eyes longitudinally keeled (Fig. 3), sometimes obtusely so or virtually smooth but (Neptune I. specimens excepted) never coarsely wrinkled; no mid-dorsal row of scales with longitudinally aligned keels along back (at most a short incomplete row in some *A. decresii*): adult males without orange or reddish spots on sides of body coalescing into vertical bars or, if so, then maculations extending across vertebral region (Fig. 11); mottling on sides of female variable . . . . . 2.

   2. Sides of body with a few to many scattered tubercles which are usually pale and contrast with ground colour; body colour pattern of adult male consisting essentially of a blackish lateral stripe each side, margined above and below by paler lines or rows of spots; lower jaw of adult male usually bright yellow, orange, or blue . *A. decresii*

   2. Sides of body without scattered tubercles; body colour pattern of adult male consisting essentially of pale spots or blotches often aligned transversely, sometimes large and coalescing into bars, sometimes reduced and limited mainly to dorsolateral folds; lower jaw of adult male usually with bright yellow wash over greyish reticulations but never with bright blue wash . . *A. fionni*

Amphibolurus decresii (Duméril & Bibron)

FIGS. 1, 4, 14-16

Grammatophora decresii Duméril & Bibron, 1837: 472-4; 1854, pl. 41, figs. 1, 1a-c.

Agama decresiensis Fitzinger, 1843: 83 (new name for *G. decresii* D. & B.).

Ctenophorus decresii (D. & B.), Fitzinger, 1843: 18, 83.

Amphibolurus decresii (D. & B.), Peters, 1864: 229.

Types: Ile de Decres (= Kangaroo I., S. Aust.), collected by Peron and Lesueur. Duméril & Bibron apparently had several specimens of both sexes but did not designate one as the type. They figured a male. Guibé (1954) records the presence of two syntypes (no. 6545) in the Muséum National d'Histoire Naturelle, Paris.

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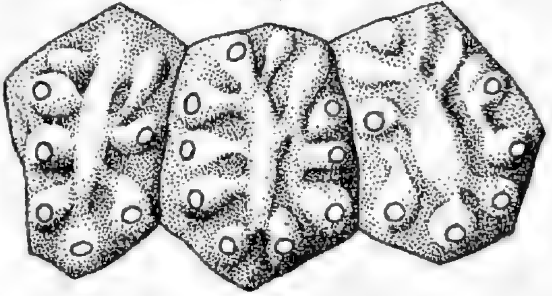

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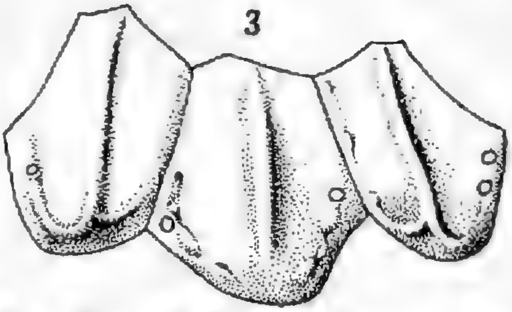

Fig. 2. Three scales from top of snout of *Amphibolurus vadnappa.*

Fig. 3. Same from *A. fionni.*

Duméril & Bibron's (1854) coloured figure of an adult male *A. decresii* clearly shows a black lateral stripe margined above and below with pale spots and their (1837) description mentions small tubercles sprinkled over the flanks. I have no hesitation, then, in applying the name *A. decresii* to the populations inhabiting areas 6–8 (Fig. 1) which are distinguished by these features.

SOUTHERN (TYPICAL) RACE (Area 8, Fig. 1)

This race appears to be confined to the western end of Kangaroo I., the western scarps and gorges of the southern Mt. Lofty Ranges and the southern margin of Fleurieu Peninsula. It is comparatively uniform throughout this range.

Adult male pattern: Head light brown; lower jaw and lips diffusely bright blue; throat and sometimes shoulders bright yellow; black patch in fold of skin each side of neck usually separated by pale brown from blackish lateral stripes on body.

Female pattern: Ground colour usually dull brown or grey-brown; lateral body stripes often developed as in males but black speckling and mottling variable.

NORTHERN RACE(S) (Areas 6 and 7, Fig. 1)

Males from areas 6 and 7 show far more variation in colour pattern than those of the southern race. However, I have seen too few specimens (particularly live males in full coloration) to know whether the variation is regionally dependent or individual only. The bright colour markings and washes about the head and neck closely resemble those of some *A. fionni* males.

Adult male pattern: Head usually grey or dark dorsally; lower jaw reticulated with grey and suffused with bright yellow or with a large orange patch centrally but never with a bright blue wash; throat yellow or orange; markings about ears, neck, nape and sometimes eyelids orange.

Female pattern: Very similar to that of southern females.

SPECIMENS EXAMINED: AREA 6: Arkaroola HS, R10916; East Painter Gorge, R10940; Echo Camp, Arkaroola Creek, R10917; Mern Merna, R2660; west of Mt. Painter Camp, R10915; Mt. Serle, R5902, R5914; Nooldoonnooldoona Waterhole, R10952; North Tusk, Gammon Range, R3942; Paralana Springs, R10938, R10961, R10963; St. Mary Peak, R6004; Wilpena Gorge, R3806; 19 km W of Wirrealpa, R3753; Yudnamutana Creek, R3492, R8760, R10201-2. AREA 7: Burra, R12492; Clare, R2337; Mootwingee, N.S.W., R5194; Mt. Remarkable, R3306, R6379, R9533; near Olary, R12909-10; Pt. Germein Gorge, R12792; Terowie, R2496; 13 km SE of Warcowie via Hawker, R2576; Wilmington, R3724; Wirrabara, R8862. AREA 8: Basket Range, R2834; Encounter Bay, R1686; Fifth Creek, R435; Glen Osmond, R9379-85; Kangaroo Is. (R1189; south side, R9339-40; Harveys Return, R11260; Ravine de Casoars, R3283; West Bay, Flinders Chase, R9341); Montacute, R8802; Normanville, R2881; Onkaparinga Gorge, R5854; 32 km N of Peterborough, R11356-7; Sandy Creek (E. of Gawler), R12075; Second Valley, R2505; near Tea Tree Gully, R11358-9; Waterfall Gully, R1461, R2137, R2835

Amphibolurus fionni Procter, 1923: 1075, figs. 4a-c.

FIGS. 1, 3, 5-11, 14-16

Holotype: ♀, coast of the mainland of S. Aust., F. Wood-Jones, in B.M.N.H., London. The late Dr. M. Smyth, Department of Zoology, University of Adelaide, who saw the type, informed me that the accompanying data record it from Pt. Lincoln, S. Aust.

It is unfortunate that the description of this species was based on a female only, for, as mentioned above, females may be virtually impossible to identify with any particular race on the basis of appearance. Procter's description and figure, however, and a photograph of the type (Fig. 10) agree closely with specimens from Eyre Peninsula.

Several distinctive races of this species are described below. Since adult males of all races usually have a dark grey reticulum and yellow wash on the lower jaw and throat, it is not mentioned among the diagnostic features of each race.

NORTHERN RACE (Area 1, Fig. 1)

Area 1 corresponds approximately to what was once a large tableland (Arcoona Tableland) and now consists of the low rolling Andamooka Ranges and series of isolated mesas and tenthills. The lizards inhabit the rocky scarps and stony creek beds.

Adult male pattern: Dorsal ground colour brown grading to blackish brown on neck, shoulders and flanks; irregular, often very dense pale spotting or blotching on nape, neck, shoulders and flanks sometimes coalescing to form vertical bars on sides of body (Fig. 11); at least some, and often most, of spots on flanks orange or reddish, the remainder white.

Female pattern: Dorsal ground colour brown; dark mottling on sides of body frequently tending to form alternating light and dark bars.

This race is very similar in coloration to *A. vadnappa*, although it does not exhibit the distinctly bluish tints found on the body and limbs of males of that species, nor does it have predominantly coarsely wrinkled scales on top of the snout nor a vertebral keel line. Some specimens from the southernmost locality of Area 1 (Uro Bluff) differ very little from those of the central race below.

CENTRAL RACE (Area 2, Fig. 1)

Area 2 includes the southernmost remnants of the Arcoona Tableland, the Gawler, Middleback and Blue Ranges and several smaller ranges and isolated hills.

Adult male pattern: Dorsal surface largely blackish except for brownish head and grey limbs and tail; distinct white spots scattered over back and flanks continuing into orange spots and blotches on shoulders, neck and nape (Fig. 5); eyelids often diffusely orange.

Female pattern: Highly variable; dorsal ground colour in Gawler Ranges specimens reddish-brown to brick red but brown to greyish in other areas; dorsal surface stippled and mottled with black to varying degrees and often pale spotted or ocellate in large specimens.

SOUTHERN RACE (Area 4, Fig. 1)

Area 4 coincides with the south-eastern part

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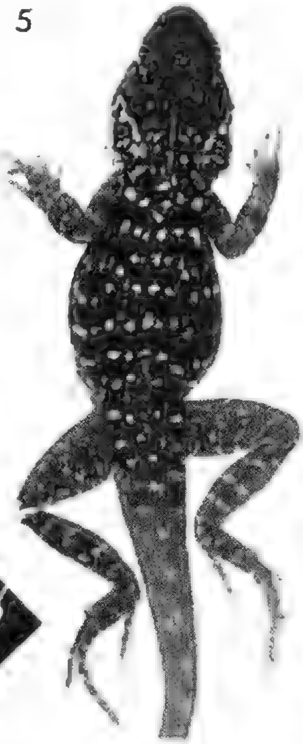

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Fig. 4. *Amphibolurus decresii*. Dorsal view of adult male from Montacute (Area 8).

Figs. 5–9. *Amphibolurus fionni*. Adults in dorsal view. Fig. 5.—Male from Lincoln Gap Stn (Area 2). Fig. 6.—Female from South Neptune I. Fig. 7.—Male from Lincoln National Park (Area 4). Fig. 8.—Female from Marble Range (Area 4). Fig. 9.—Male from same.

of a large limestone (calcareous aeolianite) expanse. The limestone is exposed on many rises and has weathered to form numerous rocks and slabs beneath which the dragons find shelter. A number of granitic and gneissic intrusions also occur in the area forming prominent hills with bare rocky outcrops which are also inhabited.

Adult male pattern: Dorsal ground colour pale grey with only a little blackish colour on sides of neck and below dorso-lateral folds anteriorly; pale spotting confined in most specimens to folds of skin about neck and anterior parts of body, especially along dorsolateral folds (Fig. 9), occasionally occurring over back generally but only weakly.

Female pattern: Highly variable; ground colour grey to brown; juveniles often finely speckled but larger specimens usually have dark mottling forming coarse irregular patterns, sometimes with pale spotting. A particularly bold pattern occurs amongst females from the Marble Range (Fig. 8).

This race has been the basis of several reports of *A. decresii* occurring on Eyre Peninsula, because of the similar colour pattern in males of the two forms. However, the absence of scattered single tubercles on the flanks of Eyre Peninsula specimens will distinguish them from *A. decresii*.

Since this race is the only one known to occur in the near vicinity of Port Lincoln, it may be that to which the holotype belongs.[1]

WEST COAST POPULATIONS (Area 3, Fig. 1)

Area 3 includes the northern section of the limestone expanse mentioned above, the Isles of St. Francis and the Investigator Group (Flinders and Pearson Is.). Few male specimens are available from this area so that a clear picture of their variation is not yet available.

Males from Area 3 differ from those of Area 4 in their generally larger size and somewhat bolder colour pattern; the blackish neck patches and lateral body bands are more intense, a pale line or series of spots defines the black neck patches, and enlarged pale spots margin the lateral stripes above and below (Fig. 7). They are even more like males of *A. decresii* than are males of the southern race.

Females tend to have patterning similar to males but in shades of brown rather than grey.

Without further collecting in West Coast localities one cannot be sure that their *A. fionni* populations do not intergrade with those of Area 4.

NEPTUNE AND WEDGE IS. RACES

The populations of these islands differ from those of Area 4 in colour pattern and their generally larger adult size.

Adult male pattern: Dorsal ground colour brown tending to black on neck, shoulders and flanks; scattered distinct white spots on nape, neck, back and base of tail tending to align in transverse rows; blackish coloration intensified around many pale spots on back, almost forming ocelli. Since only preserved specimens were examined, the presence of bright colour washes (other than yellow on the throat) was not observed.

Female pattern: Very similar to male pattern although generally paler with even more distinct ocelli and much black stippling (Fig. 6).

Neptune Is. specimens have conspicuously rougher and more mucronate scales on the base of the tail and hind legs than specimens from Wedge I. and other areas. They are also unusual in that the scales on top of the snout tend to be wrinkled (as in Fig. 2, but not so coarsely). The dorsal snout scales of Wedge I. specimens are mainly smooth.

While the various races outlined above show marked differences from one another in male coloration viewed overall, there is considerable variation within each race and convergence of features may be found in specimens from different races. In view of this, I have preferred not to erect subspecies of *A. fionni*.

SPECIMENS EXAMINED: AREA 1: 3 km SW of Beda Hill, R3877; Bowmans Creek, Bosworth Stn, R3833; north-west tip of Curripaceena Arm of Lake Torrens, R13315; Eucolo Creek, R13323 R13485; eastern side of Lake Hart, R8065-7 south end of Lake Torrens, R3832; 24 km S of Pimba, R6189; Uro Bluff, R12832, R12835-6, R12904; Woodforde Creek, R2795, R2798. AREA 2: Blue Range, R10121, R10173; Carappee Hill, R9313, R12927; Corunna Hill, R12445, R12741; Kondoolka Stn, R12755; Lincoln Gap Stn, R12466-70; Middleback Range, S of Iron Baron, R12929, R13055; Mt. Nott, S of Thurlga HS, R6229-30; Payney Stn, R8804; South Tent Hill, 24 km WNW of Pt. Augusta, R13054; Tandaie Rock Holes, R12592; Thurlga Stn, R5894. AREA 3: 6.5 km S of Baird Bay, R9241-2; Flinders I., R1445; Mt. Wedge, R5732, R5830, R9243; Pear-

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[1] Another race was found recently on granite outcrops immediately north of Pt. Lincoln by Mr. J. Gibbons, Dept. of Zoology, University of Adelaide. This race, adult males of which are superficially like those of the Neptune I. race in coloration, may equally well be the typical one.

son Is. (R10239, R10833-5; northern island, R10208); St. Francis I., R1196, R3009, R12874; Streaky Bay, R392. AREA 4: eastern edge of Bascombes Well National Park, R12615; Blesing Reserve, R9227-40; near Fishery Bay, R2551; Hincks National Park, R10100; Hundred of Nicholls, R10101, R10103-5, R10107-10, R10113, R10116, R10119; R10178; 19 km NW of Karkoo, R9417; Lincoln National Park, R12924-5, southern end of same, R12926, R13056; Marble Range, R12930; Mikkira HS, R8752-3; 19 km from Sheringa, R3626; Sleaford Mere, R8402; 3 km W of same, R12928, NEPTUNE IS.: R2230, R8722-3; south island, R5351, R5440, R10829-32; north island, R12892, WEDGE I.: R5340, R10636-7, R11375

Amphibolurus vadnappa, sp. nov.

FIGS. 1, 2, 12, 13, 14-16

Holotype: ♂ (R3416B), Aroona Waters (138°21'E, 30°35'S), Flinders Ranges, S. Aust., 3.v.1953, P. F. Lawson.

This species inhabits Areas 5 and 6 (Fig. 1), the type locality being in the latter. Proximity of the range of this species to that of the northern race of *A. fionni* and the remarkably similar coloration of adult males of both forms might suggest that they are merely races of the one species. However, the two may be distinguished on the features outlined in the key. Adult males of *A. vadnappa* also tend to exhibit a bright bluish suffusion of the chin, flanks, and limbs which is not known in northern *A. fionni*. Some differences in body proportions also occur (see below).

This attractive species was well known to Aborigines of the Flinders Ranges from whose language the specific name has been taken. The Aborigines were impressed by the presence of red bars on the males alone and likened males to boys about to be initiated who are painted with red stripes on the back. The females they likened to girls who are never so adorned. They call the lizard 'Itivadnappa' ('iti' = lizard, 'vadnappa' = boy painted for initiation ceremony). (R. W. Ellis, personal communication).

The specific name is used as a noun and is not liable to termination changes.

FLINDERS RANGES (TYPICAL) RACE (Area 6, Fig. 1)

Head and body only moderately depressed (less than the other two species); neck in adult males at least as wide as head so that latter appear to sit directly on shoulders.

Measurements of holotype: Total length, 252 mm; snout-vent length, 79 mm; tail length, 173 mm; hind limb length, 70 mm; head width, 22 mm; snout-gular fold length, 29 mm; total femoral and preanal pores, 43.

Scalation: Scales on top of snout coarsely wrinkled (Fig. 2), seldom almost smooth, never simply keeled as in Fig. 3; folds of skin above and behind ears and on sides of neck with clusters of small spines (feebly developed in juveniles and females); scales of flanks very small, subtubercular and homogeneous, grading into slightly larger, flatter dorsal scales which are very feebly keeled; flanks without scattered single tubercles; a row of perfectly aligned, longitudinally keeled scales extending from nuchal crest about three quarters of length of back (less well-developed in females); this keel line frequently accentuated by being raised on fold of skin.

Adult male coloration: Head pale brown dorsally; broad mid-dorsal stripe from nape to base of tail and upper parts of limbs and tail light grey or blue-grey; sides of neck and body blackish with orange or red spots and blotches usually partly coalesced forming irregular vertical bars (Fig. 12); chest with large diffuse black patch anterior to which skin is bright yellow, the yellow extending onto throat and shoulders and occasionally as spots along flanks; chin and 3–4 longitudinal lines on each side of lower jaw blue or blue-grey; limbs and dark ground colour of flanks slightly to strongly suffused with blue (the yellow, orange, red and, to a lesser extent, blue colorations gradually fade away in spirit).

Female coloration: Dull brown above with coarse dark mottling on sides of neck and body forming a pattern of alternating, irregular, light and dark bars; dorsal surface with scattered blackish spots; lower jaw and throat with longitudinal dark grey lines (more numerous and prominent in juveniles).

WILLOURAN RANGES RACE (Area 5, Fig. 1)

The Willouran Ranges, lying west of the Lyndhurst-Marree road, represent a north-western spur of the Flinders Ranges system but are isolated by wide tracts of sand and soil plain.

Three males from this area differed from the typical form in their less robust build and narrower necks. The pale spots on their bodies were smaller and while tending to be aligned transversely, did not coalesce to the same degree (Fig. 13).

SPECIMENS EXAMINED: Paratypes—Angepena, 32 km E of, R3423; Arkaroola, R10918-23, R11361, R11373; Aroona Waters, R3416 A and C, R4821; Beltana, R3001; Boulder Bore, R10934-5; Com-

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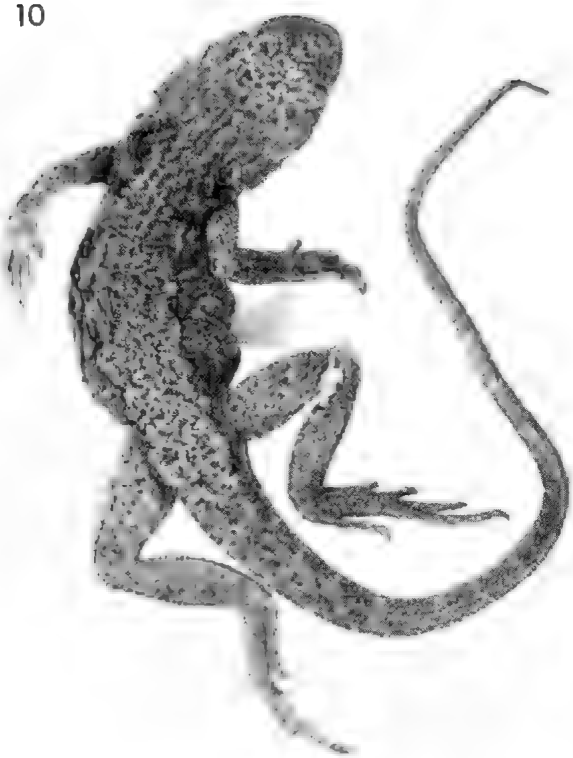

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modore, 9.7 km NE of, R2819; East Painter Gorge, last 8 km of, R10965-7; Echo Camp, Arkaroola Stn, R10946; Illinawortina Pound, R3950; Mt. Aroona, R3314A, B and D; Mt. Fitton, Moolawatana Stn, R8114; Narrina Stn, R10402-4; Oraparinna National Park, R12749, R13053; Parachilna Gorge, R4321; Terrapinna Springs, R12432; Waukawoodna Gap, 96 km N of Blinman, R12837; Yudnamutana Gorge, R3492, R13135; Wilpena Pound, R10638. Allotype—Mt. Aroona, R3314C.

Morpho-metrics

Maximum size

The maximum size attained by adults was found to vary somewhat between races as shown in the following table.

Species or Race	*Maximum snout-vent length in mm* (♂ and ♀)	
A. decresii		
(Northern)	82	73
(Southern)	75	75
A. fionni		
(Northern)	94	82
(Central)	78	72
(West Coast)	85	79
(Southern)	77	76
(Neptune Is.)	96	87
A. vadnappa	82	75

These figures suggest a north-south trend of decreasing body size apart from the Neptune Is. race which attains the greatest body size of all.

Relative length of hind limbs and tail

In this comparison only data from adult and subadult specimens were incorporated, since the relative lengths of appendages decrease slightly with increasing body size (i.e. with age). The lengths of the limbs and tail are expressed as functions of the snout-vent length (SVL). The range and mean for each form is shown graphically in Figs. 14 and 15. Unfortunately, the sample size in some cases is extremely small because of the number of specimens which had broken tails.

A general trend is noticeable towards slightly relatively longer limbs and tails in males (except perhaps in *A. decresii*). While there is wide overlap in the data of each form and the means of most of them approximate, *A. vadnappa* stands out from the rest in its greater mean relative length of both hind limbs and tail.

Femoral and preanal pores

The total number of pores was counted on as many specimens as possible. Unfortunately, the pores on female *A. decresii* specimens were so faint (especially distally) that reliable counts could not be obtained.

The ranges and means of data for each form are shown graphically in Fig. 16. Wide overlap occurs in all forms with means of most approximating. However, the Neptune Is. sample is outstanding in the relatively low means of both sexes.

The data represented in Figs. 14–16 reflect the morphological uniformity of the complex and confirm that pore counts and the relative lengths of hind limbs and tail will not serve as useful characters for the recognition of different forms.

Discussion

Affinities of the complex

The *A. decresii* complex shows obvious affinity with two other species: *Amphibolurus rufescens* Stirling & Zietz of north-western South Australia and *A. ornatus* (Gray) of south-western Australia. Both these species are rock-dwellers agreeing with the diagnosis given above for the *A. decresii* complex except in features of coloration. The adult male of *A. ornatus* is boldly patterned dorsally with black and yellow and the tail is banded. Sexual dichromatism is not so pronounced in *A. rufescens* as in *A. ornatus* or members of the *A. decresii* complex: males lack bright colour washes about the lower jaw and throat but are bright ferruginous dorsally, matching well the colour of the rocks which they inhabit.

These two species and the *A. decresii* complex constitute a fairly well-defined and probably natural group which may be called the *Amphibolurus decresii* species-group.

Storr (1967) included *A. rufescens* as a race of *A. caudicinctus* (Günther), a species composed of several races distributed widely throughout northern, central and north-western Australia. I regard *A. rufescens* as sufficiently distinctive to merit specific rank but I do not dispute its close affinity with some races of *A. caudicinctus*. It is quite probable that the *A. decresii* species-group and *A. caudicinctus* share a common ancestry.

Figs. 10–11. *Amphibolurus fionni*. Adults in dorsal view. Fig. 10.—Holotype female from Pt. Lincoln (Area 4). Fig. 11.—Male from near Carrapateena Arm of Lake Torrens (Area 1).

Figs. 12–13. *Amphibolurus vadnappa*. Adults in dorsal view. Fig. 12.—Holotype male from Aroona Waters (Area 6). Fig. 13.—Male from Mirrec Picnic Ground (Area 5).

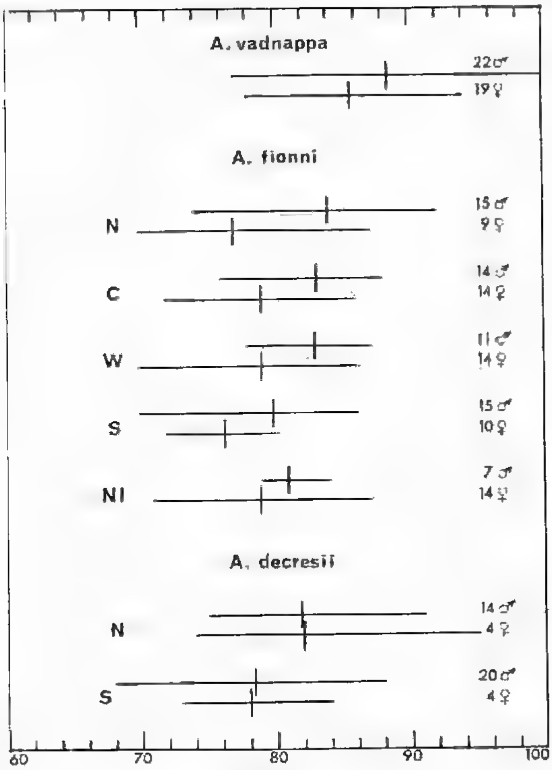

Fig. 14

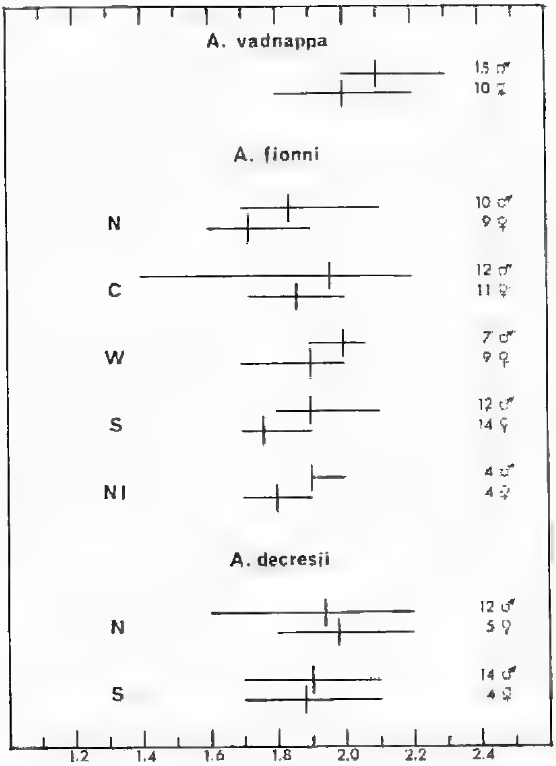

Fig. 15

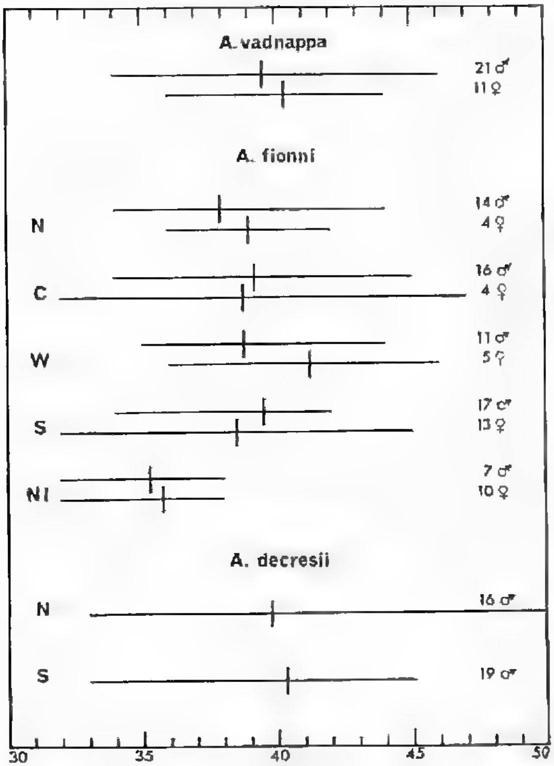

Fig 16

Fig. 14. Hind limb length as a per cent of snout-vent length in mature and near mature individuals of the *Amphibolurus decresii* complex. Ranges of variation represented by horizontal lines and means by vertical lines. Sex and sample size shown to right of each. N = northern race, C = central race, W = West Coast populations, S = southern race, NI = Neptune Is. race.

Fig. 15. Tail length as a multiple of snout-vent length in mature and near mature individuals of the *Amphibolurus decresii* complex. Explanation as for Fig. 14.

Fig. 16. Total number of femoral and preanal pores in various forms of the *Amphibolurus decresii* complex. Explanation as in Fig. 14.

Superficially, at least, there is fairly close resemblance between members of the *A. decresii* species group and *A. pictus* which inhabits chiefly sandy, shrub-dominated habitats.

Dispersal—past and present

Since the lizards of this complex appear to inhabit only rock-strewn terrain, the question arises as to how they could have colonized the many isolated hills and ranges where they now occur without having crossed wide expanses of soil plain.

While I have never seen adult and subadult specimens anywhere other than amongst rock outcrops, I have observed very small juveniles of *A. decresii* up to 100 metres away from the nearest rocks amongst dense heath and one was observed wallowing in loose sand on a bare path. This suggests that small juveniles are not behaviourally tied to rocks as are older animals and that some degree of dispersal over non-rocky terrain may be possible in the juvenile stage. I would expect, however, that the distances which such small lizards could cover would be relatively small and not sufficient to explain the colonization of hills separated by tens of kilometres of soil plain.

Because all members of the *A. decresii* species-group confine themselves to rocky habitats, I must assume that their ancestors did the same and I believe they could have dispersed over long distances only where there was sufficient rocky cover and where the gaps between outcrops did not exceed the dispersal ability of juveniles.

It is necessary to suppose, then, that rocky terrain in past times was far more extensive in South Australia than at present, providing several corridors for dragon lizard dispersal and that erosion and deposition over very long periods eventually marooned many populations as valleys widened and filled with alluvium.

I consider, too, that the lizards would not be able to cross sea barriers in the way some others are able (such as by the rafting of adults or their eggs in flood debris). The occurrence of members of the complex on several islands off the coast of South Australia appears to necessitate the assumption that the islands were once part of the mainland and that the lizards colonized them at that time.

Since the nearest living relatives of the *A. decresii* complex occur north and west of South Australia, it is likely that ancestors of the complex migrated in from those directions. Migration is unlikely to have come through the west of the State where lies the Nullarbor Plain and the sandy Great Victoria Desert, or the north-east where lies the sandy Simpson Desert. The only corridor which would have been available to the lizards lies between these deserts and is constituted by the Peake and Denison Ranges. Through these ranges the lizards could have migrated from the Musgrave and Everard Ranges, past the western side of Lake Eyre to the northern end of Lake Torrens.

This last mentioned lake and Spencer and St. Vincent Gulfs lie in the great, sediment-filled South Australian Rift Valley which is bordered along its eastern margin by the Flinders-Mt. Lofty Range system and along its western margin by the Andamooka Ranges and a series of low ranges along the eastern margin of Eyre Peninsula. Further migration may then have occurred in two separate paths, one each side of the sunklands. The eastern path probably led them south to the area now forming Kangaroo I. and a branch could have spread along the Olary Ridge (from Peterborough to the region of Broken Hill). The western path may have led south to areas of which the Neptune and Gambier Is. are now remnants.

Expansion of the lizards' range westwards possibly occurred in two areas: (1) from the hills near the junction of Lake Torrens and Spencer Gulf through the Gawler Ranges system as far west as Lake Everard, and (2) from southern Eyre Peninsula north-westwards as far as Nuyts Archipelago across a great expanse of aeolianite (limestone) country.

While the latter expanse of rock does not form any ranges, it does outcrop on low rises and in gullies. It is not necessary to suppose that this expanse was once exposed along the full length of the West Coast to explain the dragon lizards crossing it. Pockets of exposed rock, as occur today, may have expanded, coalesced, shifted and shrunken with the processes of erosion so that lizards may have been able to move from one patch to another from time to time, gradually expanding their range. The limestone sheet surrounds many granitic, gneissic and sandstone outcrops and probably provided a pathway to them.

Evolution of races

I have sought below to fit the picture of variation within the complex to the conventional concept of new forms arising through geographic isolation, although realizing that alternative explanations may be advanced.

Following colonization of major areas of South Australia by the ancestral form, changes must have arisen which rendered the area north of Lake Torrens unsuitable for habitation as it now appears to be. Thus, populations of the east were separated from those of the west by the Lake Torrens-Spencer Gulf sunklands. Perhaps coincident with these changes was the isolation of populations in the Northern Flinders Ranges from those further south. In this hypothetical situation we may envisage the independent evolution of the three main forms found today.

(a) *Amphibolurus decresii*

Because a single colour form occupies areas on both Kangaroo I. and the southern Mt. Lofty Ranges while another is found in the more northerly ranges, it must be supposed that a barrier to dispersal existed between the North and South Mt. Lofty Ranges well before the separation of Kangaroo I. by the formation of Backstairs Passage. The area now, between Gawler and Kapunda, consists of very low rolling hills which do not provide any suitable outcrops for habitation by *A. decresii*.

The widening and filling of valleys between individual ranges and hills has isolated many populations in the more northerly parts of the range of this species and, presumably as a result, a minor degree of diversity in coloration has arisen amongst them.

(b) *A. fionni*

The present distribution of male colour forms suggests isolation occurred of populations in Areas 1, 2, 3–4 (Fig. 1) and on Neptune and Wedge Is. allowing genetic divergence to develop.

Since the populations of Neptune and Wedge Is. show strong differences from those of the near mainland, it may be suggested that these islands were separated (by the sea level rising in relation to the land) much earlier than islands to the north-west, where populations appear more like those of the near mainland. The generally deeper waters surrounding Neptune and Wedge Is. give some credence to this theory. However, it could also be suggested that there are some differences in the habitats occupied on these islands which exerted strong selective pressures and brought about changes in the inhabitants whereas the habitats of the north-west islands were much the same as those of the mainland.

Two barriers to dispersal must have arisen on the mainland: one north-west of Pt. Augusta (separating area 1 from 2) and another on southern Eyre Peninsula (isolating area 2 from area 3-4). In these two areas development of rocky terrain was presumably weaker than elsewhere so that the processes of erosion and deposition were able to break down or bury the rocks over a sufficiently wide area to disrupt dispersal.

As time went on, this process continued within each area splitting off more and more isolates. Even very small populations may show evidence of their isolation. For example, an unusually bold colour pattern characterises females from the Marble Range.

(c) *A. vadnappa*

Only one major barrier to dispersal of this species appears to have arisen: a broad tract of sandy country passing through Farina and separating the Willouran Ranges from the northern Flinders Ranges.

Perhaps subsequent to the formation of this gap, the barrier separating *A. decresii* from *A. vadnappa* was overcome by the former, thus allowing colonization of the eastern part of the range of the latter. I am at a loss, however, to suggest just how this could have come about.

The evolution of the *A. decresii* complex, as envisaged above, parallels the model of speciation proposed by Pianka (1972) for habitat-restricted lizards living in "shrub-*Acacia*" or "sandplain-*Triodia*" habitats: in both cases, habitats fluctuating in space and time are believed to be the key factor.

Acknowledgements

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NOTES ON THE SMALL MAMMALS OF NORTH-EASTERN SOUTH AUSTRALIA AND SOUTH-WESTERN QUEENSLAND

BY C. H. S. WATTS AND HEATHER J. ASLIN**

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Distribution, status, and habitat preference within the area is discussed for a number of species collected. In particular, *R. sordidus* was found to be common in 1968 and 1972, but uncommon in 1971, when it was restricted to wet areas around bores and floodplains. It is suggested that, following periods of good rainfall, *R. sordidus* spreads from mesic refuges and temporarily occupies surrounding areas, giving rise to plagues in exceptional years.

Introduction

Knowledge of the distribution and habits of many of Australia's small desert mammals is accumulating only very slowly. There is little or no published information on many species of native rodents and small marsupials from the central areas of the continent. Without further distributional records it is impossible to assess whether these species are maintaining their numbers, or have been seriously affected by land-use practices and by the presence of exotic mammals.

In the hope of adding to present knowledge of the distribution and habits of small desert mammals, this paper reports the findings of five field trips to north-eastern South Australia and south-western Queensland. The field work was carried out with the aim of collecting small mammals to establish breeding colonies in captivity. However, in the course of this work information was obtained on the distribution, status, habitat preference, and habits of the species collected. This information is a necessary prerequisite for effective conservation of the various species in the wild.

The species collected were the following: the dasyurid marsupials *Sminthopsis crassicaudata, S. froggatti, Dasyuroides byrnei*, and *Antechinomys spenceri;* the rodents *Notomys alexis, N. cervinus, N. fuscus; Pseudomys australis, P. hermannsburgensis, P. forresti*, and *Rattus sordidus*. Information was also obtained about the status of the Rabbit Bandicoot (*Macrotis lagotis*) in Queensland. A representative specimen of each species collected has been lodged in the South Australian Museum.

Methods

Five trips were made, in September 1968, June 1969, June-July 1971, July 1972 and October 1972. A total of 43 days was spent in the field. A summary of routes taken is shown in Fig. 1.

Most animals were caught by spot-lighting on 33 nights, usually between the hours of 20.00 to 24.00. After detection, animals were caught in a hand-held net. Sherman live mammal traps (7 x 8 x 23 cm) were set on several occasions. Two species were obtained by digging up burrows.

Some animals were released after examination, but most were transported to the laboratory alive.

As it was difficult to determine precise locations at which animals were caught, the locations given are approximate.

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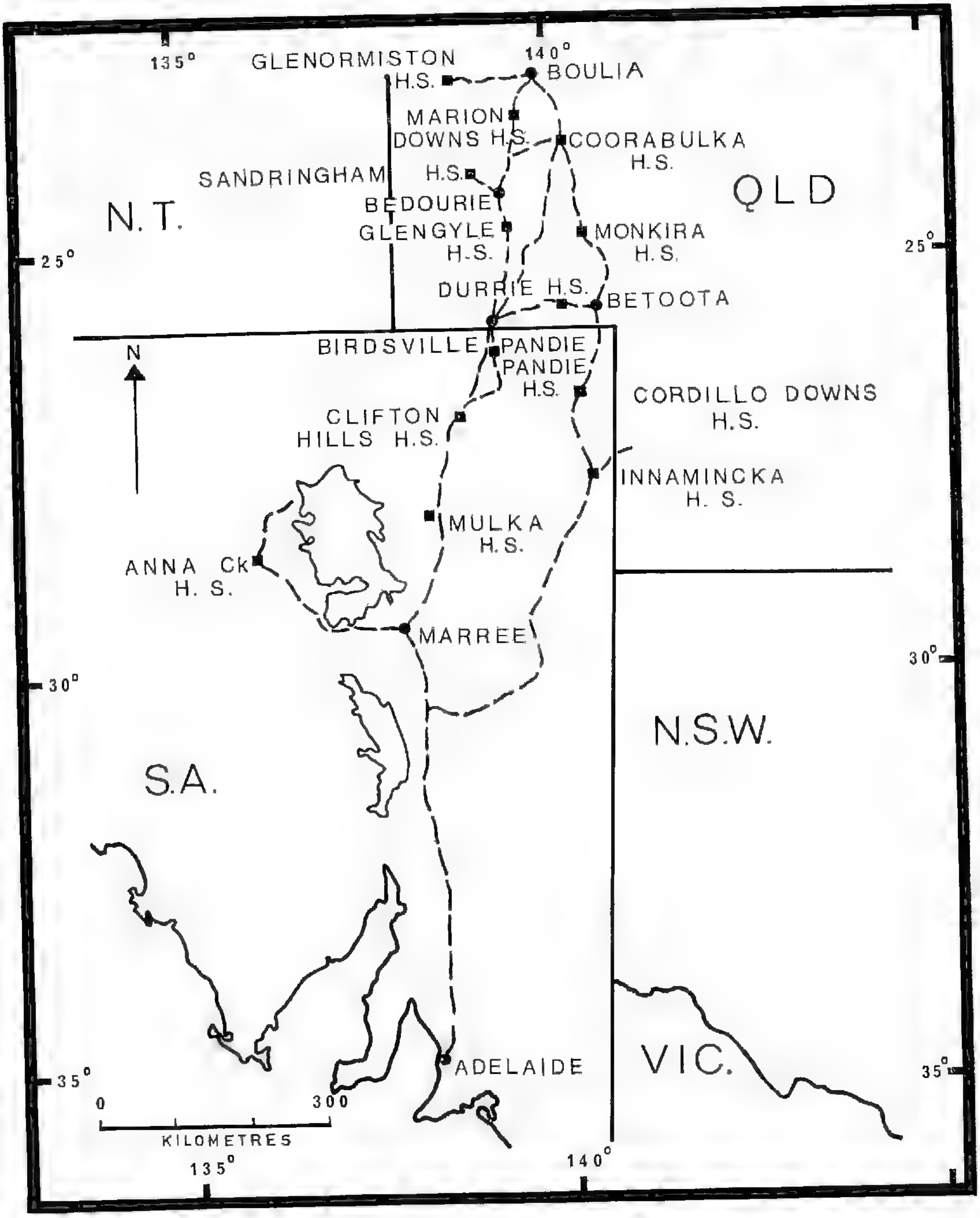

Fig. 1. Summary of the routes taken on the five field trips. The routes followed are indicated by a broken line.

Nomenclature used in this paper follows that of Ride (1970), with the exception of the Long-haired Rat, which is now considered by Taylor & Horner (1973) to be a subspecies of the Dusky Field-rat, and is therefore referred to as *Rattus sordidus villosissimus*, not *Rattus villosissimus*.

Results

MARSUPIALIA

Family PERAMELIDAE

1. **Macrotis lagotis** (Reid), Rabbit Bandicoot

Locality: 16 km N Coorabulka Homestead, Qld; July 1972; 1 (sex unknown).

Notes: One Rabbit Bandicoot was sighted on gibber plain while spot-lighting, and this animal took refuge in a complex burrow system, consisting of approximately 20 holes. Reports from local residents indicate that a colony of *M. lagotis* exists in an area extending from Coorabulka Station into the adjoining stations of Marion Downs and Lorna Downs.

In addition to this colony, reports of animals answering the description of Rabbit Bandicoots were obtained from residents of Glengyle and Sandringham Stations.

Family DASYURIDAE

1. **Sminthopsis crassicaudata** (Gould), Fat-tailed Dunnart

Localities: (i) 72 km NE Anna Creek Homestead, S.A.; June 1971; 2 ♂. (ii) 8 km E Mulka Homestead, S.A.; June 1969, July 1972; 2 ♂. (iii) 112 km SW Innamincka Homestead, S.A.; June 1969; 1 ♀. (iv) 80 km N Innamincka Homestead, S.A.; June 1969; 1 ♀, 1 ♂. (v) 8 km S of Birdsville, Qld; Sept. 1968, June 1969, Oct. 1972; 4 ♀, 12 ♂. (vi) 48 km SE Pandie Pandie Homestead, S.A.; July 1972; 1 ♀. (vii) 16 km W Betoota, Qld; June 1969, July 1972; 5 ♂. (viii) 32 km W Durrie Homestead, Qld; July 1972; 1 ?. (ix) 32 km NW Monkira Homestead, Qld; July 1972; 1 ♂. (x) 16 km W Corrabulka Homestead, Qld; July 1972; 8 ♂. (xi) 32 km NW Coorabulka Homestead, Qld; July 1972; 1 ♀. (xii) 16 km N Coorabulka Homestead, Qld; July 1971, July 1972; 5 ♂. (xiii) 8 km SE Sandringham Homestead, Qld; Sept. 1968; female with three young. (xiv) 8 km S Glengyle Homestead, Qld; Sept. 1968; 2 ♀, 9 ♂. (xv) 8 km E Glenormiston Homestead, Qld; Sept. 1968; 1 ♂.

Notes: S. crassicaudata was found in a variety of habitats, including gibber and sand plain, alluvial flats, and clay pans. One animal was trapped by a bore drain. The species appeared to be thinly spread in most areas, but 11 animals were caught by spot-lighting in an area of less than 2 hectares near Glengyle Homestead, on recently flooded clay pans.

2. **Sminthopsis froggatti** (Ramsay), Stripe-faced Dunnart

Localities: (i) 16 km N Pandie Pandie Homestead, S.A.; Sept. 1969; 1 ♂. (ii) 16 km N Coorabulka

2

Fig. 2. Habitat of *Sminthopsis froggatti* on Coorabulka Station, Qld.

Fig. 3. Adult male *S. froggatti* from Coorabulka, Qld.

Homestead, Qld; July 1972; 1 ♂. (iii) 32 km NW Coorabulka Homestead, Qld; July 1972; 1 ♂.

Notes: One of the three *S. froggatti* is illustrated in Fig. 3, together with the habitat in which it was collected.

3. **Antechinomys spenceri** Thomas, Wuhl-wuhl

Localities: (i) 8 km W Birdsville, Qld; July 1969; 1 ♂. (ii) 16 km W Betoota, Qld; June 1969, July 1972, Oct. 1972; 3 ♀, 5 ♂. (iii) 16 km W Coorabulka Homestead, Qld; Sept. 1968, July 1971, July 1972; 2 ♀, 2 ♂.

Notes: A. spenceri was captured on gibber plain, by spot-lighting, and at each of the three localities was sympatric with the rodent, *Notomys cervinus.* One female *A. spenceri* took refuge in what appeared to be a disused burrow of *N. cervinus.*

4. **Dasyuroides byrnei** Spencer, Kowari

Localities: (i) 8 km SE Coorabulka Homestead, Qld; Sept. 1968; 1 ♀. (ii) 16 km N Coorabulka Homestead, Qld; July 1971; 8 ♀, 6 ♂. (iii) 16 km W. Coorabulka Homestead, Qld; July 1971; 2 ♂. (iv) 8 km N Coorabulka Homestead, Qld; July 1972; 1 ♂.

Notes: Of the 18 animals collected, 14 were trapped, two were caught by spot-lighting, and one was a road-kill.

In July 1972, seven *D. byrnei* were sighted on station roads north of Coorabulka Homestead. When pursued, two of these animals took refuge in burrows occupied by Long-haired Rats (*R. s. villosissimus*) which were abundant at the time. All *D. byrnei* were captured on gibber plain.

Reports of animals which may have been *D. byrnei* were obtained at Betoota, Qld, and a skull of *D. byrnei* was found under an airport marker near Betoota.

RODENTIA

Family **MURIDAE**

1. **Notomys alexis** Thomas, Spinifex Hopping-mouse

Localities: (i) 80 km N Innamincka Homestead, S.A.; June 1969; 2 ♂. (ii) 8 km SE Sandringham Homestead, Qld; Sept. 1968; 1 ♂

2. **Notomys cervinus** (Gould), Fawn Hopping-mouse

Localities: (i) 48 km S Pandie Pandie Homestead, S.A.; July 1972; 1 ?. (ii) 8 km S Birdsville, Qld; June 1969; 1 ♀, 2 ♂. (iii) 16 km N Birdsville, Qld; Sept. 1968; 3 ♀, 13 ♂. (iv) 16 km W Betoota, Qld; June 1969, July 1972, Oct. 1972; 3 ♀, 3 ♂. (v) 32 km W Durrie Homestead, Qld; July 1972; 2 ♀. (vi) 16 km S Glengyle Homestead, Qld;

Sept. 1968; 5 ♀, 9 ♂. (vii) 16 km S Glengyle Homestead, Qld; July 1971, 1 ♀, 4 ♂. (viii) 16 km N Coorabulka Homestead, Qld; July 1972; 1 ♀.

Notes: A total of 15 females and 31 males of *N. cervinus* were captured, by spot-lighting, either on open gibber plain, or gibber plain with alluvial flats. Several *N. cervinus* took refuge in burrows which consisted of one to three closely grouped entrance holes, situated on open gibber plain.

3. **Notomys fuscus** (Jones), Dusky Hopping-mouse

Localities: (i) 16 km N Birdsville, Qld; Sept. 1968; 1 ♂. (ii) 16 km W Betoota, Qld; June 1969, July 1972, Oct. 1972; 21 ♀, 17 ♂.

Notes: All *N. fuscus* from Betoota were obtained from a limited area of sand ridge which was visited on four occasions (Fig. 4).

Two burrow systems of *N. fuscus* were excavated, and a diagram of one is shown in Fig 6. Neither of the burrows contained animals.

4. **Pseudomys forresti** (Thomas), Forrest's Mouse

Localities: (i) 16 km W Coorabulka Homestead, Qld; July 1972; 1 ♀. (ii) 32 km NW Coorabulka Homestead, Qld; July 1972; 1 ♀.

5. **Pseudomys (Leggadina) hermannsburgensis** (Waite), Sandy Inland Mouse

Localities: (i) 8 km SE Sandringham Homestead, Qld; Sept. 1968; 1 ♀. (ii) 16 km W Betoota, Qld; June 1969, July 1972, Oct. 1972; 3 ♀, 3 ♂. (iii) 32 km NW Coorabulka Homestead, Qld; July 1972; 1 ♂.

6. **Pseudomys australis** Gray, Plains Rat

Locality: 96 km NE Cordillo Downs Homestead, S.A.; June 1969; 3 ♀, 1 ♂.

Notes: the four *P. australis* were obtained from a single burrow, which was one in an extensive area of burrows situated on gibber plain with clay-pans. Seven burrows were dug up, but only one was occupied. Sections of some burrows were stuffed with green vegetation.

7. **Rattus sordidus villosissimus** (Waite), Long-haired Rat

Localities: (i) 16 km N Clifton Hills Homestead, S.A.; Sept. 1968; 3 ♀, 5 ♂. (ii) 32 km NE Clifton Hills Homestead, S.A.; Sept. 1968; 7 ♀, 1 ♂. (iii) 16 km N Birdsville, Qld; Sept. 1968, July 1971; 9 ♀, 11 ♂. (iv) 72 km NE Anna Creek Homestead, S.A.; June 1971; 2 ♀, 1 ♂. (v) 32 km SE Pandie Pandie Homestead, S.A.; July 1971; 1 ♀ and 6 young, 1 ♂. (vi) 16 km N Coorabulka Homestead, Qld; July 1972; many animals.

Notes: Sixteen *R. s. villosissimus* were trapped on sand-ridges and flood-plain at Clifton Hills Station in 1968. Green vegetation was plentiful at this time. A further 20 animals were trapped near Birdsville on gibber plain in 1968 and 1971.

The locality on Anna Creek Station was a reed and sedge area around a bore drain, while on Pandie Pandie Station a female and her six young were dug out from a simple burrow in a sand ridge close to flood-plain. The young were enclosed in a spherical nest of shredded plant material.

In July 1972, signs of *R. s. villosissimus* were found in most areas visited, from Mulka Station northwards. Many rats were sighted during spot-lighting on Pandie Pandie, Durrie, Monkira and Coorabulka Stations, and also near Betoota. They were in plague proportions on Coorabulka Station, where many were trapped on gibber plain, and extended north to Boulia.

Discussion

The finding of *Macrotis lagotis* in south-western Queensland is of interest because of its present rarity and great decrease in range this century. Mack (1961) obtained Rabbit Bandicoots from near Birdsville in 1957-59, but the species has not been seen recently in this area. Smyth & Philpott (1967) found the species to be common at Warburton Mission, W.A., and Watts (1969) located colonies at Yuendumu, Hamilton Downs and Papunya in the Northern Territory. This study suggests that Rabbit Bandicoots may still occur in several areas of western Queensland, where rabbits and foxes are in low numbers.

Of the four species of dasyurid marsupials collected, *Sminthopsis crassicaudata* was the most common, and appears to occur in all types of habitat in the area studied. *S. crassicaudata* from these areas were characterized by larger ears, longer tails and paler coat colour than animals from southern South Australia, and are referrable to the sub-species *S. crassicaudata centralis* Thomas.

Another species of *Sminthopsis*, identified by M. Archer (pers. comm.) as *S. froggatti* (sens. Ride 1970), was obtained in the same areas as *S. crassicaudata*, but was much less common.

An extremely biassed sex ratio of 46 males to 11 females (four animals were not sexed), was found for *S. crassicaudata* captured by spot-lighting. This contrasts with Wood Jones' (1923) finding that many more females than males were captured by trapping and by domestic cats. This serves to illustrate the way in which methods of capture may discriminate against one sex in favour of the other.

Of the 11 female *S. crassicaudata* captured, only two had young, both in the spring months. Since all animals were captured in winter or spring, and since most breeding in *S. crassicaudata* occurs between July and February, both in the field and in the laboratory (Godfrey & Crowcroft 1971), it is surprising that more females with young were not captured. It seems that either only a small percentage of females are breeding at any one time, or that methods of capture which depend on the amount of time which the animals spends active outside refuges discriminate against females with pouch young. This is consistent with Ewer's (1968) observations that captive females with pouch young were less active than usual.

The small dasyurid *Antechinomys spenceri* was found to be moderately common in several areas of south-western Queensland, but was not taken in South Australia, and appears to be rare in the north-east of the State, although Finlayson (1961) found it plentiful in the Everard and Musgrave Ranges of the north-west. All the animals captured in Queensland were taken on gibber plain, which contrasts with Wood Jones' (1923) statement that *A. spenceri* is an animal of sand-ridge desert. Marlow (1968) also found *A. spenceri* in areas of gibber plain habitat.

Until recently *A. spenceri* was believed to hop bipedally like the murids of the genus *Notomys*. Ride (1965) showed, however, that *A. spenceri* moves quadrupedally at all times, and Marlow (1968) found that *A. spenceri* also adopted different escape tactics from *N. cervinus* when pursued in similar habitat. This was also noted in the present study. *A. spenceri* frequently crouched behind small clumps of vegetation, relying on concealment to escape capture, whereas *N. cervinus* invariably hopped at high speed, and frequently changed direction.

Unfortunately none of the female *A. spenceri* from Queensland had pouch young, although there is a record of one female with young which was captured in September in the Northern Territory (unpublished data). If this species breeds during the winter and spring months, once again it is surprising that none of the five females captured had pouch young. The argument used to account for the similar situation with *S. crassicaudata* may not be applicable to *A. spenceri*, as only a slight excess of males (8 males, 5 females) was recorded for this species.

Dasyuroides byrnei was found in a limited area of south-western Queensland, and appears to be restricted to gibber plain. The type locality of this species is Charlotte Waters in the Northern Territory, and it has been taken as far south as Killalpaninna, on Cooper's Creek in South Australia (Wood Jones 1923). However, *D. byrnei* has seldom been collected from the Northern Territory or South Australia in recent times, although it remains common in parts of south-western Queensland.

Seven of the eight female *D. byrnei* collected in July, 1971, had pouch young, all of which were estimated to have been born in June. Woolley (1971) collected pouch-gravid females in June, and pregnant females in November. Female cycles appear to be synchronized in this species, and most females come into breeding condition in May or June both in the field and in the laboratory.

Turning to the rodents, firstly it is worth noting that although seven species of native rodents were collected, the introduced house mouse (*Mus musculus*) was not found in the area under study. Of the native rodents obtained, *Notomys cervinus* was the most common; 48 were collected in South Australia and Queensland. *N. cervinus* was found on both gibber plain and alluvial flats, but not on sandy areas. It was abundant in some parts, particularly near Betoota. *N. cervinus* appears to be a social species as indicated by the groups of three to four animals sighted simultaneously in the field.

Of the 15 female *N. cervinus* collected, one was lactating in September, and another pregnant in July. One juvenile was also collected in July. These records suggest that *N. cervinus* may be a winter breeder in the wild.

Notomys fuscus was obtained at Betoota in the same area as *N. cervinus*, which it closely resembles. However, both sexes of *N. fuscus* have an obvious gular pouch, which distinguishes the species from *N. cervinus*, in which neither sex possesses a gular pouch (Aitken 1968).

N. fuscus was found to be abundant on one sand-ridge near Betoota, and was apparently confined to this ridge. *N. cervinus* was collected from the adjacent gibber flats, but only one *N. fuscus* was captured on these flats. It seemed, therefore, that *N. fuscus* ventured only rarely onto open gibber plain. Aitken (1968) has mapped the distribution of *N.*

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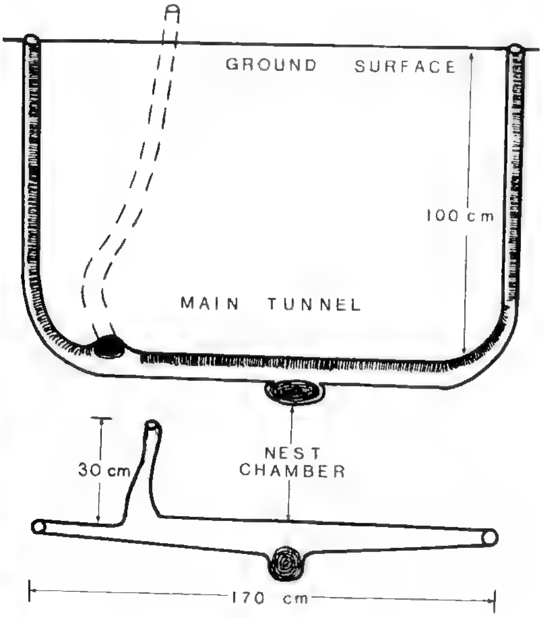

Fig. 4. Habitat of *Notomys fuscus* near Betoota, Qld.

Fig. 5. Adult female *N. fuscus*.

Fig. 6. Diagram of a burrow system of *N. fuscus* excavated on the sand-ridge shown in Fig. 4.

fuscus, and has shown that most records of this species are from north-eastern South Australia, with the greatest concentration between Lake Eyre and the Queensland border. The present record from Betoota appears to be the most northerly locality at which the species has been taken.

Burrows of *N. fuscus* located on the sand-ridge conformed to the typical *Notomys* pattern (Fig. 6), having several vertical shafts descending to a depth of 70–140 cm (two to four feet). The number of animals present on the sand-ridge appears to fluctuate, as none was sighted in June, 1971, although conditions at this time were better than in July, 1972, when *N. fuscus* was common. In addition, two females collected in July, 1972, were pregnant; one gave birth to five young within a week of capture, and the other gave birth to one young 35 days after capture. Breeding in this species, if opportunistic as suggested for many desert rodents, may not be directly dependent on rainfall, or there may be a considerable lag in response to improved conditions. Watts (1970) has shown that *N. fuscus* eats mainly seed in the wild, and much of this seed may be lost due to germination immediately after rainfall.

A third *Notomys* species, *N. alexis*, was collected from two areas of sand-plain covered with *Triodia*, but was not common in the areas visited. From these records it can be seen that the three species of *Notomys* in south-western Queensland have distinct habitat preferences: *N. cervinus* favours open gibber or alluvial plains, *N. fuscus* inhabits sand-ridges, and *N. alexis* lives on the flatter areas of deep sand.

Three species of the genus *Pseudomys* were collected: *P. forresti*, *P. hermannsburgensis*, and *P. australis*. The records of *P. hermannsburgensis* from Queensland are unusual, as the greatest concentration of this species is to the west of Alice Springs, some 480 km from the present localities. Finlayson (1961) states that he could obtain no evidence of this species to the east of Stuart's Line, but in this study *P. hermannsburgensis* was taken from three widely separated localities in western Queensland.

Of the four female *P. hermannsburgensis* captured, one was pregnant when collected in June, 1969, and gave birth to two young eight days after capture. One juvenile male was collected in July, 1972, indicating that this species shows breeding activity in the winter months. Similarly, two of the three female *P. australis* collected in June, 1969, were pregnant, and gave birth to three and two young in the laboratory at 15 and 16 days after capture.

Rattus sordidus villosissimus was collected on many occasions, and some conclusions about its habits can be drawn. This species is known to increase vastly in numbers at intervals of five to seven years, and Finlayson (1961) suggested that at these times it swarms from a breeding centre in western Queensland into South Australia and the Northern Territory. This theory requires large-scale migration of the species into previously unoccupied areas.

Information from the present study indicates that during rat plagues the animals can be found in all types of habitat, provided green plants or roots are available as a source of water, as *R. s. villosissimus* is unable to survive without preformed water (unpublished data). These conditions prevailed in 1968 and 1972, when the species was abundant from northern South Australia to Boulia in Queensland. However, animals collected in 1971 were obtained from areas close to water, such as around bore-drains and from flood-plain

Three females obtained from Clifton Hills Station in 1968 were pregnant, but there was evidence that the rats were decreasing their range in this area, as there were many unoccupied burrows in gibber plain which had recently dried out. In a good season it seems that *R. s. villosissimus* can occupy all types of habitat, but as vegetation dries out the gibber plains are the first areas which become untenable. Similarly, in 1972, although rats were present on gibber plain in many areas, they were most numerous around bore-drains, and animals living on the open plains were often in poor condition.

This information suggests that *R. s. villosissimus* is always present in small numbers in pockets of favourable habitat, such as around bore-drains. In such pockets the rats can survive droughts, and if conditions improve in surrounding areas they are able to expand into these areas. These successive expansions from many breeding nuclei are therefore responsible for rat plagues, not mass migration from a single centre in western Queensland. In mesic refuges *R. s. villosissimus* is a relatively cryptic species, which may account for the common belief that it is completely absent from most areas in non-plague years.

In summary, it seems that a number of native mammals are moderately common in north-eastern South Australia and south-western Queensland, in spite of almost complete pastoral exploitation of the area. The small mammals have fared better than those of intermediate size. In particular, the desert bandicoots have suffered greatly in this century. *Macrotis leucura*, *Chaeropus ecaudatus*, *Perameles eremiana* and *Isoodon auratus* all appear to have vanished with the invasion of the fox into central Australia (Finlayson 1961). In view of this fact, the Rabbit Bandicoot is most urgently in need of protection in Queensland, as the colonies in this area are probably small and are widely separated from other known colonies.

Many of the small mammals, however, appear to be maintaining their numbers, although in many cases little is known about their distribution and habits. This lack of knowledge can only be remedied by more extensive field work carried out regularly over long periods. Such field work is particularly necessary for an understanding of the population dynamics of many of Australia's native rodents.

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NEW SPECIES OF HYLID AND LEPTODACTYLID FROGS FROM SOUTHERN NEW GUINEA

BY M. J. TYLER AND F. PARKER†*

Summary

TYLER, M. J., & PARKER, F. (1974).-New Species of Hylid and Leptodactylid Frogs from southern New Guinea. *Trans.* R. *Soc. S. Aust. 98* (2), 71-77, 31 May, 1974.

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Introduction

In a recent comparison of the Australian and Papuan frog faunas adjacent to Torres Strait, Tyler (1972a) indicated that few species are exclusive to the Papuan coastal area. However, it was noted that literature references to the occurrence there of the Australian leptodactylid *Crinia signifera* (Roux 1920; Van Kampen 1923; Parker 1940) antedated knowledge of the existence of a complex of species previously so identified (Moore 1954; Main 1957), and probably represented an undescribed species.

Tyler & Parker (1972) increased the known Papuan hylid frog fauna by describing *Litoria timida* from the upper tributaries of the Fly River, and from localities situated closer to the coast in the south-east of Papua New Guinea.

On 4 March, 1973, one of us (F.P.) collected eight species of frogs at Merauke, situated only 80 km west of the area from which the collections of Tyler & Parker (1972) were obtained. One of these species represents a previously undescribed hylid which we describe here. Moreover, we now have adequate material from previous collections in southern New Guinea to re-examine the taxonomic status of the leptodactylid.

Crinia Tschudi, as recognised by Parker (1940), is now regarded as constituting four distinct genera: *Assa* Tyler, *Crinia* Tschudi, *Geocrinia* Blake and *Ranidella* Girard (Tyler 1972b; Blake 1973). The *Crinia signifera* complex has been referred to *Ranidella* by Blake, and the species that we describe here is a member of that genus.

Methods

The specimens discussed here are deposited in the collections of institutions abbreviated in the text as follows: American Museum of Natural History (AMNH); Museum of Comparative Zoology (MCZ), Naturhistorisches Museum Basel (NMB); South Australian Museum (SAM), and Department of Biology, University of Papua New Guinea (UPNG).

The methods of measurement and morphological and descriptive terminology follow those of Tyler (1968). The descriptive abbreviations used are: E (horizontal diameter of the eye); E-N (distance between the eye and the naris); IN (internarial span); HL (head length); HW (head width); S-V (snout to vent length); and TL (tibia length). Techniques of call recording and analysis follow Tyler & Menzies (1971).

Merauke is situated approximately 80 km west, Gubam 30 km east, and Mata 10 km east, of Morehead (Tyler & Parker 1972, Fig. 1).

Litoria quadrilineata n.sp.

Holotype: SAM R13489. An adult male collected on land adjacent to the Post Office, Jalan Trikora (=Trikora Road), at Merauke, Irian Jaya (formerly West Irian), New Guinea, by F. Parker on 4 March, 1973.

Definition: A small lowland species (males 27.4–30.5 mm S-V) characterised by a narrow

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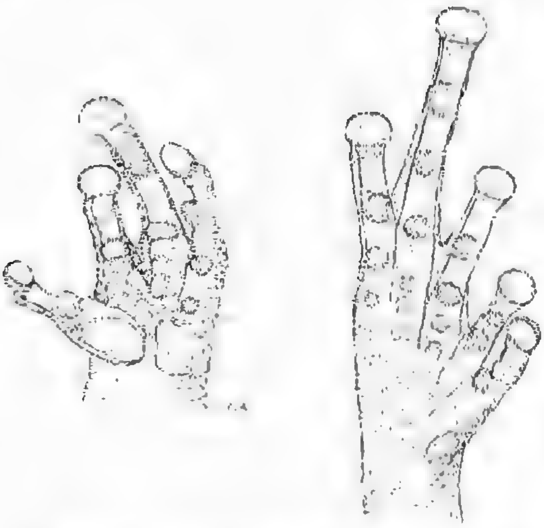

Fig. 1: Hand and foot of *Litoria quadrilineata.*

and rather elongated head and body, short limbs, unwebbed fingers, vestigially webbed toes and four dark, longitudinal stripes on the lateral and dorsal surfaces of the body.

Description of Holotype: The head is high, triangular when viewed from above, and longer than broad (HL/HW 1.089), its length equivalent to slightly more than one-third of the snout to vent length. The snout is high and prominent when viewed from above, rounded and projecting beyond the anterior limit of the mandible in profile. The nostrils are situated laterally, their distance from the end of the snout being approximately one-half that from the anterior margin of the eye. The distance between the eye and the naris is greater than the internarial span (E-N/IN 1.083). The canthus rostralis is of moderate length, clearly defined and very slightly curved, whilst the loreal region is markedly concave. The eye is of moderate size and not conspicuously prominent, its diameter equivalent to the distance between the eye and the naris. The tympanum is conspicuous, with a narrow annulus partly hidden superiorly by a supra-tympanic fold. The tympanic diameter is equivalent to approximately one-half of the horizontal diameter of the eye. Vomerine teeth are absent: there is a slightly raised elevation on the left side but not on the right. This elevation is situated between the choanae. The tongue is broadly oval with a very weak posterior indentation.

The fingers are long, slender, unwebbed, and possess only extremely slender lateral fringes (Fig. 1). The decreasing order of length of the fingers is 3>4>2>1. The terminal discs are moderate, the diameter of the discs of the third finger being approximately one and one-half times the diameter of the penultimate phalanx.

The hind limbs are relatively short and slender, with a TL/S-V ratio of 0.407, and toes in decreasing order of length 4>5>3>2 = 1. Only a vestigial trace of webbing occurs between the fourth and the fifth, and third and fourth digits (Fig. 1). There is a small circular inner but no outer metatarsal tubercle.

The dorsal surfaces of the head, body and limbs are minutely granular. Distinct tubercles are lacking. The skin of the throat and chest lacks tubercles, but is greatly folded and convoluted in association with the vocal sac, and is clearly a reflection of the calling activity of the specimen prior to preservation. The abdomen and ventral surfaces of the femora are granular. There is an extremely prominent gland at the post-articular margins of the mandibles.

This male specimen has a large, single submandibular vocal sac with longitudinal paired apertures bounded by the anterior cornua, and glandular but completely unpigmented nuptial pads.

The dorsum is a very pale brown, on which there are four narrow, but conspicuous, longitudinal black stripes. The median pair commences on a level with the anterior margins of the upper eyelids and extends to the femora. The lateral stripes extend from the tip of the snout to the inguinal region. In addition there is a very narrow and much less conspicuous mid-vertebral stripe, and a pair of short dark stripes on each side of the cloaca, extending to a position anterior to the level of the femora. There is a dark stripe on the outer margin of the forearm and a pair of more conspicuous dark stripes on the dorsal surface of the tibia and the tarsus. The post-labial gland is white and the ventral surfaces of the body and limbs are dull cream and immaculate.

Dimensions: Snout to vent length 29.9 mm; tibia length 12.2 mm; head length 9.5 mm; head width 8.6 mm; eye to naris distance 2.6 mm; internarial span 2.3 mm; eye diameter 3.1 mm; tympanum diameter 1.9 mm.

Variation: The paratype series consists of twelve adult males (MCZ 86014-21; SAM R13490–93), collected at Merauke with the

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Fig. 2. *Litoria quadrilineata* in posed position shortly after preservation.

holotype. They differ only slightly in size, the snout to vent length range being 27.1–30.0 mm, with a mean of 28.8 mm. The limbs are consistently very short (TL/S-V ratio 0.39–0.44) and the body slender. The HL/HW range is 1.100–1.143 and the E-N/IN range 1.125–1.182. Figure 2 is of a freshly killed specimen in a posed position.

Vomerine teeth are present on distinctly raised vomerine elevations; the vomerine elevations may be present and teeth absent or both elevations and teeth entirely absent.

The post-labial gland is present and conspicuous in ten paratypes but is entirely lacking in two. Although all specimens have the skin of the throat gently convoluted and folded, indicating a period of prolonged vocal activity prior to collection, the nuptial pads are unpigmented.

In preservative the four longitudinal stripes are present throughout the series, the specimens differing only slightly in the background coloration: some being dark brown and others a sandy brown.

The description of colour in preservative was prepared within only a few weeks of their collection. Living specimens differed principally in that the anterior and posterior surfaces of the thighs were bright red and the skin of the throat a deep yellow. The portion of the iris above the pupil was pale brown and that below it dark brown.

Comparison with other species: Litoria quadrilineata can be readily distinguished from all other species currently known to occur in New Guinea, but its phylogenetic relationships are difficult to establish.

Ignoring the possession of the four dark longitudinal stripes, which are not exhibited by any previously described species, the size and general proportions are consistent with those exhibited by members of the *Litoria rubella* complex. This group, as defined by Tyler (1968), comprises *L. congenita, L. capitula, L. rubella* and *L. wisselensis.* All are of moderate size (snout to vent length rarely exceeding 35 mm) and have short limbs. Distinct markings in these species, when present, trend towards the lateral orientation so clearly depicted by *L. quadrilineata.* Where *L. quadrilineata* differs from the members of the *L. rubella* group most conspicuously is in the nature of the digits in terms of length, proportion of digits and webbing. In these respects the only hylids with feet resembling those of *L. quadrilineata* are the south-eastern Australian species *L. brevipalmata* and *L. citropa,* neither of which exhibit other obvious affinities to it.

In the key to Papuan *Hyla* (Tyler 1968) (now *Litoria*, vide Tyler 1971), *L. quadrilineata* keys most closely to *L. jeudei*. The latter species lacks longitudinal markings, has a higher TL/S-V ratio (0.48, as opposed to 0.39–0.44 in *L. quadrilineata*) and a considerably longer snout (E–N/IN 1.435 in *L. jeudei* and 1.125–1.182 in *L. quadrilineata*).

Litoria quadrilineata is a highly distinctive New Guinea hylid frog, and there is currently no evidence of a particularly close phylogenetic relationship with any other species known from the island.

Habitat: The series was collected on a plot of low-lying, swampy vacant land in the township, amongst matted grass above and adjacent to water. Collecting in similar habitats occurring to the east and south-east of the township yielded other species of *Litoria*, but no further representatives of *L. quadrilineata* were observed or heard calling there.

Call: Most of the specimens were calling when collected. They were in a horizontal position on the grass producing a low-pitched buzz-like call of approximately 2–3 seconds duration. The species was by no means timid, continuing to call when illuminated by a spotlight.

Ranidella remota n.sp.

Crinia signifera, Roux (1920).

Crinia signifera signifera, Parker (1940) (part)

Holotype: SAM R13524. A gravid female collected at Morehead, Papua New Guinea by F. Parker on 18 June, 1972.

Definition: A small lowland species (males 13.2–15.6 mm; females 14.3–18.7 mm S-V) characterised by its short and rather rounded snout, lack of a tympanum, and smooth or weakly granular abdominal skin.

Description of holotype: Maxillary teeth present. Vomerine teeth absent. Snout short, blunt and rounded when viewed from above and in profile, and not projecting conspicuously. Eye to naris distance slightly less than the internarial span (E-N/IN 0.80). Canthus rostralis poorly defined and straight, loreal region slightly concave. Tympanum absent.

Fingers relatively long, unwebbed and unfringed, with well developed subarticular tubercles. Hind limbs short (TL/S-V 0.44). Toes long, unwebbed and with very slightly developed lateral fringes. A small inner but no outer metatarsal tubercle.

Dorsal surface of head, body and limbs covered with very small tubercles. Throat smooth, abdomen very slightly granular. A glandular post-labial area.

The dorsal surfaces of the body and limbs are dark grey with a pair of pale creamish dorsal stripes extending from the scapular to the coccygeal regions. The ventral surface is pale cream with a uniform, but very sparse, faint grey stippling.

Dimensions: Snout to vent length 16.5 mm; tibia length 7.3 mm; head length 7.2 mm; head width 6.1 mm; eye diameter 2.2 mm; eye to naris distance 1.2 mm; internarial span 1.5 mm.

Variation: There are 24 paratypes consisting of 6 adult females (3 of them gravid), 9 males (8 adult), and 9 juveniles: MCZ 86119–21, SAM R13527–28, Gubam, 16.vi.1972; UPNG 1190, Morehead, 28.i.1969; AMNH 88031–32, SAM R13525–26, R13681–82, UPNG 3847–50, MCZ 86127, Morehead, 19.v.1969; MCZ 86122–26, NMB 3180, Merauke 1920; Morehead 18.vi.1972; MCZ 86128, Mata, 19.vi.1971. Of the paratypes UPNG 1190 was collected by J. I. Menzies, NMB 3180 by P. Wirz and the remainder by F. Parker. A living specimen is depicted in Figure 3.

An additional 8 specimens (MCZ 86111–18) were found in the stomach of a specimen of the colubrine snake *Amphiesma mairii* collected by F. P. at Morehead on 18.vi.1972. These specimens are identifiable as *R. remota*, but are so misshapen that it has proved impossible to obtain measurements or any other data from them. Because they have in no way contributed to our knowledge of the species and have not been taken into account in our assessment of variation, we have not accorded them paratype status.

Snout to vent lengths of the adult males vary from 13.2–15.6 mm; gravid females vary from 15.5–18.7 mm; the smallest juvenile 10.4 mm. Variation in proportions of the adults in the paratype series are as follows: TL/S-V 0.44–0.50; HL/HW 1.09–1.27; E-N/IN 0.80–1.00.

Polymorphism in terms of dorsal skin texture as defined by Parker (1940) and Main (1957) involves the smooth, lyrate and warty morphs in the ratio of 8:5:10. Variation in dorsal appearance of most adults involves the pair of longitudinal stripes exhibited by the holotype. They vary only in their intensity and extent of contrast from the dull general dorsal colouration.

3

Fig. 3. *Ranidella remota.*

Ventral markings are confined to very fine and quite uniform stippling in all specimens, except for one adult in which the throat and pectoral regions are densely pigmented with black, and bisected by a narrow, median unpigmented line.

In life the dorsum is either predominantly grey or brown, the throat and ventral surfaces of the limbs grey, and the abdomen white. The portion of the iris above the pupil is gold and the portion below grey.

Call: Males call from a horizontal position on the ground, usually beneath a leaf or some other form of cover. The animals appear ventriloquial, making it difficult to locate them, particularly because they cease calling when disturbed.

Data on the male mating call structure are based on recordings made by J. I. Menzies of UPNG 1190 calling amongst flooded grass tussocks by the river at Morehead on 28.i.1969.

A sonagram of this call is depicted in Figure 4, showing a dominant frequency of 4250 Hz, a duration of 720 milliseconds, and being composed of 14 pulses with an individual pulse duration of approximately 28 milliseconds. Menzies (pers. comm.) reports that there are from 12 to 15 pulses per call and that the last two or three tend to have a shorter duration: the acoustic impression is one of a series of short buzzes.

Comparison with other species: The status of the populations of *Ranidella* occurring in the Northern Territory and in northern Queensland are currently unknown. Although it would be preferable to have these populations defined and described before describing what constitutes the northern peripheral member of the genus, we seek only to establish that the population that we describe here is new. Thus, although a close phylogenetic relationship may ultimately be demonstrated with such northern Australian species, we are now only able to distinguish *R. remota* from those species that have been described.

Morphologically *R. remota* firstly must be compared with the species known to occur in Queensland: *R. signifera, R. parinsignifera,* and *R. tinnula.* Absence of a tympanum and the greatly reduced pigmentation of the ventral surface distinguishes *R. remota* from each of these species. *Ranidella tinnula* is also shown by Straughan & Main (1966) to have a

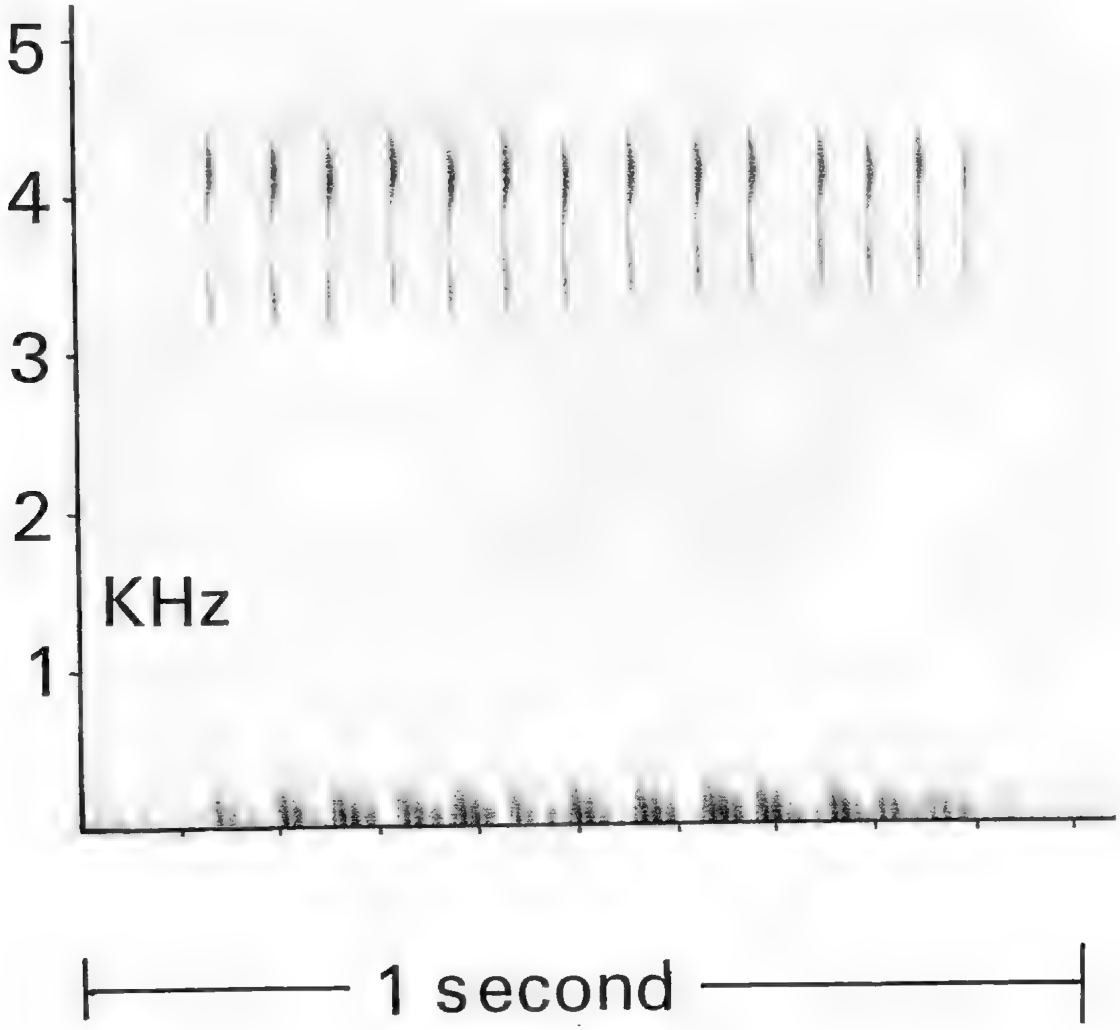

Fig. 4. Sonagram of mating call of *Ranidella remota*.

conspicuous snout, greatly projecting in profile, contrasting with the gently rounded snout profile of *R. remota.*

Ranidella signifera extends from southern Queensland to the southern portion of South Australia. Many of the specimens from the western portion of the range have reduced ventral pigmentation, but the species is consistently larger. Ranges of snout to vent length for *R. signifera* derived from Littlejohn (1963) and Littlejohn & Martin (1965) are: males 18.0–24.2 mm; females 19.0–27.7 mm.

Ranidella riparia of the Flinders Ranges in South Australia is the only Australian species known to lack a tympanum. This species is also consistently larger than *R. remota* with snout to vent length ranges of 19.5–25.2 (males) and 23.0–25.2 (females). It also has extensive ventral pigmentation and further differs from *R. remota* in possessing broadly fringed toes.

The most striking characteristics of the mating call of *R. remota* are its long duration of 720 msec and the number of pulses (14). Within *Ranidella* this duration is considerably greater than the ranges of all except one of the species summarised by Littlejohn (1959) and Littlejohn & Martin (1965). The upper limit of *R. riparia* is quoted at 497 msec, but it is the south-western Australian species *R. glauerti,* with its maximum call duration of 820 msec which surpasses *R. remota. Ranidella glauerti* differs in its pulse frequency (7–12). The nature of the call differences between *R. remota* and *R. glauerti* are not considerable. Of the described Queensland species it is worth noting that the call duration of *R. tinnula* is less than 100 msec. The pulse rate of *R. remota* is relatively low but such low rates are, in *Ranidella*, associated with a particularly short duration in the species compared by Littlejohn (1959).

Habitat and habits: In the Morehead and Weam areas, *R. remota* was found in areas of low mixed savannahs, particularly along the fringes of low-lying grass-covered flats having a grey clay soil. The occurrence of the species in low monsoon scrubland and tall mixed savannas was restricted to the area around Balumuk.

Ranidella remota was usually found away from permanent water, and was observed to be a secretive species living beneath leaf litter and amongst grass on damp soil, but was not found beneath logs or bark fragments on the ground. It appears to be predominantly nocturnal, although it has been observed hopping amongst grass on days when the skies were overcast.

Acknowledgments

We are indebted to Mr. J. I. Menzies (University of Papua New Guinea) for permission to reproduce the sonagram of *R. remota*, to Dr. L. Forcart (Naturhistorisches Museum Basel) for the loan of a specimen, to Miss M. Anstis for preparation of the line drawings and to Dr. J. Ling for reading the manuscript.

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EARTHWORMS (OLIGOCHAETA: MEGASCOLECIDAE) FROM SOUTH AUSTRALIA

*BY B. G. M. JAMIESON**

Summary

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The Megascolecidae is the only family of earthworms indigenous in South Australia. The megascolecid fauna of the state is impoverished, though specific endemicity is high, consisting of five genera with thirteen species. These are the circum-mundane *Microscolex dubius* (Fletcher, 1888a); the new endemic species *Perionychella (P.) inconstans, Spenceriella imparicystis, S. penolaensis, Gemascolex bursatus, G. mirabilis, G. octothecatus, G. similis,* and *G. walkeri* spp. nov.; the previously known endemic species *G. newmani* Edmonds & Jamieson, 1973, and *G. stirlingi* (Fletcher, 1888a); and two species known also from Victoria, *G. lateralis* (Spencer, 1892; syn. *Megascolex zeitzi* Michaelsen, 1907b) and *Heteroporodrilus shephardi* (Spencer, 1900). the latter being represented by the new subspecies *H. shephardi armatus.* In sharing its four indigenous genera and two of its species with Victoria, South Australia shows close zoogeographic affinities with this state whereas affinities with Western Australia are minimal, consisting only of a close relationship between *Perionychella* and the Western Australian genus *Graliophilus.* The paucity of the fauna is attributed to the low rainfall and it is noted that ten of South Australia's thirteen species have excretory adaptations, in the form of intestinal enteronephry, which favour water conservation.

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Introduction

Three indigenous species of earthworms (Family Megascolecidae) have previously been recorded from South Australia. All were assigned to a single genus, *Gemascolex* by Edmonds & Jamieson (1973). The three species are *G. stirlingi* (Fletcher, 1888a) of which *Megascolex fletcheri* Shannon (1920) is a junior synonym; *G. zietzi* (Michaelsen 1907b) which (see below) is a junior synonym of *G. lateralis* (Spencer, 1892); and *G. newmani* Edmonds & Jamieson, the type-species of *Gemascolex*. The only other megascolecid earthworm previously recorded from the state is *Microscolex dubius* (Fletcher, 1888a), for which Adelaide is a type-locality. This species is euryhaline and is circum-mundane in warmer, though not tropical, regions. Its centre of origin is unknown.

The only other earthworms from South Australia belong to the holarctic family Lumbricidae. This non-indigenous family is beyond the scope of this work. It is nevertheless of interest to note localities from which lumbricids were obtained in the present survey and these are included in the map (Fig. 1).

With the assistance of Mr. T. Walker, the author collected earthworms in August 1972, after favourable rains, from 26 localities (see Fig. 1), from Mt. Remarkable in the north to the Fleurieu Peninsula in the south. Collecting yielded twelve species of Megascolecidae, including the three previously described *Gemascolex* spp. and *Microscolex dubius*. A further species, collected by Mr. Ifor Thomas from Kangaroo Island, brings the total of known megascolecid species from the state to 13. No collection was done on Yorke and Eyre Peninsulas in the west, nor in much of the wetter south-eastern portion of the state, and it seems likely that further species will be found in those areas. It is hoped that this study will stimulate others to make the further collections necessary to yield a definitive check-list of South Australian earthworms.

Systematics

The megascolecid species of South Australia fall into the subfamilies Acanthodrilinae, rep-

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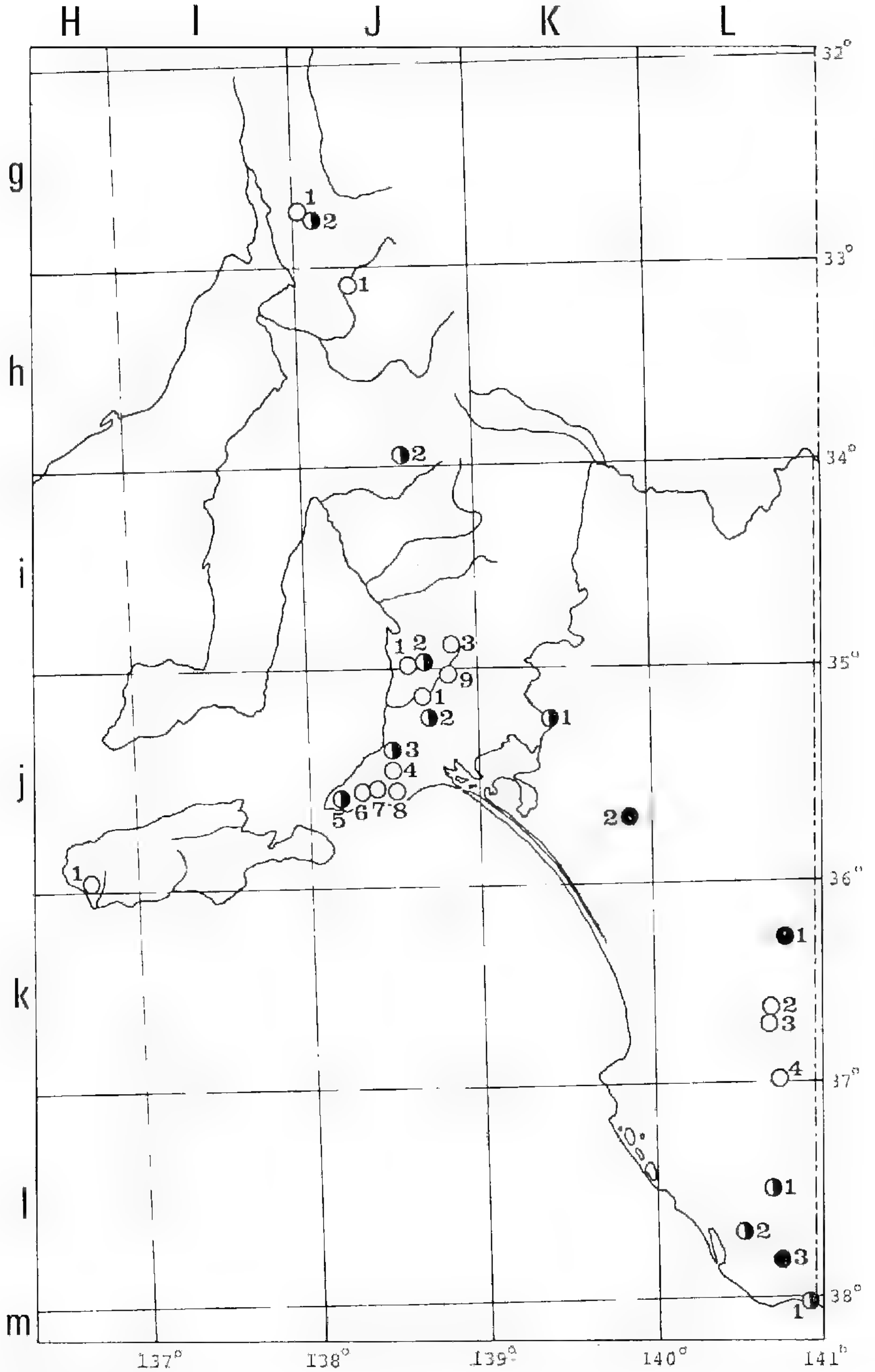

Fig. 1. Map showing all known records of earthworms from South Australia. White circle, Megascolecidae only. Black and white circle, Megascolecidae and Lumbricidae. Black circle, Lumbricidae only.

resented by the tribe Acanthodrilini, and Megascolecinae, represented by the tribes Perionychini and Megascolecini sensu Jamieson, 1971a. The sub-families and tribes are set out in this order in the present account and the species are listed in alphabetical order under their genera within each tribe. Abbreviations for institutions in which specimens have been lodged are: AM (Australian Museum, Sydney), BJ (Author's collections), BM (British Museum (Natural History)) and SAM (South Australian Museum). The major collectors, B. G. M. Jamieson and T. Walker, are indicated by the initials *B.J.* and *T.W*, respectively. The abbreviation H signifies holotype and P paratype. Explanations of terminology used in descriptions may be found in Michaelsen (1900), Stephenson (1930) and (nephridia) in Jamieson (1971a).

A key to the Megascolecidae of South Australia follows. To permit ready identification, without necessitating detailed study of the excretory system which is the basis for tribal classification, tribes have been omitted and the key proceeds directly to species. As unknown species may be encountered by collectors, agreement with illustrations cited in the key is required, and the detailed descriptions should be checked to confirm identification.

Family MEGASCOLECIDAE

Subfamily ACANTHODRILINAE s. Jamieson, 1971a

Tribe ACANTHODRILINI s. Jamieson, 1971a

Holonephric, or, if wholly or partly meronephric, with a single pair of prostates. Prostates tubular, one to three pairs. Stomate meronephridia, where present, not forming a series median to astomate micromeronephridia.

Genus MICROSCOLEX Rosa, 1887

Microscolex dubius (Fletcher, 1888a), Rosa, 1890: 511. Michaelsen, 1907a: 146-148; 1907b: 5. Pickford, 1937: 429-432, figs 398-399. Gates, 1962: 7-15.

FIGS 2A, 12; TABLE 1

Eudrilus (?) dubius Fletcher, 1888a: 378-381.

Length = 36 mm, w (midclitellar) = 3.4 mm, s = 88 (specimen 1). Circular in cross section. Pigmentless in alcohol. Prostomium not canaliculate, epilobous 1/2, closed. Peristomium not bisected ventrally. Dorsal pores absent. Setae 8 per segment, commencing in II, in regular longitudinal rows throughout. Setae *a* and *b* absent in XVII.

Key to the megascolecid species of South Australia

1 Combined male and prostatic pores a pair on XVII (16th setigerous segment). Spermathecal pores absent ... *Microscolex dubius*, Fig. 2A
1 Combined male and prostatic pores a pair on XVIII (17th setigerous segment). Spermathecal pores present ... 2
  2. Nephridia one pair per segment ... 3
  2. Nephridia several to many in a segment ... 4
3. Nephridia with terminal bladders which alternate from lateral to ventral ... *Heteroporodrilus shephardi armatus*, Fig. 2B
3. Nephridia without bladders; ducts in a single series on each side ... *Perionychella (P.) inconstans*, Fig. 6C
  4. Calciferous glands present on the oesophagus, paired in X, XI-XIII ... 5
  4. Calciferous glands absent ... 6
5 Calciferous glands 4 pairs, in X-XIII. Spermathecae unpaired ... *Spenceriella imparicystis*, Fig. 9A
5. Calciferous glands 3 pairs, in XI-XIII. Spermathecae paired ... *Spenceriella penolaensis*, Fig. 9B
  6. Spermathecal pores 1 pair, in 5/6 ... *Gemascolex walkeri*, Fig. 7A
  6. Spermathecal pores more than 1 pair, in 7/8 or 8/9 anteriorly ... 7
7. Spermathecal pores 2 pairs ... 8
7. Spermathecal pores more than 2 pairs ... 9
  8. Last spermathecal pores in 7/8 ... *Gemascolex mirabilis*, Fig. 5
  8. Last spermathecal pores in 8/9 ... *Gemascolex bursatus*, Fig. 3A
9. Spermathecal pores 4 pairs ... *Gemascolex octothecatus*, Fig. 6A, B
9. Spermathecal pores 3 pairs ... 10
  10. Last hearts in XII ... *Gemascolex lateralis*, Fig. 4A, B
  10. Last hearts in XIII ... 11
11. Genital marking(s) unpaired, midventral ... *Gemascolex newmani*, Fig. 7B
11. Genital markings paired ... 12
  12. Male pores about one third of the body circumference apart. No genital markings present behind them ... *Gemascolex similis*, Fig. 3B
  12. Male pores about one fifth of the body circumference apart. Paired genital markings behind them ... *Gemascolex stirlingi*, Fig. 8A, B

TABLE 1

Intersetal distances in Microscolex dubius

	(mm)							
	aa	ab	bc	cd	dd	dc	cb	ba
Segment XII	0.9	0.6	1.3	1.0	2.2	1.0	1.3	0.6
Segment XX	1.1	0.5	1.5	1.1	2.7	1.0	1.7	0.5
	standardized as % of circumference							
	aa	ab	bc	cd	dd	dc	cb	ba
Segment XII	10.0	6.8	14.8	10.8	24.3	11.6	14.4	6.8
Segment XX	11.3	5.1	15.3	11.7	27.7	10.2	17.5	5.1
Mean	10.7	6.0	15.1	11.2	26.3	10.9	16.0	6.0
Interval/ab	1.8	1.0	2.5	1.9	4.1	1.8	2.7	1.0

Nephropores inconspicuous, in the intersegmental furrows a little less than 1/3 *bc* below *c*; first observed at 6/7. Clitellum annular, XIII–XVI with weak development through XVII, well developed but not strongly protuberant, apparent as a smooth region owing to supression of intersegmental furrows 14/15 and 15/16; setae and nephropores retained. Male pores minute, equatorial in XVII, lateral of setal lines *a*, each in an oval field, which is not sufficiently elevated to be termed a porophore, the pores 1.26 mm, 0.14 circumference, apart. Accessory genital markings absent. Female pores paired, almost at the anterior margin of XIV, shortly median of *a* lines. Spermathecal pores absent.

Strongest septa 8/9–13/14, moderately strong. Dorsal blood vessel single, continuous onto the pharynx. Last hearts in XII, those in X–XII latero-oesophageal, each with a connective from the dorsal and from the poorly distinguishable supra-oesophageal vessel; the latter oesophageal only. Commissurals in VI–IX dorsoventral only. Subneural vessel absent. Gizzard rudimentary, in V. Oesophagus thicker walled and more rugose internally in X–XIV than anteriorly, moniliform throughout though narrower in XV. Extramural calciferous glands absent. Intestinal origin XVI; typhlosole, caeca and muscular thickening absent. Nephridia stomate, vesiculate holonephridia; those in II–IV each sending a duct laterally to discharge presetally in *d* line, the duct in II avesiculate, the ducts in III and IV each with a small subspherical bladder; the nephridia in V discharging through small subspherical somewhat crenulated bladders presetally immediately below *c* lines, the bladders joined medianly and slightly subterminally by the ducts; by segment VIII the duct median to the bladder is itself swollen and by XII the original bladder protrudes from the lateral aspect of the wedge shaped expansion of the duct and may be considered a short rounded diverticulum; the bladders reach their furthest separation from *c* line, at approximately one fourth *cb*, in the vicinity of XVII and maintain this position further posteriorly. Caudally the diverticulum becomes a definite lateral caecum, about twice as long as wide, though hidden by coils of the nephridium. Holandric, clavate testes and non-iridescent funnels in X and XI; seminal vesicles 2 pairs, racemose, in XI and XII. Metagynous; ovaries, flattened lobes with several conjoined strings of large oocytes, and funnels in XIII; small ovisacs in XIV. Prostates almost straight, tubular, passing laterally from the ducts in XVII and widening evenly to the rounded free extremity so as to appear slenderly clavate; the external duct indistinctly demarcated but with a slight muscular sheen; the double vas deferens joining the duct at its ental third. Penial setae present in two follicles, *a* and *b*, the *b* follicle entering the body wall in common with the prostate duct. Each penisetal follicle with two functional and two reserve setae; each seta almost straight, ectally tapering slightly to a blunt point, the ectal fifth bearing a longitudinal series of approximately 7 to 10 circumferential sets of short transverse incisions, the posterior border of each incision forming a few minute anteriorly directed denticles; the incisions in a set arranged obliquely around the circumference of the seta; this ornamentation poorly visible under the light microscope; lengths of two functional setae 0.52 and 0.72 mm, general width of the shaft 16μm and 26μm respectively. Spermathecae absent.

Material examined: Lm1, 140°55'E, 38°01'S, 26 km from Mt. Gambier along road to Nelson, in sandy loam under grass among wattles and gums and some garden escapes, *B.J.* and *T.W.*, 15.viii.1972– 2 specimens (*BJ*).

Type-locality: Sydney, Mulwala (N.S.W.); Adelaide.

Other Australian localities: Tas. (*fide* Michaelsen 1900); N.S.W.–Newcastle, Paramatta (Michaelsen 1907a, b); Jenolan Caves area (Boardman 1943). South western Australia (Michaelsen 1907a). Qld–Toowoomba (Stephenson 1933). A.C.T. (Gates 1962).

Remarks: Microscolex dubius is a euryhaline species circum-mundane in the northern and southern hemispheres mostly in warmer regions, though not tropical.

Absence of spermathecal pores, location of combined male and prostatic pores on XVII and progressive narrowing of setal interval *ab* in an anterior direction from approximately

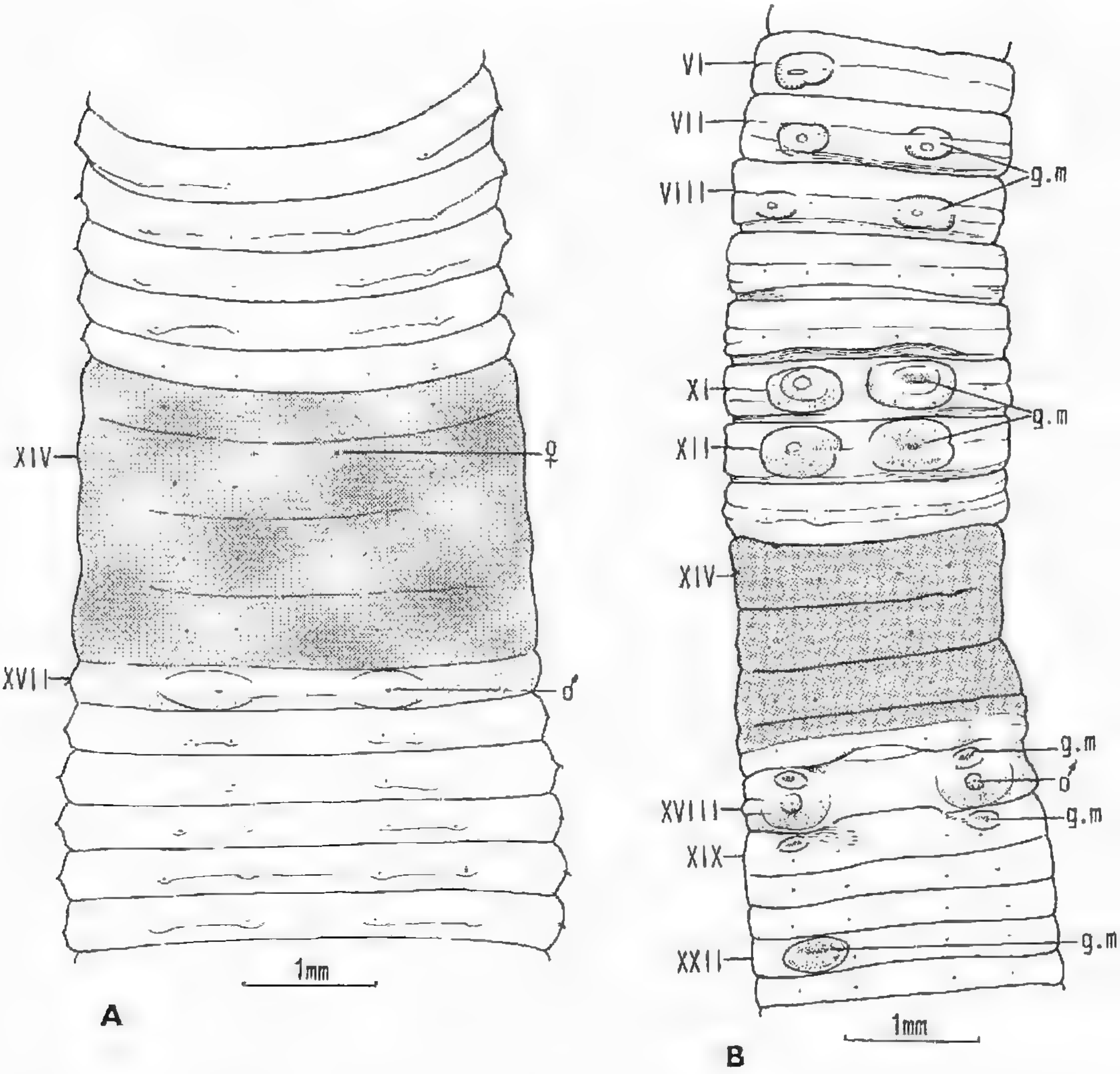

Fig. 2. Genital fields of: *A*, *Microscolex dubius*, specimen 1, Lm1. *B*, *Heteroporodrilus shephardi armatus*, holotype, L11.

Symbols used in illustrations of genital fields: ♀, female pore; g.m., accessory genital marking; ♂, male pore; sp.p., spermathecal pore. Roman numerals are segment numbers. Clitellum shaded. All by camera lucida.

segment XXII to XVIII allow ready recognition of this species.

Subfamily MEGASCOLECINAE s. Jamieson, 1971a

Tribe PERIONYCHINI s. Jamieson, 1971a

Male and prostatic pores coincident or (*Diplotrema* part, New Caledonia) near together on XVIII; sometimes with a single median combined male and prostatic pore. Prostates one pair, tubular to racemose. Purely holonephric, or with meronephridia in a varying number of segments anterior to holonephridia; never (?) with intestinal enteronephry.

Genus PERIONYCHELLA Michaelsen, 1907a

Perionychella (P.) inconstans sp. nov.

FIGS 6C, 10A; TABLE 2

Length = 63(H)–77(P1) mm, W (midclitellar) - 2 mm, s — 122(H)–131(P1). Pigmentless in alcohol with the exception of the reddish brown clitellum. Form attenuated; circular in cross section. Prostomium epilobous 2/3, acute, closed; not canaliculate. Peristomium not bisected ventrally. Setae 8 per segment, in regular longitudinal rows throughout (H) or *c* and *d* irregular posteriorly (P1); *a* and *b* absent in XVIII.

Nephropores sporadically visible, on and behind the clitellum, anteriorly in their segments in *b* lines. Clitellum annular, very conspicuous owing to strong tumescence and its reddish color (almost fusiform and reminiscent of that of the aquatic genus *Sparganophilus*), clearly demarcated in XIII–2/3 XVIII, but some clitellar modification and pinkish pigmentation present throughout XII and XVIII dorsally, i.e. extent XII–XVIII (= 7 segments); intersegments 13/14–17/18 totally obliterated dorsally. Male pores equatorial in *a* lines of XVIII on strongly protuberant, subcircular papillae which fill all but a small anterior part of the segment, the lateral borders of the papillae less clearly demarcated than the median borders. The papillae lie in a whitish glandular field which interrupts the clitellum from shortly presetally in XVII, laterally beyond *b* in XVII and XVIII, and which extends posteriorly to include (H) or just precede (P1) the setal arc of XX. The setal annulus of XVII to shortly lateral of *b* forms a transverse ventral ridge. Distinct accessory genital markings are not recognizable in the male field but there is a suggestion of a transverse pad from mid *ab* to lateral of *b* on each side filling the anterior third of XVIII. An unpaired, midventral, circular accessory genital marking with depressed central area and porelike centre almost fills the length of each of segments VII, VIII and IX and extends laterally to *a* or into *ab* (H, P1; see Field Variation). Female pores paired, shortly anterior to (H) or anteromedian (P1) to setae *a* of XIV, in a common glandular field which fills *bb* and longitudinally extends from 13/14 posteriorly to just include the ventral setal couples. Spermathecal pores in 7/8 and 8/9, each on an inconspicuous papilla almost concealed in the intersegment, unpaired midventral (P1) or paired immediately median to *a* lines (H).

Thickest septa 7/8–9/10, moderately strongly thickened (H, P1). Dorsal blood vessel single, continuous onto the pharynx (H). Last hearts in XIII, those in X–XIII latero-oesophageal, each receiving a connective from the dorsal vessel and from the supra-oesophageal vessel. The latter vessel extends from 1/2 VIII–XIV (P1), 1/2 XV (H1) and except at its extremities, is larger than the dorsal vessel. No subneural vessel detectable.

TABLE 2

Intersetal distances in Perionychella (P.) inconstans

	mm							
	aa	ab	bc	cd	dd	dc	cb	ba
Segment XII								
Holotype	0.5	0.2	0.5	0.4	2.4	0.3	0.5	0.1
Paratype 1	0.3	0.2	0.4	0.3	2.1	0.3	0.4	0.2
Segment XX								
Holotype	0.4	0.2	0.5	0.3	2.0	0.3	0.5	0.2
Paratype 1	0.5	0.2	0.5	0.3	2.0	0.3	0.4	0.2
	standardized as % of circumference							
	aa	ab	bc	cd	dd	dc	cb	ba
Segment XII								
Holotype	10.6	4.1	10.6	7.1	46.6	6.5	9.8	4.9
Paratype 1	7.7	5.4	9.1	6.3	49.8	7.7	9.8	4.9
Mean	9.1	4.7	9.8	6.7	48.2	7.1	9.8	4.9
Interval/an	1.9	1.0	2.1	1.4	10.2	1.5	2.1	1.0
Segment XX								
Holotype	9.7	4.9	11.6	5.8	46.4	6.7	10.7	4.2
Paratype 1	9.9	5.0	10.9	6.4	47.2	5.9	9.0	5.0
Mean	9.8	4.9	11.2	6.1	46.8	6.3	9.8	4.6
Interval/an	2.0	1.0	2.3	1.2	9.5	1.3	2.0	0.9

Gizzard small and globose in V, its posterior limit being at 1/2 VI; muscular but easily compressed. Oesophagus moniliform but not evidently vascularized in VI–VIII, in IX–XIV moniliform and apparently with increased vascularization (especially vascular in IX), in XV–XVII (H)–XIX (P1) tubular and only slightly vascularized, in XVIII (H) similar to that in XVII but globose. Intestinal origin apparently XIX where the wall is thinner (H) or XX (P1, with oesophageal valve at 19/20), not reaching full width until XXI; typhlosole absent, though a rudimentary mid-dorsal ridge is observable in paratype 1, muscular thickening and caeca absent (H, P1). Nephridia holonephridia first recognizable in XI (P1) or XIII (H) but 2 pairs of small tuftlike structures on the body wall, in IV and V (P1) may be tufted nephridia (the extreme narrowness of the worm rendering dissection very difficult); each holonephridium with a large preseptal funnel and narrow duct discharging presetally in *b* line.

Holandric, testes and iridescent funnels in X and XI; seminal vesicles large, racemose, with many large discrete loculi, in IX and XII. Metagynous (ovaries consisting of a few irregular chains of very large oocytes and funnels in XIII); true ovisacs, each with several very large oocytes, in XIV. Prostates a pair of thick short tortuous tubes restricted to XVIII (P1) or their ental ends just entering XIX (H); muscular ducts straight or slightly curved, not sinuous. Penial setae present, their follicles extending from XVIII into XX, filiform.

Spermathecae in VIII and IX, each with a sacciform, narrow-stalked ampulla and a digitiform-clavate (inseminated) sinuous diverticulum joining the base of the duct and longer than duct plus ampulla. In paratype 1 there is only a single spermatheca in each segment, its duct entering the body wall below the ventral nerve cord. In the holotype there are 2 spermathecae in each segment, discharging median to *a* lines, and the right spermatheca in each segment has a replicated ampulla.

Field variation: The male genital field has the form described for the holotype in the 9 specimens selected as paratypes but the right prostate (and male porophore) is replicated in paratype 4 so that there is one in XVIII and a further one in XIX. Midventral unpaired accessory genital markings are present in VII, VIII and IX in 3 specimens (including the holotype), in VII and VIII, in 3 specimens, and in VIII and IX in 4 specimens. Spermathecal pores, in 7/8 and 8/9, are paired shortly median of *a* lines in 5 specimens, paired but ventrally almost contiguous in 1 specimen, and are unpaired, midventral, in 3 specimens, being externally unrecognizable in the remaining specimen.

Material examined: Hj1, 136°44'E, 35°56'S, in soft, waterlogged earth, bonded with grass and grass roots, on the banks of Rocky River, about 1.6 km N of Rocky River Homestead, Kangaroo I.; approximately 50 worms per square foot, *I. Thomas*, date?–H, P1–9 (plus many additional specimens). H, P2–4 (AM); P1, 5, 6(BM); P7 (SAM); P8, 9 and additional specimens (BJ).

Remarks: This species differs from others in *Perionychella* in location of nephropores in *b* lines and in that *cd* is not as large relative to *ab*. These differences may indicate that it is phylogenetically distinct from the remainder of the genus but erection of a separate genus for its reception does not appear necessary.

Genus HETEROPORODRILUS Jamieson, 1970

Heteroporodrilus shephardi (Spencer, 1900) **armatus** subsp. nov.

FIGS 2B, 10B, 11A, 13; TABLE 3

Length = 113+(H) mm–132(P1) mm. w (midclitellar) = 7(P1)–8(H) mm. s = 109+ (H, posterior amputee; P1 damaged). Form angular in cross section the periphery being straight between adjacent setal lines. Pigmented greyish brown but pale ventrally in alcohol. Prostomium protanylobous, with a transverse furrow at 0/1 (H) or epitanylobous with a transverse furrow at ½ 1; the peristomium with several longitudinal furrows so that extension of a dorsal prostomial tongue to 1/2 is questionable. Canalicula absent. First dorsal pore 6/7 (H, P1). Setae 8 per segment, in regular longitudinal rows throughout; setae *a* and *b* absent, replaced by penial setae, in XVIII.

Nephropores conspicuous, anterior in their segments in the holotype in II(?), III–IV in d lines; in V–IX alternating from *d* to mid *bc* (commencing in V in *d* on the right and mid *bc* on the left); thereafter alternating from *d* to *b* (in X in *b* on the right and *d* on the left); the nephropores symmetrically disposed in paratype 1: in II–IV in *d* lines; in V and VI in mid *bc*; in VII–IX alternating from *d* to mid *bc*; in X backwards alternating from *b* to *d* (examined in H and P1 to 20/21). Clitellum annular, XIV–1/3 XVII; dorsal pores occluded in 14/15–16/17; intersegmental furrows fainter dorsally; setae and nephropores clearly visible. Male pores on XVIII in *b*, each on a slender papilla strongly protuberant from an indistinct low circular prominence. Accessory genital markings: transverse oval to oblong pads with porelike centres in VI (unilateral, right), VII and VIII (paired) filling *ab* and with centres at or slightly behind the setal arc; similar but larger pads almost filling the segments longitudinally and with centres immediately presetal in *ab* paired in XI and XII and unilateral, right, in XXII; paired deep pits in *ab* in 17/18 and immediately behind

TABLE 3

Intersetal distances in Heteroporodrilus shephardi armatus

	aa	ab	bc	cd	mm dd	dc	cb	ba
Segment XII								
Holotype	2.6	2.1	3.3	3.8	6.8	3.6	3.1	1.9
Paratype 2	2.3	1.4	2.2	2.4	4.4	2.4	2.2	1.7
Paratype 3	1.9	1.5	2.3	2.6	5.4	2.5	2.3	1.5
Segment XX								
Holotype	3.0	1.6	2.9	3.9	6.2	3.7	2.9	1.5
Paratype 2	2.3	1.2	1.8	2.9	4.4	3.1	2.2	1.4
Paratype 3	1.9	1.3	2.4	2.4	5.2	2.4	2.4	1.1
	standardized as % of circumference							
	aa	ab	bc	cd	dd	dc	cb	ba
Segment XII								
Holotype	9.6	7.8	12.2	14.0	25.0	13.3	11.4	7.0
Paratype 2	12.1	7.4	11.6	12.6	23.1	12.6	11.6	9.0
Paratype 3	9.5	7.5	11.6	13.1	27.1	12.6	11.1	7.5
Mean	10.4	7.6	11.8	13.2	25.1	12.8	11.4	7.8
Interval/ab	1.4	1.0	1.6	1.8	3.3	1.7	1.5	1.0
Segment XX								
Holotype	11.7	6.2	11.3	15.2	24.1	14.4	11.3	5.8
Paratype 2	11.9	6.2	9.3	15.0	22.8	16.0	11.4	7.3
Paratype 3	9.9	6.8	12.6	12.6	27.2	12.6	12.6	5.8
Mean	11.3	6.4	11.1	14.3	24.7	14.3	11.8	6.3
Interval/ab	1.7	1.0	1.7	2.2	3.9	2.2	1.8	1.0

18/19, a small indistinct eyelike marking present postero-laterally to each pit (H, see Field Variation). Female pores inconspicuous midway between the setal arc and anterior border of XIV, shortly median of *a* (H, P1). Spermathecal pores 3 pairs in 6/7, 7/8 and 8/9, in *b* lines (and with inconspicuous elliptical lips, (H)) or shortly lateral of *b* lines and preceded by a semicircular swelling which fills the posterior third of the previous segment (P1).

Septa 8/9–11/12 strongly thickened. Dorsal blood vessel single, continuous onto the pharynx. Supra-oesophageal vessel traced into VIII, not demonstrable in VII, ending posteriorly in XIII, receiving a transverse vessel from each of the calciferous glands, in X–XIII. Last hearts in XIII, those in X–XIII, which are stout, originating from the calciferous vessels and receiving slender connectives from the dorsal vessel (latero-oesophageal hearts); commissurals in VII–IX more slender, dorsoventral only and, unlike the latero-oesophageal hearts, with parietal branches but nevertheless valvular; vessels from the dorsal vessel in V and VI branching on the gut. Gizzard broad, glossy, strong but fairly easily compressible (H) or elongate and firm (P1), the preceding oesophagus, in IV, forming a wide flaccid proventriculus. Oesophagus unmodified in IX, bearing 4 pairs of ventrolateral broadly sessile extramural calciferous glands, in X–XIII, the lumen of each gland almost occluded by numerous radial lamellae. Oesophagus short, narrow and chloragogenous in XIV. Intestinal origin XV; typhlosole absent. Holonephric, nephridia with moderately large subspherical terminal vesicles, which are readily visible in the posterior intestinal region, are less well developed in the anterior intestinal region and not apparent in the forebody; preseptal funnels large, in *ab* irrespective of position of bladder (first demonstrated in XIV). Compacted sperm masses surrounding iridescent sperm funnels in X and XI; seminal vesicles racemose, in IX and XII. Large racemose prostates a pair, in XVI–XXI, a U-shaped muscular duct passing medianly from the middle region of the gland; the duct bifurcating at its ental extremity to receive ducts from the anterior and posterior portions of the gland; vas deferens joining the duct near its ectal end.

Penial setae slender, sinuous, almost filiform, the ectal region, viewed from either side, ornamented with irregular, approximately transverse to oblique rows of a few (P1) to several (H) triangular flattened scales, which except at their bases, are free from the setal surface but point towards the ectal extremity of the seta; the scales in the holotype with single, bifid or trifid points and in two or three groups, each group corresponding approximately with one of the coarser scales of paratype 1; total number of scales counted in a longitudinal line approximately 21 (in 0.21 mm) and 37 (in 0.44 mm) in two setae of the holotype; each seta tapering to a rounded but delicate point; length of a fully developed seta 2.9(P1)–3.7(H) mm; width of the most strongly ornamented region 27 or 20 μm (H) and 23 μm (P1). Female organs not observable (H); ovaries with numerous egg strings, and funnels in XIII; ovisacs absent. Spermathecae three pairs discharging anteriorly in their segments; ampulla subspherical, slightly shorter than the stoutly fusiform muscular glossy duct; an abruptly widening clavate diverticulum less than one third the length of the duct arising from the median aspect of the duct shortly ectal of the ampulla (H, P1).

Field variation: In the four type specimens paired pads in *ab*, which do not include the anterior portions of their segments, are present in VI, VII and VIII in H (R), P2 and P3. A liplike swelling extending to the preceding setal arc is present in these segments in front of each spermathecal pore in P1–3. An unpaired midventral circular postsetal marking with porelike centre is present in each of segments VI, VII and VIII in P2 or in VIII only in P3. Paired pads median to setae *b* and occupying much of the length of the segment are present in X in P1 and P3, in XI in H and P1 and 3, and in XII in H, P2 and P3. Paired pits in *ab* lie in intersegment 17/18 and immediately behind 18/19 in H, P1, 2 and 3. Paired oval pads in *ab* occur in XXII in P2 but there is only one unilateral pad in H(R), P1(R) and P3(L). Indefinite tumid areas may be present in the vicinity of the paired pits of 17/18 and 18/19, i.e. ill defined eyelike markings posterolateral to the pits in XVIII and XIX in H or posteromedian to the pits in XVIII in P1 and P3 and in XIX also in P1.

Material examined: L11, 140°49′E, 37°28′S, 11 km S of Penola in eucalypts fringing *Pinus radiata*, *B.J.* and *T.W.*, 15.viii.1972–H. Lk2, 140°42′E, 36°37′S, 37 km from Bordertown along road to Naracoorte, in bank of temporary pool in grassland with sparse grasstrees and eucalypts, *T.W.*, 16.viii.1972–P4. Lk4, 140°44′E, 36°59′S, 2 km S of

Naracoorte, in sandy soil with bracken and wattles near pasture, *B.J.* and *T.W.*, 16.viii.1972–P1–3. H(AM); P1–2(BJ); P4(BM); P3(SAM).

Remarks: The new material agrees with *H. shephardi* alone in the genus (*vide* Jamieson 1970) in alternation of nephropores between *d* and mid *bc*, rather than the usual *d* to *c*, and it is here included in *H. shephardi* as a new subspecies although it shows differences, including the distribution of genital markings and the presence of penial setae, which might be considered to warrant separate specific status. Whether or not it be reproductively isolated from the nominate subspecies it is unquestionably, from its morphology, more closely related to the latter than to any other taxon in *Heteroporodrilus*. *H. shephardi* belongs to a group of species with four pairs of calciferous glands, the other members of which are *H. canaliculatus* (Fletcher 1889a) and *H. mediterreus* (Fletcher 1888b). The latter two species occur terrestrially in upper reaches of the Murray-Darling river system while *H. shephardi* occurs on the Wimmera River.

Tribe MEGASCOLECINI s. Jamieson, 1971a

Male and prostatic pores coincident on XVIII (rarely XVII); prostates one pair, racemose (with branched internal ducts and no single central lumen) or tubular (with a single central lumen). Purely meronephric; median stomate nephridium, if present, opening into the intestine.

Genus GEMASCOLEX Edmonds & Jamieson, 1973

Terrestrial. Body circular in cross section or (*G. bursatus*) dorsoventrally depressed. Prostomium epilobous to tanylobous; peristomium bisected by a longitudinal furrow ventrally, which is more conspicuous than other grooving which may be present, or (*G. mirabilis* and *G. stirlingi*) grooving present all round but not more conspicuous ventrally. Setae numerous (more than 8) in each segment. Nephropores not externally recognizable. A pair of combined male and prostatic pores on XVIII. Clitellum annular anterior to 18/19; its intersegments and dorsal pores obscured at maturity but setae visible. Intersegmental accessory genital markings always present. Female pore presetal in XIV and midventral or, as a rare individual variation (*G. lateralis*), paired. Spermathecal pores 2–4 pairs in 5/6–8/9, 2 pairs in 6/7 and 7/8, or a pair in 5/6 only.

Dorsal blood vessel single; continuous onto pharynx. Hearts in X posteriorly latero-oesophageal, each arising from the short supra-oesophageal vessel and from the dorsal vessel. Last hearts in XII or XIII, latero-oesophageal vessels (always?) present median to the hearts. Subneural vessel absent. Gizzard large, in V or VI. Oesophagus lacking extramural calciferous glands. Intestine commencing in XVII; a ridge-like low or (*G. walkeri*) deep dorsal typhlosole present; caeca and muscular thickening absent. Excretory system meronephric. Paired tufts present in II, III–V of which at least those in IV and V are enteronephric, with ducts entering the buccal cavity and/or the pharynx. Caudally with numerous enteronephric meronephridia, each with a preseptal funnel, discharging into the intestine in each segment and with or without a longitudinal collecting duct (ureter) on each side. Testes and funnels in X and XI; testis-sacs absent; seminal vesicles in XI and XII or rarely in IX, XI and XII.

Ovaries and funnels in XIII; ovisacs present or absent. Prostates tubuloracemose: linear, lobulated, with axial lumen throughout which receives lateral canaliculi; vas deferens joining their muscular ducts. Penial setae absent. Spermathecae with diverticula.

Type-species: Gemascolex newmani Edmonds & Jamieson, 1973.

Distribution: South Australia and Victoria.

CHECKLIST OF SPECIES

*New combinations in *Gemascolex*

South Australia:

1. *Gemascolex bursatus* sp. nov.
2. *Perichaeta lateralis** Spencer, 1892 (also Victoria), syn. *Megascolex zietzi* Michaelsen, 1907b
3. *Gemascolex mirabilis* sp. nov.
4. *Gemascolex newmani* Edmonds & Jamieson, 1973
5. *Gemascolex octothecatus* sp. nov.
6. *Gemascolex similis* sp. nov.
7. *Perichaeta stirlingi** Fletcher, 1888a, syn. *Megascolex fletcheri* Shannon, 1920
8. *Gemascolex walkeri* sp. nov.

Victoria:

9. *Perichaeta dorsalis** Fletcher, 1888b

Gemascolex bursatus sp. nov.

FIGS 3A, 10C, 11B–E; TABLE 4

Length = 52(P1)–64(H) mm, W (midclitellar) = 1.5(P1)–2.5(H) mm, s = 81(P1)–102(H). Pigmented purplish-brown dorsally, pale ventrally; setae in pale circular fields.

TABLE 4

Intersetal distances in Gemascolex bursalus

	mm					standardized as % of circumference			
	aa	ab	zy	zz	u	aa	ab	zy	zz
Segment XII									
Holotype	0.6	0.4	0.4	0.5	5.2	12.2	7.6	7.3	10.3
Paratype 1	0.4	0.3	0.3	0.4	4.2	8.4	6.0	7.1	10.1
Mean						10.3	6.8	7.2	10.2
Interval/ab						1.5	1.0	1.1	1.5
Segment XX									
Holotype	0.7	0.5	0.4	0.8	5.8	12.8	8.8	7.3	14.0
Paratype 1	0.6	0.3	0.3	0.5	4.6	13.6	6.5	6.9	10.6
Mean						13.2	7.6	7.1	12.3
Interval/ab						1.1	1.0	0.9	1.6

Prostomium tanylobous, narrow, acute (H) or epilobous, 3/4, open. Canalicula absent. Dorsal pores minute, the first in 4/5. Setae of each side more closely spaced laterally than dorsally and ventrally; *ab* and *bc* approximately equal. Numbers of setae per segment 18 in XII, 16 in XX (H, P1), 20(P1)–22(H) fifteen segments from the caudal end; *a* and *z* lines straight throughout; anteriorly with a wide break in the setal circlet dorsally and ventrally; posteriorly with a moderate ventral and almost inappreciable dorsal break. Setae *a* and *b* but not *c* absent in XVIII. Clitellum (developed in holotype only) XIII–XVI (= 4 segments). Male pores extensive transverse slits, with puckered lips but no porophores, immediately median to setae *c* of XVIII, 1.05(H)–1.30(P1) mm, 0.29(P1)–0.38(H) circumference, apart. A circular, low dome-shaped accessory genital marking present at 17/18 and 18/19 in front of and behind the male pore, on the left side, but at 18/19 only on the right side (H); paired in these locations in P1. A pair of elliptical eyelike markings in 16/17 in *ab* (H only) and a further pair of circular to elliptical markings in 8/9 slightly lateral of *b* lines (H, P1); all accessory genital markings rudimentary in P1. Spermathecal pores 2 pairs, in 7/8 and 8/9, laterally situated gaping clefts, shortly lateral of setal lines 4, 1.32(H)–2.0(P1) mm, 0.48(P1)–0.56(H) circumference, apart.

Strongest septa 9/10–13/14, moderately strongly thickened. Last hearts in XII. Supra-oesophageal recognizable in VII(H), VIII(P1)–½ XIII(P1), XIII(H), well developed. Gizzard in V. Intestine originating in XVII in which it resembles the vascularized regions of the oesophagus; a low tortuous dorsal typhlosole first considerably developed in XXVIII but traceable forward as a rudiment to XXIII. Nephridia: a pair of tufts in each of segments II–V, increasing from small to large posteriad; those in IV and V sending composite ducts to the pharynx; those in II and III apparently exonephric; small exonephric tufts in VI accompanied laterally by micromeronephridia (H, P1); numerous integumentary micromeronephridia in VII posteriorly, at first posterior in their segments (H, P1); in XVI–XVII especially conspicuous and densely crowded on the body wall (H); thereafter (H, P1) moderately numerous on each side and posterior in each segment; caudally with several (as many as 8 or 9) enlarged nephridia on each side with a preseptal funnel, at least some of these nephridia on each side sending ducts to the roof of the intestine; accompanied in the holotype by smaller astomate, (exonephric?) nephridia; no ureters demonstrable. Precise description of the nephridia must be postponed until more appropriately fixed material is available.

Sperm funnels in X and XI (iridescent in the mature holotype); seminal vesicles racemose, in XI and XII. Ovaries oval laminae with several large oocytes (H), rudimentary in the paratype; accompanied medianly by small sacs of unknown function; ovisacs present. Prostates tubuloracemose, each with flattened leaflike glandular portion, in XXII–XXVI, XXVII, deeply incised by the septa and adherent to the intestine; the muscular duct straight in XIX–XXII but in XVIII curving medianly around the anterior face of a large subspherical bursa copulatrix. A conical penis-like structure projecting from the bursa into the male genital aperture though not visible externally; vas deferens joining the junction of prostate duct and gland (H); prostate glands rudimentary in P1.

Spermathecae 2 pairs, in VIII and IX; duct, ampulla and diverticulum tortuous; the diverticulum (inseminated) slender, tubular, uniloculate, a little larger than the ampulla (H); spermathecae rudimentary in P1.

Material examined: JJ3, 138°30'E, 35°22'S, hill 8 km from Myponga, *S. Edmonds*, 16.viii.1972–H(AM), P1(BJ).

Remarks: The muscular bursae at the ectal ends of the prostate ducts in this species are unique in the genus.

Gemascolex lateralis (Spencer, 1892)

FIGS 4A, B, 10D–F, 11F; TABLE 5

Perichaeta lateralis Spencer, 1892: 11–12, Pl VI, figs 55–57, 78.

Megascolex lateralis Michaelsen, 1900: 220. Jamieson, 1971b: 95.

Megascolex zietzi Michaelsen, 1907b: 17–19. Jamieson, 1971b: 95.

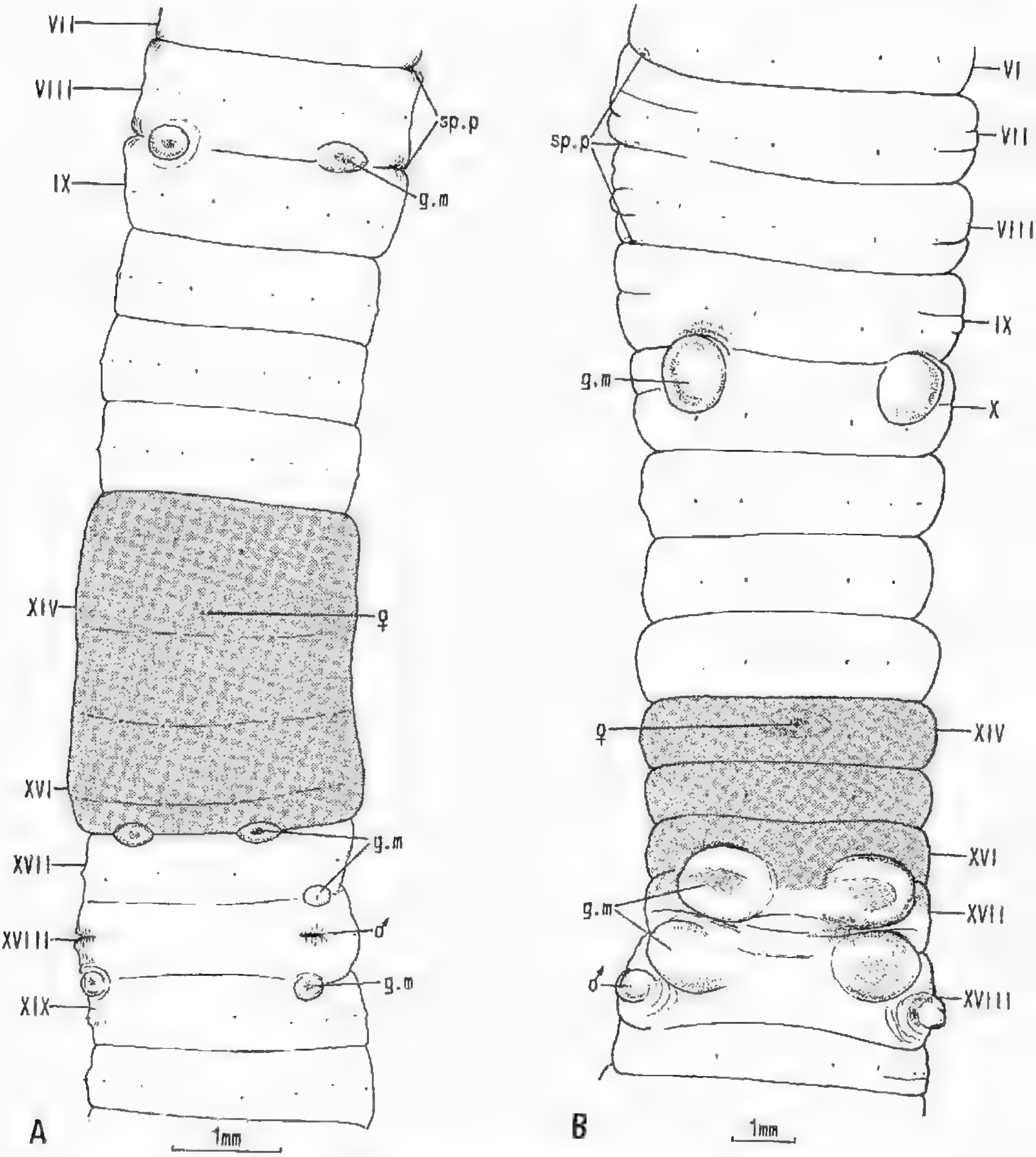

Fig. 3. Genital fields of: *A*, *Gemascolex bursatus*, holotype, Jj3. *B*, *G. similis*, holotype, Ll2.

The following account is drawn from the lectotype, two specimens from locality Ji2 (SA77, 79), a specimen from Ll1 (SA15), and one from Lk3 (SA229). These are referred to as L, and specimens 1, 2, 3 and 4 respectively in the account.

Length = 45 (specimen 3), 74 (specimen 2)–80(L) mm (specimens 1 and 4 are posterior regenerates), w (midclitellar) = 3–4 mm, s = 87 (specimen 3), 109 (specimen 2)–122(L). Circular in cross section. Pigmented purplish brown dorsally with the setae in pale fields (specimens 1 and 2); or pigmentless (bleached?) (L; specimens 3 and 4). Prostomium epilobous 1/2 (specimens 3 and 4) and 2/3 (specimens 1 and 2) or appearing

TABLE 5

Intersetal distances in Gemascolex lateralis

	mm					standardized as % of circumference			
	aa	ab	zy	zz	u	aa	ab	zy	zz
Segment XII									
1 SA 77	1.1	0.5	0.7	1.1	11.6	9.4	4.6	6.1	9.4
2 SA 79	1.0	0.8	0.9	1.4	11.9	6.5	6.6	7.6	11.3
3 SA 15	0.6	0.3	0.3	0.9	7.8	7.2	4.0	3.6	11.3
4 SA 229	0.7	0.4	0.5	0.9	9.2	7.6	4.4	5.4	9.2
Segment XX									
1 SA 77	1.3	0.5	0.5	1.4	12.1	10.4	4.5	4.4	8.9
2 SA 79	1.4	0.8	0.6	1.2	13.1	10.7	5.9	4.8	8.9
3 SA 15	1.0	0.5	0.4	1.1	9.3	10.5	5.3	3.8	11.9
4 SA 229	1.1	0.5	0.5	1.3	9.5	11.6	5.3	5.3	13.7

tanylobous (L); not or faintly canaliculate, closed or open. First dorsal pore 4/5. Setae more closely spaced ventrolaterally than dorsally and ventrally on each side; *ab* significantly, but not greatly larger than *bc* in most segments; numbers of setae per segment 21–31 (mean of 5 = 26) in XII, 17–24 (mean of 5 = 22) in XX, 20–38 (mean of 5 = 26) fifteen segments from the caudal end; a distinct though only moderately wide ventral break present throughout; a dorsal break present in the forebody but behind the clitellum only initially recognizable, or present but narrow throughout. Setae *a*, *b* and *c* absent in XVIII or (L) *a* and *b*, only absent.

Clitellum XIII (specimens 2–4), XIV (L; specimen 1)–XVI (L, specimen 1, 2), 1/3 XVII (specimens 3 and 4) (= 3–4 1/3 segments). Male pores on prominent rounded porophores in *c* lines of XVIII, distance apart = 2.04 (specimen 3), 2.81 (specimen 4), 3.1 (L), 4.04 (specimen 1), 4.92 (specimen 2) mm; ratio of this to circumference = 0.26 (L), 0.30 (specimen 4), 0.31 (specimen 3), 0.33 (specimens 1 and 2). Accessory genital markings: a pair of eyelike markings in each of intersegments 9/10 and 10/11 in *ab* (L; specimens 1–4). Additional markings in 17/18–21/22, varying from *a* lines at 17/18 to slightly median of *a* at 21/22 (L), or in 17/18–22/23 (specimens 1 and 2) or absent (specimens 3 and 4). A further pair of subcircular markings present in XVIII in front of the male pores (L; specimens 1–4) and a second pair behind them (specimens 1 and 2) (see Field Variation). Spermathecal pores 3 pairs, clearly visible sunken orifices or inconspicuous, in 6/7–8/9, between setal lines 4 and 5; distance between pores = 2.04 (specimen 3), 3.0 (specimen 4), 4.5 (lectotype), 4.92 (specimen 1), 5.62 (specimen 2) mm; ratio of this distance to circumference = 0.24 (specimen 3), 0.34 (specimen 4), 0.35 (lectotype), 0.38 (specimen 2), 0.42 (specimen 1).

Several pre-intestinal septa thickened but none strongly. Last hearts in XII. Supra-oesophageal vessel in 1/2 VIII–1/2 XIII, well developed (specimens 1 and 2); ill-defined in specimens 3 and 4. Vascular system not intact in the lectotype. Gizzard in V. Intestinal origin XVII; a very low, rudimentary, dorsal typhlosole first definitely recognizable in XXVII. Nephridia: small paired tufts in II and III with anterolaterally directed composite ducts which in specimens 1–4 appear to be exonephric but in the lectotype join the buccal cavity at its anterior limit. Large tufts in IV and V enteronephric, their composite ducts running anteromedially to join the pharynx. Numerous exonephric astomate micromeronephridia present in 1 or more bands in V posteriorly (visible from II in specimens 3 and 4), associated with the anterior and posterior septa in XV (specimens 1 and 2) or XVII (specimens 3 and 4) posteriorly. Caudally with approximately 8 enlarged nephridia, each with a preseptal funnel on each side; one or two nephridial ducts traced to the roof of the intestine but probably all enteronephric; no longitudinal collecting ducts demonstrable. Sperm funnels iridescent in X and XI; seminal vesicles slightly racemose, almost sacciform, 2 or 3 pairs, in IX (L, specimens 1 and 2), XI and XII (all specimens). Ovaries, flattened webs or lobes with several conjoined strings of large oocytes, and funnels; a crescentic sac of unknown function seen on the anterior septum of XIII median to the ovaries in the lectotype and specimens 1 and 2; sacs on the anterior septum of XIV questionably ovisacs. Prostates tubuloracemose, hand-sections of one of specimen 3 revealing a very narrow central lumen; the broad glandular portion linear, in XVIII–XXII, XXIII deeply incised by the septa; the muscular duct forming a loop at least the ectal limb of which widens strongly but a copulatory bursa absent; the vas deferens joining the duct near its junction with the gland. No glandular masses distinguishable internally at the sites of the accessory genital markings. Spermathecae 3 pairs, diverticulum (inseminated) single, tubular, very long and much coiled.

Field variation: Anterior genital markings are commonly absent in specimens with well developed markings in the vicinity of the male genital field. When anterior markings are present they usually occur in 9/10 and 10/11 but they sometimes are present in 10/11 only and rarely in 8/9 only; there are rarely 3 pairs,

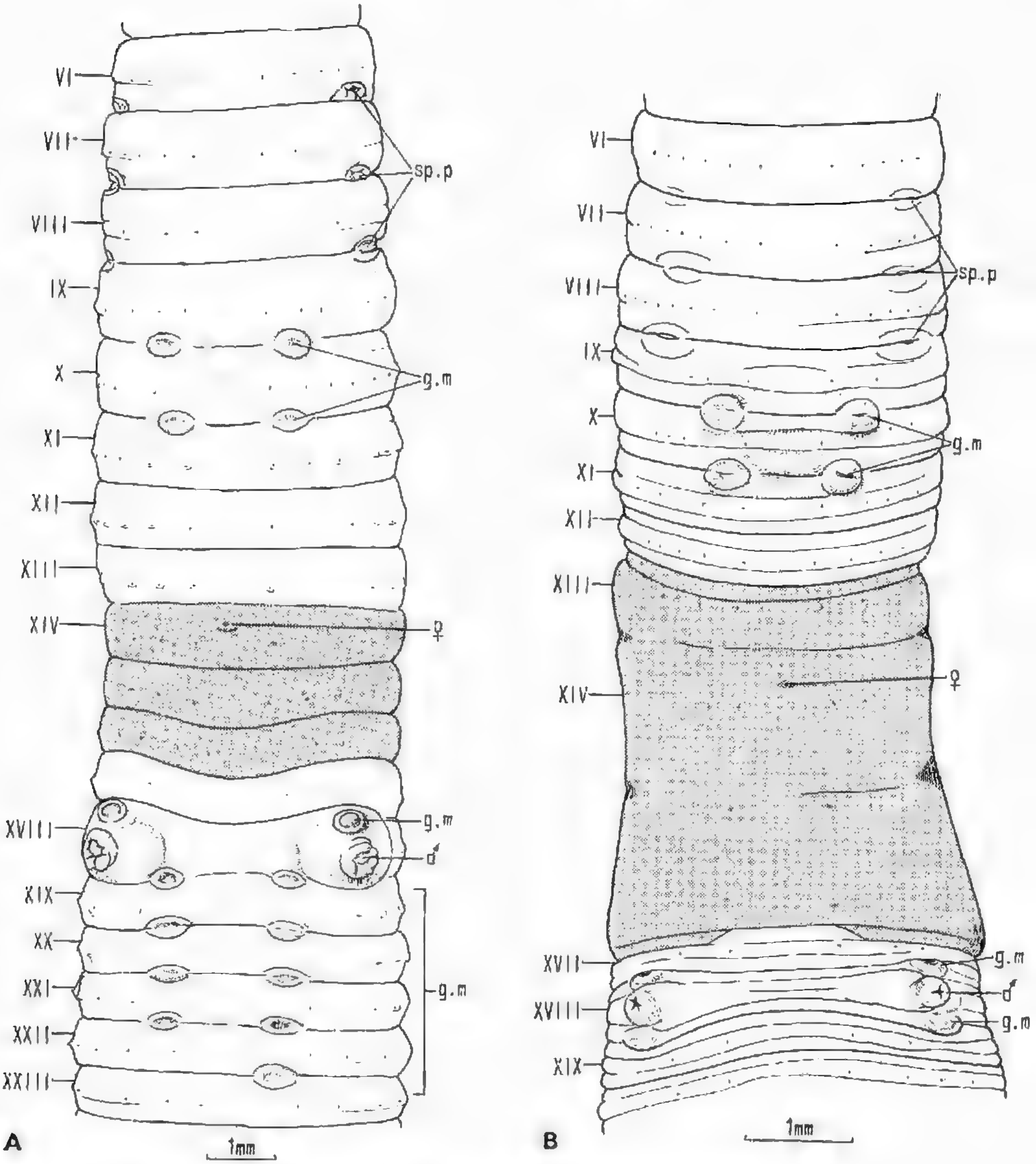

Fig. 4. *Gemascolex lateralis.* Genital fields of: *A*, specimen 1, Ji2; *B*, specimen 3, Ll1.

in 8/9, 9/10 and 10/11. A pair of markings is invariably present in XVIII in front of the male pores and a further pair is usually present behind the pores. In no specimens are the posterior markings present in the absence of the anterior pair.

Paired intersegmental genital markings in the vicinity of the male pores may be absent but they are usually present in 18/19, 19/20, commonly in 20/21 and 21/22 and less frequently in 17/18 and 22/23.

In all but one of the many specimens examined, the female pore was unpaired.

Material examined: Jg1, 138°03'E, 32°46'S, Alligator Gorge National Park, under rocks near creek in gorge, *B.J.* and *T.W.*, 19.viii.1972—SA 26–30, 33. Jh2, 138°38'E, 33°55'S, 10 km S of Clare on road to Auburn, under eucalypts, *B.J.* and *T.W.*, 18.viii.1972—SA 165, SA 170, SA 318, 319. Ji2, 138°24'E, 34°58'S, Mt. Lofty, *T.W.*, 16.viii.1972—SA 306. Mt. Lofty, in eucalypt woodland, *B.J.* and *T.W.*, 16.viii.1972—SA 289–296, 298, 299, 301–302, 304, 305; Mt. Lofty area, in moist soil in eucalypt sclerophyll, *T.W.*, 20.viii.1972—SA 77, 78, 79, 82, 85. Jj1, 138°41'E, 35°07'S, Mt. Bold reservoir, on hillside with eucalypts and grass, *T.W.*, 21.viii.1972—SA 57–60. Jj2, 138°43'E, 34°14'S, Kyeema National Park, near creek and under logs in eucalypt sclerophyll and in swamp, *T.W.*, 21.viii.1972—SA 271, 279, 286, 287. Jj3, 138°30'E, 35°22'S, 6.5 km from Myponga, *S. Edmonds*, 16.viii.1972—SA 236, 237. Jj4, 138°31'E, 35°26'S, near Mt. Clark (S of Myponga), eucalypt sclerophyll, *T.W.*, 21.viii.1972—SA 64, 69–72. Jj5, 138°11'E, 35°36'S, 8 km from Cape Jervis along road to Victor Harbor, in grasstree, bracken and eucalypt bushland, *T.W.*, 21.viii.1972—SA 265, 267. Jj6, 138°21'E, 35°34'S, 24 km from Cape Jervis along road to Victor Harbor, under rocks and logs in poor soil, *T.W.*, 21.viii.1972—SA 207, 209, 210, 215. Jj7, 138°25'E, 35°33'S, 30 km from Cape Jervis along road to Victor Harbor, in grasstree and eucalypt mulga, *T.W.*, 21.viii.1972—SA 172, 176. Jj8, 138°32'E, 35°34'S, 10 km from Victor Harbor to Cape Jervis, under roadside log, *T.W.*, 21.viii.1972—SA 42 (immature). Kj1, 139°28'E, 35°15'S, Tailem Bend, under rocks on bank of the Murray River, *B.J.* and *T.W.*, 16.viii.1972—SA 188–190, 192–193, 195–201, 203–205. Lk3, 140°38'E, 36°42'S, 32 km from Naracoorte to Bordertown, in sandy soil among *Banksia*, gums and bracken, *B.J.* and *T.W.*, 16.viii.1972—SA 219–230. Ll1, 140°49'E, 37°28'S, 11 km S of Penola at roadside, under eucalypts fringing *Pinus radiata*, *B.J.* and *T.W.*, 15.viii.1972—SA 15. Ll2, 140°32'E, 37°41'S, 18 km SE of Millicent on road to Mt. Gambier, in sandy soil with grass, bracken and *Drosera* fringing a *Pinus radiata* plantation, *T.W.*, 15.viii.1972—SA 47. SA 15, 79 (AM); SA 77, 229 (BM); SA 289 (SAM); the remaining specimens (BJ).

Remarks: Examination of the lectotype of *Perichaeta lateralis* reveals the presence of paired genital markings, overlooked by Spencer, in 9/10 and 10/11 and does not confirm pairing of the female pore reported in his description. Agreement of the new material, and Michaelsen's description of *Megascolex zietzi*, with the lectotype is so close as to allow no doubt of conspecificity.

The possibility that an infraspecific morph, subspecies or, less likely, a sibling species should be recognized for at least some populations which have genital markings on XVIII both behind and in front of the male pores deserves investigation. In such specimens (exemplified by specimens 3 and 4) the male spermathecal pores, although in the same setal lines as the typical morph (exemplified by the lectotype and specimens 1 and 2) are usually closer together transversely. The spermathecal diverticula are, so far as investigated, shorter and less convoluted. Furthermore, paired intersegmental genital markings in the vicinity of the male pores may be absent though frequently present. The occurrence sympatrically on Mt. Lofty of specimens with or without markings behind the male pores, in addition to those in front, at present militates against recognition of subspecies. However, it is hoped that a statistical examination of morphology in populations of *G. lateralis* and of their biology will be undertaken by workers in South Australia with a view to determining the status of the variants mentioned.

G. lateralis is the only indigenous megascolecid, other than *Heteroporodrilus shephardi*, known to occur outside South Australia (in Victoria).

Gemascolex mirabilis sp. nov.

FIGS 5, 10G; TABLE 6

Length = 60(H)–83(P1) mm, w (midclitellar) = 5.5(H)–6.9(P1) mm, s = 120(P1)–128(H). Circular in cross section. Pigmentless with the exception of the brownish clitellum. Prostomium epitanylobous, closed at 1/3 peristomium and lateral borders to 0/1 not certainly distinguishable from longitudinal furrows on the peristomium but bisected by a deep canalicula to 0/1. Peristomium longitudinally grooved all round but not bisected ventrally. First dorsal pore 3/4, (imperforate?, P1), 4/5 (H, P1). Setae subequally spaced, though *bc* is slightly wider than *ab* throughout. Numbers of setae per segment 20(P1)–21(H) in XII, 21(P1)–22(H) in XX, 20(H)–21(P1) fifteen segments from the caudal end; *a* lines straight throughout; *z* lines straight anterior to, irregular posterior to the clitellum; a ventral

TABLE 6

Intersetal distances in Gemascolex mirabilis

	mm.					standardized as % of circumference			
	aa	ab	zy	zz	u	aa	ab	zy	zz
Segment XII									
Holotype	1.0	0.4	0.7	1.5	12.5	7.6	3.5	5.7	11.8
Paratype 1	1.2	0.6	0.8	1.7	15.7	7.4	4.0	5.4	10.5
Mean						7.5	3.8	5.5	11.1
Interval/ab						2.0	1.0	1.4	3.0
Segment XX									
Holotype	0.7	0.4	1.2	1.9	13.9	5.3	2.5	8.6	13.9
Paratype 1	1.4	0.6	1.0	2.0	17.6	8.0	3.4	5.8	11.2
Mean						6.7	3.1	7.2	12.5
Interval/ab						2.2	1.0	2.4	4.1

and a dorsal break present throughout. Setae *a* and *b*, but not *c*, absent in XVIII.

Clitellum XIII(P1), 1/3XIII(H)–XVII(H); 1/3XVIII(P1) (= 4 2/3–5 1/3 segments). Male pores minute longitudinal slits in *ab* near the median borders of a pair of large porophores; the pores 1.40(H)–1.79(P1) mm, 0.09(H)–0.10(P1) circumference apart. Accessory genital markings paired transversely elliptical tumescences, with slit like centres, extending from lateral of *c* to median of *b*, in 16/17(P1), 19/20, 20/21(H, P1), 21/22 and 22/23(H). Spermathecal pores 2 pairs of small pores concealed in 6/7 and 7/8, in *ab*, nearer *a*, with a faintly demarcated lip in front of each on the preceding segment; the pores 1.37(H)–1.72(P1) mm, 0.09–0.11 circumference apart.

Strongest septa 9/10–12/13, moderately strongly thickened. Last septal glands in IV, not involving the gizzard. Last hearts in XIII. connectives in X-XIII from supra-oesophageal larger than the dorsal connectives and each joined before it reaches the latter vessel by a vessel from the corresponding side of the oesophageal wall. Supra-oesophageal in X–XIII, weakly developed despite the large size of the connectives to the hearts. Gizzard in V. Oesophagus almost suppressed to VIII and short in IX owing to backwards projection of the gizzard; vascularized (though not conspicuously) and dilated in X–XIII, with high internal villi almost occluding the lumen but not uniting axially. Intestinal origin XVII; a well developed, though low, tortuous dorsal typhlosole commencing in XXV(P1) or XXVI(H). Nephridia: a large pair of tufted nephridia, with innumerable spiral loops, in VI sending several composite ducts anterolaterally and anteromedially to the body wall anteriorly in this segment; an extremely large pair of tufts in V sending composite ducts to the pharynx and additional long composite ducts far forward to the vicinity of intersegment 1/2. Very small pharyngeal tufts in IV (H, P1) a rudimentary tuft on each side in III(H); none detectable in II(H) or in II and III(P1). Lateral bands of astomate, exonephric micromeronephridia posterior in their segments in VII–XII(H), XIII(P1) then becoming progressively more anterior until in XV(P1) or XVI(H) they are attached to the anterior septum, the bands especially dense in XIII–XVII; in the anterior intestinal region with approximately 13 compact astomate micromeronephridia on each side dependent from the anterior septum but exonephric. Caudally with approximately 8 enlarged nephridia on each side, closely adjacent to and encircling the intestine from almost the middorsal line laterally; each with a large, long-stalked preseptal funnel; these nephridia sending separate ducts medially to unite as a common duct which passes diagonally, posteromedially, beneath the dorsal blood vessel on each side, to enter the body wall posteriorly in the segment; the diagonal duct on each side communicating by a narrower duct with that of the

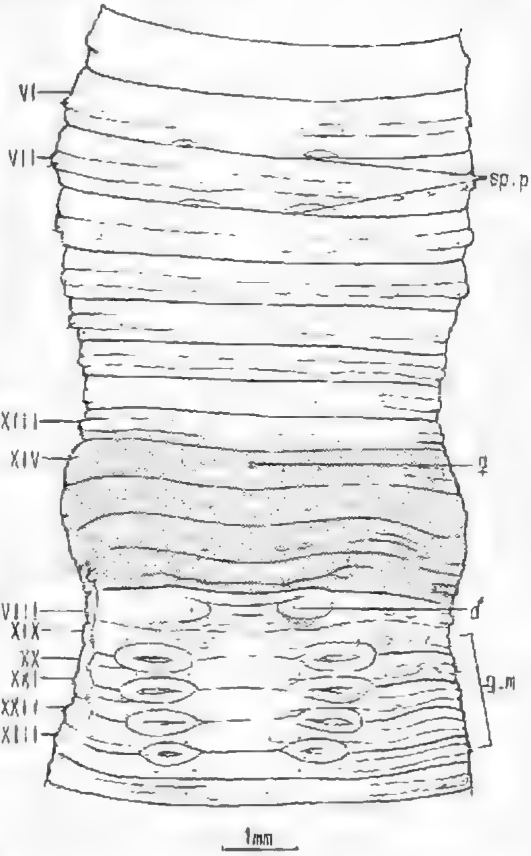

Fig. 5. *Gemascolex mirabilis*. Genital field, holotype Jg2.

next adjacent segments. Numerous astomate, apparently exonephric, septal micromeronephridia present at the parietes, surrounding and concentric with the enlarged, enteronephric nephridia (H, P1). Sperm funnels weakly iridescent in X and XI. Seminal vesicles racemose, in XI and XII. Ovaries composed of several partly united strings of large oocytes. Flattened saclike structures in XIV may be ovisacs. Prostates tongue-shaped, restricted to and passing laterally in XVIII, incised once to twice so as to suggest a modified, depressed tubular form (H, P1); with a narrow central lumen throughout which has epithelium-lined side branches (schizoparatype); the muscular duct widening significantly towards the pore and joined near its ental end by the vasa deferentia, these male ducts running separately from each other in the thick muscular wall of the prostate duct near the lumen of the latter, but not penetrating the lining epithelium to join the lumen until the male pore is almost reached (schizoparatype); copulatory bursa absent. Spermathecae 2 pairs, in VII and VIII, the single diverticulum subspherical, sessile, with several internal inseminated loculi; the duct inflated, spindle shaped (H, P1, schizoparatype).

Field variation: In 11 clitellate type-specimens, including the holotype, genital markings are in 15/16 (left) in specimen (P10); 16/17 in 6 (5 paired, 1 right); 19/20 and 20/21 in 11 (all paired in 19/20; unilateral right or left in 2 in 20/21); 21/22 in 2 (1 paired, 1 right); and 22/23 in 1 (paired). The male porophores in some specimens are surrounded by a common, medianly narrowing field raised at its edges as a rimlike tumescensce which is closely adjacent to the lateral borders of the porophores.

Material examined: Jg2, 138°10'E, 32°48'S, Mt. Remarkable, on slopes of mountain in rocky soil covered with animal (wallaby?) droppings, *B.J.* and *T.W.*, 18.viii.1972—H, P1–10, P11 (schizoparatype); many other specimens collected but not designated type-specimens. Jg1, 138°03'E, 32°46'S, Alligator Gorge National Park, under rocks near creek in gorge, *B.J.* and *T.W.*, 19.viii.1972—P12. H, P2–5 (AM); P1, P6 (BM); P7–8 (SAM); P9–12 and others (BJ).

Remarks: Location of the two pairs of spermathecal pores in 6/7 and 8/9 and the configuration of the genital markings readily distinguish *G. mirabilis* from other species.

Gemascolex octothecatus sp. nov.

FIGS 6A, B, 10H, I; TABLE 7

Length = 45(P1)–64(H) mm, w (midclitellar) = 4.7–5.4 mm, s = 71(P1)–84(H) (posterior regenerates?). Generally circular in cross section but the ventral surface somewhat flattened at and anterior to the male genital field. Pigmented purplish brown dorsally, colorless ventrally, in alcohol; each seta in the pigmented areas surrounded by a colorless circular field. Prostomium not canaliculate (H) or with weak dorsal canalicula (P1), epilobous 1/3(H)–1/2(P1), closed by a deep transverse furrow but continuing posterior as an acute (H) or parallel-sided (P1) tongue which almost reaches the first intersegment. First dorsal pore 4/5. Setae of each side more closely spaced laterally than dorsally and ventrally; *ab* significantly larger than *bc*; the setae of the ventral couple more conspicuous than others. Numbers of setae per segment 20 in XII(H, P1); 18(P1)–19(H) in XX; 26(P1)–28(H) fifteen segments from the caudal end; *a* lines straight, *z* lines irregular; a wide ventral and dorsal break in the setal circlet present throughout. Setae *a*, *b* and *c* absent in XVIII in the prostatic holotype but present in the aprostatic paratype 1.

Clitellum XIII(H), XIV(P1)–1/2XVII dorsally (= 3 1/2–4 1/2 segments) annular but ventrally (H) weakly developed in XIII and apparently not developed in XVII, intersegmental furrow 13/14 well demarcated ventrally (though not dorsally), the succeeding furrows weakly indicated; dorsal pore 13/14 well developed, 16/17 partly occluded, the others obliterated; setae *a* and *b* clearly visible, the remainder only sporadically visible (H). Male pores minute, on stump-like, annulated pseudopenes, in *cd* of XVIII, which are strongly protuberant from gaping slit-like surrounding basal areas which may represent the male pores before eversion of the pseudopenes, the basal slits each borne on a large annulated porophore; the bases of the pseudopenes 6.4 mm, 0.35 circumference apart (H). Male pores and porophores totally absent in paratype 1. Accessory genital markings paired with pore-like centres, presetally in X in *b*; in 16/17 centred in or slightly median of *b*; in 17/18 and 18/19 slightly lateral of *b*; and in 19/20 and 20/21 slightly median of *b* (H, see Field Variation). Spermathecal pores 4 pairs, in 5/6, 6/7, 7/8 and 8/9; in a straight line on each side but between setal lines 5 and 6 in 5/6, and between 6 and 7 in 8/9, distinctly

TABLE 7

Intersetal distances in Gemascolex octothecatus

	mm					standardized as % of circumference			
	aa	ab	zy	zz	u	aa	ab	zy	u
Segment XII									
Holotype	1.7	1.0	0.7	2.5	17.9	9.5	5.6	4.0	14.0
Paratype 1	1.1	0.8	0.6	1.2	13.4	8.2	5.6	4.5	9.0
Mean						8.9	5.6	4.3	11.5
Interval/ab						1.6	1.0	0.8	2.1
Segment XX									
Holotype	1.7	1.1	1.0	2.6	18.5	9.2	6.0	5.4	14.0
Paratype 1	1.1	0.8	0.6	1.3	14.1	7.8	5.3	4.3	9.2
Mean						8.5	5.7	4.9	11.6
Interval/ab						1.5	1.0	0.9	2.1

visible small whitish oval papillae confined to the intersegmental furrows; in 8/9, 7.7(P1)–9.9(H) mm, 0.57(H)–0.58(P1) circumference apart, i.e. slightly dorsal (H, P1).

Strongest septa 11/12–13/14, moderately strong. Last hearts in XIII. Supra-oesophageal vessel in VII, 1/2VIII–1/2XIII, well developed. Hearts in V, VII–IX dorsoventral only, though still valvular, giving branches to septa and body wall, unlike the more posterior hearts. Gizzard in VI. Intestinal origin XVII; a very low, fairly broad dorsal typhlosole commencing in XIX. Nephridia: a pair of large tufts with many spiral loops in each of segments II–V, increasing in size posteriad, to very large in V; the tufts in II and III sending composite ducts forward in common to join the body wall near the buccal cavity and into the peristomium where they possibly enter the buccal cavity; those in IV and V discharging into the pharynx. Meronephridia parietal and apparently exonephric in transverse bands in VI posteriorly; caudally, from approximately the 50th segment with 8 or more long-necked preseptal funnels on each side and with the median 2 of these stomate nephridia enlarged as megameronephridia the 4 of which lie on the dorsal surface of the intestine and send their ducts to the intestinal wall; the two ducts uniting on each side of the dorsal vessel, and in continuity with those of neighbouring segments; the longitudinal duct apparently but not certainly opening into the intestine posteriorly in each segment. Laterally the nephridia become progressively smaller, though each retains a preseptal funnel; they are dependent from the anterior septum and some at least send ducts to the roof of the intestine and are apparently also enteronephric. Elongate lobed testes and large complexly folded, pearly but not iridescent sperm funnels in X and XI; 2 or 3 pairs of moderately large sacciform seminal vesicles in IX(H), XI and XII (H, P1). Prostates large, broad lobed structures in XVIII–XXI (left), –XXII right), each deeply incised laterally and less so medianly by the septa; the ∩-shaped muscular duct ectally narrow, widening strongly and uniformly ectalwards but lacking a terminal bursa; vas deferens joining it near its junction with the gland (H). Large, paired, low internal glandular masses in XVI–XXI corresponding with external accessory genital markings (H, P1). Prostates totally absent from paratype 1 although the specimen is mature; ectal portions of vasa deferentia not observable. Ovaries (bushy with many large oocytes (P1) or poorly developed (H)) and funnels in XIII, accompanied medianly by sacs of unknown function; sacs on the anterior septum of XIV may be ovisacs. Spermathecae 4 pairs, diverticulum single, elongate clavate, uniloculate, shorter (P1) or longer (H) than the spermatheca, sometimes coiled.

Field variation: Of the 6 type-specimens, only the holotype has male pores; 3 of the paratypes dissected, 1 of which is longer than the holotype and fully clitellate, have no prostate glands. Paired accessory genital markings anteriorly in X in *b* lines are invariably present as are paired markings in 16/17–19/20. They are present in 20/21 in paratypes 1 and 2, as in the holotype. Additional paired markings are present in 15/16 in paratype 3. A rudimentary marking is present unilaterally on the right, in 12/13 in paratype 4. In specimens lacking male pores the genital markings in 17/18–18/19 are slightly more median than in the prostatic holotype, lying in *ab* nearer *b*, rather than in *b* lines.

Material examined: L11, 140°49'E, 37°28'S, 11 km S of Penola in eucalypts fringing *Pinus radiata*, *B.J.* and *T.W.*, 15.viii.1972—P1. Lm1, 140°55'E, 38°01'S, 27 km from Mt. Gambier along road to Nelson, in sandy loam under grass among wattles and gums with some herbaceous garden escapes, *B.J.* and *T.W.*, 15.viii.1972—H, P2–5. H, P2 (AM); P1 (BM); P3 (SAM); P4 & 5 (BJ).

Remarks: G. octothecatus resembles *G. dorsalis* (Fletcher), from Victoria, in possessing four pairs of spermathecae and in the dorsal location of their pores. A further similarity between the two species is the pair of genital markings at the anterior margins of X and XVII. *G. dorsalis* differs, however, in restriction of genital markings to these locations in all localities from which it has been reported (Fletcher 1888b; Spencer 1892; Michaelsen 1907b); and in the more dorsal location of the

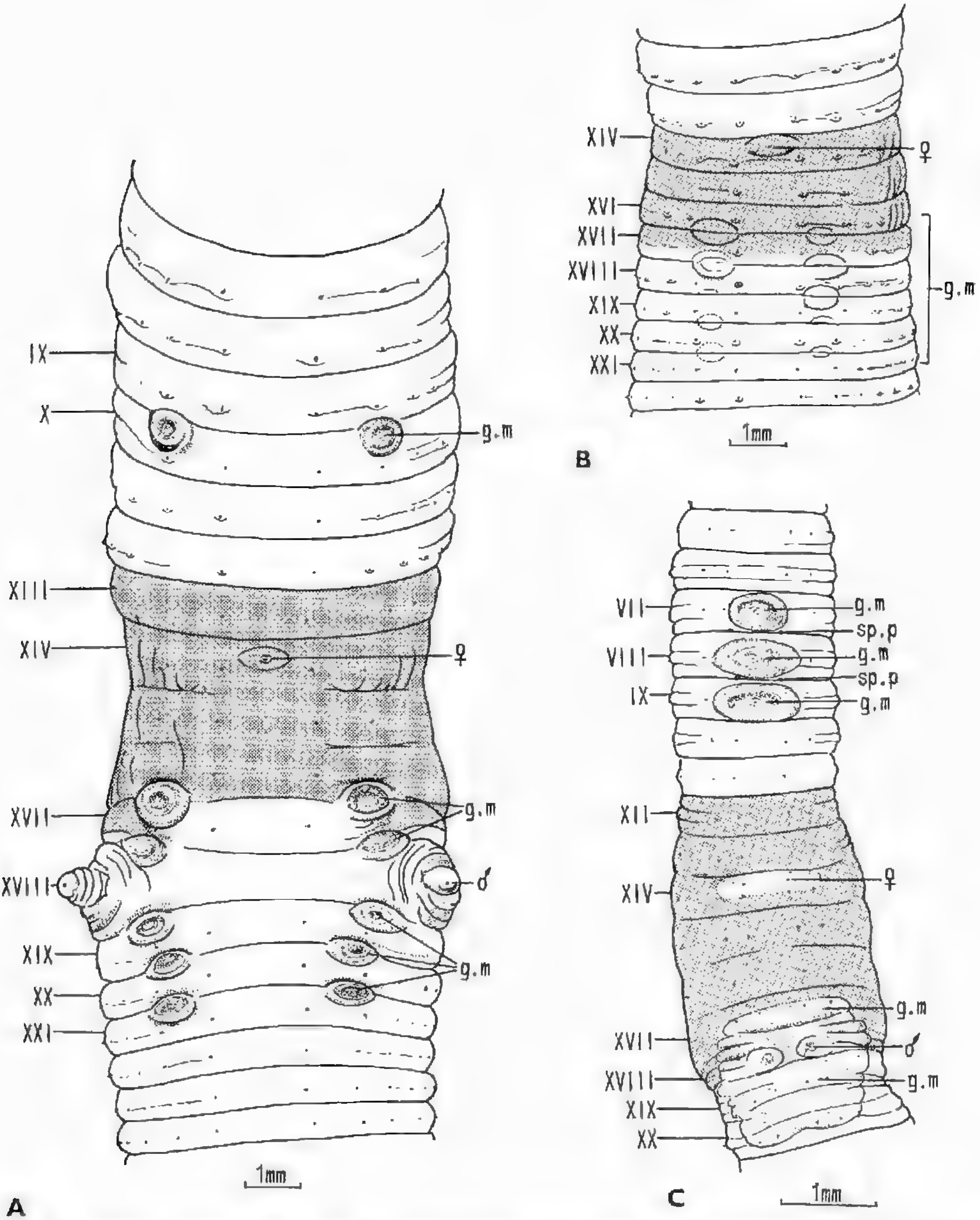

Fig. 6. Genital fields of: *A & B, G. octothecatus. A*, holotype, Lm1; *B*, paratype 1, Ll1. *C, Perionychella (P.) inconstans*, holotype, Mj1.

spermathecal pores. *G. similis* differs from *G. octothecatus* in the smaller number of spermathecal pores, restriction of accessory genital markings to X, 16/17 and 18/19, and the greater development of these markings. These differences of *G. octothecatus* from *G. dorsalis* and *G. similis* are minor compared with those between other species of the genus but union of the three entities in *G. dorsalis* nevertheless does not appear justified.

The prevalence of individuals lacking male terminalia suggests that *G. octothecatus* is commonly parthenogenetic.

Gemascolex similis sp. nov.

FIGS 3B, 10J, K; TABLE 8

Length = 40 mm + (posterior amputee), w (midclitellar) = 4.5 mm, s = ?. Pigmented, purplish brown, dorsally. Circular in cross section. Prostomium epilobous 1/3, closed. Preclitellar setae large, postclitellar indistinct, setae of a side more widely spaced dorsally and ventrally than between, decreasing in size dorsally; *ab* slightly wider than *bc* throughout. Numbers of setae per segment 18 in XII and XX, 20? (indistinct) in XXXV; *a* lines straight, *z* lines irregular throughout; a wide ventral break evident throughout; dorsal break wider and clearly visible anterior to the clitellum, poorly defined behind it owing to minuteness and irregularity of the setae; *a* and *b* absent in XVIII, *c* and *d* faintly visible on the lateral face of the porophore.

Clitellum rudimentary, apparently occupying XIV–1/2 XVII (= 3 1/2 segments), not sufficiently developed to obscure dorsal pores, intersegments or setae. Male pores minute, on stump-like, annulated pseudopenes, median to *c* of XVIII; a basal circumferential groove around each pseudopenis may represent the margins of male pore before eversion of the pseudopenis, this basal groove is itself borne on a large annulated porophore; the centres of the bases of the pseudopenes 4.8 mm, 0.33 circumference, apart. Accessory genital markings paired subcircular, buttonlike, sharply demarcated tumescences, each differentiated into a peripheral rim and flat or depressed central area, filling the presetal part of X in *b*; in 16/17 and 17/18 in *ab*, filling the space between the setal arcs of the adjacent segments, those in 16/17 more median than those in 17/18. Female pore unpaired, midventral in XIV, presetal in an elliptical field. Spermathecal pores 3 pairs, in 6/7, 7/8 and 8/9, inconspicuous whitish ellipses, in setal lines 5–6, 4–5 and 5–6 respectively (right side, not certainly visible externally on left side); 9 mm, 0.54 circumference apart, i.e. slightly dorsal.

TABLE 8

Intersetal distances in Gemascolex similis

	mm					standardized as % of circumference			
	aa	ab	yz	zz	u	aa	ab	yz	zz
Segment XII									
Holotype	1.7	0.9	0.9	2.0	14.0	12.1	6.1	6.4	13.9
Interval/ab						2.0	1.0	1.1	2.3

Strongest septa 10/11 and 11/12, very strong; 8/9, 9/10, 12/13 and 13/14 also strong. Last hearts in XIII. Supra-oesophageal vessel in IX–1/2 XIII; moderately developed. Gizzard in VI. Intestinal origin XVII; a very low ridgelike dorsal typhlosole commencing in approximately XVIII. Nephridia: paired tufts in II–V, increasing posteriad from small to large; those in II and III discharging exonephrically anteriorly in their respective segments; those in IV apparently, but not certainly, discharging into the pharynx; those in V each with a wide composite (multiple) duct running anteromedially to the pharynx wall in III. Numerous exonephric micromeronephridia mostly in posterior bands in their segments in VI–XII; mostly presetal in XIII; anterior and posterior bands of micromeronephridia in XIV–XXI; thereafter mostly anterior in each segment; no nephrostomes present but posterior end missing behind the 40th segment. Sperm funnels iridescent in X and XI; seminal vesicles saccular, in XI and XII; a pair of small sacs on the anterior wall of X resemble seminal vesicles but in this location presumably do not have a seminal function. Ovaries with several chains of large oocytes, small flattened sacs on each side of them; ovisacs absent. Prostates large flattened lobes, with irregular, lobed, moderately deeply incised margins, restricted to but greatly enlarging XVIII; the tortuous muscular duct gradually but considerably widening through its length to the pore. Large intracoelomic glandular masses are associated with the accessory genital markings. Spermathecae 3 pairs, approximately uniform in size; diverticulum (inseminated) single, digitiform, but that of the left spermatheca of IX with a triloculate terminal dilatation.

Material examined: L12. 140°32'E, 37°41'S, 17 km SE of Millicent on road to Mt. Gambier, in sandy soil with grass, bracken and *Drosera*, fringing a *Pinus radiata* plantation, *T.W.*, 15.viii.1972—H (AM).

Remarks: G. similis belongs to a *G. dorsalis* complex including also *G. octothecatus*. It differs from both the latter species in having only 3 pairs of spermathecae. Its accessory genital markings have the same distribution as in *G. dorsalis*, though better developed, but it differs from this species in the unpaired female pore and absence of seminal vesicles from IX, in addition to the smaller number of spermathecae and their more ventral location relative to setal lines. Differences between the three species are minor relative to those between most other species of the genus but union of the three entities under *G. dorsalis* at present appears unjustified.

Gemascolex stirlingi (Fletcher, 1888a)

FIGS 8A, B, 10L, 11G; TABLE 9

Perichaeta stirlingi Fletcher, 1888a: 395–398; 1889b: 1017–1019.

Megascolex stirlingi Beddard, 1895: 373. Michaelsen, 1900: 222. Jamieson, 1971b: 95. Edmonds & Jamieson, 1973: 23.

Megascolex fletcheri Shannon, 1920: 301-313, Pl. XXVII–XXXI.

[*non*] *Megascolex fletcheri* Michaelsen, 1907b: 21.

Length — 300 mm, w (midclitellar) = 12 mm, s = 258 (Specimen 1. Specimen 2 is a posterior amputee). Pigmented dark olive-brown dorsally. Circular in cross section. Prostomium deeply bisected by a dorsal canalicula, epilobous 1/2, closed, but peristomium with numerous longitudinal furrows all round so that prostomium might be considered epitanylobous; transverse furrows render peristomium and prostomium mammilate. First dorsal pore 4/5 with, in specimen 1, an imperforate rudiment at 3/4. Setae well developed ventrally to midlaterally, rudimentary further dorsally; *aa* ≏ *ab* but setae progressively more closely spaced dorsally. Numbers of setae per segment not or only approximately countable, 22 in XII, 20 fifteen segments from the caudal end in specimen 1; *a* lines straight, *z* lines irregular, a wide ventral and wider dorsal break in the setal circlet present throughout. Setae *a*, *b* and *c* absent in XVIII. Few intersetal distances measurable.

Clitellum XIV–XVII (= 4 segments). Male pores transverse slits with low but tumid lips, shortly median of setal lines *c* of XVIII, the pores 6.43–6.71 mm, 0.20–0.21 circumference apart (specimens 1 and 2); each low porophore lying in a depression and accompanied laterally by a raised slightly larger transverse ridge; the border of the segment immediately in front of and behind the pore also thickened to form a narrow callosity (specimens 1 and 2) or a small intersegmental tubercle present in front of and behind each pore at 17/18 (specimen 3). Paired eyelike accessory genital markings in 16/17, centred in *ab* nearer *b*, and in 19/20–22/23 (specimens 1–3), those in 19/20 centred slightly median of *c*, those in 22/23 slightly lateral of *c* (specimens 1 and 2) or those in 19/20–22/23 all in *bc* (specimen 3); the markings with raised whitish central area.

TABLE 9

Intersetal distances in Gemascolex stirlingi

	mm aa	ab	u	standardized as % of circumference aa	ab
Segment XII					
Specimen 1	2.0	1.2	28.0	7.1	4.3
Specimen 2	1.9	1.1	28.0	6.8	4.1
Mean				6.9	4.2
Interval/ab				1.6	1.0
Segment XX					
Specimen 1	2.6	1.2	35.0	7.3	3.5
Specimen 2	2.3	1.1	35.0	6.5	3.3
Mean				6.9	3.4
Interval/ab				2.1	1.0

Paired postsetal oval genital markings with porelike centres immediately in front of and slightly lateral of but contiguous with the spermathecal pores, in VI, VII and VIII (specimens 2 and 3). Spermathecal pores 3 pairs, in 6/7, 7/8 and 8/9, large pores with wide lips forming an ellipse, in the 5th to 7th setal line; the pores, at 8/9, 13.57–14.43 mm, 0.44–0.45 circumference apart (specimen 1 and 2).

Strongest septa 9/10–12/13, very thick. Last hearts in XIII. Supra-oesophageal 1/2 VIII–XIII, well developed. Gizzard in VI. Intestinal origin XVII; typhlosole rudimentary, a slight thickening of the roof of the intestine middorsally, first discernible in XXVI. Nephridia: paired tufts with composite (multiple) ducts in II, III, IV and V, all large but increasing in size posteriorly, those in V very large; the tufts in IV and V open into the pharynx; the ducts of those in III apparently join the buccal cavity though some ducts open at intersegment 1/2; whereas those in II appear all to be exonephric in the vicinity of 1/2 (specimens 1 and 2). Dense lateral bands of numerous (exonephric?) micromeronephridia lie in VI–XI on the parietes at the posterior septum; in XII–XIX nephridia are anterior as well as posterior in the segment, being especially dense in XIII–XVI; in XX posteriorly they are anterior only in the segment. Caudally with numerous large meronephridia on each side, adherent to the posterior faces of the septa on the intestine and body wall, each with a large single preseptal funnel which has a long inflated neck, the nephridial ducts difficult to trace but apparently (all?) opening into the intestine (specimen 1).

Sperm funnels iridescent in X and XI. Seminal vesicles racemose, in XI and XII; a further pair of similar but smaller sacs on the anterior septum of XIII (specimens 1 and 2) median to the ovaries (1) or separate ovaries not developed (2). Ovaries consisting of many attenuated chains of large oocytes (specimen 1). Large sacs on the anterior septum of XIV may be ovisacs but show no loculi (specimens 1 and 2). Prostates tongue-shaped, lobulated and incised, restricted to XVIII, the glandular part passing directly laterally, with slit-like central lumen the greatest width of which is only about one tenth the width of the gland, i.e. gland tubuloracemose; the muscular duct S-shaped, with an abrupt bursa-like terminal dilatation. White paired glandular masses in each of segments XVII, XIX–XXIII, corresponding with the external genital markings, large with the exception of those in XIX which correspond with the rudimentary markings in 18/19. Similar paired masses on the body wall in VI, VII and VIII in line with the spermathecal ducts; and corresponding with the external genital markings. Spermathecae 3 pairs, in VII, VIII and IX, increasing in size posteriorly; diverticulum (inseminated) single, clavate, uniloculate (specimens 1 and 2).

Field variation: Specimens 1–4 have a circular genital marking anterolateral to each spermathecal pore (with sporadic omissions) whereas in specimen 5 the marking is posterolateral, in the succeeding segment. Genital markings at 16/17, at or near 17/18 and 18/19, and in 19/20–22/23 are constant in all specimens and are paired with the exception that that on the left in 22/23 is absent in specimen 3.

Material examined: Jg1, 138°03′E, 32°46′S, Alligator Gorge National Park, under rocks near creek in gorge, *B.J.* and *T.W.*, 19.viii.1972—specimens 1 and 2. Jg2, 138°10′E, 32°48′S, Mt. Remarkable, under moss in soil pocket in scree on mountain side, *B.J.*, 17.viii.1972—specimen 3. Jh1;

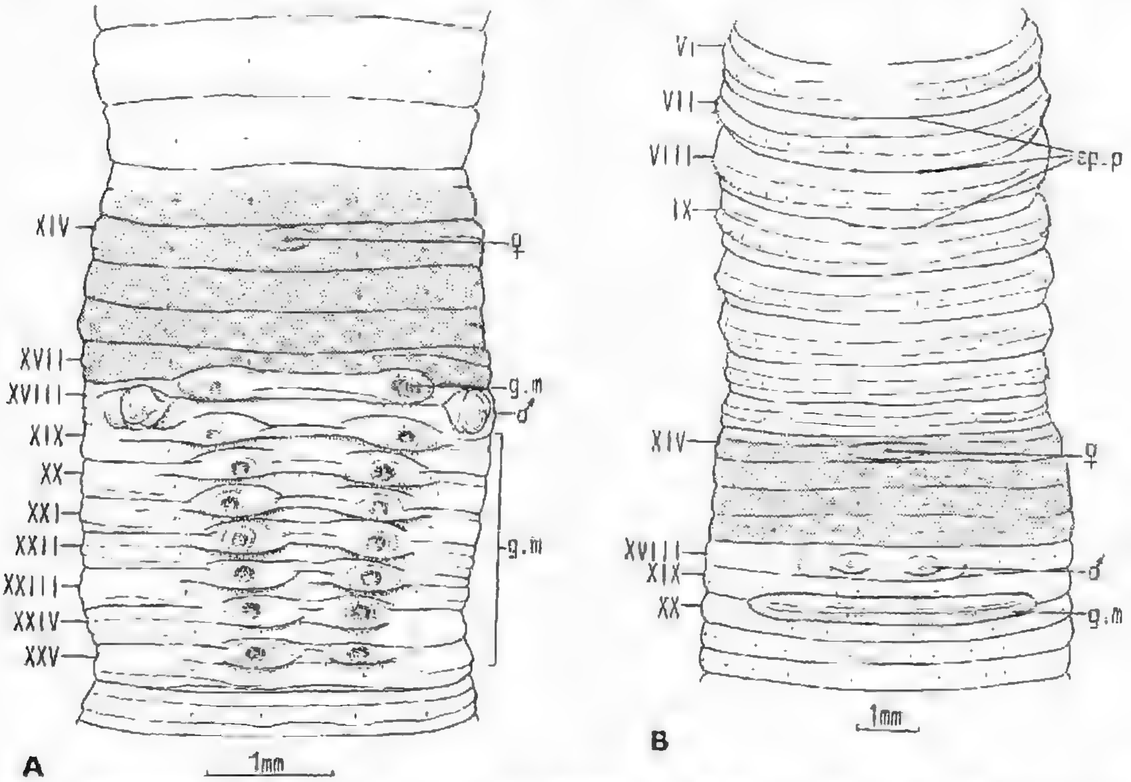

Fig. 7. Genital fields of: *A, Gemascolex walkeri*, holotype, Jil. *B, G. newmani*, *Warren Gorge* specimen.

138°18′E, 33°05′S, 21 km from Gladstone along road to Port Augusta, in red loam among red gums by road, *B.J.* and *T.W.*, 18.viii.1972—specimen 4. Ji2, 138°42′E, 35°00′S, Craters, near Adelaide, *R.A.* 24.xi.1971—specimen 5. Specimen 1 (BM), specimen 3 (AM); specimen 2 (SAM); specimen 4 and 5 (BJ).

Remarks: Location of the genital markings in 16/17 median to the male pores, while those in 17/18–22/23 are approximately in line with these pores, permits ready identification of *G. stirlingi*.

Gemascolex walkeri sp. nov.

FIGS 7A, 10M, 11H; TABLE 10

Length = 42 mm, w (midclitellar) = 3 mm, s = 107, 111(H, P1). Pigmentless in alcohol. Circular in cross section. Prostomium epitanylobous, posteriorly convergent, narrow. First dorsal pore 4/5. Setae *ab* and *bc* wide throughout and approximately equal, being slightly wider than other intersetal distances of a side anterior to the clitellum; posterior to the clitellum *ab* and *bc* remain the largest intervals but spacing of other setae becomes very irregular. Numbers of setae per segment 14 in XII and XX (H, P1), 18(P1)–22(H) fifteen segments from the caudal end; *a* lines straight throughout; *z* lines straight in the forebody, irregular in the hindbody; a moderately wide ventral break visible throughout; a dorsal break discernible in the forebody but not present in the hindbody. Setae *a* and *b* absent in XVIII.

Clitellum rudimentary, some annular modification on XIV–XVI. Male pores on hemispheroidal porophores in XVIII; the pores 2.29(P1)–2.78(H) mm, 0.30(P1)–0.34(H) circumference apart. Paired eyelike ventrally conjoined genital markings in intersegments 17/18–24/25, converging posteriorly from *ab* in 17/18 to *a* in 24/25 (H, see Field Variation). Spermathecal pores 1 pair, ventral in 5/6, small elliptical papillae in setal lines *c*; 2.43(H)–2.64(P1) mm, 0.34(P1)–0.38 circumference, apart. Strongest septa 10/11 and 11/12, moderately strong. Last hearts in XIII. Supra-oesophageal traced in IX–XIII. Gizzard in V. Intestinal origin XVII; a deep laminar dorsal typhlosole commencing in XXI or XXII but continuous as a rudiment forward into XVIII. Nephridia: Paired meronephric tufts in II, III, IV and V with composite ducts opening into the pharynx; very large in V, decreasing in size anteriad (H, P1). Transverse bands of numerous astomate, micromeronephridia exonephric on the body wall in VI–VIII; associated in IX–XV with the posterior septa, in XVI with the anterior and posterior septa, and in XVII and succeeding segments with the anterior septa; all septal nephridia lacking detectable parietal ducts (enteronephric?) (H). Caudally, from about segment 70, with fewer, larger nephridia, approximately 5 on each side, each with a preseptal funnel, the nephridial ducts running on the posterior face of the septum to join the ventrolateral wall of the intestine, some suggestion of a longitudinal duct joining those of adjacent segments seen on the side of the gut but requiring confirmation; postseptal nephrostomes absent; some astomate, parietal and apparently exonephric micromeronephridia present in caudal segments in addition to the stomate nephridia (H, P1). Sperm funnels weakly iridescent in X and XI; seminal vesicles racemose, almost sacciform, in XI and XII. Ovaries bushy with several strings of large oocytes; small sacs in XIV may be ovisacs. Prostates flattened, leaflike, with deeply incised margins and a groovelike 'midrib'; restricted to XVIII; duct U-shaped, bent medianwards, the ectal limb greatly thickened; vas deferens joining the ental limb at midlength. Spermathecae one pair, in VI, diverticulum (uninseminated) single, digitiform, uniloculate, slightly longer than the ampulla (H, P1).

TABLE 10

Intersetal distances in Gemascolex walkeri

	mm					standardized as % of circumference			
	aa	ab	yz	zz	u	aa	ab	yz	zz
Segment XII									
Holotype	0.8	0.6	0.6	0.7	7.7	10.5	7.8	7.9	9.1
Paratype 1	0.8	0.5	0.5	0.8	7.6	10.7	7.0	6.1	10.7
Mean						10.6	7.4	6.5	9.9
Interval/ab						1.4	1.0	0.9	1.3
Segment XX									
Holotype	0.8	0.7	0.7	0.6	8.0	10.1	8.4	9.1	7.9
Paratype 1	0.8	0.6	0.6	0.8	7.9	9.8	7.6	7.4	9.8
Mean						10.0	8.0	7.8	8.8
Interval/ab						1.2	1.0	1.0	1.0

Field variation: In the sexual, though imperfectly clitellate types (holotype and 4 paratypes), genital markings are consistently present in the seven intersegments 17/18–23/24 but those in 20/21–23/24 may be sporadically absent unilaterally. Only P1 agrees with the holotype in having a marking (unilateral, right) in 24/25.

Material examined: Ji1, 138°38′E, 35°00′S, Belair National Park, dry grass and eucalypt sclerophyll, *T.W.*, 21.viii.1972—H, P1–4. Ji2, 138°42′E, 34°58′S, Mt. Lofty, in eucalypt woodland, *B.J.* and *T.W.*,

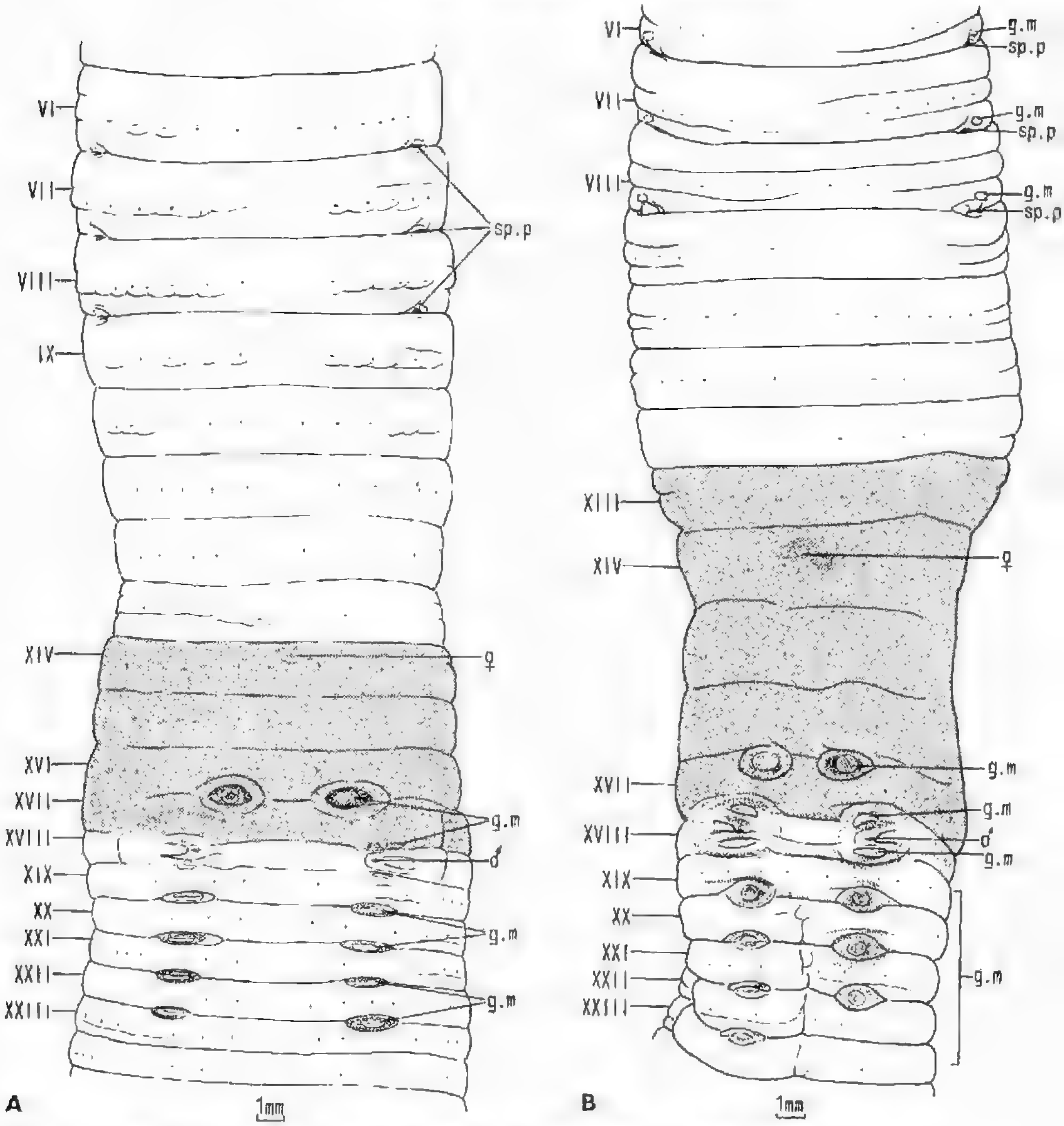

Fig. 8. *Gemascolex stirlingi.* Genital fields of: *A*, specimen 1, Jg1. *B*, specimen 3, Jg2.

16.viii.1972—P5 and 6. H, P2 (AM); P1, P3 (BM); P4 (SAM); P5 and 6 (BJ).

Remarks: The single pair of spermathecae, restricted to VI, distinguishes this species.

Genus SPENCERIELLA Michaelsen, 1907a emend.

Terrestrial. Body circular in cross section. Prostomium epilobous; peristomium usually bisected by a longitudinal furrow ventrally which is more conspicuous than other grooving which may be present. First dorsal pore 4/5 or 5/6. Setae numerous in each segment. A pair of combined male and prostatic pores on XVIII. Clitellum annular, anterior to 17/18, its intersegments and dorsal pores obscured at maturity but setae visible. Segmental accessory genital markings present. Female pores paired, in XIV, anteromedian of setae *a*. Spermathecal pores in 2–5 intersegments ending in 8/9, or a pair in 7/8 only; single or paired.

Dorsal blood vessel single, continuous onto the pharynx. Last hearts in XII or XIII, those in X posteriorly latero-oesophageal, each arising from the short supra-oesophageal vessel and from the dorsal vessel. Subneural vessel absent. Gizzard large, in V. Three or four pairs of well-defined extramural glands, typically with many internal septa, dorsolateral on the oesophagus, in X, XI–XIII. Typically with a latero-oesophageal vessel on each side supplying the calciferous glands. Intestine commencing in XV or XVI or (*S. halli*) XVII; typhlosole a low dorsal ridge or absent; caeca and muscular thickening absent. Excretory system meronephric. Pharyngeal tufts present anteriorly; succeeding segments with astomate, exonephric micromeronephridia. Caudally (always?) with several nephrostomes on each side in each segment or with all but the median-most funnel reduced; with (always?) some at least of the meronephridia enteronephric and interconnected by a longitudinal paired excretory duct (ureter). Testes and funnels in X and XI; testis-sacs absent; seminal vesicles in IX and XII.

Ovaries and funnels in XIII; ovisacs present. Prostates tubuloracemose (partly or wholly linear with central lumen) or racemose (here bipartite); vasa deferentia joining their muscular ducts near the glands. Spermathecae each with one or more clavate, uniloculate diverticula.

Type-species: *Diporochaeta notabilis* Spencer, 1900

Distribution: South Australia, Victoria and Tasmania, New Zealand?

CHECKLIST OF SPECIES

* New combinations in *Spenceriella.*

South Australia:
1. *Spenceriella imparicystis* sp. nov.
2. *Spenceriella penolaensis* sp. nov.

Victoria:
3. *Perichaeta frenchi** Spencer, 1892
4. *Perichaeta halli** Spencer, 1892
5. *Perichaeta hoggi** Spencer, 1892
6. *Diporochaeta notabilis* Spencer, 1900
7. *Perichaeta rubra** Spencer, 1892
8. *Perichaeta steeli** Spencer, 1892
9. *Perichaeta sylvatica** Spencer, 1892

Tasmania:
10. *Perichaeta tasmanica** Spencer, 1895

Species incertae sedis:
11. *Megascolex antarctica* Baird, 1871
    syn. *Diporochaeta shakespeari* Benham, 1906 (New Zealand)
12. *Spenceriella argillae* Lee, 1959 (New Zealand)
13. *Diporochaeta gigantea* Benham, 1906 (New Zealand)
14. *Diporochaeta mapplestoni* Spencer, 1900 (Victoria)
15. *Spenceriella pallida* Lee, 1959 (New Zealand)

Remarks: Jamieson (1972) described a neotypic specimen of the type-species, *Spenceriella notabilis*. The specimen was in very poor condition and it was only possible to say of the several rows of meronephridia that a preseptal funnel was seen in one segment on the nephridium nearest the nerve cord. This suggested membership in the tribe Dichogastrini, a group characterized by a single preseptal funnel on the medianmost nephridium on each side in caudal segments. Three other species, of which material has been examined by the author, are clearly congeneric with *Spenceriella notabilis* from their general morphology and particularly from the form and arrangement of extramural calciferous glands. These are the two new species *S. imparicystis* and *S. penolaensis* and a species provisionally placed in *Megascolex* by Jamieson, 1974, *Perichaeta tasmanica* Spencer, 1895. The two South Australian species have multiple caudal nephrostomes with enteronephry and therefore show that *Spenceriella* must be consigned to the tribe Megascolecini. Only the median funnel on each side was identified with certainty in the new material of *P. tasmanica* but what appeared to be vestigial funnels were present laterally to this and caudal enteronephry was demonstrated for the median nephridium. This suggests a secondary approach to the dichogastrin condition in this species. The other species included above in *Spenceriella* agree closely with the three studied in general morphology, including the arrangement of calciferous glands, though details of excretory and vascular systems are unknown. Occurrence in one and the same genus of linear tubuloracemose or bipartite prostates with branched ducts, further confirms the author's contention (Jamieson 1971a) that the form of prostate glands has only very secondary importance in the classification of megascolecids, contrary to the view of Gates (1959).

Other species included by former workers in *Spenceriella* are listed by Jamieson (1972: 73). Of these *Perichaeta lateralis*, tentatively included by Michaelsen 1907a, is here placed in *Gemascolex*. The remaining species previously included are treated above as *incertae sedis* because, though not placeable in *Spenceriella* as homogeneously defined above, they are not at present placeable elsewhere without premature erection of new genera for their reception. *Megascolex antarctica* placed, as *Diporochaeta shakespeari*, in *Spenceriella* by Michaelsen (1907a) deserves separate comment. From its, albeit inadequate descriptions this conforms sufficiently closely with the above generic definition (including calciferous glands in XI-XIII) to conceivably be congeneric with *Spenceriella notabilis* but little is known of its nephridia beyond the existence of bands of meronephridia. Its peregrine distribution in New Zealand and its islands makes an Australian origin of this species or an ancestor conceivable.

Spenceriella imparicystis sp. nov.

FIGS 9A, 10N; TABLE 11

Length = 44(H)–45(P1) mm, w (midclitellar) = 2.8 mm, s = 107(P1)–122(H). Pigmentless in alcohol. Prostomium not canaliculate, epilobous 1/2(H)–2/3(P1) open but with two weak transverse furrows anterior to its posterior limit. First dorsal pore 4/5, but an imperforate rudiment at 3/4. Setae subequally spaced: 24 in XII, 22(H)–23(P1) in XX, 22 caudally; *a* lines straight, *z* lines irregular; a ventral break appreciable throughout; a dorsal break present only in some anterior segments. Setae *a* and *b* absent in XVIII.

Clitellum weakly developed, 1/2 XIII–XVII (4 1/2 segments), dorsal pores, intersegments and setae retained (H; not developed in P1). Male pores quadriradiate apertures in *ab* of XVIII, each at the centre of an oval papilla in a very strongly protuberant paired porophore which fills the segment longitudinally and is wider than long; each porophore almost touching the other; the pores 0.77 (P1)–0.88 mm (H), 0.1 circumference apart. Accessory genital markings paired midventrally conjoined tumescences filling their segments longitudinally and with presetal pore-like centres lateral of *b* in X, and in *ab* in XVII and XIX. A pair of small glandular areas present posteriorly in each of VII and VIII on each side of the spermathecal pore of the segment, on a midventral elliptical tumescence straddling 7/8 and 8/9 (H, P1; see Field Variation). Spermathecal pores unpaired, midventral, in 7/8 and 8/9, each continued anteriorly as a short slit bisecting the posterior part of the surrounding tumescence.

TABLE 11

Intersetal distances in Spenceriella *imparicystis*

	mm					standardized as % of circumference			
	aa	ab	zy	zz	u	aa	ab	zy	zz
Segment XII									
Holotype	0.7	0.3	0.3	0.4	7.8	9.5	3.5	4.2	5.0
Paratype 1	0.7	0.2	0.3	0.4	7.4	9.5	3.1	3.8	5.4
Mean						9.5	3.3	4.0	5.2
Interval/ab						2.9	1.0	1.2	1.6
Segment XX									
Holotype	0.7	0.3	0.2	0.3	9.9	7.0	2.5	2.0	2.5
Paratype 1	0.6	0.2	0.3	0.3	8.0	7.9	2.9	3.4	3.1
Mean						7.4	2.7	2.7	2.8
Interval/ab						2.7	1.0	1.0	1.0

Strongest septa 9/10–11/12, moderately strong. Last hearts in XII; those in X–XII latero-oesophageal, each originating from a transverse vessel (calciferous vessel) which bounds, and ramifies over the corresponding calciferous gland and receiving (observation from one heart) at its junction with this vessel, a slender connective from the dorsal blood vessel; a continuous supra-oesophageal vessel not demonstrable; the two calciferous vessels on each side in a segment join in the midline below the dorsal vessel, at the dorsal extremities of the glands high above the oesophagus. Commissurals in VII–IX well developed but dorsoventral only and, unlike the latero-oesophageal hearts, giving ventrally branches to the parietes. A latero-oesophageal vessel present on each side median to the hearts, thickest in front of the calciferous glands to each of which it contributes a branch, becoming suboesophageal and subpharyngeal in front of the gizzard.

Gizzard large, with anterior rim, firmly muscular in V, extending posteriorly to intersegment 10/11; free oesophagus in IV not as wide as the gizzard. Oesophagus only slightly shorter in VI than further posteriorly; conspicuously vascularized, moniliform but fairly narrow in VIII and IX; in each of X, XI, XII and XIII bearing a pair of ovoid vertically elongated true calciferous glands, the short narrow stalks of which join the dorsolateral wall of the oesophagus, the glands lying above the oesophagus and each contiguous with its partner medianly; each gland with numerous lamellae projecting from the walls and grouped radially around the long (vertical) axis of the gland, almost contiguous axially but no union demonstrated; each gland, with the exception of the pair in XIII, circumscribed on its outer side by the corresponding heart. Intestinal origin XVI; a very low, indefinite dorsal ridge commencing in XVII, scarcely justifying recognition as a typhlosole; muscular thickening and

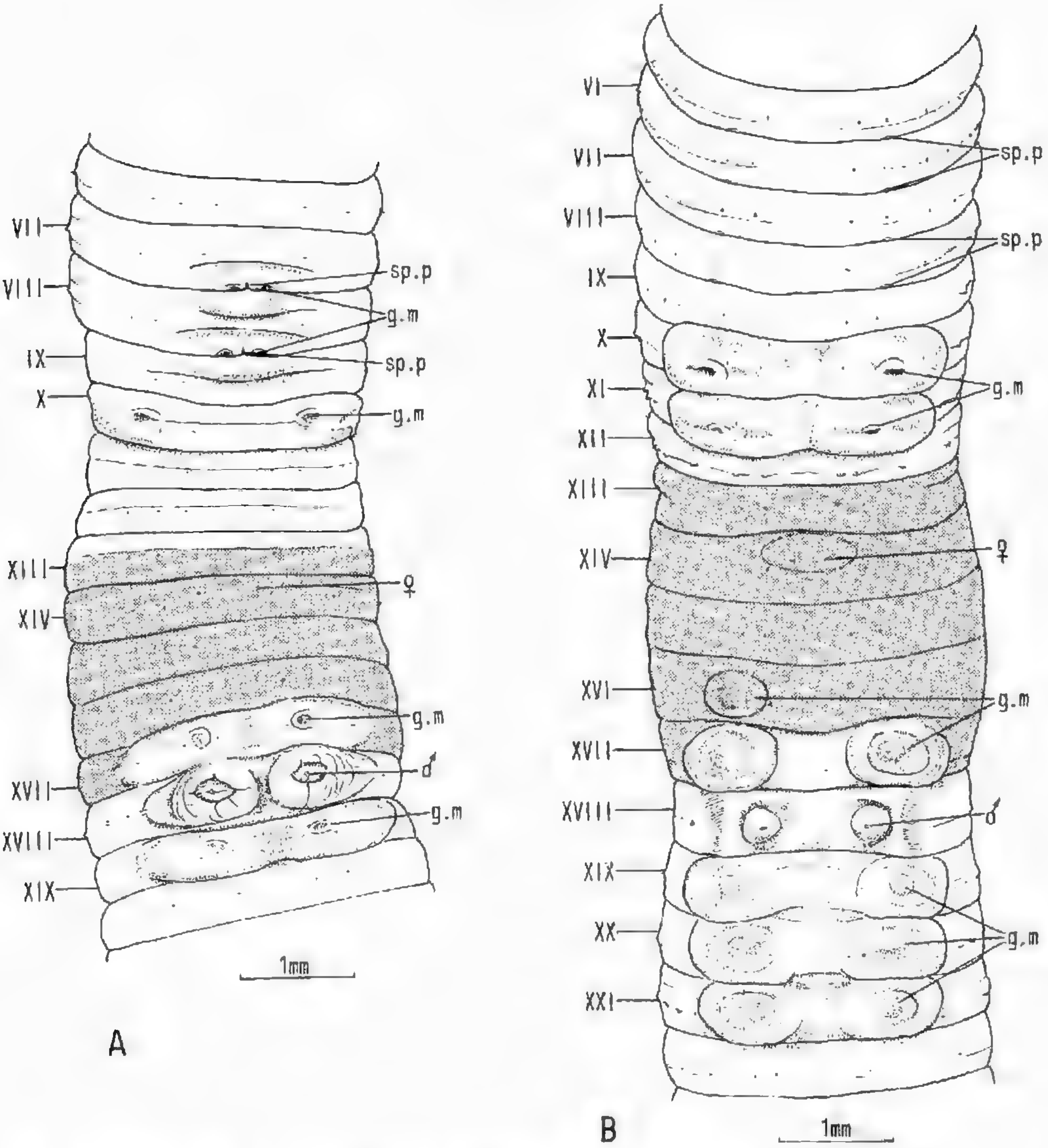

Fig. 9. Genital fields of: *A. Spenceriella imparicystis*, holotype, Lk4. *B. S. penolaensis* holotype, Lm1.

caeca absent. Nephridia: a pair of very large tufts with innumerable spiral loops in V sends composite ducts anteriorly to join the wall of the anterior region of the pharynx (enteronephric); much smaller tufts in IV are not certainly exonephric; while aggregations of nephridial tubules in II and III are exonephric, via sheaves of ducts, at the anterior margins of their respective segments. In the anterior intestinal region with numerous parietal astomate, exonephric, micromeronephridia. Caudally with several enlarged nephridia on each side, each with a single (preseptal?) funnel. Lateral nephridia exonephric; more median nephridia contributing their ducts to a common transverse medianly directed duct which joins the dorsal surface of the intestine shortly lateral of the dorsal blood vessel; a longitudinal duct which apparently connects these segmental nephridial ducts visible running through some caudal segments (H, P1). Sperm funnels iridescent in X and XI. Ovaries slender, pinnate, with large oocytes. True ovisacs containing oocytes in XIV. Prostates with a flattened laterally directed tongue like portion in XVIII which is joined at approximately mid length by a tortuous, depressed almost tubular portion in XIX, the entire gland not linear but having the appearance of derivation from a tortuous depressed tubular gland in which some adjacent adpressed coils have united; vas deferens joining the straight muscular duct where this joins the gland. Spermathecae unpaired, midventral, in VIII and IX; each with 2 (inseminated?) clavate uniloculate diverticula, the two diverticula projecting on both sides of the ventral nerve cord and one of them passing under it to join the wide spermathecal duct where this enters the body wall (H, P1).

Field variation: In the four type-specimens the accessory genital fields are constant, with the exception that the paired markings in X are absent in paratype 2, probably owing to immaturity. Two immature specimens, not designated types, from locality L12 have genital fields and an internal anatomy which suggests they belong to this species but all genital markings are slightly more median than in the types. The median markings at 7/8 and 8/9 are absent but spermathecae are unpaired midventral at 7/8 and 8/9, the paired segmental markings in X have centres presetal in *ab;* those in XVII are absent but there is a pair in each of XIX and XX presetally and slightly median of *a;* the male pores are median to *a* lines.

Material examined: Lk4, 140°44'E, 36°59'S, 1.6 km S of Naracoorte, in sandy soil with bracken and wattles near pasture, *B.J.* and *T.W.*, 16.viii.1972—H, P1–3. L12, 16 km SE of Millicent on road to Mount Gambier, in black soil under mallee gums, *B.J.* and *T.W.*, 15.viii.1972—2 semi-mature specimens not designated types. H (AM); P1–2 (BM); P3 and L12 (BJ).

Remarks: Spenceriella imparicystis is morphologically very similar to the type-species *S. notabilis* (see Jamieson 1972), the genital fields in the specimens from locality L12 being especially similar. The similarity extends to location of latero-oesophageal hearts in X–XII with calciferous glands in X–XIII. The unpaired spermathecae in VIII and IX in *S. imparicystis* clearly distinguish it from *S. notabilis* which has a pair of spermathecae in VIII only. The paired spermathecal diverticula are also distinctive. The distribution of calciferous glands and hearts distinguishes it, among other features, from *S. penolaensis.*

Spenceriella penolaensis sp. n.

FIGS 9B, 10 0; TABLE 12

Length = 43–54 mm, w (midclitellar) = 3 mm, s = 79–128 (H, posterior amputee?, P1). Pigmentless in alcohol. Prostomium canaliculate, epilobous 1/2, with transverse furrow at 1/4, the lateral grooves continuing almost to intersegment 1/2. Dorsal pores very large, the first at 4/5. Setae small and difficult to discern, subequally spaced but *bc* significantly wider than *ab; a* lines straight, *z* lines irregular; a ventral break well developed throughout, a dorsal break present except in some caudal segments. Intersetal distances in XX not measurable. Setae *a* and *b* absent in XVIII.

Clitellum XIII–XVII, but in XVII present only dorsal to the genital markings. Male pores in *ab* of XVIII, each a small orifice on an approximately hemispheroidal porophore which is laterally skirted by a tumid ridge; the pores 0.56(P1)–0.88(H) mm, 0.05(P1)–0.12(H) circumference apart but not accurately measurable as body wall is depressed between pores. Accessory genital markings all segmental, not intersegmental; a pair of large tumid whitish pads filling their segments longitudinally, each with central circular area distinct from a peripheral strongly tumid rim, extending laterally of *c* lines in X and XI, with centres slightly postsetal and lateral of *b* (H, P1), and in XVI (right only) (H), XVII, XIX, XX (H, P1) and XXI (paired) (H), with centres slightly presetal and lateral of *b;* most genital markings medianly conjoined (see Field Variation). Spermathecal pores 5 pairs, in 4/5–8/9, in *b* lines; scarcely recognizable externally; the pores 1.47 mm (H, P1), 0.15(P1)–0.16(H) circumference apart.

Strongest septa 9/10–11/12, moderately strong. Last hearts in XIII, those in X–XIII, each arising from a supra-oesophageal vessel (in X) or from a transverse vessel bounding

TABLE 12

Intersetal distances in Spenceriella penolaensis

	mm.					standardized as % of circumference			
	aa	ab	zy	zz	u	aa	ab	zy	zz
Segment XII									
Holotype	0.6	0.2	0.5	0.8	7.2	8.7	2.9	3.5	11.6
Paratype 1	0.7	0.2	0.5	0.7	11.0	6.1	1.7	2.8	6.3
Mean						7.4	2.3	3.1	8.9
Interval/ab						3.2	1.0	1.4	3.9

the corresponding calciferous gland (in XI–XIII) and receiving a long slender connective from the dorsal blood vessel; otherwise unbranched. Commissurals of VI–IX dorsoventral only, slender though, like the posterior hearts, valvular, but differing from the latter in ventrally giving branches to the parietes. Supra-oesophageal vessel not demonstrable as a continuous vessel but seen in X and XIII.

Gizzard very large, ovoid but flattened at the anterior wider end, firmly muscular in V, (septum 5/6 exceedingly attenuated) its posterior end extending almost to intersegment 10/11. Oesophagus very short in VI–X but in each of XI, XII and XIII bearing a pair of ovoid vertically elongated true calciferous glands, the short narrow stalks of which join the dorsolateral wall of the oesophagus, the glands lying above the oesophagus and each contiguous with its partner medianly; each gland with numerous lamellae projecting from the walls and grouped radially around the long (vertical) axis of the gland, several uniting axially, the others almost contiguous but not uniting; each gland circumscribed on its outer side by the corresponding heart. Intestinal origin XVI; a low irregular dorsal typhlosole commencing in XXI; caeca and muscular thickening absent. Nephridia: astomate meronephridia in II loosely aggregated into tufts send sheaves of ducts dorsolaterally to intersegment 1/2; similar aggregations in III–V also appear to be exonephric, are adherent to the pharynx and are apparently at least partly enteronephric, what appear to be pharyngeal ducts being demonstrable in P1. Succeeding oesophageal and intestinal segments have each a transverse row of approximately 10 astomate parietal micromeronephridia on each side. Caudally (P1 and 2) with several small nephrostomes (one to a meronephridium) on each side in each segment, each funnel lying in the segment projecting from its nephridial body near its duct and not preseptal with the exception of the medianmost nephridium which, in some segments was seen to have a preseptal funnel. At least some of the nephridial ducts in each segment combine to send a duct to the dorsolateral surface of the intestine; these ducts communicating from segment to segment by a longitudinal duct on each side which runs on the external surface of the intestine of several segments where visible but is not demonstrable, and is therefore questionably continuous, throughout the caudal region. Confirmation of the exact arrangement of the nephridia of this species is required as unusual difficulty in demonstrating the structures described precludes certainty that the pharyngeal and all caudal nephridia are enteronephric and actual openings of the caudal ducts into the intestinal lumen have not been demonstrated. Sperm funnels iridescent in X and XI. Ovaries bushy with many chains of very large oocytes (H, P1); ovisacs absent (H) or well developed, containing numerous oocytes, on the anterior septum of XIV (P1). Prostates tubuloracemose, lobulated but linear, the gland folded once and occupying XVIII and XIX, with very narrow central lumen throughout, surrounded by thick glandular walls; the curved muscular duct joined near its junction with the gland by the vas deferens. Penial setae, and internal glands corresponding with the accessory genital markings, absent. Spermathecae 5 pairs, diverticulum (inseminated) single, clavate, uniloculate.

Field variation: In the eleven type-specimens, including the holotype, paired genital markings with centres lateral to *b* and slightly postsetal are invariably present in X and XI; paired genital markings with centres lateral to *b* and slightly presetal are invariably present in XVII and XIX, occur in 6 specimens in XX (H, P1–3, 6, 10), and are represented, on the right only, in 2 specimens (H, P6). Female pores are always paired, presetal, 1/3–1/2 *aa* apart and spermathecal pores are never discernible with certainty externally.

Material examined: Ll1, 140°49′E, 37°28′S, 11 km S of Penola, in eucalypts fringing *Pinus radiata*, *B.J.* and *T.W.*, 15.viii.1972—P7–10. Lm1, 140°55′E, 38°01′S, 26 km from Mt. Gambier along road to Nelson, in sandy loam under grass among wattles and gums with some herbaceous garden escapes, *B.J.* and *T.W.*, 15.viii.1972—H, P1–6. H, P2–4 (AM); P1, 5, 6 (BM); P7–8 (SAM); P9, 10 (BJ).

Remarks: S. penolaensis is distinguished from the type-species, *S. notabilis*, and from *S. imparicystis*, in having only three pairs of calciferous glands, lacking those of X. It differs from both species in having five pairs of spermathecae and in other respects.

Discussion

The earthworm fauna of South Australia is remarkably impoverished, though of high specific endemicity. It has been shown above that the total known fauna in the only indigenous family, the Megascolecidae, con-

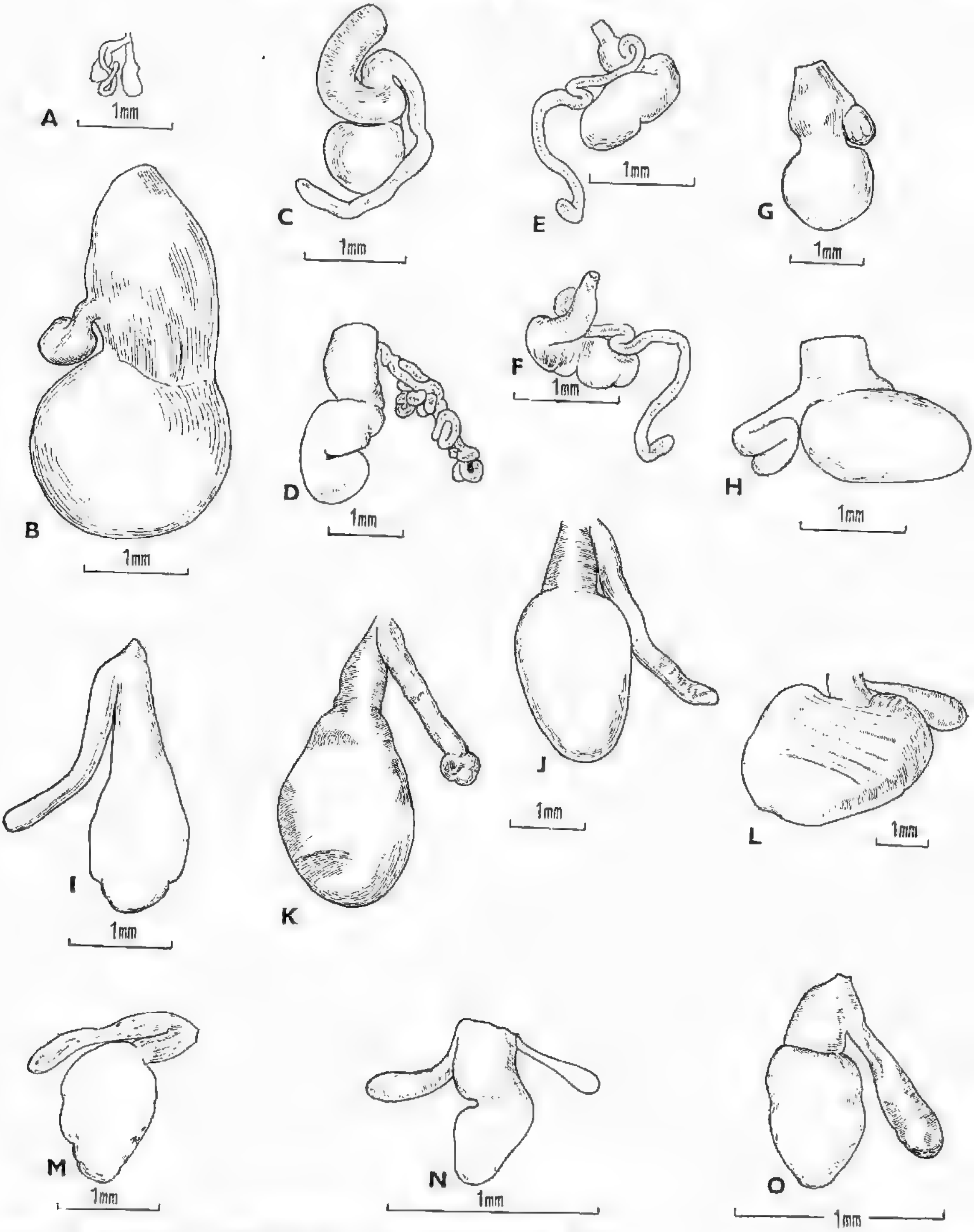

Fig. 10. Spermathecae (right segment 1X unless otherwise indicated): *A*, *Perionychella (P.) inconstans*, holotype, Hj1. *B*, *Heteroporodrilus shephardi armatus*, Ll1. *C*, *Gemascolex bursatus*, holotype, Jj3. *D-F*, *Gemascolex lateralis; D*, specimen 1, Ji2; *E & F*, specimen 3, Ll1 (dorsal and ventral views, right VIII). *G*, *Gemascolex mirabilis*, holotype, Jg2. *H & I*, *Gemascolex octothecatus; H*, holotype, Lm1; *I*, paratype Ll1. *J. & K*, *Gemascolex similis;* holotype, Ll2 (*J*, left VIII; *K*, left IX). *L*, *Gemascolex stirlingi*, specimen 1, Jg1 (left IX). *M*, *Gemascolex walkeri*, holotype, Ji1 (right VI). *N*, *Spenceriella imparicystis*, holotype, Lk4 (unpaired, IX). *O*, *Spenceriella penolaensis*, holotype, Lm1.

sists of a peregrine species of *Microscolex*, a single species questionably assignable to *Perionychella* (from Kangaroo Island), a subspecies of a Victorian species of *Heteroporodrilus*, eight species of *Gemascolex* and two species of *Spenceriella*; in all, ignoring the peregrine *Microscolex*, four genera with twelve species in contrast with thirteen genera with seventy eight species in neighbouring Victoria and twelve genera with forty eight species in the small island state of Tasmania. All of its genera and two species are shared with Victoria. South Australia therefore has close zoogeographic affinities with Eastern Australia. Apart from the fact that the Kangaroo Island *Perionychella* shows affinities with the genus *Graliophilus* in Western Australia, there are no generic or specific affinities with the latter state.

The paucity of the fauna of South Australia is correlated with its low rainfall. A south-eastern coastal wedge, the Fleurieu and Yorke Peninsulas and Kangaroo Island are the wettest parts, with an annual rainfall, with local exceptions, of between 500–750 mm (20–30 inches) but the remaining coastal region, including the Eyre Peninsula, has only 400–500 mm (16–20 inches) or very much less and the interior is virtually desert. Pickford (1937) in a very thorough survey of the earthworm fauna of South Africa found no earthworms where the rainfall was less than 25 inches and the wetter parts of South Australia are near, often below, this limit. The rainfall in coastal Victoria, in contrast, varies from 500–750 mm (20–30 inches) in the drier west to 750–1975 mm (30–80 inches) in the east while Tasmania also has areas ranging from 500–2000 mm but is generally wetter than Victoria.

Of the regions in South Australia not investigated for earthworms, only the Yorke Peninsula appears to be wet enough to yield earthworms and though some additional species doubtless remain to be discovered in the areas from which they have been collected, it is unlikely that further collecting will elevate the South Australian fauna above a total of about twenty species.

It is noteworthy that the great majority of South Australian species, all in *Gemascolex* and *Spenceriella*, have caudal enteronephry, a condition which would appear to be an adaptation for water conservation as urine excreted into the intestine is presumably concentrated by resorption of water in the hind gut. The close similarity of the species within *Gemascolex*, as in *Spenceriella*, suggests relatively recent speciation from an even smaller fauna.

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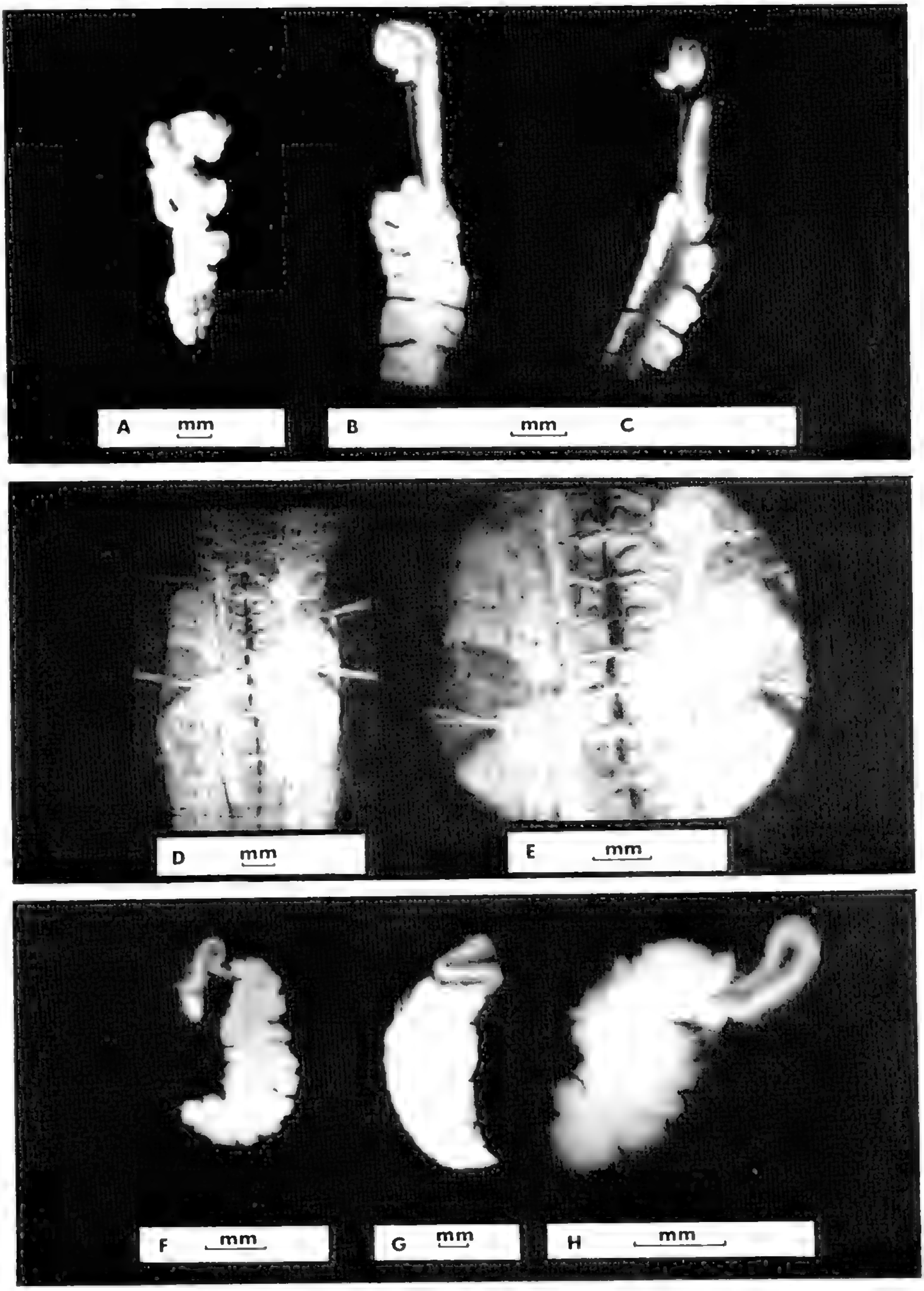

Fig. 11. Prostates of: *A*, *Heteroporodrilus shephardi armatus*, paratype 3, Lk4. *B-E*, *Gemascolex bursatus*, holotype, Jj3; *B*, dorsal; *C*, ventral; *D* & *E*, prostates *in situ*, showing bursae, muscular ducts, and glands adherent to the intestine. *F*, *Gemascolex lateralis*, specimen 3, Ll1. *G*, *Gemascolex stirlingi*, specimen 1, Jg1. *H*, *Gemascolex walkeri*, holotype, Ji1. Scale 1 mm.

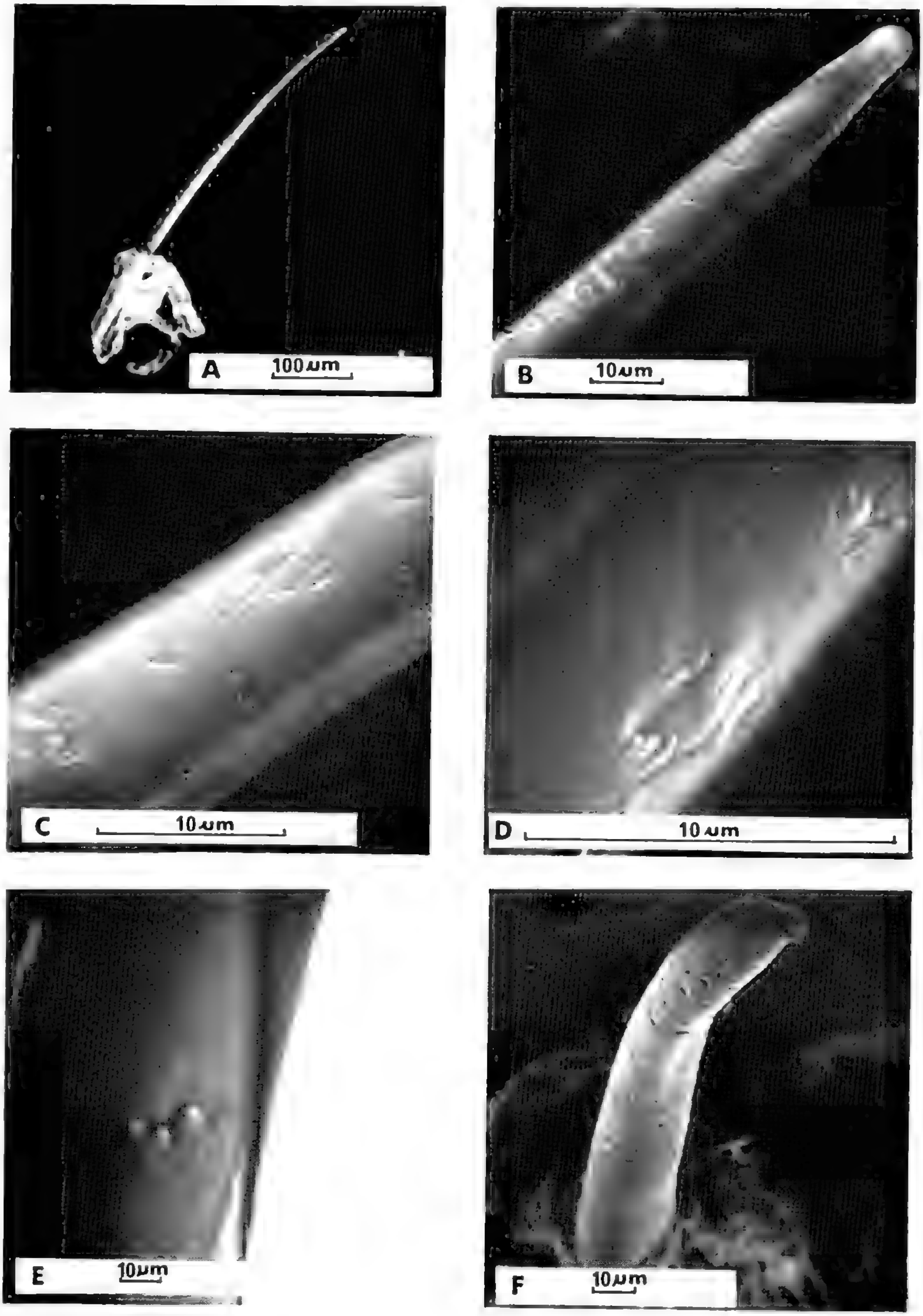

Fig. 12. Penial setae of *Microscolex dubius,* by scanning electron microscope. *A*, entire seta with muscle adherent basally; *B*, tip of same seta; *C*, *D*, *E*, sculpturing of same; *F*, seta of second specimen. L14.

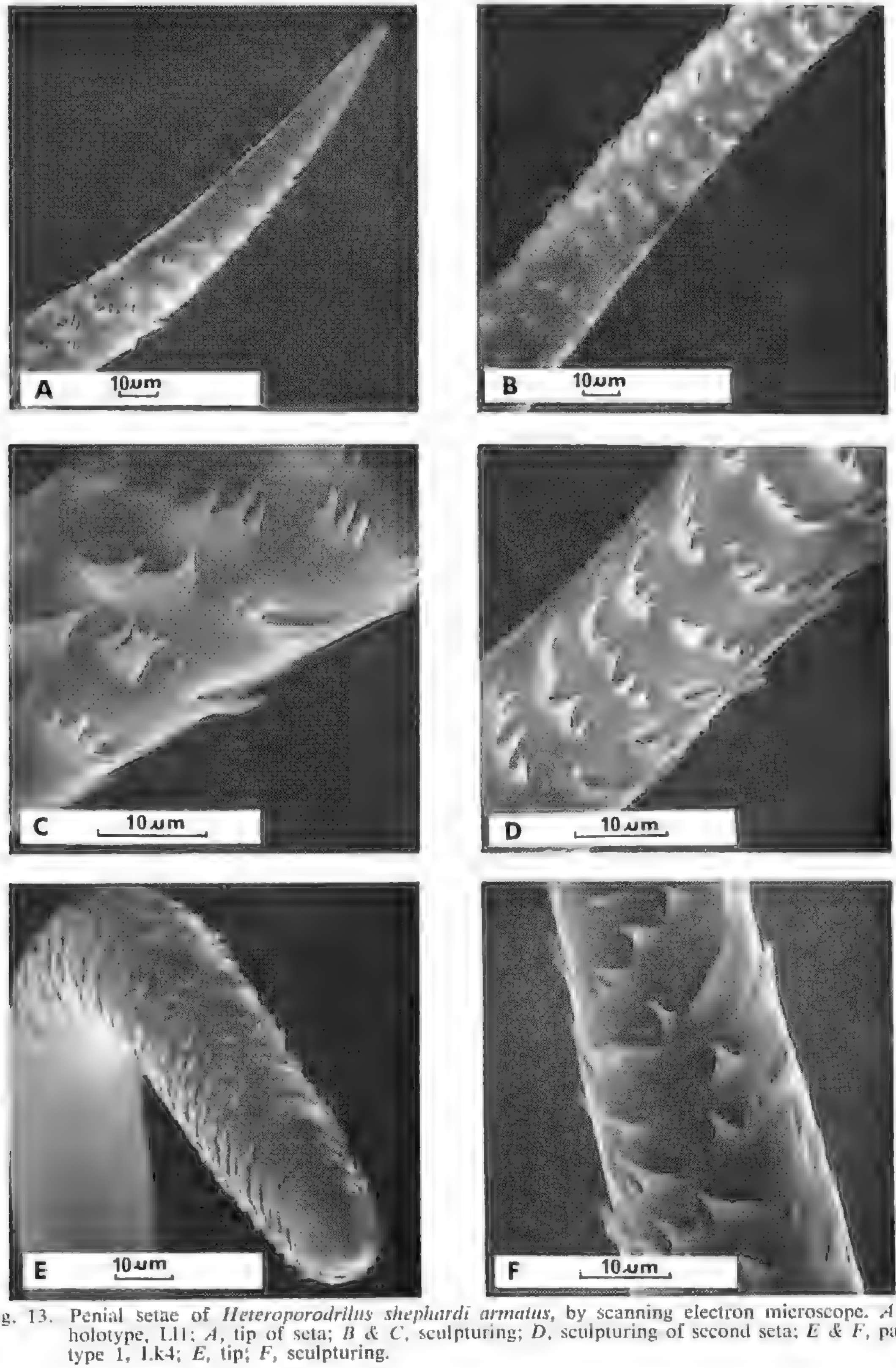

Fig. 13. Penial setae of *Heteroporodrilus shephardi armatus*, by scanning electron microscope. *A-D*, holotype, L11; *A*, tip of seta; *B* & *C*, sculpturing; *D*, sculpturing of second seta; *E* & *F*, paratype 1, Lk4; *E*, tip; *F*, sculpturing.

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LICHENS FROM THE T. G. B. OSBORN VEGETATION RESERVE AT KOONAMORE IN ARID SOUTH AUSTRALIA

*BY R. W. ROGERS**

Summary

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Introduction

There have been a number of recent studies concerning lichens in arid southern Australia (Rogers 1971, 1972a, 1972b; Rogers & Lange 1971, 1972); however, these have dealt only with species growing on the soil.

The T. G. B. Osborn Vegetation Reserve at Koonamore (139°27′E, 32°15′S) was established in 1925 to study the regeneration of over-grazed arid shrubland, this work being summarised by Hall, Specht & Eardley (1964). Although it is only small (390 hectares), it has a vegetation representative of much of arid South Australia. The Reserve is located in an area where vegetation formations of the more arid, low, open shrublands to the north occur admixed with formations from the low woodlands to the south. The Reserve has a rainfall of only 182 mm per annum, and, using the criteria of Meigs (1953) is Arid.

The only report concerning lichens from the Reserve is in Osborn, Wood & Paltridge (1935). The collections were made by C. Barnard, and specimens sent to Kew for determination. Examination of the material retained as duplicates in the herbarium of the University of Adelaide (ADU) shows that some of the confusion in the discussion of lichens by Osborn, Wood & Paltridge was due to limited knowledge of lichens and their structure.

The "undetermined species of *Acarospora*" referred to as forming patches up to 8 cm in diameter is, in the specimens retained, mostly large colonies of *Diploschistes scruposus*. However, in a few cases, small, fertile thalli of *A. smaragdula* (rarely 2 cm in diameter) are present in the crust of *D. scruposus*. It is probable that similar material was sent to Kew, and the obviously fertile *Acarospora*, but not the often sterile *Diploschistes*, determined. Two of the three other soil-surface species discussed as being conspicuous because of their apothecia, are not so. *Lecidea decipiens* has small pink squamules with a white edge, and rarely, black marginal apothecia. Osborn, Wood & Paltridge apparently mistook the small thallus for an apothecium. Similarly, they confused the thallus of *Dermatocarpon hepaticum* with apothecia: *D. hepaticum* has immersed perithecia, not apothecia.

During 1965-1971 the Reserve was visited frequently by the author who collected specimens for lichen studies.

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The Lichen Flora

The soil lichens at Koonamore are a striking feature of the Reserve. Over much of the area the lichens form a continuous carpet, which is rich in species. Many of the small calcareous pebbles on the soil surface are completely encrusted with lichens, often with a variety of species on a pebble no more than 1 cm in diameter. Bark and wood of live or dead trees and shrubs supports a usually sparse growth of lichens.

From the collections made in 1965-1971, and from collections housed in the Botany Department, University of Adelaide, 38 species in 25 genera were determined by reference to the literature and herbarium material. These are listed in the Appendix. The flora is comparable in number of species to that found in south-western Africa (41 species; Doidge 1950), in Arizona (33 species; Fink 1909) and in the Negev (37 species; Galun & Reichert 1960).

Brief descriptions and a key to the species from the Reserve appear in the Appendix.

Biogeographic Considerations

Weber (1962) commented on the similarity of arid zone lichen floras from various continents. Rogers & Lange (1972) illustrated this by reference to the soil-surface lichens from all continents except South America.

In desert areas, the genera *Acarospora*, *Aspicilia*, *Buellia*, *Caloplaca*, *Collema*, *Dermatocarpon*, *Endocarpon*, *Heppia*, *Lecanora*, *Rinodina* and *Verrucaria* dominate the lichen floras. All these genera are crustose. The most common foliose genus is apparently *Physcia*, but *Parmelia*, *Teloschistes* and *Xanthoria* are also widespread. All of these genera are recorded in the Reserve although it is likely that the records for *Rinodina* and *Buellia* are based on identical material (see comment in species descriptions).

Literature was searched to see whether the species occurring at Koonamore grow in other deserts. Reports were placed into four regional groupings: North America (Fink 1909, Herre 1911, Rudolph 1953, Weber 1963), North Africa (Faurel, Ozenda & Schotter 1953), western Asia (Steiner 1921, Lamb 1936, Szatala 1957, Galun & Reichert 1960, Poelt & Wirth 1968), and southern Africa (Doidge 1950).

Of the 38 species found in the Reserve, four occur in each of the other four desert regions considered. These are *Acarospora schleicheri*, *Caloplaca murorum*, *Dermatocarpon lachneum* and *Lecidea decipiens*. A further four species, *Endocarpon pusillum*, *Parmelia pulla*, *Physcia stellaris* and *Toninia caeruleonigricans* occur in three of the four regions.

The seven taxa (19%) asterisked in Appendix II are endemic to Australia, with the exception of *Chondropsis semiviridis* and *Parmelia reptans*, which also occur in New Zealand. This is lower than the 30% endemism recorded by Faurel, Ozenda & Schotter (1953) for the Sahara, and similar to the endemism reported by Galun & Reichert (1960) for lichens from the Negev, Israel. Of the other species, 18 (48%) are also found in North American deserts, 14 (37%) in southern Africa, 11 (28%) in western Asian deserts, and 8 (21%) in the Sahara.

Comparison with floras from other arid lands (Table 1) indicates that the flora at Koonamore is unusually rich in foliose species. The most

TABLE 1

Life-form spectra for the lichen population in desert regions, with other South Australian spectra for comparison.

Location	% crustose and squamulose species	% foliose species	% fruticose species
Koonamore	58	42	0
Reno (Herre 1911)	75	25	0
Tucson (Fink 1909)	91	9	0
Negev (Galun and Reichert 1960)	91	6	3
Sahara (Faurel, Ozenda and Schotter 1953)	97	3	0
Arid South Australia*	75	23	2
Semi-Arid South Australia*	57	35	8
Temperate South Australia*	37	41	22
All of South Australia*	45	36	19

*Rogers, R. W. (1971) Unpublished Ph.D. thesis (University of Adelaide) Appendix I, pp. 183-186.

directly comparable area is that studied by Fink (1909) at Tucson. That area was somewhat larger with more diverse substrates and a slightly higher rainfall. The area studied by Herre (1911) at Reno included an altitudinal range of several thousand feet, also with a higher rainfall than Koonamore. Both of these areas were, however, poorer in foliose species. From Table 1 it is also evident that the Koonamore Reserve is relatively richer in foliose species than arid South Australia taken as a whole.

Renaut, Marrache & Trotet (1968) examined the use of lichen life-form spectra as indicators of aridity. With 42% foliose species, Koonamore would rate as sub-humid or perhaps semi-arid on their scale whereas it is classed as arid by use of climatic indices (Meigs 1953). At first this suggests that either the climate at Koonamore is less harsh in relation to its rainfall and temperature regime than other desert regions, or that southern Australian foliose lichens are more drought resistant than their counterparts elsewhere. However, the relatively high percentage of foliose lichens on the Koonamore Reserve may be due in part to the absence of outcropping rocks in the area. Two species absent from the Reserve, but which occur on rocky outcrops in the nearby Yunta and Waukaringa hills, are *Diploschistes gypsaceans* (crustose) and *Heppia euploca* (squamulose). Another factor may be the broad species concept followed in naming the Koonamore lichens. While many taxonomists will not accept the revision of *Acarospora* subgenus *Xanthothallia* by Weber (1968), in which about 80 accepted species were reduced to two, his conclusion that the number of crustose lichens from arid areas is greatly inflated by description of environmental modifications as distinct taxa (Weber 1962) is sound. Apart from the genus *Acarospora*, the genera *Lecanora* and *Lecidea* have also been split to accommodate numerous environmental modifications. It is likely that other authors have followed rather narrow species concepts, increasing the total number and hence proportion of crustose species recorded from arid lands. This may also explain the similarity with the North American desert lichen flora, since both the present author and North American authors have followed a similar broad species concept.

Ecology of Soil Surface Species

To study the soil-surface lichens, 26 transects were randomly located in the physiographically diverse south-eastern half of the reserve. Along each transect, ten 15 cm by 20 cm quadrats were laid at random intervals between zero and ten metres apart, and the soil surface lichens within the quadrats listed. The soil type was classified into one of two categories, calcareous loam or sand.

Thirteen taxa occurred in more than ten of these quadrats; these are listed in Table 2, along with their frequency in loamy and sandy quadrats. Of the 260 quadrats, 67 were without lichens. Fifty-five of the quadrats without lichens were on sandy areas, 12 on loamy areas. Of the loamy quadrats 85% had lichens, whereas only 52% of the sandy quadrats did. The site with the greatest number of species (nine) was on loamy soil, whereas the richest site on sandy soil had seven species. The mean number of species on sandy sites bearing lichens was 3.5, significantly lower ($p<1\%$) than the mean of 4.3 on loamy sites with lichens.

If it is assumed that there is an increase in species diversity as a community develops towards its climax composition (Whittaker 1953), then it follows that species which tend to occur alone are more likely to be pioneer species than those which tend to occur only with others. From Table 2, it is apparent that *Collema coccophorus*, *Endocarpon pusillum*, *Dermatocarpon lachneum* and *Heppia lutosa* are the species most commonly occurring alone, or with few others. These species are therefore likely to be the pioneer species, occurring early in successional development on soil surfaces.

A number of sites on the reserve were discovered where lichen fronts were judged to be advancing on to previously uncrusted areas. This judgment was based on the presence of scattered squamules at a distance from a developed crust, the squamules becoming smaller and apparently younger as distance from the crust increased. *Dermatocarpon lachneum*, *Endocarpon pusillum* and *Heppia lutosa* were the species commonly found in such situations.

These observations, together with the observations of Rogers & Lange (1971) that *Collema coccophorus, Dermatocarpon lachneum, Endocarpon pusillum* and *Heppia lutosa* are the species least affected by trampling of sheep around waterholes, all point to the same group of species as the pioneers in lichen succession on arid soils in South Australia.

The distribution of lichen crusts in relation to shrub coverage was studied on Quadrat 100, an area of 100 m^2 of fine, calcareous soil on which regeneration of *Atriplex* spp. has been

TABLE 2

Frequency of soil-surface species on loamy soils and sandy soils from the Koonamore Vegetation Reserve, and the frequency with which these were either the only species in a quadrat, or were with only one other species.

Species	Frequency on loam	Frequency on sand	Number of occurrences alone	with one other
Acarospora smaragdula	9	0	0	0
Aspicilia calcarea (crustose)	54	22	1	2
A. calcarea (fruticose)	18	1	0	1
Chondropsis semiviridis	1	0	0	0
Collema coccophorus	55	49	14	16
Dermatocarpon lachneum	63	11	2	4
Endocarpon pusillum	43	35	3	15
Fulgensia subbracteata	24	12	0	1
Heppia polyspora	35	3	0	1
H. lutosa	30	18	1	6
Lecidea crystallifera	20	3	0	2
L. decipiens	66	19	0	2
Toninia coeruleonigricans	13	12	1	0

studied since 1925. On this quadrat it was possible in 1969 to find areas on which no perennial plant growth had been recorded in the past 44 years. These areas were without lichen growth. On areas with mature perennial shrub growth, a lichen crust had developed; the older the shrub stand, the more developed the lichen crust. A few areas were found in which the shrubs had virtually all died: in these the lichen crust remained intact. In yet other areas, young shrubs were starting to grow on areas quite devoid of lichen growth.

It is apparent from these observations that the lichen crust develops on fine calcareous soils only after a shrub cover has been established, thus stabilising the soil. However, it is also apparent that the lichens are able to prevent erosion of the soil once the shrub cover has disappeared. Lichen crusts thus increase the stability of desert soils: they cannot themselves stabilise an actively eroding surface.

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Appendix

I. KEY TO SPECIES

1. Thallus fruticose—i.e. without dorsiventral differentiation 4
1. Thallus foliose, squamulose or crustose—i.e with dorsiventral differentiation 2
    2. Thallus foliose or squamulose either free from the substrate, or attached to it by rhizoids, but with a distinct lower surface 3
    2. Thallus crustose, attached to the substrate and inseparable from it, no lower surface discernible, or thallus absent 29
3. Thallus foliose, i.e. of elongate, often branched lobes 7
3. Thallus squamulose, i.e. of round to ovoid scales which may be crowded together 21

FRUTICOSE SPECIES

4. Thallus gold to grey, on wood or bark ... *Teloschistes chysophthalmus*
4. Thallus grey, black or dark olive green, on rock or soil 5
5. Thallus grey, of anastomosing cylindrical lobes .... *Aspicilia calcarea*
5. Thallus black or dark olive green, the lobes not anastomosing 6
    6. Thallus of cylindrical lobules or flattened lobes up to 5 mm high, forming a rosette *Collema coccophorus*
    6. Thallus of cylindrical lobes up to 2 mm high, the individuals densely packed to form an apparent crust .... *Synalissa symphorea*

FOLIOSE SPECIES

7. Thallus black or dark olive green, gelatinous when wet .... *Collema coccophorus*
7. Thallus not black nor gelatinous when wet .. 8
    8. Thallus bright yellow, gold or orange 9
    8. Thallus olive, grey, blue or yellow-green 11
9. Thallus of minute, flattened, eciliate lobes (less than 1 mm broad), upper cortex K— *Candelaria concolor*
9. Thallus of broader lobes, sometimes ciliate, upper cortex K+ burgundy 10
10. Lobes eciliate, appressed to the substrate *Xanthoria ectanea*
10. Lobes ciliate, ascending from the substrate *Teloschistes chrysophthalmus*
11. Upper surface yellow green 12
11. Upper surface grey, blue or olive 16
    12. Thallus rolling into a ball when dry, unrolling when wet .... *Chondropsis semiviridis*
    12. Thallus not rolling and unrolling 13
13. On soil surfaces 14
13. On rocks, wood or bark 15
    14. Thallus free on the surface, much distorted and convoluted *Parmelia convoluta*
    14. Thallus attached to the surface by rhizoids, lobes slightly convex, appressed .... *Parmelia reptans*
15. On wood or bark .... *Parmelia ferax*
15. On rocks .... *Parmelia* cf. *lineola*
    16. Thallus olive 17
    16. Thallus blue or grey 18
17. Lobes 1 mm broad or less .... *Physciopsis syncolla*
17. Lobes more than 1 mm broad .... *Parmelia pulla*
    18. Lobes more than 3 mm broad .... *Parmelia subalbicans*
    18. Lobes less than 2 mm broad 19
19. Lobes with marginal soralia .... *Physcia albicans*
19. Lobes esorediate 20
    20. Medulla K+ yellow .... *Physcia alba*
    20. Medulla K— .... *Physcia stellaris*

SQUAMULOSE SPECIES

21. Phycobiont blue-green 22
21. Phycobiont green 23
    22. Squamules elongate, margins granular but not thickened, forming a rosette .... *Heppia lutosa*
    22. Squamules ovoid or crenate, margins smooth, thickened, not forming a rosette *Heppia polyspora*

23. Squamules orange to red, often with a white margin … *Lecidea decipiens*
23. Squamules brown, black, grey-green or grey … 24
    24. Squamules thin, pale grey-green, the margins curling up when dry … *Cladonia* squamules
    24. Squamules thicker, brown, black or grey, the margins not curling up when dry … 25
25. Asci in perithecia immersed in the thallus 26
25. Asci in apothecia sessile on the thallus … 28
    26. Spores muriform, algae in the hymenium *Endocarpon pusillum*
    26. Spores not septate, algae absent from the hymenium … 27
27. On soil, squamules brown 2-3 mm across *Dermatocarpon lachneum*
27. On rock, squamules black less than 1 mm across *Dermatocarpon compactum*
    28. Squamules pale grey or brown, epruinose, the upper surface deeply cracked, giving a crystalline appearance, apothecia small in relation to the squamules … *Lecidea crystallifera*
    28. Squamules dark grey or black, often pruinose, the upper surface shallowly cracked, apothecia large in relation to the squamules … *Toninia coeruleonigricans*

CRUSTOSE SPECIES

29. Thallus or apothecia yellow or orange 30
29. Thallus and apothecia devoid of orange or yellow coloration … 34
    30. Thallus with small but distinct marginal lobes … 31
    30. Thallus without distinct marginal lobes or thallus absent … 32
31. Thallus smooth, orange to orange brown *Caloplaca murorum*
31. Thallus mealy, very pale yellow when dry becoming bright yellow when wet … *Fulgensia subbracteata*
    32. On rocks or soil, spores more than 64 per ascus … *Acarospora schleicheri*
    32. On wood, spores 8 per ascus … 33
33. Apothecia bright yellow, thallus absent or only a prothallus present … *Candelariella antennaria*
33. Apothecia dull orange, thallus of greyish areoles … *Bombyliospora domingense* var. *aurantiaca*
    34. Crust black, of minute squamules or minute fruticose individuals closely packed … 35
    34. Crust white to brown, sometimes areolate or granular, but not squamulose or fruticose individuals … 36
35. Thallus gelatinous when wet, individuals minutely fruticose about 0.1 mm diameter; asci in apothecia … *Synalissa symphorea*
35. Thallus not gelatinous when wet, individuals squamulose, asci in perithecia … *Dermatocarpon compactum*
    36. Spores 64 or more per ascus … 37
    36. Spores less than 16 per ascus … 38
37. Thallus brown, without marginal lobes, usually one apothecium per areole, on rock *Acarospora cervina*
37. Thallus grey, with distinct marginal lobes, apothecia usually several per areole, on soil and rock … *Acarospora smaragdula*
    38. Asci in perithecia, thallus virtually indistinguishable from the substrate … *Verrucaria* cf. *calciseda*
    38. Asci in apothecia, thallus quite distinct … 39
39. Apothecia immersed or adnate on the thallus … 40
39. Apothecia sessile on the thallus … 42
    40. Apothecia 3 mm or more in diameter … *Diploschistes ocellatus*
    40. Apothecia less than 2 mm diameter 41
41. Spores black or brown … *Diploschistes scruposus*
41. Spores hyaline … *Aspicilia calcarea*
    42. Spores black or brown … *Buellia subalbula*
    42. Spores hyaline … *Lecanora sphaerospora*

II. DESCRIPTIONS OF THE SPECIES

Acarospora cervina (Ach.) Mass. 1852:28.

Lecanora cervina Ach. 1814:188.

Thallus of small (1–2 mm broad) brown squamules with white margins, usually scattered but occasionally compacted. Apothecia immersed, pruinose, usually one per squamule. Spores many (>100) per ascus, non-septate.

Occasional on small calcareous pebbles. Specimen examined*: *Rogers*, 24.iii.1969.

Acarospora schleicheri (Ach.) Mass. 1852:27.

Urceolaria schleicheri Ach. 1810:332.

Thallus of minute (<1 mm diam.) sulphur yellow squamules, usually scattered, but sometimes becoming areolate. Apothecia immersed, one per squamule. Spores many (>100) per ascus, non-septate.

Rare, found only on silicious pebbles at Koonamore, but may also occur on compacted soil. Specimen examined: *Womersley*, 6.vi.1946.

Acarospora smaragdula (Wahlenb.) Mass. 1852:29.

Endocarpon smaragdulum Wahlenb. apud Ach 1803:29.

Thallus of small (1–2 mm in diam.), chalky white to brown squamules, forming plaques up to 2 cm in diam. Apothecia immersed, sometimes pruinose, one to five per squamule, a well developed exciple concolourous with the thallus. Spores many (>100) per ascus, non-septate.

Common on calcareous soil surfaces, often with *Diploschistes scruposus*. Specimens examined: *Barnard*, 12.xii.1927; Anon., May 1943; *Eardley*, June 1946; *Rogers*, 20.xi.1967.

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* Specimens cited as *Rogers* are in the author's private herbarium, all others in the herbarium of the University of Adelaide (*ADU*).

Aspicilia calcarea (L.) Mudd 1861:161.

Lichen calcareus L. 1753:1140.

Thallus white to greyish, either crustose or more or less fruticose; if crustose then areolate, if fruticose the lobes cylindrical, pseudocyphellate, anastomosing, 0.5-1.0 mm thick. Apothecia known only on crustose forms, immersed with a crenate margin, the disc densely pruinose. Spores 2-8 per ascus, non-septate.

Virtually any calcareous pebble on the reserve has the crustose form on it somewhere. The fruticose form is less common but occurs most often at the junction of pebbles and soil. Both forms also occur on calcareous soil alone. Numerous intergrades have been observed on the reserve. Specimens examined: Anon., May 1948; *Rogers*, 8.xii.1967.

Bombyliospora domingensis (Pers.) Zahlbr. var. *aurantiaca* Zahlbr., in Magnusson & Zahlbruckner 1945:32.

Thallus an obscure yellow-grey crust covering extensive areas on old wood. Apothecia orange, <1 mm in diam., very numerous, sessile, convex. Spores 8 per ascus, usually 5 septate.

Very common on dead, decorticate twigs, especially of *Cassia* spp. and *Eremophila* spp., where entire branches may be covered. Specimens examined: *Barnard*, 12.xii.1927; *Rogers*, 5.xi.1967.

Buellia subalbula (Nyl.) Muell. 1880:79.

Lecidea subalbula Nyl. 1868:516.

Thallus a white, areolate crust forming patches up to 5 cm in diam. Apothecia black, up to 1 mm in diam., numerous, sessile, convex, with a false white exciple disappearing early in development. Spores 8 per ascus, black, septate.

Very common on calcareous pebbles. Specimens examined: Anon., June 1946; Anon., May 1948; *Rogers*, 24.iii.1969.

Although the material has not been examined it is likely that specimens determined at Kew as *Rinodina diffractella* Muell. for Osborn, Wood & Paltridge (1935), was identical with the material here called *B. subalbula*. The two species are very similar according to their descriptions, each having a thalloid exciple when young, which disappears with age, hence confusion about the appropriate genus for the material. The species differ, however, in that there are slightly larger spores (12–12.6 x 5.7–6 μm) in *B. subalbula* than in *R. diffractella* (7–10 x 4–4.5 μm).

Caloplaca murorum (Hoffm.) Th. Fr. 1871:170.

Lichen murorum Hoffm. 1784:63.

Thallus crustose, areolate at the centre, sometimes with distinct marginal lobes 1–2 mm long, or the thallus of verrucose squamules, light orange-brown. Apothecia sessile, the disc orange to rusty brown, the exciple concolourous with the thallus. Spores 8 per ascus, polari-bilocular.

On siliceous rocks, not common. Specimens examined: *Womersley*, 6.vi.1946; Anon., May 1948.

Candelaria concolor (Dicks.) Stein in Cohn 1879: 84.

Lichen concolor Dicks. 1793:18.

Thallus yellow, minutely foliose, lobes 0.1–0.5 mm broad, c. 1 mm. long, forming rosettes or spreading irregularly, the margins irregularly granular. Fertile specimens have not been found in South Australia. According to Osborn, Wood & Paltridge (1935) this species is uncommon, but forms extensive patches on twigs. This species has not been relocated by recent collectors despite careful examination of the area.

Record: *Barnard*, 12.xii.1927 (not seen).

Candelariella antennaria Ras. 1939:137

Thallus missing. Apothecia sessile on the substrate, the disc and exciple greenish yellow. Spores 8 per ascus, non-septate. Paraphyses septate, sometimes branched.

A common but obscure species occurring admixed with *Bombyliospora domingense* var. *aurantiaca* on wood. Specimens examined: *Rogers*, 22.ix.1969; *Rogers*, 14.i.1971.

†*Chondropsis semiviridis* (F. Muell. ex Nyl.) Nyl. ex Cromb. 1880:397.

Parmeliopsis semiviridis F. Muell ex Nyl. 1885: 57.

Thallus foliose, green above, pale yellow-brown below, lobes 3–5 mm broad, strictly dichotomously branched, rolling into a ball when dry, lying flat when wet. Apothecia extremely rare, sessile, disc brown, exciple concolourous with the thallus. Spores 8, non-septate.

At Koonamore this species has lobes approaching 5 mm wide, possibly the broadest form found in Australia. Common on soil surfaces in scattered patches. Barnard apparently did not find this distinctive species on the reserve in 1927. Specimens examined: Anon., May 1942; *Burrell*, ?1944; *Rogers*, 29.xi.1968.

Cladonia sp.

Scattered squamules grey green above, white below, without podetial development.

Very rare on shaded soil under *Heterodendrum*. Specimen examined: *Rogers*, 8.xii.1967.

Collema coccophorum Tuck. 1862:385.

Thallus a rosette of deep olive to black crenate lobes 2–3 mm long, much convoluted, sometimes with cylindrical lobules, gelatinous when wet. Apothecia not common, about 1 mm broad, the disc and exciple concolorous with the thallus. Spores 8 per ascus, once septate

Infrequent, on calcareous or sandy soil. Specimen examined: *Rogers*, 8.xii.1967.

Dermatocarpon compactum (Mass.) Lettau 1912: 52.

Placidium compactum Mass. 1856:32.

Thallus of minute (0.2–0.3 mm) squamules packed together forming a dark brown plaque. Perithecia opening by pores, spores 8 per ascus, non-septate.

Common, but inconspicuous on calcareous pebbles. Specimen examined: *Rogers*, 9.ix.1969.

Dermatocarpon lachneum (Ach.) Smith 1911:270.

Lichen lachneus Ach. 1798:140.

Thallus of tan to dark brown squamules 1–2 mm across, initially ovate, entire, plane to slightly convex but becoming crenate and distorted with age. The rhizoids of this species remain fine, permitting it to be distinguished from the coarse rhizined *Endocarpon pusillum*. Perithecia opening by pores. Spores 8 per ascus, non-septate.

Common and conspicuous on calcareous soil, superficially like *Endocarpon pusillum*. Specimens examined: *Barnard*, 12.xii.1927: *Rogers*, 20.xi.1967.

Diploschistes ocellatus (Vill.) Norm. 1853:232.

Lichen ocellatus Vill. 1789:988.

Thallus an extensive white crust of smooth, chalky areoles up to 1 mm broad. Apothecia poorly developed or absent on the reserve, but sessile with a thick thalloid exciple and a black, flat disc. Spores 8 per ascus, black, muriform.

A rare, but quite striking lichen on calcareous soil in deeply shaded sites. Specimens examined: Anon., May 1942; *Eardley*, June 1946; *Rogers*, 2.v.1969.

Diploschistes scruposus (Schreb.) Norm. 1853:232.

Lichen scruposus Schreb. 1771:133.

Thallus an extensive floury grey or white crust with areoles <1 mm across. Apothecia very common, immersed, c. 0.5 mm in diam., the disc black. Spores 8 per ascus, black, muriform.

Common on calcareous soils. Specimens examined: *Barnard*, 12.xii.1927: *Eardley*, June 1946: *Rogers*, 20.xi.1967.

Endocarpon pusillum Hedw. 1789:56.

Thallus of brown, usually crenate, squamules with extensive rhizoidal and stolon development below. Perithecia immersed, opening by a black pore on the upper surface. Spores usually 2 per ascus, black, muriform.

Common on calcareous soils and firm sands, easily confused with *Dermatocarpon lachneum*, Specimen examined: *Rogers*, 20.xi.1967.

Fulgensia subbracteata (Nyl.) Poelt 1961, no. 137.

Lecanora subbracteata Nyl. 1883:534.

Thallus crustose, somewhat granular, very pale yellow when dry, bright yellow when wet, the margins showing minute lobes. Apothecia adnate, rare, the exciple colored like the disc, deep rusty brown. Spores 8 per ascus, non-septate.

Rare, on sandy and calcareous soils. Specimen examined: *Rogers*, 2.v.1969.

Heppia lutosa (Ach.) Nyl. 1885:45.

Collema lutosum Ach. 1814:309.

Thallus squamulose grey-green to olive, squamules forming small rosettes (5 mm in diam.) the margins granular. Apothecia immersed, usually one per squamule, disc red. Spores 8 per ascus, non-septate.

Common on calcareous soils. Specimen examined: *Rogers*, 4.vii.1969.

Heppia polyspora Tuck. 1882:115.

Thallus squamulose, tan to olive, squamules 1–4 mm in diam., round or crenate with a thickened margin. Apothecia usually one per squamule, immersed, the disc red. Spores many (>32) per ascus, non-septate.

Common, but very obscure on sandy and calcareous soils. Specimen examined: *Rogers*, 4.vii.1969.

**Lecanora sphaerospora* Muell. 1892:196.

Thallus crustose, white to grey, areolate, areoles up to 1 mm in diam. Apothecia sessile with a white margin, usually crenate, the disc grey, at first flat then becoming markedly convex. Spores 8 per ascus, non-septate.

Very common on calcareous pebbles. Specimens examined: *Rogers*, 8.xii.1967; *Rogers*, 30.vi.1969.

**Lecidea crystallifera* Tayl. 1847:148.

Thallus of grey-brown squamules 1–3 mm broad, entire to crenate or somewhat lacerate, the upper surface sculptured into a mass of pyramid-like solid angles, giving it a crystalline appearance, Apothecia not found at Koonamore, but sessile, flat to convex, the disc dark grey to black. Spores 8 per ascus, non-septate.

Very common on calcareous soils. Specimen examined: *Rogers*, 20.xi.1967,

Lecidea decipiens (Hoffm.) Ach. 1803:80

Psora decipiens Hoffm. 1794:68.

Thallus of pink squamules 1–7 mm broad, the margins or the whole thallus white pruinose, the squamules entire to crenate or lacerate, often markedly concave at the centre with deflexed margins. Apothecia rare, marginal, sessile, the disc black, markedly convex. Spores 8 per ascus, non-septate.

One of the most common and obvious lichens on soil in the reserve. Specimens examined: *Barnard*, 12.xii.1927; Anon., 1.ix.1932; *Eardley*, June 1946; *Rogers*, 20.xi.1967.

**Parmelia convoluta* Kremph. 1880:337.

Thallus yellow-green above, foliose; the lower surface light brown, sparsely rhizinate, usually concealed within the rolled and convoluted lobes, the older lobes often rugose above, up to 5 mm broad. Apothecia very rare, sessile, the disc brown, the margin yellow green.

This species is separated from the very similar *P. australiense* by the presence of salicinic acid (medulla K+ yellow becoming red) whereas *P. australiense* lacks salicinic acid and is therefore K— (Kurokawa 1969). Mixed populations have been found in some places, but all Koonamore material examined is *P. convoluta*.

Common, lying free on the soil surface. Specimens examined: *Barnard*, 12.xii.1927; Anon., May 1942; *Rogers* 20.xi.1967; *Rogers*, 17.v.1969.

**Parmelia ferax* Muell. 1886:257.

Thallus yellow-green above, foliose, the lower surface black, sparsely rhizinate, lobes 0.5–1.5 mm broad, margins crenate, branching irregular. Apothecia common, margin colored like the thallus, the disc brown. Spores 8 per ascus, non-septate.

Parmelia ferax may be confused with *P. rutidota*, but it has a more rugose thallus, has no K+ acids, and produces physodalic not protocetraric acid (Kurokawa 1967).

Common on dead twigs and bark of trees. Specimens examined; *Barnard*, 12.xii.1927; Anon., May 1942; *Womersley*, 6.vi.1946; *Rogers*, 20.xi.1967.

Parmelia cf. *lineola* Berry 1941:77.

Thallus yellow-green above, foliose, the lower surface pale to dark brown, closely adnate to the substrate, lobes 2–5 mm broad, sub-dichotomous, the upper surface becoming rugose and cracking. Apothecia not seen.

The subgenus *Xanthoparmelia* to which this material belongs is complex and poorly understood. Absence of isidia and soredia, and presence of salicinic acid, place this species close to *P. lineola*, a western North American species.

Rare on quartzitic pebbles. Specimens examined: *Womersley*, 6.vi.1946; Anon., May 1948; *Rogers*, 21.xi.1967.

Parmelia pulla (Schreb.) Ach. 1814:206

Lichen pullus Schreb. 1771:131.

Thallus dark olive or brown above, foliose, the lower surface dark, lobes 1.5–3.0 mm broad, sparsely rhizinate, the margins crenate, branching irregular. Apothecia rare, the margin concolorous with the thallus, disc dark brown. Spores 8 per ascus, non-septate.

Rare, on deeply shaded calcareous soils and rocks. Specimens examined: *Womersley*, 6.vi.1946; Anon., May 1948.

†*Parmelia reptans* Kurok. in Baker *et al.* 1973:137.

Thallus yellow-green above, foliose, forming rosettes 1–3 cm in diam., more or less dichotomously branched, lobes linear, 0.7–2.0 mm broad, lower surface pale brown with long black rhizoids. Apothecia unknown.

Very similar to *P. amphixantha* Muell., however *P. reptans* tends to have wider lobes (*P. amphixantha* up to 1 mm) and has fumaprotocetraric, succinprotocetraric and usnic acids (Pd— yellow turning crimson) whereas *P. amphixantha* has norstictic, stictic and usnic acids (Pd+ yellow) (Baker *et al.* 1973).

On soil, usually in deep shade. Specimens examined: *Barnard*, 12.xii.1927; *Eardley*, June, 1946.

**Parmelia subalbicans* Stirt. 1877-78:254.

Thallus grey-blue, foliose, light brown below, lobes 1.5–4.0 mm broad, sparsely rhizinate, the margins irregular, branching sub-dichotomous. Apothecia common, the margin concolorous with the thallus, disc brown. Spores 8 per ascus, non-septate.

Very common on bark and dead twigs, usually with *P. ferax*. Specimens examined: Anon., May 1942; *Womersley*, 6.vi.1946; *Rogers*, 20.ix.1967.

Physcia alba (Fée) Muell. 1887:12.

Parmelia alba Fée 1824:125.

Thallus grey-blue, foliose, forming distinct rosettes, closely adnate, lobes up to 3 mm broad, without soredia or isidia, pale below. Apothecia common, the margin concolorous with the thallus, disc brown, usually pruinose. Spores 8 per ascus, once septate, brown. Cortex K+ yellow, Pd+ yellow. Medulla K+ yellow, Pd+ yellow.

Rare on the bark of trees. Easily confused with *P. stellaris* in the field. Specimens examined: Anon., May 1948.

Physcia albicans (Pers.) Thoms. 1963:88.

Parmelia albicans Pers. 1811:17.

Thallus blue to somewhat olive, foliose, forming distinct rosettes, closely adnate, lobes 1–4 mm broad, contiguous to the margin with ascendent labriform soralia; pale below, becoming dark. Apothecia rare, spores 8 per ascus, once septate, brown. Cortex K+ yellow becoming red, Pd—; medulla K+ yellow becoming red, Pd—.

Rare, found on the bark of *Casuarina cristata*. Specimens examined: Anon., May 1948; *Rogers*, 20.xi.1967.

Physcia stellaris (Ach.) Nyl. 1856:307.

Parmelia stellaris Ach. 1803:209.

Thallus blue-grey, foliose, forming rosettes or extended patches, not closely appressed, lobes 0.5–1.5 mm broad, without isidia or soredia, pale below. Apothecia common, the margin coloured like the thallus, the disc brown, often bluish pruinose. Spores 8 per ascus, once septate, brown. Cortex K+ yellow, Pd—; medulla K—, Pd+ yellow brown.

On the bark of trees, not common. Specimen examined: *Rogers*, 20.xi.1967.

Physciopsis syncolla (Tuck.) Poelt 1965:30.

Physcia syncolla Tuck. in Nyl. 1858:428

Thallus brown, foliose, forming extensive patches, closely adnate, lobes about 1 mm broad, dark below. Apothecia up to 1.5 mm broad, the margin concolorous with the thallus, the disc brown, sometimes pruinose. Spores 8 per ascus, once septate, brown.

Obscure, but in extensive patches on the bark of *Acacia aneura*. Specimen examined: *Rogers*, 20.xi.1967.

Synalissa symphorea (Ach.) Nyl. 1856:264.

Lichen symphoreus Ach. 1798:135.

Thallus dark olive-green to black, minutely fruticose, packed into patches up to 3 cm in diam., individual thalli 1 mm high, less than 1 mm in diam., branched, the lobes tightly packed, somewhat nodulate. Apothecia up to 0.2 mm in diam., more or less immersed in the tips of the upright lobes. Spores usually 8 per ascus, non-septate.

A very inconspicuous species on calcareous soil. Specimen examined: *Rogers*, 20.xi.1967.

Teloschistes chrysophthalmus (L.) Th. Fr. 1861:51.

Lichen chrysophthalmus L. 1771:311.

Thallus gold to grey, foliose, forming a shrubby clump, the lobes 0.5–2.5 mm broad with long marginal fibrils, with neither isidia nor soredia. Apothecia common, pedicellate, up to 6 mm in diam., with fibrils on the margin, concolorous with the thallus. Spores 8 per ascus, septate.

On twigs of bushes and bark of trees. Specimens examined: *Barnard*, 12.xii.1927; Anon., May 1942.

Toninia coeruleonigricans (Lightf.) Th. Fr. 1871: 336.

Lichen coeruleonigricans Lightf. 1777:805

Thallus of dark grey, small (1 mm in diam.) inflated, reticulately cracked, usually blue-pruinose squamules. Apothecia often larger than the squamules, the margin and the disc both black, often pruinose. Spores 8 per ascus, fusiform, once septate.

Common on calcareous and sandy soils. Specimens examined: *Barnard*, 12.xii.1927; Anon., May 1942; *Womersley*, 6.vi.1946; Anon., May 1948; *Rogers*, 30.iv.1969.

Verrucaria aff. *calciseda* DC. in M. Lam. & DC. 1805:317.

Thallus a whitish crust, almost indistinguishable from the substrate, smooth, somewhat powdery. Perithecia immersed in pits in the thallus, showing as sunken black spots barely 0.1 mm in diam. Spores 8 per ascus, 24 μm by 12 μm, non-septate, hyaline.

An extremely obscure species on calcareous pebbles, appearing to be a pitted limestone surface unless carefully examined. Specimen examined: Anon., June 1946.

Xanthoria ectanea (Ach.) Räs. ex R. Filson 1969: 83.

Parmelia parietina var. *ectanea* Ach. 1810:464.

Thallus forming a golden rosette, foliose, adnate to the substrate, the lobes smooth, up to 2.5 mm broad, the margin raised then deflexed. Apothecia common, about 2 mm in diam. Spores 8 per ascus, septate.

Rare on twigs of *Lycium australe*. Specimens examined: Anon., May 1942; *Rogers*, 30.iv.1969.

SALT CRUST DISTRIBUTION AND LAKE BED CONDITIONS IN SOUTHERN AREAS OF LAKE EYRE NORTH

*BY J. A. DULHUNTY**

Summary

DULHUNTY, J. A. (1974).-Salt crust distribution and lake bed conditions in southern areas of Lake Eyre North. *Trans.* R. *Soc. S. Aust* **98**(3), 125-133, 31 August, 1974.

Investigations and surveys of salt crusts and the lake bed conditions in southern areas of Lake Eyre North were carried out during 1972-73, using specially adapted transport and equipment. The nature and extent of salt crusts in Jackboot and Belt Bays are described. An east-west belt of watery silt with little or no salt crust, separating the main southern salt crusts from northern red-clay surfaces, is described and termed the Slush Zone. Progressive changes in crust thickness and distribution of salt, over a period of 43 years, are described in Madigan Gulf and their significance is discussed in relation to early unrecorded floodings of Lake Eyre and possible instability of the lake bed.

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Investigations and surveys of salt crusts and the lake bed conditions in southern areas of Lake Eyre North were carried out during 1972-73, using specially adapted transport and equipment. The nature and extent of salt crusts in Jackboot and Belt Bays are described. An east-west belt of watery silt with little or no salt crust, separating the main southern salt crusts from northern red-clay surfaces, is described and termed the Slush Zone. Progressive changes in crust thickness and distribution of salt, over a period of 43 years, are described in Madigan Gulf and their significance is discussed in relation to early unrecorded floodings of Lake Eyre and possible instability of the lake bed.

Introduction

Lake Eyre North is a large salina approximately 145 km long, from north to south, and 65 km wide, connected by a narrow channel at its southern end to a relatively small salina known as Lake Eyre South. For general geographical and geological settings of the Lake Eyre Basin, reference should be made to Johns (1963), Wopfner & Twidale (1967) and Williams (1973). The investigations described here are concerned with Lake Eyre North, and principally its southern half including Madigan Gulf, Jackboot Bay and Belt Bay (Fig. 1).

The lake bed, which lies between 10 and 15 m below sea level (Bonython 1955, p. 69; 1956; 1960; Wopfner & Twidale 1967), is gently tilted from north to south, falling some 4 m in 120 km from the northern shoreline to the lowest areas in Madigan Gulf and Belt Bay. When flood waters from the Northern Territory and Western Queensland reach the lake, they enter at its northern end and north-eastern side, and flow south across the lake bed to the southern bays where salt is dissolved, fine silt deposited, and salt redeposited on evaporation of the water (Bonython 1956). This has resulted in the occurrence of crusts overlying Recent sediments in southern areas of the lake and a red clay surface over its slightly elevated northern half from which salt is periodically transferred to the lower southern half. Small quantities of water, insufficient to cover the whole lake bed or dissolve all the salt, enter the lake and reach the southern bays at relatively frequent intervals of 1 to 10 years. Major floodings, covering the lake bed completely and dissolving all the salt crust, would appear to occur at widely separated intervals of the order of 50 years (Bonython & Mason 1953). This occurred in 1949-50 and was well documented (Bonython & Mason 1953; Bonython 1955; Mason 1955).

Observations and investigations of the salt crust in Madigan Gulf were first made by Madigan (1930) and later by Bonython (1956) and the Geological Survey of the South Australian Department of Mines (Johns 1963). In 1963 Bonython compiled an isopachytes map of salt crust thickness in Madigan Gulf (pers. comm., C. W. Bonython, Adelaide, S.A.). By 1963 reasonably comprehensive information had been recorded about the occurrence of salt in Madigan Gulf. The existence of salt crust in Belt and Jackboot Bays had been noted (Bonython 1956; Johns 1963) but no quantitative data had been recorded about its thickness or extent.

In 1972-73 the present author, assisted and accompanied by his wife on all occasions, carried out surveys of the distribution of salt crust and variation in its thickness in Belt and

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Jackboot Bays, and lake bed conditions were investigated between shorelines and crusts, and between crusts and northern red-clay muds. Surveys were also carried out in Madigan Gulf to investigate lake bed conditions along the northern limits of salt crust, and also to obtain evidence of any changes in salt distribution which may have occurred since measurements were first made in 1929. Results of these surveys and investigations are presented here.

Lake Bed Surveys

Conditions on the so-called "dry" lake bed, or lake bed without water cover, vary widely from place to place. Damp or wet marginal muds along southern shorelines are usually sufficiently firm to walk on, but boggy for conventional and four-wheel drive motor vehicles, and in places too soft for motor bicycles with normal-width tyres. Salt crusts in the southern bays overlie slushy mud. The strength of the crust varies from place to place, depending largely on bulk density. In general, however, crusts less than 2.5 cm in thickness may not support persons on foot or motor bicycles, and anything breaking through will sink into underlying slush. Crusts over 10 cm in thickness will support light vehicles and those over 20 cm will support heavier vehicles such as medium-weight trucks.

To carry out comprehensive surveys on the lake bed, it was necessary to have a means of transport for persons and equipment which would travel over as wide a range of surface conditions as possible, at speeds up to about 40 km.p.h. Honda "ATC 90" motor tricycles, weighing about 90 kg each and equipped with balloon tyres 34 cm wide and 68 cm in diameter, were successfully used. These machines, towing light equipment trailers, would each carry one person over surfaces on which it was not possible to walk. When they broke through into watery slush the buoyancy of the three balloon tyres kept the machines afloat and facilitated recovery from otherwise hopelessly bogged conditions

Maps used for the surveys were based on the 1:250,000 topographical sheet SH53-4 Ed. 1, Series R502, prepared by the Commonwealth Division of National Mapping from aerial photography. Aerial photo-mosaics prepared by the South Australian Department of Lands were also used for mapping and photo-interpretation in the investigation of lake bed conditions. Distances on the lake bed were measured by cyclometers attached to the wheels of the tricycles. Magnetic bearings were established by surveying compasses, and lines along bearings were marked by black flags at intervals of 1 mile (1.609 km). Salt thickness was determined by boring an 8 mm diameter hole through the crust, with an auger and brace, then inserting a metal rod with a right angle hook at its end, hooking the base of the crust, and measuring its thickness. Where salt crust was absent, or less than 1 cm in thickness, the condition of the lake bed was assessed as "competent" where it would support a standing person, or as "incompetent" where a person attempting to stand would sink into fluid mud or watery silt.

Before commencing lake bed surveys, broad reconnaissances were carried out over the three southern bays of the lake, and for 24 km north across the centre of the lake from Hambidge Point. Survey lines, most likely to yield significant data, were first selected on the map across Madigan Gulf, Jackboot Bay and Belt Bay. The selected survey lines were then established on the lake, and salt crust thicknesses and lake bed conditions were measured and assessed at numerous points along each line. After consideration of results, additional lines and points were selected for further surveys. In some places levelling was carried out along survey lines, as the first part of a comprehensive level survey, as yet incomplete. Aerial photo-interpretation, based on ground control established during lake bed surveys, was carried out and followed by a low altitude aerial reconnaissance.

Results and Conclusions

Results of surveys and investigations of the lake bed are illustrated in Fig. 1. Thicknesses of salt along survey lines, and at isolated points, are shown in centimetres at points of measurement. Many more measurements were made along survey lines than could be shown in Fig. 1. Areas of competent mud are shown between shorelines and salt crust sheets in the three southern bays. Areas of incompetent silt or slush are shown extending east and west across the lake between the southern salt sheets and the red clay surface to the north.

Salt Crusts of Jackboot and Belt Bays

Well developed salt crusts were found in both Jackboot and Belt Bays. The thickness and extent of salt in each bay at the time of the survey during the winter of 1972, is illustrated in Fig. 1. The crusts were separated from the shore by zones of shoreline mud, from 0.1–2 km wide, which were moist and

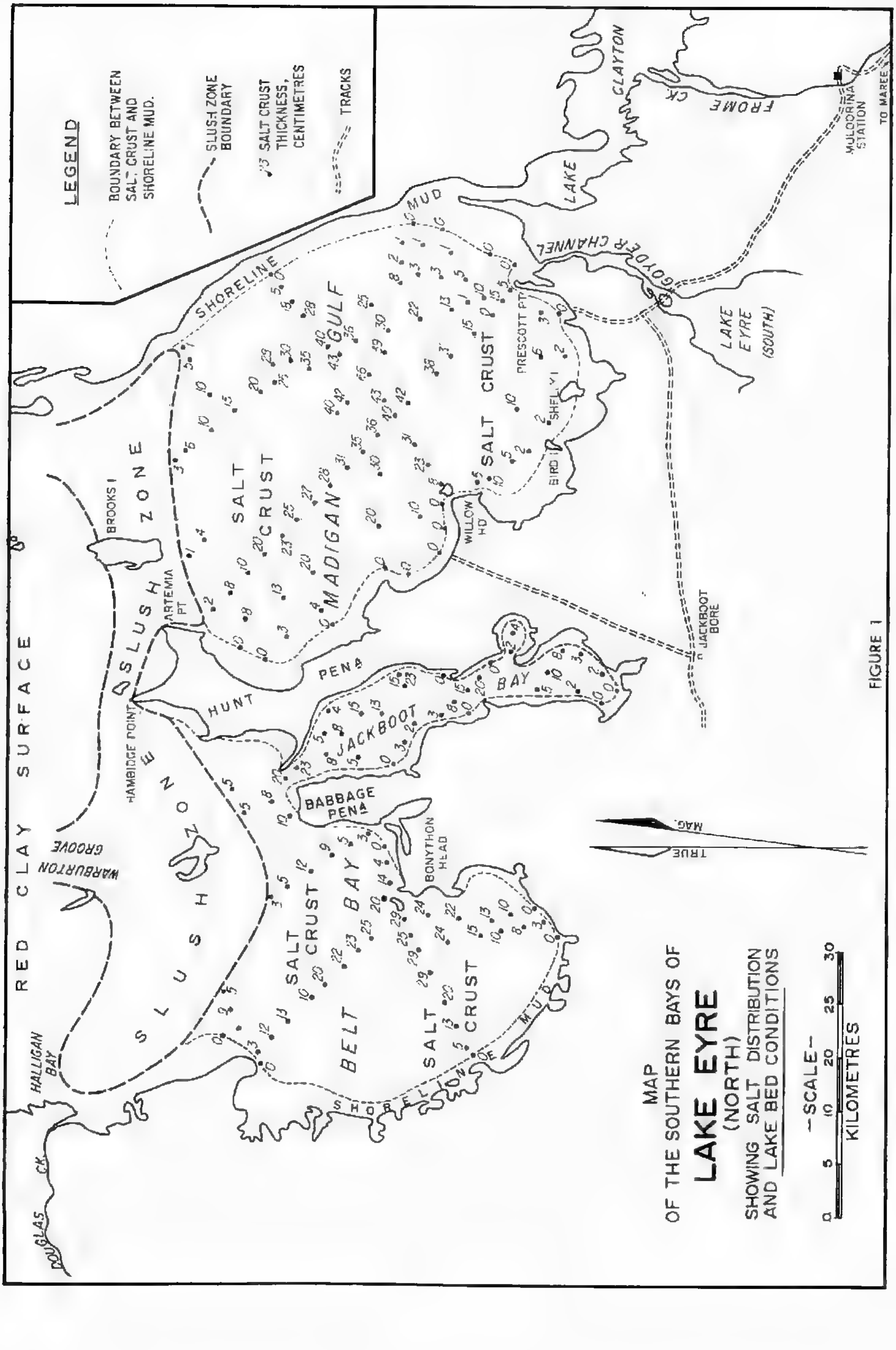
MAP
OF THE SOUTHERN BAYS OF
LAKE EYRE
(NORTH)
SHOWING SALT DISTRIBUTION
AND LAKE BED CONDITIONS
—SCALE—
0 5 10 20 25 30
KILOMETRES
LEGEND
BOUNDARY BETWEEN SALT CRUST AND SHORELINE MUD.
SLUSH ZONE BOUNDARY
13 SALT CRUST THICKNESS, CENTIMETRES
TRACKS
RED CLAY SURFACE
SLUSH ZONE
SALT CRUST
MADIGAN GULF
SHORELINE
MUD
LAKE CLAYTON
FROME CK.
MULOORINA STATION
TO MAREE
GOYDER CHANNEL
LAKE EYRE (SOUTH)
PRESCOTT PT
SHELLY I
BIRD I
WILLOW HD
JACKBOOT BORE
JACKBOOT BAY
HUNT PENA
ARTEMIA PT
BROOKS I
HAMBIDGE POINT
BABBAGE PENA
BONYTHON HEAD
BELT BAY
WARBURTON GROOVE
HALLIGAN BAY
DOUGLAS CK
TRUE
MAG.

FIGURE 1

soft, somewhat sandy, mostly competent to walk on but boggy to motor vehicles. Salt crust was continuous round the northern end of Babbage Peninsula. The greatest thicknesses of salt measured were 29 cm in Belt Bay and 23 cm in Jackboot Bay. In both bays the maximum thickness of salt occurred close to, and about midway along, their eastern shores.

In central areas of the salt sheets, thickness changes were mostly very gradual, but at some places sudden changes occurred. Along a bearing of 307° magnetic from Bonython Head to the northwest head of Belt Bay (Fig. 1), salt crust thickness decreased gradually from 29 cm near Bonython Head to 20 cm near the centre of the bay, over a distance of 10 km. Then it decreased suddenly to 10 cm over approximately 1.5 km (between the thickness points of 20 and 10 cm shown in Fig. 1), following which it increased gradually to 13 cm, then remained between 12–13 cm for 5 km, and finally thinned rapidly, as usual, near the shoreline. A level survey along the same line across the centre of the bay showed a gradual uniform rise on the upper surface of the salt, indicating that the sudden thickness changes were step-like undulation in the lake bed at the base of the crust. Similar, but less pronounced evidence of sub-crustal steps in the lake bed was found in Jackboot Bay and Madigan Gulf. The lower portions of the salt crust, present in 1972, had probably formed during 1952 by evaporation of the 1949-50 flood waters, and remained unaffected by subsequent minor fillings which dissolved and redeposited only the upper portions of the salt crust. From this it would seem likely that the step-like undulations were formed by scouring of channels or areas in the lake bed after solution of the whole crust in 1950 and 1951, and before its subsequent redeposition in 1952.

The Slush Zone

To the north of Jackboot and Belt Bays between Hunt Peninsula and the western shore, and in the northern areas of Madigan Gulf between Hunt Peninsula and the eastern shore, salt crusts thin out as they pass to the north, and underlying silts consist of incompetent slush. In these areas salt crusts are of low strength. Light motor vehicles and heavy animals such as camel break through crusts of 7–8 cm; persons on foot or conventional motor cycles break through crusts of 2–5 cm, and motor tricycles with balloon tyres, as used in the present surveys, break through crusts of 1–3 cm. Anything breaking through the thin crust sinks into underlying slush and becomes bogged. Wild camels, which had broken through 7 cm of salt, were found 8 km east of Hunt Peninsula in the north-western area of Madigan Gulf. They had floundered or struggled for only 9 m before dying of exhaustion earlier in 1972, to be entombed in Recent sediments and preserved as future fossils under conditions similar to those which trapped and preserved the now extinct diprotodons whose remains are found in Pleistocene sediments around Lake Eyre (Stirton, Tedford & Miller 1961). Persons sinking into the slush can neither swim nor wade, and must crawl or roll over crumbling salt and mud to reach crust strong enough to support their weight when standing. In some places the crust is only 0.5–1 cm thick, whilst in others it is little more than an encrustation of 1 mm or less which is dissolved and removed by each fall of rain, but built up again between rainfalls by evaporation of brine rising through the silt.

Areas described above are the most treacherous and difficult to negotiate in the whole of Lake Eyre. As far as could be ascertained from surface exploration and aerial photo-interpretation, the areas extend right across the lake for about 65 km, on an east-west alignment through the north head of Hunt Peninsula. They form a zone from about 7–12 km wide, for which the term "Slush Zone" is proposed, as illustrated in Fig. 1. It encloses practically all of Brooks Island, the north head of Hunt Peninsula including Hambidge and Artemia Points, and a large island situated 11 km west of Hunt Peninsula. It is almost impossible to travel into the Slush Zone over the surface of the lake bed. Prior to the present survey, the only party to reach Brooks Island travelled by boat during the 1949-50 flood (Bonython 1955, p. 27). During the investigations of surface conditions in 1972, the lake bed from Hunt Peninsula to Brooks Island was crossed by Honda motor tricycles, travelling over 1–2 cm of crust in the Slush Zone. The crossing was perilous and succeeded only by travelling at a speed of about 35 km.p.h., as at lower speeds the machines would have sunk into the slush. A similar attempt to travel over the lake bed to the large island west of Hunt Peninsula was unsuccessful as the machines and riders broke through a crust of 1 cm or less and sank into the underlying slush. However, it was reached by boat during a minor flooding of Belt Bay in July 1973, which made possible an examination of the island and lake bed in the western Slush Zone. A permanent survey mark, consisting of 1.5 m of copper pipe driven 0.75 m into the ground, was left at an elevated place, situated 640 m in a direction 325° magnetic from the most southern point of the island. As far as is known this was the first occasion on which anyone had reached the island.

Hambidge Point

The Slush Zone, situated a little south of the geographical centre of the lake, forms a barrier to north-south travel on its bed. There is only one place at which, if conditions are suitable, it can be crossed by persons on foot or on conventional motor cycles. This is from the northern shoreline of Hunt Peninsula, where sand has been carried out into the Slush Zone by south-east to south-west winds. Bonython crossed the Slush Zone from the tip of Hambidge Point in 1970, and walked for some 20 km to a point bearing 348° magnetic from Hambidge Point, which he calculated as close to the geographical centre of the lake (pers. comm. C. Warren Bonython, 1972, Adelaide, S.A.). During the present lake bed survey, a reconnaissance was made from a point on the shoreline about 2 km south-east from Hambidge Point to true north across the Slush Zone, for 24 km over the central region of the lake.

Between Hambidge Point and a small island about 0.5 km to the north, the level of the lake bed falls slightly, by about 30 cm to a channel along which water flows round Hunt Peninsula when sufficient accumulates in either Belt Bay or Madigan Gulf to cover the lake bed as far north as Hambidge Point. The existence of such a channel, linking Belt Bay and Madigan Gulf, and the possibility of water flowing along it from one bay to the other, was first suggested by Bonython (1955, p. 8). This process was observed in operation during the winter of 1973. Water flowing down the Warburton Groove filled Belt Bay almost to Hambidge Point. When strong south-westerly winds moved the water north-east, it reached a depth of about 15 cm at the Point, and flowed east along the channel. It then spread out over a wide area north-west and west of Brooks island, communicating with Madigan Gulf only by a narrow and shallow area along the eastern side of Hunt Peninsula, south from Artemia Point. Before finding its way into Madigan Gulf, most of the water was blown back round Hambidge Point into Belt Bay by south-easterly to north-easterly winds, which usually follow soon after south-westerly winds.

The Northern Red Clay Surface

During the reconnaissance 24 km north from Hambidge Point, some information was gained about the general nature of the lake bed in central areas. North of the channel in the Slush Zone round Hambidge Point, the lake bed gradually became firmer and drier, as the wet, black, grey and green silts of the Slush Zone carrying a soft thin salt crust, were replaced by damp red or yellow-red clay, carrying in places a thin soft powdery salt, but no crust. Between 20 and 24 km north of Hambidge Point, the surface of the clay was almost dry and suncracked, with thin upturned flakes of dry clay and very little dry powdery salt.

A comprehensive and detailed study of the northern half of the lake bed remains to be accomplished; however, progressive changes to the north in the nature of the lake bed, described above, are in accord with the fact that the lake bed falls gently to the south, providing drainage into the southern bays which serve as a sump, or "geodetic centre", of 1,300,000 sq. km of internal drainage.

Salt Crusts of Madigan Gulf

Salt crust thicknesses in Madigan Gulf, measured during the winter of 1972, confirmed the occurrence of a large area of salt crust as described in previously recorded information, to which reference has already been made. It was separated from the shore by shoreline mud from 0.5–4 km wide, averaging about 2.5 km. A maximum crust thickness of 46 cm, the greatest thickness of salt ever recorded in Lake Eyre, was found near the centre of Madigan Gulf, and a considerable area was over 30 cm thick, as illustrated in Fig. 1. Detail surveys of salt crust thickness were carried out, across the previously mapped and measured salt crust of the gulf, with the object of detecting changes in thickness and distribution which may have occurred over the period of 43 years, from the first recorded measurements to 1972.

In 1929 Madigan (1930) walked for 18.5 km in a direction 324° magnetic from Prescott Point to the central area of Madigan Gulf, and measured salt thickness at 6 places along the route. During 1954, Bonython (1956) carried out an extensive survey for 24 km along 305° magnetic, from Prescott Point, and also 6 other lines across and near the central area of the gulf, measuring salt thickness at numerous places. In 1961, the Geological Sur-

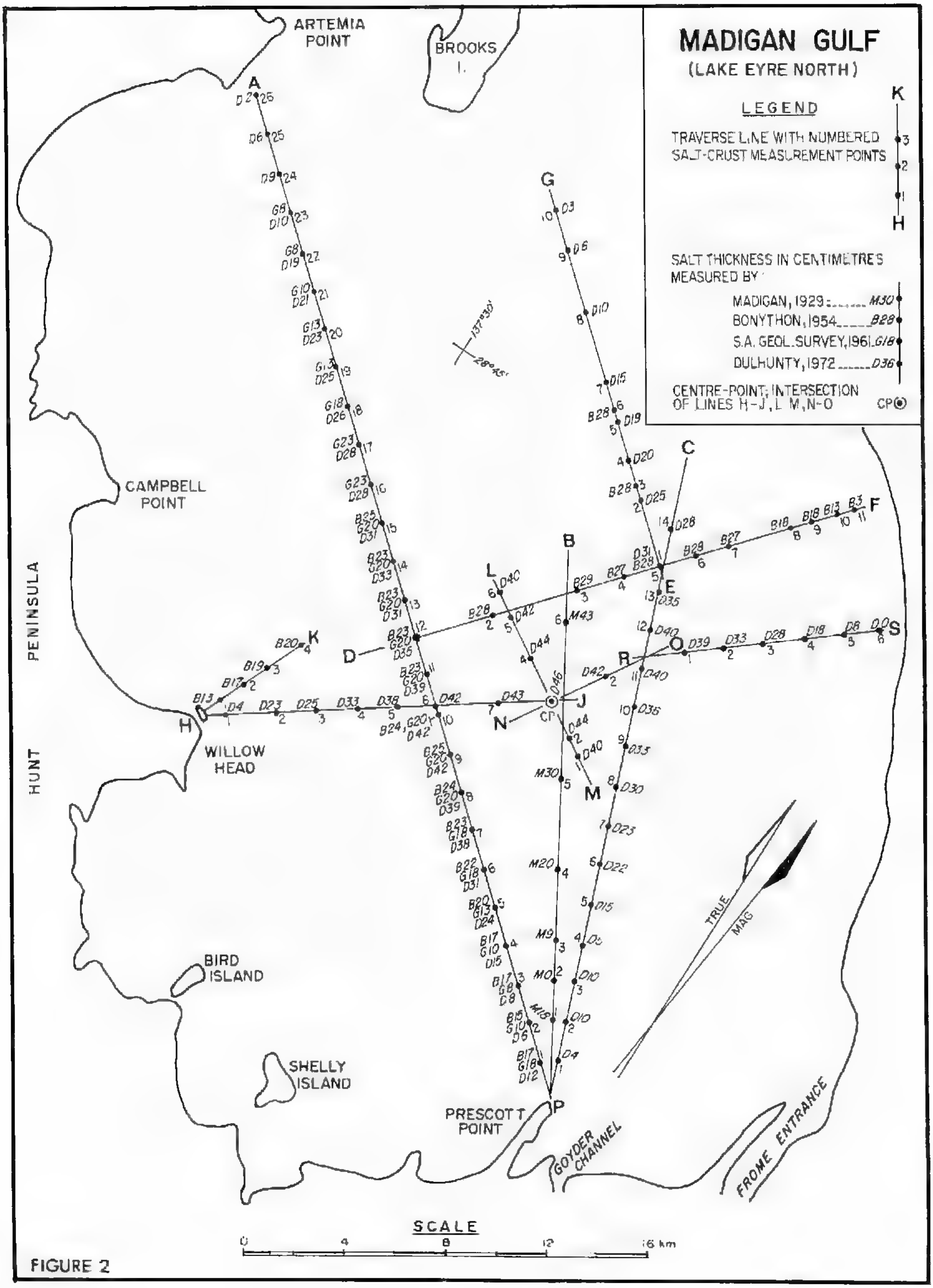
MADIGAN GULF
(LAKE EYRE NORTH)
LEGEND
TRAVERSE LINE WITH NUMBERED SALT-CRUST MEASUREMENT POINTS
K
3
2
1
H
SALT THICKNESS IN CENTIMETRES MEASURED BY:
MADIGAN, 1929 .... M30
BONYTHON, 1954 .... B28
S.A. GEOL. SURVEY, 1961 .. G18
DULHUNTY, 1972 .... D36
CENTRE-POINT; INTERSECTION OF LINES H-J, L-M, N-O
CP
ARTEMIA POINT
BROOKS I.
CAMPBELL POINT
HUNT PENINSULA
WILLOW HEAD
BIRD ISLAND
SHELLY ISLAND
PRESCOTT POINT
GOYDER CHANNEL
FROME ENTRANCE
137°30'
28°45'
TRUE
MAG
A
B
C
D
E
F
G
H
J
K
L
M
N
O
P
R
S
CP
SCALE
0
4
8
12
16 km

FIGURE 2

vey of the South Australian Department of Mines (Johns 1963) measured thicknesses for over 40 km from Prescott Point along 305° magnetic. Finally, in 1972 the present author measured thicknesses along 305° magnetic for 44 km from Prescott Point to the shore of Hunt Peninsula near Artemia Point, and also along 6 other lines over Madigan Gulf.

Results of the foregoing salt crust thickness-measurements are shown on the map of Madigan Gulf in Fig. 2. Lines along which measurements were made are designated by capital letters. Positions at which measurements were made along each line are numbered consecutively from the more southerly end of the line. Thicknesses at each point are preceded by letters indicating the persons who made the measurements, as indicated in the legend of Fig. 2. For example, at point 8 on line P–A, 24 cm of salt was measured by Bonython in 1954, 20 cm by the Geological Survey in 1961, and 39 cm by Dulhunty in 1972; at point 4 on line P–B, Madigan measured 20 cm in 1929; along line E–G, Bonython measured 28 cm at point 6 in 1954 and Dulhunty measured 19 cm at point 5 in 1972. Along line P–A, measurements by the Geological Survey and Dulhunty were made at intervals of 1 mile, or 1.609 km, as shown in Fig. 2. Measurements by Bonython (1956) were not all at 1 mile intervals, and a small amount of interpolation was necessary in transferring his results to the intervals shown along line P–A in Fig. 2. In all other cases, thicknesses are shown at the points measured by the persons concerned.

Some interesting facts, problems and conclusions emerge from the data assembled in Fig. 2:

1. Salt crust measurements by Madigan, along line P–B in 1929, show 18 cm at 3 km from Prescott Point, no crust at point 2 on Kunoth Shoal, and an increase in thickness from 9 cm at point 3 to a maximum of 43 cm at point 6, the limit of his traverse. The rate of increase falls off between points 5 and 6, indicating the existence in 1929 of an appreciable area, perhaps 4 km in diameter, with a crust thickness of at least 40 cm. This crust, which may be referred to as the "Madigan Crust", had been in existence for some years before Madigan measured it in 1929. It must have originated by redeposition of salt during the drying up of the gulf after an early, unrecorded major filling which had dissolved the whole of the pre-existing crust. The Madigan Crust, so formed, survived partial solution and redeposition during minor floodings, until the next major filling in 1949-50 when it was completely dissolved (Bonython & Mason 1953; Bonython 1955, 1956). A new crust, which could well be called the "Bonython Crust" was then formed by redeposition of salt as the gulf dried up during 1952.

In 1954, when the Bonython Crust was only 2 years old, Bonython measured thicknesses of 28 and 29 cm at points 2 and 3 on line D–E (Fig. 2) near the centre of the gulf, close to where the Madigan Crust had been 43 cm in 1929. When the Bonython Crust was 20 years old, in 1972, Dulhunty measured 40–46 cm of salt in the central area where it had been 28–29 cm in 1954. From this it is evident that the crusts of Madigan Gulf change in thickness with time, following complete solution and redeposition (Bonython 1956). Within an area of about 16 sq. km, near the centre of the gulf, the Madigan Crust had reached a thickness of 40–43 cm by 1929; the new Bonython Crust was 28–29 cm thick when 2 years old in 1954, and 40–46 cm thick when 20 years old in 1972. If the increase to a thickness of 40–46 cm in 20 years is representative, or approximates to normal rate of change in the central area of the gulf, then it could be suggested that the old Madigan Crust was of the order of 20 years old when measured by Madigan in 1929. Careful studies of rainfall records (Bonython & Mason 1953; Mason 1955, p. 11) from 1880 to 1948, compared with rainfalls for 1949-50 which produced a major filling and completely dissolved the crust, suggest possible floodings in 1887-88, 1890-91, 1906-07, 1917-18 and 1920-21. Water could have entered the lake on these occasions, but not always in sufficient quantity to fill it and dissolve the whole crust. If the Madigan Crust was 20 years old, and no more, in 1929, then it would have been the high-rainfall year in 1906-07 that led to major filling with solution of the pre-existing crust. It is possible, however, that crusts of Madigan Gulf may increase in thickness to between 40–46 cm over 20 years, and then remain more or less constant. In this case, the earlier high-rainfall year of 1890-91, regarded by Bonython (1953) as the most likely to have produced a major filling, could have led to the deposition of the Madigan Crust 36 years before Madigan measured it.

In general, the present evidence and conclusions based on studies of changes in salt crust thickness with time, support previous opinions (Bonython & Mason 1953; Mason 1955, p. 11) that Lake Eyre had been filled to cover its whole bed and dissolve the whole crust no more than twice in the last 90 years, approximating perhaps to an event which happens twice a century under existing environmental conditions.

2. The crust thicknesses shown along line P–A, from points 1 to 15, were measured by Bonython, the Geological Survey and Dulhunty when the Bonython Crust was 2, 9 and 20 years old, respectively. From points 16 to 23, measurements were made at 9 years by the Geological Survey and 20 years by Dulhunty, and from points 24 to 26 at 20 years by Dulhunty only. The line P–A, bearing 305° magnetic, extends across the gulf somewhat to the south-west of the central area.

From points 1 to 15 along line P–A, thickness figures show a general thinning of the crust for 7 years after it was 2 years old. Then it increased in thickness over the next 11 years, to 20 years old. Similar thickening also occurred further along the line between points 15 and 23. Although amounts of thinning and thickening were somewhat irregular, in general early thinning was greater in more marginal areas but extended right across the more central area, and later thickening was greater in the more central area but extended well into marginal areas. The general principle of transfer of salt from higher marginal areas to lower central areas with time (Bonython 1956) no doubt operated throughout the history of the crust, but some other factors must have caused early thinning across the more central area, and extension of later thickening well into marginal areas. Such factors, as yet unknown, but possibly associated with lake bed instability, could have influenced the direction of gradients on the surface of the crust, changing directions of water drainage and salt transfer.

3. In 1954, Bonython (1956) measured salt crust thicknesses at points, 2, 3, 4 and 5 along line D–E bearing 35° magnetic, and also at points 3 and 6 along line E–G bearing 305° magnetic. Line D–E traversed the central area of the gulf and line E–G trended north-westerly away from the centre as illustrated in Fig. 2. The crust was of very uniform thickness of about 28 cm, with one point at 27 cm and another at 29 cm at points 3 and 4 on line D–E.

At the intersection of lines M–L and D–E, Dulhunty in 1972 measured 41 cm of salt where Bonython had found 28 cm in 1954. About 6 km north-easterly, at the intersection of lines D–E and E–G, the crust was 31 cm in 1972 and 28 cm in 1954, and in the vicinity of points 2 and 3 on line E–G thickness fell to 25 cm where it had been 28 cm in 1954. Further north-westerly along line E–G near points 5 and 6, where Bonython (1956) had recorded his lowest level in Madigan Gulf, the crust was only 19 cm in 1972 compared with 28 cm in 1954.

From the foregoing data, it is evident that, between 1954 and 1972, salt crust thickness had increased by 13 cm near point 2 on line D–E in the central area, remained constant between points 1 and 2 on line E–G 7 km north-easterly, and decreased by 9 cm near points 5 and 6 on line E–G 6 km north-westerly. This would appear to mean that an appreciable transfer of salt had taken place in 18 years, from north to south, from Bonython's lowest place towards the centre of the gulf over a distance of 10 km. As shown by Bonython's level figures (1956) the surface of the lake bed, at the base of the crust, in 1954 sloped down generally to the north, from point 2 on D–E to point 6 on E–G, by an amount of 0.52 m (1.7 ft.). The salt crust in this vicinity varied only between 28 and 29 cm, so its upper surface must have sloped generally north at about the same gradient. Therefore the transfer of salt from north to south between 1954 and 1972, although from more marginal to central areas, would appear to have been "up hill" over a gradient averaging 5.2 cm per km. The normal transfer of salt with time, described by Bonython (1956), takes place across surfaces sloping down from marginal to central areas, over which water carrying salt in solution flows to deposit salt on drying in lower areas.

It would seem that transfer of salt from north to south, across the area described above, could have been made possible only by some change in levels of the lake bed over the period concerned. This and other problems of relations between salt distribution and levels of the lake bed warrant further research beyond the scope of this paper. As a result of the present investigations, it is believed that changes with time in relative levels of different parts of the lake bed should at least be considered possible, until the occurrence of any such phenomena has been more definitely established and its nature and causes are more clearly understood.

Acknowledgements

It is wished to acknowledge (i) co-operation and assistance generously provided by Muloorina Station, without which field investigations would not have been possible, (ii) valuable discussion with C. Warren Bonython of Adelaide, members of the Department of Geology, University of Adelaide, and the Geological Survey of South Australia, and (iii) provision of research facilities and field equipment by the Department of Geology and Geophysics, University of Sydney.

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THE GENUS POTOROSTRONGYLUS JOHNSTON AND MAWSON (NEMATODA: TRICHONEMATIDAE) FROM MACROPOD MARSUPIALS

BY PATRICIA M. MAWSON*

Summary

MAWSON, Patricia M. (1974).-The genus *Potorostrongylus* Johnston and Mawson (Nematoda: Trichonematidae) from macropod marsupials. Trans. R. Soc. *S.* Aust. **98**(3), 135-137, 31 August, 1974.

The genus *Potorostrongylus* is redefined, and it is suggested that it is most closely related to the genera *Zoniolaimus* and *Labiostrongylus*. *P. finlaysoni*, the genotype, is recorded with additional details of morphology from *Potorous apicalis* and *Bettongia gaimardi* from Tasmania. *P. aepyprymnus* n.sp. is described from *Aepyprymnus rufescens* from Queensland.

THE GENUS *POTOROSTRONGYLUS* JOHNSTON AND MAWSON (NEMATODA: TRICHONEMATIDAE) FROM MACROPOD MARSUPIALS

by Patricia M. Mawson*

Summary

Mawson, Patricia M. (1974).—The genus *Potorostrongylus* Johnston and Mawson (Nematoda: Trichonematidae) from macropod marsupials. *Trans. R. Soc. S. Aust.* **98** (3), 135-137, 31 August, 1974.

The genus *Potorostrongylus* is redefined, and it is suggested that it is most closely related to the genera *Zoniolaimus* and *Labiostrongylus*. *P. finlaysoni*, the genotype, is recorded with additional details of morphology from *Potorous apicalis* and *Bettongia gaimardi* from Tasmania. *P. aepyprymnus* n.sp. is described from *Aepyprymnus rufescens* from Queensland.

Introduction

The genus *Potorostrongylus* Johnston & Mawson (1939, p. 306) was placed by Yamaguti (1960, p. 403) as a subgenus of *Zoniolaimus* Cobb, and by Popova (1960, p. 220) among genera insufficiently known; Chabaud (1965) did not mention it.

New material is now available, including the type species *P. finlaysoni* Johnston & Mawson from the type host from a new locality, as well as specimens from a different host and locality, apparently representing a new species.

It appears that *Zoniolaimus*† Cobb (1898, p. 312), *Labiostrongylus* Yorke & Maplestone (1926, p. 67) and *Potorostrongylus* have many features in common. *Potorostrongylus* is distinguished from *Labiostrongylus* mainly by the shape of the oesophagus and the type of papillae on the genital cone, and from *Zoniolaimus* by these features and by the very small buccal capsule. A revised diagnosis is given:

Trichonematidae: Zoniolaiminae: Cervical cuticle inflated; anterior end with eight well developed lips, four submedian cephalic papillae and two lateral amphids on corresponding labia, dorsal and ventral labia without papillae. Short cylindrical cuticular buccal capsule; oesophagus cylindrical, ending in a constriction followed by elongate bulb. Male: spicules equal; bursa only slightly lobed; dorsal ray bifid, each branch giving off a short lateral stem, externo-dorsal ray arising separately; ventro-lateral separate for most of its length; the ventral genital cone well developed, bearing a row of stout setae on ventral lip of cloaca, and two small cuticular alae laterally. Female: vulva shortly in front of anus, vagina short, ovejectors opposed, uteri both anterior to vulva.

Parasitic in stomach of macropod marsupials.

Type species: *P. finlaysoni* Johnston & Mawson.

Other species: *P. aepyprymnus* n.sp.

Potorostrongylus finlaysoni Johnston & Mawson, 1939: 308, from *Potorous apicalis* (Syn. *P. tridactylus*), from Gippsland, Vic.

FIGS. 1–6

Hosts and localities: *Potorous apicalis*, *Bettongia gaimardi*, from Tas.

The new specimens agree with the earlier descriptions in most features, but some additional points have been noted. The length of the new, uncontracted, specimens is up to 13 mm in the male, to 15 mm in the female. The cuticular swelling at the anterior end is usually confined to the region from just behind the lips to about a third or half the length of the oesophagus. At the anterior end of this swelling there is a ring of refractile bodies in the cuticle: this probably has a strengthening

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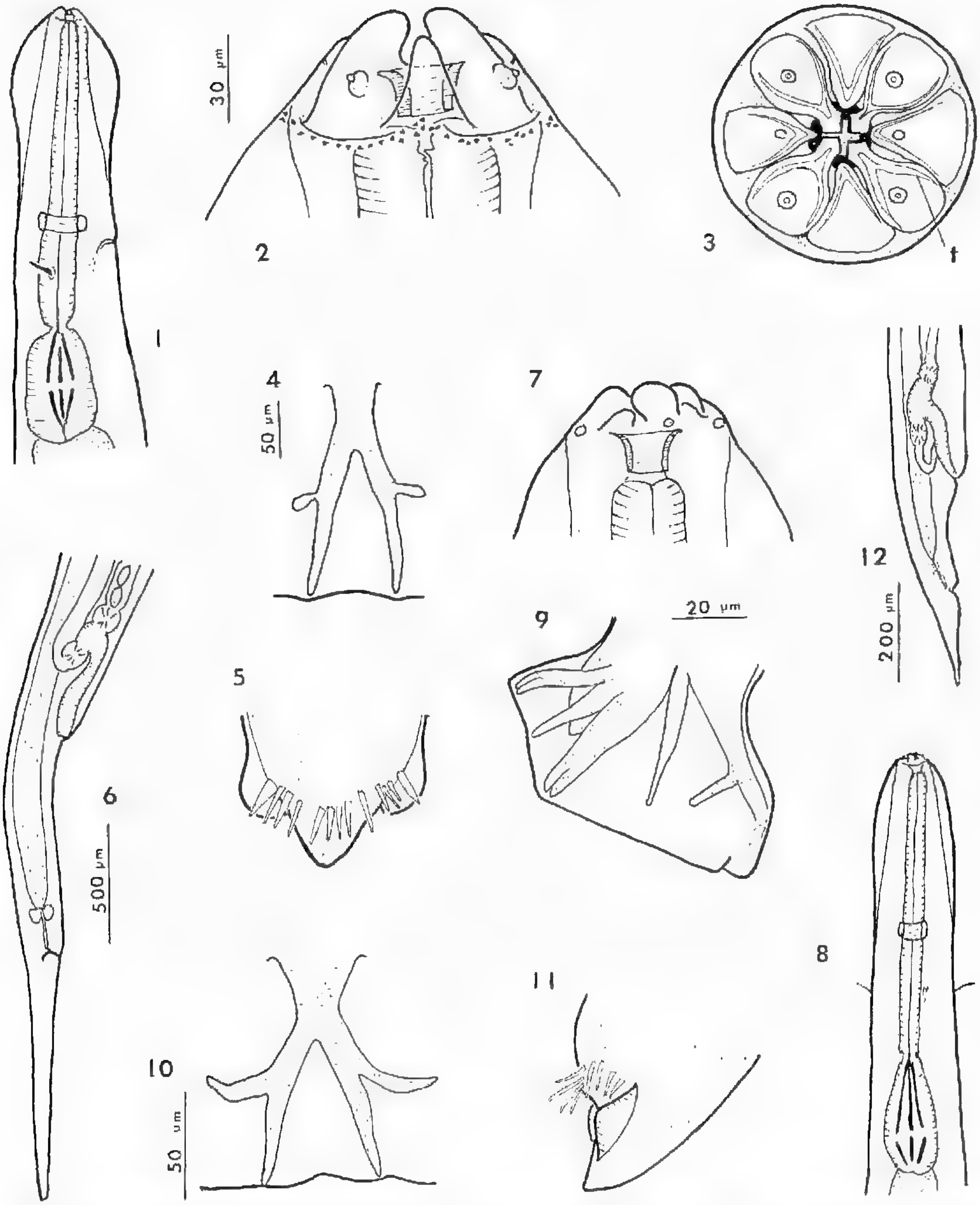
† *Zoniolaimus* is considered as having the characters of the type species *Z. setifera* Cobb; some species with "teeth" have been wrongly attributed to this genus.



Figs. 1–6. *Potorostrongylus finlaysoni*. Fig. 1.—Oesophageal region. Fig. 2.—Head of female, dorsal view. Fig. 3.—Head of female, en face; t = thickening in cuticle. Fig. 4.—Dorsal ray. Fig. 5.—Genital cone, ventral view. Fig. 6.—Tail of female.

Figs. 7–12. *P. aepyprymnus*. Fig. 7.—Head of male. Fig. 8.—Oesophageal region. Fig. 9.—Bursa. Fig. 10.—Dorsal ray. Fig. 11.—Genital cone, lateral view. Fig. 12.—Tail of female.

effect. The eight lips also are strengthened, each having a V-shaped thickening of the cuticle just inside the free margin (Fig. 3, 1). No papillae have been seen on the dorsal and ventral lips, which are mostly cuticular thickenings, with very little pulp. The shallow buccal capsule is faintly striated, and its anterior end is turned outwards (Fig. 2). The lining of the oesophagus is strongly cuticularised at the angles of the triradiate lumen, giving the appearance of three longitudinal rods down the length of the oesophagus. These rods are particularly thick in the terminal bulb, and are interrupted at its midlength. The setiform cervical papillae lie at about the level of, or just behind, the excretory pore.

The bursa and bursal rays agree with the original description. The genital cone is well developed, and bears a small ala on each side, as well as about 12–13 cuticular projections forming a fringe along the ventral lip of the cloaca.

The tail of the female is long and slender, tapering to a blunt tip; the vulva is about twice the tail length from the posterior end of the body.

Potorostrongylus aepyprymnus n.sp.

FIGS. 7–12

Host and locality: *Aepyprymnus rufescens*, from Warwick, Qld.

The general morphology of the specimens from Queensland is very similar to that described for *P. finlaysoni*. The differences are: *P. aepyprymnus* is a smaller worm; the lips are shorter, so that the buccal capsule lies behind the lips instead of, as in *P. finlaysoni*, at the level of the lower half of the lip region. The oesophageal bulb of *P. aepyprymnus* is much more elongate than that of *P. finlaysoni* and the break in the cuticular lining is at two-thirds of its length.

The bursal rays are similar except for the dorsal ray, of which the lateral branches are distinctly longer; the genital cone is similar in shape and bears a precloacal row of about 12 setae as well as a pair of lateral alae which are however situated slightly more posteriorly on the cone than those of *P. finlaysoni*. The spicules are slightly shorter in *P. aepyprymnus*.

The tail of the female is shorter and relatively thicker than that of *P. finlaysoni*. No eggs are present.

Measurements are given in Table 1.

TABLE 1

Measurements of P. aepyprymnus. *All measurements are in μm.*

	♂	♀
Length	5200-8000	5010-5500
Oesophagus	830-950	820-900
Antr. end—nerve ring	350-420	310-350
—cervical pap.	470-600	390-490
—excr. pore	460-580	380-490
Spicules	960-1050	-
Tail	-	170-200
Vulva—postr. end	-	350-450
Body length/oesoph. length	5.4-7.6	
Body length/spicule length	6.2-8.4	

Acknowledgements

The specimens from Tasmania were obtained through the kindness of Dr. J. Hickman of the Zoology Department, University of Tasmania, and Dr. B. Munday of the Tasmanian Department of Agriculture, Launceston. The single specimen of *Aepyprymnus rufescens* was obtained through the courtesy of the South Australian Museum. I am most grateful for this help.

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THE CORROBINNIE DEPRESSION, EYRE PENINSULA, SOUTH AUSTRALIA

BY JENNIFER A. BOURNE, C. R. TWINDALE* AND DIANE M. SMITH**

Summary

BOURNE, Jennifer A., TWIDALE, C. R., & SMITH, Dianne M. (1974).-
The Corrobinnie Depression, Eyre Peninsula, South Australia. *Trans.* R. *Soc. S. Aust.* **98** (3). 139-152, 31 August, 1974.

The Corrobinnie Depression is a narrow, elongate, essentially linear feature which trends NW-SE across northern Eyre Peninsula, South Australia. It is characterised by the presence of numerous salinas and parabolic dune fields, which stand in contrast to the linear sand ridges of the adjacent, higher plains. The Depression is certainly a structural feature, though its precise origin remains obscure. It could be a fault-line valley eroded by rivers, the outlet of which can no longer be detected, or it could have originated as a fault-line depression due to the weathering of the rocks in and adjacent to a fracture zone by groundwaters, or by volume decrease of the weathered rocks and consequent subsidence of the land surface. The Depression dates back to at least the early Tertiary, and its advanced development is due to its proximity to the upstanding Gawler Ranges which shed water to the fracture zone, thus causing it to be weathered and lowered to a much greater degree than other fracture zones in the vicinity.

THE CORROBINNIE DEPRESSION, EYRE PENINSULA, SOUTH AUSTRALIA

by JENNIFER A. BOURNE*, C. R. TWIDALE* and DIANNE M. SMITH*

Summary

BOURNE, Jennifer A., TWIDALE, C. R., & SMITH, Dianne M. (1974).—The Corrobinnie Depression, Eyre Peninsula, South Australia. *Trans. R. Soc. S. Aust.* 98 (3), 139-152, 31 August, 1974.

The Corrobinnie Depression is a narrow, elongate, essentially linear feature which trends NW–SE across northern Eyre Peninsula, South Australia. It is characterised by the presence of numerous salinas and parabolic dune fields which stand in contrast to the linear sand ridges of the adjacent, higher plains. The Depression is certainly a structural feature, though its precise origin remains obscure. It could be a fault-line valley eroded by rivers, the outlet of which can no longer be detected, or it could have originated as a fault-line depression due to the weathering of the rocks in and adjacent to a fracture zone by groundwaters, or by volume decrease of the weathered rocks and consequent subsidence of the land surface. The Depression dates back to at least the early Tertiary, and its advanced development is due to its proximity to the upstanding Gawler Ranges which shed water to the fracture zone, thus causing it to be weathered and lowered to a much greater degree than other fracture zones in the vicinity.

Introduction

Following a geological exploration of north-west Eyre Peninsula, Jack (1912, p. 19) reported a "depression between the granitic ridge, the peaks of which are visible from Wallala Rock to Weedina" (i.e. Mt. Wudinna) "and the Gawler Ranges . . . ". This depression, which has been called the Corrobinnie Depression after the prominent granite inselberg which lies within the lowland, extends unbroken from the vicinity of Balumbah, 12–13 km south-west of Kimba (Fig. 1) to the neighbourhood of Toondulya Bluff, 200 km to the north-west.

The Corrobinnie Depression is most readily discernible on topographic maps or air photo-mosaics where it is seen to form an elongate, narrow zone of complex but dominantly parabolic dunes which carry a thick and virtually undisturbed cover of eucalypt and acacia scrub. These arcuate dunes stand in strong contrast to the fields of regular NW–SE trending longitudinal dunes which occur on the slightly higher ground to either side of the Depression. Despite its shallowness—it stands only 35–40 m below the level of the adjacent plains—the Depression is also readily detected on the ground, for there is a pronounced descent into it from both north and south (Figs. 2 and 8). Moreover the varied dune orientation within the Depression makes travel within the area difficult: more than 70 years before Jack noted and very briefly described the Depression, E. J. Eyre and his companions must have traversed it while crossing from Streaky Bay to Baxter Range for they camped at Mt. Sturt which lies close to the northern margin of the feature. Eyre did not specifically record having noted a depression, which is scarcely surprising in view of its shallowness and the other problems with which he had to contend, but "the steep sandy ridges and dense eucalypt scrub" which together caused heavy going certainly made an impression, as Eyre's journal entry for 21 September, 1839, clearly shows (Eyre 1845). A few years later J. C. Darke crossed the Depression from Mt. Wudinna to the southern base of Mt. Sturt and the difficulties he and his companions encountered in the way of swampy salinas and deep sands can be gauged from the fact that they took more than three days to travel the

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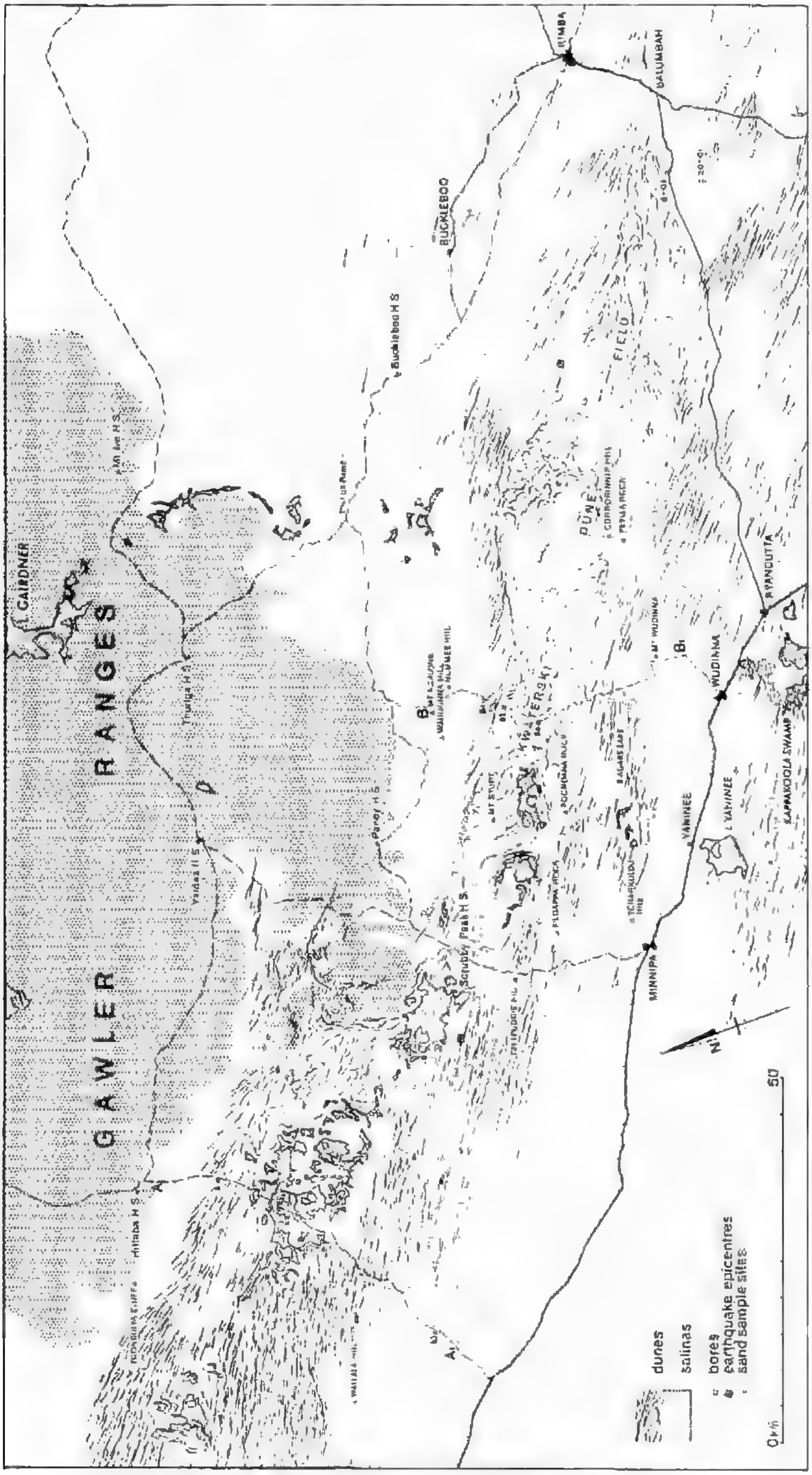

Fig. 1. Locations referred to in the text and major landforms within and adjacent to the Corrobinnie Depression which is distinguished by the numerous salinas and the field of parabolic dunes—the Kwaterski Dune Field. Drawn from air photographs and field data.

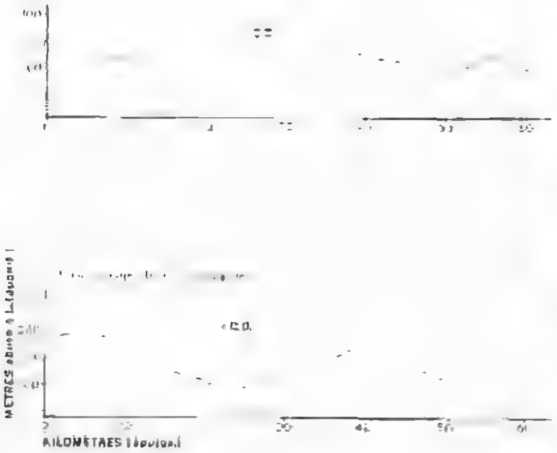

Fig. 2. Topographic sections between A and A_1 and B and B_1 (on Fig. 1) across the Corrobinnie Depression. Drawn from field data.

32 km between the two points (S.A. Register, 13 November, 1844; Twidale 1974).

Thus though not a spectacular topographic form, the Corrobinnie Depression constitutes a distinct and, by virtue of its extent, a major geomorphological feature cutting diagonally across the broad northern base of Eyre Peninsula.

What is the reason for the Depression and its distinctive assemblage of landforms?

Origin of the Depression

Structural considerations. Both the extent and linearity of the Corrobinnie Depression suggest a structural, and in particular, a fault-generated origin. No other explanation can satisfactorily account for these characteristics in combination: few rocks older than Quaternary are exposed in the Depression and no faults have been observed, but a number of lines of evidence and argument support the general inference that the topographic feature is related to fractures in the crust.

Geophysical surveys, for example, suggest that the Depression in general terms is aligned parallel to dykes and sills which traverse northern Eyre Peninsula and adjacent areas in a NW–SE direction (Boyd 1970[1]). Several of these occur within the Depression though they have been detected only on aeromagnetic surveys. It is reasonable to suppose that their trend reflects weaknesses or fractures in the crust, and similar possible fracture zones have been located in the areas south-east of Eyre Peninsula where they evidently play an important part in delineating and determining major relief features (see Twidale 1971, pp. 144–149). Such a NW–SE trend is indeed an important feature of the structural pattern of the entire Australian continent (Hills 1946, 1955).

There is also some slight evidence of seismicity within the suggested fracture zone, for two earthquake epicentres (Fig. 1) have been recorded along its trend in recent years (Sutton & White 1968; Sutton, pers. comm.). Many more have been recorded near the east coast, and to a lesser degree the west coast, of Eyre Peninsula (Sutton & White 1968; Stewart, Slade & Sutton 1973) and possibly this reflects the relative instability of the margins of the Peninsula compared to its interior. Thus late Cainozoic faulting has been demonstrated (Miles 1952) over a wide area between Whyalla and Cowell and suggested for the north-western margin, in the eastern part of the Nullarbor Plain (Jones 1880; Jennings 1963).

These areas are however remote from the feature under discussion where, within and at the margins of the Corrobinnie Depression, there is no evidence of any recent dislocation of an order adequate to explain the topographic low. This conclusion is necessarily tentative for small fault scarps may have developed only to be obscured by alluvium or sand drifts. But on the available evidence the Depression originated by faulting in the distant past. There is no evidence of recent tectonism of geomorphological significance in the vicinity of the Depression. It seems more likely to be a fault zone of great antiquity which has been subject to recurrent joggling.

The presumed fracture zone separates distinct lithological provinces, for apart from some (?) Archaean sediments in the Mt. Allalone area and granitic outcrops at and around Nummee and Waulkinna hills and in the Buckleboo area (Fig. 1), the area north of the Depression is occupied by the Gawler Range Volcanics (Fig. 3), a predominantly dacitic lava flow but with some rhyodacites

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[1] Boyd, D. (1970). –Eyre Peninsula: Regional Magnetic Interpretation (1:1,000,000). Unpublished map, Dept. of Economic Geology, University of Adelaide.

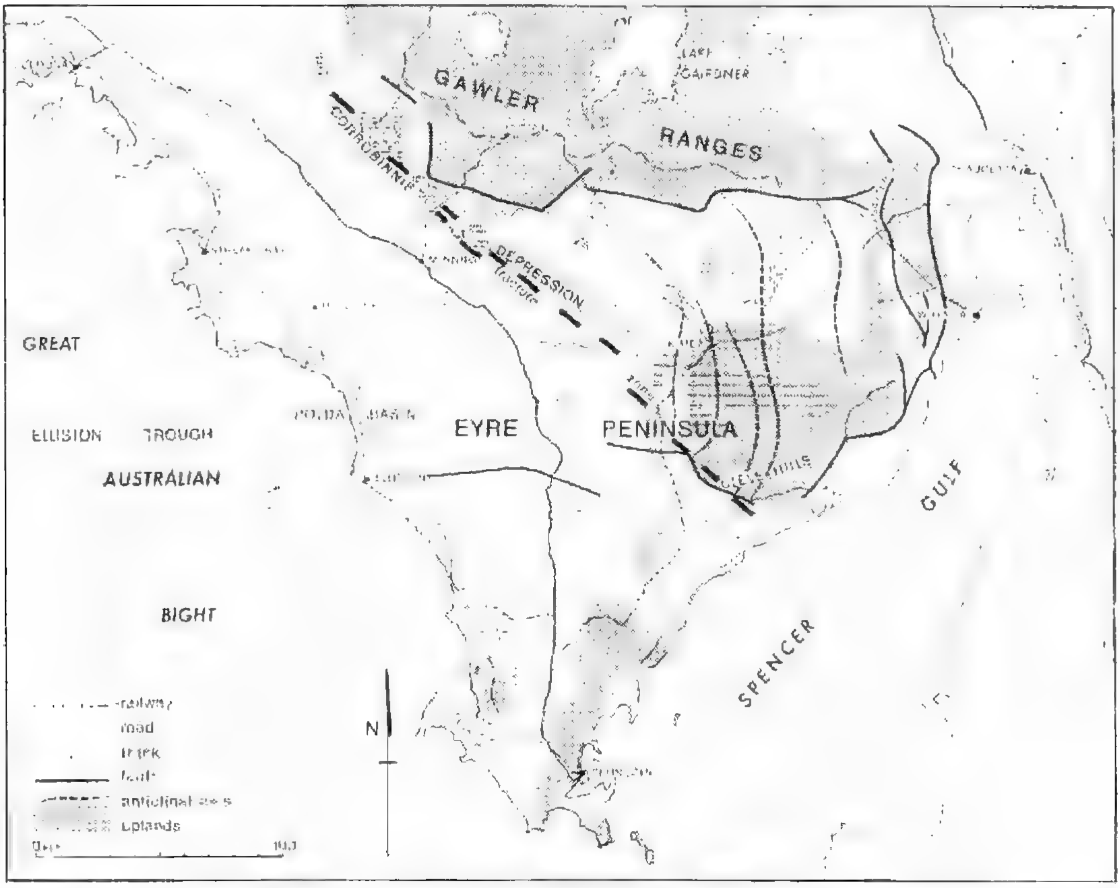

Fig. 3. Regional location map and major geological structures of northern Eyre Peninsula. Compiled from existing geology maps and field data.

and rhyolites (A. H. Blissett, pers. comm.) of Precambrian age and dated by radiometric means as being of the order of 1,535 million years old (Compston, Crawford & Bofinger 1966; Compston & Arriens 1968). To the south and south-west of the Depression, on the other hand, the bedrock is essentially granitic. Admittedly at Mount Cooper and on Hart Island (in the Nuyts Group, some 80 km SW of Ceduna) there are small outcrops of porphyritic rock but they are of very limited extent and are in any case not of Gawler Range type. Also, though certain discrepancies have appeared in the dating of granitic and gneissic basement rocks of Eyre Peninsula, their reported ages are in the range of 1,590–2,800 m.y. (Thomson 1969, pp. 30–31). Thus whatever the details of the relative ages of the various masses of granite and gneiss, they are consistently older than the Volcanics.

The limits of the suggested fault zone are reasonably clear in the south-east where it extends at least as far as Spencer Gulf; in the Cleve Hills there are exposures of deformed Precambrian sediments and metasediments the folds of which are truncated by a linear structure running NW–SE through Cleve (Fig. 3).

To the north-west however, the fault zone gradually fades. There is neither morphological nor geological evidence of its continuation beyond the Hundred of Toondulya. Furthermore the stratum contours of the base of the Tertiary rocks in the Eucla Basin (Tectonic Map of Australia 1960)[2] give no indication of

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[2] Published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development, Canberra.

tonguing south-eastwards toward the Depression.

Structure of the Depression. Whether the Corrobinnie Depression is essentially a tectonic or a structural feature cannot be determined with any certainty. It could be seen as occupying a graben which has largely been filled in by detritus washed in from the adjacent areas. The feature is long and narrow and though there is some offsetting of the margins all these features are characteristic of known graben. The prominent granite ridge running through the Minnipa and Wudinna districts, south-west of the Depression, could be an adjacent horst or anticlinal block (Twidale 1964). Corrobinnie Hill and Peella Rock could be regarded as minor horsts or as components of a single horst block within the major depressed structure. Parabolic dunes are closely associated with the Depression and their distribution south-east of Kimba suggests that one branch of the postulated fracture zone bifurcates in a manner typical of known graben (Twidale 1971, p. 121). However none of this evidence is conclusive and can be interpreted in other ways.

The Depression could occupy a fault-angle valley similar to that which occurs to the south-west of the feature under discussion, in the Polda Basin (Rowan 1968) and in its westerly submarine extension in the Elliston Trough (Smith & Kamerling 1969). Only one fault has been identified by geophysical means and the two structures together are regarded as a fault-angle trough in which are preserved Mesozoic and Tertiary strata (Harris 1964; Rowan 1968; Smith & Kamerling 1969).

Support for the view that the Depression occupies the site of an ancient fault-angle structure derives from the gross morphology of the Gawler Ranges which are delimited on their southern margin by a series of faults. The uplands rise abruptly from the plains to the south but slope gently down to the north. They could be viewed in gross as a fault-tilted block, with a prominent though now much dissected fault scarp forming the southern boundary of the Ranges and the northern limit of the Corrobinnie Depression. If this interpretation is correct, the faulting responsible for the tilting was active during the early Cretaceous for high energy streams from the (recently uplifted?) Ranges carried pebbles and boulders of Gawler Range Volcanics to the north where they occur in strata of early Cretaceous age (Wopfner 1969, p. 152).

However this is speculation. There is no unequivocal evidence that the Corrobinnie Depression is tectonic. If it were initiated as a graben or fault-angle depression then the tectonic outlines of the feature have long since been blurred and obscured by weathering, erosion and deposition.

An alternative possibility is that the Corrobinnie Depression is not primarily tectonic but is of structural origin *sensu stricto*; i.e., it has evolved through the exploitation of a major fracture zone by agents of weathering and/or erosion. If this were so then two major questions arise:

1. What agents are responsible for the development of the Depression? This problem in turn necessitates a consideration of the age of the feature.
2. Why has the fracture zone to which the Corrobinnie Depression owes its origin been exploited to a much greater extent than the others which evidently are present in the region?

Formation and age of the feature. Though the faulting to which the Corrobinnie Depression is related is probably of great antiquity, this provides no real measure of the age of the feature under investigation. The only evidence relevant to this question derives from a bore located some 12–13 km west of Balumbah and logged by R. G. Shepherd (S.A. Geol. Survey, Report Book 67/113, Bore 6–01, Hundred of Panitya). This bore is located at the margin of the Corrobinnie Depression, but it is typical of the Depression as indicated by a comparison with Bore 20–1 (Hundred of Caralue) located some 2 km to the SSW. The latter ran through less than 6 m of sand before penetrating the gneiss basement, whereas 6–01 penetrated some 50 m of sediment before reaching the weathered granitic bedrock. The upper two thirds of the sedimentary fill consisted of sand, gravel and clay assigned to the Pleistocene and Recent, but within the lower third, which also consisted of gravel, sand and silt, was a lignitic horizon which is compared with known Lower Tertiary lignites at Kopi (Fig. 1) and other shallow basins on Eyre Peninsula. It is emphasized that this is extrapolation and is not based on an examination of the contained organic materials, of which, unfortunately, none were preserved (W. K. Harris, pers. comm.). But if this interpretation is correct, then clearly the Corrobinnie Depression was already in existence as a topographic feature by the Eocene.

If the Depression were essentially initiated during the later Mesozoic or the earliest Tertiary, then it is in relation to the climates and conditions of these times that its mode of formation should be sought. Apart from dreikanter found in the present Lake Eyre region in strata of Upper Jurassic age (Wopfner 1969, p. 147), there is no evidence and no argument from general considerations (Brown, Campbell & Crook 1968, p. 245 *et seq.*; Wellman, McElhinny & McDougall 1969; Embleton 1973) pointing to desertic conditions in or in the vicinity of northern Eyre Peninsula at any time from the later Mesozoic until the late Pleistocene. Though aeolian action is responsible for moulding much of the present surface of the Depression, it is difficult to substantiate any argument which attributes the erosion of the feature to wind action.

Two agents of degradation that warrant serious consideration are rivers and weathering.

It may be argued that the fracture zone has been preferentially weathered because the faults allowed ready penetration of groundwater which altered the rock with which it came into contact within and adjacent to the fracture zone. This weathering may have contributed to the formation of a topographic depression either by permitting ready stream erosion, or by causing volume reduction of the bedrock and consequent lowering of the land surface.

If streams had flowed in and caused the lowering of the floor of the Depression, there should in theory be some evidence of an outlet through which water and sediment were evacuated. No such outlets have been located though little information is available concerning the morphology of the bedrock surface beneath the cover of surficial materials. At its south-eastern extremity the Depression terminates against the recently upfaulted Cleve Hills, and there is very little data concerning the stratigraphy of the sediments deposited in the relevant part of Spencer Gulf. To the north-west and west there is no evidence to hand of a former outlet either to the Great Australian Bight or to the Eucla Basin. If the Corrobinnie Depression were in existence as long ago as the early Tertiary it is perhaps unreasonable to expect to find evidence of ancient stream courses still preserved at this time. Thus it cannot now be proved that the Corrobinnie Depression is a fault-line valley.

An alternative mechanism which should be considered is based on volume decrease of granitic rocks consequent upon intense chemical alteration, which can be inferred to bring about a significant, even a dramatic, reduction in volume. Ruxton (1958) has suggested that as much as 50% by volume of granite bedrock may be lost either in solution or as fines as a result of intense weathering and subsurface flushing by water. Outcrops of intensely weathered granitic gneisses have been reported from low shoreline cliffs of salinas within the Depression (Shepherd 1961) and the stepped morphology of Corrobinnie Hill argues repeated weathering and lowering of the granite bedrock to a total depth of at least 15 m. Thus rock types prone to volume reduction on chemical attack occur within the Depression and there is evidence that they have been subjected to such alteration.

There can be little doubt that where there is a repeated accession of water to attack and flush the bedrock, as for instance in the scarp foot zone of granitic residuals in West Africa (Clayton 1956), the Libyan Desert (Dumanowski 1960) and Eyre Peninsula (Twidale 1962, 1967), this process of alteration, flushing, volume decrease and surface subsidence could be an important contributory factor in the development of scarp foot depressions (Fig. 9). But these are minor forms; whether such a process could account for a regional feature like the Corrobinnie Depression is questionable. The evacuation of fines and solutes from the Depression would require an hydraulic gradient away from the postulated fault zone, a condition which could only be achieved by assuming that the region lay well above sea-level throughout the period of development and that no geological barriers intervened to prevent the escape of the subsurface waters.

Moreover there is no general agreement that chemical alteration of granite everywhere results in volume decrease and surface subsidence. Thomas (1966) has pointed out that in Nigeria deep weathering of granitic bedrock is not reflected in the development of topographic basins. Ollier (1969, p. 181) has challenged the general concept of surface lowering consequent on weathering presented in relation to the formation of laterite in East Africa (Trendall 1962), pointing to evidence of alteration which has taken place with no significant volume change. On the other hand, the volume increase consequent on the weathering of certain clays is commonly called upon in explanation of certain features and forms, such as gilgai.

These several difficulties are not denied. It may be that the character of the volume change, if any, resulting from chemical weathering varies according to climate and vegetation, and hence the chemical nature of the groundwaters, and upon whether the system is open or closed. Certainly the course of chemical weathering and the end products of such changes varied with these factors (Loughnan 1969, p. 27) and it may be that volumetric changes vary also.

In light of these problems and uncertainties it is possible only to indicate what may have occurred rather than what did take place. The Corrobinnie Depression could have originated in several ways. It could have a composite origin. It could for instance have been initiated as a fault-angle depression during the later Mesozoic, been further exploited by a river system or systems the outlet of which is no longer in evidence, and been further enlarged as a result of volume decrease consequent upon the intense weathering of the granite and gneiss basement. Alternatively, any tectonic dislocations which occurred during the later Cainozoic and which are invoked to achieve the closure of the Depression and the truncation of any pre-existing external drainage, may have initiated the partial infilling of the Depression which is evidenced by the cover of Pleistocene sand, gravel and silt.

Distinctive development of the Corrobinnie Depression. The Corrobinnie Depression is unique due to the juxtaposition of the Corrobinnie Fault Zone and the resistant and upstanding outcrop of the Gawler Range Volcanics. Other fractures suggested by geophysical survey and geomorphological expression are developed largely in granitic rocks and have not achieved such marked topographic expression. There is little relief adjacent to them, and in consequence little runoff to the fracture zones and therefore no great disparity of weathering between the fracture zone and the surrounding country rock.

North of the Corrobinnie Fault Zone on the other hand, the hills of the Gawler Ranges stand up to 300 m above the valley floors and a large part of the upland region drains to the lowland which borders it on its southern side. Mr. John Kwaterski, Senior, an early agriculturalist of the Minnipa district and explorer of the Depression, reports that after heavy rains in the Gawler Ranges great shallow sheets of water stand for a few days in the Depression. Thus in 1946, which was a year of above average rainfall throughout northern Eyre Peninsula (Minnipa recorded 48 cm compared with an annual average of 35.1 cm, and Yardea 40.3 cm against the usual 27 cm), the salinas in the Depression carried over 2 m of water. He has also been told that in 1890 the Minnipa–Yardea road was covered by water where it passes through the Depression: though this information is second-hand its accuracy is borne out by the fact that the rainfall records show that year also to have been one of unusually heavy rains in the district, with Yardea for example receiving 43.3 cm.

Quite apart from present tendencies, there is evidence of an even greater former influx of water to the Depression from the Gawler Ranges. Relicts of a now disrupted and dismembered former drainage system in the form of strings of salinas and curvilinear depressions, which link them and which contain weathered alluvium, attest to the presence in former times of a well-developed drainage system flowing from the present Thurlga and Mt. Ive properties to the Corrobinnie Depression. The width of the meander belt delineated by these relict forms is approximately 11 km (though it cannot be measured with certainty because of subsequent modification of the eastern shores of the lake by lunettes), compared with 1.5 km for the present stream courses. This surely suggests a drainage system of much greater discharge than the present streams achieve even in times of flood.

Thus although there are similar fracture zones elsewhere on the Peninsula and in the area to the north, only in the vicinity of the Corrobinnie Depression are there rocks other than granite. Thus it is only there that there are uplands of any consequence and hence only in this area is there a disproportionately large runoff to one of the fracture zones. This is the reason for the Corrobinnie Fault Zone alone having developed into a feature of regional topographic significance. Topographic lows, such as that occupied by Lakes Yaninee, Wannamana and Warramboo and Kappakoola Swamp (Fig. 3), appear to be coincident with another possible fracture zone but it is neither as well nor as extensively developed, presumably because of the presence of granite bedrock throughout the area and the absence of any upland areas of significant extent.

These then are the reasons for the evolution of the Corrobinnie Depression and for its being a major constituent of the geomorphological framework of Eyre Peninsula.

Landforms

The landform assemblage within the Corrobinnie Depression differs greatly from those in adjacent areas and comprises principally salinas and dune fields. The granite hills which are present are broadly similar to those described from other parts of north-western Eyre Peninsula (Twidale 1962, 1971, pp. 4–96), though one, Corrobinnie Hill, is sufficiently distinctive to warrant description and explanation. In addition there are within the Depression a number of characteristically rounded porphyry hills. The highest is the upland complex of Mt. Sturt which rises abruptly from the lowlands.

The salinas. These occur in a few extensive zones within the Depression, and especially toward the northwestern extremity (Fig. 1). Many carry a halite crust though the edges are commonly sandy or muddy. Some of the smaller salinas nestle amongst the dune ridges, but the larger ones are bordered by cliffs up to 7 m high in which are exposed dolomitic silts and silicified dolomite. Similar outcrops occur in the cliffed margins of islands within the lakes, and, like the bordering cliffs, are a measure of the lowering of the lake beds in recent times. The dolomitic sediments are of lacustrine origin and represent a higher level of lake accumulation. Unfortunately the sediments appear unfossiliferous so that it is not possible at present to date the erosion (deflation?) responsible for the lowering of the greater parts of the playa depressions and the development of islands and cliffs.

The dune fields. The greater part of the Corrobinnie Depression is occupied by Quaternary sands. There is only one bore which penetrates through the sands to the underlying bedrock, and as mentioned previously this passed through some 50 m of sand before reaching weathered bedrock. Elsewhere the thickness of the sand has to be inferred. For instance, weathered gneisses are exposed in and around salinas south of Mt. Sturt so that the elevation of the dunes above these salinas provides a measure of the thickness of the sands, and on this basis the latter seem to be 30–40 m thick.

The sand could have been blown into the Depression by the wind from adjacent areas, it could have been washed in or it might have formed essentially *in situ* due to the weathering of the underlying granitic bedrock within and adjacent to the fracture zone; or it could have been derived from all three sources.

The sands are overwhelmingly of quartz though there is about 7% by weight of fines. The sands are predominantly in the fine–medium range (Fig. 4), being mainly in the range 0.105–0.35 mm. Some of the grains are quite well-rounded but most are angular to subangular. The rounded grains display frosting and reddish brown haematite staining is common. The clay fraction of the fines acts as a cement, for the quartz fragments are commonly in the form of aggregates of unwashed sand.

The angular character of the bulk of the sands suggests that the sands are locally derived: they have probably been washed or blown into the Depression from the immediately adjacent areas. The larger, rounded grains probably represent sand which has been transported along the axis of the Depression either by wind or by ancient rivers.

Ferruginised and mottled sands are exposed in the Depression north of Wudinna. The ferruginous indurations have presumably formed at the base of dunes and close to the water table and are due to the illuviation of iron salts and their precipitation at lower levels; similar accumulations have been noted low on the flanks of late Pleistocene dunes at Agars Lake, near Minnipa, north-western Eyre Peninsula. Calcrete is also well developed in the dunes. Assuming that this pedogenic accumulation began soon after relative stabilisation of the sands, it provides a means of dating the deposits. Samples of calcrete close to Corrobinnie Hill and from dunes near the southern margin of the Depression 25 km ENE of Wudinna gave dates of 15,780 ± 350 (GaK 3451) and 22,040 ± 760 (GaK 3452) respectively, indicating that the sands are at least of late Pleistocene age.

The surface of the sand has been moulded by the wind and shaped into dunes mainly of parabolic type. Dunes which are reticulate or box-like in plan also occur in some areas. There are also patterns which while broadly rectangular or rhomboidal in plan are less angular than the truly reticulate forms. As these are thought possibly to result from the deflation of sand from the hollows and leaving the ridges as residual forms, they are termed *alveolar* (cf. Féderovitch 1956). Also

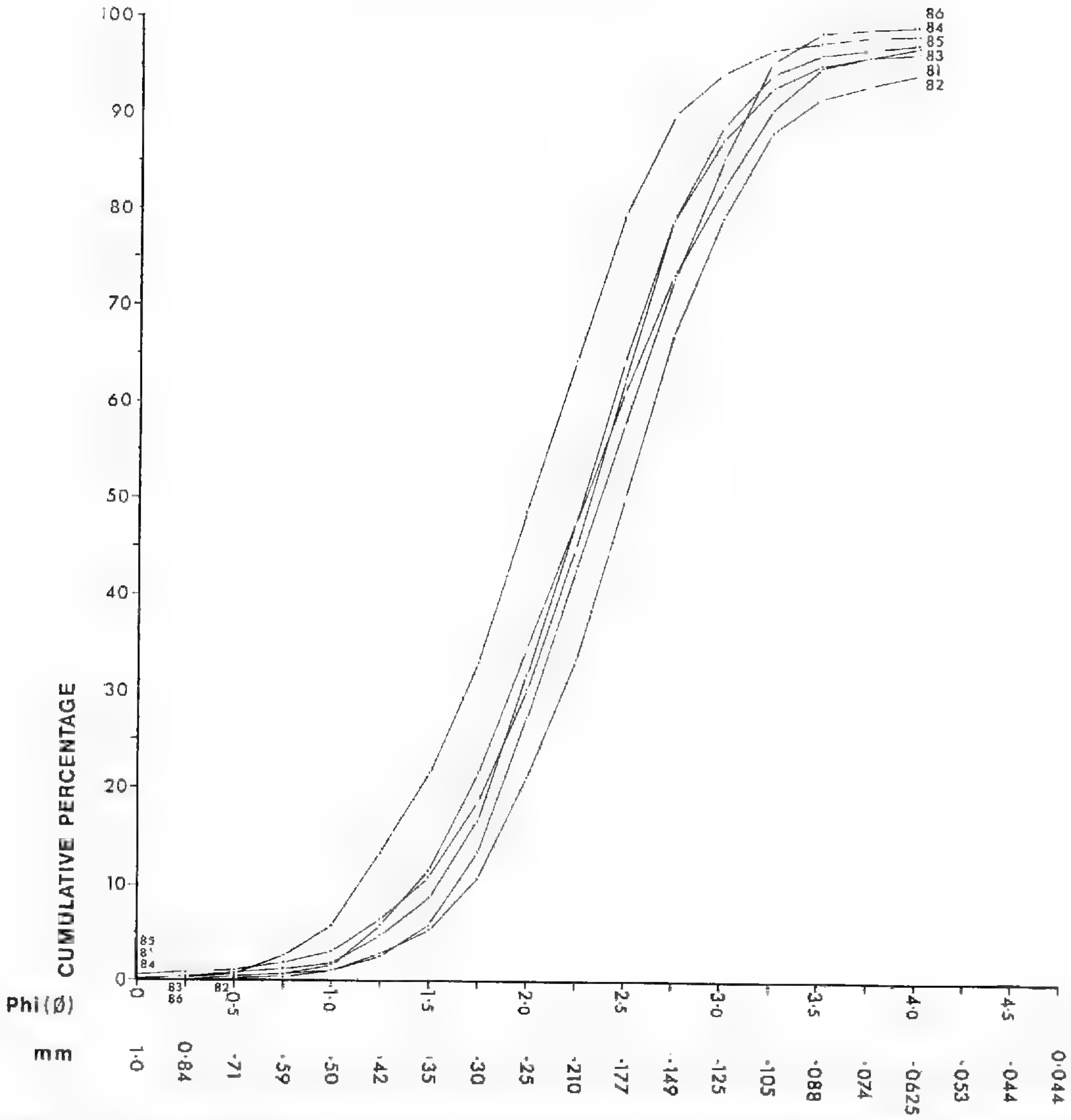

Fig. 4. Graphs showing grain-size analysis of sand samples, the locations of which are shown on Fig. 1.

present are true dunes which are almost circular and form either in the lee or to windward of obstacles (Fig. 7). It is not uncommon for several ridges to be arranged concentrically in such circular patterns.

The deep sands and vegetated surface favour the development of parabolic types, but the concentric dunes and particularly the long diagonal straight ridges of sand (Fig. 5) are unusual. It seems that the ridges formed in response to a W–NW wind as ordinary linear sand ridges or longitudinal dunes aligned parallel to the vector of the varied but essentially NW–W winds (cf. Simpson Desert—Wopfner & Twidale 1967; Twidale 1972); they were then stabilised by vegetation. The wind, possibly from a slightly different direction (either present day secondary winds or former ones of a different wind regime) may then have blown out some of the linear ridges into parabolic dunes.

The wind shaping the linear dunes was W–NW, as attested by the encroachment of some of the ridges on to the western margins of

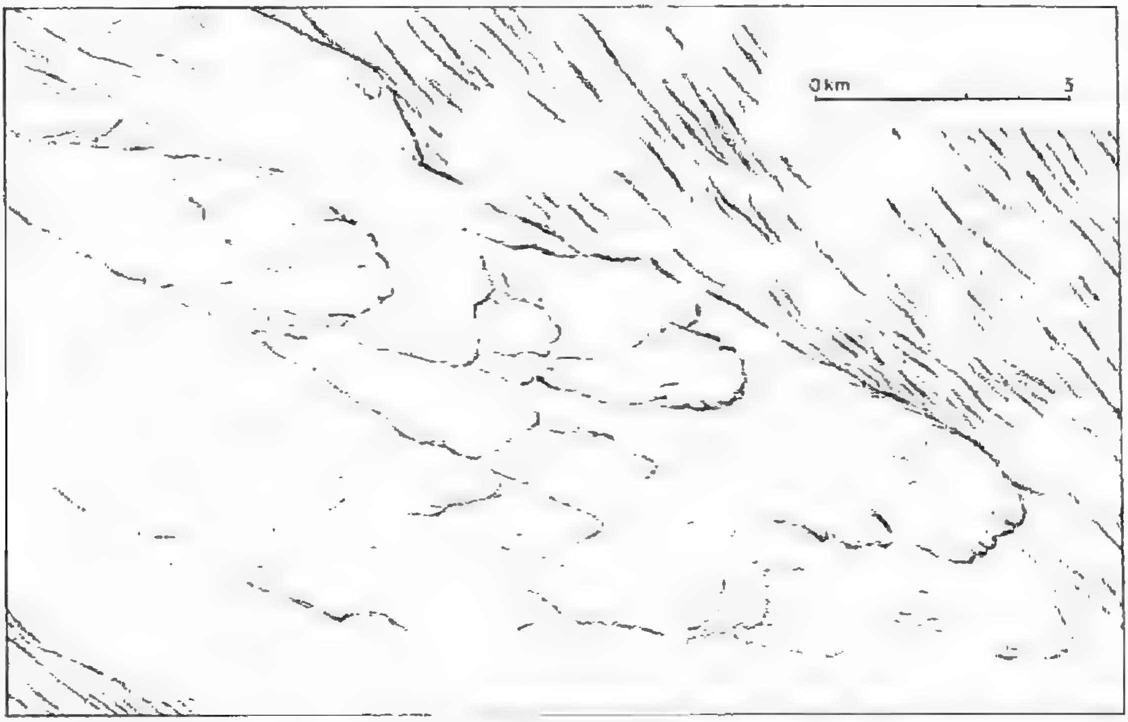

Fig. 5. South-eastern extremity of Corrobinnie Depression showing major parabolic dunes, linear connecting sand ridges, and longitudinal dunes to NE and SW. (Drawn from air photographs.)

salinas, and by the downwind convergence of ridges. However a consideration of the Kyancutta wind rose shows that at present the sand-moving (i.e. 11 knots (20.4 km/hr) and over) winds are from the south-western sector. This implies that the dunes of the Depression, which are here called the Kwaterski Dune Field after the pioneer and friend to whom earlier reference has been made, were formed under a very different wind regime, and are thus suggestive of climatic change. Evidence of a similar late Pleistocene change in climate and wind regime has been adduced in the Riverina districts of western N.S.W. and northern Victoria (Bowler *et al.* 1970, Bowler 1971). However there is no evidence from the area under discussion of an age contrast between the parabolic dunes of the Corrobinnie Depression and the longitudinal dunes of the area to the south. As mentioned previously calcrete from the sands of the Kwaterski Dune Field gave dates of almost 16,000 and just over 22,000 years B.P. (GaK 4351 and 4352). Similar material from the linear dune field provided dates of just over 10,300, almost 16,700, and almost 27,000 years B.P. (GaK 4071, 4072, and 4639). Thus the sand within the Depression is of the same order of age, and falls within the same range as that of the longitudinal dunes.

The granite forms. Two granite hills stand above the level of the dune complex. Peella Rock is a low whaleback which displays flared slopes, gnammas, many of them developed along joints, and boulders with tafoni; i.e., many of the minor granite landforms commonly evolved and exhibited on granite residuals of southern Australia (Twidale 1971, pp. 80–96). Like many other granite outcrops of northern Eyre Peninsula, Peella Rock has in the past been used for water conservation and an elaborate scheme of gutters and drains leads runoff from the bare rock surface to storage tanks (Twidale & Smith 1971).

Corrobinnie Hill is both more extensive and stands much higher than does Peella Rock which is located some 2 km to the south-west (Fig. 1). The inselberg displays multiple flared slopes, sheet structure, magnificent tafoni, gnammas, wedges and boulders superimposed on a curious cottage-loaf shape, with one large

Fig. 6. Corrobinnie Hill showing the inselberg and the areas of granite outcrop surrounded by sand plains and dune fields.

boulder or turret rising above a broader mass of rock, and with this in turn resting upon an extensive platform of granite (Figs. 6 and 10).

Corrobinnie Hill (Fig. 6) rises via a narrow step to a broad even surface which stands some 15 m above this broad granite platform, the level of which is coincident with that of the surrounding sand surface. This suggests that the granite mass may have suffered repeated weathering and planation by moisture (Twidale 1962; Mabbutt 1966) held within the sands lapping up against the flanks of the hills. The moisture could disintegrate the rock and cause the granite slope both to be steepened and to recede, forming the platform which presently surrounds the residual. If this were the case a recession of the order of 500–700 m is indicated by the platforms nearby and extending to Corrobinnie Hill. Presumably far more time than the twenty-odd millennia indicated by the C14 date cited above for the age of the dunes is implied. This last date probably indicates the time of the last onset of aridity and calcrete accumulation whereas sands had been in the Depression at much the same level for some time previously in order for the planation of the inselberg to have occurred. Thus a measure of equilibrium in the Depression between the accession and evacuation of debris is inferred.

Subsurface weathering, which is the essential preparation for the extensive planation, must have occurred when the sand surface stood perhaps 5–6 m higher than at present; flared slopes of this order now border the main mass of Corrobinnie Hill and suggest a land surface which stood level with the then upper extremity for some considerable time. Since that time the sand and weathered granite have been eroded from the higher areas near the upland, exposing both the flared slopes and the essentially planate weathering front in granite as an etch surface. The calcrete accumulated in the sand cover on the granite platform and is preserved on lower slopes. Thus the late Pleistocene date for the calcrete near Corrobinnie Hill provides a minimum date for the granite platform.

Conclusion

The Corrobinnie Depression is characterised by an assemblage of landforms which differs greatly from those on either side. The Depression is considered to be basically a weathering feature. It is due to the exploitation of a major fracture zone in the granitic bedrock of northern Eyre Peninsula by waters flowing from the southern Gawler Ranges.

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Fig. 7. Part of the Kwaterski Dune Field showing parabolic and irregular dune forms, in particular the circular dune complexes (A) comprising patterns of concentric dunes. Longitudinal dunes are seen in bottom left of photograph. (Reproduced by permission, S.A. Lands Department.)

Fig. 8. View across Corrobinnie Depression from Chilpuddie Hill (Fig. 1), showing granite boulder and pavement in foreground, salinas in far middle distance and Gawler Ranges in background. (C. R. Twidale.)

Fig. 9. Shallow depressions or moats at base of granite residual north of Wudinna. (C. R. Twidale.)

Fig. 10. Corrobinnie Hill stands some 15 m above a pitted granite platform (foreground) and is surmounted by a prominent tower, also of granite. (C. R. Twidale.)

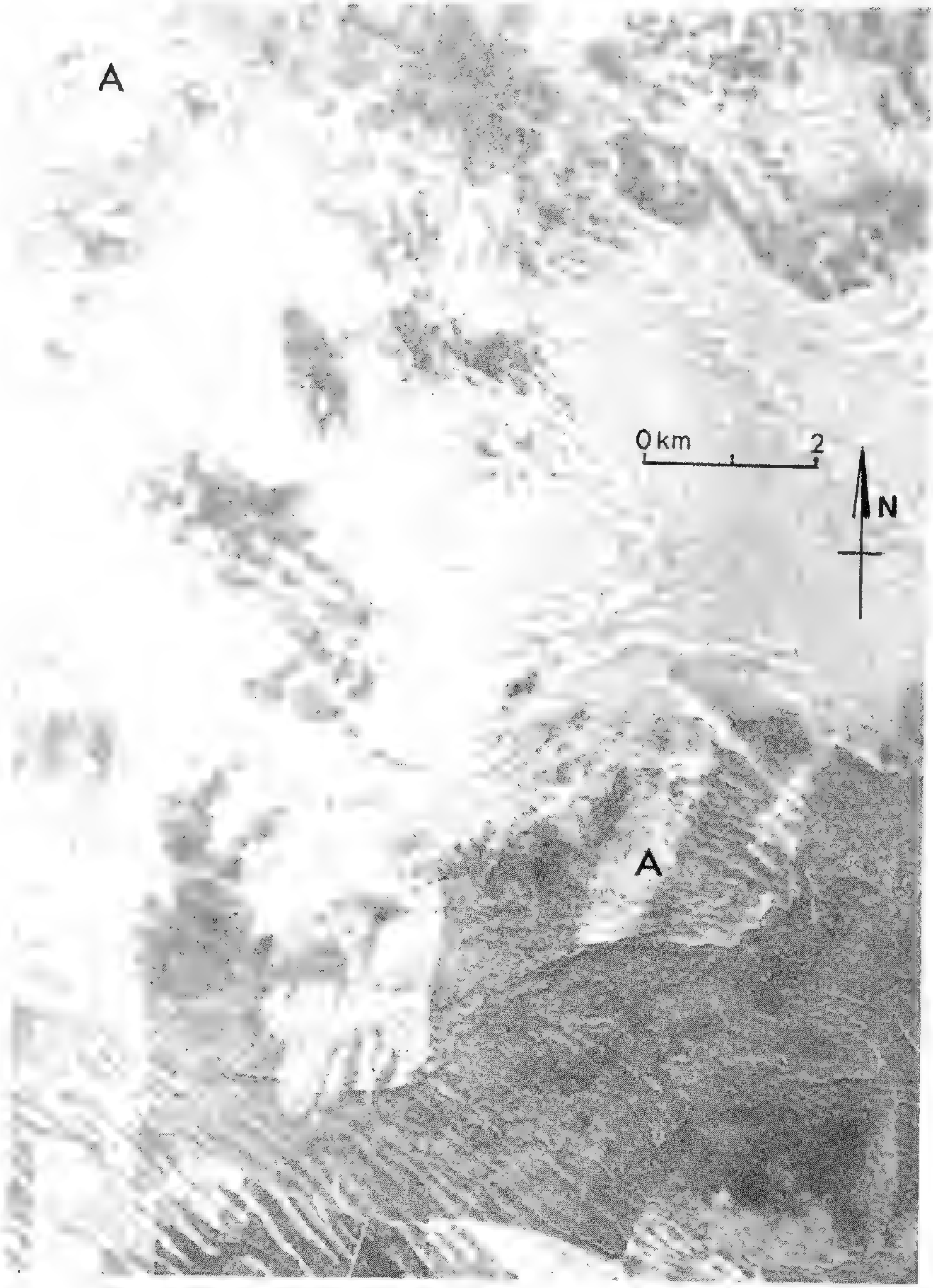

Fig. 7.

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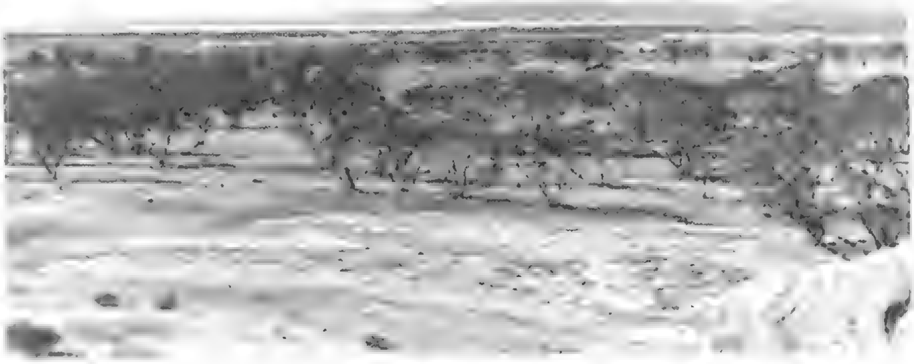

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Figs 8-10

STRUCTURAL LINEAMENTS IN SOUTH AUSTRALIA

*BY J. B. FIRMAN**

Summary

FIRMAN, J. B. (1974) .-Structural Lineaments in South Australia. *Trans.* R. *Soc. S. Aust. 98*(3), 153-171, 31 August, 1974.

Particular linear features can be seen on photo-mosaics at a scale of about 1:63,360. Some sets are better developed in one natural morpholithological subdivision than another. Sets trending approximately NW, NNW, NNE and NE are more common than sets trending WNW and ENE.

The features have been compared with geological and geophysical patterns and trends. There is reasonable agreement between patterns and trends of the linear features and of geological features on maps at scales as small as about 1: 1,000,000, and quite good agreement between linear features and geological and geophysical features at scales of 1:250,000 and 1:63,360.

The comparison of maps of linear features with geological and geophysical maps shows sufficient correspondence of patterns and trends to confirm that particular linear features on photographs are structural features. The persistence of these features as straight lines through different landscapes suggests that they are planar structures with a vertical dip. For these reasons the features have been named *structural lineaments*. Their development appears to be associated with major tectonic events such as warping of the basins and uplifting of the ranges, and it is suggested that they reflect profound structures and tectonic elements in the crystalline basement.

Structural lineaments appear to post-date very young deposits, and to be cross-cutting with respect to Palaeozoic and older fold trends. They also outline basin margins and the structural boundaries of crystalline basement and, in these situations, may be rejuvenated structures as old as the time of formation of the basins and the time of origin of the welded blocks themselves.

Because the youngest structural lineaments are parallel to old structural features marking the margins of ancient blocks, it appears that there has been no major disorientation within the study area of even the oldest structural units.

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Introduction

Extensive patterns of rectilinear fractures—including joints and major faults—were first observed by the author during field-work for the Bureau of Mineral Resources in the Darwin-Katherine, Georgetown-Einasleigh, Calvert Hills-Robinson River, and Port Headland-Ripon Hills areas in Northern Australia during the 1950's. The regional extent of these linear features became apparent when the author compiled early versions of portions of the 1960 Tectonic Map of Australia, including Western Australia, the Northern Territory and parts of Northern Queensland. Later photo-interpretation of areas in the Northern Territory between the MacDonnell Ranges and the Victoria River Basin revealed similar rectilinear patterns, in this case in sparsely vegetated and soil covered areas.

The recognition of similar features in soil covered areas in the Murray Basin of South Australia from low-flying aircraft and on photo mosaics led to a study of these features in 1966 (Firman 1970). The work was continued in later years when student geologists from the University of Adelaide and other geologists from the Geological Survey of South Australia assisted the author to identify and plot the lineaments on available 1:63,360 photo-mosaics for the rest of the State. In 1972, a different method was used to compile a map of lineaments in the Great Artesian Basin on the eastern margin of the State. In 1973, compilation was continued using other methods for lineaments in an area including

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the eastern Eucla Basin and the western margin of the Gawler Block (see Fig. 1).

The paper begins with a brief description of the lineaments, discusses different methods used to compile maps of the lineaments, and concludes with a comparison of the lineaments with geological and geophysical features.

Structural Lineaments

For reasons set down in Firman (1970) and elaborated later in this paper, the particular features appearing on photo-mosaics and described in the introduction as "linear features" have been called "structural lineaments". The linear features appear as local features on individual mosaics, but these can be traced through other mosaics for great distances, or can be seen to be parallel to other similar features having regional extent. There can be, therefore, no simple classification into separate "linears" of local extent and "lineaments" of regional extent as defined by Dennis

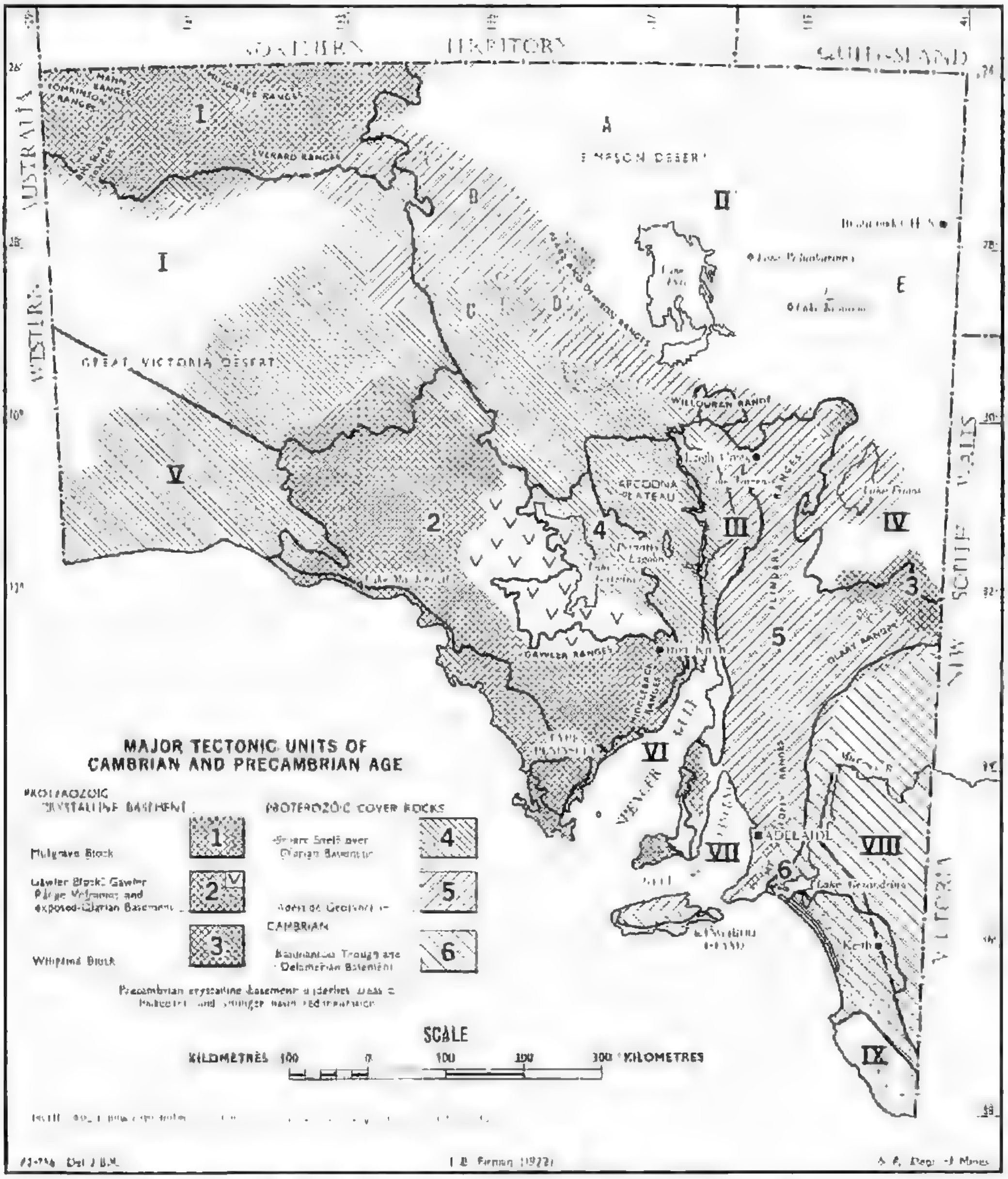

Fig. 1. Locality Map. Morpholithological subdivisions in South Australia.

(1967). Although some local features are obviously joints, there are also local features known to be faults, so there is no simple classification possible into local "linears" which are joints and regional "lineaments" which are faults. Huntington (1973)[1] uses "fracture trace" to describe the kind of feature described herein. Unfortunately, some of the topographic and other features included in his definition have been specifically excluded from the definition of structural lineaments because they are not the particular features recognised on photo-mosaics in this study. For these reasons, the names "linear" and "fracture trace" have not been used.

"Structural lineament" as used herein refers to straight linear features. The features mark structures which are mainly, but not exclusively, fractures (faults and joints). They have both local and regional expression. The structural lineaments described herein occur as particular features on photo-mosaics, at a scale of about 1:63,360. On photo-mosaics of larger scale and smaller area—or on individual air photos—the lineaments cannot be seen so easily. There is no doubt that structural lineaments also have expression on other imagery.

Lineaments are real for the following reasons: They can be seen in the zone of overlap of individual air photos taken at different times from different places, and they are also traceable across adjoining runs in each 1:63,360 photo-mosaic (where at least four different air photos are involved) and from one photo-mosaic to another. Lineaments can be seen from low-flying aircraft, and they have been checked in this way between Adelaide and Coober Pedy, Adelaide and Port Augusta aand Adelaide and Renmark.

There appears to be no unique reason connected with rock type or topography to explain why lineaments should be so clearly visible. The lineaments are equally well defined in terrain developed on crystalline basement—where they are parallel to jointing in outcropping rock—and on terrain developed on flat-lying sediments. In folded sedimentary sequences, most of the third order landforms reflecting fold structures appear to have no relationship at all to the lineaments which cut across them. In faulted areas, some lineaments lie along or closely parallel to fault-line scarps where structural control of landform is clear. Other lineaments in these areas appear to have no relationship to third order landform at all. It is suggested that the lineaments are the result of jointing and faulting, and that they can be seen and photographed even in soil-covered areas of no obvious topographic contrast because vegetation changes occur along them, probably due to moisture variation within the zone penetrated by the roots of growing plants.

A ground check of structural lineaments has been made at various places in the Murray Basin (see Figs. 9 and 10 for locations). Examination of terrain along the Morgan Fault, Marmon Jabuk Fault and Kanawinka Fault (Lineament), which are all marked by

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[1] Huntington, J. F. (1973).—Fracture Analysis. *In* "Photo-Interpretation for exploration and survey geologists". Australian Mineral Foundation (Inc.). Study Course (unpubl.).

MORPHO-LITHOLOGICAL SUBDIVISIONS

Western Basins	Western Shield	Central Basins	Highland Chain	Eastern Basins
I OFFICER BASIN PROVINCE			1. MUSGRAVE RANGES PROVINCE Peake and Denison Ranges	II GREAT ARTESIAN BASIN PROVINCE
	2. GAIRDNER PROVINCE Lake Gairdner area	III TORRENS BASIN PROVINCE VI SPENCER BASIN PROVINCE	5. CENTRAL RANGES PROVINCE Flinders Ranges Olary "Ranges"	IV "FROME EMBAYMENT" PROVINCE
V EUCLA BASIN PROVINCE	Eyre Peninsula	VII ST. VINCENT BASIN PROVINCE	Mt. Lofty Ranges	VIII MURRAY BASIN PROVINCE
			Kangaroo Island	6. in IX Padthaway Ridge
				IX OTWAY BASIN PROVINCE
		INFRABASINS		
A Pedirka Basin	B Arckaringa Basin	C Lake Phillipson Trough	D Boorthanna Trough	E Cooper Basin

structural lineaments, shows the usual features suggesting faulting. These include fault-line scarps and linear third order landforms parallel to the structure (and the structural lineaments), and juxtaposition of different materials at the surface or in bores. Sprigg (1952, pp. 32–38) records dolomitization of small faults and joints marked by secondary calcium carbonate which appear to match regional structural trends in the south-east of South Australia. No separate unique feature appears to mark the lineaments. Elsewhere, for example at some places in the Murray River cliffs, weak fracturing is the only structure matching structural lineaments. Neither lineaments marking the Encounter Fault Zone nor those marking the Hamley Fault have surface expression in basin sediments, although a monocline affecting the Morgan Limestone is exposed in river cliffs near where the matching structural lineament intersects the Murray River. The absence of strong individual fractures in basin sediments should not be taken to mean that displacement does not occur, because strong warping may result from small movements on close-spaced parallel fractures.

The recognition of structural lineaments on photo-mosaics is made easier if the observer takes an oblique view of the mosaic in bright natural light. The position of the photo-mosaic should be changed so as to ensure that all possible directions are covered. The more diffuse lineaments are easier to see when a number of mosaics are matched together. The recognition of lineaments is also controlled to some extent by the quality of the mosaics. Some of the mosaics used in this study are so poor photographically and photo edges are so dominant, that it is extremely difficult to locate any linear features at all. Alignment of photo corners trimmed at 45° interferes with lineament trends to some extent, but this is a minor matter compared to the interference of the EW and NS trending photo edges. These trends are so strong, particularly when combined with processing marks in the same direction, that possible meridional (NS) and latitudinal (EW) lineaments over large areas could well be obscured.

The most prominent characteristic of structural lineaments is their persistence over great distances through different landscapes. Many of the prominent lineaments shown on Fig. 7 are between 100 and 300 km in length, and some exceed 400 km including lineaments belonging to high frequency sets. One of the longest lineaments of Figs. 7 and 8 is that trending NE from the NE shore of L. Gairdner across the Arcoona Plateau, L. Torrens, the Northern Flinders Ranges and Willouran Ranges to near the NW shore of L. Blanche midway between L. Eyre and L. Frome. This prominent lineament matches geological boundaries on maps at a scale of 1:250,000 in the SW and trends on the State Bouguer Gravity Map in the NE. The presence of through-going lineaments of this kind in particular sets of lineaments is evidence that the lineaments are indeed structural features.

The structural lineaments do not necessarily reflect either simple linear topographic features or complex alignments of topographic features, although in many cases they parallel such features and in some cases are probably genetically related. Throughout this work only particular lineaments with the characteristics already described have been recorded. Other structures prominently displayed on photo-mosaics by obvious topographic features—but not by structural lineaments—have been deliberately omitted from the study. The structures omitted include the Eden Fault near Adelaide, small meridional structures marked by low scarps on northern Eyre Peninsula (Miles 1952) and the structure underlying the Ooldea Sand Range on the northern margin of the Eucla Basin (although there are a number of closely parallel lineaments in the last case).

The persistence of the lineaments as straight lines through different landscapes suggests that they are traces of planar structures with a vertical dip. Traces of such structural features on different maps—if followed far enough—must eventually reflect the map projection used, but no systematic variation from a straight line is apparent on the maps produced in this study. The straightness of the lineaments is of practical value for purposes of compilation. Where a suspected structural lineament occurs within or alongside obviously parallel topographic features, the suspected lineament can be traced through a series of mosaics to the point where —if it is a structural lineament—the topographic trends diverge and the lineament continues on in the original direction. Not all situations may be so simply resolved. Slightly curved lineaments have been developed in the NW and S portions of a map of the Murray Basin in South Australia (Firman 1970, p. 2). In the NW these lineaments probably reflect bedding trends in folded Cambrian Kanmantoo Group metasediments beneath a thin veneer of basin sediments. In the south they represent stranded shore-line or linear dune features. Both may be straight line features in part. An important point is that it is only when the lineaments are compiled on a number of photo-mosaics that long-distance trends can be appreciated.

The general trend of the lineaments is NE and NW, but there are several sets, and these intersect to form rectangular and rhomboid blocks. The presence of structures with these trends has long been proposed as a result of studies of topographic patterns (Umbgrove 1947, pp. 294–296; Hills 1956). The presence of similar but less obvious structures with meridional (NS) and latitudinal (EW) trends has also been proposed from studies of topographic patterns, but these were not thought to be as important as the others by earlier investigators. In this study, meridional (NS) lineaments have been drawn on a few photo-mosaics showing parts of the Musgrave Block, and the Flinders Ranges. Latitudinal (EW) lineaments have been drawn on individual photo-mosaics of the Officer Basin, the area near Cook in the Eucla Basin, the area near Lake Gairdner on the Gawler Block, and areas near Innamincka in the Great Artesian Basin and on the southern margin of the Willyama Block. Neither the meridional (NS) nor the latitudinal (EW) lineaments have been continuous enough to retain on the generalised maps accompanying this report. One reason could be that the lineaments are not continuous, but it is more likely that their omission is connected with certain features of the mosaics themselves, as already noted.

Methods of Compilation

Various methods of compilation were used as the study proceeded. These are now described in the original order of their development. Areas involved are shown on the study area diagram (Fig. 2).

Murray Basin

During the preparation of a structural lineament map of the Murray Basin in South Australia (Firman 1970), photo-mosaics at 1:63,360 scale were taken at random from the set of 12 covering each 1:250,000 map sheet. Lineaments were drawn and those which continued across at least two of the 1:63,360 scale photo-mosaics were then transferred to a base map.

Some apparent off-setting appeared at map borders where one lineament in a set of parallel lineaments was selected rather than another. This produced a pseudo *en echelon* effect which was eliminated by tracing one strong and continuous lineament throughout and abandoning the others. There were, however, zones comprised of parallel close-spaced lineaments which were well defined and continuous. An attempt was made in this case to map more than one lineament so as to portray the zone. Figure 3 results from this method.

Preliminary State-wide Study

The coincidence of regional trends and of specific lineaments with faults and with other trends on aeromagnetic maps in the Murray Basin study was sufficiently encouraging to extend the work to the rest of the State. The size of such a project—the whole State is covered by about 280 one-mile mosaics, including about 79 in the Murray Basin—led to the division of that part of the State outside the Murray Basin into five areas on each of which lineaments were mapped by about eight individuals. A total of 192 man-hours was required to complete the task.

Individuals new to this work were shown structural lineaments on a mosaic selected at random and they then delineated the lineaments on other mosaics selected at random from those within the zone. The result was a discontinuous pattern of lineaments having similar trends, but with major interruptions along the mosaic boundaries. Re-examination of the mosaics showed a number of reasons for the discontinuity. Some individuals found the recognition of lineaments very difficult and they developed a pattern parallel to the linear trends of obvious topographic features. The trends identified in this way were either discontinuous or not exactly aligned with trends of structural lineaments on adjoining mosaics. These differences sufficed to eliminate the non-aligned topographic lineaments during later generalisation. The majority of individuals could see the structural lineaments. In this case, the number of lineaments mapped depended upon the observers confidence. Some observers, the more confident, having identified a lineament proceeded to delineate all the parallel lineaments in that set appearing on the mosaic. Others, the less confident or more cautious, delineated only the strongest and more obvious lineaments. An example of this phase of the work is shown on Fig. 4. Although the pattern of lineaments on each mosaic was itself useful, the overall discontinuity of the State-wide pattern was a prob-

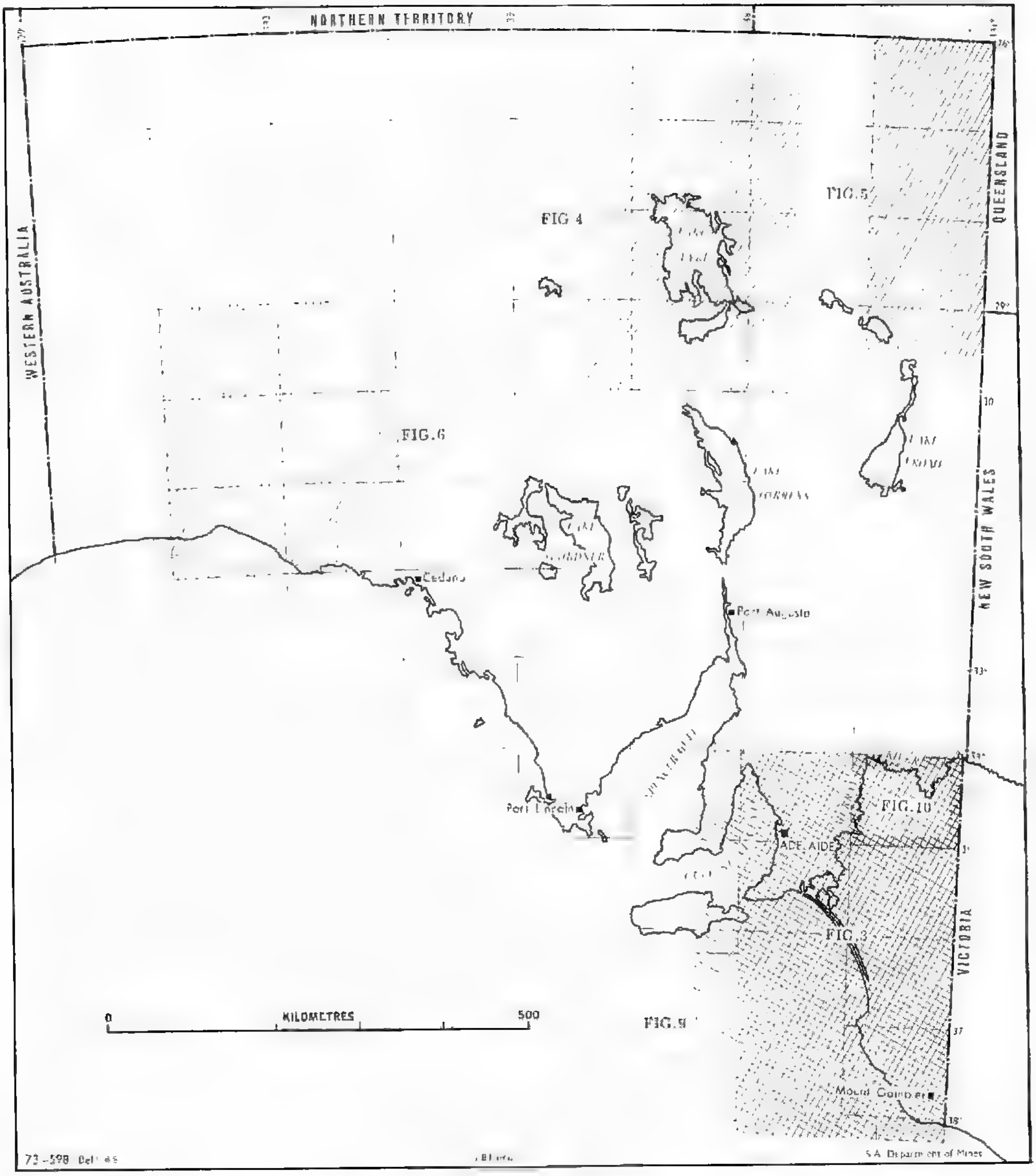

Fig. 2. Study area diagram.

lem. This was overcome by a simple generalisation as later described.

Great Artesian Basin

A deliberate attempt was made to map all the lineaments appearing on the photo-mosaics continuously across adjacent photo-mosaic boundaries in an area extending from the Murray Basin north to the Great Artesian Basin along the eastern boundary of the State. The compilation began in the south in a zone of overlap one photo-mosaic across from north to south, and lineaments were then followed to the north through successive mosaics. During this phase of the work, each mosaic was checked in an attempt to locate prominent

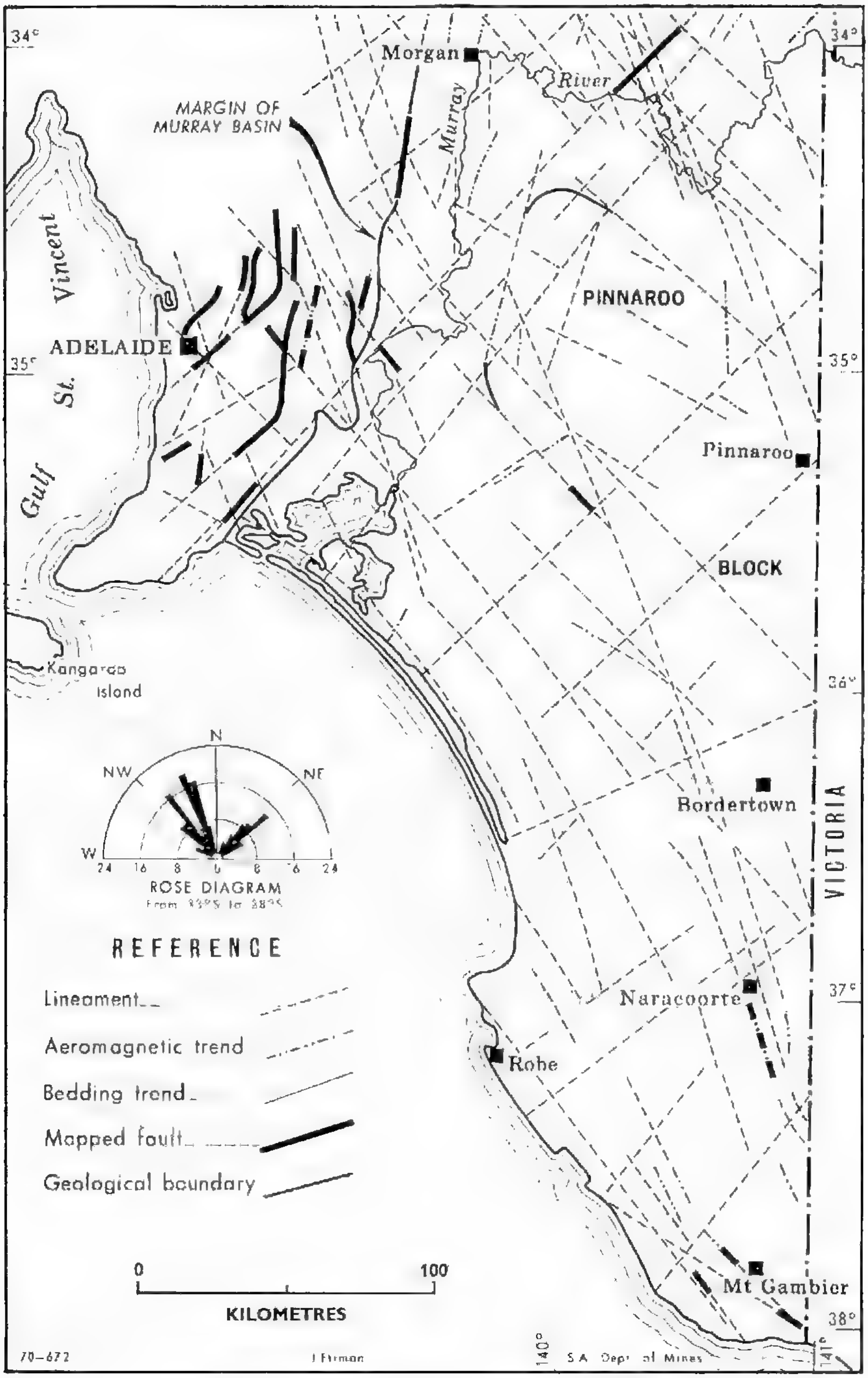

Fig. 3. Murray Basin—Structural lineaments.

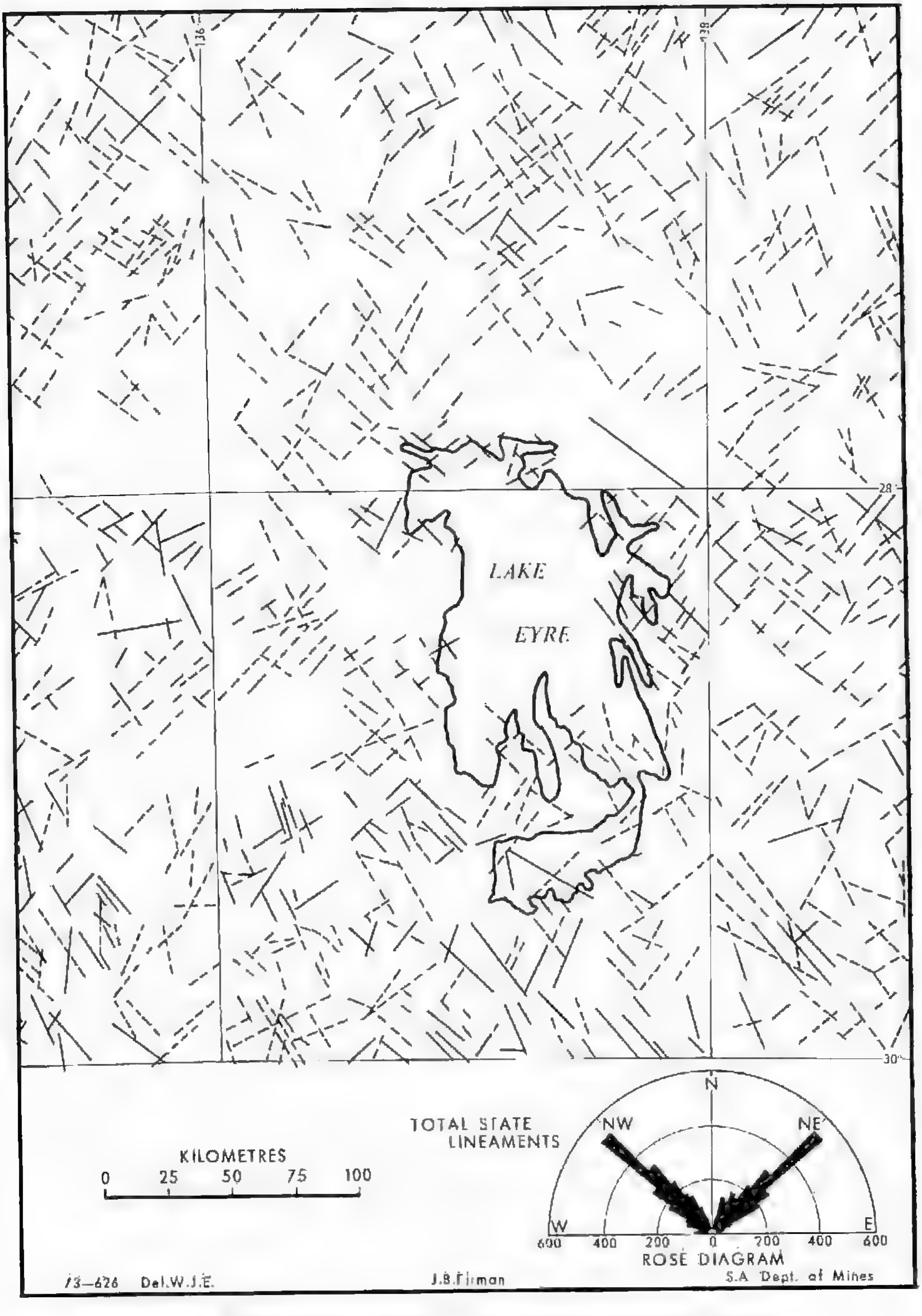

Fig. 4. State-wide study—Structural lineaments from photo-mosaics.

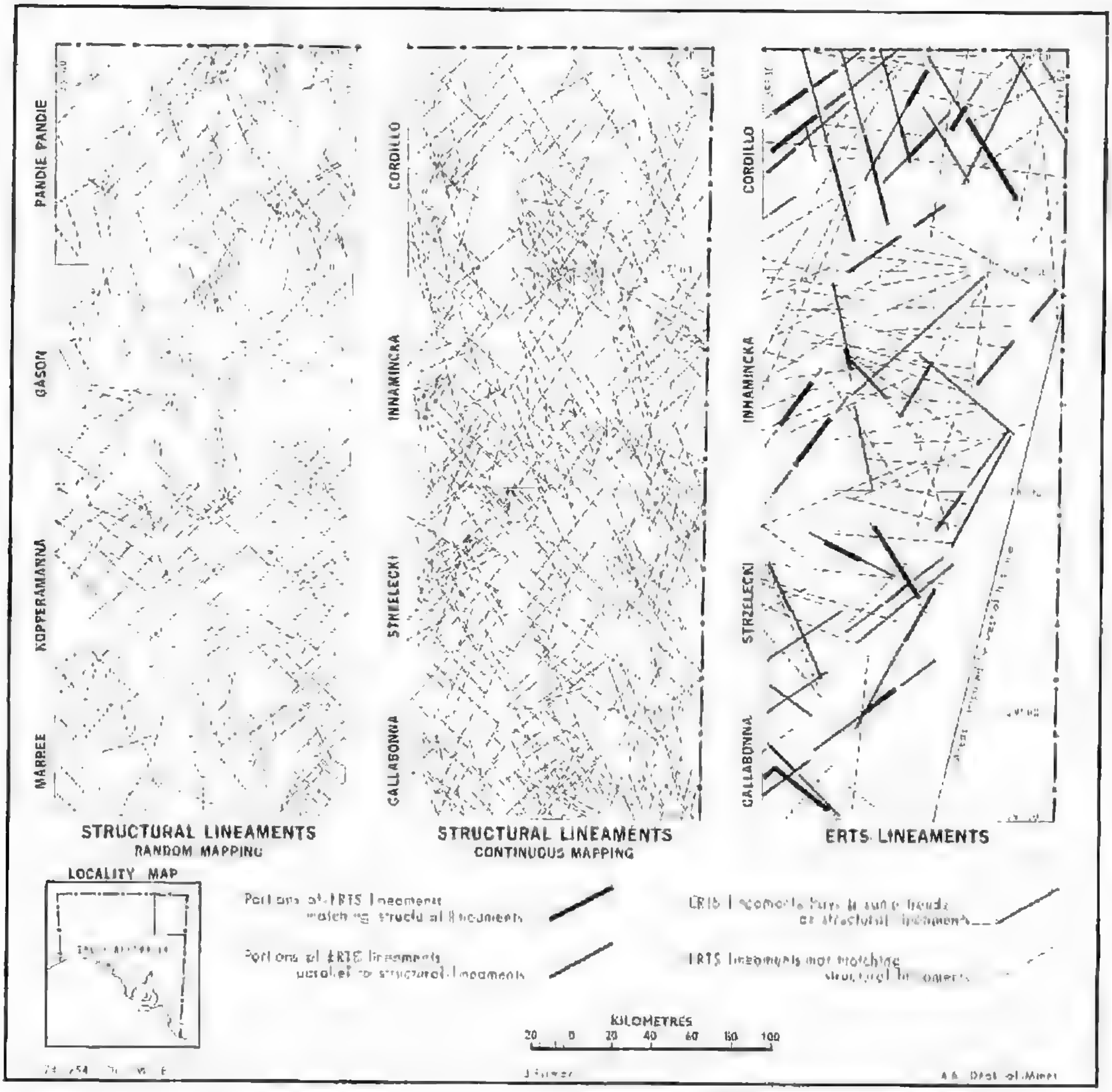

Fig. 5. Great Artesian Basin. Comparison of ERTS lineaments and structural lineaments (right and centre). Areas drawn by different methods and integrated on Figure 7 (left and centre).

lineaments not appearing on mosaics previously examined to the south. Such lineaments were then mapped along with the others.

The attempt to trace lineaments continuously removed the artificial break produced along the EW trending margins of one-mile mosaics, but did not entirely remove the artificial break along the NS trending margins. This was mainly due to the difficulty of recognising continuation of lineaments intersecting the shorter NS trending side of the mosaic at a small angle. The problem was resolved for the Eucla Basin (later described). Although the method was successful, in that a relatively uninterrupted pattern of lineaments was produced, it had the disadvantage common to all methods using only one observer. That is, some lineaments not forming part of the dominant pattern recognised in the region were overlooked.

The contrast between the pattern of lineaments derived by this method and that derived by the earlier method involving random selection of mosaics and delineation of lineaments by a number of observers is shown on Fig. 5. The procedure for generalising structural lineaments—later described—successfully removes the contrast. The actual integration of the two rather different patterns is shown by a comparison of lineaments on the strip maps of Fig. 5 along longitude 139°30′ with the lineaments for the same area shown on Fig. 7.

Because all the lineaments were drawn and then the number reduced systematically with reduction in scale, the spacing of the lineaments on the map prepared by the author is meaningful. Because the lineaments on this map integrate with the lineaments on the rather different map prepared by students on adjoining areas, the spacing of lineaments on the students map is also meaningful at a scale of 1:5,000,000. A comparison of the lengths of prominent lineaments with the lengths of matching structures (see later) suggests that the lengths of the lineaments derived by this generalisation are also meaningful.

A check has been made on an area in the NE of the State where a large number of lineaments have been drawn independently on ERTS imagery by Devine[2] and on photo-mosaics by the author (Fig. 5). The correspondence of some lineaments is so close that they appear to be the same features on the ground identified by the two different methods. Many of the lineaments are not related and it seems that they may represent quite different features on the ground. Although different patterns of lineaments have been delineated by different observers using ERTS imagery, this is not the reason for the difference between the lineaments drawn by Devine and the author. Perhaps some kinds of lineaments can only be identified on photo maps of large areas such as those compiled from ERTS imagery. Again, different methods and different altitudes of cameras and scanners may reveal different features.

Other important references relating to the study of ERTS imagery in South Australia are given in Thomson (1974)[3].

Eucla Basin

A large area including the eastern Eucla Basin and the western margin of the Gawler Block had not previously been studied because photo-mosaics were not available. In this area, lineaments were identified on two blocks of adjoining photo-mosaics with an irregular east-west boundary close to 31°S latitude. The mosaics in each block were arranged for best fit at edge centres. Despite some obvious offsetting due to lack of control on each mosaic the lineaments could be traced through adjoining photo-mosaics without interruption.

This method had the advantage that the more prominent and continuous lineaments could be readily identified. Furthermore, compilation time was markedly reduced. Apart from the disadvantages which arise when only one observer does the work, such as omission of some less obvious lineaments, there was another unusual result. Because some of the lineaments were more prominent in each block an exaggerated zone of discontinuity was developed between the blocks. This was removed by checking to see if lineaments developed on one block did in fact continue on the other. This revealed that the differences had been exaggerated and that this could be corrected by continuing the less obvious trends from one block of photo-mosaics to the other. Fig. 6 shows the pattern of lineaments resulting from the use of this method.

The exercise does show the need for checking so that only real differences in the pattern of lineaments are recorded. The presence of regional differences in the pattern of lineaments is important and is mentioned below.

In built-up areas, structural lineaments are obscured and may be difficult to separate from engineering structures with linear trends. In these areas, the methods of laying down a large number of photo-mosaics has obvious advantages. The most important is that structural lineaments can be identified outside the built-up area and then traced through it. The method has also been proved useful on coastal margins, particularly where a confused pattern of younger aeolian and transitional deposits occurs together with the structural lineaments.

Generalisation of Structural Lineaments

The patterns of lineaments drawn for local areas were added to the State lineament map compiled by the author and others at a scale of 1:1,000,000. Lineaments for small areas previously omitted for a variety of reasons

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[2] Devine, S. B. (1973).—Studies in small-scale geological mapping, South Australia (Corridor 4, Cooper Basin). ERTS-1 Type II Report. July 1972 to January 1973. Dept. Mines S.A. Report 73/67 (unpubl.).

[3] Thomson, B. P. (1974).—ERTS-1 Imagery and small-scale mapping studies in South Australia. Final Report, Dept. Mines S.A. NASA final report (Type III). DM 1097/72 (unpubl.)

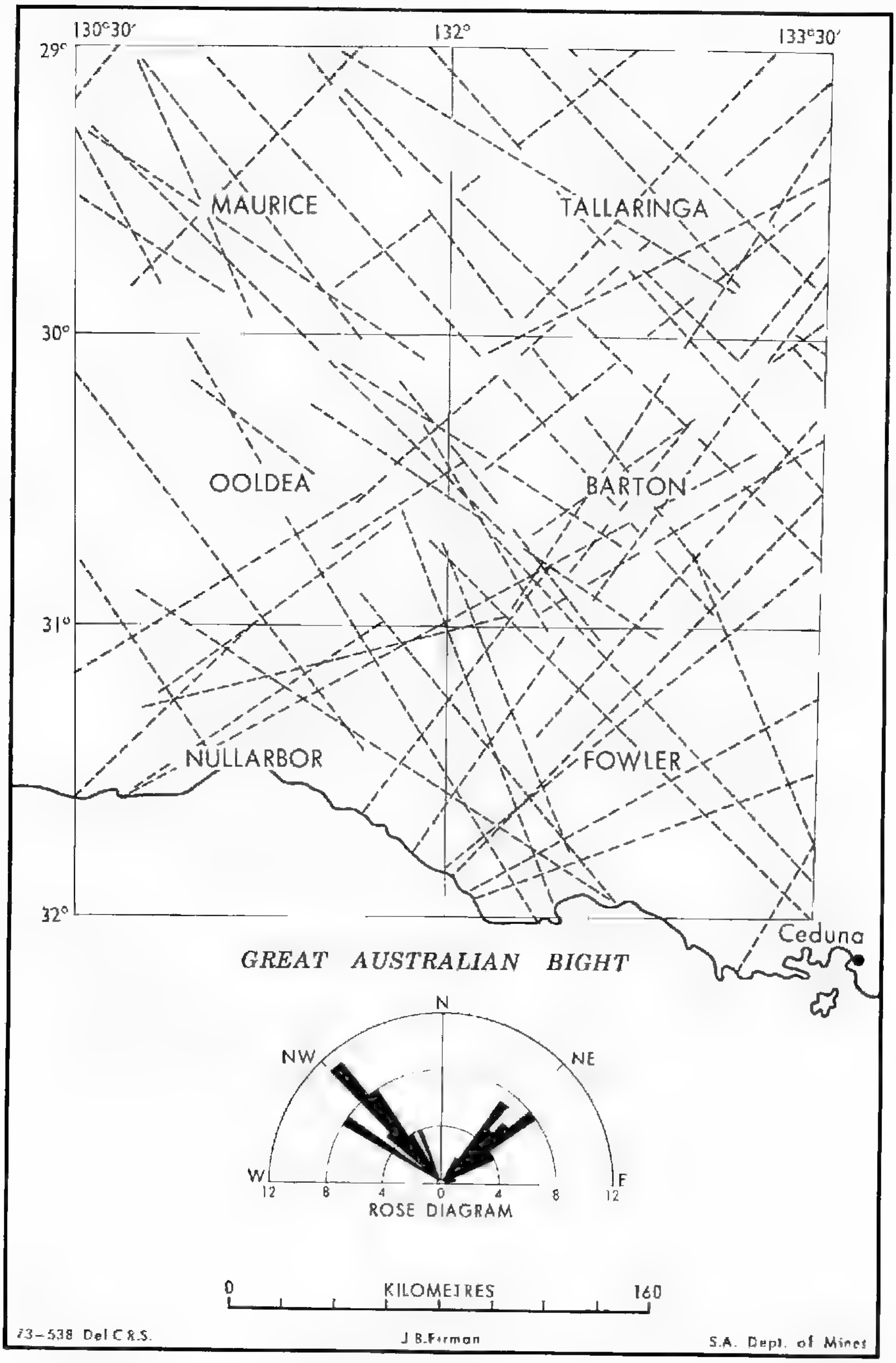

Fig. 6. Eucla Basin—Structural lineaments.

were also added at this stage. The largest of these was a NS trending strip of photo-mosaics on the western margin of the Great Artesian Basin, including Irwin, Ungoolatanna, Granite Downs, Yoolperlunna, Marla, Ouldburra and Manya. The method used for this area was that of continuous mapping as developed in the Great Artesian Basin.

The procedure for generalising structural lineaments was as follows. The 1:1,000,000 scale compilation was first reduced to 1:2,500,000 and work was begun on those parts of this map drawn from the preliminary State map. That is, the parts showing greatest discontinuity across photo-mosaic boundaries. The continuation of aligned but disconnected lineaments could best be seen within "rectangular" areas of about 2° on the side. No attempt was made to connect lineaments that were not aligned at the original scale of 1:1,000,00, that is were further apart than 0.5 km when the lineaments were projected. Interpolation between aligned lineaments was carried out within each rectangle wherever the distance apart was no greater than the sum of the lengths of the aligned lineaments. This restriction was necessary to avoid interpolation across areas where it was likely that the lineaments did not in fact occur.

At this point in the procedure, lineaments developed on the Eucla Basin, Great Artesian Basin and Murray Basin compilations by other methods could be integrated because some were aligned and continued across the boundaries of the different map areas, and because others were of about the same length and spacing. The map was then reduced to 1:5,000,000 and the more prominent lineaments were identified and marked, including those in local areas delineated originally by a variety of methods. This pattern of lineaments is shown on Fig. 7

The reality of the prominent lineaments as to trend, length and spacing throughout the State derives from the original attempt by the author to trace all visible lineaments in certain areas throughout their length, and depends upon the method of generalisation used, and upon the integration of the prominent lineaments so defined with lineaments originally mapped in a random way by a number of other observers. A comparison of prominent lineaments and known faults shown on geological maps at the same scale shows that the prominent lineaments are of about the same length as the major faults. At this scale (1:2,500,000) the major faults have been traced to their natural limits. Lineaments of greater length could be drawn by continuing the generalisation step by step with reduction in scale. It is probable that lineaments so drawn would no longer mark simple faults, but would mark more complicated tectonic features of another order.

The generalisation of structural lineaments and selection of the more continuous leads to the omission of some discontinuous but prominent lineaments which are possibly of considerable local importance. These, however, are recorded on the original mosaics at a useful scale of 1:63,360. In contrast to more general methods, those used herein make the closer investigation of interesting local areas at a larger scale a relatively simple matter.

Discussion of structural lineaments throughout the State can be simplified if the sets are assumed to belong to conjugate systems of intersecting lineaments with an inferred meridional axis, as suggested by inspection of Fig. 7. Described in this way, the lineaments are grouped into a system with a large meridional component in which sets trend approximately NNW and NNE, a system with sets trending approximately NW and NE, and a system with a large latitudinal component in which sets trend approximately WNW and ENE. The system with a large latitudinal component contains few lineaments and is therefore not as obvious as the other systems.

The set of lineaments in the system with a large meridional component which trends approximately NNW is prominent in the southern Eucla Basin, south-east Great Artesian Basin and Murray Basin. The set of lineaments in this system which trends approximately NNE is prominent in part at least of all the Provinces. Neither the NNW nor the NNE trending sets of lineaments are prominent in the Musgrave and Gawler Blocks. In the system with sets of lineaments trending approximately NW and NE, the lineaments of both sets are prominent throughout the State. In the system with a large latitudinal component, the set of lineaments trending approximately WNW is prominent in the west of the State, particularly in the Officer and Eucla Basins, but is not so prominent in the eastern basins. The set of lineaments in this system which trends ENE occurs in all blocks and basins throughout the State, and is well developed in the Eucla Basin.

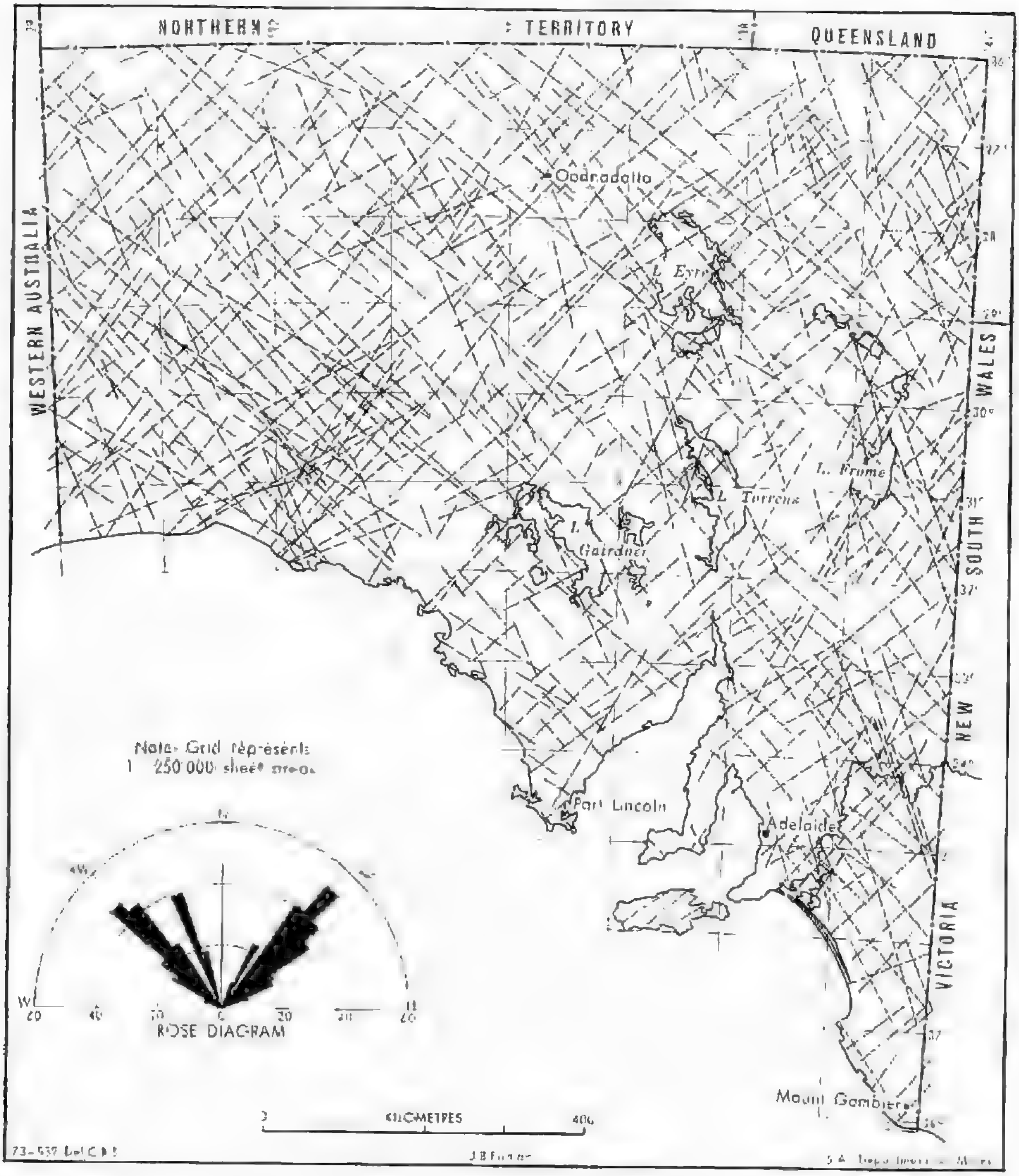

Fig. 7. Prominent structural lineaments in South Australia.

The above comments derive from a careful inspection of the lineaments themselves. The rose diagrams acompanying maps of various areas do not reveal this kind of detail. Diagrams of lineaments drawn by other observers can be excluded because frequency and trend is biased by artificial discontinuity at mosaic boundaries. Other rose diagrams on maps drawn by the author of various parts of the State do not show the same areas as the morpholithological subdivisions. On the map of prominent lineaments, longer lineaments and sets of lineaments in certain subdivisions made obvious because of strongly contrasting trends are not revealed by the diagrams.

Comparison with other features

During the Murray Basin study, structural lineaments were compared with known faults, basement trends, and other trends derived from aeromagnetic maps compiled by the S.A. Department of Mines and Geological Survey. The coincidence of these features was surprisingly close. For example, structural lineaments and aeromagnetic trends marking the western edge of the Murray Basin all fell upon a major "hardrock" boundary originally delineated by B. P. Thomson (unpub.) (see Firman 1970, p. 2, and Fig. 3 of this report).

Geological

The 1:5,000,000 compilation showing the more prominent structural lineaments was compared with geological and geophysical maps. The purpose of this comparison was to check the amount of coincidence at various scales of the patterns and trends of structural lineaments with the patterns and trends shown on other geological and geophysical maps.

A comparison of the structural lineaments with small-scale maps showed only a general agreement of patterns and trends. A check of the State geological 1:10,000,000 map with other geological maps at about this scale showed gross differences in geological pattern for the same area, due no doubt to the extreme simplification of outcrop boundaries concomitant with geological interpretation on maps at this scale. For this reason, a close fit with general maps of this kind could not be expected.

The agreement between structural lineaments and large scale maps was much better. A comparison leading to selection of major lineaments has been made with features on the Tectonic Map of Australia and New Guinea (1971) at a scale of 1:5,000,000. A comparison of structural lineaments with all the available regional geological maps at a scale of 1:250,000 showed by far the best match of structural lineaments with geological patterns and trends.

Structural lineaments that match the tectonic and regional geological maps are shown on Fig. 8. This match could probably be improved by the omission of those parts of the lineaments extending beyond the region wherein the fit is best. Although this work could not provide a complete structural map because of the restriction of features delineated to the particular lineaments discussed herein, a large number of important structures are in fact identified.

B. G. Forbes has suggested (pers. comm.) that areas of different density of lineaments require explanation. It could be argued that some of the areas of sparse lineaments are due to a cover of surficial deposits, but it is the author's experience that the lineaments are quite well displayed upon photo-mosaics of terrain veneered by such deposits. An explanation of the Officer-Eucla Basin area of sparse lineaments surrounded by a zone of greater density of lines is that there is a well developed zone of lineaments marginal to the adjoining Musgrave and Gawler Blocks. No such explanation can be made for the zone of greater density of lineaments trending ENE through the Cooper Basin (see Fig. 8).

There are numerous N-S and E-W trending features on the tectonic and regional geological maps for which there are no corresponding structural lineaments, probably for the reasons already outlined. Given that the close fit between features on the different kinds of maps is real, a case could be made for a final phase in this kind of study in which the original mosaics were again examined to locate any important lineaments omitted during generalisation. A re-examination of the original mosaics or detailed maps could also be made to check for lineaments with an even better fit than those selected from the generalised maps.

It does seem that separate investigations of the fit of structural lineaments with other geological patterns and trends could be eliminated if the lineaments were mapped along with other detailed geological features at an early stage in regional mapping.

Geophysical

Three kinds of geophysical maps have been compared with the maps of structural lineaments. These are the Bouguer gravity map of the State (Coppin, Hall & Milton 1971), the map of the Great Artesian Basin province showing contours of magnetic intensity and interpreted depths to magnetic basement (Coppin & Hall 1972), both at a scale of 1:1,000,000, and the 1:250,000 and 1:63,360 aeromagnetic maps used in the original study of the Murray Basin in South Australia. Although some of the following comments are based upon the comparison of structural lineaments with all the geophysical maps men-

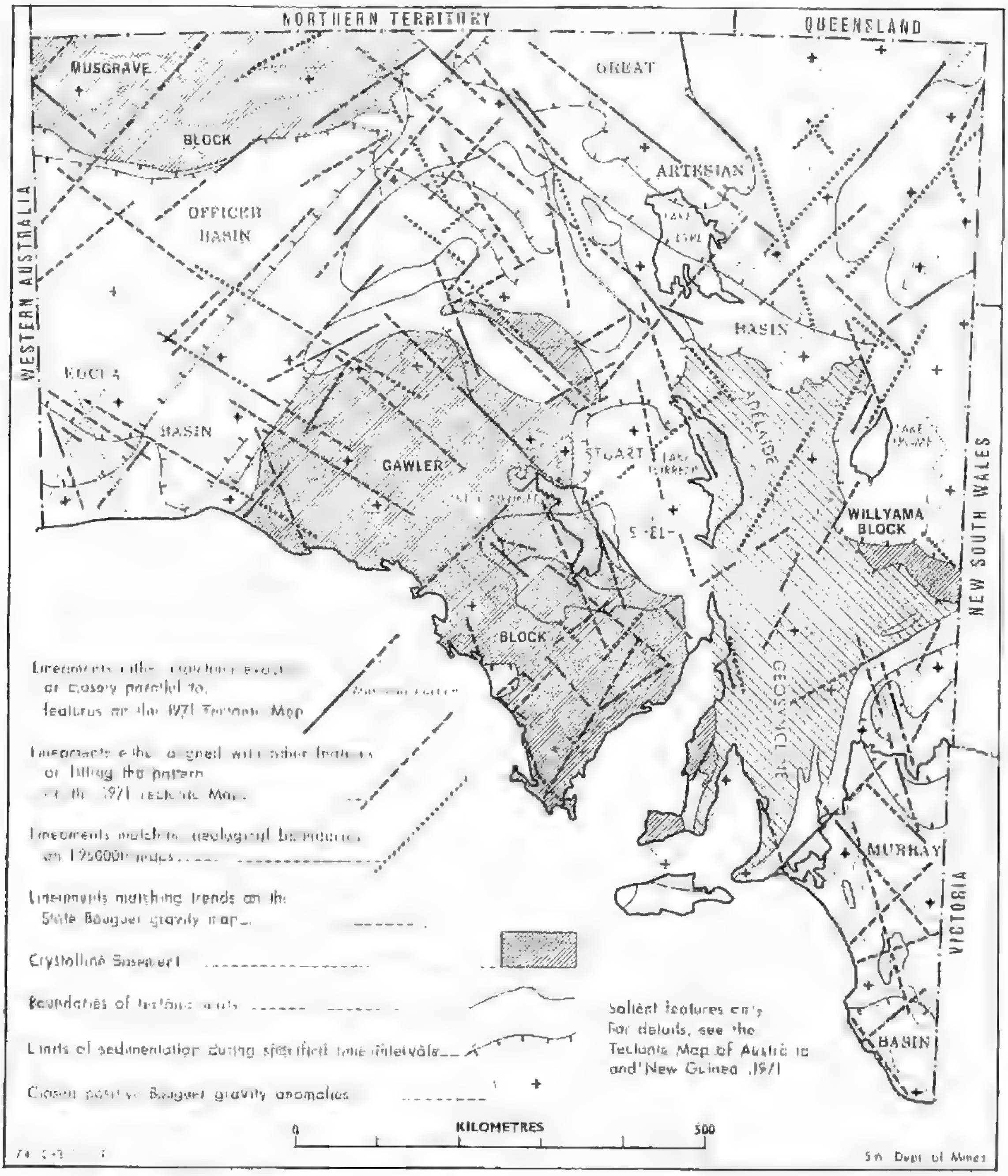

Fig. 8. Structural lineaments matching geological and geophysical patterns and trends.

tioned, only the Bouguer gravity map with complete State coverage has been used to compile the appropriate lineaments on Fig. 8.

The Bouguer gravity map does show similar trends, but selection of coincident features is not easy because a number of contour lines are shown rather than single features, which on checking can be shown to be either coincident or not coincident with a particular lineament. There are two kinds of geophysical features on the gravity plan parallel to lineaments. These are gravity contour shapes which

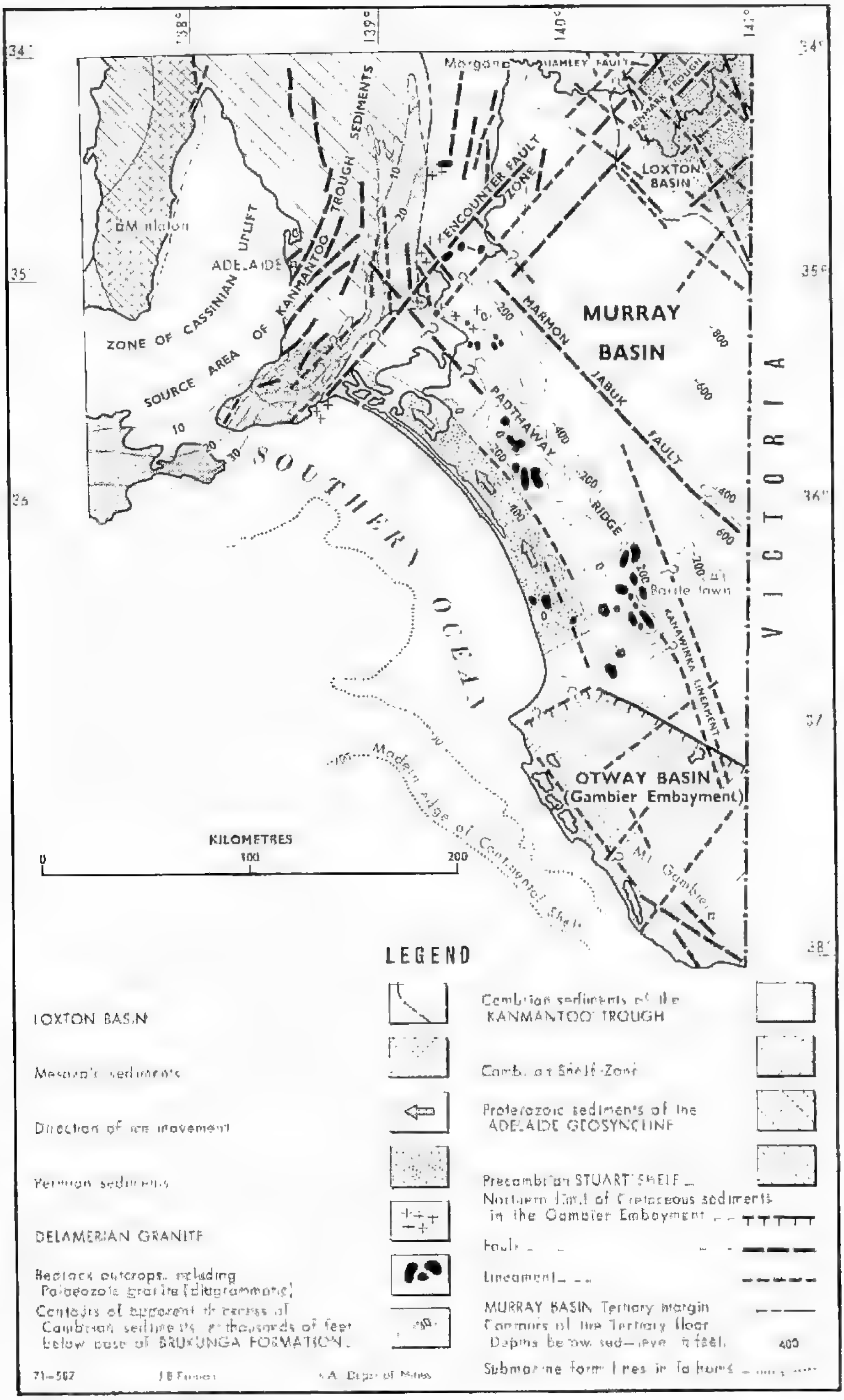

Fig. 9. Murray Basin. Development of the western margin and geology of the Tertiary floor.

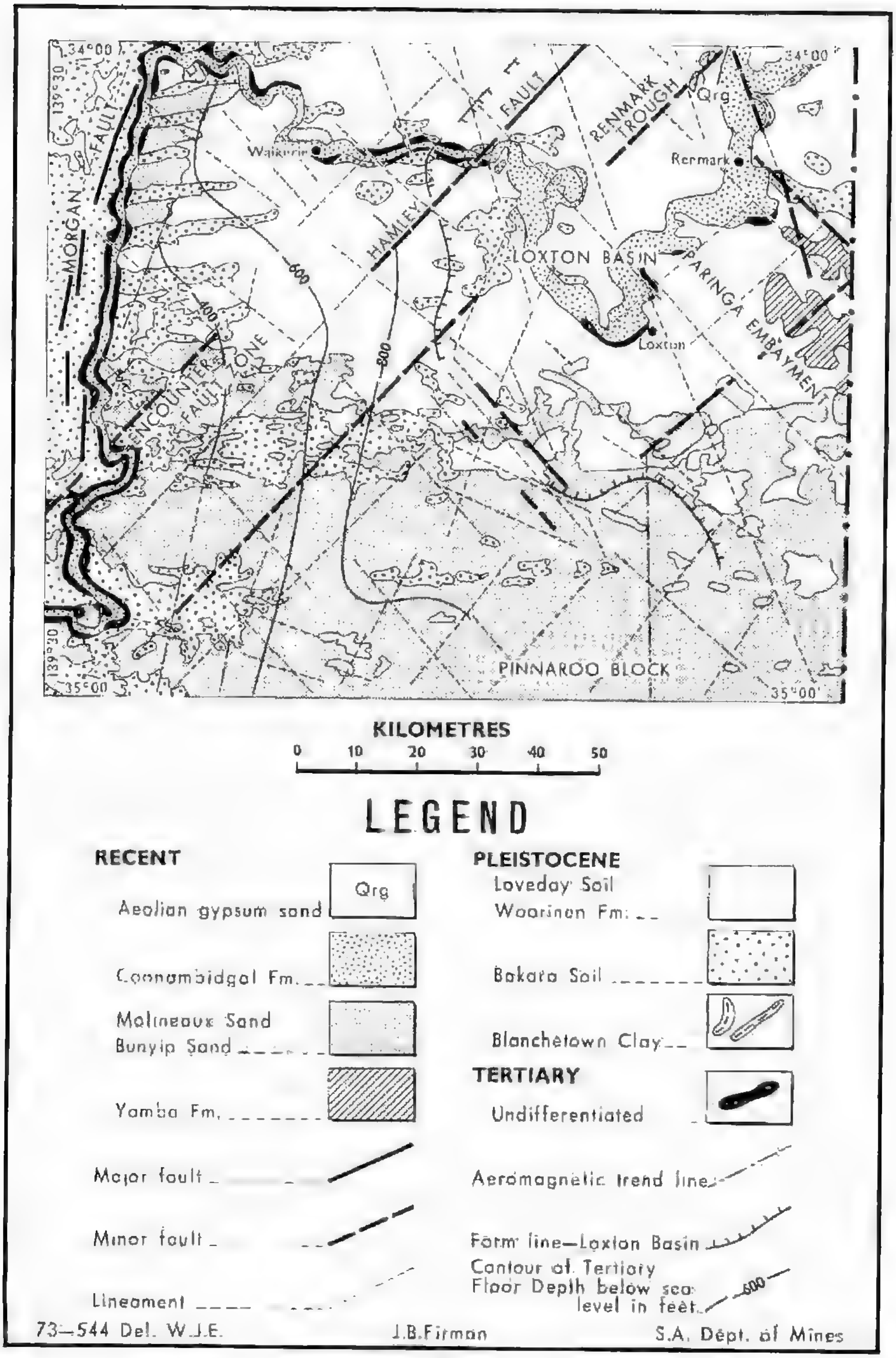

Fig. 10. Tectonic sketch on RENMARK sheet S1/54-10.

in detail fit fairly closely to shapes formed by intersecting lineaments—this fit may be rather more apparent than real, because selection of another contour interval could produce a rather poor fit—and major trends on the gravity map which parallel major trends on the map of structural lineaments. In some places small closed features on the gravity map are marked by the intersection of several lineaments or are framed by a pattern of lineaments around the periphery of the feature.

On the 1:1,000,000 geophysical map showing contours of magnetic intensity and interpreted depths to magnetic basement, the fit of structural lineaments with geophysical features is not good. The trend of structural lineaments coincides best of all with the trend of contours showing depths to magnetic basement. There is a very poor fit of the trends of structural lineaments and trends of contours of total magnetic intensity, except where the trends of contours of depths to magnetic basement and of contours of total magnetic intensity are in a similar direction. Only a few of the structural lineaments are coincident with inferred basement faults shown on the geophysical map.

Aeromagnetic maps at a scale of 1:63,360 were used to compile trends of aeromagnetic features in the Murray Basin. Structural lineaments were in very good agreement with aeromagnetic trends on this map (Firman 1970, p. 2).

The comparison of maps of structural lineaments with other geological and geophysical maps shows sufficient correspondence of patterns and trends to confirm the earlier conclusion from the Murray Basin study that the linear features on photo-mosaics are actually structural features. Many of the lineaments mark structures associated with warping of the basins and uplifting of the ranges, and reflect profound structures and tectonic elements in the crystalline basement.

An incidental observation resulting from this study is that the selection of more important structural lineaments can best be made by comparison with other geological and geophysical features associated with the lineaments. Firman (1972, RENMARK sheet) and Fig. 9, and the tectonic sketch in Firman (1972) together with Fig. 10, provide examples

Time of Origin of Structural Lineaments

In general, structural lineaments appear to post-date very young deposits. This is a conclusion based upon their presence in areas mantled by surficial deposits thick enough to bury the older rocks. Some of the lineaments serve to outline the margins of basins containing relatively flat-lying Cainozoic, Mesozoic and Palaeozoic rocks and these lineaments could mark much older rejuvenated structures as old as the first deformation of the original basins.

In regions of strongly folded Palaeozoic and older rocks, the lineaments are cross-cutting with respect to major fold trends and obviously post-date them. However, major structural boundaries between the fold belts and adjoining blocks of crystalline basement are also marked by structural lineaments. The implication is that the lineaments mark much older structures, some of which must immediately post-date the welding of ancient sedimentary and metamorphic components to form the blocks themselves.

Because both the oldest structures delineating basement blocks and the youngest lineaments form part of the same through-going and ubiquitous sets of structural lineaments, it appears that there has been no major disorientation within the study area of even the oldest structures.

Acknowledgements

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*BY A. E. ORCHARD**

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Myriophyllum callitrichoides Orchard, sp. nov

Herba aquatica ad 25 cm alta, caules et folia dimorpha. Caules primarii moderate robusti ascendens ad basim radicantes 5–7 cm alti 2–4 mm diametris sparsim ramosi; folia alterna obovoidea (in vivo) vel spathulata (in sicco) 6–8 mm longa 1.5–2.0 mm lata apicum versus contracta ad 1.0 mm basin versus succulenta integra, apices rotundati callo atrato praediti, plusminusve recurvata glandibus 2 minutis filiformibus stipuloidibus deciduis atratis subtenta. Caules secundarii filiformes axillis foliorum inferioris exorientes, ad 15 cm longi 0.2–0.3 mm diametris, axillis foliorum 1.0–1.5 mm longorum distantium alternorum (raro suboppositorum) reductorum bracteoidum ramificantes. Folia emergentia ad extremum caulium secundariorum arcte aggregata alterna petiolata, lamina succulenta ovata 2.0–3.5 mm longa 2.0–2.5 mm lata integra, apex rotundatus callo atro apicali, basis contracta abrupte ad petiolum, nervi indistincti plusminusve paralleli, petiolus 1.0–1.5 mm longus, appendicibus stipuloidibus 2–4 atris filiformibus ad basim petiolorum, unusquisque folium emergens florem unum bisexualem adnatum ad petiolum praeditus

Flores 4-meri sessiles appendicibus 2 stipuloidibus subtenti. Sepala 4 anguste deltoidea 0.2 mm longa 0.1 mm lata integra vel infirme denticulata. Petala 4 cucullata 0.8–1.0 mm longa 0.3 mm lata infirme carinata. Stamina 4 antipetala fila 0.1 mm longa ad ca 0.5 mm post anthesin protenta, antherae luteae ovoideae 0.6 mm longae 0.2–0.3 mm latae minute apiculatae. Styli 4 filiformes 1.5 mm longi. Ovarium sessile obturbinatum 0.4–0.5 mm longum 0.7–0.8 mm latum sub petalis saccatum sub sepalis sulcatum 4-loculare ovulis unis in unusquisque.

Fructus cruciformis petiolus varicus, mericarpia ad apices connata deorsum extrinsecusque ad angulum 45° divergentia anguste obovoidea 1.1–1.2 mm longa 0.3–0.4 mm diametro verrucosa in superficie exteriore praecipue in parte inferiore tuberculis retrorsis; semen 1 in unusquisque mericarpo.

Holotypus: C. Dunlop 3387, 28.ii.1973, Nourlangie Creek, 12°52'S, 132°47'E. Rockhole in sandstone conglomerate. Aquatic rooted in organic sludge: dimorphic leaves, submerged leaves fleshy. CANB243801 (fl., fr.)! (Fig. 1). *Isotypi:* AK! DNA, NT!, BRI, K, L.

Weak aquatic herb to 25 cm high, stems and leaves dimorphic. Primary stems moderately robust, ascending, rooting at base, 5–7 cm tall, 2–4 mm in diam., sparsely branched, leaves alternate, succulent, obovoid (in vivo) or spathulate (in sicco), 6–8 mm long, 1.5–2.0 mm broad towards tip, tapering to 1.0 mm towards base, entire, slightly recurved, tip rounded, with black terminal callus. Leaves with 2 minute filiform stipule-like deciduous black glands at base of petiole.

Filiform secondary stems arising in axils of lower (primary) leaves, to 15 cm long, 0.2–0.3 mm in diam., branching from axils of distant alternate (rarely subopposite) bract-like reduced leaves 1.0–1.5 mm long. Emergent leaves closely clustered at tips of secondary stems, alternate, petiolate, lamina succulent, ovate, 2.0–3.5 mm long, 2.0–2.5 mm wide, entire, tip rounded with black apical callus, base abruptly tapered to petiole, veins indistinct, ± parallel, petiole 1.0–1.5 mm long, with 2–4 black filiform, stipule-like appendages at its base. Each emergent leaf provided with

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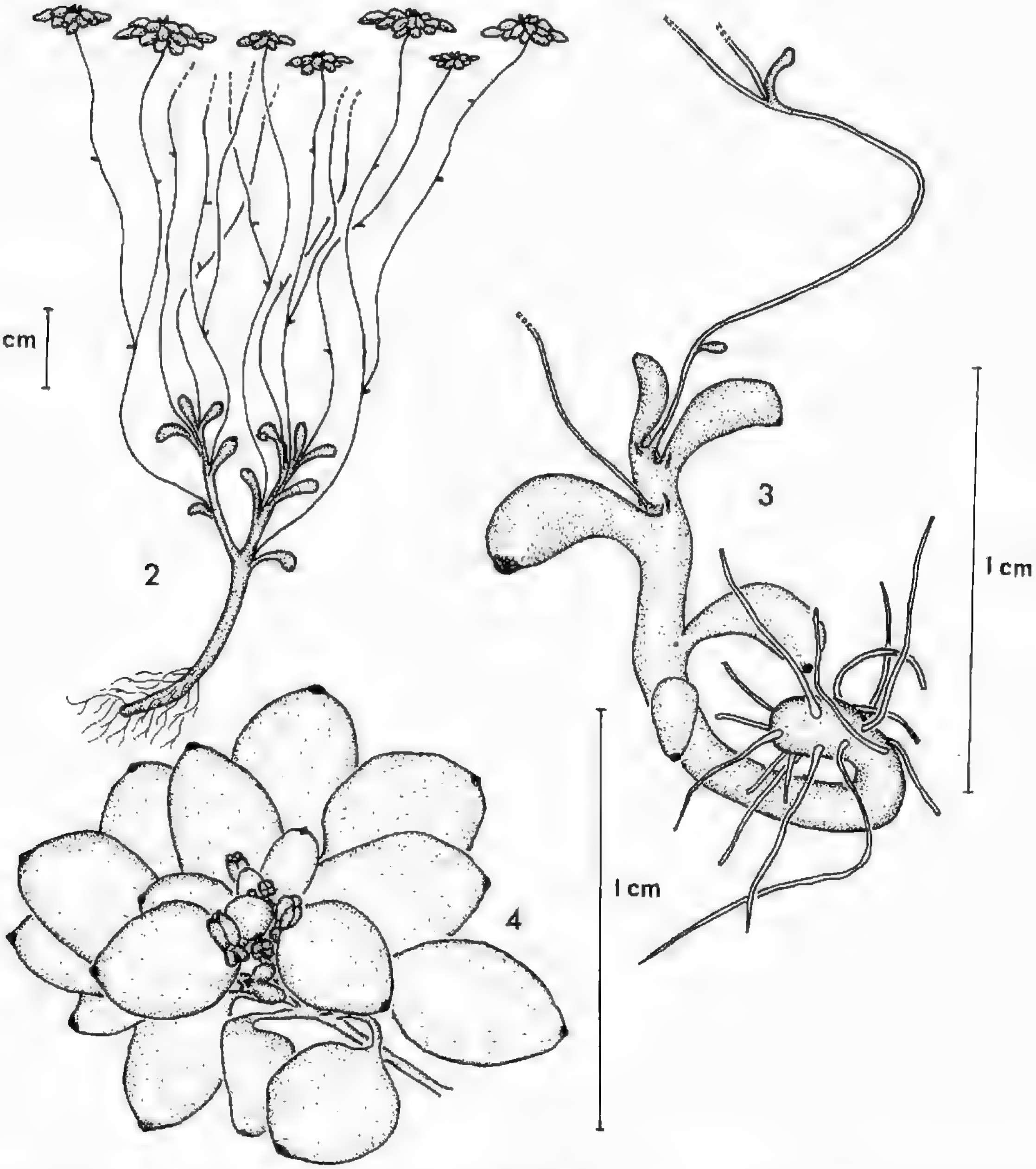
* Auckland Institute & Museum, Private Bag, Auckland, New Zealand.

Fig. 1. The holotype of *Myriophyllum callitrichoides* Orchard.

single bisexual flower, adnate to middle of petiole.

Flowers 4-merous, ± sessile, flanked by 2 stipuloid appendanges as for leaves. Sepals 4, narrow-deltoid, 0.2 mm long, 0.1 mm wide, entire or weakly denticulate. Petals 4, hooded, 0.8–1.0 mm long, 0.3 mm wide, weakly keeled. Stamens 4, antipetalous, filaments 0.1 mm long, lengthening to ca 0.5 mm after anthesis; anthers yellow, ovoid, 0.6 mm long, 0.2–0.3 mm wide, minutely apiculate. Styles 4, filiform, 1.5 mm long. Ovary ± sessile, obturbinate, 0.4–0.5 mm



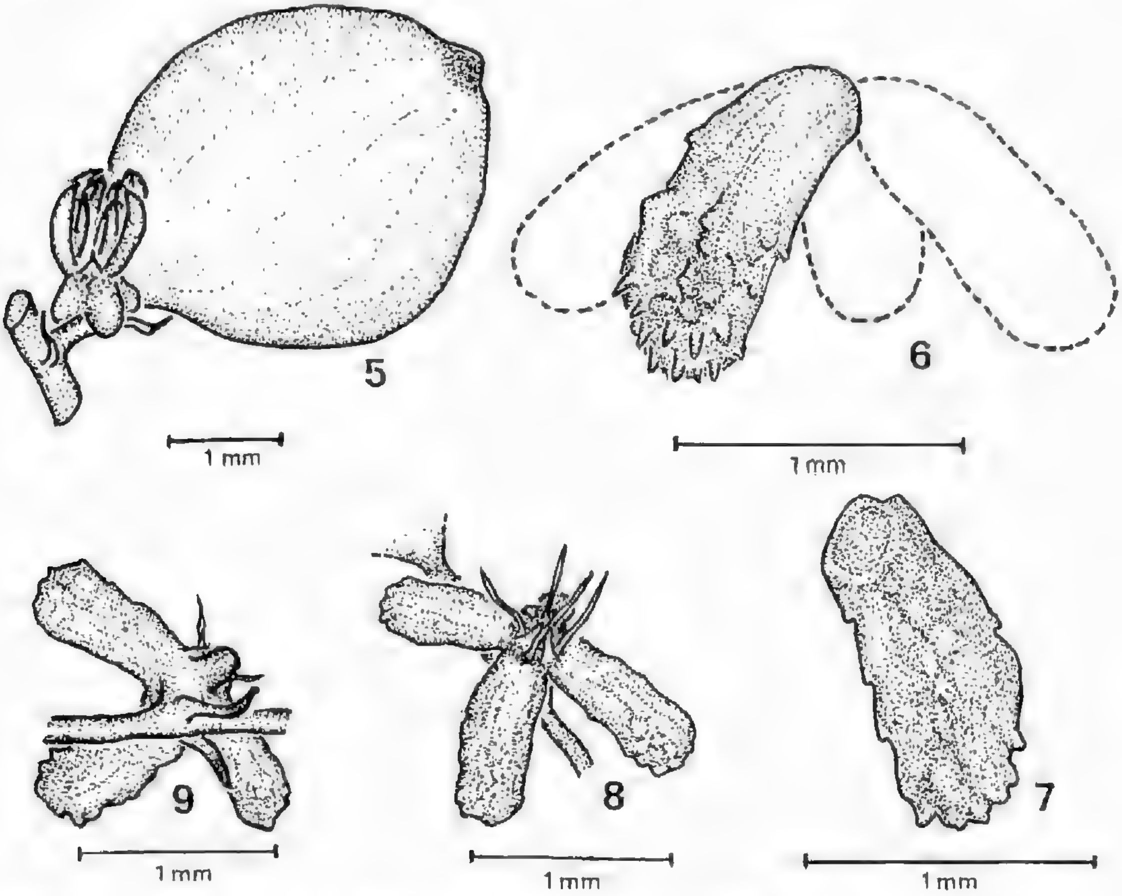
Figs. 2–4. Habit of *M. callitrichoides*. Fig. 2.—Whole plant. Fig. 3.—Base of plant showing young primary stem and leaves, and lower part of secondary stems. Fig. 4.—"Rosette" of emergent leaves, flowers and immature fruit, viewed from above. (All from *Dunlop* 3387; fig. 2 from dried material, figs. 3 and 4 from liquid preserved specimens.)

long, 0.7–0.8 mm wide, saccate below petals, grooved below sepals, 4 locules with 1 ovule in each.

Fruit black, cruciform, straddling petiole, mericarps fused at apices, diverging downwards and outwards at 45°, mericarps narrowly obovoid, 1.1–1.2 mm long, 0.3–0.4 mm in diam., verrucose on outer face, particularly in lower part, with downward pointing asperities; 1 seed per mericarp.

The epithet "callitrichoides" refers to the emergent leaves, which very closely resemble the rosette of floating leaves of *Callitriche stagnalis*.

This remarkable plant differs from all previously described *Myriophyllum* species in a number of respects. Although dimorphy of the leaves is common in the genus, with the emergent leaves often very different from the submerged ones, this seems to be the only species that also has dimorphic stems (Fig. 2). The primary stems (Fig. 3) are the relatively stout, honeycombed axes common in the genus, but the secondary stems bearing reduced, bract-like leaves at wide intervals, and arising from the axils of the primary leaves, are filiform and flexible. In contrast to the primary stems they are frequently branched. The emergent leaves are borne in a tight rosette-like cluster at the tips of the secondary stems (Fig. 4), and are unusual in that they apparently float on the surface of the water, rather than being held aloft as in most other species. Furthermore, the flowers are adnate to the petioles of the emergent leaves, instead of being borne in their axils (Fig. 5). The styles are filiform, instead



Figs. 5–9. Flowers and fruit of *M. callitrichoides*. Fig. 5.—Flower adnate to petiole of emergent leaf. Fig. 6.—Isolated mericarp viewed from slightly above, with positions of other mericarps indicated. Fig. 7.—Single mericarp viewed from below. Fig. 8.—Semimature fruit with one abortive mericarp, viewed from above. Fig. 9.—The same, viewed from below. (All from *Dunlop* 3387; fig. 5 drawn from liquid preserved material, figs. 6–9 from dried material.)

of clavate, and more closely resemble those of *Gunnera* than those of other *Myriophyllum* species. The fruit is unique, not only in its peculiar radiating mericarps, but also in the fact that they are fused near their apices, rather than lower down (Figs. 6–7). Occasionally 1 (very rarely 2) of the mericarps fails to develop, and an irregular fruit results (Figs. 8–9).

With all of the above peculiar features, it is difficult to place *M. callitrichoides* in existing treatments of the genus. In the standard monograph (Schindler 1905), it keys out to subgen. *Myriophyllum* ["Eumyriophyllum"] sect. *Tessaronia*, but does not fit well into any of the subsections. Van der Meijden (1969, extended in van der Meijden & Caspers 1971) has recently published a revision of the south-east Asian, Malesian, Mascarene, and African species of the genus. Using his key, *M. callitrichoides* comes closest to *M. oliganthum* (W. & A.)F.v.M. and *M. tuberculatum* Roxb., but this reflects only leaf arrangement and the tetrandrous flowers; in leaf, flower and fruit morphology there is little similarity.

The nearest relatives of *M. callitrichoides* are probably *M. integrifolium* Hook.f. and *M. drummondii* Benth., with which species it shares its alternate, entire leaves, tetrandrous flowers and ovoid anthers. However, the relationship is not close, as *M. callitrichoides* differs from the other two species in its dimorphic stems, broader and more succulent leaves, bisexual flowers which are adnate to the petioles of their subtending leaves, filiform styles and cruciform fruits.

At present *M. callitrichoides* is known only from the type collection. Further specimens are needed to determine whether its peculiar habit is a constant feature or merely a reflection of ecological influences (e.g. a sudden change in water level during the growing season). However, even if this should be shown to be true, the species is still adequately characterized by its flowers and fruits to merit recognition as a most unusual member of its genus.

Acknowledgements

I am grateful to Mr C. R. Dunlop, of the Animal Industry and Agriculture Branch, Department of the Northern Territory, who first brought this plant to my attention. The duplicate collections in Herbarium Australiense (CANB) and the Arid Zone Research Institute (NT) were kindly loaned by the curators.

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CHEMICAL CHARACTERIZATION AND WEATHERING CHANGES IN HOLOCENE VOLCANIC ASH IN SOILS NEAR MOUNT GAMBIER, SOUTH AUSTRALIA

*BY J. T. HUTTON**

Summary

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Surface soil samples collected within 12 km of the volcanic crater of Mt Gambier, South Australia, have been analysed for thirteen elements by X-ray fluorescent spectrography. The amounts of eight of these elements in each of ten samples have been compared with the amount present in a sample collected close to the volcano and it is clear that the ejected material was of uniform composition. The amount of ash deposited on the Pleistocene beach dune sands decreases as distance from the Mount increases.

By comparing the present composition of the ash with the composition of a sample of Mt Gambier basalt, it is shown that 60-80% of the calcium, magnesium and sodium has been lost but there has been essentially no loss of titanium, silicon or aluminium. In 5,000 years, about one half of the volcanic ash has weathered to clay minerals which do not readily disperse and the leached sodium and magnesium appear to reach the groundwater.

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Introduction

Hutton, Blackburn & Clarke (1959) indicated the distribution of soils affected by volcanic ash from Mt Gambier by a study of the size of the particles added to the siliceous sand of former beach dunes. As this earlier work had shown that the material ejected and deposited on the existing dunes was uniform in the physical size of the particles, it should be possible from a study of the elemental composition of the same soils to confirm the uniform nature of the ash and also see what elements may have been differentially lost by weathering since the deposition of the ash 5,000 years ago (Fergusson & Rafter 1957).

Methods of Analysis

Eleven surface samples studied previously were analysed for thirteen elements by X-ray fluorescent spectrography. For the eight major elements, magnesium, aluminium, silicon, phosphorus, potassium, calcium, titanium and iron, the ignited soil samples were fused with a lithium borate flux as described by Norrish & Hutton (1969) and cast into glass discs. Calibration for these elements was based on fusions of pure chemicals in the borate flux and results were all corrected for variations in mass absorption due to variations in sample composition.

For the elements chromium, manganese, nickel and zinc, present in low concentration (10–1,000 ppm), and for sodium, the finely ground samples were pressed into suitable discs without any dilution (Norrish & Hutton 1964) in order to obtain sufficient sensitivity. Calibration was made again by comparison with standards prepared from pure chemicals mixed with a sample of clean quartz. Variations in mass absorption due to changes in sample composition were measured and the appropriate corrections applied.

Results

The results of analysis of sample A 363/1[1], collected about 3 km northwest of the Mt Gambier crater and considered from field morphology to have the greatest amount of ash mixed with the leached siliceous sand, are given in Table 1. For comparison the results of analysis of sample A 361/1, collected from near

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* CSIRO Division of Soils, Glen Osmond, S. Aust. 5064.

[1] CSIRO Division of Soils sample reference number.

TABLE 1

Composition of soils, volcanic ash (calculated) and estimated change during weathering

Element	Soil largely dune sand	Soil largely volcanic ash	Present composition of ash*	Composition of basalt†	% change (relative to basalt)
	A 361/1	A 363/1			
Na, %	0.08	0.17	0.4	2.60	−80
Mg, %	0.03	1.47	2.4	8.12	−70
Al, %	0.90	5.35	9.0	7.62	+20
Si, %	45.7	34.9	26.0	22.0	+20
P, %	0.01	0.29		0.20	
K, %	0.22	0.59	1.3	1.27	0
Ca, %	0.07	1.04	3.1	7.18	60
Ti, %	0.15	0.96	1.5	1.22	+20
Cr, ppm	29	118			
Mn, ppm	115	826			
Fe, %	0.52	5.08	8.2	8.35	0
Ni, ppm	2	65			
Zn, ppm	5	96			

* Average of values calculated on assumption that A 363/1 contains 40% dune sand, A 464/1 contains 45% and A 349/1 contains 50%.

† Stanley (1909).

TABLE 2

Composition of ash soils expressed as % composition of A 363/1

Sample number	Distance Mt Gambier km	Direction	Mg	Al	Ti	Fe	Cr	Mn	Ni	Zn
A 363/1	3	NW	100	100	100	100	100	100	100	100
A 464/1	2½	E	91	87	79	81	82	66	118	85
A 349/1	3	S	83	92	77	83	88	75	118	71
A 351/1	6½	SE	46	104	54	60	67	76	46	48
A 364/1	5	S	56	60	66	58	57	64	50	52
A 360/1	6½	N	28	53	50	47	68	47	40	28
A 355/1	3	E	38	36	41	38	33	43	49	22
A 292/1	11	NE	*	29	39	27	31	28	16	25
A 358/1	6½	NE	*	23	12	25	31	21	3	6
A 467/1	5½	NW	*	20	11	12	19	21	3	7

* Amount too low to be determined with sufficient accuracy to obtain a meaningful figure.

the northern limit of the influence of the ash, are also given.

Of the thirteen elements determined, magnesium, aluminium, titanium, iron, chromium, manganese, nickel and zinc are considered to be associated with volcanic ash and the results for these elements in the other nine samples are given in Table 2, where they are expressed as a percentage of the concentration found in sample A 363/1.

Discussion

The eight elements chosen for listing in Table 2, namely magnesium, aluminium, titanium, chromium, manganese, iron, nickel and zinc, are present in higher concentration in basaltic type rocks than in other types such as sands, limestones or granites. For this reason they were chosen in this investigation to be indicators of material of volcanic origin in a region of sand dunes and swales. Sample A 361/1 is typical of the surface of the sand dunes and sample A 363/1 taken 3 km NE of the crater of Mt Gambier is typical of the material of volcanic origin after 5,000 years exposure. The data in Table 1 show that the dune sand is not pure quartz as it appears to contain a titanium mineral and some clay or feldspar to account for the potassium. The amount of potassium would indicate that weathering and leaching have not been excessive and so the low levels of some elements, particularly magnesium and nickel, suggest the absence of volcanic ash from this site 11 km N of Mt Gambier.

By calculating the amount of these eight "basaltic" elements present in the ten samples of surface soils as a percentage of the amounts in sample A 363/1, the significance of the difference in the composition of these soils becomes apparent. As distance from the Mount increases, the amount of each element is reduced by a similar proportion. In order to determine the amount of ash in the soils studied, relative to sample A 363/1, three somewhat independent sets of chemical data and the particle size data given in Hutton, Blackburn & Clarke (1959) can be used. Of the eight elements recorded in Table 2, magnesium, aluminium, titanium and iron are present in A 363/1 at about 1% or more. They can be determined accurately but as some variation in ash composition can be expected, the relative percentages given for these elements in Table 2 were averaged for listing in Table 3. Chromium, manganese, nickel and zinc are present in smaller amounts (less than 0.1%) and are therefore determined less accurately, but they do represent a different geochemical parameter from the major elements, and again, to reduced individual fluctuations, the data of Table 2 were averaged for presentation in Table 3. The third chemical measure of the amount of ash material is obtained from the results of the determination of the silicon content of each sample because the addition of the basaltic minerals will reduce the high silicon content of the silica sand of the dunes. (This measure is not strictly independent of the other chemical values in that when expressed as oxides, SiO_2 constitutes the bulk of the sample that is not Al_2O_3, MgO, Fe_2O_3 and TiO_2). The amount of particles in the size range 2 μm to 50 μm found in these same soils is given by Hutton, Blackburn & Clarke (1959) and the very high ash soils close to Mt Gambier have about 40% of these particles. Again, the amount of 2 μm to 50 μm particles in the samples from the other sites can be calculated relative to this figure and the data are given in Table 3. These four estimates have been used to calculate mean values for the relative proportions of the basaltic material added to the sand dunes. The comparatively low values of standard deviation (Table 3) suggest that all four measures are of the one property.

The samples examined in this study had mostly been collected from soil profiles associated with the higher sand dunes, where some mixture of ash and sand has occurred. The data given by Hutton, Blackburn & Clarke (1959) had indicated that in many cases the resulting mixture is uniform down to 40 cm. This mixing is not due to cultivation as many of the samples were collected from roadside cuttings, but is attributed to the activities of soil animals in fertile, well-aggregated soils. Evidence suggests that where more than 150 cm of ash was deposited there was less mixing of sand and ash, while as the deposit of ash became thinner more mixing and resultant dilution took place. Hence it is difficult to define the true limit of the area that received the volcanic accession.

The climate of Mt Gambier, with the average maximum temperature ranging from 12°C to 25°C and with about 700 mm of rain falling mostly in winter, is condusive to the weathering and leaching of the deposited ash. Stanley (1909) analysed the basalt from Mt Gambier and his results are given in Table 1. An estimate of the present average composition of the ash, obtained from samples A 363/1, A 464/1 and A 349/1, is also given in Table 1.

TABLE 3

Relative amount of volcanic ash in soils

	Average based on Mg, Al, Ti, Fe	Average based on Cr, Mn, Ni, Zn	Dilution of Si by ash	Particles* 2–50 μm	Mean & S.D.	
A 363/1	100	100	100	100	100	—
A 464/1	84	88	98	93	91	6
A 349/1	84	88	86	93	88	4
A 351/1	66	59	89	58	68	14
A 364/1	60	56	57	70	61	6
A 360/1	44	45	44	47	45	1
A 355/1	38	37	35	42	38	3
A 292/1	32	25	23	32	28	5
A 358/1	20	15	15	10	15	4
A 467/1	14	12	7	10	11	3

* Values from Hutton, Blackburn, & Clarke (1959).

For this estimate it has been assumed that 60% of profile A 363/1 is of volcanic origin, 55% of A 464/1 and 50% of A 349/1 and the balance is silica, and these assumptions are consistent with the particle size distribution curve for profile A 349 given by Hutton, Blackburn & Clarke (1959). From comparison with this estimated present composition of the ash and analysis of the basalt, it is possible to calculate the change in elemental composition on the assumption that ash and basalt were from the same source. The results (Table 1) show that in the 5,000 years of exposure there has been considerable (60–80%) loss of sodium, magnesium and calcium due to the weathering of minerals such as olivine and plagioclase and some loss of potassium and iron relative to aluminium, silicon and titanium. The calculated gain in these elements is due to the loss of the other elements and the similarity in the gain figure for silicon compared with those for aluminium and titanium confirms the assumed ratio of sand to ash in the three soil samples. Thus from these ratios and the data of Table 3, the amount of ash in all ten soil samples can be calculated (Table 4).

The relative gain of 20% in the "insoluble" elements suggests that 20% of the ash has been lost in 5,000 years, i.e. 1% in 250 years. This loss of 20% of the weight of ash due to the loss of 70% of the original sodium, magnesium and calcium has meant considerable change has taken place. The soils with 35% to 60% ash have exchange capacities of 30 m. equiv. per 100 g (Clarke 1965) and in sample A 972 taken close to sample A 464 the clay minerals have been identified as illite, kaolin and randomly interstratified material and the mixture has an exchange capacity of about 70 m. equiv. per 100 g (Stace *et al.* 1968, p. 133). Assuming 12 m. equiv. of the exchange capacity is due to organic matter, there is then 18 m. equiv. per 100 g due to clay minerals. Thus the exchange capacity suggests that the clay minerals constitute about 25% of these soils which originally were about 50% ash, 50% sand. The clay minerals have formed *in situ* and have not moved down the profile—in fact using standard laboratory dispersing techniques, the soils yielded little material less than 2 μm, enabling the unsorted distribution of the particles in the range 2 μm to 50 μm to be used as a characteristic.

TABLE 4

Calculated amount of volcanic ash in soils

	% (nearest 5%)
A 363/1	60
A 464/1	55
A 349/1	50
A 351/1	40
A 364/1	35
A 360/1	25
A 355/1	25
A 292/1	15
A 358/1	10
A 467/1	5

As there is no run-off of water from the soils around Mt Gambier, the sodium, magnesium and calcium released by weathering should be leached to the groundwater. Sodium and magnesium are quite soluble and calcium is moderately soluble in the presence of the high concentration of carbon dioxide found in fertile soils. As the water percolates out of the organic soil, carbon dioxide is lost and calcium becomes less soluble. O'Driscoll (1960) has published analyses of groundwater from the Hundreds of Blanche, Gambier and MacDonnell which surround Mt Gambier. Of the samples with less than 400 ppm dissolved solids, nine had been collected either from within the area considered by Hutton, Blackburn & Clarke (1959) to have received volcanic ash or from immediately south of the area, and five samples outside these two areas. The average calcium content for each of the two areas is 70 ppm, while the sodium content of the waters from the area that received volcanic ash is 45 ppm and that outside is 35 ppm, and for magnesium the corresponding figures are 13 ppm and 3.5 ppm.

It has thus been possible to confirm the earlier map of the distribution of volcanic ash around Mt Gambier (Hutton, Blackburn & Clarke 1959) and to show that considerable change has taken place in 5,000 years. About one half of the ash has weathered to clay minerals with the loss of 20% of weight and the leached sodium and magnesium appears to have reached the groundwater.

Acknowledgement

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THE SYSTEMATICS OF SOUTH AUSTRALIAN PRECAMBRIAN AND CAMBRIAN STROMATOLITES. PART III

*BY W. V. PREISS**

Summary

PREISS, W. V. (1974). -The systematics of South Australian Precambrian and Cambrian stromatolites. Part III. *Trans.* R. *Soc. S. Aust.* **98**(4), 185-208, 30 November, 1974.
Three new forms of stromatolites from South Australia *(Linella munyallina, Tungussia etina,* and *T. wilkatanna)* are described. South Australian occurrences of *Omachtenia utschurica* and *Linella ukka,* previously known from the USSR, are also discussed.

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Introduction

This paper is a continuation of Parts I & II (Preiss 1972; 1973a), in which the principles of stromatolite classification were outlined and new forms of stromatolites described. The glossary appended to Part I also applies to this paper

Systematics

Group LINELLA Krylov

Linella Krylov 1967: 37.

Type Form: Linella ukka Krylov, from the Uk Suite of the Southern Urals.

Diagnosis: Bumpy, subcylindrical or tuberous, usually walled columns with parallel to markedly divergent branching and numerous, often pointed, projections.

Content: L. ukka Krylov, *L. simica* Krylov, *L. avis* Krylov, *L. munyallina* Preiss, and *L. zhuica* Shenfil' (*in* Khomentovskiy *et al.* 1972).

Age: Apparently only Vendian in the USSR, but in Central Australia *L. avis* occurs in rocks correlated with the Late Riphean (Walter 1972). In South Australia, *Linella* occurs in beds probably approximating to the Late Riphean–Vendian boundary in age.

Linella ukka Krylov 1967: 39.

FIGS. 1a–h, 5a, 6a, 7a–e

Material: Six specimens from Burr Well and Leigh Creek.

Description

Mode of Occurrence: The stromatolites form lenticular beds, not more than 20 m long and 0.5 m thick, consisting of adjoining domed bioherms 2 m in diameter. In the centres of individual bioherms, columns are vertical or variously inclined (Fig. 7a), but at the bioherm margins they become uniformly reclined (Fig. 7b). Margins of adjacent bioherms are poorly defined. At one point, at the edge of a lenticular bed, the columns commence growth vertically, but then curve over and grow horizontally outwards. Biohermal beds grade into laterally linked hemispheroidal and pseudocolumnar stromatolites, which intertongue with the underlying intraclastic limestone. They are overlain by oolitic limestones or grey calcareous shales.

Column Shape and Arrangement: Columns are subcylindrical to tuberous, sometimes slightly flattened in various directions. Transverse sections are round, oval, rounded polygonal or complexly lobate, 1–8 cm in diam. Columns may swell and constrict markedly over a length of a few centimetres. The length of columns between branches is usually less than 5 cm, but individuals reach a height of up to 30 cm (Figs 1a–h). Columns may be variously oriented, from vertical and parallel to inclined at up to 45° to the vertical, but at bioherm margins columns are radially or horizontally arranged.

Branching is frequent and varies in style from β- to γ-parallel, or slightly divergent to markedly divergent. Moderately divergent branching is the most frequent (Figs 7c,d,e). Columns may be constricted at the base of branching (Fig. 1a). Approximately 50% of branching does not result in new complete

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columns, but forms narrow, pointed, or sometimes slightly flattened outgrowths 1–4 cm long, generally less than 1 cm in diam. (Figs 1a–h). These pointed outgrowths are also variously oriented, and may project at a high angle from the main column. Coalescing of adjacent columns is moderately frequent.

Margin Structure: Column margins vary mainly from smooth to gently bumpy; occasionally sharper bumps of approximately 1 cm diam. occur. Very short ribs are rarely present. Short overhanging peaks occur in a few places, especially near points of bridging. Bridges, where present, consist of many laminae. A wall up to 3 mm thick is present on the whole lateral surface not affected by peaks and bridges. The number of laminae participating is difficult to estimate, due to secondary recrystallization (Fig. 7d). Columns are sometimes coated with a selvage of fine sparry calcite, of xenotopic equigranular texture and grain size 0.01 mm. The selvage is up to 1.5 mm thick and post-dates the formation of the wall, but pre-dates the filling of the interspace.

Lamina shape varies greatly within single columns, from almost flat or rectangular to very steeply convex (Fig. 5a). The majority (79% of laminae measured) have h/d between 0.2 and 0.6 (Fig. 6a). Laminae are very poorly preserved, so that their detailed shape is difficult to estimate. Most are smooth, but some are finely wavy, with a wavelength of 2–3 mm. Single laminae are difficult to follow across a whole column width. The degree of inheritance of lamina shape varies along a column length; in places laminae change rapidly from gently convex or rectangular to steeply convex.

Microstructure is poorly preserved, and the lamination is extremely indistinct. There is little contrast between light and dark laminae, except a slight difference in pigmentation and in grain size (Fig. 7d). *Dark laminae* are smooth to slightly wavy and lenticular, 0.1–0.4 mm thick. Single laminae cannot be traced right across columns, partly because of recrystallization. Upper and lower boundaries are very diffuse and more or less parallel. In most places, laminae are reduced to aligned lenses of fine grained carbonate. Dark laminae consist of hypidiotopic to xenotopic inequigranular calcite, grain size 0.003–0.015 mm. Most crystals are lightly pigmented pale grey (possibly an organic pigment). In one specimen, dark laminae are dolomitized. Subangular quartz silt of grain size 0.02–0.05 mm occurs in places in both dark and light laminae. *Light laminae* are 0.2–0.6 mm thick, and as discontinuous as the dark laminae between them. They consist either of acicular, or equidimensional mosaic calcite. Acicular crystals are 0.01–0.02 mm wide, and are arranged perpendicular to the laminae, and often extend also into the dark adjacent laminae. They are therefore clearly secondary. The equidimensional calcite is xenotopic, grain size 0.02–0.04 mm.

Interspaces between columns are filled mainly with poorly bedded intraclast grainstone. Allochems, including fine pellets of dense, dolomitized micrite, 0.02–0.1 mm in diam., and small, flat, curved or irregular intraclasts up to 0.5 mm long, are packed and mostly in contact. They are cemented by transparent sparry, xenotopic calcite of grain size up to 0.2 mm. A few crude bands of dolomitized micrite, up to 1 cm thick, occur in places. These are extremely dense, fine grained, but contain some pellets and intraclasts.

Secondary Alteration: Stromatolite columns are severely recrystallized, especially near column margins (Fig. 7d). Here laminae are severely disrupted by lenses and irregular patches of recrystallized, xenotopic to hypidiotopic sparry calcite, of grain size up to 0.2 mm. The laminae are reduced to small, irregular or curved, disoriented remnants; in places a secondary grumous texture is developed. In addition there are numerous irregular lenses, up to 4 mm thick, of nearly opaque, white, fine dolomite, aligned parallel to the lamination (Fig. 7e). The dolomite is equigranular, hypidiotopic, grain size 0.01–0.02 mm. Most intraclasts in the interspaces are also dolomitized, or at least surrounded by dolomitic rims, but the sparry cement is unaffected. Straight and irregular calcite veins post-date the dolomitization. Stylolites in places cut across all structures of the rock, but were not seen in thin sections. Nodules of coarsely crystalline calcite similar to those in *Inzeria* cf. *tjomusi* from Burr Well (Preiss 1973a) are locally present.

Comparisons

The stromatolites are identified as *Linella* by their bumpy, subcylindrical and tuberous, parallel to markedly divergent branching, walled columns, and numerous pointed projections. Many specimens of *Baicalia* have similar gross shape, but lack the almost ubiquitous wall and the numerous pointed projections of *Linella*. They are assigned to *Linella ukka* Krylov on the basis of column shape, style of branching, and margin structure. Unlike *L. simica* Krylov, ribs are poorly developed or absent. The columns are more broadly bumpy, more divergently branching, and less gnarled than those of *L. avis* Krylov. Microstructure is less well preserved than in the type material but lamina shape is very similar. *Linella ukka* from Burr Well is very similar in microstructure, margin structure, lamina shape and mode of preservation to *Gymnosolen* cf. *ramsayi* from limestone clasts in the Tapley Hill Fm. but is distinguished by its bumpier, more tuberous, divergently branching columns. Krylov (1967) described *Tungussia bassa* as a separate form, but states that it occurs at the margins of *Linella ukka* bioherms. Similarly, at Burr Well, inclined and horizontal columns occur at bioherm margins, but these are here included in *Linella ukka*. *L. zhuica* Shenfil' rarely has a wall.

Distribution: Uk Suite of the Southern Urals and in beds correlated with the Klyktan Suite of the Central Urals, USSR; Balcanoona Formation, Burr Well and Leigh Creek, Northern Flinders Ranges, S. Aust. *Linella* aff. *L. ukka* (Cloud & Semikhatov 1969) occurs in the Johnnie Formation, South Ibex Hills, California, USA.

Age: Late Adelaidean; in the USSR it is apparently restricted to the Vendian.

Linella munyallina f. nov

FIGS. 1i–y, 2a–n, 5b, 6b, 8a–f, 9a–c

Material: Twenty-six specimens from West Mount Hut, Termination Hill, Lake Arthur, Myrtle Springs, Burr Well, Roebuck Bore and Arkaroola areas.

Holotype: S495 (Figs. 1x,y; 2a–c; 9b), 5 km east of Myrtle Springs.

Name: After Munyallina Valley, where the stromatolites of the Arkaroola area occur.

Diagnosis: *Linella* with dominantly parallel branching, a wall that is discontinuous on some columns, and with highly variable lamina shape. Columns are gently bumpy, and pointed projections are subordinate.

Description

Mode of Occurrence: These stromatolites are widespread in the Wundowie Limestone of the Northern Flinders Ranges, where they occur in domed biostromes and lenticular beds consisting of contiguous domed bioherms, commonly overlain by thin sandy limestones, and/or interbedded in green or red shales. The biostromes vary in thickness in different areas from 50 cm to 2 m, depending on the relief of the individual bioherms they comprise. At Burr Well, individual bioherms are isolated (Figs. 8a,c,d) or contiguous, so that stromatolite beds are lenticular, and recur at different stratigraphic levels. These bioherms, with growth relief of about 1 m, are of ellipsoidal shape, with strongly inclined columns at their margins. Laminated shale or limestone fills the spaces between bioherms (Figs. 8a,c); in places, sandy limestone laps on to the bioherm margins, and then covers the whole biostrome or bed. Transverse sections of bioherms are rarely seen, except where dips are gentle: e.g. near Myrtle Springs oval bioherms occur, while at Arkaroola they are sinuous and irregular. Small, isolated bioherms only 30 cm wide also occur at Arkaroola.

Column Shape and Arrangement: There is great variability of column shape even within single specimens. Most commonly, columns are vertical or inclined, gently curved, non-parallel and bumpy, varying from subcylindrical to tuberous (Figs 1i–y; 2a–n; 8b,c,f; 9a–c). Columns vary in diam. from 1 to 8 cm, and swell and constrict moderately throughout their length. Transverse sections are commonly oval, variously elongated, lobate or rounded-polygonal, occasionally circular. Columns are up to 10 cm long between branches, but individuals attain a height of about 50 cm. The terminations of columns may be either rounded or pointed (Fig 1p,r,t,x,y). Columns are poorly developed in the bioherms at Arkaroola, where they are bridged over after a few centimetres of growth (Fig. 8f).

Branching is very frequent, variable, but most commonly subparallel (mostly α- and β-parallel, some γ-parallel) and moderately divergent (Figs 1i–y; 2a–n; 9a–c). In all specimens, there are a few branches which do not grow into large columns, but terminate as narrow, pointed projections, 1–4 cm long, often less than 1 cm wide (e.g. Fig. 1x,y). These are subordinate and may either be parallel to the main column, or diverge from it laterally.

Margin Structure: Columns are moderately bumpy; in general the bumps are low, rounded, 1–3 cm in diam. and with a relief of usually less than 0.5 cm. Bumps may grade into short pointed projections. Some columns from Myrtle Springs are rather smooth (Figs 1w,y). The margins of columns are mostly walled, but for short distances the wall may be absent. Short overhanging laminae and peaks are pre-

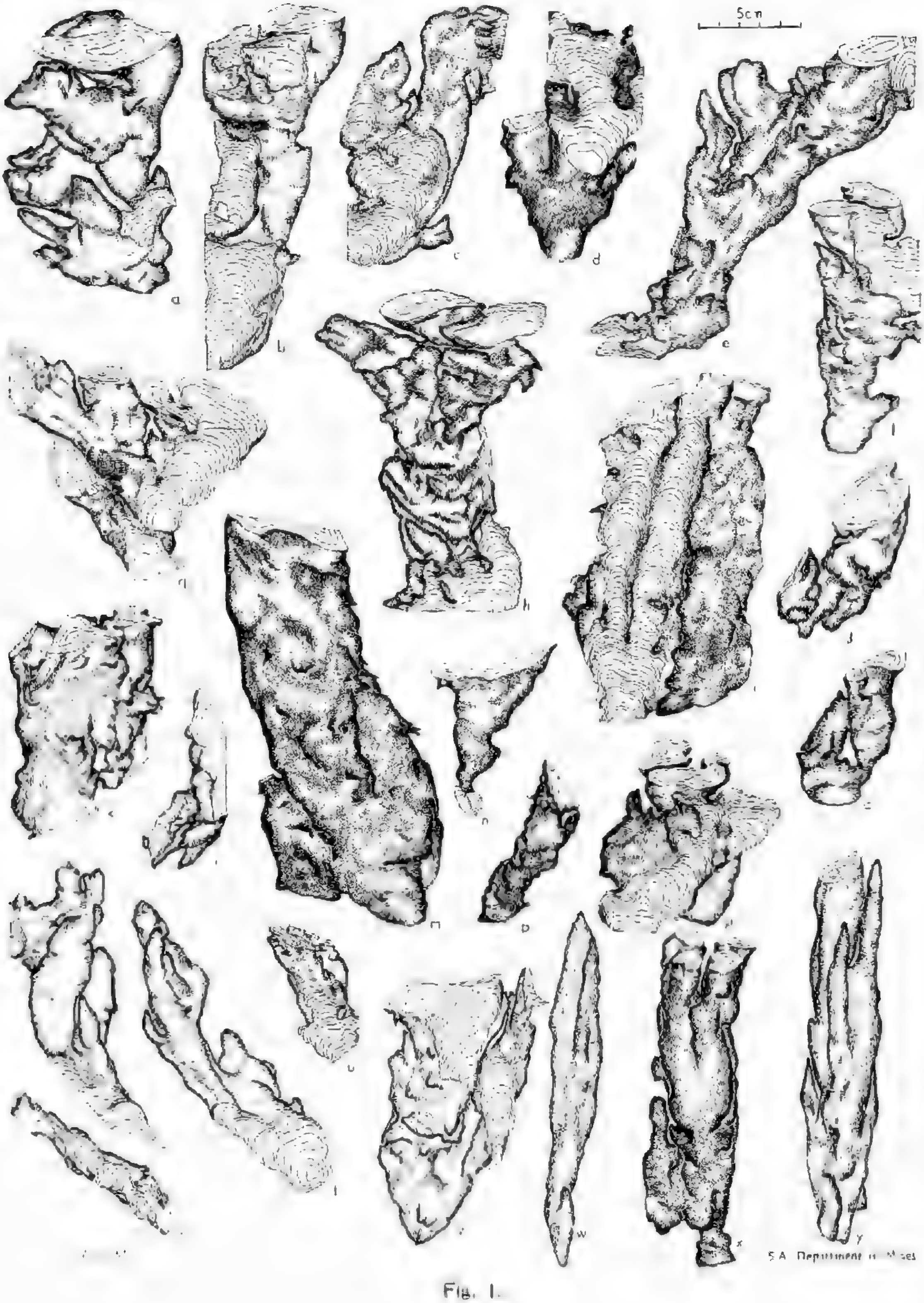

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Fig. 1.

sent moderately frequently, while adjacent columns are sometimes linked by bridges of varying thickness. Some inclined columns at bioherm margins at Burr Well are largely unwalled (Fig. 8e). In many outcrops, columns are seen to be bridged over at the top. The wall is formed by the marginal portions of both steeply and gently convex laminae covering the lateral surface of columns, but the number of laminae participating is difficult to estimate, due to recrystallization of the wall zone. Well preserved specimens from Myrtle Springs show that up to 20 laminae may be involved, the wall zone here being up to 5 mm thick (Fig. 9b).

Lamina shape is highly variable (Fig. 5b), with a large spread of values of h/d from 0.2 to 1.3: the greatest variability is seen in single specimens at Myrtle Springs, and laminae from other areas fall within this range; 76% of laminae measured have h/d between 0.3 and 0.7 (Fig. 6b). The most steeply convex laminae occur in the pointed columns at Myrtle Springs, where they approach subconical shape; otherwise laminae are smoothly domed, rarely rectangular or flattened. On a finer scale, well-preserved laminae are smooth or very gently wavy; no primary wrinkling is seen, although in some specimens, recrystallization has embayed laminae so as to produce a secondary wrinkling.

Microstructure is best preserved in specimens from Myrtle Springs, where it is seen to consist of thin, even, light and dark laminae, which are generally continuous, but may be cut by small micro-unconformities. Both lamina types thin markedly and become more distinct towards the column margins. Laminae are especially prominent in the wall zone, where they are of more uniform thickness (0.05–0.1 mm), with smooth, parallel boundaries, but lens out gradually down the column margin (Fig. 9b). Here dark laminae, composed of an interlocking mosaic of xenotopic calcite, of grain size 0.006–0.02 mm, alternate with lighter laminae of similar texture and slightly coarser grain size (0.015–0.04 mm). In the central portions of columns, laminae are 0.1 to 0.5 mm thick, the pale laminae generally being thicker than the dark. The laminae are of similar texture and grain size to those at column margins, but the light laminae contain abundant irregular, xenotopic dolomite crystals of grain size 0.03–0.05 mm. Microstructures from other areas are less well preserved; frequently the finest laminae have been obliterated by greater dolomitization (e.g. Roebuck Bore, Fig. 9a), or by more pervasive recrystallization of the limestone. Small areas with unaltered very thin laminae usually occur as remnants of the original microstructure.

Interspaces: The sediment filling interspaces varies from area to area. At Myrtle Springs, columns are widely separated (1 to 10 cm apart), and the interspace sediment is layered, consisting of alternating bands of sand and micritic limestone. The micritic bands are homogeneous, 2–25 mm thick, and consist of slightly recrystallized xenotopic calcite (grain size 0.003–0.01 mm) with rare, scattered dolomite rhombs. In places, algal laminae form continuous bridges capping the tops of columns, but also occur as upward-concave laminated sediment between walled columns, indicating that they post-date the column growth. Such algal laminae may in turn grade up into new columns. Both the micrite and the algal laminae are scoured in places to a depth of up to 3 cm, and the channels so formed are filled with coarse sand, of grain size 0.5–2 mm, with ooids, minor lime mud, and cemented by fine, sparry and acicular calcite. The growth relief of columns must have exceeded about 5 cm above the surrounding sediment, which was formed by slow deposition of lime mud and periodic rapid deposition of coarse detritus. Intraclastic limestones (often sandy) occur at Roebuck Bore (here intraclasts are limestone while their matrix is dolomitized) and Burr Well (Figs. 9a; 8c). Intraclasts are randomly oriented, slightly rounded, structureless flat pebbles up to 1 cm long, consisting of recrystallized xenotopic calcite of grain size 0.01–0.03 mm. The matrix consists of equigranular, xenotopic dolomite of grain size 0.05–0.08 mm with minor fine quartz sand and iron-stained dolomitic pellets. Specimens from the middle member of the Wundowie Limestone at Arka-

Fig. 1. Reconstructions of *Linella*, Umberatana Group, Flinders Ranges; (a–h)—*Linella ukka*, Balcanoona Formation, Burr Well; (a, b, f, h)—S478; (c, e, g)—S477; (d)—S541; (i–q)—*Linella munyallina* Wundowie Limestone Member, Roebuck Bore; (j, k, l, n, q)—S431; (p)—S430; (i, o)—S428; (m)—S427; (r–v)—*Linella munyallina*, Wundowie Limestone Member, Burr Well: (r, t, v)—S486; (s, u)—S484, Inclined columns from bioherm margins; (w, x, y)—*Linella munyallina*, Wundowie Limestone Member, 8 km east of Myrtle Springs H.S. Holotype S495.

roola contain banded interspace sediment; the alternating bands, up to 1 cm thick, contain micrite and fine intrasparite respectively, suggesting periodic current action to rework lime mud fragments. In the upper member of the Wundowie Limestone at Arkaroola, interspaces are filled with homogeneous fine subangular quartz sand, cemented by minor calcite.

Secondary Alteration: Specimens from Myrtle Springs are best preserved, the chief alteration being partial dolomitization of light laminae. Alteration of the wall zone by recrystallization of calcite is common in all areas; the outer portions of laminae are recrystallized to an equigranular, hypidiotopic calcite mosaic. Where recrystallization is slight, a few relics of dark laminae are preserved in a sparry calcite mosaic, of grain size 0.03–0.05 mm, often with scattered dolomite crystals. With extreme recrystallization, the whole of a column may be affected, resulting in a coarse hypidiotopic mosaic of equidimensional, twinned calcite crystals, 0.5–2 mm diam. A secondary green clayey mineral forms an interstitial matrix between calcite crystals, and probably represents a segregation of impurities during recrystallization. Even in these cases, the wall is usually preserved as a thin layer of very fine calcite, and the interspace outside it is unaffected. These patches of coarse recrystallization, together with the fine calcite veins they grade into, apparently post-date the dolomitization of light laminae, since relics of this dolomite are preserved within them. Specimens from Roebuck Bore are very largely dolomitized, appreciable amounts of calcite being preserved only in the columns and in some intraclasts. The interspace matrix is completely dolomitized, dolomitization pre-dating stylolites and calcite veins.

Comparisons

The stromatolites from the Wundowie Limestone at Myrtle Springs, Burr Well, Roebuck Bore and the Willouran Ranges are identified as *Linella* on the basis of their branching, bumpy, tuberous columns and the presence of a wall and pointed projections. Specimens from Arkaroola are also included, although here the columnar beds are thin, and columns rapidly coalesce or are bridged over by wavy-laminated stromatolite. *Linella munyallina* is similar to *Kulparia* [illegible]*rensis* Preiss and *Kulavia costata* Preiss in having bumpy walled columns with pointed projections, but the columns of the latter two forms are more closely spaced, subcylindrical and always parallel, with no divergent branching. *Linella munyallina* is distinguished from *L. ukka* Krylov by its dominantly parallel branching, fewer pointed projections, the presence of moderately frequent peaks, bridges and unwalled patches of columns. *Linella simica* Krylov has ribbed columns, while *L. avis* Krylov has more gnarled, thickly walled columns with very frequent pointed projections. *L. zhuica* Shenfil' rarely has a wall and has markedly divergent branching.

Distribution: Widespread in the Wundowie Limestone, Umberatana Group, of the Northern Flinders Ranges: near the West Mount Copper Mine, 5 km east of West Mount Hut, 9 km north of Termination Hill and at Lake Arthur, Willouran Ranges; middle member of the Wundowie Limestone, 8 km east of Myrtle Springs; lower member of the Wundowie Limestone, Burr Well; middle member of the Wundowie Limestone, Roebuck Bore; and lower and upper members of the Wundowie Limestone, 2 km south of the Arkaroola Airstrip. A small specimen from the South Australian Museum collection (supplied by Mr. N. Pledge), found in the Etina Formation near Artipena Hut, Central Flinders Ranges, east of Martin's Well may also be *Linella munyallina*.

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

Fig. 2. Reconstructions of *Linella munyallina*, *Omachtenia utschurica* and *Tungussia etina*. (a–n)—*Linella munyallina*, Wundowie Limestone Member; (a, b, c)—Holotype S495, 8 km east of Myrtle Springs H.S.; (d, i)—S549, Lake Arthur, south-western Willouran Ranges (Collected by Mr. B. Murrell); (e)—S485, Burr Well; (f)—S556, West Mount Hut, Willouran Ranges (Collected by Mr. B Murrell); (g, h)—S486, Burr Well; (j)—S552, Lake Arthur, South-western Willouran Ranges (Collected by Mr. B. Murrell); (k)—S544, 3 km east of Copley; (l)—S555, West Mount Hut, Willouran Ranges (Collected by Mr. B. Murrell); (m)—S566, 9 km north of Termination Hill (Collected by Mr. B. Murrell); (n)—S294, Munyallina Valley; (o–r)—*Omachtenia utschurica*, from the uppermost beds of the Tapley Hill Formation, Depot Creek; (o, p, r)—S398; (q)—S392. Note: Not all bridges could be shown on diagrams; (s)—S158, *Tungussia etina*, Etina Formation, 5 km east of Blinman; (t)—S157, *Tungussia etina*, Etina Formation, Enorama Creek.

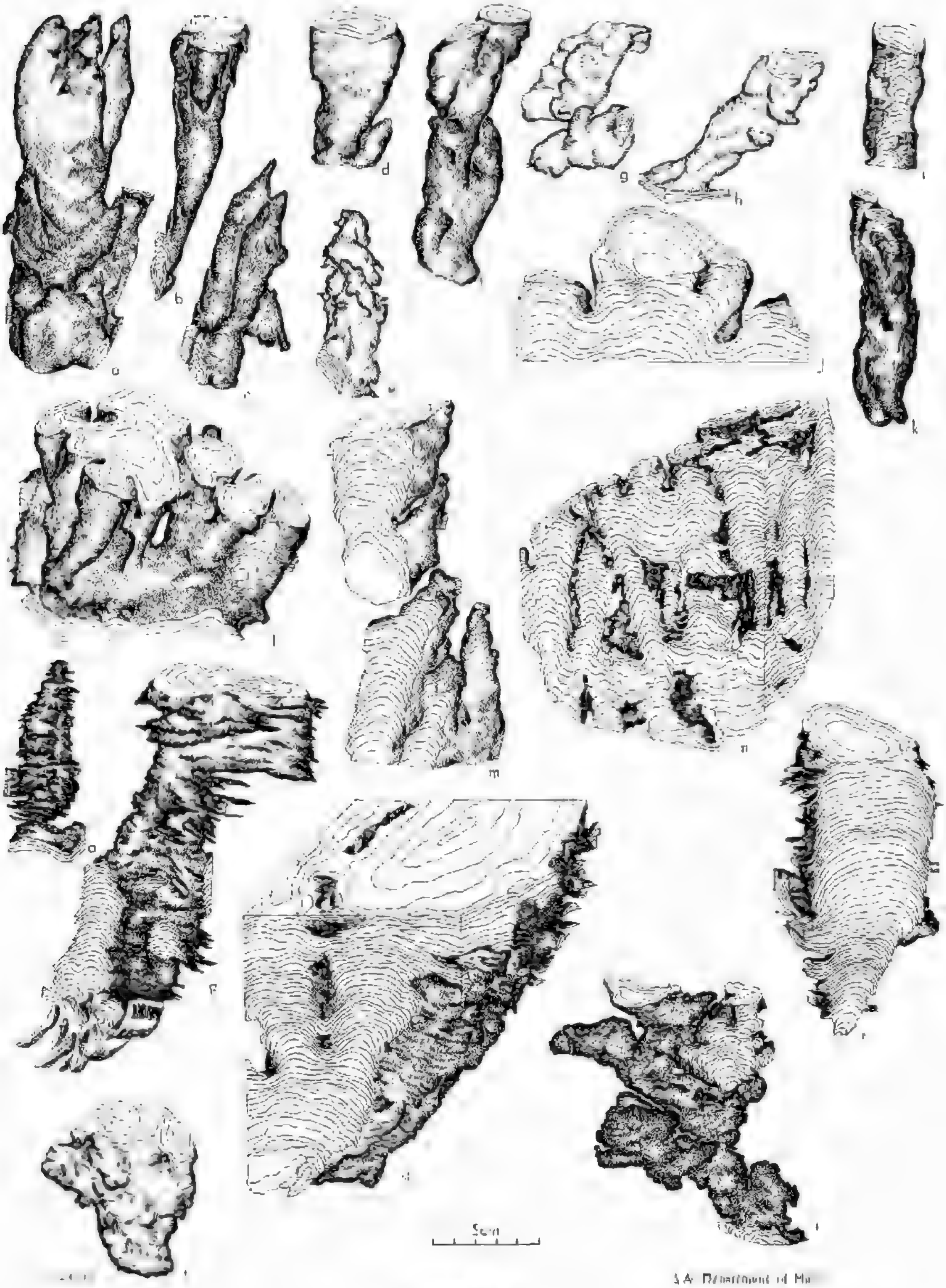

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Fig. 2

Group OMACHTENIA Nuzhnov

Collenia omachtensis Nuzhnov 1960: 1422.
Omachtenia Nuzhnov 1967: 131.

Type Form: Omachtenia omachtensis Nuzhnov, from the Omakhtin Suite of the Uchur Basin, Uchuro-Maya region, S.E. Siberian Platform.

Diagnosis: Columnar-layered stromatolites consisting of cylindrical and subcylindrical unwalled columns, frequently widening upwards, with numerous cornices and bridges linking several columns. Branching is mainly α-parallel; columns are usually vertical, sometimes radiating or curved.

Content: Omachtenia omachtensis Nuzhnov, *O. utschurica* Nuzhnov and *O. givunensis* Nuzhov.

Age and Distribution: Early Riphean in the Uchuro-Maya region of the USSR, but in South Australia, *O. utschurica* occurs in rocks correlated with the Late Riphean.

Omachtenia utschurica Nuzhnov 1967: 133.

FIGS. 2o–r, 5c, 6c, 9d,e, 10a–c

Material: Nine specimens from Depot Creek and Mundallio Creek.

Description

Mode of Occurrence: The stromatolites form small lenticular bioherms repeatedly intercalated in very finely laminated calcareous siltstones of the top of the Tapley Hill Formation, south-western Flinders Ranges. Commonly discrete, bioherms 2 to several tens of metres wide, develop on erosional surfaces on the underlying laminated siltstones (Preiss 1973b, pl. 28) and are closely associated with channels filled with imbricated flat-pebble breccias, often surrounding the bioherm. Bioherms are generally less than 1 m thick. All gradations from flat-laminated to domed, club-shaped, pseudocolumnar and columnar stromatolites exist (Figs. 2o–r, 9d,e). Where columns are developed, their axes are mostly vertical, but their sides may slope in various directions, and overhang the interspaces (Fig. 10a).

Column Shape and Arrangement: Where columns are discrete, they are generally subcylindrical, sometimes widening upwards, either vertical, or radially arranged. Columns are rarely completely discrete for more than a few centimetres, but are either linked by bridges or completely coalesced. They may pass laterally as well as vertically into laterally linked or flat-laminated stromatolites, which may in turn pass into flat-pebble breccia, at least some of the intraclasts being reworked chips of algal mats. Columns commonly commence growth upon some irregularity of the substratum, e.g. on the erosional surface of the underlying silts or on upturned flat pebbles (Fig. 2p). Columns are mostly circular in cross section, 2–15 cm in diam., but may be complexly lobate.

Branching: True branching into discrete columns is moderately rare, but may be multiple. Branching may be α-, β- or γ-parallel, sometimes markedly γ-parallel, or slightly divergent. Branched columns are frequently bridged over, or coalesce, after a few centimetres.

Margin Structure: Column margins are extremely irregular with numerous short cornices, bridges and overhanging laminae, which drape over the periodically deposited interspace sediment (Fig. 10b). Bridges consist of from one to many laminae, up to several centimetres thick. Over intervals without bridges or overhanging laminae (which may represent periods of growth during which interspaces were not filled) the column margin bears small ribs and bumps. Nowhere is a wall developed.

Lamina Shape: Laminae are never steeply convex: in most cases, they are flat-topped, with down-turned edges, i.e. rhombic or rectangular. They may grade both laterally and vertically into continuous flat laminae. Typical lamina shapes are illustrated in Fig. 5c. Of 40 laminae measured, 83% have h/d between 0.2 and 0.4 (Fig. 6c). If the growth of a column is asymmetrical, laminae are also asymmetrical, but growth always proceeds vertically, although column sides may be sloping. Laminae are smooth, very rarely wrinkled or finely wavy, occasionally with micro-unconformities.

Microstructure is distinctly banded and consists of an alternation of sparry and pelletal calcite laminae and fine, granular dolomite laminae (Fig. 10b,c). Dolomite laminae are 0.2 to 1.0 mm thick, and thin only slightly towards column margins. Their upper and lower boundaries are more or less parallel; the upper boundary is always sharp and often smooth, while the lower is usually gradational into pelletal laminae. Dolomite laminae, with almost no calcite, consist of granular, equidimensional hypidiotopic to idiotopic dolomite, grain size 0.01–0.03 mm. At the boundaries, euhedral dolomite crystals protrude into the adjacent sparry laminae. In places, several thin dolomite laminae are grouped to form macrolaminae up to 2 mm thick; here the dolomite laminae are separated by thin, discontinuous lenses of sparry calcite, which may be open space fillings (Fig. 10b).

Dolomite layers are overlain with sharp and sometimes slightly eroded contact by coarsely sparry calcite laminae varying in thickness from 0.1–1.00 mm, which pinch and swell and may lens out laterally. The calcite is hypidiotopic to xenotopic, transparent, consisting of frequently twinned crystals, grain size 0.04–0.2 mm. In places there are lenses of coarser, polygonal calcite of grain size up to 0.6 mm, and rarely, of acicular calcite. Scattered very small dolomite rhombs occur in places. Sparry calcite laminae grade up into pelletal laminae, consisting of subrounded pellets 0.06–0.1 mm in diam., of fine grained hypidiotopic dolomite (0.01–0.02 mm grain size), with clear, xenotopic calcite cement filling the voids. Pellets become more tightly packed upwards, so that they grade into homogeneous dolomite laminae. In one specimen (Fig. 10c) pelletal laminae are poorly developed.

Interspaces between columns are filled with intraclast and pellet grainstones, periodically interrupted by bridging laminae. Essentially the same sediment occurs outside the bioherms in channels cut into the underlying silts, but there it is bedded, and clasts are imbricated. In the interspaces, the sediment is largely unbedded (Fig. 10a,b) consisting of flat intraclasts up to several centimetres long, 1–4 mm thick, randomly oriented and loosely packed with numerous round to ovoid pellets, 0.15–0.3 mm in diam. Pellets and intraclasts consist of equigranular hypidiotopic dolomite similar to that of the dolomite laminae; the intraclasts were probably derived from the erosion of the flat-laminated variety of the stromatolites, while pellets are interpreted as comminuted and rounded, repeatedly reworked dolomite intraclasts. Allochems must have been in part matrix supported, but only locally is a lime mud matrix preserved. Most grains are cemented by a clear, sparry cement of xenotopic inequigranular calcite, grain size up to 0.4 mm. What must have been primary lime mud supporting scattered intraclasts now consists of recrystallized hypidiotopic calcite, grain size 0.05–0.1 mm with scattered dolomite rhombs. In places, large allochems or overhanging column margins sheltered the underlying areas from settling mud, and these are now filled with course, open space filling sparry calcite.

Secondary Alteration: Dolomite pellets and intraclasts were probably reworked as dolomite, i.e. the original sediment was affected by early diagenetic dolomitization and then redeposited; many intraclasts are long and flat, and could not have withstood transport without being lithified. These allochems were partly supported by lime mud, and partly winnowed, leaving open spaces filled with sparry cement. The time of dolomitization of the dolomitic stromatolite laminae is not clear; dolomite pellets are cemented with sparry calcite, suggesting that the sediment was brought in as dolomite. But dolomite rhombs in the laminae appear to post-date the calcite cement. In addition, dolomite rhombs occur scattered throughout the recrystallized lime mud (now microspar), and the sparry, open space filling calcite. It is likely that minor secondary dolomitization affected the whole sediment after its deposition. Post-depositional pyrite cubes, 0.08–0.20 mm wide, are scattered throughout the rock. Stylolites are rare, and are restricted to broadly conformable types which follow bridging laminae between columns.

Comparisons

The columnar and columnar-layered portions of this stromatolite accord with Nuzhnov's description of *Omachtenia* in having cylindrical or sub-cylindrical columns with frequent cornices and overhangs on the lateral surfaces, which are linked by numerous bridges and layers common to several columns. Branching in both is dichotomous or multiple, usually α-parallel. Columns are usually vertical, or rarely, radiating. As the domed and flat-laminated stromatolites cannot be separated from the columnar and columnar-layered portions, these must be included as environmental variations of *Omachtenia*. The stromatolites differ from *Jurusania* Krylov and *Kussiella* Krylov in having more irregular, more frequently branching columns repeatedly linked by bridges. The repeated bridging and characteristic thick, pelletal laminae distinguishes them from the basal portions of *Inzeria conjuncta* and *Acaciella augusta*. *O. utschurica* Nuzhnov differs from *O. givunensis* Nuzhnov in having more gently convex laminae (h/d less than 0.5). *O. omachtensis* Nuzhnov has generally narrower columns and some short, lateral outgrowths, and thinner, non-pelletal laminae. *O. utschurica* from the Tapley Hill Formation is extremely similar to *O. utschurica* from the Uchur River, USSR, in gross shape, type of bridges and lamina shape, but has slightly thicker pelletal laminae. (Pellets may also be present in the type material, as in Nuzhnov 1967, Pl. 11(4)). *Omachtenia* closely resembles *Schancharia* Korolyuk in gross shape, lamination and bridging; *Schancharia*, however, apparently has a thin, one-layered wall (Korolyuk, 1960).

Distribution: The Omakhtin Suite of the Uchur River, S.E. Siberian Platform, and the upper Tapley Hill Formation, Depot Creek and Mundallio Creek, S.W. Flinders Ranges, S. Aust.

Age: Early Riphean in the USSR, but here it is Late Adelaidean, in beds correlated by other stromatolites with the Late Riphean.

Group TUNGUSSIA Semikhatov

Collenia suchotungusica Semikhatov 1960: 1481.

Tungussia Semikhatov 1962: 205.

Type Form: Tungussia nodosa Semikhatov, from the Sukhotungusin Suite, Yenisei Mountains.

Diagnosis: Tuberous to subcylindrical, horizontal to vertical columns with frequent, multiple, markedly divergent branching; lateral surface is smooth or with small peaks, and at least locally with a wall.

Content: T. nodosa Semikhatov, *T. confusa* Semikhatov, *T. sibirica* Nuzhnov, *T. inna* Walter and *T. erecta* Walter. *T. bassa* is a lateral variant of *Linella ukka* Krylov. *T. enpiggeni* Raaben and *T. russa* Raaben are insufficiently described and illustrated to allow comparison, and the description of *T. arctica* Raaben is unavailable. New forms are *T. etina* and *T. wilkatanna*.

Age: Middle to Late Riphean, and probably Vendian.

Tungussia etina f. nov.

FIGS. 2s,t, 3a–m, 4a,b, 5d, 6d, 10d,e, 11a–e, 12a

Material: Twenty-eight specimens from Mt Chambers Gorge, Teatree O.S., Blinman, Martin's Well, Enorama and Arkaba areas.

Holotype: S435 (Figs. 3i,1, 4a,b, 11c), Mt Chambers Gorge.

Name: After the Etina Formation, in which the stromatolites partly occur.

Diagnosis: Tungussia with a wide variation of branching style from subparallel to markedly divergent, a thin, interrupted wall, and thick, pinching and swelling, wavy laminae. Coarse detritus can be incorporated in light laminae, if it was available during growth.

Description

Mode of Occurrence: The stromatolites occur in irregular tonguing bioherms and lenticular beds in the Etina Formation and its extensions in the Northern Flinders Ranges. Exposures are often inadequate to determine the exact shape of the lenses, but generally they are discrete isolated bodies, surrounded by sandy and oolitic limestones. In the occurrence near Mt Chambers Gorge, the columnar stromatolites overlie irregularly laminated sandy and oolitic limestone (the contact is now stylolitic), and form a lens up to 2 m thick in its thickest part. In places, growth continued on the top of the lens in the form of irregularly wavy and pseudocolumnar stromatolites. At the margins of the bioherm, columns grade laterally into pseudocolumns and wavy laminae, which intertongue with oolitic limestone. At Teatree O.S., the stromatolitic bed again intertongues with oolitic limestones, but here columns are more inclined at the bioherm margins than in their centres. Similar relations of stromatolitic bioherms intertonguing with sandy ooid and intraclast grainstones were observed in the Etina Formation in the Arkaba Hills, Enorama Creek (Fig. 10c), Blinman and on the south-western flank of the Enorama Diapir. However, at many locations in the Central Flinders Ranges, the columnar portions are poorly developed.

Columnar Shape and Arrangement: Well developed columns persist vertically for more than 10 cm only in the sections at Mt Chambers Gorge, Enorama Diapir and at Teatree O.S.; elsewhere short, irregular columns quickly grade up into linked pseudocolumns. At Mt Chambers Gorge, the orientation of columns varies from vertical to variously inclined, to subhorizontal (Fig. 10d). Columns from the Teatree O.S. locality are also variously inclined, but rarely subhorizontal; some are subparallel (Figs 2s,t, 12a). Columns from all areas are tuberous, bumpy, swelling and constricting, or,

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Fig. 3. Reconstructions of *Tungussia etina*, Umberatana Group, Central and Northern Flinders Ranges. (a)—S286, Wundowie Limestone, near Teatree O.S.; (b)—S158, Etina Formation, 5 km east of Blinman; (c)—S561, Etina Formation, S.E. margin of Enorama Diapir; (d)—S522, Etina Formation, Arkaba Hills; (e)—S526, Balcanoona Formation, near Mount Chambers; (f, g, h)—Wundowie Limestone Member, near Teatree O.S.; (f) S441, (g) S444, (h) S440; (i, j, k, m)—Balcanoona Formation, near Mount Chambers; (i, l)—Holotype, S435; (j)—S436, (k)—S525, (m)—S524.

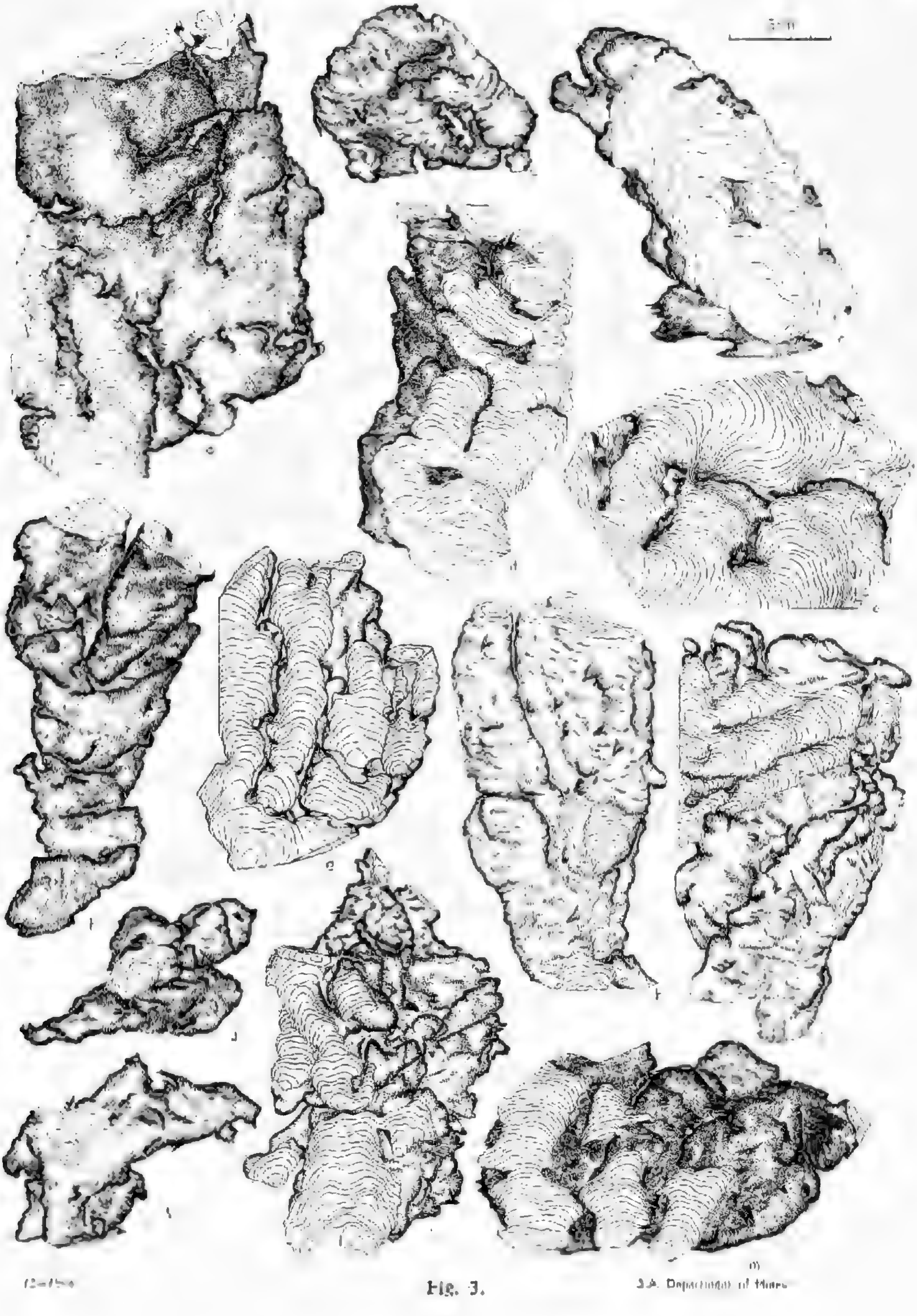

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Fig. 3.

S.A. Department of Mines

less commonly, straight, subcylindrical. Short columns from Central Flinders localities are frequently bulbous (Fig. 11d). Bumps and swellings are generally broad and rounded, while constrictions sometimes take the form of deep indentations into the main column, at points of branching (Fig. 3a,f,h). Some columns branching from the main column are only a few centimetres long, with either pointed or rounded terminations (Fig. 3a). Columns vary greatly in diameter from 1 to 10 cm, the largest occurring at Mt Chambers Gorge. Transverse sections vary from elliptical to complexly lobate; circular sections are rare.

Branching is very frequent and highly variable; even within single specimens, both parallel and markedly divergent branching may occur. Specimens from Mt Chambers Gorge have predominantly multiple, markedly divergent branching, although columns may become subparallel soon after branching (Fig. 3m). At Teatree O.S., markedly divergent branching and parallel or slightly divergent branching occur together (Figs. 3f,g,h, 11a, 12a). Columns from Enorama Creek are frequently truncated by stylolites parallel to overall bedding, so that the style of branching is obscured. Columns from this locality that allowed reconstruction (Fig. 2i), show markedly divergent branching.

Margin Structure: Primary margin structure is frequently obscured by stylolites; in some specimens from Arkaba, Teatree O.S. and Mt Chambers Gorge, almost no column margins are preserved. Where columns are relatively unaffected by stylolites, they are seen to bear thin, interrupted walls, involving two or three laminae only, or very locally, multilaminate walls, e.g. Enorama Creek and Teatree O.S. (Figs. 11a,h,i). But the latter are affected by pervasive recrystallization, so that commonly only the outer margin of the wall is preserved. Adjacent columns frequently coalesce, or are linked by massive bridges up to several centimetres thick. Bridges and overhanging laminae are common on unwalled portions of columns, especially from Mt Chambers Gorge (Fig. 3m). Column margins are gently bumpy, with occasional short transverse ribs. Most of the surface irregularity of some specimens from Teatree O.S. is due to stylolitic solution of column margins (e.g. Fig. 3a).

Lamina Shape is most commonly moderately steeply convex (Fig. 5d). Measurement of h/d ratio is difficult in some specimens due to removal of column margins by stylolitic solution; thus measured ratios may be too low in these cases. Of 131 laminae measured, 93% have ratios of h/d between 0.2 and 0.7, the mode being between 0.3 and 0.4. Laminae are moderately to markedly wavy, the undulations having a wavelength of 3–10 mm, and amplitude 1–5 mm. Laminae are lenticular, and pinch and swell markedly over short distances; this irregularity is caused at least in part by erosional micro-unconformities (Fig. 11c,e).

Microstructure: A broad, irregular lamination is well preserved in some specimens from Teatree O.S., Blinman, Enorama Creek and Mt Chambers Gorge, where thick, wavy, pinching and swelling light laminae alternate with darker thin, fine-grained laminae frequently with clay or iron oxide impurities. *Light laminae* vary rapidly in thickness from 0.2–2.00 mm, and frequently lens out laterally; few extend across a full column width. Very commonly, the light laminae are truncated by erosion surfaces, especially in specimens from Mt Chambers Gorge (Fig. 11e). They are composed of equigranular xenotopic to hypidiotopic mosaic calcite, grain size 0.006–0.03 mm. Occasionally, coarser detritus is incorporated, if it was available. For example, the Enorama Creek stromatolites contain up to 50% of ooids and coated grains, 0.3–1.00 mm in diam., within their light laminae. Elongated ooids and coated grains are aligned parallel to the lamination, and are always supported by the finer sediment of the stromatolitic laminae. Ooids are extremely abundant in the interspaces. Specimens from Teatree O.S. contain very few ooids, but here the supply was not great, as seen from the preponderance of lime mud in the interspaces. At Mt Chambers Gorge, ooids are absent both in interspaces and stromatolite laminae, but fine sand present in interspaces is also incorporated into laminae. These observations suggest that the algal mats were capable of trapping coarser detritus, if it was brought to the site. The thinner *dark laminae* are 0.05–0.15 mm thick, and composed of very fine micritic calcite, of xenotopic, equigranular texture and grain size 0.003–0.01 mm. At Mt Chambers, the dark laminae are emphasized by very fine, hypidiotopic ferruginous dolomite concentrated along them. In places (e.g. Blinman), dark laminae with sharp lower boundaries grade up into light laminae (Fig. 11d). At Arkaba Hills, the dark laminae are largely stylolitic.

Interspaces: Columns are moderately closely spaced, interspaces 5 mm–2 cm wide. The type of sediment filling the interspaces varies in the different areas, and its relation to the quantity of detritus in laminae has already been discussed. At Mt Chambers Gorge, interspaces are filled mainly with slightly dolomitized and recrystallized partly laminated lime mud, with a few bands up to 2 cm thick of very fine, subangular quartz sand. Flat intraclasts up to 2 cm long are in places stacked vertically in interspaces between walled columns, indicating a minimum relief of 2 cm. Discrete areas of intraclast grainstone suggest that after column growth, coarser detritus was occasionally washed in between times of settling of lime mud. At Teatree O.S. interspaces contain poorly bedded micritic limestone and ooid wackestone; in one specimen (Fig. 11h), these alternate in 5 mm bands. Ooids are commonly preserved only as moulds infilled with sparry calcite. Unbedded fine or medium sand with a micrite matrix commonly fills interspaces in the Etina Formation. At Blinman, the sand contains rounded medium grained quartz, red feldspar and green pellets consisting of a chloritic mineral. Since little sand is incorporated into the stromatolitic laminae, the interspaces were probably rapidly filled after, not during, column growth. Interspaces at Enorama Creek are filled with ooid grainstone exclusively—the allochems are chiefly ooids with a single outer lamina and coated, flat intraclasts. Oolitic laminae may be partly detached, perhaps due to the growth of sparry cement.

Secondary Alteration: Specimens from Blinman and Enorama Creek are the best preserved, the chief alteration being the formation of calcite veins, cut by later stylolites parallel to bedding. Dolomitization is restricted to specimens from Teatree O.S. and Mt Chambers Gorge: rhombs of dolomite varying from 0.01–0.015 mm, sometimes ferruginous, are scattered throughout both lamina types. Ferruginous dolomite is concentrated in the dark laminae and the interspace sediment at Mt Chambers Gorge. Small areas of recrystallization of fine grained calcite to grumous texture are present in all specimens; the wall zone especially may be almost totally recrystallized, leaving only the outer lamina preserved. Light laminae are completely recrystallized in one specimen from Mt Chambers Gorge. Stylolites on column margins are very frequent at Teatree O.S., Arkaba Hills and Martin's Well, postdating the recrystallization of laminae and replacement of ooids by sparry calcite, but apparently pre-dating dolomitization. Local large solution cavities are rimmed with zoned ferruginous dolomite rhombs, then filled with coarse, granular sparry calcite.

Comparisons

The stromatolites are characterized by a very wide variation of gross morphology, especially branching, which distinguishes them from all parallel-branching stromatolites, although some resemble *Inzeria* Krylov in having deep indentations into the main column at branching. They are assigned to the group *Tungussia* on the presence of markedly divergent branching, subhorizontal columns, and thus differ from the other divergent branching groups *Linella* Krylov, *Baicalia* Krylov, *Anabaria* Komar, *Poludia* Raaben and *Parmites* Raaben. *Linella* has very numerous pointed projections, and columns are subhorizontal only in the marginal portions of bioherms. *Baicalia* differs in having chiefly ragged, unwalled, margins, with frequent overhanging laminae. *Anabaria* has consistent, slightly divergent branching, and cylindrical columns. The columns of *Poludia* are complexly curved and intertwined, while those of *Parmites* are anastomosing.

Tungussia etina differs from all other forms of the group in its great variation of branching style, and its microstructure. Some specimens closely resemble *Tungussia inna* Walter in having oolitic, wavy laminae, but *T. etina* is distinguished by its distinct thicker, pinching and swelling lamination and variable branching.

Distribution: Etina Formation and equivalents, Umberatana Group, Central and Northern Flinders Ranges; Balcanoona Formation at Mt Chambers Gorge; Wundowie Limestone at Teatree O.S.; Etina Formation near Blinman, Martin's Well, the S.E. flank of the Enorama Diapir, Enorama Creek and the Arkaba Hills area.

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

Tungussia wilkatanna f. nov.

FIGS. 4c–i, 5e, 6e, 12b–e

Material: Five specimens from Depot Creek and Mundallio Creek.

Holotype: S412 (Figs. 4f, 12e), Depot Creek.

Name: After Wilkatanna H.S., 8 km northwest of the type locality.

Diagnosis: *Tungussia* with smooth to gently bumpy subcylindrical to tuberous, frequently walled columns, with markedly divergent multiple branching and continuous thinly banded, hemispherical laminae.

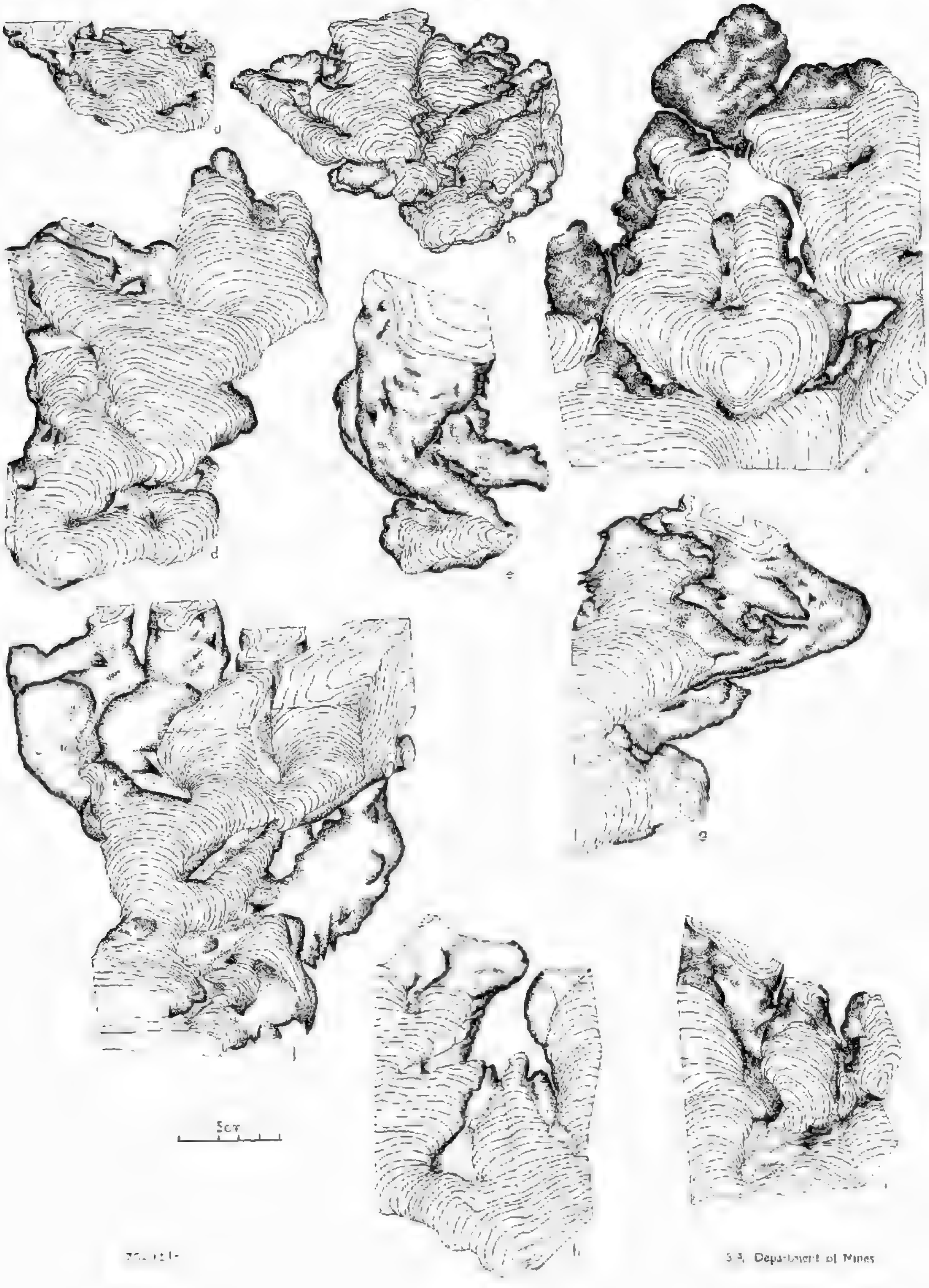

FIG. 4.

Description

Mode of Occurrence: The stromatolites occur in pale pink to white pure dolomites and possibly also in dark grey dolomites, as extensive biostromes, 0.3–2 m thick, interbedded in laminated siltstones and shales. The upper surfaces of biostromes are irregular, undulating, and in places, erosional. Stromatolitic columns arise from flat-laminated or cumulate bases (Fig. 12c), growth frequently commencing upon the eroded surface of the underlying shale. In some beds, only the flat-laminated or cumulate stage of growth is attained, in others, up to 2 m thickness of columns develops. Columns are either bridged over at the top by laterally linked hemispheroids, or eroded. Columnar portions may grade laterally along the biostrome into laterally linked hemispheroids.

Column Shape and Arrangement: Columns are subcylindrical to tuberous, bumpy, 2–10 cm in diam., with low broad swellings and constrictions; portions of columns widen rapidly above a constriction (Fig. 4c,d,f). Cross-sections vary from subcircular to highly lobate. The orientation of columns is highly variable, both horizontal and vertical columns being common. Individual columns are 5–20 cm high, but the whole structure may attain a height of 2 m.

Branching: Both vertical columns and broad cumuli may arise from the flat-laminated base. These typically give rise to a number of horizontal columns, from which in turn either vertical columns branch upwards, or the horizontal columns themselves turn sharply upwards (Fig. 4c–i). Columns are frequently constricted at branching, and then expand upwards rapidly. Multiple, markedly divergent, branching from one point is common.

Margin Structure: The lateral surface bears numerous broad bumps of up to several centimetres (Fig. 4c), but in places columns are quite smooth (Figs. 4f, 12e). Overhanging laminae are relatively rare, and any peaks and cornices present are only a few millimetres long (Fig. 4f). A wall is usually present but may be absent; unwalled areas are relatively smooth or finely fringed, the laminae abutting against the column margin at various angles (Fig. 12b,d). In walled areas, the laminae gradually thin and cover the surface for a distance of up to 1 cm. The wall varies in thickness from 1 to 10 laminae (Fig. 12e). Bridges become prominent near the top of the structure.

Lamina Shape is mostly hemispherical, but gently convex laminae occur in wide columns and in some horizontal columns, especially in unwalled portions. Laminae are smoothly curved, without sharp flexures, their shape being inherited from underlying laminae. Micro-unconformities occur, but are mostly only slight. Fig. 5e illustrates some representative lamina shapes. 83% of laminae have h/d between 0.2 and 0.5, the mode (33%) being between 0.3 and 0.4 (Fig. 6e). In places laminae develop two crests, anticipating branching. Near the margins of columns, laminae thin, and either abut against the margin (in places eroded) or bend over to form a wall. Laminae are either smooth or very gently undulating, with amplitude not exceeding one millimetre.

Microstructure is best preserved in silicified portions of columns; it is finely banded, consisting of alternating thin continuous dark and light laminae; continuity is broken only by micro-unconformities (Fig. 12e). In the less well preserved dolomitic stromatolites, the finest laminae are frequently obliterated and macrolaminae tend to predominate (Fig. 12b). *Light laminae* vary in thickness from 0.05–0.2 mm, most commonly 0.05–0.1 mm, but thin towards the column margins where they form the wall. The upper and lower boundaries are parallel, and usually distinct and smooth. No unequivocal detrital grains were seen; some thicker pale laminae are of finely grumous texture, representing partially recrystallized dark macrolaminae. Well preserved light laminae in silicified columns consists of extremely fine transparent chert—a xenotopic aggregate of equidimensional quartz grains, 0.001–0.01 mm in diam. Where preserved as carbonate, the light laminae consist of xenotopic to hypidiotopic dolomite of equidimensional 0.005–0.02 mm grains. *Dark laminae* are generally thinner than light laminae (0.02–0.2 mm, most commonly 0.02–0.08 mm). Where well preserved they have smooth, distinct boundaries, and are quite continuous, but in parts of dolomitic columns, they are preserved only as chains of elongated lenses, 0.1 to 0.5 mm long (Fig.

Fig. 4. Reconstructions of *Tungussia etina* and *Tungussia wilkatanna*. (a, b)—*Tungussia etina*, Holotype S435, Balcanoona Formation, near Mount Chambers; (c–i)—*Tungussia wilkatanna*, Skillogalee Dolomite, Southern Flinders Ranges; (c, h)—S169, Depot Creek; (d)—S323, Mundallio Creek; (e)—S410, Depot Creek; (f)—Holotype, S412, Depot Creek; (g)—S408, Depot Creek; (i)—S209, Depot Creek.

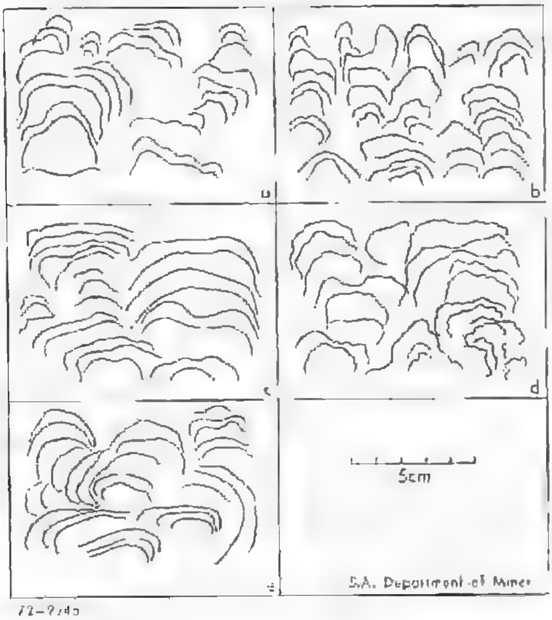

Fig. 5. Examples of Lamina shapes of stromatolites, traced from thin sections. (a)—*Linella ukka*; (b)—*Linella munyallina*; (c)—*Omachtenia utschurica*; (d)—*Tungussia etina*; (e)—*Tungussia wilkatanna*.

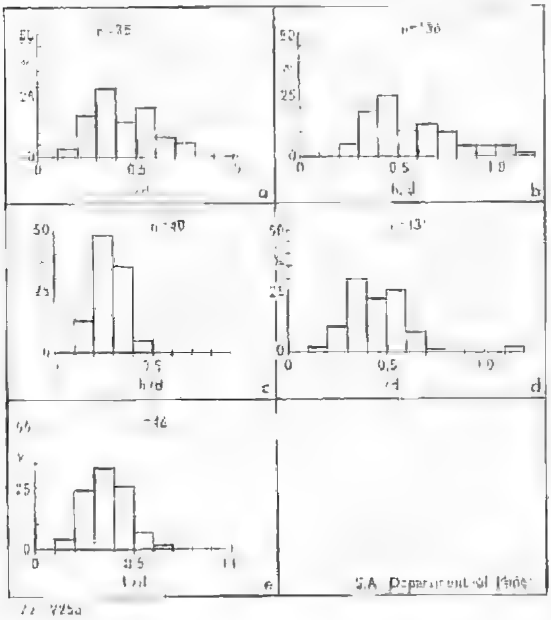

Fig. 6. Frequency distribution of lamina convexities for stromatolites illustrated in Fig. 5

12b). Silicified dark laminae consist of extremely fine, pale brownish-grey organic stained chert, of grain size 0.001–0.005 mm. Carbonate laminae consist of xenotopic dolomite of equidimensional 0.003–0.005 mm grains. Macrolaminae, 1–3 mm thick, consisting of up to 10 light-dark lamination pairs, occur only in the dolomitic portions of columns (Fig. 12b). In places, the fine internal lamination of macrolaminae is obliterated almost entirely, but these grade laterally into unaltered light and dark, very thin laminae.

Interspaces: The distances between neighbouring columns vary from several millimetres to several centimetres. The interspaces are filled with almost completely unbedded intraclast wackestone. Clasts vary from 0.5–2 cm; most are well rounded, and composed of homogeneous dolomicrite. Some are partially recrystallized to grumous-textured dolomite. Long, flat intraclasts, 0.5–1 mm thick, up to 2 cm long, are common near the base of one specimen; these are commonly replaced by coarse sparry hypidiotopic dolomite. Intraclasts are randomly oriented, loosely packed and generally matrix-supported.

Secondary Alteration: All definitely identified occurrences are found in pale pink to white dolomites; other specimens from dark grey dolomites at Depot Creek probably also belong to this group but are inadequate for reliable identification. The dolomite generally preserves most fine structure (as does the Skillogalee Dolomite of many other areas), but in places is significantly recrystallized. Silicification of portions of columns occurred after the growth of whole columns, but before partial alteration of the surrounding carbonate, since it best preserves the finest lamination. In places it is possible to trace unaltered very thin laminae from silicified to carbonate portions of columns; in the latter, only broad light and dark macrolaminae are preserved. The dolomitic nature of the whole (unsilicified) sediment suggests either penecontemporaneous dolomitization (during stromatolite growth) or trapping of dolomitized lime mud. Silicification therefore probably post-dates dolomitization. Grumous textures are developed sporadically throughout stromatolite and interspace sediment, and were probably formed by partial recrystallization during later diagenesis. Irregular stylolites, both cutting columns and following column margins, post-date the development of grumous texture. They are commonly rich in limonite, and, in places, pale green chlorite.

Comparisons

The stromatolites are assigned to the group Tungussia on the basis of their multiple, markedly divergent branching and frequent horizontal and gently inclined columns. These characters, in addition to a consistently smoother margin structure and frequent presence of a wall, distinguish them from *Baicalia burra* which occurs elsewhere in the Skillogalee Dolomite. *Tungussia wilkatanna* is differentiated from *T. nodosa* Semikhatov by its smoother column margins, smoother, consistently hemispherical and never disharmonic laminae. It resembles *T. sibirica* Nuzhnov in having numerous horizontal columns with upturned ends, but is distinguished by its smoother margin and presence of a wall. *T. wilkatanna* is distinguished from *T. bassa* Krylov in lacking long horizontal columns, and in occurring independently, not as a lateral variant of *Linella ukka* Krylov. Unlike *T. erecta* Walter, it lacks long erect columns, and is distinguished from *T. luna* Walter by its smooth laminae. *T. wilkatanna* most closely resembles *T. confusa* Semikhatov, but is distinguished by its thinner, more continuous laminae of predominantly hemispherical shape. *T. wilkatanna* has more regular and discrete columns of constant shape and branching than *T. etina*, and has thinner, more continuous, smoother laminae.

Distribution: In the lower third of the Skillogalee Dolomite, Burra Group; South-western Flinders Ranges: Depot Creek and Mundallio Creek. Small specimens possibly to be included, come from near the base and near the top of the formation.

Age: Early Adelaidean.

Acknowledgments

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Fig. 7. *Linella ukka*, Balcanoona Formation, Burr Well, Northern Flinders Ranges. (a)—Longitudinal sections of tuberous columns with pointed projections in outcrop. Marking pen is 10 cm long; (b)—Longitudinal sections of inclined columns at a bioherm margin. Diameter of lens cap is 5 cm; (c)—Cut slab, showing divergently branching columns. The white areas are patches of coarsely crystalline calcite. S478; (d)—Longitudinal thin section (S477); Laminae are largely obliterated by recrystallization; (e)—A cut slab, adjacent to thin section in (d).

Fig. 8. *Linella munyallina*, Wundowie Limestone Member, Northern Flinders Ranges. (a)—Recurved margin of a bioherm, lowest limestone band, Burr Well; (b)—Longitudinal sections of complexly branching columns, Roebuck Bore; (c)—Inclined columns at a bioherm margin. Lowest limestone band, Burr Well; (d)—Outcrop of a small bioherm. Lowest limestone band, Burr Well; (e)—Thin section inclined columns from a bioherm margin. Here the wall is poorly developed. Lowest limestone band, Burr Well. S486; (f)—Thin section of columns with numerous bridges, Munyallina Valley. S294.

Fig. 9. (a–c)—*Linella munyallina*, Wundowie Limestone Member. (a)—Thin section of slightly divergent branching columns. Roebuck Bore. S431; (b)—Thin section of holotype, S495, showing steeply domed laminae in parallel, walled columns. Note sandy lenses in the interspaces; (c)—Thin section of slightly divergent branching columns. West Mount Hut. S555; (d)—*Omachtenia utschurica*, outcrop, uppermost beds of the Tapley Hill Formation, Depot Creek; (e)—As for (d), showing numerous bridges between columns.

Fig. 10. (a–c)—Longitudinal thin sections, *Omachtenia utschurica*. (a)—Illustrating pelletal lamination and coarse intraclasts in interspaces. S166, Depot Creek; (b)—Illustrating details of pelletal microstructure. S399, Depot Creek; (c)—Illustrating broadly banded microstructure; (d, e)—*Tungussia etina;* (d)—Longitudinal outcrop section showing markedly divergent branching, Balcanoona Formation, near Mount Chambers; (e)—Outcrop of irregularly tuberous columns, Etina Formation, Enorama Creek.

Fig. 11. (a) —*Tungussia etina*, Umberatana Group, Flinders Ranges, Longitudinal cut slab showing markedly divergent branching of columns. Wundowie Limestone Member, near Teatree O.S. S441; (b)—Longitudinal thin section of walled columns, Wundowie Limestone Member, near Teatree O.S. S446; (c)—Vertical thin section of variously oriented columns, Balcanoona Formation, near Mount Chambers. Holotype S435; (d) –Wavy, banded lamination seen in thin section, Etina Formation, east of Blinman. S158; (e)—Longitudinal thin section, Balcanoona Formation, near Mount Chambers. S525.

Fig. 12. (a)—Longitudinal thin section, *Tungussia etina*, Wundowie Limestone Member, near Teatree O.S. S286; (b–e)—*Tungussia wilkatanna*, Skillogalee Dolomite, Depot Creek; (b)—Longitudinal thin section illustrating sharp flexure in column. S169; (c)—Outcrop of bushy, divergently branching clump of columns; (d)—Cut slab, S169, illustrating markedly divergent branching; (e)—Thin section, holotype S412, showing markedly divergent branching columns. White areas are silicified.

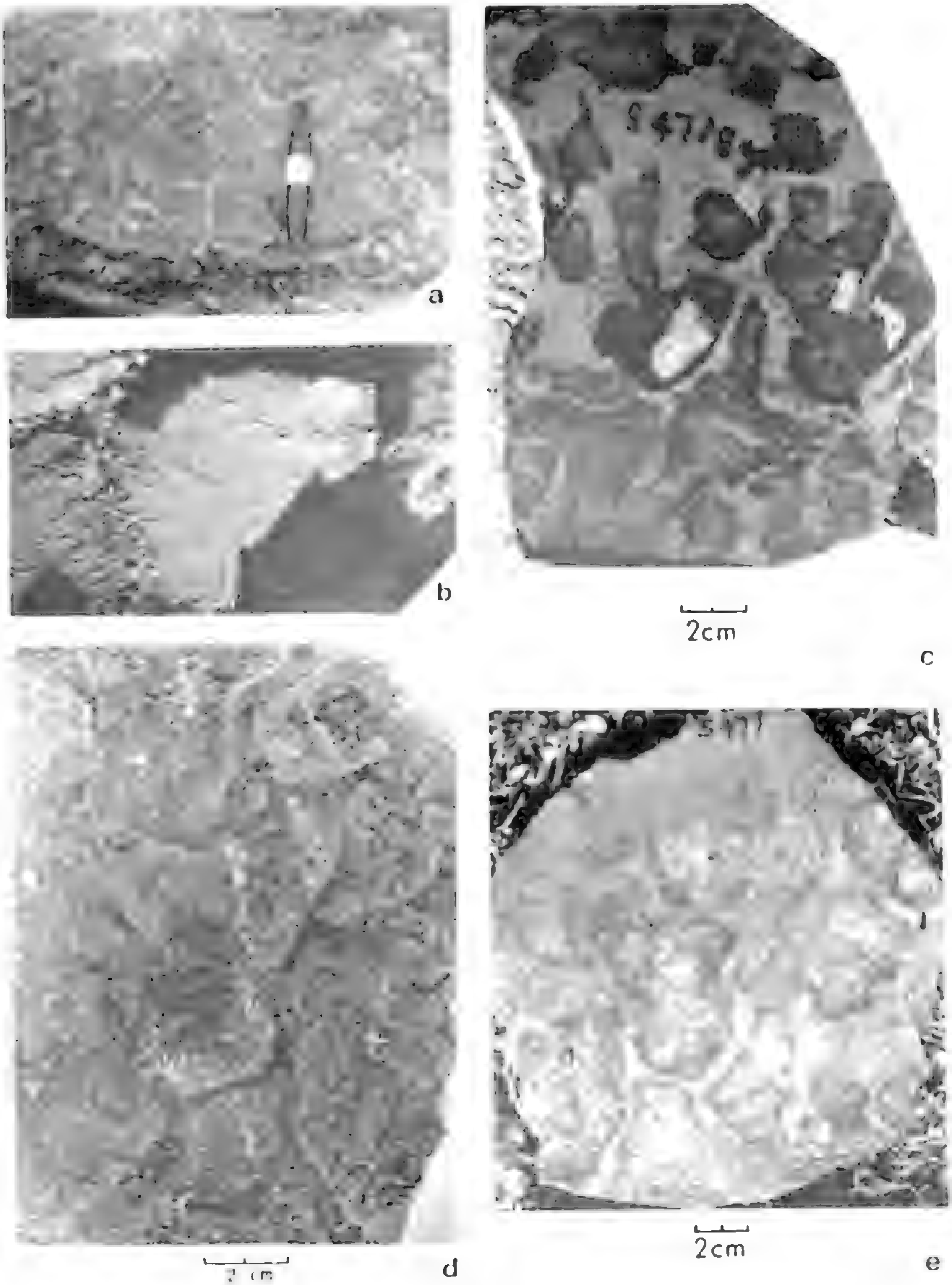
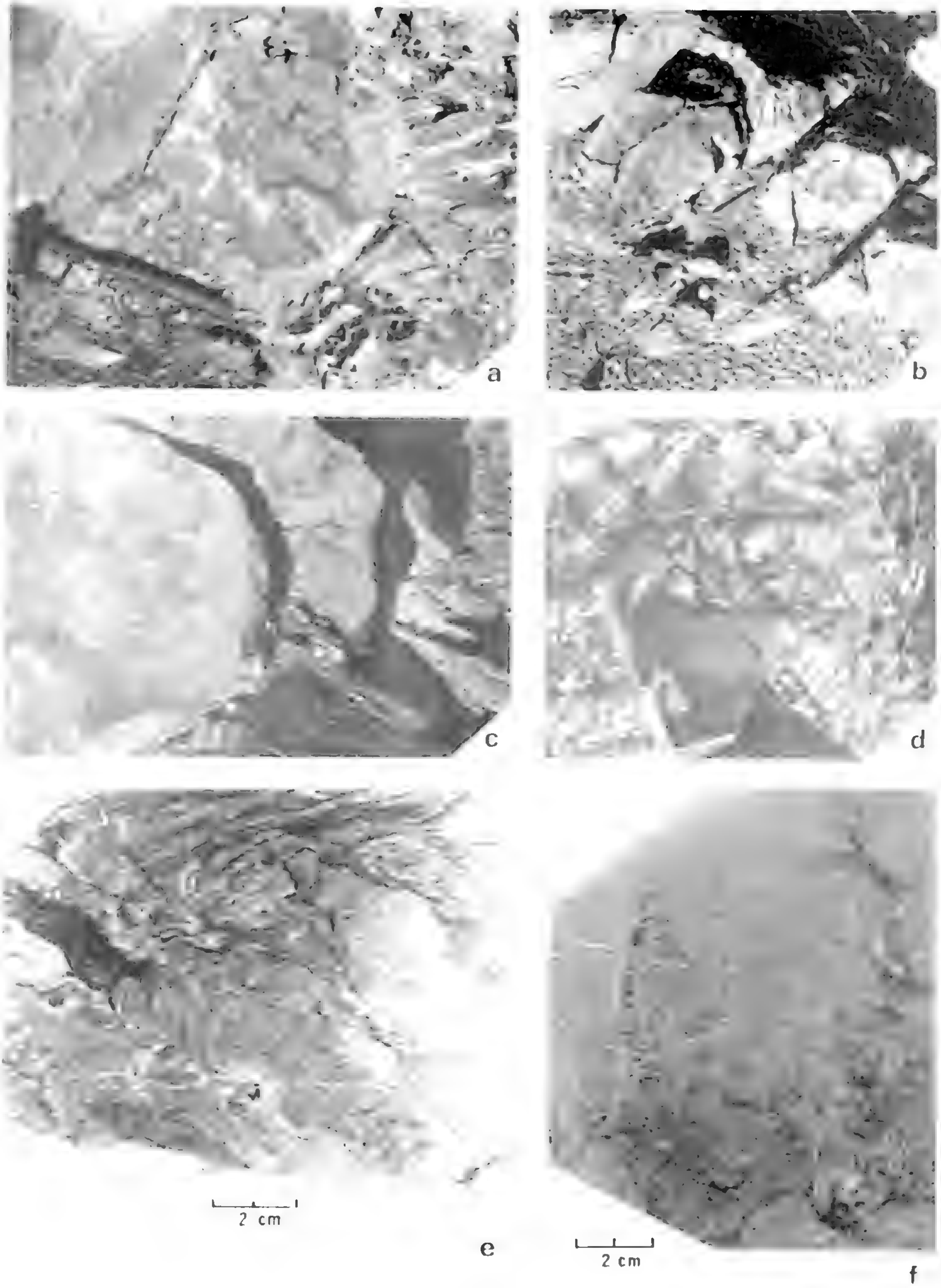


Fig. 7



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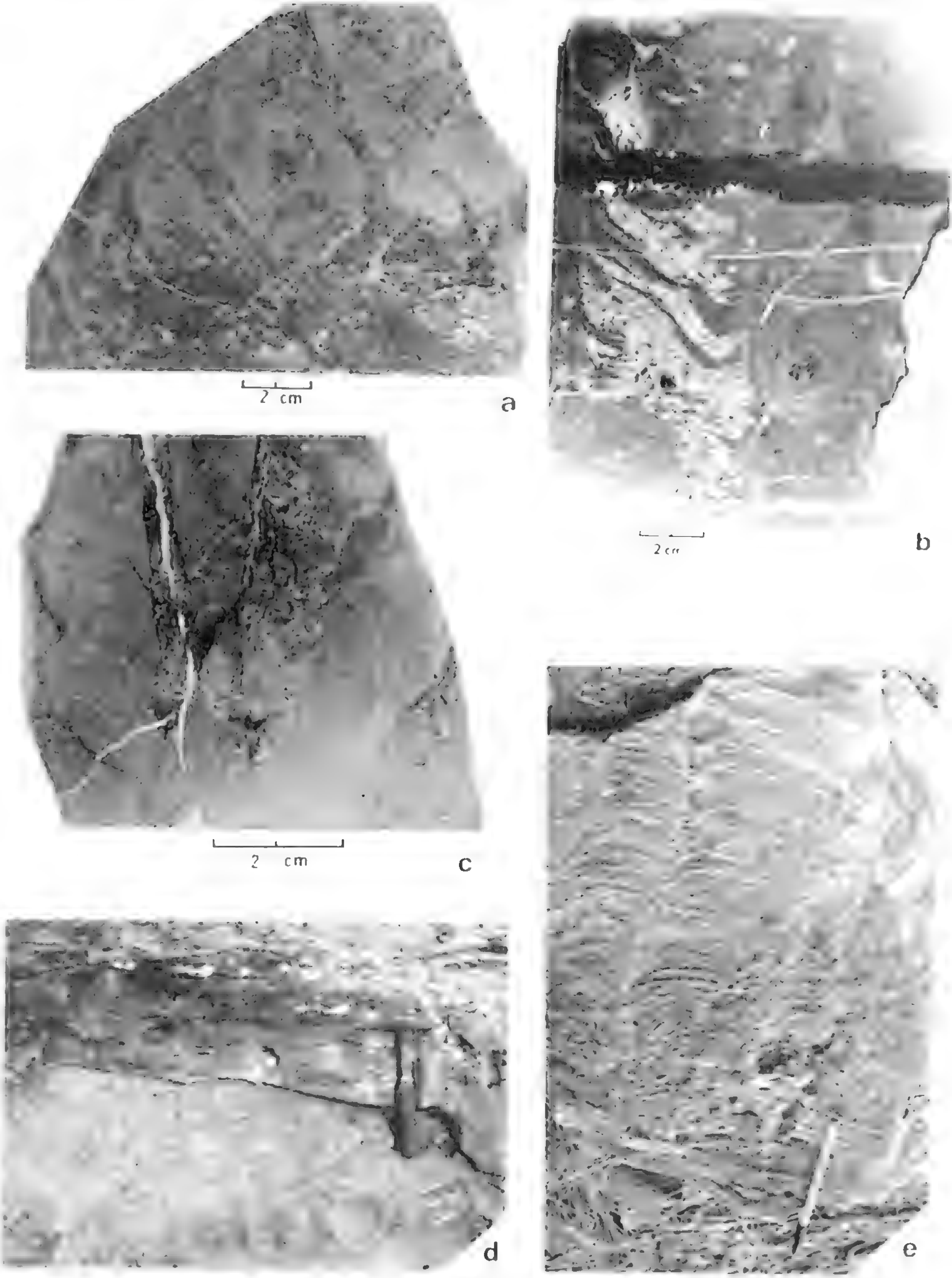

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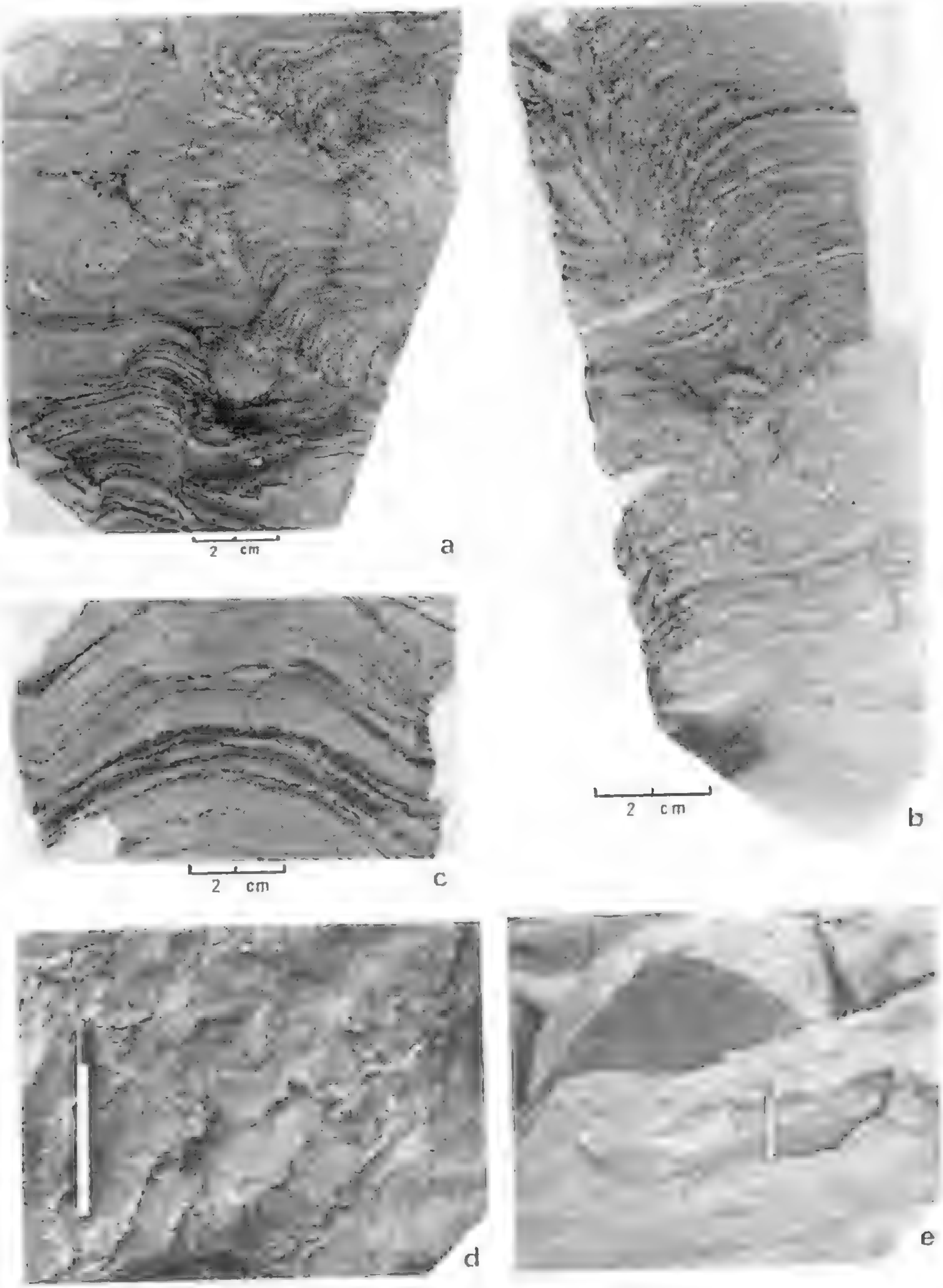

Fig. 10

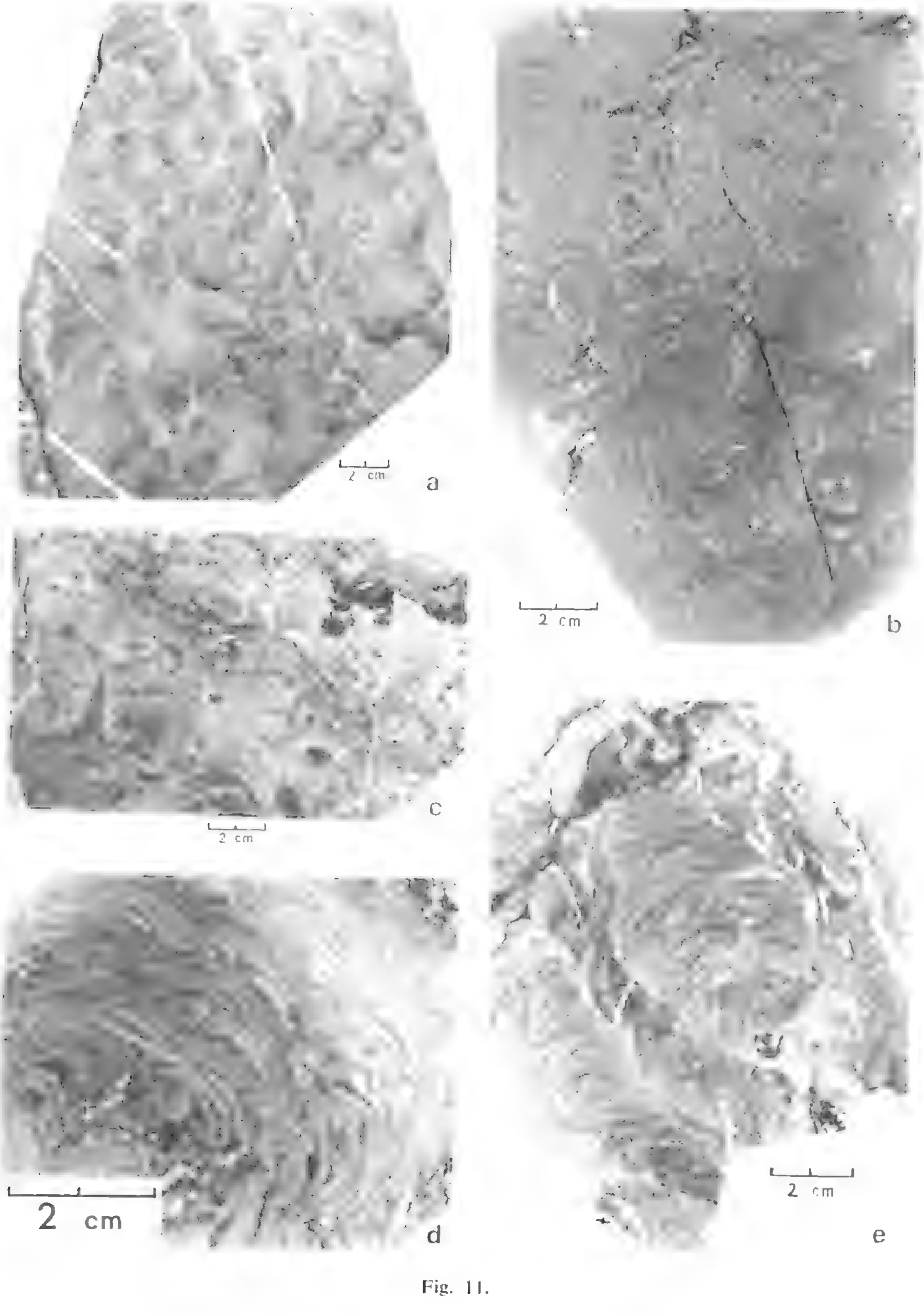

Fig. 11.

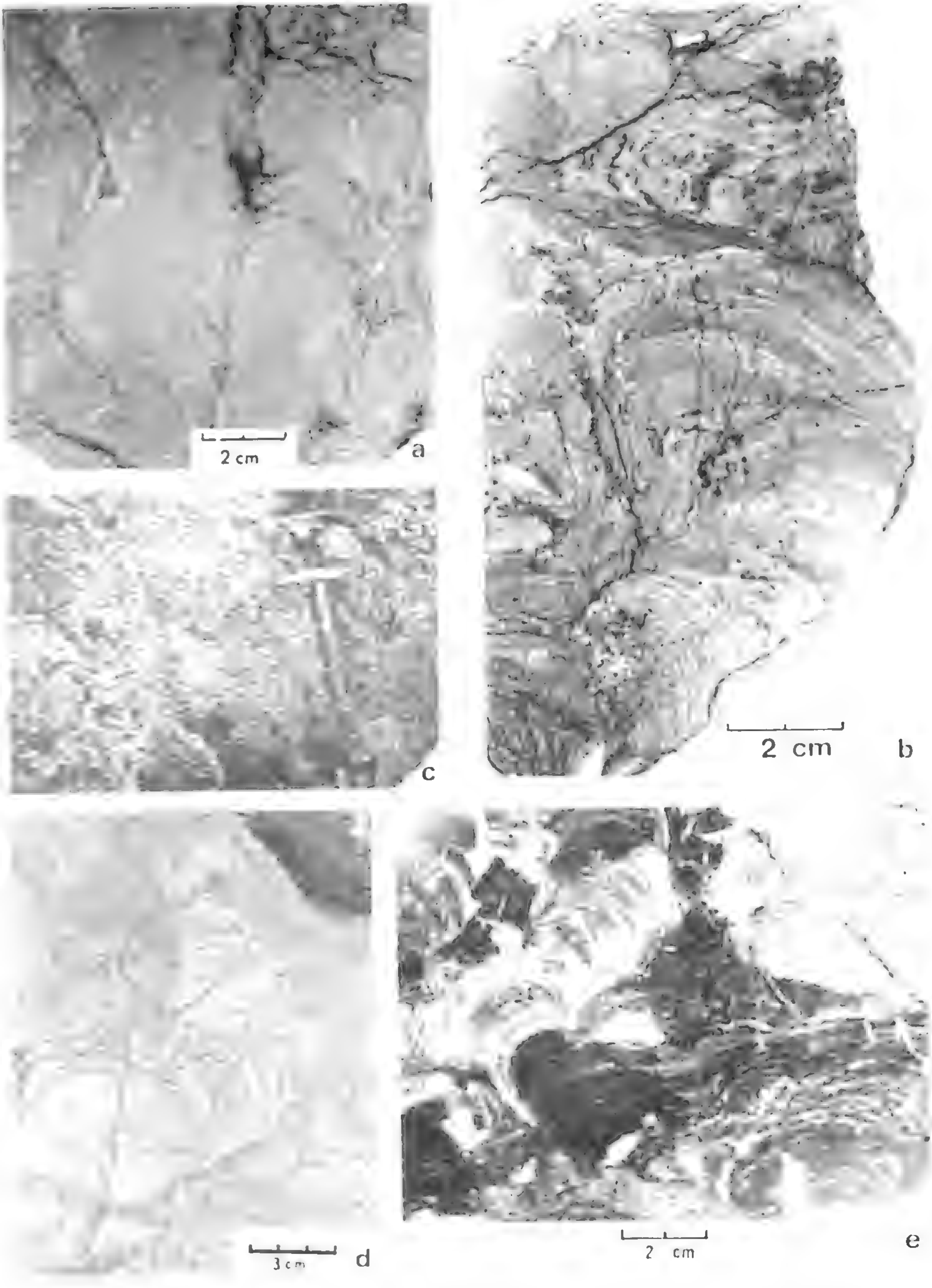

Fig. 12.

AMPHIBOLURUS GIBBA, A NEW DRAGON LIZARD (LACERTILIA:AGAMIDAE) FROM NORTHERN SOUTH AUSTRALIA

BY T. F. HOUSTON*

Summary

HOUSTON, T. F. (1974). -*Amplibolurus gibba,* a new dragon lizard (Lacertilia: Agamidae) from northern South Australia. *Trans.* R. *Soc. S. Aust.* 98(4), 209-212, 30 November, 1974.

A new species of agamid lizard is described and figured. It is regarded as a member of the *Amplibolurus reticulatus* species-group and shows close affinity with *A. maculosus* (Mitchell). It appears to be confined to the gibber plains of northern South Australia.

AMPHIBOLURUS GIBBA, A NEW DRAGON LIZARD (LACERTILIA: AGAMIDAE) FROM NORTHERN SOUTH AUSTRALIA

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Summary

HOUSTON, T. F. (1974).—*Amphibolurus gibba*, a new dragon lizard (Lacertilia: Agamidae) from northern South Australia. *Trans. R. Soc. S. Aust.* 98(4), 209-212. 30 November, 1974.

A new species of agamid lizard is described and figured. It is regarded as a member of the *Amphibolurus reticulatus* species-group and shows close affinity with *A. maculosus* (Mitchell). It appears to be confined to the gibber plains of northern South Australia.

Introduction

The species described herein as new is a little known inhabitant of the barren, stone-strewn gibber plains of far northern South Australia. Specimens have been received at the South Australian Museum over the past 27 years but were variously misidentified, most of them as *Amphibolurus imbricatus* Peters (=*A. c. caudicinctus* (Gunther)—Storr 1967). Mitchell's (1955, p. 387) reference to the occurrence of *A. imbricatus* near Marree and Finniss Springs, S. Aust., was based on these specimens.

Enquiries by the present author revealed one specimen in the National Museum of Victoria, Melbourne, but none in other Australian museums. Except where indicated otherwise, all specimens listed below are in the South Australian Museum. All localities mentioned are in South Australia.

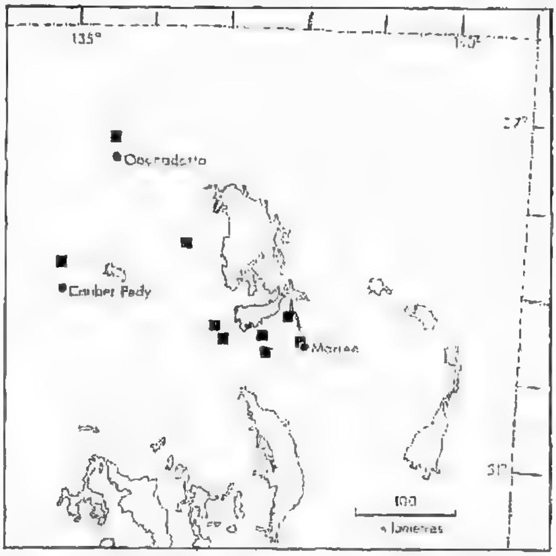

Fig. 1. Map of north-eastern South Australia showing collection localities (solid squares) of *Amphibolurus gibba*.

Amphibolurus gibba n.sp.

FIGS. 1–4; TABLE 1

Holotype: ♀, R13954A, 5.5 km NNW of Alberrie Creek Railway Siding, S. Aust. (29°35'S, 137°31'E), 14.i.1974, ex burrow under cracked mud crust of gibber plain, *R. Forsyth & T. Houston.*

Diagnosis: Agrees with *A. reticulatus* (Gray), *A. inermis* (De Vis) and *A. maculosus* (Mitchell) in general form (short deep head, abrupt profile, denticulate eye lids, smooth-scaled back and relatively short tail). Agrees with *A. maculosus*, but not *A. reticulatus* and *A. inermis*, in having nostrils situated below (not on) canthus rostralis. Differs from the three in having relatively longer hind limbs (mean ratio of leg length to snout-vent length =81%; cf. 57–67% in other species); femoral and preanal pores (mean = 30) more numerous than in *A. inermis* (21) and *A. maculosus* (10, femoral only) but fewer than in *A. reticulatus* (37); ear openings relatively smaller than in *A. reticulatus* and *A. inermis* but not scale-covered as in *A. maculosus*. Dis-

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* South Australian Museum, North Terrace, Adelaide, S. Aust. 5000.

tinguishable also by coloration: throat with conspicuous round black patch (with dark reticulum in *A. reticulatus* and *A. inermis;* with longitudinal black streak in *A. maculosus*); chin with median black streak; back buff to terra-cotta red, often darkly speckled, usually with 6–8 pairs of blackish paravertebral spots (with blackish reticulum in adult *A. reticulatus* and *A. inermis;* white to grey in *A. maculosus* with bolder paravertebral spots); tail with linear series of 20–30 dark spots each side (absent in other species).

Description: Stout, moderate-sized dragon lizards reaching a snout-vent length of 82 mm and total length of 190 mm; head relatively short and deep; snout obtuse, rising steeply in profile; nostril situated below slightly swollen canthus rostralis; ear aperture relatively small and elliptical; body depressed; fore limbs relatively large, reaching or almost reaching groin when adpressed; hind limbs moderately long; tail moderately long and evenly tapering. (See Table 1 for proportions). In juveniles the head and appendages are relatively longer than in adults.

TABLE 1

Body proportions expressed as percentage ratios for specimens of A. gibba *with a snout-vent length of 55 mm or more*

(n = sample size, r = range, m = mean, s = standard deviation)

Proportion	n	r	m	s
Head length: SVL	14	28–32	30	1.3
Head width: length	14	68–85	75	4.5
Ear diameter: head width	14	16–21	18	1.5
Fore limb length: SVL	14	39–48	43	2.1
Hind limb length: SVL	14	75–90	81	3.8
Tail length: SVL	12	126–154	143	7.8

Dorsal scales of head weakly to strongly convex, angular, transversely carinate or ridged in front of and behind supra-orbital areas; a row of enlarged, longitudinally ridged or carinate scales from below eye to above ear; outer margin of lower eyelid fringed with a row of very acute scales; 4–6 scale rows separating nasals from upper labials; 12–17 upper labial scales each side; temporal, occipital, nuchal and axillary scales very small and convex, interspersed on the head (sometimes) with a few spinous tubercles; no nuchal crest but a few median scales slightly enlarged; scales on remainder of body, legs and tail (dorsally) flat and smooth, those of the back largest medially; keels appearing only on ventral side of tail, strongest distally; 26–35 (mean = 30) femoral and preanal pores well-spaced along a fairly straight line extending full length of each thigh; each pore surrounded by several scales, those anterior to it being slightly enlarged.

Dorsally grey to buff-brown, tinged in some individuals with pink or terra-cotta; each side of head with 3–4 alternating light and dark vertical bars from eye to lower lip (sometimes faint); back with 6–8 pairs of blackish paravertebral spots from shoulders to rump; similar spots sometimes present on flanks; tail with 20–30 dark blotches along each side; chin with a small black median streak and throat with a large median black patch; chest with a faint grey to intense black patch medially. The holotype, in life, had a light yellow wash across the anterior part of the chest and shoulders.

Measurements of holotype (in mm): Head length, 21; head width, 16; maximum diameter of ear, 2.8; snout-vent length, 72; fore limb length, 31; hind limb length, 58; tail length, 100.

The specific epithet, taken from Cooper's (1949) list of Aboriginal words and meaning desert stone or rock, is used as a noun in apposition and is not subject to termination changes.

Specimens examined: Paratypes: same data as the holotype, R13954B–K; 34 km N of Coober Pedy, *E. Story,* 6.x.1973, R13953; 37 km S of Coward Springs on road to Stuart Creek H. S., "gibber, crumbly clay soil, ran into burrow", Zoology Dept., University of Adelaide, 26.x.1969, R11165; Finniss Springs, *A. J. Pearce,* 17.i.1947, R2525, R13894A–B; same loc., *F. J. Mitchell,* 6.ii.1964, R13891; Lake Lettie Waterhole, *G. F. Gross,* 23.iii.1956, R3805; Marree, *F. J. Mitchell,* June 1966, R9499; 3.2 km S of Marree, *F. J. Mitchell,* Feb. 1966, R7605–6, R8310; 19 km SE of Mt Hamilton Stn on Margaret River, *R. Tedford,* 19.v.1953, R3542; 32 km N of Oodnadatta, *J. Bredl,* 1971, R12494A–B; Johnsons Bore track midway between William Creek and the Neales, 23.viii.1969, Nat. Mus. Vic., D39917.

Systematic position

The genus *Amphibolurus* Wagler, as it currently stands, contains many diverse elements and no satisfactory definition of it is available. Its species cohere more by the lack of specialized features characterizing other genera than by possession of features unique to them as a group.

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Figs. 2–3. Anterior and lateral views of holotype of *Amphibolurus gibba* in life.
Fig. 4. Juvenile of *A. gibba* in life.

The placement of *A. gibba* in *Amphibolurus* is based on its apparent affinity and close similarity to species (*A. reticulatus* and *A. inermis*) long placed in this genus.

In the totality of its features, *A. gibba* is intermediate between *A. reticulatus* and *A. inermis* on the one hand and *A. maculosus* on the other. Structurally it most closely resembles *A. reticulatus* but in size, nostril position and coloration it approaches *A. maculosus*. The latter species was originally included in the genus *Tympanocryptis* Peters (Mitchell 1948, Storr 1964) on account of its scale-covered ears but was subsequently removed to *Amphibolurus* on the basis of osteological evidence (Mitchell 1965). Closure of the ear openings was believed to be a secondary development.

I support Mitchell's conclusions and suggest that *A. maculosus* and *A. gibba* are derived from a common ancestor and that the covered ears of the former evolved through an intermediate stage such as is now seen in *A. gibba*.

I also suggest that *A. gibba* and *A. maculosus* be regarded as members of the *A. reticulatus* species-group (Storr 1966), although my conception of this group does not extend to include *A. decresii* (Duméril & Bibron) or *A. pictus* Peters (see Houston 1974, pp. 57–58). The species-group as understood here contains habitual burrowers in which sexual dichromatism is either not evident or only feebly developed.

Acknowledgments

I am grateful to Mr. M. J. Tyler, Honorary Associate in Herpetology, South Australian Museum, who sought specimens of the new species on my behalf during visits to two Australian Museums, to Mr. Ross Forsyth who energetically assisted me in field collection, and to Mr. A. J. Coventry, Field Officer, National Museum of Victoria, Melbourne, for providing a specimen for study.

The distribution map (Fig. 1) was prepared by Miss Adrienne Edwards.

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A REVISION OF THE FOSSIL MEGAPODIIDAE (AVES), INCLUDING A DESCRIPTION OF A NEW SPECIES OF PROGURA DE VIS

*BY G. F. VAN TETS**

Summary

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The smaller of the two is named *Progura naracoortensis* n. sp. It differs from its congener by having a relatively shorter tarsometatarsus.

Of other megapodes, fossil remains have been found only of one specimen of *Leipoa ocellata*, Malleefowl, and of one or more indeterminable juvenile megapodes. Fossil remains reported as those of *Alectura lathami*, Brush-turkey, are of Progura gallinacea and *P. naracoortensis*.

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Introduction

Brodkorb (1964, p. 307) mentions only two fossils in the Megapodiidae, a carpometacarpus which is the holotype of *Chosornis praeteritus* De Vis, 1889, and a coracoid which Lydekker (1891) determined as that of a large gallinaceous bird and provisionally referred to *Alectura lathami* J. E. Gray, 1831, Brush-turkey. A tarsometatarsus, closely comparable with that of *A. lathami*, was reported by Longman (1945).

Recently more fossil material of megapodes was located in south-eastern Australia, including remains of an undescribed species. These, and four tarsometatarsi, the syntypes of *Progura gallinacea* De Vis, 1888a, are here reassigned to the Megapodiidae. *Progura* was placed by De Vis in the Columbidae near the crowned pigeons (*Goura* Stephens, 1819). De Vis (1888a) considered both *Progura* and *Goura* to be close to the common ancestor of poultry and pigeons.

In this paper the new species is described, and the long bones of fossil megapodes are compared with those of extant megapodes (*Megapodius pritchardi* G. R. Gray, 1864, Niuafou Fowl; *M. (freycinet) reinwardt* Dumont, 1823, Scrubfowl; *Alectura lathami*, Brush-turkey; and *Leipoa ocellata* Gould, 1840, Malleefowl); and of crowned pigeons (*Goura scheepmakeri* Finsch, 1876, and *G. victoria* (Fraser, 1844)).

Methods

The study material was made available by the following museums and is identified in the text by their initials and numbers: Australian Museum, Sydney (AM); British Museum (Natural History), London (BMNH); National Museum of Victoria, Melbourne (NMV); Queensland Museum, Brisbane (QM); South Australian Museum, Adelaide (SAM); United States National Museum, Washington (USNM); and CSIRO, Division of Wildlife Research, Canberra (CSIRO).

The terminology of Harvey *et al.* (1968) is used for bones and their parts. Examples of fossil bones are figured together with a corresponding bone of a Scrubfowl. Mirror images of some bones have been drawn, so that all bones on a figure appear as if they are from the same side.

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Measurements of the bones were made as recommended by Scarlett (1972) and Schnell (1970) and as indicated on the figures. They include: length; width at proximal or dorsal end; width at narrowest point on shaft; and width at distal or ventral end. On the carpometacarpus, the greatest and least width of the proximal end was measured in accordance with De Vis (1889), and the greatest and least width at the narrowest point on the shaft of metacarpal III. On the tarsometatarsus, the width below the articular impression of the first metatarsal or hallux and the width of the central trochlea was measured. On the scapula the width of the blade was measured.

Weights of Malleefowl were obtained from the records of the CSIRO Bird-Banding Scheme, and weights of Scrubfowl from the labels on specimens in the collections of the Western Australian Museum, Perth and the Division of Wildlife Research, Canberra.

Material and Synonymy of *Progura gallinacea*

Progura gallinacea De Vis, 1888: 131.
Chosornis praeteritus De Vis, 1889: 55.
Palaeopelargus nobilis De Vis, 1891: 441 (new synonymy).

The syntypes of *Progura gallinacea* De Vis, 1888a, are those De Vis figured on Plate VI, two proximal parts of left tarsometatarsi (QM, F1134 and F1143) and two distal parts of right tarsometatarsi (QM, F5556–7). Because the syntypes are complementary fragments of the tarsometatarsus I have not selected a lectotype.

De Vis (1889) in his description of the holotype of *Chosornis praeteritus*, refers to "the metacarp of the left manus", but he figures on Plate IV a proximal part of a right carpometacarpus which is now numbered QM, F1132. Another proximal part of a right carpometacarpus bore the same number, but has been renumbered QM, F7005. It is more worn than QM, F1132 and is not the one figured on Plate IV. The description could pertain to either specimen. QM, F1132 should be regarded as the holotype of *Chosornis praeteritus* and the reference to "the left manus" should be dismissed as a *lapsus calami*.

A distal part of a right carpometacarpus (QM, F1139) is figured by De Vis (1891) on Plate 24 as the holotype of a stork, *Palaeopelargus nobilis*, Ciconiidae. Pat Vickers Rich and I found the holotypes of *Chosornis praeteritus* and of *Palaeopelargus nobilis* (QM, F1132 and F1139) to be matching fragments of the same bone.

Referred Specimens: The following material agrees in size with the type of *Progura gallinacea*. In shape, all specimens resemble the corresponding parts of extant megapodes, but they are very much larger in size. *Progura gallinacea* is the oldest available name for them. They are: the material of *Chosornis praeteritus* (QM, F1132 and F7005); the material of *Palaeopelargus nobilis* (QM, F1139), and a distal part of a right ulna (QM, F5553) (referred by De Vis (1891)); a proximal part of a right scapula (QM, F5558) (figured on Plate 35 and referred to the Otididae as an undetermined genus and species of bustard by De Vis (1888b)); an almost complete left coracoid (BMNH, A3244) (*Talegalla lathami* 43879 of Lydekker (1891)); an almost complete right coracoid (AM, F54720); a proximal part of a right ulna (AM, F54721); distal parts of two right ulnas (AM, F54722–3); a proximal part of a left tarsometatarsus (AM, F54724); a distal part of a left tarsometatarsus (AM, F54725); a distal part of a right tarsometatarsus (AM, F54726); and an incomplete distal part of a right tarsometatarsus (AM, F7033) (formerly also numbered QM, F1134).

Description of *Progura naracoortensis* n.sp.

Though the following material resembles corresponding parts of extant megapodes in shape, it is intermediate in size between *P. gallinacea* and extant megapodes. The material is consistent in size. The most distinctive bone is an almost complete right tarsometatarsus (SAM, P17856). It is not only smaller, but its relative length is also very much shorter than that of the syntypes of *P. gallinacea*.

Holotype: I have therefore selected SAM, P17856 as the holotype of *Progura naracoortensis* n.sp. It is named after Naracoorte, South Australia, where the holotype and most of the other remains of *P. naracoortensis* were found.

Referred specimens: The proximal part of a left tarsometatarsus (QM, F2769) was reported by Longman (1945) as closely comparable with that of a Brush-turkey. In size and shape it looks like a mirror image of SAM, P17856, the holotype of *P. naracoortensis*.

Further material of *P. naracoortensis* consists of an almost complete right coracoid (SAM, P16700); a complete and two distal ends of left humeri (SAM, P17153–4 and P17878); a proximal and a distal part of a right humerus (SAM, P18183); an almost complete right ulna (SAM, P17877); and two distal parts of left ulnae (SAM, P17879 and P18182); a complete left radius (SAM, P18184); a proximal part of a right femur (SAM, P17857); a distal part of a right femur (SAM, P18186); a complete right tibiotarsus (SAM, P17152); a distal part of a right tibiotarsus (SAM, P17876); a proximal part of a right tarsometatarsus (SAM, P18185); a cervical vertebra (SAM, P18181); and an anterior fragment of a synsacrum (SAM, P18187).

Fossil remains of other megapode species

Compared to *Progura* very few fossil remains have been found of other megapodes. As explained above, specimens reported as *Alectura lathami* by Lydekker (1891) and Longman (1945), are also *Progura* remains, and there are no other known fossil remains of the Brush-Turkey.

Fragments of a cranium of a Malleefowl (SAM, P16738) were found in the same deposit with the following remains of one or more juvenile megapodes of similar size but of indeterminable genus and species: a premaxilla (SAM, P16739), a sternum (SAM, P16740); a proximal part of a right ulna (SAM, P16741); a proximal part of a left femur (SAM, P16742); a distal part of a right femur (SAM, P16743); a distal part of a left tibiotarsus (SAM, P16744); and an almost complete right tibiotarsus (SAM, P16745).

Age and distribution of fossil megapodes

The following fossils of megapodes have been found in Pleistocene deposits in south-eastern Australia. None have been found in association with human remains nor with those of dogs and other domestic and feral animals. The map (Fig. 1) has been adapted from Frith (1962).

South-eastern Queensland

The syntypes of *Progura gallinacea* (QM, F1134, F1143 and F5556–7) and *P. gallinacea* (QM, F7033) were collected at Ravensthorpe near Pilton, Darling Downs (27°54'S, 152°10'E). According to a label associated with QM, F7033, it was collected on "11-9-1888" by R. W. Frost. QM, F1132, the holotype of *Chosornis praeteritus*, and QM, F5558 were, according to labels associated with the specimens, collected at Chinchilla, Darling Downs (26°45'S, 150°40'E). The holotype of *Palaeopelargus nobilis* (QM, F1139), QM, F5553 and QM, F7005 are from unknown localities in the Darling Downs.

Fig. 1: Distribution of fossil and extant megapodes in Australia.

P. naracoortensis (QM, F2769) was collected on 24 May, 1945, by E. T. O'Roarke at the Gore Limestone Quarries (28°18'S, 151°30'E) (Longman 1945).

Eastern New South Wales

The first material to be collected of *P. gallinacea* (BMNH, A3244), was obtained from a cave in the Wellington Valley near Wellington (32°35'S, 148°55'E), and was presented in 1870 to the British Museum (Natural History) by the Trustees of the Australian Museum (Lydekker 1891). Another specimen of *P. gallinacea* (AM, F54723) was collected from one of the Walli Caves in the Wellington Valley in 1966 or 1967 by R. M. Frank[1], Jeanette Hope found *P. gallinacea* (AM, F54720–2, and F54724–6), in the one lump of matrix at the Wombeyan Quarry of Industrial Rock Mines Ltd. about 1½ km west of Wombeyan Caves Reserve (34°19'S, 149°56'E), in April 1970. They may be of a single individual which appears to have fallen down a vertical entrance shaft and to have been crushed by subsequent deposits.

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[1] Frank, R. M. (1972).—Sedimentological and morphological study of selected cave systems in eastern N.S.W., Australia, Ph.D. thesis, A.N.U. (unpublished).

South-eastern South Australia

The holotype of *Progura naracoortensis* (SAM. P17856), as well as *P. naracoortensis* (SAM. P17152–4, P17857, P17876–9, and P18181–7) were collected at Henschke's Quarry Cave near Naracoorte (37°00′S, 140°45′E) by Mr. F. Aslin. Sample SUA243 from Henschke's Quarry Cave has a radiocarbon date of about 33,800 BP (N. Pledge, pers. comm.). *P. naracoortensis* (SAM, P16700) was collected by Dr. R. T. Wells and other members of the Cave Exploration Group of South Australia at Victoria Cave near Naracoorte, together with Malleefowl (SAM, 16738) and juvenile megapode(s) (SAM, P16739–45).

Comparisons of long bones of megapodes and crowned pigeons

Coracoid

The coracoids of *Goura* have relatively broader dorsal and ventral ends than those of megapodes. The coracoids of the species of megapodes differ mainly in length (see Table 1 and Fig. 2).

TABLE 1

Measurements of Coracoids of Megapodes and Crowned Pigeons

Species	Number	Sex	Side	Length mm	Dorsal Width mm	Shaft Width mm	Ventral Width mm
P. gallinacea	BMNH, A3244		L			10	
	AM. F54720		R	94		10	30
P. naracoortensis	SAM. P16700		R	85	18	10	24
G. victoria	NMV, W6676		L	83	19	9	25
			R	83	19	9	25
G. scheepmakeri	NMV. B8054		L	78	17	9	26
			R	78	17	9	25
L. ocellata	SAM, B11482	♂	L	64	14	6	18
			R	63	13	6	18
	SAM, B24306	♀	L	64	14	6	18
			R	64	14	6	19
	SAM, B5039	♀	L	62	14	6	19
			R	62	14	6	20
	NMV. B9276		L	64	14	6	17
			R	66	13	7	18
A. lathami	NMV, W5964		L	60	11	6	15
			R	60	11	5	15
	NMV, W4554		L	61	11	5	16
			R	61	11	5	17
	NMV, W4555		L	60	12	5	15
			R	59	11	5	15
M. reinwardt	CSIRO. GALS 2	♂	L	54	12	5	17
			R	54	12	5	17
	CSIRO. GALS 3	♂	L	55	11	5	17
			R	55	11	5	17
M. pritchardi	USNM, 319634		L	37	7	3	10
			R	37	7	3	10

Scapula

The scapulae of megapodes and other galliform birds have a scapular tubercle. This tubercle does not occur in most other kinds of birds including Otididae and *Goura*. The glenoid facet is round in *Goura* and is quadrangular in Otididae and Megapodiidae. The long axis of the glenoid facet is parallel to the shaft in Otididae and at right angles to the shaft in Megapodiidae.

The scapula of *P. naracoortensis* is not known. The scapulae of the species of megapodes differ in size (see Table 2 and Fig. 2).

Humerus

The humeri of *Goura* are relatively shorter, more massive and have more prominent deltoid crests than those of megapodes. The humerus of *P. gallinacea* is not known. The humeri of the species of megapodes differ mainly in length (see Table 3 and Fig. 3).

Ulna

The ulnae of *Goura* are straighter and have more prominent feather bases than those of megapodes. The ulnae of the species of megapodes differ in size, except for an overlap in length between Scrubfowl and Brush-turkey (see Table 4 and Fig. 3).

Radius

The radii of *Goura* are arched upwards and those of megapodes are arched forwards.

The radii of the species of megapodes differ in size except for an overlap in length between Scrubfowl and Brush-turkey (see Table 5 and Fig. 3).

Carpometacarpus

The carpal II process of *Goura* is relatively larger and more prominent than that of megapodes. De Vis (1889) noted the absence of an intermetacarpal process in the holotype of *Chosornis praeteritus*. This process is a prominent structure in the Passeriformes and the Northern Hemisphere based galliform families, Phasianidae, Tetraonidae and Meleagridae. It is absent in the Columbiformes including *Goura* and the Southern Hemisphere based galliform families, Megapodiidae, Cracidae and Numididae. The carpometacarpus of *P. naracoortensis* is not known. The carpometacarpi of the species of

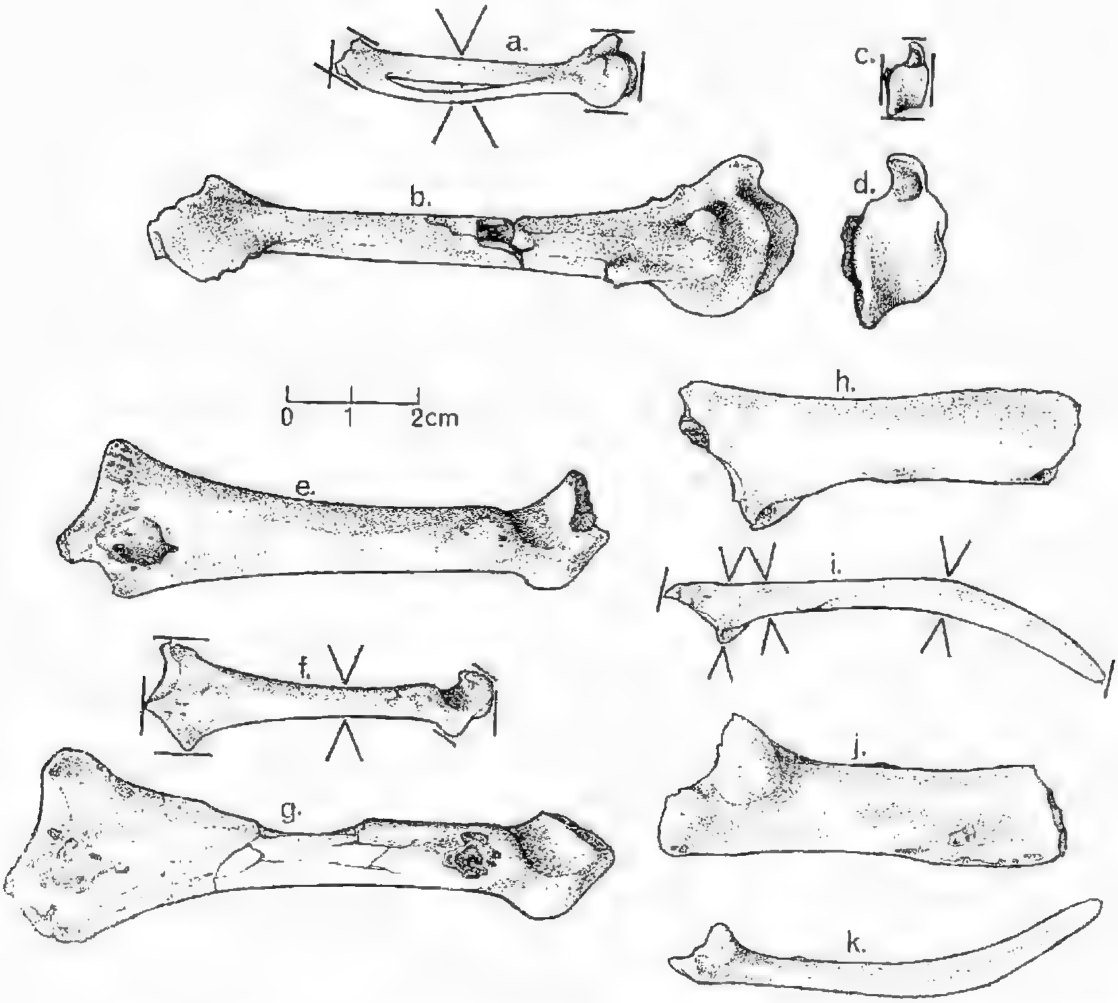


Fig. 2. *a.* and *c.*—right carpometacarpus, *M. reinwardt* (CSIRO, GALS3); *b.* and *d.*—right carpometacarpus, *P. gallinacea* (QM, F1132 and F1139); *e.*—right coracoid, *P. naracoortensis* (SAM, P16760); *f.*—right coracoid, *M. reinwardt* (CSIRO, GALS3); *g.*—right coracoid, *P. gallinacea* (AM, F54720); *h.* and *j.*—right scapula, *P. gallinacea* (QM, F5558); *i.* and *k.*—right scapula, *M. reinwardt* (CSIRO, GALS3).

megapodes differ in size, except for an overlap in length between Scrubfowl and Brush-turkey (see Table 6 and Fig. 2).

Synsacrum

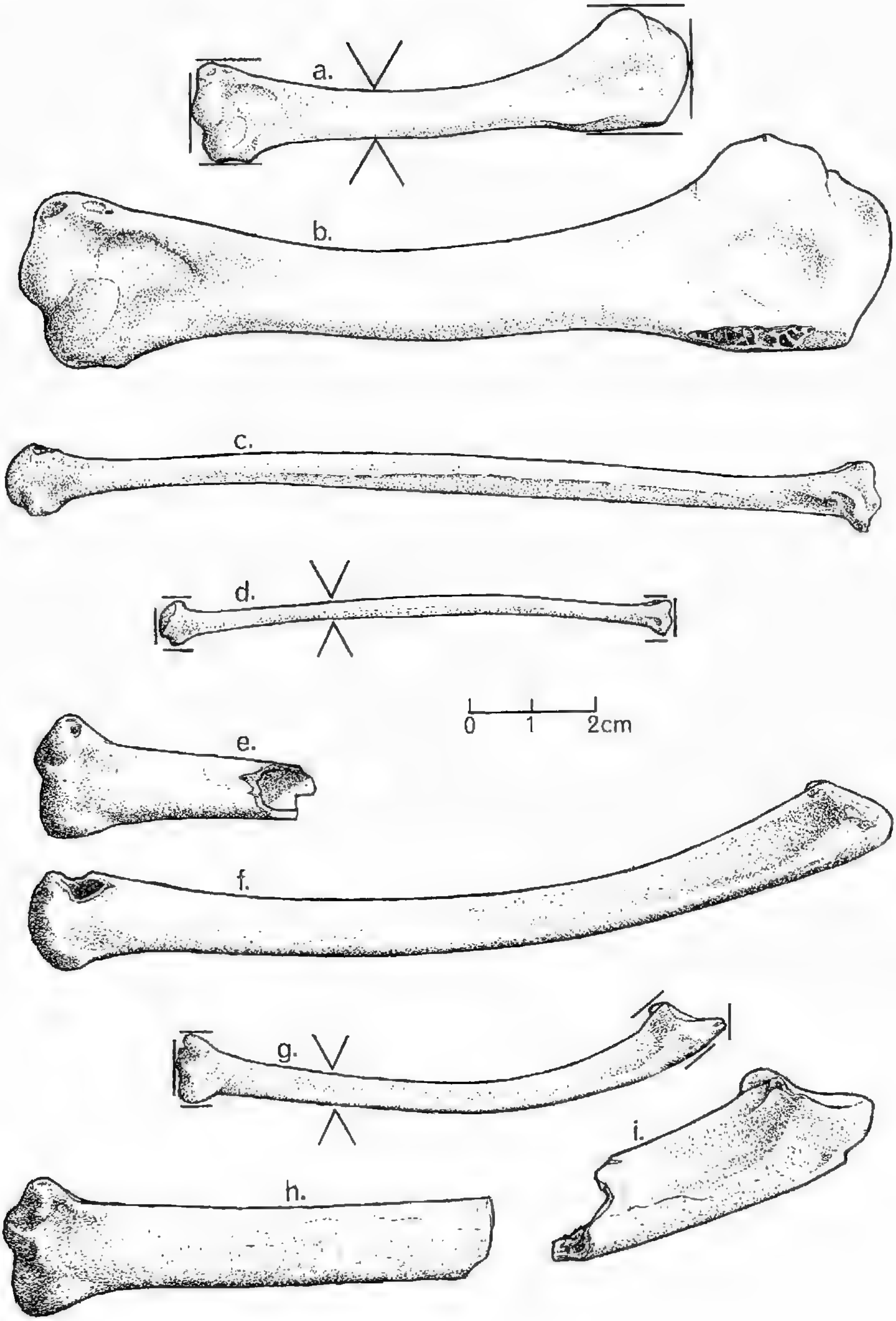
The synsacra of *Goura* have a median ventral ridge at the anterior end. This ridge does not occur in megapodes. The synsacra of megapodes differ in size (see Fig. 4).

Femur

The shaft is narrowest distally in *Goura* and proximally in megapodes. The trochanteric ridge is more pronounced in megapodes than in *Goura*. The femur of *P. gallinacea* is not known. The femora of the species of megapodes differ in size except for an overlap in length between Malleefowl and Brush-turkey (see Table 7 and Fig. 4).

Tibiotarsus

The tibiotarsi of *Goura* lack a prominent notch on the medial condyle which is present in megapodes. The tibiotarsus of *P. gallinacea* is not known. The tibiotarsi of the species of megapodes differ in size except for an overlap


a.
b.
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0
1
2cm
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f.
g.
i.
h.

TABLE 2

Measurements of Scapulae of Megapodes and Crowned Pigeons

Species	Number	Sex	Side	Length mm	Proximal Width mm	Shaft Width mm	Blade Width mm
P. gallinacea	QM. F5558		R		22	14	
G. victoria	NMV. W6676		L	86	14	7	12
			R	87	14	7	11
G. scheepmakeri	NMV. R8054		L	87	13	6	12
			R	88	12	6	13
L. ocellata	NMV. B9276		L	79	12	6	10
			R	80	12	6	10
A. lathami	NMV. W5964		L	79	10	6	9
			R	77	10	6	9
	NMV. W4554		L	78	10	5	9
			R	77	10	5	9
	NMV. W4555		L	75	9	5	8
			R	75	10	5	8
M. reinwardt	CSIRO, GALS 2	♂	L	68	9	5	6
			R	68	10	5	7
	CSIRO, GALS 3	♂	R	69	9	5	6
M. pritchardi	USNM. 319634		L	48	6	3	4
			R	48	6	3	4

TABLE 3

Measurements of Humeri of Megapodes and Crowned Pigeons

Species	Number	Sex/Age	Side	Length mm	Proximal Width mm	Shaft Width mm	Distal Width mm
P. naracoortensis	SAM. P17153		L	144	36	14	30
	SAM. P17154		L				32
	SAM. P18183		R		39	15	32
	SAM. P17878	*	L			13	26
G. victoria	NMV. W6676		L	108	34	12	25
			R	108	33	12	25
G. scheepmakeri	NMV. R8054		L	101	30	11	23
			R	102	30	11	23
L. ocellata	SAM. B11482	♂	L	100	22	8	19
			R	101	22	8	19
	SAM. B5039	♀	L	102	24	9	19
			R	103	24	8	19
	NMV. B9276		L	107	23	9	19
			R	108	24	9	20
A. lathami	NMV. W5964		L	87	21	9	18
			R	86	20	8	18
	NMV. W4554		L	90	21	8	18
			R	90	21	8	18
	NMV. W4555		L	88	21	8	18
			R	89	31	8	18
M. reinwardt	CSIRO, GALS 2	♂	L	82	19	8	15
			R	82	19	8	16
	CSIRO, GALS 3	♂	L	83	19	8	17
			R	84	19	8	16
M. pritchardi	USNM. 319634		L	59	12	4	11
			R	59	12	4	11

* Juvenile.

in length between Malleefowl and Brush-turkey (see Table 8 and Fig. 4).

Tarsometatarsus

The articular impression of the 1st metatarsal is prominent in megapodes and inconspicuous in *Goura*. The shaft is narrow below the impression in *Goura* and broad in megapodes. The hypotarsus is more slender and finely formed in *Goura* than in megapodes. The tarsometatarsi of the species of megapodes differ in size (see Table 9 and Fig. 4).

Relative bone lengths

In Table 10, the lengths of the limb bones are expressed in terms of coracoid lengths. *Goura* differs by having relatively shorter humeri, femora and tibiotarsi, than megapodes. The tarsometatarsi of *Goura*, *P. naracoortensis* and *L. ocellata* are relatively shorter than those of *P. gallinacea*, *A. lathami*, *M. reinwardt* and *M. pritchardi*.

Weights

Weights of seven male Malleefowl ranged from 2.0 to 2.2 kg and of four females from 1.8 to 1.9 kg. Weights of five male Scrubfowl ranged from 0.8 to 1.2 kg and of seven females from 0.6 to 1.1 kg. Maschlanka (1972) found no significant sexual differences in the bone lengths of Malleefowl, and Sutter (1965) found that of three Brush-turkey raised in captivity, two females reached weights of 2.0 and 2.1 kg and a male 2.5 kg. This limited evidence suggests that male megapodes are only slightly larger than females.

If it is assumed that weight is proportional to the cube of the length of the coracoid and that the average weight of Malleefowl is two

Fig. 3. *a.*—left humerus, *M. reinwardt* (CSIRO, GALS3); *b.*—left humerus, *P. naracoortensis* (SAM, P17153); *c.*—left radius, *P. naracoortensis* (SAM, P18184); *d.*—left radius, *M. reinwardt* (CSIRO, GALS3); *e.*—left reversed ulna, *P. naracoortensis* (SAM, P17879); *f.*—right ulna, juvenile *P. naracoortensis* (SAM, P17877); *g.*—right ulna, *M. reinwardt* (CSIRO, GALS3); *h.* and *i.*—right ulna, *P. gallinacea* (AM, F54721 and F54722).

TABLE 4

Measurements of Ulnae of Megapodes and Crowned Pigeons

Species	Number	Sex/Age	Side	Length mm	Proximal Width mm	Shaft Width mm	Distal Width mm
P. gallinacea	QM, F5553		R			11	20
	AM, F54721		R		23		
	AM, F54722		R			12	22
	AM, F54723		R			11	22
P. naracoortensis	SAM, P17879		L			10	19
	SAM, P18182		L			10	19
	SAM, P17877	*	R	137	19	10	
G. victoria	NMV, W6676		L	131	19	9	17
			R	131	18	8	17
G. scheepmakeri	NMV, R8054		L	124	18	8	14
			R	124	17	9	14
L. ocellata	SAM, B11482	♂	L	103	14	7	13
			R	103	14	7	13
	SAM, B5039	♀	L	106	15	6	13
			R	106	15	7	13
	NMV, B9276		L	114	14	7	12
			R	114	15	7	13
A. lathami	NMV, W5964		L	89	13	7	12
			R	89	13	6	11
	NMV, W4554		L	88	13	7	11
			R	88	13	7	11
	NMV, W4555		L	88	13	7	11
			R	88	13	6	11
M. reinwardt	CSIRO, GALS 2	♂	L	85	12	6	10
			R	85	12	6	10
	CSIRO, GALS 3	♂	L	87	13	5	11
			R	88	13	6	11
M. pritchardi	USNM, 319634		L	67	8	4	7
			R	66	8	3	7

* Juvenile.

kg and of Scrubfowl one kg, then the weight of *P. gallinacea* would have been about five to seven kg and of *P. naracoortensis* about four to five kg.

A reconstruction of the relative sizes of the Australian megapodes is given in Fig. 5.

Power of flight

There are several kinds of birds that are over seven kg in weight and are capable of flying, e.g., turkeys, bustards, cranes and swans. The wing bones of the two *Progura* species are relatively and absolutely long and strong enough for them to have been capable of at least limited flight.

Ecology

Until more material, especially of the skull, of the species of *Progura* becomes available for study, very little can be said about how and in what habitats they lived. As large land

TABLE 5

Measurements of Radii of Megapodes and Crowned Pigeons

Species	Number	Sex	Side	Length mm	Proximal Width mm	Shaft Width mm	Distal Width mm
P. naracoortensis	SAM, P18184		L	135	10	6	13
G. victoria	NMV, W6676		L	120	9	5	10
			R	120	10	5	10
G. scheepmakeri	NMV, R8054		L	114	7	5	10
			R	114	9	5	10
L. ocellata	NMV, B9276		L	104	7	4	8
			R	105	7	4	8
A. lathami	NMV, W5964		L	80	5	3	8
			R	79	6	3	8
	NMV, W4554		L	81	6	3	8
			R	80	6	3	8
	NMV, W4555		L	81	6	3	8
			R	81	6	3	8
M. reinwardt	CSIRO, GALS 2	♂	L	79	6	3	8
			R	79	6	3	8
	CSIRO, GALS 3	♂	L	80	6	3	7
			R	80	6	3	7
M. pritchardi	USNM, 319634		L	61	5	2	5
			R	61	4	2	5

TABLE 6

Measurements of Carpometacarpi of Megapodes and Crowned Pigeons

Species	Number	Sex	Side	Length mm	Proximal Width mm	Shaft Width mm	Distal Width mm
P. gallinacea	QM, F1132 QM, F1139		R	99	27 x 16	11 x 7	19
	QM, F7005		R		x 16	11 x 8	
G. victoria	NMV, W6676		L	69	21 x 12	7 x 5	12
			R	69	22 x 13	7 x 5	12
G. scheepmakeri	NMV, R8054		L	64	21 x 11	7 x 5	14
			R	65	19 x 12	7 x 5	14
L. ocellata	SAM, B11482	♂	L	53	15 x 9	6 x 4	9
			R	54	15 x 9	6 x 5	9
	NMV, B9276		L	56	16 x 10	6 x 5	11
			R	55	16 x 10	6 x 5	9
	NMV, B9057		L	54	15 x 9	5 x 4	10
			R	54	16 x 9	5 x 4	10
A. lathami	NMV, W5964		L	49	13 x 9	5 x 4	10
			R	49	12 x 8	5 x 4	9
	NMV, W4554		L	47	13 x 8	5 x 3	9
			R	47	13 x 8	5 x 3	9
	NMV, W4555		L	46	13 x 8	5 x 3	9
			R	46	13 x 7	5 x 3	9
M. reinwardt	CSIRO, GALS 2	♂	L	45	12 x 7	5 x 4	8
			R	46	12 x 7	5 x 4	8
	CSIRO, GALS 3	♂	L	47	13 x 7	5 x 3	8
			R	46		5 x 4	8
M. pritchardi	USNM, 319634		L	33	7 x 4	3 x 2	5
			R	33	8 x 4	3 x 2	5

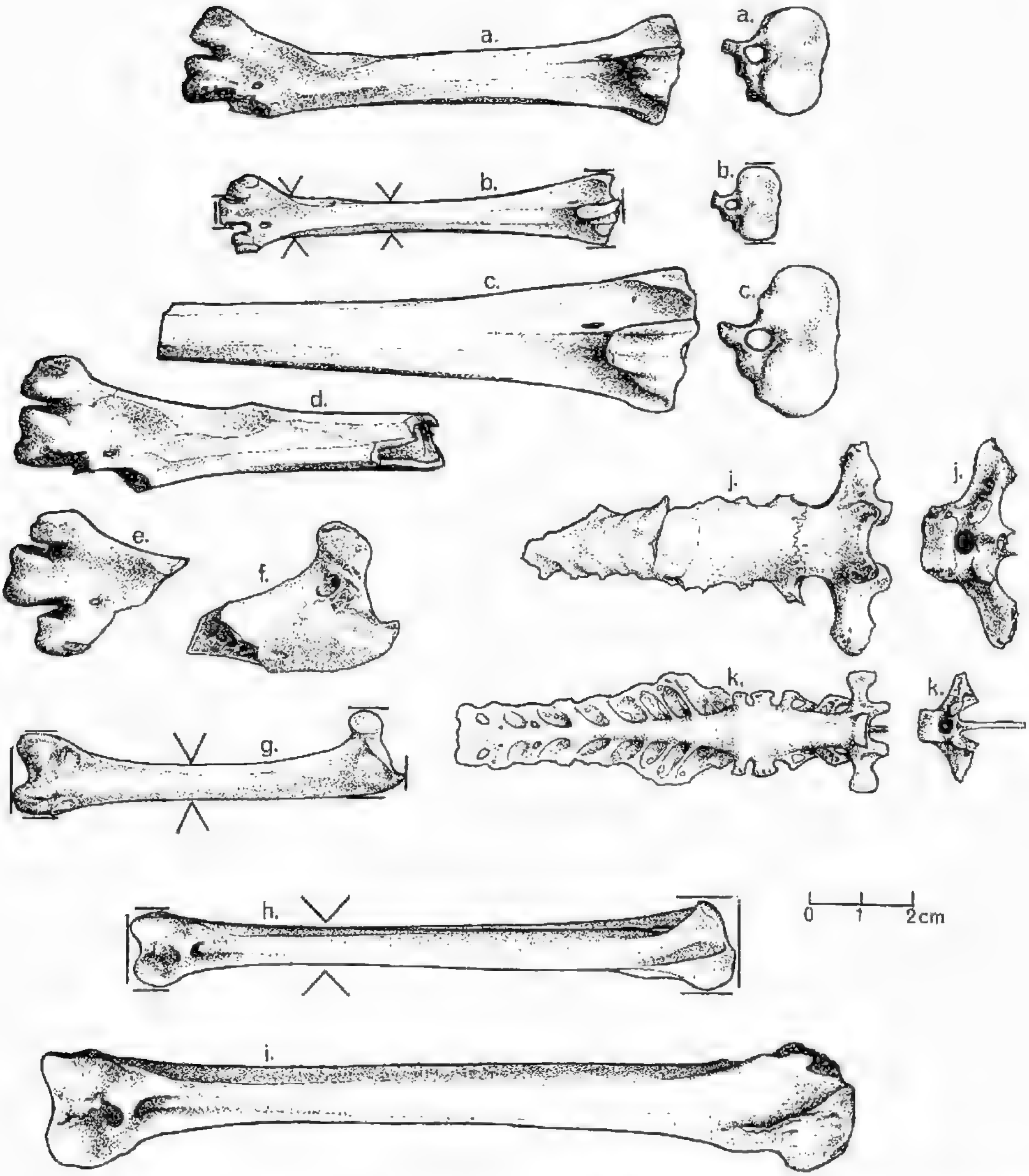

Fig. 4. *a.*—right tarsometatarsus, *P. naracoortensis* (SAM, P17856); *b.*—right tarsometatarsus, *M. reinwardt* (CSIRO, GALS3); *c.*—left reversed tarsometatarsus, *P. gallinacea* (QM. F1143); *d.* and *e.*—right tarsometatarsi, *P. gallinacea* (QM, F5556 and F5557); *f.*—right femur, *P. naracoortensis* (SAM, P17857); *g.*—right femur, *M. reinwardt* (CSIRO, GALS3); *h.*—right tibiotarsus, *M. reinwardt* (CSIRO, GALS3); *i.*—right tibiotarsus, *P. naracoortensis* (SAM, P17152); *j.*—synsacrum, *P. naracoortensis* (SAM, P18187); *k.*—synsacrum, *M. reinwardt* CSIRO, GALS3).

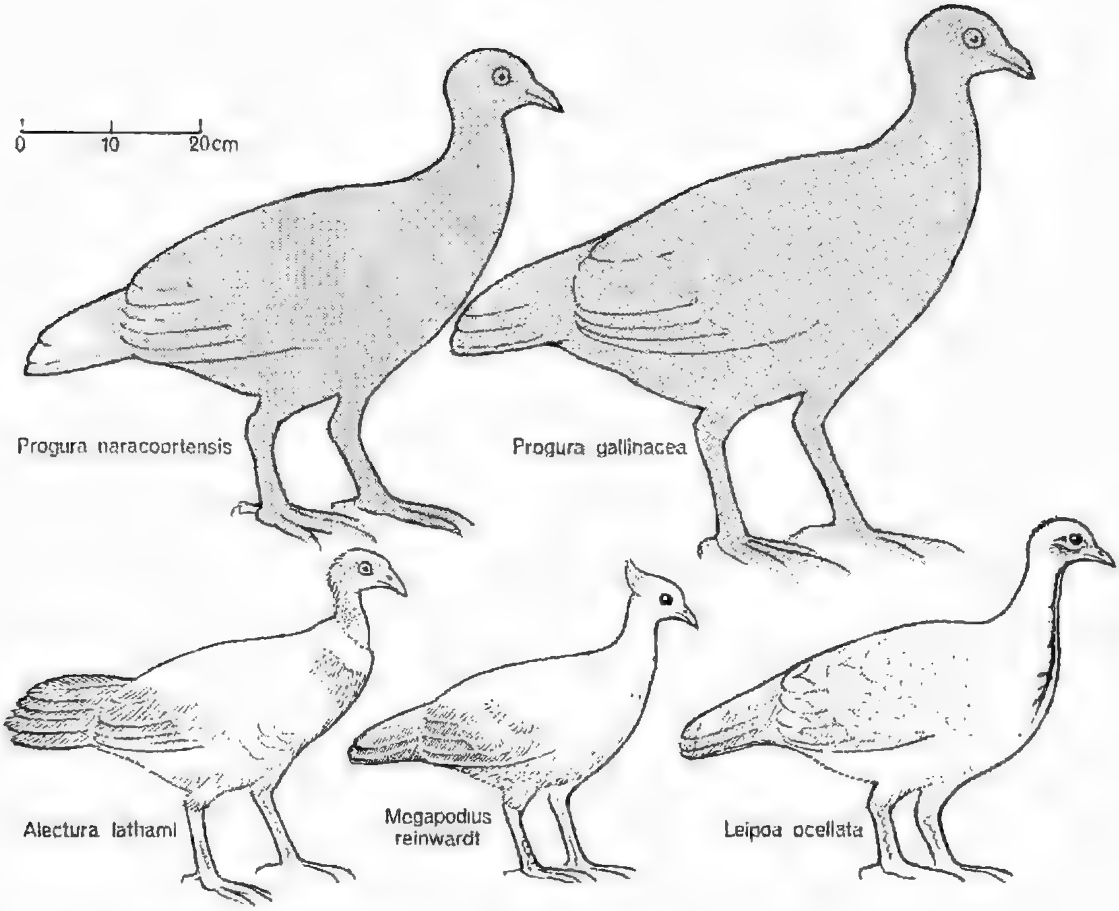

Fig. 5. Extant and reconstructed fossil megapodes of Australia.

birds, they presumably could survive in a wide range of habitats.

The relatively long legs of *P. gallinacea*, the Brush-turkey and the Scrubfowl suggest that *P. gallinacea* was also a rain forest species. Conversely the relatively short legs of *P. naracoortensis* suggest that it was an open shrub land bird like the Malleefowl. This assumption is supported by the discovery of remains of both of these latter species at Victoria Cave together with remains of other birds of open habitats (van Tets & Smith 1974).

Why the species of *Progura* died out may be related to the extinction of many other large vertebrates during the last peak in world glaciation. It may have been caused by environmental changes in Australia associated with increasing aridity, and with the displacement of native marsupial predators by men and dogs.

Systematics

The material of *Progura* indicates that there were two very large species of megapodes in south-eastern Australia, *P. gallinacea* and *P. naracoortensis*, during Pleistocene times. Other than size there are no clear characters that separate *Progura* from the other genera of megapodes nor that indicate to which of these genera it is closest. Relative tarsometatarsal lengths do indicate similarities between *P. naracoortensis* and *Leipoa* and between *P. gallinacea* and the other two Australian megapode genera, *Alectura* and *Megapodius*. Until further fossil material becomes available for study and there is a modern revision of the mainly monotypic megapode genera, it is preferable to use the genus *Progura* for the two fossil megapode species, *gallinacea* and *naracoortensis*.

TABLE 7

Measurements of Femora of Megapodes and Crowned Pigeons

Species	Number	Sex	Side	Length mm	Proximal Width mm	Shaft Width mm	Distal Width mm
P. naracoortensis	SAM, P17857		R		30		
	SAM, P18186		R				28
G. victoria	NMV, W6676		L	88	21	8	19
			R	88	21	8	19
G. scheepmakeri	NMV, R8054		L	83	19	8	18
			R	83	19	8	18
L. ocellata	SAM, B11482	♂	L	84	20	8	19
			R	84	21	8	19
	SAM, B5039	♀	L	84	20	8	19
			R	84	21	9	19
	NMV, B9276		L	88	20	8	19
			R	90	20	8	19
A. lathami	NMV, W5964		L	90	21	9	19
			R	90	21	9	19
	NMV, W4554		L	92	19	9	19
			R	92	19	10	19
	NMV, W4555		L	90	20	10	18
			R	89	20	9	18
M. reinwardt	CSIRO, GALS 2	♂	L	75	17	8	17
			R	75	17	8	17
	CSIRO, GALS 3	♂	L	77	17	7	17
			R	77	17	8	17
M. pritchardi	USNM, 319634		L	52	10	4	11
			R	52	10	4	11

TABLE 8

Measurements of Tibiotarsi of Megapodes and Crowned Pigeons

Species	Number	Sex	Side	Length mm	Proximal Width mm	Shaft Width mm	Distal Width mm
P. naracoortensis	SAM, P17152		R	158	25	11	23
	SAM, P17876		R			10	21
G. victoria	NMV, W6676		L	135	19	7	16
			R	135	20	7	16
G. scheepmakeri	NMV, R8054		L	126	17	7	14
			R	126	18	8	14
L. ocellata	SAM, B11482	♂	L	121	25	6	14
			R	121	25	6	14
	SAM, B5039	♀	L	123	22	6	13
			R	123	23	6	13
	NMV, B9276		L	130	21	7	15
			R	129	21	7	15
A. lathami	NMV, W5964		L	129	20	8	14
			R	130	19	7	14
	NMV, W4554		L	135	19	7	14
			R	135	19	7	14
	NMV, W4555		L	134	18	7	14
			R	134	18	7	14
M. reinwardt	CSIRO, GALS 2	♂	L	114	19	7	13
			R	114	19	7	13
	CSIRO, GALS 3	♂	L	115	20	7	13
			R	115	19	7	12
M. pritchardi	USNM, 319634		L	84	12	4	8
			R	83	13	4	8

Acknowledgments

This paper owes a great debt to the many persons involved during the past century in collecting, cleaning and curating the bones that were made available for this study by the museums listed under methods.

I have benefitted greatly from discussions with colleagues in these museums and in CSIRO. In particular I am grateful to Jeanette Hope, Meredith Smith and Pat Vickers Rich who brought most of the undescribed fossil megapode material to my attention.

The figures were drawn by F. Knight.

TABLE 10

Megapode and Crowned Pigeon bone lengths expressed as Coracoid lengths

Species	Humerus	Ulna	Radius	Carpo-metacarpus	Femur	Tibiotarsus	Tarso-metatarsus
P. gallinacea				1.1			1.6
P. naracoortensis	1.7	1.6	1.6			1.9	1.1
G. victoria	1.3	1.6	1.4	0.8	1.1	1.6	1.2
G. scheepmakeri	1.3	1.6	1.5	0.8	1.1	1.6	1.2
L. ocellata	1.6	1.6	1.6	0.9	1.3	1.9	1.2
A. lathami	1.5	1.5	1.3	0.8	1.5	2.2	1.4
M. reinwardt	1.5	1.6	1.5	0.8	1.4	2.1	1.4
M. pritchardi	1.6	1.8	1.6	0.9	1.4	2.3	1.6

TABLE 9

Measurements of Tarsometatarsi of Megapodes and Crowned Pigeons

Species	Number	Sex	Side	Length mm	Proximal width mm	Shaft width mm	Distal width mm	Shaft width below hallux mm.	Central trochlea width mm
P. gallinacea	QM, F1134		Left		29				
	QM, F1143		Left		29	12			
	QM, F5556		Right	148		11		13	12
	QM, F5557		Right				30		11
	QM, F7033		Right						10+
	AM, F54724		Left		26				
	AM, F54725		Left				27	13	10
	AM, F54726		Right				29	12	10
P. naracoortensis	SAM, P17856		Right	96	22	9		11	9
	QM, F2769		Left		23				
	SAM, P18185		Right		21	10			
G. victoria	NMV, W6676		Left	98	17	7	17	7	6
			Right	99	17	7	17	7	6
G. scheepmakeri	NMV, R8054		Left	93	17	7	14	7	6
			Right	93	17	6	14	7	6
L. ocellata	SAM, B11482	♂	Left	72	15	7	18		
			Right	72	15	7	17		
	SAM, B5039	♀	Right	77	16	7	17	10	6
	NMV, B9276		Left	74	15	7	17	9	6
			Right	74	16	7	17	9	6
A. lathami	NMV, W5964		Left	87	16	6	16	8	6
			Right	87	16	7	16	8	6
	NMV, W4554		Left	89	15	6	14	8	7
			Right	89	15	6	15	8	6
	NMV, W4555		Left	89	15	6	16	8	6
			Right	90	15	6	17	8	6
M. Reinwardt	CSIRO, GALS 2		Left	76	14	6	15	7	6
			Right	76	14	6	14	7	5
	CSIRO, GALS 3		Left	77	14	6	15	7	6
			Right	77	14	6	15	7	6
M. pritchardi	USNM, 319634		Left		9	4	11	5	4
			Right	59	9	4	10	5	4

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SMALL FOSSIL VERTEBRATES FROM VICTORIA CAVE, NARACOORTE, SOUTH AUSTRALIA
III. BIRDS (AVES)

BY G. F. VAN TETS AND MEREDITH J. SMITH†*

Summary

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The Sheathbill is a new record for Australasia. *Progura naracoortensis* is extinct. Most of the other species are still extant in south-eastern South Australia. They suggest that at the time of deposition Victoria Cave was surrounded by savannah woodland with substantial areas of heath, wet and dry grasslands, and mudflats.

SMALL FOSSIL VERTEBRATES FROM VICTORIA CAVE, NARACOORTE, SOUTH AUSTRALIA

III. BIRDS (AVES)

by G. F. VAN TETS* and MEREDITH J. SMITH†

Summary

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Introduction

The fossil bone deposits and their method of extraction from Victoria Cave near Naracoorte (37°00'S, 149°48'E) have been described by Smith (1971, 1972). They contain remains of large marsupials which are believed to have become extinct at the end of the Pleistocene (Tedford 1967). The present paper describes bird remains that have been identified by comparison with bones of extant species in the collections of the South Australian Museum (SAM), the National Museum of Victoria (NMV), the American Museum of Natural History (AMNH), and the Division of Wildlife Research, CSIRO.

Family DROMAIIDAE

Dromaius cf. **novaehollandiae** (Latham, 1790), Emu.

A synsacrum (SAM, P16501) was identified by Pat Vickers Rich (pers. comm.).

Family MEGAPODIIDAE

The fossil material of megapodes from Victoria Cave and elsewhere is described and discussed in van Tets (1974a). It included material of *Progura naracoortensis* van Tets, 1974, a giant megapode (SAM, P16700); *Leipoa ocellata* Gould, 1840, a Malleefowl (SAM, P16738); and one or more juvenile megapode(s) (SAM, P16739–45). The juvenile megapode material is of a species about the same size as Malleefowl, but indeterminable to genus and species.

Family PHASIANIDAE

Coturnix pectoralis Gould, 1837, Stubble Quail.

The following bones were found of at least three birds; three crania, two right humeri, two right and one left carpometacarpi, two sternal manubria, three synsacra, one left tibiotarsus and one left tarsometatarsus (SAM, P16701–10 and P16746–50).

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Coturnix australis (Latham, 1801), Brown Quail.

The following bones were found of at least four birds: one cranium, one right carpometacarpus and four synsacra (SAM, P16711–6). Another synsacral fragment (SAM, P16717) could have belonged to either *Coturnix* species.

Family TURNICIDAE

Turnix sp., a buttonquail.

One right humerus (SAM, P16751) of an unknown species of *Turnix*, which is neither *T. maculosa*, *T. varia*, *T. melanogaster*, *T. velox* nor *T. pyrrhothorax*.

Turnix varia (Latham, 1801), Painted Button-quail.

One right humerus (SAM, P16752).

Family PEDIONOMIDAE

Pedionomus torquatus Gould, 1840, Plains-wanderer.

One synsacrum (SAM, P16718).

Family RALLIDAE

Rallus philippensis Linnaeus, 1766, Land Rail.

One synsacrum (SAM, P16719).

Family CHARADRIIDAE

Peltohyas australis (Gould, 1840), Australian Dotterel.

Three synsacra (SAM, P16720–2).

Family SCOLOPACIDAE

Tringa glareola Linnaeus, 1758, Wood Sandpiper.

One synsacrum (SAM, P16723). A proximal part of a left tibiotarsus (SAM, P11555) was collected at Naracoorte long before 1954, when it was registered.

Gallinago hardwickii (Gray, 1831), Japanese Snipe.

Three synsacra (SAM, P16724–6).

Calidris ruficollis (Pallas, 1776), Red-necked Stint.

Four synsacra (SAM, P16727–30).

Family CHIONIIDAE

Chionis minor Hartlaub, 1841, Black-faced Sheathbill.

One synsacrum (SAM, P16731). It was indistinguishable from synsacra from extant *Chionis minor* (NMV, W2234, W3457, W6443, W6444 and W6476) collected at Kerguelen and Heard Islands. A synsacrum of *Chionis alba* (AMNH, 879), differed mainly by having an additional vertebra fused to the anterior end.

Sheathbills have not previously been reported in Australia. They now only occur in sub-antarctic regions, *Chionis alba* around the tip of South America and *Ch. minor* on islands south of the Indian Ocean. They scavenge on beaches and icebergs. It is possible that some rafted to Australia during a glacial period and died out during the subsequent inter-glacial period. There is no evidence of sheathbills having ocurred at Macquarie Island and at the sub-antarctic islands of New Zealand, where there should be suitable habitat for them.

Family PLATYCERCIDAE

Pezoporus wallicus (Kerr, 1792), Ground Parrot.

Three naso-premaxillae (SAM, P16732–4). Ground Parrots occurred in the Naracoorte area in historic times, but are now locally extinct because of habitat destruction.

Family TYTONIDAE

Tyto novaehollandiae (Stephens, 1826), Masked Owl.

Cranium (SAM, P16735) and a synsacrum (SAM, P16736)

Family GRALLINIDAE

Grallina cyanoleuca (Latham, 1801), Magpie-lark.

One synsacrum and a distal part of a left tarsometatarsus. (SAM, P16753 and P16754).

Family CRATICIDAE

Gymnorhina tibicen (Latham, 1801), Australian Magpie.

One left humerus (SAM, P16737). Two forms of *Gymnorhina* may occur in the Naracoorte area, *tibicen* and *hypoleuca*. They are considered conspecific by some and separate species by others.

Discussion

(a) *Method of accumulation of deposit*

Because of the preponderance of juvenile remains among the larger mammal species as compared with a greater proportion of adults among the smaller species, Smith (1971, 1972) postulated that the small vertebrate remains were brought to the cave by predators. The bird remains are not inconsistent with this hypothesis, but are too few to support it.

Remains were found of an avian predator, the Masked Owl and an avian scavenger, the Black-faced Sheathbill. The owl is known to have inhabited caves on the Nullarbor Plain of South Australia (Richards 1971) and is able to prey on animals up to the size of small rabbits (Calaby 1969). The sheathbill also nests in caves and crevices (Downes *et al.* 1959). On the Nullarbor Plain, the Peregrine Falcon, *Falco peregrinus*, Brown Falcon, *F. berigora*, and Nankeen Kestrel, *F. cenchroides* reside in cave entrances (Richards 1971). Remains of the Brown Goshawk, *Accipiter fasciatus* were found in Weekes Cave on the Nullarbor Plain (van Tets 1974b).

Some of the bird remains could have come from owl pellets or from carcasses brought into the cave by avian and mammalian predators and scavengers. Another explanation may have to be found for the great number of synsacra with no associated bones. They are of small wet-land birds in the families Pedionomidae, Rallidae, Charadriidae and Scolopacidae. The remains of these birds may have been washed into the cave and the synsacra may have been separated from the other bones by the washing and sorting action of running water.

(b) *Climatic interpretations*

From the small mammal remains, Smith (1971, 1972) concluded that at the time of deposition Victoria Cave was surrounded by sclerophyll forest.

The bird remains suggest the presence of savannah woodland with substantial areas of heath, wet and dry grassland and mudflats. All the bird species found thrive under wet coastal conditions, although some of them also occur in dry inland locations. Except for the extinct giant megapode and the sheathbill, all the bird species found have occurred in south-eastern South Australia in historic times (Condon 1968).

Acknowledgments

Excavation of the deposit would not have proceeded without the enthusiastic help of CEGSA members in digging and sieving. Transport costs for these helpers were defrayed by a grant from the South Australian Government Tourist Bureau. The late Mr. E. Maddock ably mediated between CEGSA and the Tourist Bureau and actively assisted in the working of the deposit.

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BY *G. F. VAN TETS**

Summary

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At Weekes Cave, a sink hole on the Nullarbor Plain near Koonalda Station, South Australia, remains have been found of *Platibis flavipes,* Yellow-billed Spoonbill; *Accipiter fasciatus,* Brown Goshawk; *Falco cenchroides,* Nankeen Kestrel; either *Turnix velox* or *T. pyrrhothorax,* a buttonquail; *Cinclorhamphus cruralis,* Brown Songlark; *Cinclorhamphus mathewsi,* Rufous Songlark; *Poephila guttata,* Zebra Finch; and *Artamus leucorhynchus,* Whitebreasted Wood-swallow. Some of these birds times.

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Introduction

Weekes Cave (N15) is a sink hole near Koonalda Station on the Nullarbor Plain in South Australia, near the border with Western Australia. Multiple entrances drop 10 m to a flat silt-floored chamber (Hill 1967). The bird bones reported in this paper were collected by members of the Cave Exploration Group of South Australia, and are part of the collections of the South Australian Museum (SAM). The bones were identified by comparisons with reference bones in the collections of the National Museum of Victoria and the Division of Wildlife Research, CSIRO.

Family THRESKIORNITHIDAE

Platibis flavipes (Gould, 1838), Yellow-billed Spoonbill.

Almost complete skeleton (SAM, P17927).

Family ACCIPITRIDAE

Accipiter fasciatus Vigors & Horsfield, 1827, Brown Goshawk.

Skull (SAM, P18060) and a synsacrum (SAM, P18061).

Family FALCONIDAE

Falco cenchroides Vigors & Horsfield, 1827, Nankeen Kestrel.

Skull (SAM, P18062). This species nests and roosts in several caves on the Nullarbor Plain (Richards 1971).

Family TURNICIDAE

Turnix sp., a buttonquail.

Four crania (SAM, P18063–6), and a right tibiotarsus (SAM, P18067) resembling *Turnix velox* (Gould, 1841) and *T. pyrrhothorax* (Gould, 1841). At present only *T. velox* occurs in the area (Condon 1968, McEvey & Middleton 1968).

Family SYLVIIDAE

Cinclorhamphus cruralis (Vigors & Horsfield, 1827), Brown Songlark.

Sternum (SAM, P18068). One was noted on the Nullarbor Plain by McEvoy & Middleton (1968).

Cinclorhamphus mathewsi Iredale, 1911, Rufous Songlark.

Skull (SAM, P18069).

Family ESTRILDIDAE

Poephila guttata (Vieillot, 1817), Zebra Finch.

Skull (SAM, P18070).

Family ARTAMIDAE

Artamus leucorhynchus (Linnaeus, 1771), White-breasted Wood-Swallow.

Three skulls (SAM, P18071–3).

Discussion

Some of the bird species, notably the Yellow-billed Spoonbill and the White-breasted Wood-swallow, require wetter conditions than have prevailed on the Nullarbor in recent

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times. As a group, the bird remains found in the cave are those one would expect to see in savannah woodlands with areas of open grassland and shallow pools of water. They may have come on to the Nullarbor Plain during brief spells of exceptionally wet weather and sought shelter in the cave when the country dried up again.

The spoonbill may have become trapped in the sink hole after blundering into it. Some of the smaller birds may have been brought into the cave by hawks and owls. *Tyto novaehollandiae* (Stephens), Masked Owl, formerly resided in caves on the Nullarbor Plain and *Falco peregrinus* Tunstall, Peregrine Falcon, *F. berigora* Vigors & Horsfield, Brown Falcon, and *F. cenchroides*, Nankeen Kestrel, still reside in them (Hamilton-Smith 1967, Richards 1971).

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