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OF
NEW SOUTH WALES

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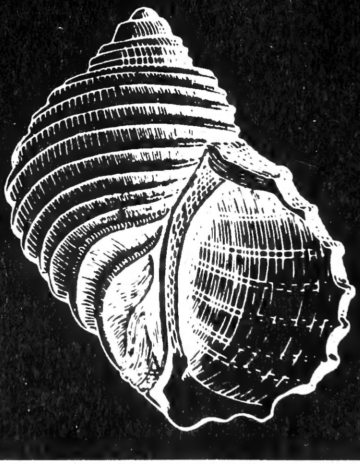
VOLUME 104
PARTS 1 & 2



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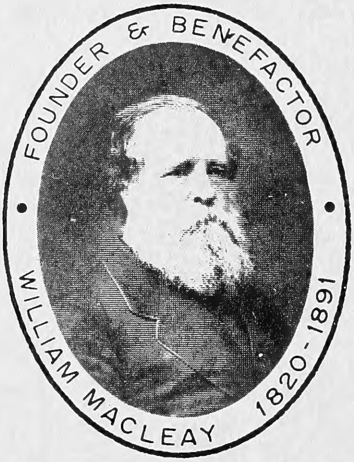
THE LINNEAN SOCIETY OF NEW SOUTH WALES



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Balmoral Beach, Sydney
(*Proc. Linn. Soc. N.S.W.* 35, 1900:89)

PROCEEDINGS
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LINNEAN SOCIETY

of
NEW SOUTH WALES

VOLUME 104
PART 1

Some Carboniferous Articulate Brachiopods from Eastern New South Wales

S. PEOU

PEOU, S. Some Carboniferous articulate brachiopods from eastern New South Wales. *Proc. Linn. Soc. N.S.W.* 104 (1), (1979) 1980: 1-15.

Nine fossil localities in the Carboniferous Berrico Creek Formation at Berrico-Rawdon Vale and an unnamed formation at Brownmore in eastern New South Wales, have yielded a number of new brachiopod taxa belonging to the *Rhipidomella fortimuscula* Zone. Among these taxa are *Quadratia engeli* sp. nov., *Q. booniensis* sp. nov., Productoid gen. et sp. nov., *'Camarotoechia' subtrigonalis* sp. nov., *Schizophoria subelliptica* sp. nov., *Podtsheremia fasciculata* sp. nov., and *Brachythyris cobarkensis* sp. nov. They are short-ranging species and hence are suitable as zonal index fossils.

S. Peou, Department of Geology, University of Newcastle, Australia 2308; *manuscript received 28 September 1978, accepted in revised form 21 February 1979.*

INTRODUCTION

The *Rhipidomella fortimuscula* Zone is one of nine major brachiopod zones in the Carboniferous of eastern Australia (Campbell and McKellar, 1969; Campbell and Roberts, 1969; Jones *et al.,* 1973; Roberts, 1975; Roberts *et al.,* 1976). The fauna of this zone was first studied by Cvancara (1958) and then by Campbell and McKelvey (1972) from the Barrington District, New South Wales. McKellar (1967) and Driscoll (1960) recognized this fauna from the Yarrol Trough, Queensland.

Over the past twenty years, a large number of brachiopod genera and species have been described from the *Rhipidomella fortimuscula* Zone, many of them are short-ranging forms and clearly indicative of a late Visean age (Roberts, 1975, 1976). Recent work on rocks of this age in the Berrico Creek Formation at Berrico-Rawdon Vale (Whitford, 1971; Peou, 1977) and an unnamed formation at Brownmore (McDonald, 1972; Roberts, 1975) (Fig.1), has resulted in discrimination of several new taxa. Good stratigraphical control and short ranges suggest that these taxa may

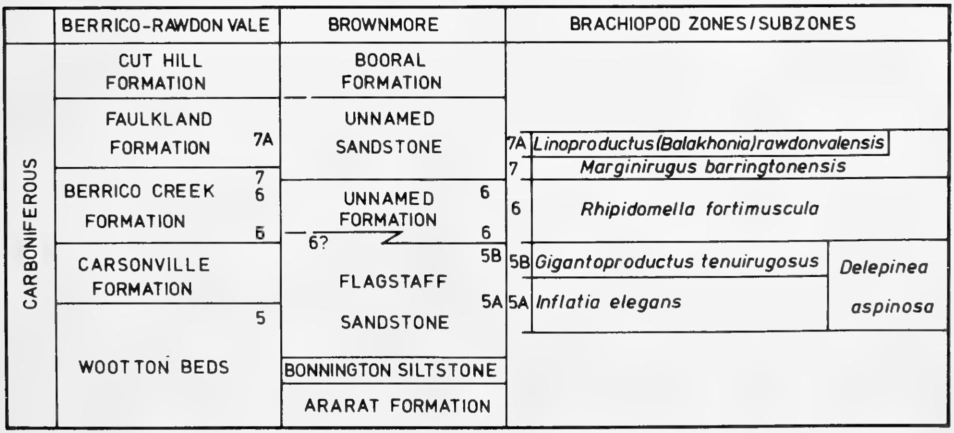

Fig. 1. Correlation of Carboniferous formations of the Berrico-Rawdon Vale and Brownmore districts, N.S.W. The brachiopod zones/subzones are indicated by numbers on the right hand side of columns (Modified from Roberts, 1975; Peou, 1977; and Peou and Engel, 1979).

be useful for zonal identification. They include two species of *Quadratia*, one species each of *'Camarotoechia', Schizophoria, Podtsheremia* and *Brachythyris*; one productoid described on the basis of only three specimens has been temporarily designated as a new genus and species.

The descriptions of these brachiopods are based on collections housed in the Department of Geology, University of Newcastle, New South Wales. The fossils have been obtained from nine localities in the Berrico-Rawdon Vale-Brownmore region, N.S.W. (Fig.2). Details of these localities (locality number, grid references and name of the topographic sheets) are given at the end of the paper.

SYSTEMATIC DESCRIPTION

Superfamily PRODUCTACEA

Family PRODUCTELLIDAE Schuchert & LeVene 1929

Subfamily CHONOPECTINAE Muir-Wood & Cooper 1960

Genus *QUADRATIA* Muir-Wood & Cooper 1960

Type species: Productus hirsutiformis Walcott 1884.
Remarks: The specimens described below differ from those of *Quadratia* from the Mississippian rocks of Oklahoma and Nevada, in having a weak ventral sulcus and dorsal fold, better developed prostrate spines on the ventral visceral disc, faintly dendritic adductor scars, broader and flat lateral ridges in the brachial valve, and a pronounced adductor platform in the same valve. In addition, the present specimens are characterized by their bilobed cardinal process whose lobes are incised and

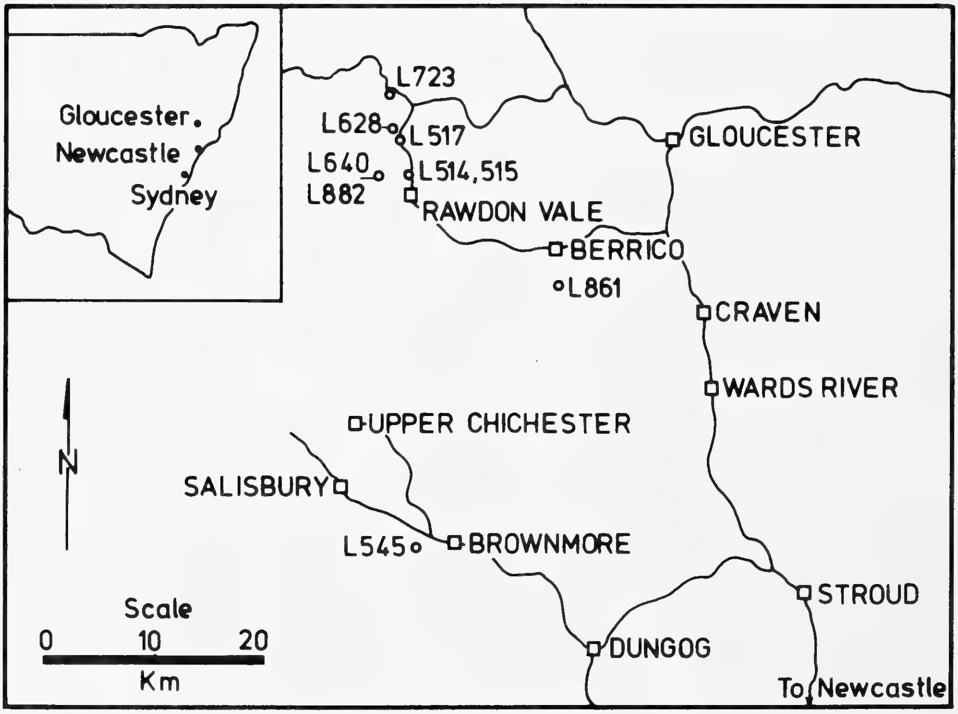

Fig. 2. Fossil locality map of the Berrico-Rawdon Vale and Brownmore districts, N.S.W.

separated by a distinct median depression, instead of a knoblike process observed in *Quadratia*, but described by Muir-Wood and Cooper (1960, p.161) as probably incomplete. Most of these differences could be of generic significance, however it would be better to await further knowledge of the type species of *Quadratia*, before separate generic status is given to the present material.

Quadratia engeli sp. nov.

Fig. 3, 1-7

Material: NUF 4049-4057, 4355; holotype NUF 4053, paratypes NUF 4049, 4054-4057, all from NUL 640 (the type locality) in the Berrico Creek Formation at Rawdon Vale.

Derivation of name: In honour of Associate Professor B.A. Engel, Department of Geology, University of Newcastle, N.S.W.

Diagnosis: A species of *Quadratia* characterized by having a distinct sulcus and fold, prostrate spines on ventral visceral disc and suberect to erect spines scattered on trail, a diamond-shaped dorsal adductor platform, a conspicuous breviseptum, and a moderate cardinal process with a median depression.

Description: Exterior. Shell medium-sized, transverse, widest at straight hinge; interareas bearing fine striations; ears broad and flattened. Pedicle valve with a convex visceral disc and a short trail; umbo small, overhanging hinge; valve surface bearing faint concentric growth lines and weak rugae; prostrate spines rare, suberect to erect spines not arranged in rows on trail. Brachial valve with a concave visceral disc and a steep trail; interarea narrower than that of the pedicle valve; concentric growth lines and rugae well developed.

Interior. Pedicle valve having an elliptical cavity of visceral disc well demarcated from impressions of external ears; anterior adductor scars either pear-shaped or elongate, elevated, placed between shallowly depressed posterior adductor scars; a shallow furrow separating adductor scars, and bearing a median ridge; diductor scars tear-drop-shaped in outline, ridged anteriorly and smooth posteriorly, enclosing adductor scars; a large shell thickening situated posterior to muscle field; two ridges borne near elongate hinge teeth, diverging at 16° from hinge. Brachial valve with an elevated adductor platform having a median depression; adductor scars weakly dendritic, spreading from the depression to lateral slopes of platform, bounded posterolaterally by two heavy ridges supporting cardinal process and diverging at 38°-40° from hinge; anterior adductor scars broad, embracing small triangular posterior adductor scars; breviseptum non-sulcate, arrow-headed, dividing adductor scars; cardinal process with two high lobes shallowly incised; a weak median ridge defined in deep depression separating the two lobes, detached from breviseptum by a small alveolus; sockets deep, bounded anteriorly by short socket ridges; narrow furrows separating these ridges from lobes of cardinal process; lateral ridges broad and flat, attached to socket ridges, following hinge margin, and dying out before reaching cardinal extremities.

Measurements: Length of shell: 18.5mm-25.5mm; width of shell: 36mm-44mm.

Remarks: Quadratia egregia Carter (1967) from the Mississippian Chapel Limestone of central Texas, U.S.A., is similar to the present species in the presence of ventral sulcus and dorsal fold. However, Carter's species has smaller ears, overlapping growth lamellae and small spine bases in concentric rows on the pedicle valve, small closely set flattened teeth, and a lower bifid cardinal process supported by a narrow median septum. The Mississippian species *Q. hirsutiformis* (Walcott) redescribed by Muir-Wood and Cooper (1960) from Oklahoma and Nevada, differs from *Q. engeli* in having stronger concentric growth lines and rugae, a more transverse cavity of the ventral visceral disc, thicker but shorter ridges arising near hinge teeth, a thinner breviseptum being not arrow-headed and originating from a low smooth platform,

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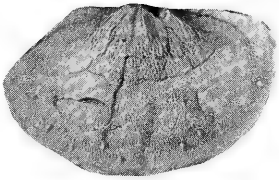

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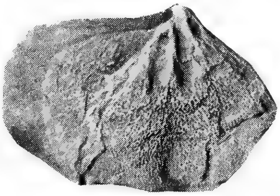

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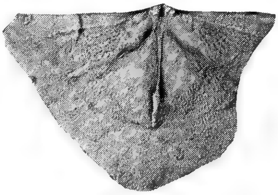

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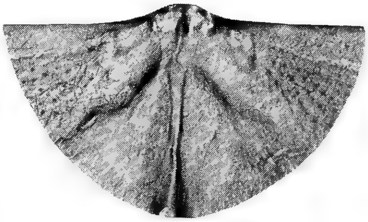

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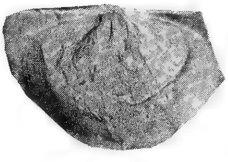

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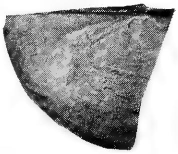

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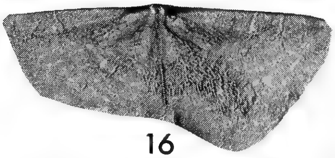

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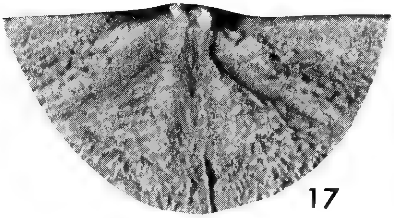

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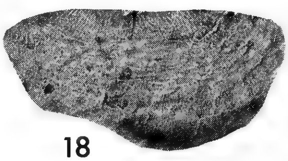

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and weaker ridges bounding the dorsal adductor scars postero-laterally. *Q. rangariensis* (Campbell, 1963) from the Tournaisian rocks of the Werrie and Belvue Synclines, N.S.W., has more numerous spines on the pedicle valve, broader but shorter adductor scars and smaller diductor scars in the same valve. The brachial valve of *Q. rangariensis* has a non-arrow-headed breviseptum developed from a flat to rounded posterior platform, and has undivided smooth adductor scars bordered postero-laterally by two short ridges arising from the central platform.

Quadratia booniensis sp. nov.

Fig.3, **8-18**

Material: NUF 4037-4048; holotype NUF 4044, paratypes NUF 4045 and 4047, all from NUL 640 (the type locality) in the Berrico Creek Formation at Rawdon Vale.

Derivation of name: After Boonie Doon farmhouse at Rawdon Vale.

Diagnosis: A species of *Quadratia* having very distinct prostrate spines, suberect to erect spines in rows on ventral trail, a low dorsal platform, a thin breviseptum, and a small cardinal process with a shallow median depression.

Description: Exterior. Shell medium-sized, transverse, with a maximum width at straight hinge; interareas flat, horizontally striated; ears subtriangular, flattened. Pedicle valve with a gently convex visceral disc and a short trail; umbo small, incurved over hinge; valve smooth on trail, bearing poorly developed concentric growth lines and rugae elsewhere; 7-8 spines on one row on trail, 2-3 spines defined on hinge margin. Brachial valve with a weakly concave visceral disc and a steep trail; interarea narrower than that of the pedicle valve; valve surface bearing prominent growth lines and rugae.

Interior. Pedicle valve having an elliptical cavity of visceral disc well separated from impressions of external ears; adductor muscle field heart-shaped in outline; anterior adductor scars slightly elevated, faintly dendritic, inserted between smooth posterior adductor scars; a furrow dividing adductor scars; a weak ridge extending on floor of the furrow near posterior end of muscle field or from a shell thickening in one specimen to a short distance from anterior ends of adductor scars; diductor scars tear-drop-shaped, either smooth or faintly ridged; two distinct ridges arising in front of small and sharp hinge teeth, diverging at 14°-15° from hinge, being curved and obsolete along inner edges of ears. Brachial valve with a gently elevated adductor platform having a shallow median depression with a sharp breviseptum being obscure between adductors scars not clearly separated; a faint median ridge sitting in shallow depression between two incised lobes of cardinal process; two short but robust ridges supporting the process, diverging at 32°-34° from hinge; alveolus ill-defined; sockets deep, elongate; socket ridges developed from lobes of cardinal process by narrow furrows, lateral ridges broad and flat, running along hinge margin, fusing on ears.

Fig. 3. **1-7.** *Quadratia engeli* sp. nov. **1.** Latex cast of a pedicle valve exterior; NUF 4049, paratype, x1. **2.** Latex cast of an incomplete pedicle valve exterior showing a sulcus; NUF 4051, x1.5. **3.** External mold of a brachial valve; NUF 4052, x1.1. **4-5.** Internal mold of two pedicle valves; NUF 4055 and 4053, both paratypes, x1.1 and x1.5 respectively. **6.** Latex cast of an incomplete brachial valve interior; NUF 4047, holotype, x1.3. **7.** Enlargement of NUF 4047 showing a bilobate cardinal process whose incised lobes are separated by a median depression bearing a distinct ridge, x3. All from NUL 640, Rawdon Vale.

8-18. *Quadratia booniensis* sp. nov. **8-9.** Latex cast of two pedicle valve exteriors; NUF 4038 and 4037, both x1. **10.** External mold of an incomplete brachial valve; NUF 4041, x1. **11.** Latex cast of NUF 4041, x1. **12.** Internal mold of a pedicle valve; NUF 4045, paratype, x1.1. **13.** Latex cast of NUF 4045, x1. **14.** Internal mold of a pedicle valve; NUF 4044, paratype, x1. **15.** Latex cast of NUF 4044, x1. **16.** Latex cast of an incomplete brachial valve interior; NUF 4057, holotype, x1.5. **17.** Enlargement of NUF 4057 showing a bilobate cardinal process with incised lobes separated by a median depression, x4.2. **18.** Latex cast of an incomplete brachial valve interior; NUF 4355, x1.5. All from NUL 640, Rawdon Vale.

Measurements: Length of shell: 18.5mm-25.5mm; width of shell: 31mm-44mm.

Remarks: Quadratia booniensis is similar to *Q. engeli* mainly in the size and the shape of the shell, straight hinge, striated interareas, flattened ears, tear-drop outlines of ventral diductor scars, broad lateral ridges and incised lobes of the cardinal process. However, *Q. engeli* differs in having distinct sulcus and fold, less developed prostrate spines on the visceral disc and scattered suberect to erect spines not arranged in rows on the trail of the pedicle valve, elongate ventral adductor scars, a better developed dorsal adductor platform, a thicker and arrow-headed breviseptum, a stronger cardinal process supported on two heavier ridges, and a deeper median depression separating the two lobes of the process. *Q. hirsutiformis* (Walcott) redescribed by Muir-Wood and Cooper (1960) possesses a more pronounced concentric ornament, a more transverse cavity of ventral visceral disc, deeply impressed ventral adductor scars, a better developed alveolus, a shorter breviseptum springing from a smooth platform, and weaker ridges supporting the cardinal process. *Q. egregia* Carter (1967) is characterized by having distinct sulcus and fold, developed overlapping growth lamellae, several small spine bases on each side of ventral umbo close to posterior margin, closely set flattened teeth, and a narrow median septum supporting the cardinal process. The only other comparable species, *Q. rangariensis* (Campbell, 1963), has strongly developed spines on the pedicle valve, suboval to subtriangular ventral adductor scars being slightly embraced by the small diductor scars, a broad posterior dorsal platform from which arises a more distinct breviseptum, and weaker and shorter ridges bounding dorsal adductor scars.

Family DICTYOCLOSTIDAE Stehli 1954
Subfamily DICTYOCLOSTINAE Stehli 1954
PRODUCTOID gen. et sp. nov.
Fig. 4, **1-6**

Material: NUF 4021-4023, all from NUL 545 in the unnamed formation at Brownmore.

Description: Exterior. Shell large, concavo-convex; hinge line short; interareas concave; ornament of costae forming a reticulation with weak concentric ridges on umbonal region, broad concentric lamellae (on brachial valve only), growth lines and spines. Pedicle valve with a small umbo, a shallow sulcus, a broad visceral disc and a long trail; costae subrounded to flat, branching, curved posteriorly on steep lateral slopes, and wrapping high knoblike structures on small ears; spines suberect to erect, big and long. Brachial valve with a short umbo, a low fold, and small ears bearing deep depressions for the reception of knoblike structures on ventral ears; costae

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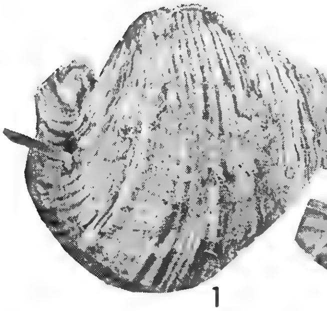
Fig. 4. **1-6.** Productoid gen. et sp. nov. **1.** Latex cast of a pedicle valve exterior; note the distinct knoblike structure on one ear; NUF 4021, figured specimen, x0.8. **2.** Latex cast of an incomplete pedicle valve exterior; NUF 4023, x1.6. **3.** Latex cast of a cardinal area and umbonal regions of pedicle valve and brachial valve exteriors; NUF 4023, x2. **4-5.** External mold of a brachial valve showing the broad visceral disc (4) and trail (5); NUF 4023, x0.9 and x0.8 respectively. **6.** External mold of a brachial valve; note the distinct reticulate and lamellose ornament; NUF 4022, figured specimen, x0.9. All from NUL 545, Brownmore.

7-17. *'Camarotoechia' subtrigonalis* sp.nov. **7.** Latex cast of a pedicle valve exterior; NUF 4059, x3. **8.** Latex cast of a brachial valve exterior; NUF 4058, x2.6. **9-10.** Internal mold of two pedicle valves; NUF 4062 and 4061, both paratypes, x2.8 and x3.5 respectively. **11.** Latex cast of NUF 4061, x4. **12.** Internal mold of a brachial valve; NUF 4066, holotype, x4.5. **13.** Latex cast of NUF 4066, x3.5. **14-15.** Internal mold of a brachial valve and latex cast of same; NUF 4065, paratype, x4.5 and x4.9 respectively. **16-17.** Internal mold of two brachial valves; NUF 4067, paratype and NUF 4068, x4.2 and x5 respectively. All from NUL 723, except NUF 4059 and 4062 from NUL 882, Rawdon Vale.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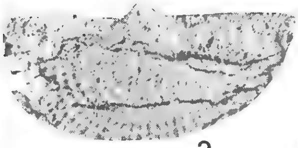
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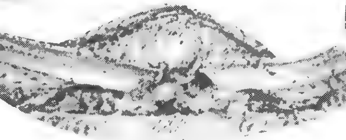
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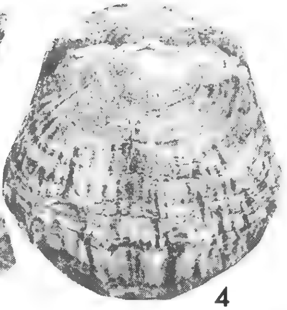
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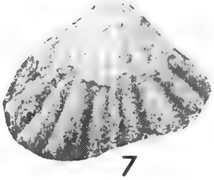
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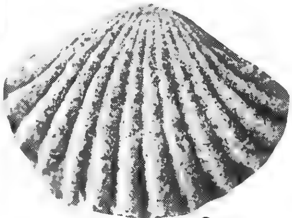
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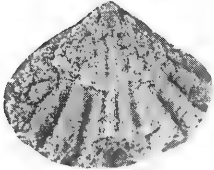
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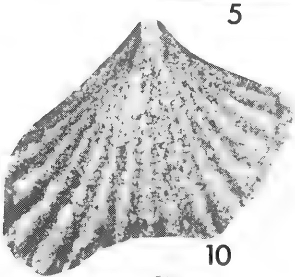
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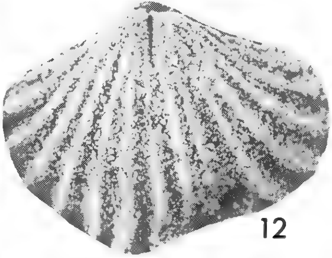
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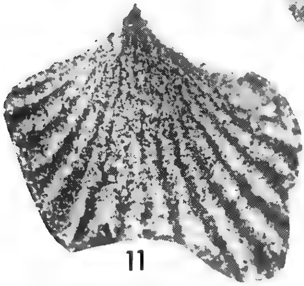
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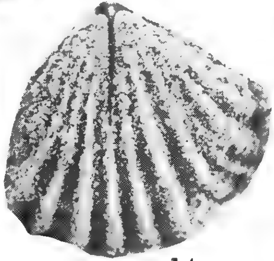
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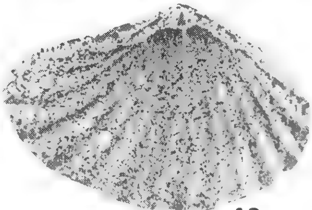
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rounded, increasing by intercalation; big spines rare, faint spines on long trail. Internal structures of both valves unknown.

Measurements: Length of shell: 43mm-51mm; width of shell: 52mm-56mm.

Remarks: Only three specimens are at present available for the description. The brachial valve exhibits three different ornamental zones: (a) a reticulate zone occupying the umbonal region and being produced by the intersection between concentric ridges and radial costae; (b) a lamellose zone situated between the other two, covering over 80% of valve surface, and bearing concentric lamellae with growth lines interrupting the radial costae, and rare spines; and (c) a narrow spinose zone on trail, bearing fine spines.

Determination of the generic affinities of the species described above is difficult, due to the lack of specimens detailing the internal structures. This form is referred to the subfamily Dictyoclostinae only on the basis of its reticulate umbonal region and costate trail. A precise assignment must await detailed study of further material. The external ornamentation of the brachial valve, especially the broadly developed concentric lamellae traversing the radial costae, and the knoblike structures on the ears of the pedicle valve are the most distinctive features which could separate the present genus from all other productid genera.

Superfamily RHYNCHONELLACEA

Family CAMAROTOECHIIDAE Schuchert & LeVene 1929

Subfamily CAMAROTOECHIINAE Schuchert & LeVene 1929

Genus *CAMAROTOECHIA* Hall & Clarke 1893

Type species: Atrypa congregata Conrad 1841.

Remarks: Numerous workers have recorded species of *Camarotoechia* from the Devonian and Carboniferous of Australia. The genus has yet to be unequivocally recorded from the southern hemisphere, or for that matter from Carboniferous rocks, so the following species, a more strongly-ribbed form than the type species *C. congregata* (Conrad, 1841), is referred to the genus as a procedural gambit until such time as the systematics of Australian Devonian and Carboniferous rhynchonellaceans are better known.

'Camarotoechia' subtrigonalis sp. nov.

Fig. 4, **7-17**

Material: NUF 4058-4070; holotype NUF 4066, paratypes NUF 4061, 4062, 4065 and 4067, from NUL 723 (the type locality) and 882 in the Berrico Creek Formation at Rawdon Vale.

Derivation of name: subtrigonalis refers to the not completely trigonal shell outline.

Diagnosis: A species of *'Camarotoechia'* with a small and plicate shell being subtrigonal in outline, a feebly uniplicate anterior commissure, a V-shaped dorsal septalium supported by a short median septum, and an unsplit to split hinge plate bearing two short crura.

Description: Exterior. Shell unequally biconvex, generally wider than long, ornamented with coarse rounded costae. Pedicle valve moderately convex; umbo slightly incurved; sulcus distinct, shallow, commencing in front of umbo, having 3 to 5 plicae; lateral slopes not steep, 4-6 plicae on each slope; concentric growth lines poorly developed. Brachial valve more convex than pedicle valve; umbo strongly incurved; fold low, having 4 plicae; lateral slopes steep, each slope bearing 5-6 plicae.

Interior. Pedicle valve with ill-defined adductor scars, smooth elongate diductor scars tapering posteriorly and sitting between two short and sharp dental lamellae; diverging angle of the lamellae 28°-34°; teeth strong, supported on dental lamellae. In brachial valve, adductor scars smooth, separated by a sharp median septum extending about one-half total length of valve; septalium shallow; sockets deep and elongate, bounded posteriorly by outer edges of hinge plate.

Measurements: Length of shell: 6mm-12.5mm; width of shell: 7mm-15mm.

Remarks: 'Camarotoechia' subtrigonalis is similar to *C.* sp. Campbell (1957) and *C.* sp. A Roberts (1963) respectively from Babbinboon and Lewinsbrook, N.S.W., particularly in the shape and size of the shell, and the number of plicae in the ventral sulcus. *C.* sp. differs from the described species in the possession of longer dental lamellae and developed rays on crura. *C.* sp. A has a more transverse shell, fewer plicae on dorsal lateral slopes, a shorter median septum and narrower sockets in the brachial valve. *C.* sp. B Roberts (1965) from Trevallyn, N.S.W., is characterized by a larger, subequally biconvex shell ornamented with angular plicae on the lateral slopes, a globular to rounded brachial valve, and a shorter dorsal median septum. In addition, *C. amnica* and *C. septima* Veevers (1959) respectively from the Carnarvon and Bonaparte Gulf Basins, Western Australia, have a pentagonal shell, a deeper ventral sulcus with fewer plicae, and a weaker dorsal median septum.

Superfamily ENTELETACEA

Family ENTELETIDAE Waagen 1884

Subfamily SCHIZOPHORIINAE Schuchert & LeVene 1929

Genus *SCHIZOPHORIA* King 1850

Type species: Conchyliolithus (Anomites) resupinatus Martin 1809.

Schizophoria subelliptica sp. nov.

Fig.5, 1-7

Material: NUF 3825-3847; holotype NUF 3839, paratypes NUF 3829-3831, 3840-3842, all from NUL 514 (the type locality) in the Berrico Creek Formation at Rawdon Vale.

Derivation of name: subelliptica refers to the not completely elliptical shell outline.

Diagnosis: A species of *Schizophoria* with a subelliptical shell outline, ventral adductor scars on a high elevation and deeply depressed diductor scars, strong pallial markings, and two subparallel main pallial trunks arising at anterior ends of ventral adductor scars.

Description: Exterior. Shell transverse, widest at about midlength; cardinal extremities well rounded; hinge about two-thirds to four-fifths maximum width of shell; capillae rounded, increasing by both intercalation and bifurcation, numbering 40 per 10mm on anterior median portion of shell; growth lines developed, spine bases not observed. Pedicle valve convex on umbonal region, concave anteriorly; beak small and short; lateral slopes steep; sulcus shallow, not reaching umbo; interarea broad; delthyrium open, triangular, as wide as high. Brachial valve strongly convex; lateral slopes very steep; fold indistinct; cardinal extremities gently concave; interarea narrow, bearing faint horizontal striations; notothyrium slightly wider than high.

Interior. Pedicle valve with robust dental plates bordering muscle field laterally and diverging at 58°-64°; teeth strong; diductor scars tapering posteriorly, either smooth or weakly striated, adductor scars smooth, narrowly elongate, sitting on flanks of a heavy longitudinal elevation; a shallow furrow defined on the elevation in some specimens, dividing adductor scars; vascula genitalia on anterior and lateral sides of muscle field. In brachial valve, brachiophores projecting from either side of notothyrial cavity, diverging at 62°-76°; sockets elongate, with a subrounded floor bearing transverse grooves which extend to distinct fulcral plates; cardinal process consisting of a high median lobe and two lateral lobes separated by deep furrows; lamellose myophores developed in the process; anterior adductor scars shallowly depressed, separated from small posterior adductor scars by two low broad ridges; adductor scars finely striated; a large swelling concave posteriorly, located between adductor scars, bearing a rounded median ridge; postero-lateral sides of muscle field pustulose; two main parallel trunks branching anteriorly, arising either from anterior ends of posterior adductor scars or from the broad ridges separating the anterior and posterior adductor scars; another two subparallel trunks borne at anterior ends of anterior adductor scars; secondary pallial markings prominent in both valves.

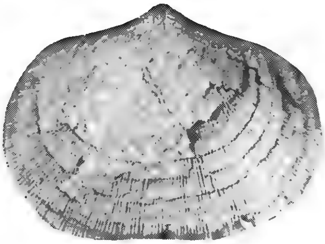
Measurements: Length of shell: 19.5mm-27.5mm; width of shell: 26.5mm-33mm.

Remarks: Schizophoria subelliptica resembles *S. verulamensis* Cvancara (1958) from Barrington, N.S.W., in the shape of the shell, and subparallel pallial trunks defined in the pedicle valve. It is distinguished from Cvancara's species by its more numerous capillae, smaller diverging angles of dental plates and brachiophores, narrower ventral adductor scars, better developed secondary pallial markings, sockets and fulcral plates bearing transverse grooves, and trilobate cardinal process containing lamellose myophores. *S.* sp. cf. *S. resupinata* (Martin) described by Roberts (1971) from Bonaparte Gulf Basin, northwestern Australia, differs from the present species in having a shorter hinge, a broader ventral muscle field, a larger dorsal median swelling, a larger diverging angle of the brachiophores, and a single to multi-lobed cardinal process. *S. resupinata* (Martin) described by Sarycheva *et al.* (1963) and *S. altaica* Besnossova (1968) respectively from Kuznetsk Basin and eastern Kazakhstan, U.S.S.R., have a longer hinge and a less convex brachial valve. In addition, *S. resupinata* has fewer radial ribs, a weak dorsal median furrow, broader ventral muscle scars and stronger dorsal brachiophores; *S. altaica* is larger and has a rounded shell, an almost flat pedicle valve and no developed ventral sulcus and dorsal fold. Two species, *S. antiqua* Solle and *S. striatula* (Schlotheim), described by Pocock (1966) from the Devonian rocks of Germany, are characterized by having an elliptical to quadrate shell with a better developed radial ornament, an angular dorsal median septum, and fewer main pallial trunks in the brachial valve. Also, *S. antiqua* is smaller and possesses broader ventral muscle scars and oval dental sockets; *S. striatula* exhibits stronger ventral sulcus and dorsal fold, and better developed myophores.

Fig. 5. **1-7.** *Schizophoria subelliptica* sp.nov. **1.** Latex cast of a pedicle exterior; NUF 3825, x1.6. **2.** Latex cast of a brachial valve exterior; NUF 3827, x2.2. **3.** Internal mold of a pedicle valve; NUF 3832, x1.2. **4.** Latex cast of NUF 3832, x1.3. **5.** Internal mold of a pedicle valve; NUF 3831, paratype, x1. **6.** Internal mold of a brachial valve; NUF 3839, holotype, x1.1. **7.** Latex cast of NUF 3839, x1.2. All from NUL 514, Rawdon Vale.

8-14. *Podtsheremia fasciculata* sp. nov. **8.** Latex cast of a pedicle valve exterior; NUF 4152, paratype, x2. **9.** Latex cast of a brachial valve exterior with an apical portion of pedicle valve exterior; NUF 4151, paratype, x1.7. **10.** Latex cast of a brachial valve exterior; NUF 4155, x2. **11.** Internal mold of a pedicle valve; NUF 4157, x1.7. **12.** Latex cast of NUF 4157, x1.9. **13.** Internal mold of a brachial valve and a posterior portion of pedicle valve; NUF 4341, holotype, x1.5. **14.** Latex cast of NUF 4341, x1.6. All from NUL 628, Rawdon Vale, except NUF 4155 from NUL 861, Berrico.

15-21. *Brachythyris cobarkensis* sp. nov. **15.** Latex cast of a pedicle valve exterior; NUF 4225, x2.1. **16.** Latex cast of a brachial valve exterior; NUF 4226, x1.7. **17-19.** Internal mold of three pedicle valves; NUF 4231, paratype, x1; NUF 4234, holotype, x1; and NUF 4233A, x1.1. **20.** Internal mold of a brachial valve; NUF 4243, paratype, x1.1. **21.** Internal mold of a brachial valve with a posterior portion of pedicle valve; NUF 4232B, paratype, x1. All from NUL 517, except NUF 4226, 4243 and 4232 B from NUL 515, Rawdon Vale.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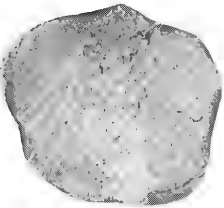
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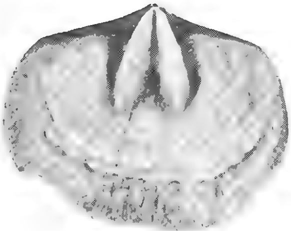
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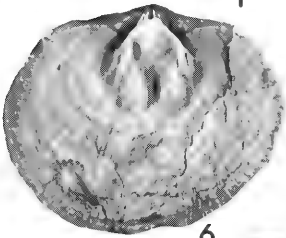
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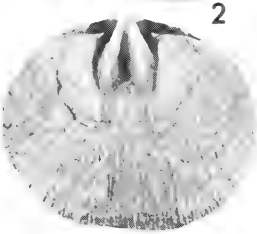
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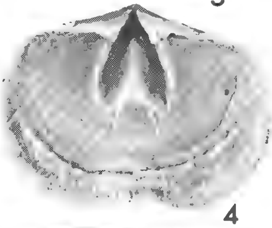
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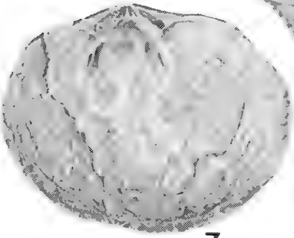
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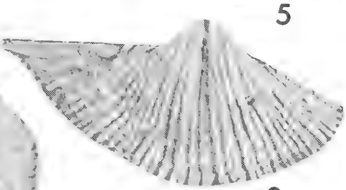
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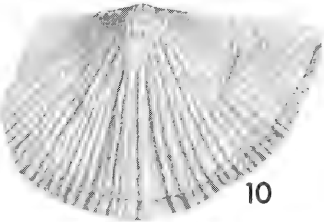
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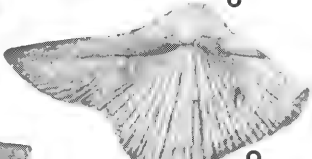
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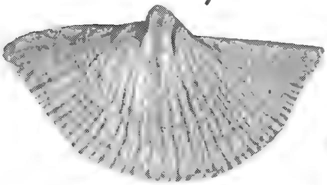
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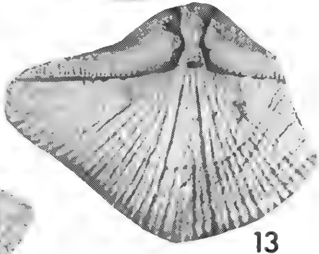
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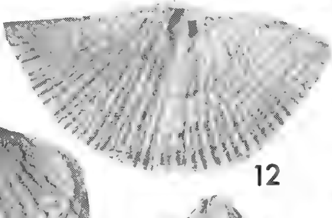
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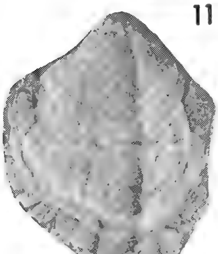
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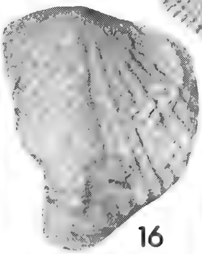
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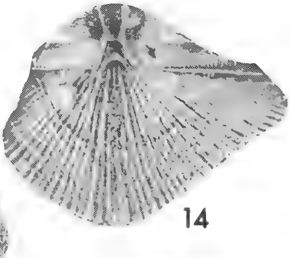
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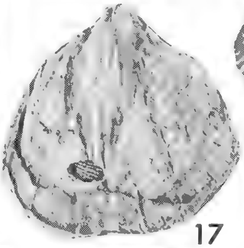
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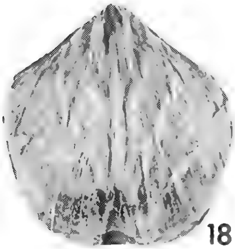
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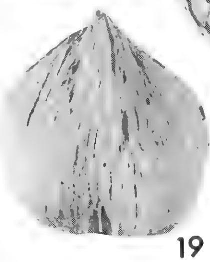
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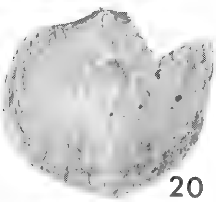
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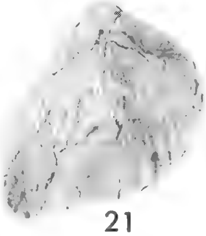
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Superfamily SPIRIFERACEA

Family SPIRIFERIDAE King 1846

Genus *PODTSHEREMIA* Kalashnikov 1966

Type species: Podtsheremia prima Kalashnikov 1966

Podtsheremia fasciculata sp. nov.

Fig.5, **8-14**

Material: NUF 4341, 4151-4152, 4155, 4157; holotype NUF 4341, paratypes NUF 4151, 4152, from NUL 628 (the type locality) in the Berrico Creek Formation at Rawdon Vale, and NUL 861 in the same formation at Berrico.

Derivation of name: fasciculata refers to the fasciculate costae on shell.

Diagnosis: A species of *Podtsheremia* characterized by its biconvex shell with rounded costae frequently branching and forming fascicles on lateral slopes, ventral sinus with a simple median costae and branching costae, dorsal fold bearing a median furrow, and rows of denticles along hinge.

Description: Exterior. Shell triangular in outline, transverse, mucronate, widest at hinge; mucros flat to slightly concave, well developed in small specimens; radial costae, fine lirae and concentric growth lines forming shell ornament; 20 to 23 fasciculate costae on each steep lateral slope, 6 to 7 simple costae on postero-lateral extremities, fascicles of 3 to 4 ribs on either side of ventral sinus and dorsal fold. Pedicle valve with a moderate and incurved umbo, a flat to weakly concave apsacline interarea ornamented with faint horizontal and vertical striations: delthyrium open, with an angle of 68°; sinus shallow, reaching umbo; sinal angle about 19°. Brachial valve with a short umbo overhanging a narrow interarea; fold costate, conspicuous.

Interior. Pedicle valve with high and sharp dental lamellae, supporting elongate teeth; denticles arranged in rows on either side of base of a shallow delthyrial cavity, oriented perpendicular to hinge; adminicula short and sharp, diverging at 10°-12°; adductor scars narrowly elongate, finely striated, and divided by a weak myophragm; diductor scars also elongate, smooth but faintly striated posteriorly; two ridges ill-defined between the two muscle scars; vascula genitalia observed on lateral sides of muscle field. Brachial valve with shallow sockets, distinct inner socket ridges diverging at 82° and terminating short crura; cardinal process supported on these ridges, containing up to 18 tiny vertical plates; adductor scars of two pairs: lateral pairs subtriangular; median pairs quadrangular, well impressed, divided by a fine median ridge; the two pairs being smooth, separated by two ridges corresponding to furrows which border external fold.

Measurements: Length of shell: 12mm-17mm; width of shell: 17mm-27mm.

Remarks: When compared with the type species, *Podtsheremia prima* Kalashnikov (1966) from northern Urals, U.S.S.R., *P. fasciculata* has a more transverse shell with a hinge reaching its maximum width and mucronate cardinal extremities. *P.? humilicostata* and *P.? thomasi* Roberts (1971) from the Bonaparte Gulf Basin, northwestern Australia, are distinguished from the present species by their fewer costae on lateral slopes and larger angle of adminicula. In addition, *P.? humilicostata* has a smaller delthyrial angle, but a larger sinal angle; *P.? thomasi* has a larger angle of inner socket ridges and more numerous vertical plates in the cardinal process.

Family BRACHYTHYRIDIDAE Fredericks 1919 (1924)

Genus *BRACHYTHYRIS* McCoy 1844

Type species: Spirifera ovalis Phillips 1836.

Brachythyris cobarkensis sp. nov.

Fig.5, 15-21

Material: NUF 4225-4243; holotype NUF 4234, paratypes NUF 4231, 4232 and 4243, from NUL 517 (the type locality) and 515 in the Berrico Creek Formation at Rawdon Vale.

Derivation of name: After Cobark River in Rawdon Vale.

Diagnosis: A species of *Brachythyris* with a parasulcate anterior commissure, broad ventral muscle field from which radiate strongly developed pallial markings, robust dental ridges supporting heavy teeth, large socket plates attached to subtriangular cardinal process.

Description: Exterior. Shell unequally biconvex, with 10-12 broad and flat plicae on each lateral slope and developed concentric growth lines; plicae bifurcating, simple on cardinal extremities. Pedicle valve strongly convex on umbonal region; umbo erect, small, sharply pointed; cardinal areas broad and concave; delthyrium open, triangular, wider than high; delthyrial angle 63°; sinus shallow, reaching umbo, costae in sinus not observed, sinal angle about 9°. Brachial valve with a small and short umbo, a distinct fold bearing a weak median furrow.

Interior. Pedicle valve thickened on umbonal region; muscle scars well impressed, variable in outline, occupying about one-third valve surface; adductor scars narrowly elongate, ridged, divided posteriorly by a distinct myophragm; diductor scars broad, fusiform, having a deep posterior median furrow. In brachial valve, socket plates enclosing elongate sockets, adductor scars finely striated and divided by a weak median ridge; cardinal process having up to 32 branching, bifurcating and simple thin vertical plates; pallial markings weakly developed.

Measurements: Length of shell: 24mm-29mm; width of shell: 23mm-28mm.

Remarks: Brachythyris solida Campbell (1963) from the Belvue Syncline, N.S.W., is similar to *B. cobarkensis* in the width/length ratio of shell, and the strong convexity of pedicle valve towards the umbo. However, it differs in having more numerous but narrower costae on the lateral slopes, and a subtriangular cardinal process containing fewer vertical plates. *B. pseudovalis* Campbell (1957) and *B. elliptica* Roberts (1963) respectively from Babbinboon and Lewinsbrook, N.S.W., are larger and have better developed costae on the lateral slopes, weaker sinus and fold, a larger sinal angle, and more numerous vertical plates in the cardinal process. *B. planulata* Roberts (1971) from the Bonaparte Gulf Basin, northwestern Australia, is characterized by its more transverse shell, uniplicate commissure, smaller delthyrial angle, larger sinal angle, and fewer vertical plates in the cardinal process. The species described by Carter (1967) as *B. chouteauensis* (Weller) and *B. girtyi* (Branson) from the Mississippian Chapel Limestone of central Texas, exhibit better developed costae being usually simple, and lack a ventral myophragm. In addition, *B. chouteauensis* has a uniplicate anterior commissure, costate ventral sulcus and dorsal fold, smaller teeth and no developed dental ridges; *B. girtyi* has a subequally biconvex shell, narrower dental ridges and no developed dorsal median ridge. *B. peculiaris* (Shumard) described by Weller (1914) from the Mississippian Chouteau Limestone at Mississippi Valley Basin, is smaller and possesses narrower cardinal areas, a rounded ridge dividing the lateral slopes into two regions, and fewer plicae being only simple and rounded.

LOCALITIES OF FIGURED SPECIMENS

Locality number	Grid references
NUL 514	738 453 Cobark 1:31680 Sheet

NUL 515	740 455 Cobark 1:31680 Sheet
NUL 517	736 490 Cobark 1:31680 Sheet
NUL 545	625 077 Dungog 1:63360 Sheet
NUL 628	732 499 Cobark 1:31680 Sheet
NUL 640	708 462 Cobark 1:31680 Sheet
NUL 723	737 553 Cobark 1:31680 Sheet
NUL 861	851 303 Gloucester 1:63360 Sheet
NUL 882	707 463 Cobark 1:31680 Sheet

NU = University of Newcastle

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The Species of the Indo-West Pacific Genus *Calumia* (Pisces: Eleotridae)

H. K. LARSON and D. F. HOESE

(Communicated by J. R. PAXTON)

LARSON, H. K., & HOESE, D. F. The species of the Indo-west Pacific genus *Calumia* (Pisces: Eleotridae). *Proc. Linn. Soc. N.S.W.* 104 (1), (1979) 1980:17-22.

A brief diagnosis of the marine fish genus *Calumia* is given. *Eleotris godeffroyi* Günther is placed in *Calumia* as a senior synonym of the type species *C. biocellata* Smith. *Calumia profunda* is described as a new species from the Solomon Islands and the New Hebrides. The species of *Calumia* are among the smallest-sized eleotrids known, and *Calumia* is one of the few eleotrid genera found on coral reefs.

It is suggested that the genus *Allomicrodesmus* be transferred to the family Eleotridae.

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INTRODUCTION

The family Eleotridae contains about forty genera of which only four, *Allomicrodesmus, Xenisthmus, Calumia* and an undescribed genus related to *Xenisthmus,* are confined to coral reefs of the Indo-west Pacific. The remaining genera are inhabitants of fresh or brackish water. *Allomicrodesmus* has been included in the family Microdesmidae (Schultz 1966), but it is apparent that the genus belongs elsewhere (Dawson, *pers. comm.*). Re-examination of the type and an additional specimen of *Allomicrodesmus dorotheae* from the Great Barrier Reef shows that the species has six branchiostegal rays characteristic of eleotrids; provisionally therefore we place *Allomicrodesmus* in the family Eleotridae. The undescribed genus and *Allomicrodesmus* are both monotypic and *Xenisthmus* contains about 10 species. Previously only a single species of *Calumia* was recognized. Examination of recently-collected material has indicated that a second undescribed species of *Calumia* exists. While examining types of gobioid fishes, it was discovered that *C. biocellata* is a senior synonym of *Eleotris godeffroyi* Günther (1877). Inaccuracies in the original description have prevented adequate identification of the species.

All of the marine eleotrid species are relatively small sized, ranging from 15 to 35 mm SL as adults. Few specimens have been collected and little is known of their distribution. For example, the species described here is known from only three specimens.

While most marine eleotrids are highly specialized forms, *Calumia* maintains a typical eleotrid physiognomy, with a broad scaled interorbital and a short robust body. The other genera are elongate with a protrusible lower jaw, presumably for burrowing in sand.

METHODS

Counts and measurements follow those given by Hubbs and Lagler (1958), except as listed below. The lateral scale count is the number of scale rows from the upper pectoral base to the end of the hypural plate. The transverse scale count (TRB) is taken from the anal base upward and backward to the base of the second dorsal fin. Colour notes of *C. godeffroyi* are based on freshly-collected specimens from the Great

Barrier Reef. Specimens studied are deposited in the following institutions: Australian Museum, Sydney, AMS; Bernice P. Bishop Museum, Honolulu, BPBM; British Museum (Natural History), London, BMNH; and J.L.B. Smith Institute of Ichthyology, Rhodes University, Grahamstown, RUSI. The osteology was studied from a single cleared and stained specimen of *C. godeffroyi.*

Systematic Description

Calumia Smith 1958

Calumia Smith 1958: 148 (type species: *C. biocellata* Smith 1958, by original designation).

Calumia is readily distinguished from other eleotrids by the following combination of characters. Head depressed. Top of head, cheeks and opercles scaled; an enlarged scale between eyes. Anterior nostril elongate, positioned on snout just behind upper lip. Gill opening broad, extending forward to below preoperculum or eye. Pectoral rays unbranched. No lateral line head pores. Sensory papillae sparse, in characteristic rows (Fig. 3). Branchiostegal rays 6. First dorsal rays VI. Second dorsal rays I, 6-8. Anal rays I, 6-7. Segmented caudal rays typically 15. Lateral scale rows 21-25. Adults small sized, reaching 15 to 20 mm SL. Vertebrae 10 + 15. Caudal skeleton with two epurals. First dorsal pterygiophore inserted after third neural spine; second and third between fourth and fifth neural spines; fourth and fifth between fifth and sixth neural spines; sixth between sixth and seventh neural spine; pterygiophore from spine in second dorsal fin between seventh and eighth neural spine, without any interneural gap. Dorsal postcleithrum present.

In general appearance *Calumia* is most similar to *Ophiocara*. *Calumia* differs from that genus in lacking head pores, the arrangement of sensory papillae, the simple pectoral rays and the small size of adults.

KEY TO SPECIES

1. Mouth short, reaching to below anterior margin of eye. Gill opening extends forward to below posterior preopercular margin. Caudal fin with two enlarged black spots, one at upper caudal base and one on lower caudal base. Tongue tip pointed or slightly rounded. Pectoral rays 16-17. Gill rakers on outer face of lower part of first arch 6; short and stubby. Pelvic rays branched. Third and fourth dorsal spines longer than other spines . . . . *C. godeffroyi* (Günther)
2. Mouth longer, reaching to below posterior half of pupil. Gill opening broader, extending forward to below middle or posterior end of pupil. Caudal fin without enlarged black spots. Tongue tip bilobed. Pectoral rays 14-15. Elongate and pointed gill rakers on outer face of first arch 13-14. Pelvic rays unbranched. Second dorsal spine longest . . . . *C. profunda* n.sp.

Calumia godeffroyi (Günther)

Fig. 1

Eleotris godeffroyi Günther 1877: 188, p. 122, fig. B, (Raiatea, Tahiti).

Calumia biocellata Smith 1958: 148, p. II, K and fig. 8 (Zanzibar).

Counts of the holotype of *Eleotris godeffroyi* are indicated with an asterisk and counts of the holotype of *C. biocellata* are indicated with a plus. First dorsal rays VI (in 6)*+. Second dorsal rays I, 6(3)*+; I, 7(3). Anal rays I, 6 (3)+; I, 7 (3)*. Pectoral rays 16 (2); 17 (4)*+. Lateral scale count 21 (1); 22 (4)*+; 23 (1). Transverse backward count 7 (3); 8 (2)+. Segmented caudal rays 15 (6)*+. Lower gill rakers on outer face of first arch 6 (4)+. Predorsal scales 7 (4)*; 8 (1); 9 (1)+.

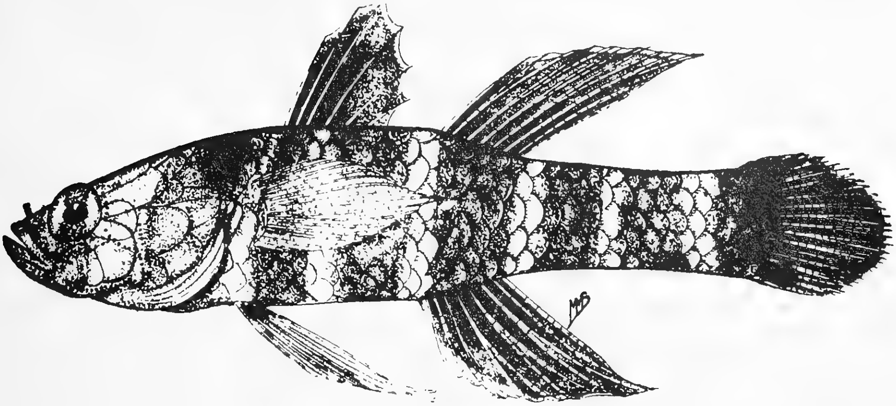

Fig. 1. Calumia godeffroyi; holotype of *C. biocellatus* (after Smith, 1958).

Smith (1958) has described the colouration of this species, under the name *Calumia biocellata*, in detail. Across the nape is a transverse dark band which begins above the end of the opercle and may be intensified as a distinct black blotch on either side of the nape. The body has five greyish black transverse bands, and a trace of a sixth incomplete band at the base of the caudal rays. At the base of each pelvic fin is a small black spot. The vertical fins are black. The two caudal spots are darkest at the caudal base and tend to fade posteriorly into the dusky anterior half of the caudal. In fresh material from the Great Barrier Reef the posterior third of the second dorsal and anal fins and the posterior half of the caudal fin are yellowish orange.

This species is distinctive in the features given in the key and has been adequately described by Smith (1958). Although the original description of *Eleotris godeffroyi* is brief, the species is well figured. Unfortunately, Günther (1877) did not mention or figure the two black caudal spots, but only indicated that the vertical fins are black. Examination of the holotype shows the spots and the five transverse body bands.

Calumia godeffroyi is a small-sized species, reaching a maximum size of 20 mm SL. The species is known from several localities in the western Indian Ocean (Smith, 1958), Christmas Island just south of Java (Allen, 1979) the Great Barrier Reef, Australia and Tahiti, and is undoubtedly widespread in the Indo-west Pacific. Smith (1958) reported collecting the species at low tide in muddy or weedy areas. On the outer islands of the Great Barrier Reef, the species was collected among coral and rubble at depths of 7 to 30 m.

Material Examined: BMNH 1877.4.26.8, a 20.5 mm female, holotype of *Eleotris godeffroyi,* Tahiti. RUSI 217, 1 (29), holotype of *Calumia biocellata*, Zanzibar. AMS I. 19472-086, 2(14-19), Yonge Reef, Great Barrier Reef, Australia, 7-15 m. I. 19480-026, 2(19-22), Yonge Reef, Great Barrier Reef, Australia, 20-30 m.

Calumia profunda sp. nov.

Figs 2, 3 and 4

Diagnosis: Mouth enlarged, reaching to below middle of eye or slightly beyond. Gill opening broad, extending forward to below middle to posterior end of pupil. Elongate rakers on outer face of first gill arch 13-14. Pectoral rays 14-15. Lateral scale count 24-25. Transverse scale count (TRB) 8. Second spine of first dorsal fin the longest and slightly prolonged. Seven dark brown transverse bands on body. Caudal fin without enlarged black spots. Anterior tip of tongue bilobed. Pelvic rays unbranched. Outer row of jaw teeth not enlarged.

Description: Based on holotype and two paratypes. Counts of holotype indicated with an asterisk. Measurements of types given in Table 1. First dorsal rays VI (3)*. Second dorsal rays I, 6 (1); I, 7 (2)*. Anal rays I, 7 (3)*. Pectoral rays 14 (1), 15 (2)*. Lower rakers on outer face of first arch 13 (2)*, 14 (1). Segmented caudal rays 14 (1), 15 (2)*. Lateral scale count 24 (1), 25 (2)*. Transverse scale count (TRB) 8 (3)*. Predorsal scales 8 (3)*.

A small species maturing at about 15 to 18 mm SL. Body compressed posteriorly, more rounded anteriorly. Head large, 36 to 39% of SL, distinctly depressed. Eyes lateral, top of eye forming top of head profile, about 4 in head length. Jaws terminal, slightly oblique; end of jaws below posterior half of pupil or below midpupil. Tip of lower jaw protrudes slightly before tip of upper jaw. Anterior nostril an elongate tube about equal to pupil diameter, positioned just behind upper lip. Posterior nostril a raised rim midway between anterior nostril and front of eye. Snout about equal to eye, with slight protuberance on dorsal profile before eye.

Dorsal and anal fins short based, shorter than caudal peduncle length. First dorsal fin slightly elongate with a pointed distal margin, formed by the elongate second dorsal spine. Dorsal and anal rays elevated becoming progressively longer posteriorly, giving fins pointed posterior margins; tips of fins reach to base of caudal rays. Pectoral rays slender, unbranched, middle rays longest reaching to above anterior part of anal fin. Pelvic fins separate, composed of one spine and five unbranched rays; first segmented ray short, rays becoming progressively longer, with fourth ray extending to below middle to end of anal base; fifth segmented ray short, about equal in length to first ray. Caudal fin short, oval in shape, shorter than head length. Gill opening broad, with branchiostegal membranes attaching to middle of isthmus below middle of eye. Body scales ctenoid, but cycloid on head, breast, belly and pectoral base. Cheek and opercles covered with large scales. Scales on top of head extend forward to above the end of the eyes and a single enlarged scale between eyes. Both jaws with a band of irregularly spaced small curved pointed teeth, and an innermost row of larger, straight, backward-pointed teeth; bands of teeth extend full lengths of jaws, but become narrower posteriorly. No vomerine or palatine teeth. No

TABLE 1

Measurements of types of *Calumia profunda* and recently collected material of *C. godeffroyi* in millimetres

Measurement	*C. profunda*			*C. godeffroyi*	
	Holotype BPBM 21158	Paratype AMS I 17477-026	Paratype AMS I 20156-001	AMS I 19472-086	
Sex	♀	♀	♀	♂	♀
Standard length	18	16.5	17	14	19
Head length	7.0	6.0	6.7	4.9	6.8
Head depth at preopercular margin	3.8	3.0	3.3	3.0	2.6
Head width at preopercular margin	4.3	3.8	4.0	2.9	2.9
Upper jaw length	3.0	2.8	2.8	1.6	1.9
Eye length	1.8	1.6	1.6	1.5	1.7
Body depth at anal origin	4.0	3.4	3.5	3.6	4.5
Caudal length	—	4.8	4.8	3.8	—

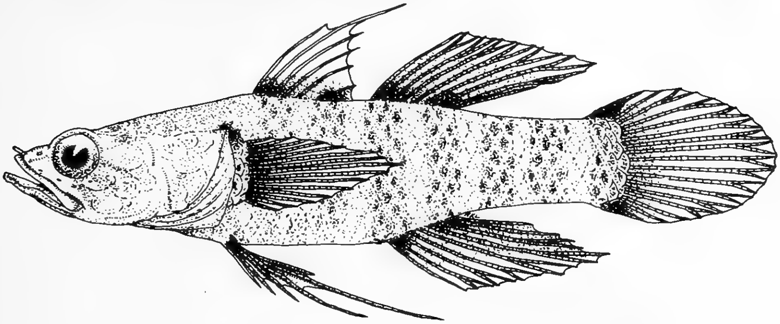

Fig. 2. Holotype of *C. profunda*. Drawing by H. K. Larson (caudal fin reconstructed).

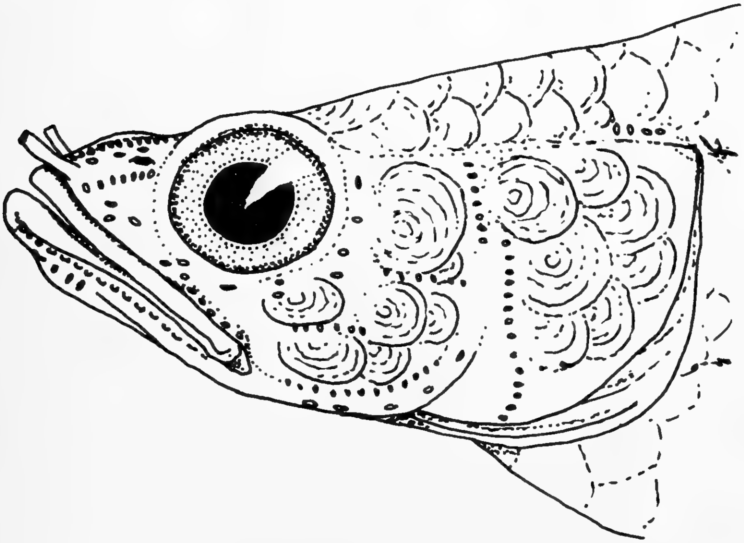

Fig. 3. Head of *C. profunda* showing arrangement of sensory papillae, side view.

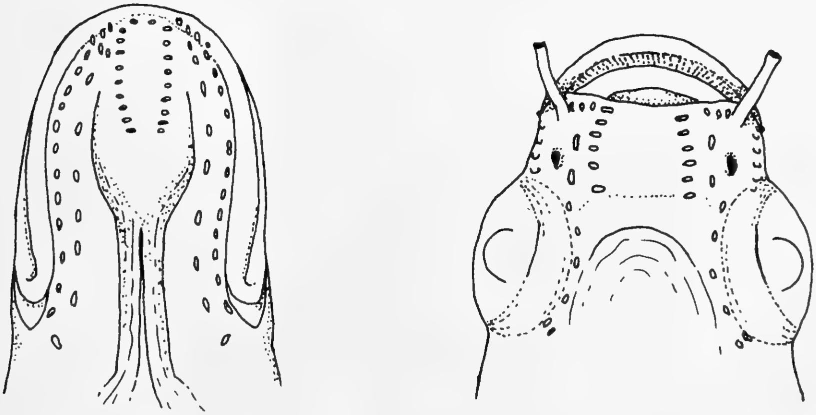

Fig. 4. Top (right) and ventral (left) views of head of *C. profunda* showing arrangement of sensory papillae.

open lateral line head pores. Sensory papillae sparse, obscured by scales on cheek, but distinct below eye, on top of snout and on lower surface of head (Figs 3, 4).

Colouration in alcohol: Head and body light brown. Centres of scales dark brown. Seven broad bands on body; first behind pectoral base; second under first dorsal fin; third and fourth under second dorsal fin; fifth and sixth on caudal peduncle; seventh at base of caudal. Head with faint brown bars radiating from eye ventrally and posteriorly. Snout, lips and underside of head dark brown. A dark brown blotch on each side of nape above upper end of operculum in front of pectoral base. Pectorals and pelvics with scattered melanophores. A dark brown spot at base of each pelvic fin. Caudal fin uniformly dusky, darker above and below base, where seventh body band extends onto fin. First dorsal fin with broad dark basal band, rest of fin clear. Second dorsal and anal fins dark brown basally, with body bands extending onto bases of fins; upper third of fins clear.

Colouration of freshly collected holotype: Head and body chocolate brown. Iris golden yellow. Nostrils white. Head with three orange stripes radiating posteriorly from eye. Posterior third of operculum and branchiostegal membranes orange. Scattered orange mottling on sides and top of head. Body bands chocolate brown, interspaces light brown anteriorly, white posteriorly. Scale centres orange in dark body bands only, forming distinct rows of small orange spots, about half of pupil diameter in size. Base of first dorsal bluish with scattered small brown and orange spots; middle of fin with a broad bright yellow stripe; tip of fin bluish. Second dorsal and anal as for first dorsal, except basal two thirds of fins with large orange spots and yellow stripe above middle of fins. Caudal yellowish above and below, middle of fin clear, with tiny white speckles; two or three small white spots along upper and lower margins near base of fin. Pectoral and pelvic fins clear to whitish. Base of pelvic fin with a black spot.

Etymology — from Latin, *profunda* — of the depths, alluding to its being found about relatively deep coral reefs.

Material Examined — Holotype: BPBM 21158, an 18mm female from 38 m depth Alite Reef, near Malaita, Solomon Islands; J. Randall and B. Goldman, 25 July 1973. Paratypes: AMS I.20156-001, a 17mm female, taken with holotype. I.17477-026, a 16.5mm female from 55m depth, Bogacio Island, Espiritu Santo, New Hebrides; G. Allen, W. Stark and D. Popper, 28 June 1973.

ACKNOWLEDGEMENTS

We would like to thank J. E. Randall for supplying some of the type material and a colour photo of the holotype. We would also like to thank M. M. Smith (RUSI) and A. Wheeler (BMNH) for making types of described species available. J. R. Paxton kindly reviewed the manuscript.

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The Eelgrass *Zostera capricorni* in Illawarra Lake, New South Wales

M. McD. HARRIS, R. J. KING and J. ELLIS

HARRIS, M. McD., KING, R. J., & ELLIS, J. The eelgrass *Zostera capricorni* in Illawarra Lake, New South Wales. *Proc. Linn. Soc. N.S.W.* 104 (1), (1979) 1980:23-33.

Zostera capricorni Aschers. is the dominant angiosperm in Illawarra Lake where it occurs over a wide range of substrate types (14-98% sand, 0.5-12% organic carbon) and salinity (3 ‰ — normal seawater). Distribution and abundance are related to light availability. The growth cycle shows a maximum in summer, with a winter minimum following shedding of the previous season's growth. Flowering is extensive but even though seedlings have been observed, propagation appears to be almost entirely vegetative. *Zostera,* complete with substrate, has been successfully transplanted.

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INTRODUCTION

Illawarra Lake is a coastal saline lagoon which straddles the boundary of the city of Wollongong (34°30′S, 150°50′E) in the north, and the Shellharbour municipality in the south, Fig. 1. The lake has evolved from a broad bay by the formation of a baymouth sand bar (Thom, 1974).

Lakes formed in this way tend to be broad, shallow, exposed and turbulent expanses of water with an extensive sandy zone supporting benthic macrophytes. Illawarra Lake is no exception. It has a maximum length of approximately 9.5 km and a width of 5.5 km with an approximate area of 33 km^2. The lake is shallow; an estimated 25% is less than 1.2 m deep and the maximum depth is only 3.7 m (Roy and Peat, 1973). The lake is oriented N-S parallel with the coast and is thus exposed to strong southerly and south westerly winds; lake water can be turbulent with wave heights approaching 0.5 m (Eliot *et al.,* 1976). This turbulence coupled with the shallow nature of the lake causes considerable turbidity and is probably a significant factor in maintaining the concentration of dissolved oxygen (Kanamori, 1976).

At present the lake enters the ocean near the southern end of the sand barrier where it is partially protected by Windang Island. This rocky prominence, which is usually land-tied by a tombola, dissipates wave energy and thus suppresses the rate of infilling of the entrance channel. The present channel from the lake to the ocean changes continually in position, width and depth depending on factors such as rainfall, wind and wave action. During 1972-1977 the entrance channel has been about 2.5 km long, winding and varying in depth up to 2.5 m. The main channel is seldom more than 100 m wide. It is restricted by a sand bar at the Windang bridge and occasionally the bar has completely choked the entrance. In late 1971 a blocking bar formed and this was subsequently cleared with earthmoving equipment. As a consequence of the restricted access to the sea very little tidal influence extends into the lake even at spring tides. Eliot *et al.* (1976) report a tidal rise of up to 0.1 m (cf. 2.0 m on the nearby ocean coast) on the western side of the lake at the Tallawarra power station. Ellis *et al.* (1977) estimate a tidal volume of 1% of the lake volume.

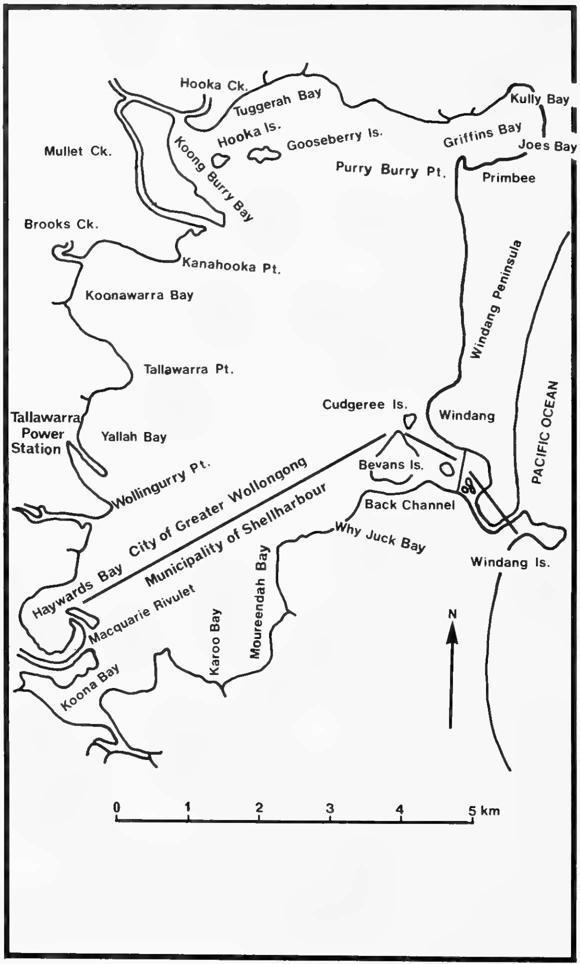

Fig. 1. Map of Illawarra Lake with geographical names

THE FLORA OF ILLAWARRA LAKE

Zostera capricorni Aschers. is the only seagrass recorded for Illawarra Lake and its distribution and abundance are the main subject of this paper. The range of morphology exhibited by *Z. capricorni* in Illawarra Lake is considerably greater than that given by Den Hartog (1970). *Ruppia* sp. is the only other angiosperm abundant in the benthic flora: it occupies approximately 30% of the eastern weed beds as a dense meadow in water 40-60 cm deep, Fig. 2. In shallow areas growth is reduced to sparse clumps. The change to *Zostera* with deeper water is abrupt. Isolated patches of *Ruppia* occur throughout the lake and in Hooka Creek, over a salinity range of 3-32 ‰. At all localities *Ruppia* grows inshore of *Zostera*, the reverse of the situation outlined by Higginson (1965) in the Tuggerah Lake system. Higginson suggested that *Ruppia* tended to favour clayey sediments, cf. *Zostera* on sandy sediments, but this conclusion was not borne out in this study. Wood (1959a) and Higginson (1965) both concluded that *Ruppia* is intolerant of strong currents and occurs mainly in sheltered bays. In this case high turbulence in Illawarra Lake may be the limiting factor for *Ruppia* which is then confined to the sheltered localities inshore of *Zostera*.

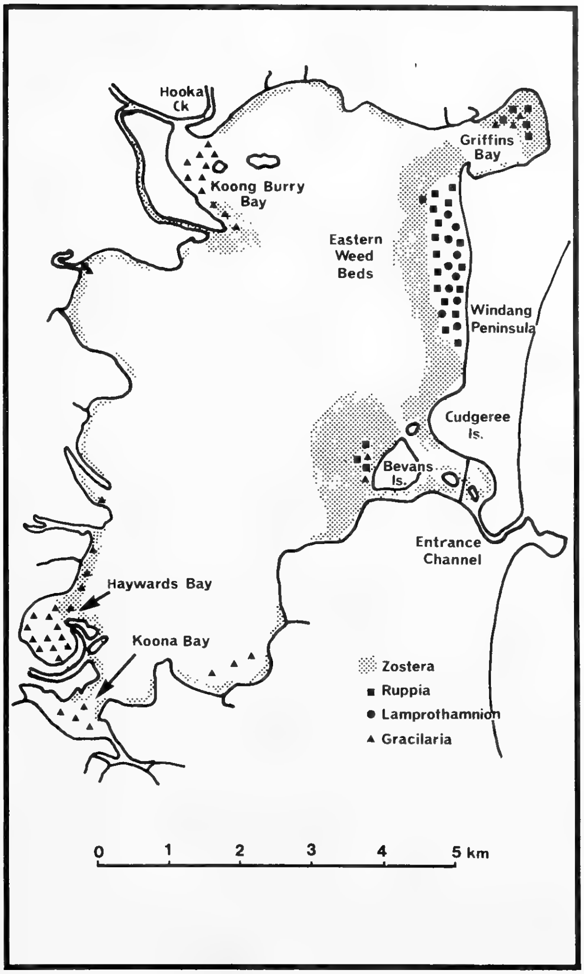

Fig. 2. Distribution of benthic plants in Illawarra Lake

Posidonia australis Hooker is not recorded in Illawarra Lake though the reasons for its absence remain obscure. *Posidonia* is reported to be intolerant of strong currents and turbulence (Wood 1959a, b; Den Hartog, 1970) and also appears to be intolerant of high turbidity. High turbidity may prevent growth of *Posidonia* in the body of the lake but could not account for its absence in the entrance channel area. Turbulence and current velocities in the channel area do not approach the rip conditions observed in the entrance to Macquarie Lake where Wood (1959a) reports growth of *Posidonia*.

Halophila ovalis (R. Brown) Hooker was also surprisingly absent from Illawarra Lake. It occurs along the N.S.W. coast on a wide range of sediment types encompassing those found in Illawarra Lake, and over a wide range of conditions of salinity and turbidity. Despite its apparent wide ecological tolerance *Halophila* has not been observed in Illawarra Lake.

Macroalgae were common in the Lake, particularly as epiphytes on *Zostera* and *Ruppia*. The most conspicuous were *Polysiphonia* sp., *Enteromorpha intestinalis* (L.) Link and *Cladophora* sp.; the latter species generally occurring in spring and early summer. The *Enteromorpha* and *Cladophora* form extensive floating mats in protected bays and in the inshore parts of the eastern weed beds. The benthic alga *Gracilaria verrucosa* (Huds.) Pap. occurred throughout the year and the broad distribution is shown in Fig. 2. In the southern bays, Koona and Haywards Bays, it was the dominant species occupying the silty sediments in the central portion of the bays. At least in initial stages plants are attached to the sediment. *Lamprothamnion* was variable in occurrence but mainly associated with *Ruppia* inshore of *Zostera* in the eastern weed beds, Fig. 2.

METHODS

The data and observations presented in this paper were gathered over the period 1971-1976. Complete details can be obtained from Harris (1977). The data include: observations on the distribution and abundance of *Zostera capricorni* and other components of the benthic flora including epiphytes; details of the relationship between *Zostera* distribution, biomass and environmental data; long term observations on growth and flowering in *Zostera*.

In the analysis of sediments and water quality the following techniques were used:

Particle size analyses were conducted according to Folk (1968).

Organic carbon was estimated from loss on ignition at 550°C as described by Dean (1974).

Total phosphorus was determined colorimetrically using the single solution method detailed in Major *et al.* (1972).

pH was measured using a specific ion meter and pH combination electrode (*Orion Model 407A* and *electrode no. 91-02*). Sediment pH is based on interstitial water extracted from the sediment by pressure.

Eh was measured using an Eh combination electrode (Orion no. 96-78) standardized using Zo Bel solutions as described by Whitfield (1971). Sediment Eh was made on carefully mixed samples.

Salinity was measured as chlorinity using a chloride electrode (Orion no. 96-17).

Temperature was measured using a standard 50°C mercury thermometer.

Turbidity measurements were initially made with a secchi disc but later using a turbidimeter (*Hach Model 2100A*).

Wherever possible data from other sources, particularly Ellis and co-workers, were used.

RESULTS AND DISCUSSION

I Distribution of *Zostera* in Illawarra Lake in relation to environmental factors

The major development of *Zostera capricorni* occurred in the eastern portion of the lake, and particularly off the Windang Peninsula and west of Bevans Island, Fig. 2. A narrow fringing zone seldom more than 20 m wide occurred around most of the bays in the western portion, except where *Gracilaria* was dominant.

(A) Sediment Factors. The composition of sediments supporting *Zostera* is given in Table 1. Extreme ranges were: particle size, sand 52 to 98%; organic carbon 0.5 to 8.5%; total phosphorus 35 to 120 $\mu g.g^{-1}$. Even greater extremes in values for particle size and organic carbon relate to the single site in Hooka Creek: 14% sand and 12% organic carbon. pH and Eh measurements were restricted to the eastern sandy portion of the Lake. Sediment pH ranged from 7.4 to 8.0 and Eh from +10 to −185 mV. This range of sediments, together with the lack of relationship between the distribution of sediment types in Illawarra Lake and the distribution of *Zostera* suggest that *Zostera* is not limited by sediment type.

TABLE 1

Composition of sediments supporting *Zostera* in Illawarra Lake
Mean values: range given in parentheses

Location	Number of samples	Sand %	Organic carbon %	Total phosphorus $\mu g.l^{-1}$
Griffins Bay	12	90 (77-97)	2.3 (0.8-3.5)	82 (35-105)
Eastern Weedbeds (off Windang Pens.)	8	96 (95-97)	1.5 (0.5-2.7)	61 (39-111)
Bevans Island	18	92 (88-97)	1.8 (0.8-4.3)	72 (53-120)
Southern Bays	5	82 (52-97)	3.3 (1.3-8.5)	—
Western Weedbeds	5	84 (58-92)	3.3 (2.1-5.2)	—
Hooka Creek	1	14	12.0	—

Where the reduction of *Zostera* beds occurred in Koona Bay and Koong Burry Bay over the period 1972 to 1977 it appeared to be related to rapid accretion of sediments. In other places in the lake (e.g. the northern side of the entrance channel east of the Windang Bridge, on the delta at the lake end of the entrance channel, in the shallows to the north of Cudgeree Island and the delta of the Griffins Bay tank trap) burial and subsequent recovery has been a frequent occurrence.

(B) Water Factors. Water quality in Illawarra Lake was highly variable. This is partially due to the fluctuating level of the lake: records of the N.S.W. Electricity Commission (1971) show an average variation in lake level of about 60cm in the period 1966-70.

Salinity. Ellis *et al.* (1977) showed that mean salinity in the Lake is controlled primarily by rainfall, and varied from 12.8 to 31.3 ‰ during a two year monitoring period. There was essentially no salinity stratification, with vertical mixing by wave action completed within 2-4 weeks. There was no significant east-west salinity gradient even though the major creeks are on the western side of the lake.

Zostera grew and even flowered over a wide range of salinity, from approximately 3 ‰ in Hooka Creek to approximately 35 ‰ in the entrance channel. This is outside the range experienced in the lake and it was concluded that salinity did not limit *Zostera* distribution.

Temperature. Ellis and Kanamori (1977) record a mean water temperature for Illawarra Lake in the range 11.6 to 25.6°C. In the Tallawarra Power Station outlet channel, water temperatures at times exceeded 35°C yet *Zostera* persisted at this site. It is concluded that water temperature was not a limiting factor since the differences in temperature between various sites on the lake was always slight, usually less than 3°C, and new growth was observed throughout the year.

Phosphorus. The nutrient status of the lake water, with regard to phosphates was generally beyond the level of enrichment needed to promote algal blooms (Anon., 1975; Wetzel, 1975). The observed total phosphorus range was 4 to 145 μg $P.l^{-1}$ (Kanamori, 1976). Because the lake was turbulent and the phosphate level of the sediment high, localized deficiencies in water phosphorus concentrations would be quickly restored by water circulation and by disturbance of the sediment. It is thus unlikely that the distribution would be limited by phosphorus deficiency.

Some very high concentrations of total phosphorus, up to 3,600 $\mu g.l^{-1}$ were observed in small creeks draining from non-sewered urban areas. Associated with this was a high *E. coli* count indicating that much of the nutrient inflow to Illawarra Lake is derived from domestic effluents and sewage. In areas adjacent to some streams, and in some bays, notably near Albion Creek in Koona Bay, in Kully Bay and Joes Bay

(Griffin Bay), Why Juck Bay, and in the Back Channel, *Zostera* grew sparsely or not at all. In these areas the green alga *Enteromorpha* grew in large floating masses shading the *Zostera*. In this way excessive phosphorus levels may have been indirectly responsible for restricting the distribution of *Zostera*.

Nitrate levels in the Lake have a mean value of 2 $\mu g.l^{-1}$ (Kanamori, 1976) which is lower than values reported by Higginson (1971) for Tuggerah Lakes or Spencer (1959) for Macquarie Lake.

pH and Eh. The observed ranges of pH and Eh for lake water were narrow; pH 8 to 8.4 and Eh +310 to +350 mV. State Pollution Control Commission figures (unpublished) give a pH range of 7.4 to 8.9. The narrow range and lack of systematic variation between different areas of the lake suggest that it is improbable that either of these factors would limit *Zostera* within the lake.

Turbidity. Light availability has often been demonstrated as the factor setting the maximum depth to which seagrasses will grow (Backman and Barilotti, 1976). In Illawarra Lake *Zostera* occurred to a depth of 2 m in the entrance channel which was twice daily filled with low turbidity sea water. Throughout most of the eastern weed beds the outer limit was usually found at 1.5 to 1.8 m even though the sandy substrate continued beyond 2m in depth. In Griffins Bay and off the mouth of Mullett Creek, areas of fine sediment and high turbidity, the limit was inside the 1 m contour.

Turbidity values and the depth limit of *Zostera* growth for near Bevans Island, the eastern weed beds, and one site in Griffins Bay are given in Table 2. Values are given for turbidity of water on the outer edge of the seagrass beds and also within the seagrass bed. Turbidity measure can often change rapidly: in the narrow fringing seagrass beds on the western side of the lake, where sediments are generally finer, turbidity could change from 2 to 40 NTU (nephelometric turbidity units) within 10 min. of a strong southerly change acting upon the lake. In the highly turbid areas of Koong Burry Bay, Haywards Bay and Koona Bay, *Zostera* is dominated by *Gracilaria*, in Griffins Bay *Zostera* and *Gracilaria* are co-dominant and in the eastern weed beds *Gracilaria* is only of minor importance.

Water Movement. Zostera is reported to grow in regions with considerable water movement (Higginson, 1965). In Illawarra Lake it appeared to tolerate currents of several knots but to be less tolerant of strong wave action. Extensive colonies occurred on the margins of the entrance channel where they experienced strong tidal flow, and colonies in Mullet and Hooka creeks were not obviously disturbed by flood flows.

The role of wave action is difficult to assess. On exposed peninsulas like Wollingurry Point, Tallawarra Point, Kanahooka Point and Wollamai Point, or in

TABLE 2

Turbidity measure at various sites in Nephelometric Turbidity Units

	SITE							
	Near Bevans Island		Eastern Weed Beds				Griffins Bay	
Depth of weed growth	1.8 m		1.8 m		1.6 m		1.0 m	
Turbidity measure	at margin	in weed bed						
10.11.75	2.0	0.5	1.5	4.5	1.75	1.0	4.5	9.5
8. 1.76	1.5	3.5	1.0	2.0	2.0	2.0	3.0	3.5
17. 1.76	1.5	.75	1.5	1.5	2.0	2.0	2.5	1.5
29. 1.76	1.5	2.75	1.25	2.0	1.75	2.5	2.0	3.0
8. 2.76	3.0	1.25	1.5	2.5	2.0	1.5	2.75	3.0
14. 2.76	3.5	3.5	3.0	4.75	3.0	3.0	4.5	3.0
Mean	2.2	2.0	1.6	2.9	2.1	2.0	3.2	3.9

open bays like Tuggerah, Yallah and Moureendah Bays, strong wave action periodically deposited several centimetres of sediment; then later removed it exposing the underlying rock. *Zostera* was unable to produce more than minor colonies in these areas.

During 1975-76 the *Zostera* beds in the northern side of the training wall in Yallah Bay degenerated greatly. This occurred during a period of high wave action generated by persistent, strong easterly winds and considerable sediment disturbance was evident. Similar observations were made in the beds south of Wollingurry Creek.

Of the environmental factors examined water depth and turbidity appear to be the most important factors limiting the lower distribution of *Zostera* in the lake. There is no evidence that sediment type plays any major role as has been suggested in the case of submerged aquatic angiosperms in the Tuggerah Lakes system (Higginson, 1965). The minimum water depth limit for *Zostera* in Illawarra Lake varied widely. In Griffins Bay, along the eastern weed beds and west of Bevans Island *Zostera* was sparse in water less than 40 cm deep. These are areas of intensive feeding by ducks and swans. The ducks have been observed feeding on the shoots of *Zostera* and the swans on the rhizomes of both *Zostera* and *Ruppia*. In areas such as the Back Channel, swans were seldom observed and here *Zostera* grew well in 15 - 20 cm of water. In September 1976, when lake levels were low *Zostera* beds in Koonawarra Bay were exposed. During this period several hundred black ducks (*Anas superciliosa*) congregated in this area and over the next 3 days cropped the exposed *Zostera* and *Ruppia* to within 1 cm of the sediment surface.

II *Zostera* biomass in relation to environmental factors

Analysis of the transect biomass data with environmental data showed no overall correlation between *Zostera* biomass and the factors particle size, sediment pH or Eh, water pH or Eh, water temperature, and water or sediment total phosphorus. Despite the greater nutrient content of sediments in Griffins Bay, compared with those near Bevans Island, *Zostera* biomass at the latter location was significantly higher (1.5 - 3 times) than in Griffins Bay. There was however a distinct relationship between *Zostera* biomass and water depth, and hence light availability, Fig. 3a. Fig. 3b shows the growth of *Zostera* expressed as shoot length at the same sites. A similar relationship holds for total plant biomass and water depth. The differences between Bevans Island and Griffins Bay data are consistent with the notion that depth limits of *Zostera* at a given locality are a function of turbidity. The reduced biomass in water less than 40 cm is presumed to relate to waterfowl grazing pressure.

III Vegetative growth of *Zostera capricorni*

The seasonal growth cycle data for *Zostera* at selected localities during 1972-73 are shown in Fig. 4. The general pattern is similar with maximum leaf length occurring during summer and the minimum in winter. The onset of the new growth cycle occurred in August - September after shedding of the previous season's growth. Wood (1959a) reported that leaf loss follows flowering and in autumn *Zostera* flats may seem completely bare of leaves. In this study full leaf development was sometimes maintained until early spring by which time new leaf growth had commenced.

In 1973 rapid degeneration of *Zostera* beds occurred during February and March coincident with heavy rainfall. Similar declines in the standing crop followed heavy late summer and autumn rains in 1974 and 1976. In 1975 when rainfall was 40% less than average little decline occurred until the June - July floods. These changes were most marked in waters shallower than 0.6 m. This relationship between flood rains

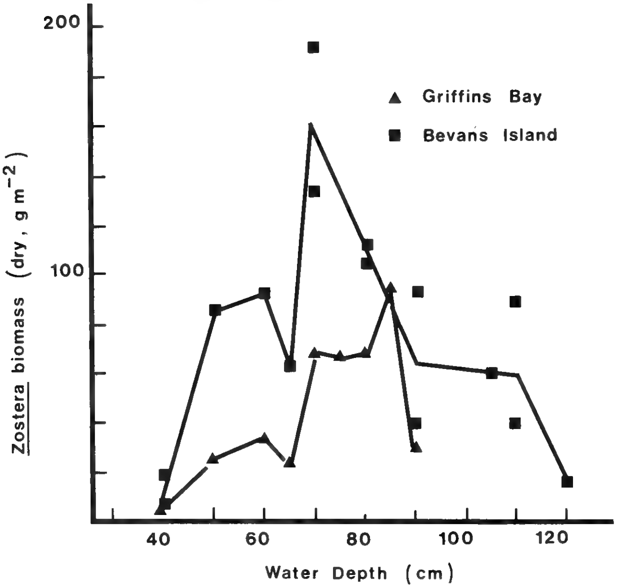

Fig. 3a. Zostera biomass (mean values) in relation to water depth — Bevans Island and Griffins Bay

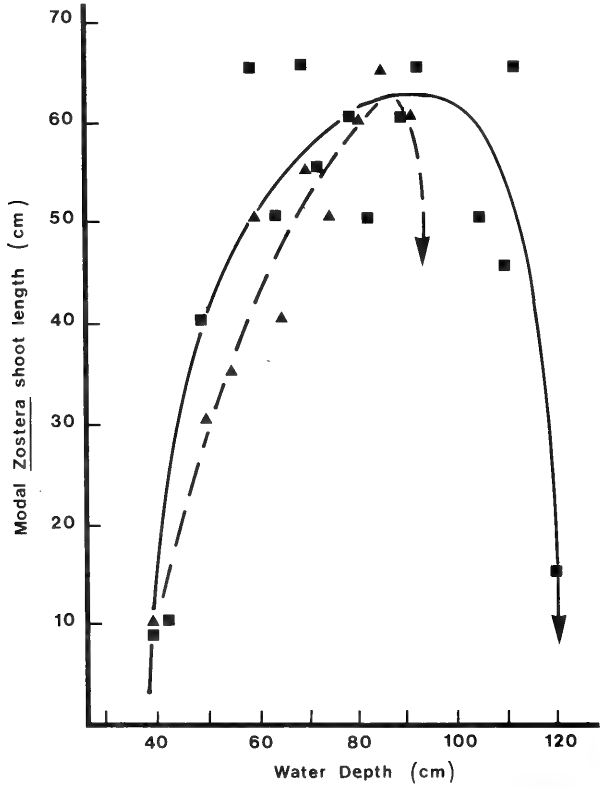

Fig. 3b. Zostera shoot length (mean values) in relation to water depth — Bevans Island and Griffins Bay, January 1976

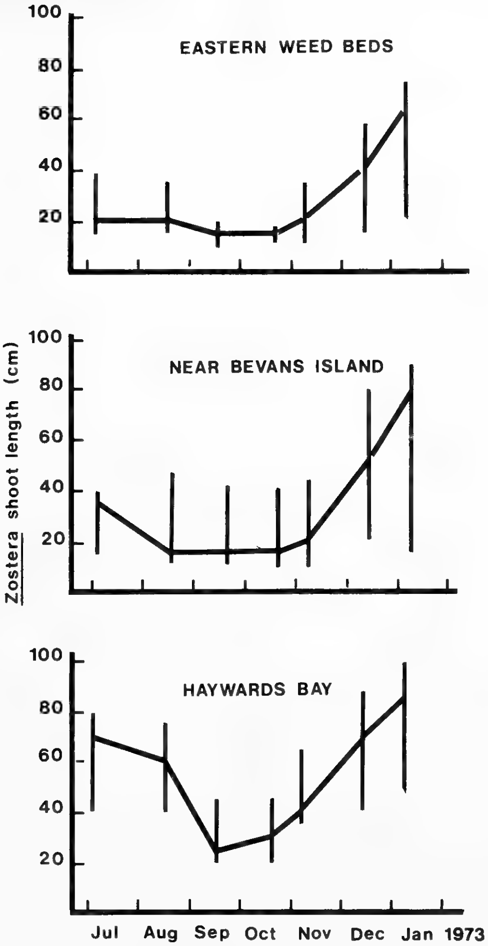

Fig. 4. Seasonal variation in shoot length of *Zostera capricorni* showing modal shoot length and range.

and leaf shedding was most marked in the eastern weed beds while colonies in sheltered localities such as Haywards and Koonawarra Bays or along the southern shore were barely affected. When the *Zostera* beds have their normal water cover, wave action is suppressed at the outer margin; however, during flooding the increased water depth allows for vigorous wave action throughout the beds, leading to extensive shedding of leaves. Associated lower salinities and increased turbidity may predispose *Zostera* towards leaf shedding but in the absence of mechanical agents it did not appear to arise from these causes alone.

IV Flowering and Seed Production

Flowering of *Zostera* in Illawarra Lake is variable both temporally and spatially. Immature flowering shoots were first observed in September and flowering sometimes extended through to August of the following year, with seed production from October to August. Generally peak flowering occurred in summer. Table 3 summarizes data for the season 1975-76. In that season flowering was abruptly terminated with

TABLE 3

Percentage of fertile shoots at three locations in summer 1975-76 based on 500 cm^2 composite sample

				Number of shoots examined	% fertile shoots	Number of seeds									
Site	October 1975			November			December			January 1976			February		
Near Bevans Island	—	nil	—	992	4.1	57	650	10.6	89	579	13.9	112	406	2.2	7
Eastern Weed Beds	136	6.6	—	1295	7.5	34	679	12.2	61	516	17.2	83	250	1.2	2
Griffins Bay	—	nil	—	257	22.2	186	397	12.1	172	405	13.6	101	—	nil	—

shedding of flowering shoots after heavy January rains. The frequency of flowering shoots showed wide variation between years: in 1972-73 the frequency reached 34% near Cudgeree Island and in Haywards Bay.

The majority of flowers did not produce seed. The observed maximum of flowers producing seed was 10.9% in 1976 compared to less than 2.6% in 1973.

Germinating seeds were found in sieved sediment samples on only one occasion: near Bevans Island in July 1975. There was no evidence that *Zostera* was colonizing bare areas by seedlings. In dredged areas any subsequent recolonization occurred by rhizome invasion from adjacent areas. As found by Wood (1964), such recolonization is slow. Preliminary experiments with transplanting *Zostera* into the back channel near the Tallawarra Power Station and in Griffins Bay were successful when the plants were transplanted complete with relatively undisturbed sediments: washed rhizomes did not recolonize. These small transplants (size range 100 - 200 cm^2) were made in June - October 1975 and 3 years later those near the Tallawarra Power Station had expanded to cover some 10 times the original area. This expansion has taken place by marginal growth of the clump into formerly uncolonized sediments. Growth in Griffins Bay has been less pronounced though clumps are still growing.

CONCLUSION

Within Illawarra Lake *Zostera capricorni* showed a marked ecological tolerance. Within the range found in the lake the distribution and abundance of *Zostera* did not appear to be controlled by substrate factors (particle size, total phosphorus, pH, Eh) or water quality factors (salinity, total phosphorus. pH, Eh). Light availability as influenced by water depth and turbidity appeared to control the lowest depth to which the plant grows. Grazing by swans and ducks may have been significant in setting the upper limit.

Zostera showed a seasonal cycle with shedding of the previous season's growth promoted by wave action. Flowering was extensive, though patchy and seed production was observed over a lengthy period, October to August of the following year. Although seedlings were observed in the field there was no evidence to suggest that seedlings play a major role in propagation. Transplant experiments, using *Zostera* clumps in relatively undisturbed sediments, have been successful and clumps have been expanded by growth into previously uncolonized sediments.

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A Key to Estuarine Polychaetes in New South Wales

PAT HUTCHINGS and SEBASTIAN RAINER

HUTCHINGS, P., & RAINER, S. A key to estuarine polychaetes in New South Wales. *Proc. Linn. Soc. N.S.W.* 104 (1), (1979) 1980:35-48.

A key to 184 species of estuarine polychaetes in New South Wales is given together with a reference to an adequate description of each named species.

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INTRODUCTION

The estuarine polychaete fauna of New South Wales includes many undescribed species and new records. Sheltered bays will share many species in common with estuarine areas. At present we know of 184 species occurring in N.S.W. estuaries of which 125 have been described. Many other species remain to be described, some perhaps belonging to families not included in this key, for example Chrysopetalidae and Amphinomidae. Many of the descriptions were published early this century in journals with limited circulation and often not in English. No key exists to enable most of these species to be identified or differentiated from species already described and this key is intended to remedy this situation.

The key is based on material collected during surveys of Careel Bay (Pittwater) and Gunnamatta Bay (Port Hacking) by the authors, from cores collected from *Posidonia* beds along the coast of New South Wales (PH and others) and other material from the Australian Museum collections. It is likely that many more species will be found in estuarine situations in New South Wales, but the key should provide a reasonable guide to at least the larger species. As it is possible that closely related species not in the key could be confused with keyed species, identifications made with the key should be checked against the literature. The number in brackets accompanying each named species indicates where an adequate description of that species may be found, using the numerical order of the references cited. Species keyed only to genus may represent undescribed species, new records that we have not been able to confirm or may refer to incomplete material that did not permit positive identification. An indication of other recorded species from Australia that may occur in N.S.W. estuaries is given by Day and Hutchings (1979).

The key is based on Day (1967) with some modifications and additions using the taxonomy of Fauchald (1977). Reference should be made to Day (1967), for diagrams indicating the important features of individual families and for a glossary of the terms used.

KEY TO ESTUARINE POLYCHAETES IN N.S.W.
(modified after Day, 1967)

			Reference
1.	—Most of the following characters: prostomium with sensory appendages; pharynx armed with jaws or teeth; parapodia well developed, compound setae often present	Polychaeta Errantia	2
	—Most of the following characters: prostomium usually		

	lacking sensory appendages, often fused to peristome, which may bear grooved palps, buccal cirri, stout setae or branchial crown; compound setae rarely present	Polychaeta Sedentaria	68	

Polychaeta Errantia

2.	—Elytra present on many segments		3	
	—Elytra absent		12	
3.	—Compound setae absent; elytra and dorsal cirri alternate fairly regularly	F. Polynoidae	4	
	—Compound setae present; elytra on alternate segments anteriorly, from about setiger 25 onwards on all segments	F. Sigalionidae	11	
4.	—Lateral antennae terminal, arising at level of median antenna, 15 pairs of elytra	*Parahalosydna chrysostichtus*		(13)
	—Lateral antennae arising below level of median antenna, 15-16 pairs of elytra		5	
5.	—Lateral antennae subterminal; ventral lamellae present	*Paralepidonotus ampulliferus*		(13)
	—Lateral antennae ventral; ventral lamellae absent		6	
6.	—Neurosetae with blades tapering to fine tips, unidentate	*Antinoe* sp.		
	—Neurosetae with blades ending in stout tips, uni- or bidentate		7	
7.	—One or more of the basal serrations on both notosetae and neurosetae enlarged to form spinous pockets; prostomium without frontal peaks	*Scalisetosus* sp.		
	—Basal serrations on setae not enlarged, prostomium with frontal peaks	*Harmothoe*	8	
8.	—Elytra ornamented with multifid tubercles	*Harmothoe* sp.		
	—Elytra ornamented with simple tubercles		9	
9.	—Elytral tubercles with flat-topped apices	*Harmothoe* sp.		
	—Elytral tubercles conical		10	
10.	—Elytral tubercles numerous	*Harmothoe* sp.		
	—Elytral tubercles short, conical, few, sometimes absent, elytra, margins with elongate papillae	*H. praeclara*		(13)
11.	—Median antenna with basal lappets on ceratophore	*Sthenelais* sp.		
	—Median antenna absent or papilliform and lacking ceratophore	*Sigalion ovigerum*		(15)
12.	—Dorsal and ventral cirri foliaceous	F. Phyllodocidae	13	
	—Dorsal and ventral cirri not foliaceous		17	
13.	—Five antennae, no occipital papilla; 4 pairs of tentacular cirri	*Eumida sanguinea*		(13)
	—Four antennae and often an occipital papilla; 3-4 pairs of tentacular cirri		14	
14.	—Setae present on third, or second and third, tentacular segments		15	
	—Setae absent from all tentacular segments		16	
15.	—Setae first present by second tentacular segment; rusty red in colour	*Genetyllis castanea*		(3)
	—Setae first present by third tentacular segment; colour otherwise	*Paranaitis* (4 spp)		
16.	—Pharynx with regular rows of papillae at sides of base, first 3 segments dusky, later segments with 3 dark spots; dorsal cirri large and cordate anteriorly	*Anaitides longipes*		(3)
	—Pharynx with irregularly arranged papillae; body			

	pale to dark brown with dark intersegmental bands; dorsal cirri almost semicircular	*Phyllodoce novaehollandiae*		(13)
17.	—Prostomium with ventrolateral palps		18	
	—Prostomium without palps		51	
18.	—Palps biarticulate, with stout basal joint and smaller distal joint		19	
	—Palps simple		35	
19.	—Compound setae absent; tentacular cirri two or fewer	F. Pilargidae	20	
	—Compound setae present; tentacular cirri four pairs or more		21	
20.	—Prostomium with three antennae; pharynx muscular	*Sigambra parva*		(3)
	—Prostomium with two antennae; pharynx epithelial	*Pilargis* sp.		
21.	—Jaws, if present, usually styliform, denticles absent; tentacular cirri often jointed	F. Hesionidae	22	
	—Two toothed jaws present and often horny denticles; tentacular cirri smooth	F. Nereidae	25	
22.	—Six pairs tentacular cirri		23	
	—Eight pairs tentacular cirri		24	
23.	—Two anterolateral antennae and one median antenna, notosetae 1/2 capillaries	*Ophiodromus* cf. *agilis*		(3)
	—Two anterolateral antennae only; notosetae present or absent	*Nerimyra* sp.		
24.	—Notopodium reduced, with few capillary setae	*Gyptis* sp.		
	—Notopodium not reduced, with numerous capillaries	cf. *Gyptis* sp.		
25.	—Anterior apodous segment absent behind peristomium; antennae absent; paragnaths absent	*Micronereis* sp.		
	—Anterior apodous segment present behind peristomium; two antennae present; paragnaths present or absent		26	
26.	—Chitinous paragnaths entirely absent; a transverse series of glandular ridges at base of anterior parapodia	*Australonereis ehlersi*		(13)
	—Chitinous paragnaths present; ventral glandular ridges absent		27	
27.	—Paragnaths all separate and conical		28	
	—Paragnaths include pectinate or transverse bars		34	
28.	—Chitinous paragnaths present on both basal and maxillary rings		29	
	—Chitinous paragnaths present on maxillary ring only	*Ceratonereis*	33	
29.	—Falcigers present in posterior notopodia, few setae; paragnaths few, absent on I, V and VI, II-1, III + IV-2-4, VII + VIII-5	*Nereis posidoniae*		(13)
	—Falcigers absent in posterior notopodia	*Neanthes*	30	
30.	—Notopodial lobe very large on both sides of dorsal cirrus in median and posterior segments	*Neanthes oxypoda*		(9)
	—Notopodial lobe not particularly enlarged		31	
31.	—Areas I and V of pharynx lacking paragnaths	*Neanthes* sp.		
	—Areas I and V of pharynx with paragnaths		32	
32.	—Paragnaths of area I-2, and area VI-3 cones in inverted triangle	*N. vaalii*		(13)
	—Paragnaths of area I-4 in triangle, and areas V + VIII — continuous band of cones 4-6 deep	*N. cricognatha*		(13)
33.	—Prostomium deeply cleft between antennae; dorsal cirri long; no simple neuropodial falcigers	*C. mirabilis*		(13)

	—Prostomium not cleft; dorsal cirri short; one large simple falciger in posterior neuropodia	*C. erythraeensis*		(13)
34.	—Areas IV, VII + VIII of pharynx with cones and pectinate paragnaths, posterior notopodia with 2-3 homogomph falcigers	*Platynereis dumerilii antipoda*		(13)
	—Area VI of pharynx with continuous transverse series of cones extending across V and VI	*Perinereis* cf. *brevicirris*		(9)
35.	—Barrel-shaped proventriculus posterior to pharynx, pharyngeal armature variable	F. Syllidae	36	
	—Proventriculus absent, four or more pairs of jaws		56	
36.	—Ventral cirri absent; dorsal cirri not annulated	*Autolytus* sp.		
	—Ventral cirri distinct, dorsal cirri annulated or smooth		37	
37.	—Palps separate; dorsal cirri jointed		38	
	—Palps fused basally or for at least half their length; dorsal cirri smooth		43	
38.	—Setae few, simple, enlarged, with 2 teeth, terminal one bifid	*Haplosyllis spongicola*		(3)
	—Setae mainly or entirely compound		39	
39.	—Mainly compound setae anteriorly, then include a few large simple setae with Y-shaped prongs	*Syllis gracilis*		(3)
	—Only compound setae present		40	
40.	—Blades of some superior setae much longer than the rest; dorsal cirri with 10-18 joints	*Langerhansia cornuta*		(3)
	—Blades of setae decrease evenly in length, dorsal cirri otherwise	*Typosyllis*	41	
41.	—Setae unidentate or minutely bidentate, dorsal cirri stout with 8-12 joints	*T. armillaris*		(3)
	—Setae strongly bidentate; dorsal cirri otherwise		42	
42.	—Dorsal cirri short, with 7-12 joints	*T.* cf. *hyalina*		(3)
	—Dorsal cirri with more than 20 joints	*T. variegata*		(13)
43.	—Palps fused basally; dorsal cirri usually smooth		44	
	—Palps fused for at least half their length; dorsal cirri smooth		45	
44.	—Pharynx unarmed; ventral cirri longer than setigerous lobes; acicula of anterior parapodia enlarged, knobbed	*Streptosyllis* sp.		
	—Pharynx with a semicircle of recurved teeth; ventral cirri not longer than setigerous lobes; acicula not knobbed	*Odontosyllis* sp.		
45.	—Dorsal cirri papilliform; 1 pair of rudimentary tentacular cirri	*Exogone*	46	
	—Dorsal cirri flask-shaped; 1 pair of tentacular cirri	*Sphaerosyllis*	48	
46.	—Dorsal cirrus present on setiger 2, single superior compound seta with dagger-like blade	*Exogone* sp.		
	—Dorsal cirrus absent on setiger 2; superior compound setae different from rest		47	
47.	—Superior compound setae with swollen shaft-head and broad triangular blade	*E. heterosetosa*		(3)
	—Three to five superior compound setae with dagger-like blades	*E.* cf. *gemmifera*		(13)
48.	—Body surface and parapodia covered with minute papillae		49	
	—Body surface and parapodia without papillae		50	
49.	—Dorsal cirrus on setiger 2	*S.* cf. *semiverrucosa*		(13)
	—Dorsal cirrus absent from setiger 2	*Sphaerosyllis* sp.		

50.	—Dorsal cirrus on setiger 2	*Sphaerosyllis* sp.		
	—Dorsal cirrus absent from setiger 2	*S. sublaevis*		(3)
51.	—Body papillose, head indistinct; pharynx unarmed	F. Sphaerodoridae- *Sphaerodoridium* sp.		
	—Body smooth, head distinct; pharynx with two or more pairs of jaws		52	
52.	—Peristomium with parapodia and setae		53	
	—Peristomium without parapodia or setae		59	
53.	—Prostomium pentagonal, body square in section; parapodia with lamellae	F. Nephtyidae	54	
	—Prostomium a pointed cone, body circular in section; parapodia without lamellae		56	
54.	—Prostomium produced anteriorly; long flowing setae.	*Nephtys longipes*		(16)
	—Prostomium not produced anteriorly; setae short		55	
55.	—Branchiae recurved, from setiger 4; pharynx with 22 longitudinal rows of papillae and single median papilla	*N. australiensis*		(16)
	—Branchiae recurved, from setiger 5; pharynx with 20 longitudinal rows of papillae and no single median papilla	*N. inornata*		(16)
56.	—Pharynx with four horny jaws; parapodia all alike and body not divided into regions	F. Glyceridae	57	
	—Pharynx with a pair of toothed jaws and a circle of denticles; body divided into different regions	F. Goniadidae	58	
57.	—Branchiae non-retractile, simple; pharyngeal papillae of two types, one with distal flange	*Glycera tridactyla**		(3)
	—Branchiae retractile, branched; pharyngeal papillae of two types, without distal flange	*G. americana*		(13)
58.	—Body divided into three regions, parapodia biramous after setiger 34	*Glycinde armigera*		(9)
	—Body divided into three regions, parapodia biramous after setiger 30	*Glycinde* sp.		
59.	—Dorsal cirri and antennae present		60	
	—Dorsal cirri absent or rudimentary; antennae usually absent	F. Lumbrineridae	66	
60.	—Maxillae of four or five paired plates, plates III and IV fused on right side; antennae variable; branchiae usually present		61	
	—Maxillae of numerous small elements in two or four longitudinal series, two antennae and two cylindrical palps; branchiae absent	F. Dorvilleidae	67	
61.	—One to five antennae, without ringed ceratophores	F. Eunicidae	62	
	—Seven antennae, posterior five with long, ringed ceratophores	F. Onuphidae	65	
62.	—One antenna; branchiae and tentacular cirri absent	*Nematonereis* cf. *unicornis*		(3)
	—Five antennae; branchiae present		63	
63.	—Tentacular cirri absent; anterior margin of prostomium bilobed; comb setae absent, compound setae spinigerous, acicular setae bidentate	*Marphysa sanguinea*		(13)
	—Tentacular cirri present	*Eunice*	64	
64.	—Anterior margin of prostomium deeply notched, antennae deeply jointed; branchiae begin on setigers 3-8; comb setae present, compound setae falcigerous, acicular setae tridentate	*E. australis*		(13)

**Glycera convoluta* Keferstein is synonymous with *G. tridactyla* Schmarda

	—Anterior margin of prostomium shallowly notched, antennae nearly smooth; branchiae from setiger 3; comb setae present, compound setae falcigerous, acicular setae tridentate	*E. vittata*		(3)
65.	—Branchial filaments arranged spirally, from setiger 5, pseudocompound hooks unidentate or with secondary tooth very weak	*Diopatra* cf. *neapolitana*		(3)
	—Branchial filaments arranged spirally, from setiger 5; pseudocompound hooks bidentate	*Diopatra* sp.		
66.	—Prostomium conical, body elongate; hooded hooks jointed in first few parapodia, later hooks simple; body reddish or orange	*Lumbrineris latreilli*		(13)
	—Prostomium conical, body elongate; hooded hooks jointed in first few parapodia, later hooks simple; body green	*Lumbrineris* sp.		
67.	—Parapodia uniramous with ovoid dorsal cirri, no cirrophores or notoacicula	*Protodorvillea* sp.		
	—Parapodia sub-biramous with dorsal cirri mounted on ceratophores containing notoacicula	*Dorvillea australiensis*		(1)

Polychaeta Sedentaria

68.	—Head not greatly modified; prostomium well developed; peristomium sometimes with pair of palps		69	
	—Head modified by development of frilly membrane, buccal tentacles or a branchial crown; prostomium often reduced		155	
69.	—Buccal segment with palps or tentacles		70	
	—Buccal segment without food gathering appendages		124	
70.	—Buccal segment with pair of adhesive palps (often broken off) or several grooved tentacles		71	
	—Buccal segments with tentacles retractile into the mouth	F. Ampharetidae	160	
71.	—Hooded hooks present in posterior setigers; well developed parapodia		72	
	—Hooded hooks entirely absent; parapodia often poorly developed		108	
72.	—Head not flattened, branchiae often present; palps grooved; posterior notosetae hooded hooks	F. Spionidae	73	
	—Head flattened and spade-shaped; palps papillose, notosetae hooded hooks from setiger 9	F. Magelonidae	106	
73.	—Setiger 5 with strongly modified setae		74	
	—Setiger 5 without modified setae		85	
74.	—Branchiae first present posterior to setiger 5		75	
	—Branchiae first present anterior to setiger 5		83	
75.	—Setiger 5 slightly to moderately modified parapodia	*Pseudopolydora*	76	
	—Setiger 5 greatly modified, with reduced parapodia		77	
76.	—Prostomium entire; neuropodial hooded hooks from setiger 8	*P. paucibranchiata*		(2)
	—Prostomium incised; bidentate neuropodial hooded hooks from setiger 8	*P. kempi*		(2)
77.	—Setiger 5 with spines of one type with or without companion capillary setae	*Polydora*	78	
	—Setiger 5 with spines of two types	*Carazziella*	82	
78.	—Setiger 5 with brush-tipped companion setae; specialized posterior notosetae absent	*P. penicillata*		(13)
	—Setiger 5 without brush-tipped companion setae; specialized posterior notosetae present or absent		79	

79.	—Hooded hooks with constriction on shaft	*P. haswelli*		(2)
	—Hooded hooks without constriction on shaft		80	
80.	—Posterior notopodial spines form dense packets of needles; gizzard absent; major spines of setiger 5 with weak subterminal swelling; eyes absent	*P. flava*		(2)
	—Posterior notopodial spines absent		81	
81.	—Gizzard present internally in setigers 18-19, seen externally as a swelling; major spines of setiger 5 with subterminal boss; eyes present	*P. socialis*		(2)
	—Gizzard absent; major spines of setiger 5 falcate, simple; eyes absent	*Polydora* sp.		
82.	—Hooded hooks from setiger 7; superior dorsal fascicle of notosetae with fimbriated setae	*C. hirsutiseta*		(2)
	—Hooded hooks from setiger 8; superior dorsal fascicle of notosetae with simple setae	*C. victoriensis*		(2)
83.	—Major spines of setiger 5 of two types, first with expanded ends bearing bristles, second simple, falcate	*Boccardia chilensis*		(2)
	—Major spines of setiger 5 of one type, simple, falcate, with smaller companion setae	*Boccardiella*	84	
84.	—Branchiae from setiger 2 onwards except for setigers 4 and 5	*B. bihamata*		(2)
	—Branchiae from setiger 2 onwards, on setiger 5 may be rudimentary	*B. limnicola*		(2)
85.	—Prostomium distally pointed		86	
	—Prostomium not distally pointed, with lateral or frontal horns, anterior margin broadly rounded or incised		90	
86.	—Branchiae beginning on setiger 1, continuing almost to posterior end	*Australospio trifida*		(2)
	—Branchiae beginning on setiger 2, continuing over variable number of setigers		87	
87.	—Branchiae completely free from dorsal lamellae, absent posteriorly	*Aonides oxycephala*		(2)
	—Branchiae fused to dorsal lamellae and continuing to end of body	*Scolelepis*	88	
88.	—Notosetae present on setiger 1, neuropodial hooks quadridentate	*S. precirriseta*		(2)
	—Notosetae absent on setiger 1, neuropodial hooks otherwise		89	
89.	—Hooded hooks multidentate, from setiger 14-15, in neuropodia only	*S. towra*		(2)
	—Hooded hooks bidentate, from setiger 24, probably only in neuropodia	*S. vexillatus (*as *Pseudomalacoceros vexillatus)*		(13)
90.	—Prostomium with lateral or frontal horns		91	
	—Prostomium without lateral or frontal horns		94	
91.	—Branchiae from setiger 1	*Malacoceros*	92	
	—Branchiae from setiger 2	*Rhynchospio*		
92.	—Bidentate ventral hooded hooks from setiger 22	*M. divisus*		(13)
	—Tridentate ventral hooded hooks from setiger 11 or later		93	
93.	—Body with dark brown pigment; tridentate ventral hooded hooks from setiger 25	*M. tripartitus*		(2)
	—Body colourless; tridentate ventral hooded hooks from setiger 11	*Malacoceros* sp.		

94.	—Branchiae limited to middle and posterior setigers except for one pair on setiger 2 in males	*Pygospio elegans*		(3)
	—Branchiae from setiger 1 or 2		95	
95.	—Branchiae concentrated in setigers 1-22		96	
	—Branchiae present over most of body		104	
96.	—Branchiae from setiger 1		97	
	—Branchiae from setiger 2	*Prionospio*	98	
97.	—Three pairs of pinnate branchiae; dorsal ridge across setiger 1	*Paraprionospio* sp.		
	—Eighteen to 22 pairs of cirriform branchiae; no dorsal ridge on setiger 1	*Orthoprionospio cirriformia*		(2)
98.	—Branchiae all cirriform	*P. cirrifera*		(2)
	—Branchiae otherwise		99	
99.	—Branchiae all pinnate		100	
	—Branchiae both pinnate and cirriform		101	
100.	—Three pairs of pinnate branchiae; low dorsal crest on setiger 7	*P. aucklandica*		(2)
	—Four pairs of pinnate branchiae, dorsal crests absent	*P. multipinnulata*		(2)
101.	—First and third pairs of branchiae pinnate (pinnules sparse), second and fourth pairs cirriform	*P. paucipinnulata*		(2)
	—Branchiae otherwise		102	
102.	—First three pairs of branchiae cirriform, fourth pair pinnate	*P. tridentata*		(2)
	—First and fourth pairs of branchiae pinnate, second and third pairs cirriform		103	
103.	—Dorsal transverse crest on setiger 7 only	*P. fallax*		(6)
	—Dorsal transverse crests from setiger 7 to about 30	*P. multicristata*		(13)
104.	—Branchiae from setiger 1	*Spio*	105	
	—Branchiae from setiger 2	*Laonice* sp.		
105.	—Neuropodial hooded hooks from setiger 10-11, bidentate; body colourless	*S. filicornis*		(3)
	—Neuropodial hooded hooks from setiger 9-11, tridentate; anterior body brown pigmented	*S. pacifica*		(2)
106.	—Hooded hooks from setiger 9, tridentate (MF:2), accompanied by single short hooded hook per fascicle	*Magelona dakini*		(13)
	—Hooded hook from setiger 9, bidentate or multidentate		107	
107.	—Hooded hooks multidentate, all hooks within a fascicle similar in size	*Magelona* sp.		
	—Hooded hooks bidentate (MF:1), all hooks within a fascicle similar in size	*Magelona* sp.		
108.	—Long filamentous branchiae at least on anterior segments; parapodia reduced to ridges	F. Cirratulidae	109	
	—Branchiae not long and filamentous; parapodia not in the form of ridges		121	
109.	—Two large grooved tentacular filaments		110	
	—Several grooved tentacular filaments		116	
110.	—Capillary setae only present	*Tharyx*	111	
	—Acicular hooks and capillaries present		112	
111.	—Branchial filaments in middle of body arise laterally just above notosetae	*T. marioni*		(3)
	—Branchial filaments in middle of body arise from mid dorsal line	*T. dorsobranchiata*		(3)
112.	—Acicular setae of posterior noto- and neuropodia			

	continuous to form two lateral arcs, on either side of body; acicular hooks present in only last 40 setigers, increasing rapidly to 5-6 per fascicle plus 5-6 capillaries	*Chaetozone* sp.		
	—Posterior noto- and neurosetae remain in separate bundles	*Caulleriella*	113	
113.	—Neuropodial hooks from setiger 3	*Caulleriella bioculatus*		(3)
	—Neuropodial hooks from setiger 3 or later		114	
114.	—Neuropodial hooks from setiger 4, bidentate	*Caulleriella tricapillata*		(13)
	—Neuropodial hooks from setiger 31 or later, bidentate		115	
115.	—Neuropodial hooks from setiger 31, minutely multidentate, accompanied by capillaries; single acicular seta present in posterior segments; elliptical eye spot	*Caulleriella* sp.		
	—Neuropodial hooks from setiger 34, multidentate by setiger 71, accompanied by capillaries; simple acicular hooks posteriorly, sigmoid anteriorly; pair of dark eye spots	*Caulleriella* sp.		
116.	—Branchial filaments arise on same segment as tentacular cirri	*Cirratulus*	117	
	—Branchial filaments arise on all segments anterior to tentacular cirri	*Cirriformia*	119	
117.	—Tentacular filaments arise above setigers 4-6	*Cirratulus chrysoderma*		(3)
	—Tentacular filaments arise otherwise		118	
118.	—Tentacular filaments arise above setigers 6-10; acicular setae absent, capillaries throughout; anterior heavily pigmented	*Cirratulus nuchalis*		(5)
	—Tentacular filaments arise above setiger 3; sigmoid hooks and capillaries present	*Cirratulus* sp.		
119.	—Tentacular filaments arise above setigers 3-4	*Cirriformia capensis*		(3)
	—Tentacular filaments arise above setigers 4-6 or 5-7		120	
120.	—Tentacular filaments arise above setigers 4-6; capillaries throughout, sigmoid hooks by setiger 12	*Cirriformia filigera*		(3)
	—Tentacular filaments above setiger 4-6 or 5-7; capillaries throughout, sigmoid hooks from setiger 50	*Cirriformia tentaculata*		(3)
121.	—Noto- and neuropodia of anterior parapodia well developed, setiger 1 with elongate setae directed forwards	F. Trochochaetidae- *Poecilochaetus serpens*		(3)
	—Anterior setigers uniramous, neuropodia lacking; posterior setigers biramous with neurosetae as minute uncini	F. Chaetopteridae	122	
122.	—Middle region with bilobed notopodia; no tentacular cirri	*Spiochaetopterus* sp.		
	—Middle region with notopodia never bilobed; no tentacular cirri		123	
123.	—Body large; palps short; some notopodia of middle region fused to form paddles; parchment tube	*Chaetopterus variopedatus*		(3)
	—Body small; palps large; notopodia of middle regions never fused; fragile sandy tube; often living in dense colonies	*Mesochaetopterus minutus*		(3)
124.	—Dentate crested hooks absent		125	
	—Dentate crested hooks present in posterior segments if not earlier		138	
125.	—Capillary setae crenulate	F. Orbiniidae	126	
	—Capillary setae smooth		132	

126.	—Prostomium round; change from thorax to abdomen about setiger 28	*Naineris grubei australis*		(4, 13)
	—Prostomium pointed; thorax of less than 23 setigers		127	
127.	—Thorax with several foot papillae and many stomach papillae	*Phylo felix*		(4, 13)
	—Thorax with 1-2 foot papillae, no stomach papillae		128	
128.	—No anterior row of hooks among thoracic neurosetae	*Leitoscoloplos*	129	
	—Anterior row or rows of hooks among thoracic neurosetae		130	
129.	—Thorax of 19-22 setigers; branchiae from setigers 8-11	*L. bifurcatus*		(4, 13)
	—Thorax of 14-15 setigers; branchiae from setigers 15-16	*L. normalis*		(4, 13)
130.	—Single row of slender hooks among thoracic neurosetae	*Scoloplos (Scoloplos)*	131	
	—Three to four rows of hooks among thoracic neurosetae	*Scoloplos (Leodamas) johnstonei*		(4)
131.	—Thorax of 13-17 setigers; branchiae from setiger 9-11	*Scoloplos (S.) simplex*		(4, 13)
	—Thorax of 16-18 setigers; branchiae from setiger 12-15	*Scoloplos (S.)* sp.		
132.	—A single long filiform branchia arising from dorsum of setiger 2 or 3	F. Cossuridae-*Cossura* sp.		
	—Branchiae, if present, not single and median		133	
133.	—Capillaries winged in anterior segments; median antenna may be present	F. Paraonidae	134	
	—Capillaries not winged; median antenna never present		135	
134.	—Prostomium with median dorsal antenna; specialized setae, 4 curved unidentate hooks among capillaries of posterior neuropodia	*Aricidea fauveli*		(3)
	—Prostomium without an antenna; specialized setae among capillaries of posterior neuropodia	*Paraonis* sp.		
135.	—Prostomium a tapered cone; body fusiform, often grooved ventrally	F. Opheliidae	136	
	—Prostomium notched or lobed; body swollen anteriorly but not grooved ventrally	F. Scalibregmidae	137	
136.	—Ventral groove present; branchiae present from setiger 2 for about 24-25 setigers; eye spots between parapodium of middle segments	*Armandia intermedia*		(3)
	—Ventral groove present, branchiae absent; eye spots absent	*Polyophthalmus pictus*		(3)
137.	—Body arenicoliform; posterior parapodia lack ventral and dorsal cirri; branchiae absent	*Hyboscolex dicranochaetus*		(14)
	—Body arenicoliform; posterior parapodia with both ventral and dorsal cirri; branchiae absent	*Pseudoscalibregma* sp.		
138.	—Body resembles an earthworm; dentate crested hooks with hoods	F. Capitellidae	139	
	—Body does not resemble an earthworm; dentate crested hooks without hoods		149	
139.	—Genital setae present in both sexes on setigers 8-9; thorax of 10 setigers	*Capitellides jonesi*		(13)
	—Genital setae absent or only present in males; thorax of 9 setigers		140	
140.	—Genital setae present in males; thorax of nine			

	setigers; capillaries in anterior thoracic setigers, hooks thereafter	*Capitella*	141	
	—Genital setae absent; ten or more thoracic setigers		142	
141.	—Body colourless; when preserved	*C. capitata*		(3)
	—Body with bright red pigment spots	*Capitella* sp.		
142.	—Ten thoracic setigers, with capillaries in setigers 1-4 and hooks in setigers 5-10	*Mediomastus californiensis*		(13)
	—More than ten thoracic setigers		143	
143.	—Eleven thoracic setigers		144	
	—More than 11 thoracic setigers		148	
144.	—Thoracic setigers all capillaries	*Notomastus*	145	
	—Thoracic setigers with capillaries and hooded hooks		147	
145.	—Neurosetae present on first thoracic setiger	*Notomastus* sp.		
	—Neurosetae absent on first thoracic setiger		146	
146.	—Eyes embedded in segment 1; globular branchiae present on posterior abdominal setigers	*N. torquatus*		(13)
	—Elliptical eye spots on segment 1; often purple in colour; branchiae absent	*Notomastus* sp.		
147.	—Thoracic setigers 1-5 with capillaries, 6-11 with hooks	*Heteromastus filiformis*		(13)
	—Thoracic setigers 1-6 with capillaries, 7-11 with hooks	*Barantolla lepte*		(13)
148.	—Twelve thoracic setigers; abdomen ends in anal plate; branchiae absent	*Scyphoproctus djiboutiensis*		(3)
	—Thirteen thoracic setigers; no anal plate; retractile branchiae	*Dasybranchus* sp.		
149.	—Middle setigers greatly elongated, never annulated; branchiae rare	F. Maldanidae	150	
	—Middle setigers not greatly elongated but annulated; branchiae present	F. Arenicolidae	154	
150.	—Cephalic plate absent; cephalic ridge well marked; pygidium petaloid with central anus	*Petaloproctus* sp.		
	—Cephalic plate well defined, surrounded by raised margin; pygidium variable		151	
151.	—Pygidium as a slanting plate with a dorsal anus above it, anal cirri absent	*Asychis* sp.		
	—Pygidium encircled by anal cirri with anus sunken in a funnel		152	
152.	—Neurosetae of setigers 1-3, four dentate crested hooks similar to subsequent ones	*Axiothella* sp.		
	—Neurosetae of setigers 1-3, four acicular setae, different from subsequent ones	*Euclymene*	153	
153.	—Setigers 1-3 with simple smooth acicular neurosetae; 2 achaetous pre-anal segments; anal funnel with 27-29 equal cirri plus one longer	*E. trinalis*		(11)
	—Setigers 1-3 with simple smooth acicular neurosetae; five achaetous pre-anal segments; anal funnel with all cirri equal in size	*Euclymene* sp.		
154.	—Branchiae from setiger 20, branchiferous segments with two annuli; animal small not exceeding 40mm	*Branchiomaldane* sp.		
	—Branchiae from setiger 7-17, branchiferous segments with five annuli; animal large	*Arenicola bombayensis*		(13)
155.	—Head with frilled food gathering membrane; lives in firm sandy tube	F. Oweniidae-*Owenia fusiformis*		(3)
	—Head without frilled food gathering membrane		156	
156.	—Head with stout setae	F. Flabelligeridae	157	
	—Head without stout setae		159	

157.	—Neurosetae simple hooks; branchiae filamentous, arise in single marginal row from cephalic hood	*Pherusa* sp.		
	—Neurosetae not simple hooks; branchiae filamentous or cirriform arise in 2 or more rows		158	
158.	—Neurosetae annulated with bent or minutely hooked tips; a few stout branchiae in 2 distinct groups	*Diplocirrus* sp.		
	—Neurosetae stout compound hooks; numerous fine branchiae in several irregular rows	*Flabelligera* sp.		
159.	—Head with soft tentacles for deposit feeding; branchiae present		160	
	—Head with branchial crown for suspension feeding; segmental branchiae absent		179	
160.	—Tentacles retractile into mouth, either grooved or papillose	F. Ampharetidae	161	
	—Tentacles not retractile into mouth, grooved, never papillose		164	
161.	—Stout postbranchial hooks present; paleae absent; buccal tentacles smooth	*Isolda pulchella*		(3)
	—Stout postbranchial hooks absent; paleae present		162	
162.	—Buccal tentacles papillose	*Pseudoamphicteis papillosa*		(12)
	—Buccal tentacles smooth		163	
163.	—Glandular ridges present; four pairs of smooth gills; 14 uncinigerous thoracic segments; body with green pigment spots	*Amphicteis dalmatica*		(13)
	—Glandular ridges absent; three pairs of smooth gills; 12 uncinigerous thoracic segments	*Samythella* sp.		
164.	—Branchiae absent; tentacular lobe expanded	F. Terebellidae SF. Polycirrinae	165	
	—Branchiae present; tentacular lobe expanded or compact		167	
165.	—Abdominal setae completely absent	*Lysilla*	166	
	—Abdominal setae restricted to acicular notosetae	*Amaeana trilobata*		(12)
166.	—Ten thoracic setigers; notosetae simple smooth capillaries, neurosetae absent	*L. apheles*		(11)
	—Nine to 12 thoracic setigers; notosetae barbed, neurosetae absent	*L. pacifica*		(12)
167.	—Tentacular lobe and peristomium compact	F. Terebellidae	168	
	—Either tentacular lobe or peristomium expanded	F. Trichobranchidae	178	
168.	—Branchiae simple filaments on setigers 1-3		169	
	—Branchiae branched or club shaped on setigers 1-3		174	
169.	—Uncini of first four rows, heavily chitinized long-handled hooks; following ones avicular	*Hadrachaeta aspeta*		(12)
	—Uncini all avicular with forwardly projecting bases		170	
170.	—Notosetae from segment 2 (first branchiferous)	*Streblosoma*	171	
	—Notosetae from segment 3 (second branchiferous)		172	
171.	—Twenty-five—29 pairs of notosetae; three pairs of branchiae forming continuous band across dorsum	*S. acymatum*		(13)
	—Twenty-one pairs of notosetae; two pairs of branchiae with distinct median gap separating left and right hand pairs	*Streblosoma* sp.		
172.	—Notosetae from segment 3 (second branchiferous); uncini from setiger 3	*Thelepus*	173	
	—Notosetae from segment 3 (second branchiferous); uncini from setiger 6	*Rhinothelepus lobatus*		(11)
173.	—Notosetae terminate halfway along abdomen, uncini			

	with terminal button; branchiae of numerous filaments	*T. setosus*		(3)
	—Notosetae more than 20 pairs; uncini otherwise; three pairs of branchiae with few branchial filaments arising on horizontal ridges, filaments of first extend laterally	*Thelepus* sp.		
174.	—Branchiae club-shaped; anterior uncini avicular but base produced backwards as long shaft	*Pista typha*		(12)
	—Branchiae branched; all uncini similar, either avicular or pectiniform		175	
175.	—Notosetae with smooth tips		176	
	—Notosetae with denticulate tips		177	
176.	—Lateral lobes absent on segments 2-4; uncini avicular	*Nicolea* sp.		
	—Lateral lobes present on segments 2-4; uncini pectiniform	*Loimia medusa*		(12)
177.	—Lateral lobes absent; notosetae from segment 3 (second branchiferous)	*Neoleprea* sp.		
	—Lateral lobes absent; notosetae from segment 4 (third branchiferous)	*Terebella* sp.		
178.	—Expanded tentacular lobe; compact peristomium; single branchiae with stout trunk bearing four lamellate lobes	*Terebellides stroemi*		(3)
	—Compact tentacular lobe; peristomium forming conspicuous proboscis; branchiae simple filaments on setigers 1-3	*Artacamella dibranchiata*		(12)
179.	—Tube sandy or muddy; an operculum never present among radioles	F. Sabellidae	180	
	—Tube calcareous; stalked operculum usually present	F. Serpulidae	183	
180.	—Thoracic neurosetae single row of long-shafted hooks; last few abdominal segments form a spoon-shaped cavity	*Euchone* sp.		
	—Thoracic neurosetae avicular; posterior abdominal segments not modified		181	
181.	—Thoracic neurosetae avicular uncini with pick-axe setae; collar replaced by triangular projection	*Amphiglena pacifica*		(13)
	—Thoracic neurosetae avicular uncini without pick-axe setae		182	
182.	—Thoracic notosetae include subspathulate setae	*cf. Laonome* sp.		
	—Thoracic notosetae winged capillaries only; branchial radioles with stylodes; body with segmental eye spots and irregular dark pigment	*Branchiomma nigromaculata*		(13)
183.	—Thorax of 3-4 segments; tube small, spirally coiled	*Janua*	184	
	—Thorax of 5 or more segments; tube straight or sinuous		185	
184.	—Tube with one to four longitudinal ridges; operculum with peripheral bilobed talon	*J. (Dexiospira) brasiliensis*		(13)
	—Tube with three longitudinal ridges; operculum concave	*J. (Dexiospira) foraminosa*		(13)
185.	—Collar setae bayonet; operculum stalk slender, wingless, operculum with basal funnel or fused radii plus central crown of 10-20 equal horny spines with lateral spinules	*Hydroides elegans**		(3)
	—Collar setae very short and fine; operculum winged, operculum with three-four basal plates from base of which arise nine moveable spines, inner smooth, outer spined	*Galeolaria caespitosa*		(17)

**Hydroides norvegica* Gunnerus is synonymous with *H. elegans* (Haswell)

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The Vegetation on two Podzols on the Hornsby Plateau, Sydney

ROBIN A. BUCHANAN and G. S. HUMPHREYS

BUCHANAN, R. A., & HUMPHREYS, G. S. The vegetation on two podzols on the Hornsby Plateau, Sydney. *Proc. Linn. Soc. N.S.W.* 104 (1), (1979) 1980:49-71

Podzol soils on the upland sandstone plateaux in the Sydney Basin have received little attention and a characteristic vegetation on these soils has not been reported previously.

Two sites on the Hornsby Plateau are selected for detailed description of the understorey vegetation on these soils and the type of vegetative changes that occur across a podzol/non-podzol soil boundary. The two podzols are in topographically different situations, one on the plateau surface and one in a gully, but like all podzols in the area they occur in sand deposits which are usually present in areas of low slope. The vegetation on the podzols in both cases is similar and typical of that on most podzols of the dissected sandstone plateaux around Sydney.

Ceratopetalum gummiferum, because of its growth form and foliage, is usually the most conspicuous species on the podzols, even where it is not abundant. Other common species are *Banksia serrata, Xanthorrhoea arborea, Xylomelum pyriforme* and to a lesser extent *Gompholobium latifolium* and *Ricinocarpos pinifolius*. Plants growing on podzols usually have a wide habitat range or are species of the upper and middle gully slopes. Species typical of the plateau surface are usually absent or infrequent, even where the podzol immediately adjoins such a community. A combination of physiography (low slope depositional areas) and floristics can be used to locate these soils.

The woodland or open-forest on podzols is usually dominated by the widespread species *Angophora costata* and *Eucalyptus gummifera* and is usually taller than on surrounding soils. *Eucalyptus haemastoma* is extremely rare on podzols.

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INTRODUCTION

A complex mosaic of vegetation is present on the deeply dissected, species-rich sandstone plateaux around Sydney. Because of this deep dissection, the flora can be grouped according to broad topographic situation with species most common on the plateau tops, on the slopes and in the gullies. The distribution of structural forms of the vegetation also follows a general topographic pattern, with variations in both species composition and structure influenced by aspect and climate (Pidgeon, 1937, 1938, 1941; Burrough, Brown and Morris, 1977).

However, many marked variations in the vegetation occur over distances of only a few metres and cannot be interpreted in terms of aspect, climate or macro-topography. Differences, although often minor, in soil properties and microtopography provide the best explanations of these changes. The rapid change in soil characteristics between a podzol and the neighbouring soil is a dramatic example of the sudden floristic change which can accompany a change in soil type.

Podzols in the Sydney region of New South Wales are well-known from the coastal dune sands and Nepean terraces (Burges and Drover, 1953; Walker and Hawkins, 1957; Walker, 1960). The podzols associated with the sandstone plateaux are at a higher topographic level and form a distinct third group, which previously has been given no more than cursory attention (Walker, 1960; Hamilton, 1976; Forster *et al.*, 1977).

An initial field survey on the sandstone plateau of Lambert Peninsula in Ku-ring-gai Chase National Park (Buchanan, 1980) showed that podzol soils occur in areas of quartz sand deposits. These deposits are 1-4 m thick and less than 5 ha in area and have accumulated in places of low slope either near the plateau surface or in gullies. The dark organically-stained upper-surface layer of the sand, 10-20 cm thick, lies on a conspicuously bleached layer, 30-50 cm thick. There is a sharp boundary against the underlying indurated pan. This pan is generally double with a brown 2-5 cm thick organic-stained layer over a 10-20 cm thick iron pan. As with most Australian podzols there is no "mor" horizon.

These podzol soils are associated with vegetation of distinctive floristic and structural characteristics. Well over fifty localities containing podzols on the sandstone plateaux around Sydney were then identified, using low slope areas, floristics and vegetation structure as search criteria. The soil type was confirmed from pits and/or auger holes. Two of these sites on the Hornsby Plateau have been chosen for detailed description of the understorey vegetation on the podzols and the type of vegetative changes that occur across a podzol/non-podzol soil boundary. The vegetation characteristics of these podzols have not been reported previously.

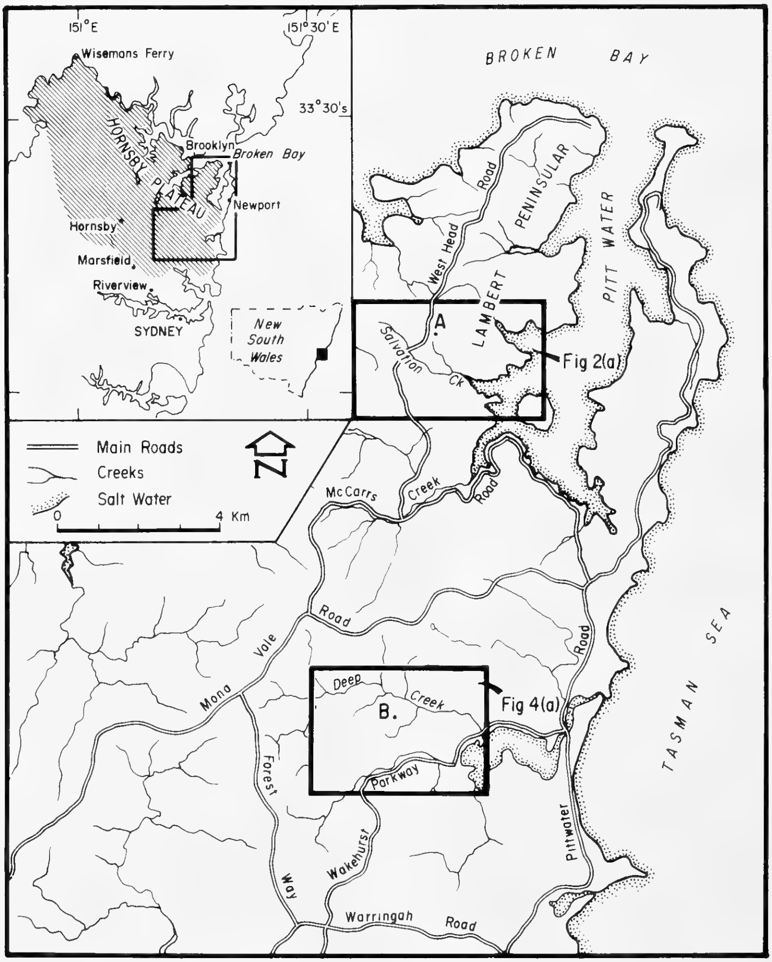


Fig. 1. Locations of the study areas.

SITE DESCRIPTION

The Hornsby Plateau (Fig. 1) is an undulating dissected surface which slopes gently from an elevation of approximately 210 m above Broken Bay in the north to about 120 m in the south about Port Jackson. It consists mostly of the near-horizontally bedded Hawkesbury Sandstone, a sequence of Triassic quartzose sandstones with minor interbedded shale units. It is underlain by rocks of the Narrabeen Group, which outcrop along the north-eastern corner of the Plateau, and is capped in places by remnants of the Wianamatta shale. Meteorological data (Bureau of Meteorology, 1948, 1975) for five stations on or near the Hornsby Plateau are summarized in Table 1.

Site A is in Ku-ring-gai Chase National Park and it is one of twenty-eight podzols in the Lambert Peninsula and McCarrs Creek area. The podzol is in a shallow, basin-shaped catchment. This catchment is located on the plateau surface at 135 m above sea level (a.s.l.) with abrupt rises to 229 m in the north-west and 200 m in the north-east (Figs 1 & 2).

The sand deposit in which the podzol has formed covers approximately 2 ha and is divided by two major creeks (Figs 2b & 3a). The channel of the larger creek has been filled to a depth of about 2 m with layers of iron-rich organic sludge and sand (Fig. 3b). The fill supports a swamp of dense *Gahnia sieberana* and *Empodisma minus* (syn. *Calorophus minor*) with other such species such as *Banksia robur* interspersed.

This sand body is divisible into two units, with the largest section surrounding the northern part of the swamp. This section contains discontinuous podzol development, while the smaller section along the western side of the swamp has a near-continuous, well-developed podzol (Fig. 3a).

TABLE 1

A summary of meteorological data for stations [1] on or near the Hornsby Plateau

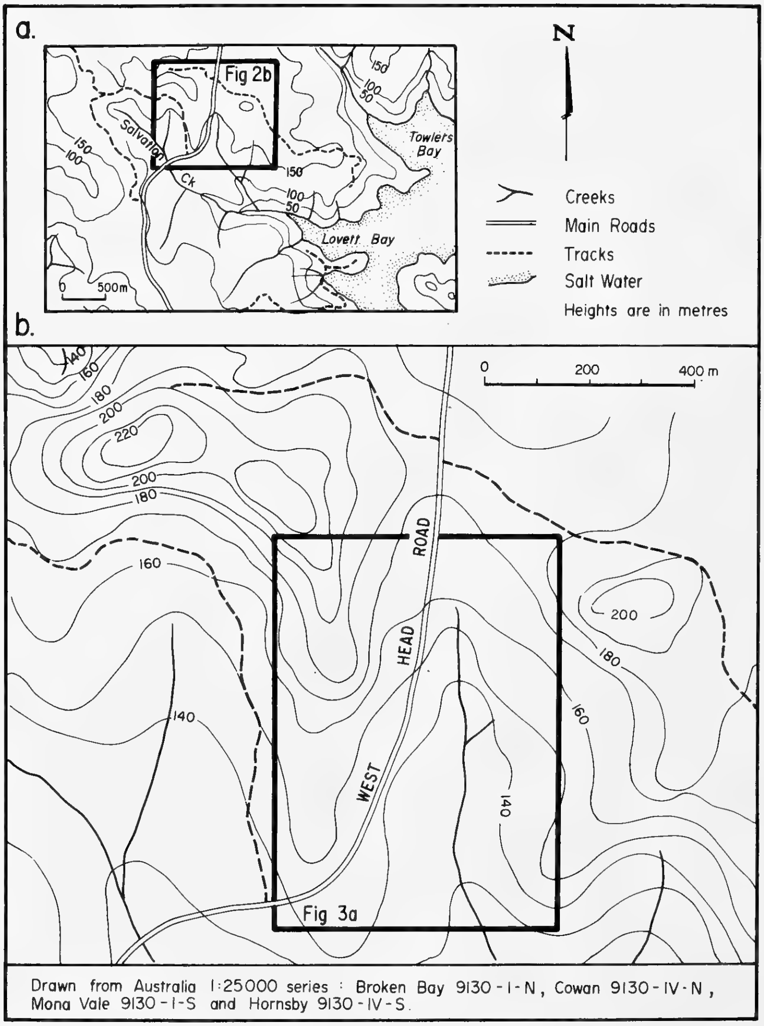
Station	Rainfall (mm) Yearly total of means	Rain days Number Yearly total of means	Daily Max Temp (°C) Yearly Mean	Daily Min Temp (°C) Yearly Mean
Marsfield[2] (33°47′S, 151°7′E) 45.7 m a.s.l.	1178	153	22.4	11.1
Riverview[2] (33°50′S, 151°10′E) 22.9 m a.s.l.	928	120	22.9	12.2
Brooklyn[3] (33°33′S, 151°13′E) 5 m a.s.l.	1279	98	—	—
Hornsby[3] (33°42′S, 151°06′E) 183 m a.s.l.	1237	99	—	—
Newport[3] (33°39′S, 151°19′E) 5 m a.s.l.	1195	113	—	—

1. : The location of these stations is shown on Fig. 1
2. : Bureau of Meteorology (1975)
3. : Bureau of Meteorology (1948)

From the edge of the sand body to the creek there is a steep slope (approximately 10-18°) and in many places along this slope the podzol pan is revealed at the surface. On the sand body proper the slope is gentle and rarely exceeds 4°. The section across the swamp and podzol (Fig. 3b) shows the sand deposit as a crest 4-5 m high between the swamp and an intermittent drainage line. Further north, in the area where the vegetation was sampled, no change in slope occurs at the sharp boundary between the non-podzolized, yellow-brown sands (non-podzol) and the podzol (Figs 3b & 10). A description of these soil types is given in Appendix 1.

The podzol supports a woodland (Specht, 1970) of *Eucalyptus gummifera, Angophora costata* and *E. piperita*, while the non-podzol that surrounds the podzol/swamp complex supports a low woodland to woodland mostly dominated by *Eucalyptus haemastoma, E. oblonga, E. gummifera* and *E. sieberi. Ceratopetalum gummiferum* is a conspicuous understorey species on the podzol.

Site B is located towards the southern margin of the deeply incised Deep Creek



Drawn from Australia 1:25000 series : Broken Bay 9130-I-N, Cowan 9130-IV-N, Mona Vale 9130-I-S and Hornsby 9130-IV-S.

Fig. 2. Site A. (a) an enlargement from Fig. 1. (b) an enlargement of (a).

catchment (Fig. 1). The site (57 m a.s.l.) is within a small basin surrounded by steep, sandstone-benched slopes which rise more than 100 m a.s.l. towards the west. The basin drains eastward into one of the main tributaries of Deep Creek (Fig. 4). A quartz sand deposit up to 4 m deep occurs within the basin and has a general surface slope of 2-3° to the east. The basin is drained by two intermittent streams, of which the more northerly one has trenched into the sand deposit along its northern margin to a depth of 3 m. (Fig. 5).

A podzol is developed in the central thicker portion of the sand body and covers 0.15 ha (Fig. 5a). There is an abrupt boundary between the central podzol and the surrounding non-podzolized, yellow-brown sands (Appendix 1).

The podzol supports a woodland of *Angophora costata, Eucalyptus gummifera* and *E. globoidea*, while the surrounding non-podzol has a low woodland of *E.*

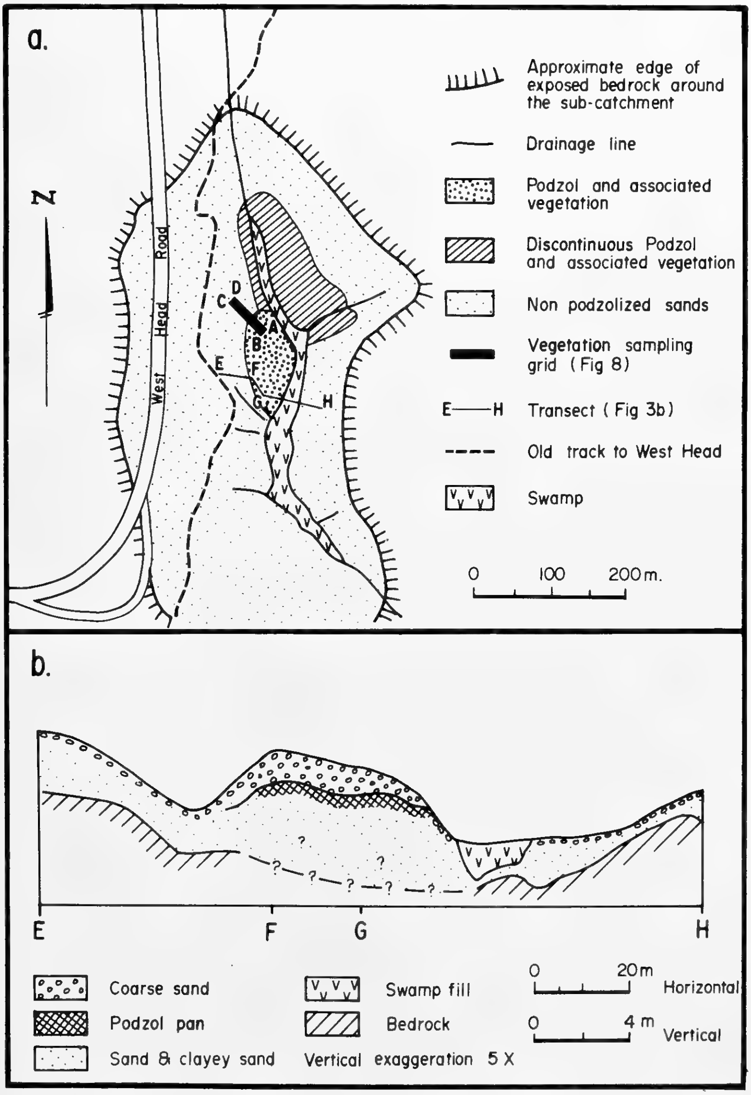


Fig. 3. Site A. (a) an enlargement from Fig. 2. (b) transect across the podzol and its surroundings.

haemastoma, E. gummifera and *E. globoidea. Ceratopetalum gummiferum* is again a conspicuous understorey shrub on the podzol.

METHODS

FIELD METHODS

Soils. The depth of the podzol pan and the lateral extent of the podzol were determined from trenches, auger holes and by probing with a 7 mm diameter steel rod. The pan could be distinctly felt with the rod. At Site B a detailed examination of

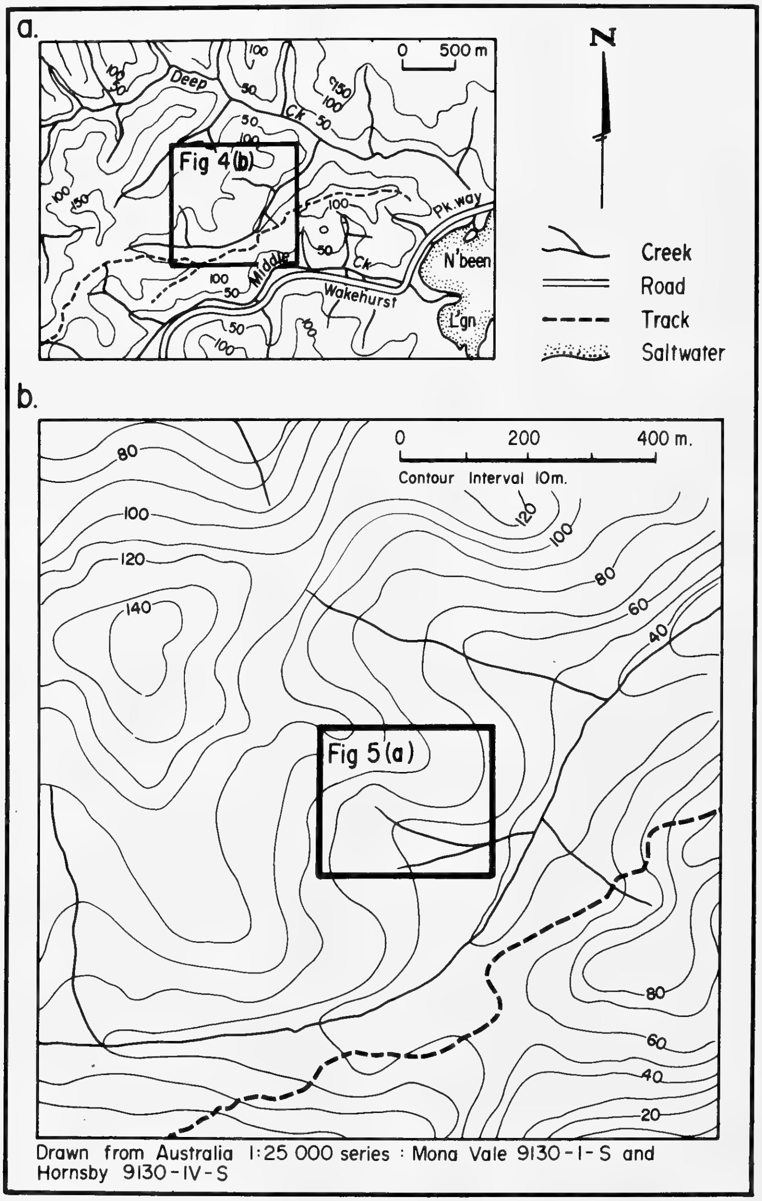


Fig. 4. Site B. (a) an enlargement from Fig. 1. (b) an enlargement of (a).

the soils was carried out and a description of the podzol and non-podzol soils from this site is given in Appendix 1.

Vegetation. Trees were not sampled as they were in insufficient numbers on the well-developed podzol at both sites to give statistically significant results. The shrub layer was sampled using 100 circular quadrats, area 2 m², set out in a rectangular grid with the longer side at right angles to the abrupt soil boundary. Half the grid and thus half the quadrats were on each soil. The distance between the centres of the quadrats was 3 m in the columns arranged parallel to the longer sides and 2 m in the rows parallel to the soil boundary. At Site A the grid consisted of five columns and twenty rows. At Site B it consisted of seven columns and fourteen rows, with an extra quadrat added to the

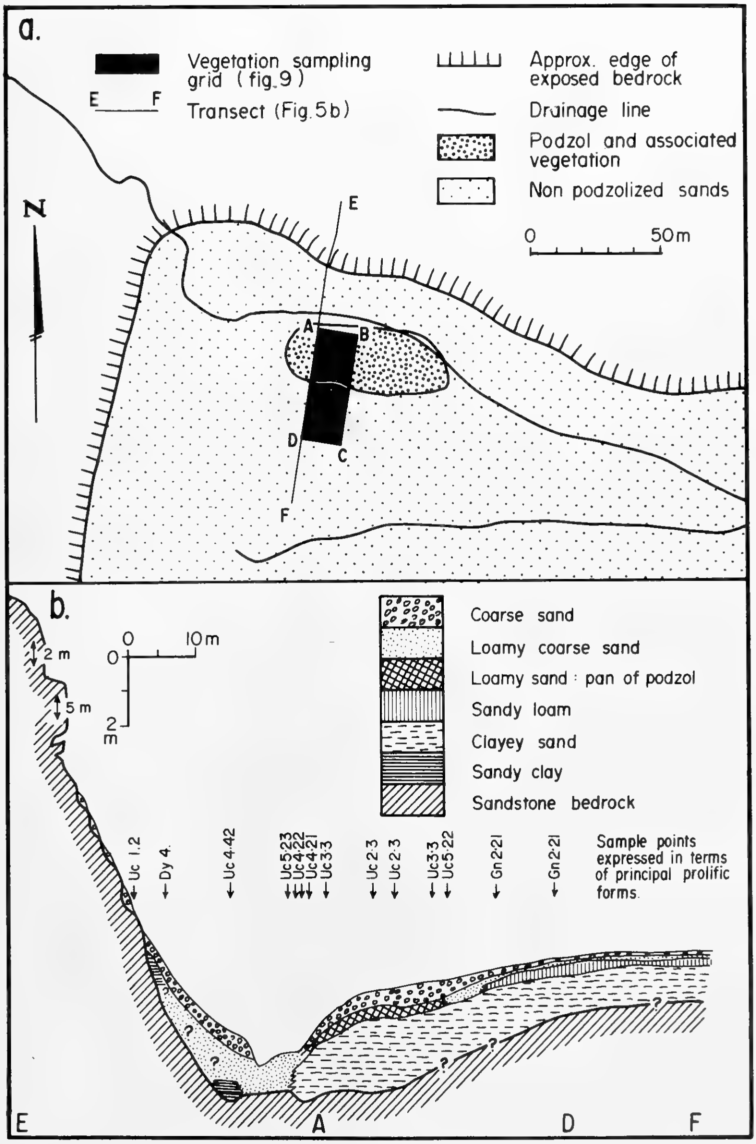


Fig. 5. Site B. (a) an enlargement from Fig. 4 b. (b) transect across the podzol and its surroundings.

podzol and non-podzol to give a total of 100 quadrats. The variation in the grid pattern was dictated by the size and shape of the podzols. Row numbers are shown on Figs 10 & 11.

The small quadrat size was chosen to facilitate sampling of the small understorey species. All dicotyledon and gymnosperm stems rooted in the quadrats and with a diameter of 4-100 mm 20 cm from the ground, were measured to the nearest millimetre. The height of each stem was estimated to the nearest 0.5 m. The monocotyledons *Xanthorrhoea arborea* and *X. media* were only recorded as present at Site A, but at Site B the number of individuals of this genus was recorded also.

TREATMENT OF DATA

In order to reduce some of the minor variation in the data, species occurring in less than 5% of the total number of quadrats at each site were excluded from the relative importance calculations and the association and principal component analyses.

Relative Importance and Exclusiveness. The frequency, density (Kershaw, 1973), average basal area and average height were calculated for each species on each soil at both sites (Tables 2 & 3). The relative importance value (RIV) for each species was obtained by summing the relative density, relative frequency, relative dominance (Kershaw, 1973), and the relative height to give a total out of 400. The relative height was calculated by:

$$\frac{\text{height of sp. on a particular soil}}{\Sigma \text{ height of all spp. on a particular soil}} \times 100$$

The RIV is similar to the "importance value" used by Curtis and McIntosh (1950). Relative height was added to give a better balance between size (dominance and height) and numbers (frequency and density).

The exclusiveness value is defined as:

$$\frac{\text{number of quadrats in which species A occurred on a particular soil}}{\text{number of quadrats in which species A occurred}}$$

and was calculated for the soil on which the species was most frequent. It is a measure of the degree to which a species is restricted to a particular soil in the sampled area. Species with an exclusiveness value of greater than 85% were assigned to the soil where they were most frequent.

All species mentioned are listed in Appendix 2.

Principal Component Analysis. Each quadrat was weighted by RIVs obtained by summing the relative density, relative dominance and the relative height of each species. The resulting RIV data for the spp. within the quadrats were subjected to principal component analysis, using a programme based on the BMDOIM programme of Dixon (1973). The small quadrat size ensured maximum variability (Table 4) and the plot of these results is not included. The quadrats were then grouped into rows parallel to the soil boundary, the RIV, also including relative frequency, was calculated for each species, and the data were then re-analysed (Table 5).

Association Analysis. The normal and inverse association analyses were applied to the data using the DIVINFRE program of the CSIRO Division of Land Research, Canberra (see Williams, 1976, p.94). This is a divisive monothetic analysis based on presence/absence data. The program was terminated at the five group level, as it was more than sufficient to show the difference in the vegetation on the podzol and non-podzol. The inverse analysis added little to the information included in Tables 2 & 3

TABLE 2

Frequency, density, average basal area, average height, relative importance value (RIV) and exclusiveness of species on the podzol (P) and non-podzpol (N-P) at Site A.

Species	Frequency (%)		Density No/100m^2		Av. basal area (cm^2)		Av. height (½ m)		RIV (400)		Exclusiveness	
	P	N-P	P	N-P	P	N-P	P	N-P	P	N-P		
†*Xanthorrhoea arborea*	30	0	—	0	—	0	—	—	—	—	100	Podzol species
**Pimelea linifolia*	4	0	3	0	0.3	0	1	0	—	—	100	
**Angophora costata*	2	0	1	0	26.4	0	5	0	—	—	100	
**Eucalyptus piperita*	2	0	1	0	2.3	0	1.5	0	—	—	100	
Ceratopetalum gummiferum	66	0	184	0	6.0	0	2.5	0	152	0	100	
Gompholobium latifolium	16	0	29	0	0.8	0	2.0	0	14	0	100	
Xylomelum pyriforme	10	0	14	0	3.8	0	0.5	0	9	0	100	
Phyllota phylicoides	42	2	93	3	0.4	0.6	1.0	1.0	35	2	95	
Ricinocarpos pinifolius	42	4	118	2	0.5	0.4	1.0	1.0	42	2	91	
Acacia suaveolens	34	4	25	2	0.8	1.8	2.0	2.0	17	2	89	
A. terminalis	18	2	10	1	1.9	0.9	2.5	2.0	9	1	90	
A. ulicifolia	16	2	13	1	0.8	4.9	1.5	3.0	8	1	99	
Boronia pinnata	22	8	47	9	0.3	0.2	1.0	1.0	18	5	73	Common species
Hibbertia linearis	36	22	23	25	0.4	0.5	1.0	1.0	15	14	62	
Leucopogon ericoides	34	28	61	38	0.3	0.3	1.5	1.0	25	20	55	
Dillwynia retorta	20	20	14	13	0.6	0.5	1.5	1.5	9	10	50	
Platysace linifolia	6	8	3	11	0.1	0.3	0.5	1.0	2	6	57	
Banksia serrata	26	30	31	23	5.0	15.6	1.0	1.5	23	56	54	
†*Xanthorrhoea media*	30	40	—	—	—	—	—	—	—	—	57	
Leptospermum attenuatum	22	50	48	108	0.8	1.8	1.0	1.0	18	68	69	
Lambertia formosa	2	16	5	54	0.9	0.7	1.0	1.0	2	27	89	Non-Podzol species
Petrophile pulchella	2	50	1	61	1.1	1.0	2.0	1.5	1	45	96	
Epacris pulchella	0	40	0	32	0	0.2	0	1.0	0	20	100	
Leucopogon microphyllus	0	32	0	30	0	0.2	0	1.0	0	17	100	
Banksia spinulosa	0	24	0	34	0	1.5	0	1.5	0	25	100	
Grevillea sericea	0	20	0	15	0	1.1	0	1.5	0	12	100	
Pultenaea elliptica	0	18	0	31	0	0.4	0	1.5	0	18	100	
Gompholobium grandiflorum	0	16	0	21	0	0.3	0	1.0	0	11	100	
Epacridaceae sp.	0	12	0	14	0	0.2	0	0.5	0	7	100	
Acacia myrtifolia	0	10	0	9	0	0.4	0	1.0	0	6	100	
Grevillea buxifolia	0	10	0	9	0	2.6	0	2.0	0	9	100	
Eucalyptus gummifera	0	10	0	5	0	18.9	0	2.5	0	15	100	
**Boronia ledifolia*	0	8	0	4	0	0.2	0	1.0	—	—	100	
**Hakea gibbosa*	0	8	0	4	0	1.8	0	2.5	—	—	100	
**H. dactyloides*	0	8	0	24	0	0.7	0	1.5	—	—	100	
**Eucalyptus* sp.	0	8	0	7	0	1.5	0	1.0	—	—	100	
**Leptospermum flavescens*	0	6	0	4	0	1.2	0	1.5	—	—	100	
**Woollsia pungens*	0	6	0	3	0	0.4	0	1.0	—	—	100	
**Lomatia silaifolia*	0	6	0	8	0	0.2	0	0.5	—	—	100	
**Persoonia levis*	0	6	0	5	0	1.1	0	1.0	—	—	100	
**P. lanceolata*	0	4	0	3	0	0.5	0	1.0	—	—	100	
**Banksia aspleniifolia*	0	4	0	3	0	0.5	0	1.0	—	—	100	
**Eucalyptus haemastoma*	0	4	0	2	0	1.0	0	2.0	—	—	100	
**Leptospermum squarrosum*	0	2	0	1	0	2.0	0	1.0	—	—	100	
**Persoonia* sp.	0	2	0	1	0	1.0	0	1.5	—	—	100	
**Bossiaea heterophylla*	0	2	0	1	0	0.1	0	1.0	—	—	100	
‡Overall average					2.2	1.7	1.5	1.0				

†Monocotyledons: not included in RIV calculations

*Species that occurred in less than 5% of all the quadrats: not included in RIV calculations

‡The overall average does not include species marked*

TABLE 3

Frequency, density, average basal area, average height, relative importance value (RIV) and exclusiveness of species on the podzol (P) and non-podzol (N-P) at Site B.

Species	Frequency (%) P	Frequency (%) N-P	Density No/100m² P	Density No/100m² N-P	Av. basal area (cm²) P	Av. basal area (cm²) N-P	Av. height (½ m) P	Av. height (½ m) N-P	RIV (400) P	RIV (400) N-P	Exclusiveness	
†*Xanthorrhoea arborea*	24	0	13	—	—	—	—	—	—	—	100	Podzol species
†*X. media*	16	0	8	0	—	—	—	—	—	—	100	
**Dodonaea triquetra*	8	0	10	0	0.7	0	2.0	0	—	—	100	
**Grevillea linearifolia*	6	0	9	0	1.3	0	2.5	0	—	—	100	
**Xylomelum pyriforme*	6	0	5	0	1.6	0	1.0	0	—	—	100	
Podocarpus spinulosus	42	0	41	0	0.2	0	0.5	0	21	0	100	
Ceratopetalum gummiferum	30	0	35	0	8.0	0	3.5	0	55	0	100	
Gompholobium latifolium	16	0	33	0	0.6	0	2.0	0	24	0	100	
Ricinocarpos pinifolius	10	0	42	0	0.3	0	1.5	0	24	0	100	
**Leucopogon ericoides*	4	2	11	3	0.2	0.2	1.0	1.0	—	—	67	Common species
**Angophora costata*	4	2	2	1	2.5	5.7	3.0	4.0	—	—	67	
Woollsia pungens	22	16	18	10	0.5	0.4	2.0	2.0	14	9	58	
Banksia serrata	16	14	11	12	19.9	7.0	1.5	1.5	30	19	53	
Dillwynia retorta	72	64	145	76	0.9	0.6	2.5	2.5	94	45	53	
Hibbertia sp.	8	8	4	4	0.5	0.5	1.5	1.5	7	4	50	
Eriostemon australasius	18	18	15	11	0.3	0.2	2.5	1.5	16	8	50	
Petrophile pulchella	22	24	14	21	2.1	1.1	3.0	2.5	16	9	52	
Acacia suaveolens	18	20	12	14	0.4	1.0	1.0	2.5	14	12	53	
Grevillea buxifolia	4	6	2	5	4.0	1.0	3.5	2.5	3	5	60	
Eucalyptus gummifera	6	10	6	7	29.1	23.7	5.0	4.0	23	22	63	
E. sp.	2	4	1	2	22.9	9.9	5.0	2.5	—	—	67	
Acacia terminalis	4	8	2	4	9.7	12.1	4.5	4.4	6	16	67	
Leptospermum attenuatum	28	62	22	55	5.8	8.9	3.0	2.5	32	73	69	
Banksia marginata	16	96	11	127	0.8	0.7	2.5	2.0	11	68	86	Non-Podzol species
Phyllota phylicoides	4	28	4	46	0.3	0.4	1.5	1.0	3	23	88	
Banksia ericifolia	2	18	1	13	21.3	8.6	4.0	3.0	4	21	90	
Hakea gibbosa	4	34	3	23	3.8	2.9	3.5	3.0	6	22	89	
Platysace linearifolia	0	20	0	20	0	0.4	0	2.0	0	14	100	
Lambertia formosa	0	12	0	26	0	1.1	0	1.0	0	13	100	
Grevillea sericea	0	12	0	6	0	0.5	0	2.0	0	7	100	
Hakea teretifolia	0	10	0	5	0	2.3	0	3.5	0	8	100	
**Pultenaea* sp.	0	4	0	2	0	0.1	0	2.0	—	—	100	
**Hakea dactyloides*	0	4	0	2	0	2.6	0	2.4	—	—	100	
**Kunzea capitata*	0	2	0	1	0	0.5	0	3.5	—	—	100	
**Leptospermum* sp.	0	2	0	1	0	0.3	0	2.0	—	—	100	
**Conospermum longifolium*	0	2	0	1	0	0.6	0	2.0	—	—	100	
**Pultenaea elliptica*	0	4	0	4	0	0.6	0	2.5	—	—	100	
‡Overall average					2.6	2.3	2.5	2.5				

†Monocotyledons: not included in RIV calculations

*Species that occurred in less than 5% of all the quadrats: not included in RIV calculations

‡The overall average does not include species marked*

and it is not presented in the results. All computations were run on a UNIVAC 1100 computer at Macquarie University.

RESULTS

TABLES 2 AND 3

When species with an exclusiveness value of greater than 85% were assigned to the soil where they were most frequent, three distinct groups which were readily visible in the field resulted: podzol species, species common to both soil types, and non-podzol species. This classification applies only to the sampled areas, as none of the podzol species is restricted regionally to this soil.

The ratio of these three groups (podzol: common: non-podzol) for the full species list at Site A is 1.5: 1: 3.25. Not only is the group of species common to both soils the smallest, but it also contributes only a quarter to the total RIV on the podzol and slightly less than half on the non-podzol. At the more sheltered, moister Site B the podzol group is the smallest, with the common and non-podzol groups the same size (1: 1.5: 1.5). At this site the group of species present on both soils contributes well over half to the RIV total on the podzol and slightly over a half on the non-podzol.

Vegetation on the Podzol. The species locally restricted to the podzol and present at each site are *Ceratopetalum gummiferum, Ricinocarpos pinifolius, Gompholobium latifolium, Xylomelum pyriforme* and *Xanthorrhoea arborea.*

At Site A, *C. gummiferum* is the principal species on the podzol. This single species contributes 70% of the summed values for the basal area, 40% for height, 26% for density and 16% for frequency to give a total score of 152 out of 400. The next two most important plants on this soil, *R. pinifolius* (RIV 42) and *Phyllota phylicoides* (RIV 35), attain a score of less than a third of that for *C. gummiferum.* Although these two podzol species are quite common, their small size makes them a less important and less conspicuous part of the flora.

At Site B there is no clear principal species on the podzol. A species common to both soils, *Dillwynia retorta*, has a score of only 94, with *C. gummiferum* reaching a value of over half this score at 55. Another species common to both soils, *Leptospermum attenuatum*, is the third most important species (RIV 32). The regionally less-common species *Podocarpus spinulosus* is confined to the podzol at Site B where it is the second most frequent species.

C. gummiferum is less important at the more sheltered Site B than at Site A even though it is usually found in moist, sheltered places. At Site B the plants were larger (average height and basal area 3.5 m and 8 cm^2 respectively) than at Site A (average height and basal area 2.5 m and 6 cm^2) but only 35 stems were recorded at Site B compared with 184 stems at Site A. This difference may be caused by a lower fire

TABLE 4

Principal component analysis, in quadrats (100) of vegetation RIV data: table of components and their respective eigenvalues

site	component	eigenvalue	% variance accounted for	cumulative variance %
A	1	2.5169	9	9
	2	1.9165	7	16
	3	1.6483	7	23
	4	1.4765	5	28
	5	1.4134	5	33
	6	1.3181	5	38
	7	1.2825	5	43
	8	1.1935	4	47
B	1	2.2376	10	10
	2	1.6529	7	17
	3	1.5981	7	24
	4	1.5219	6	30
	5	1.4715	7	37
	6	1.3452	6	43
	7	1.1847	5	48
	8	1.1707	5	53

frequency, as plants in fire-prone areas tend to have larger numbers of smaller shoots than plants in less fire-prone areas.

P. phylicoides is the only species that grows on the opposite soil at each site but a few species are confined to one soil at one site and common to both soils at the other.

Vegetation on the Non-podzol. A species common to both soils, *L. attenuatum*, is the most important species on the non-podzol at both sites.

At Site A there is no predominant species on the non-podzol. *L. attenuatum* and another species common to both soils, *Banksia serrata,* are the most important species with RIV totals of 68 and 56 respectively, while the non-podzol species, *Petrophile pulchella*, has a score of 45. There are a large number of infrequent non-podzol species at this site.

At Site B, *L. attenuatum* has a RIV of 73. The next most important species, *Banksia marginata*, is mostly restricted to this soil and has a score of 68, while another species common to both soils, *Dillwynia retorta,* has a RIV of 45. *B. marginata* has a very high frequency (98%) and is therefore a conspicuous species on this soil even though its RIV is not large.

PRINCIPAL COMPONENT ANALYSIS

The first component of the row analysis accounted for over 30% of the variability and with the second component over 40% at both sites (Table 5) with the first component representing the change in soil type.

The Site A analysis shows three groups (Fig. 6), the podzol group and two groups on the non-podzol. The two podzol border rows, nine and ten, are included within the podzol group but the non-podzol border rows, eleven, twelve and thirteen, lie midway between the podzol group and the other non-podzol rows along the first component. In these three rows, species common to both soils are important ingredients and many of the non-podzol species are absent. Within the non-podzol group there is a gradation from rows fourteen to twenty along the second component. This may relate to drainage and slope.

At Site B the podzol group is split into two sub-groups, with the two rows on the steeper slope adjacent to the creek well separated from the other podzol rows along the

TABLE 5

Principal components analysis, in rows, of vegetation RIV data: table of components and their respective eigenvalues

site	component	eigenvalue	% variance accounted for	cumulative variance %
A	1	8.5464	32	32
	2	3.0693	11	43
	3	2.5654	10	53
	4	2.3691	8	61
	5	1.7961	7	68
	6	1.5891	6	74
	7	1.5119	5	79
	8	1.3026	5	84
B	1	7.0695	31	31
	2	3.1869	14	45
	3	2.9750	13	58
	4	2.2209	9	67
	5	1.8840	8	75
	6	1.7358	8	83
	7	1.4994	6	89
	8	0.6869	3	92

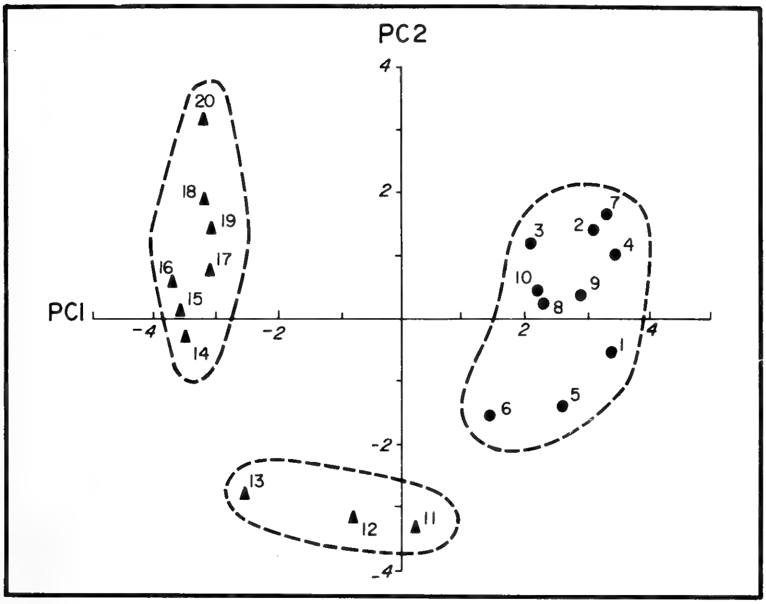


Fig. 6. Site A. Plot of the 1st x 2nd principal component scores of the twenty rows. The location of rows is shown on Fig. 10.
• Podzol row ▲ Non-podzol row.

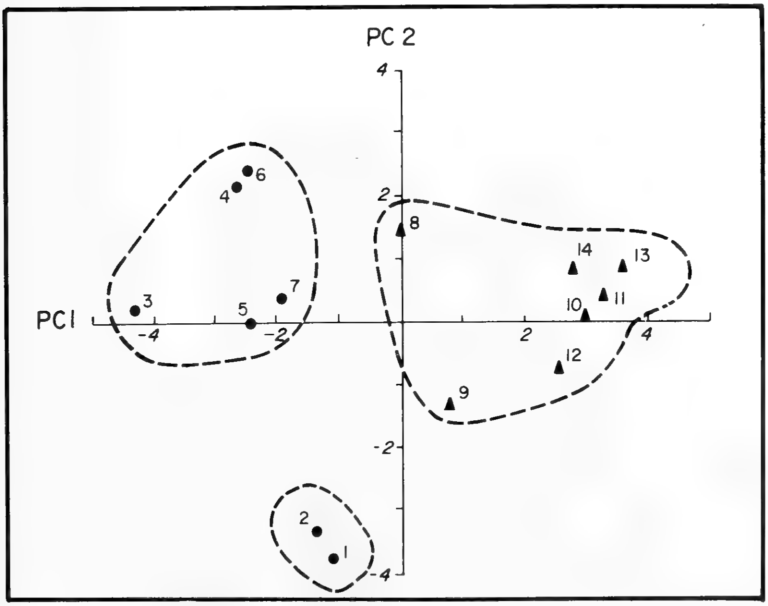


Fig. 7. Site B. Plot of the 1st x 2nd principal component scores of the fourteen rows. The location of rows is shown on Fig. 11.
• Podzol row ▲ Non-podzol row.

second component (Fig. 7). In both rows, two out of the three most important species are common to both soils but these rows contain the only intrusion of a non-podzol species, *Hakea gibbosa*. Podzol species such as *C. gummiferum* and *R. pinifolius* are also present and the mixture of podzol and non-podzol species guaranteed that these two rows would be plotted well away from the main groups.

The podzol border rows, six and seven, are within the main podzol group but the two non-podzol border rows, eight and nine, lie between the podzol and non-podzol groups along the first component. As for Site A, the non-podzol border rows are dominated by species common to both soils, while many non-podzol species are absent. Although the podzol and non-podzol plot out as two distinct groups there is a rough ordering from rows three to fourteen along the first component.

NORMAL ASSOCIATION ANALYSIS

The first two divisions in the normal association analysis at Site A define the podzol vegetation, while at Site B the first division basically divides the vegetation into podzol and non-podzol (Figs 8 & 9).

The community maps (Figs 10 and 11) show that only 6% of the quadrats at Site A and 10% of the quadrats at Site B do not conform to the soil groups. Even this small amount of non-conformity seems to be the result of the highly artificial classification system, as the chance occurrence of one species in a quadrat can dictate its final grouping. When the relative importance values of the species are considered most of

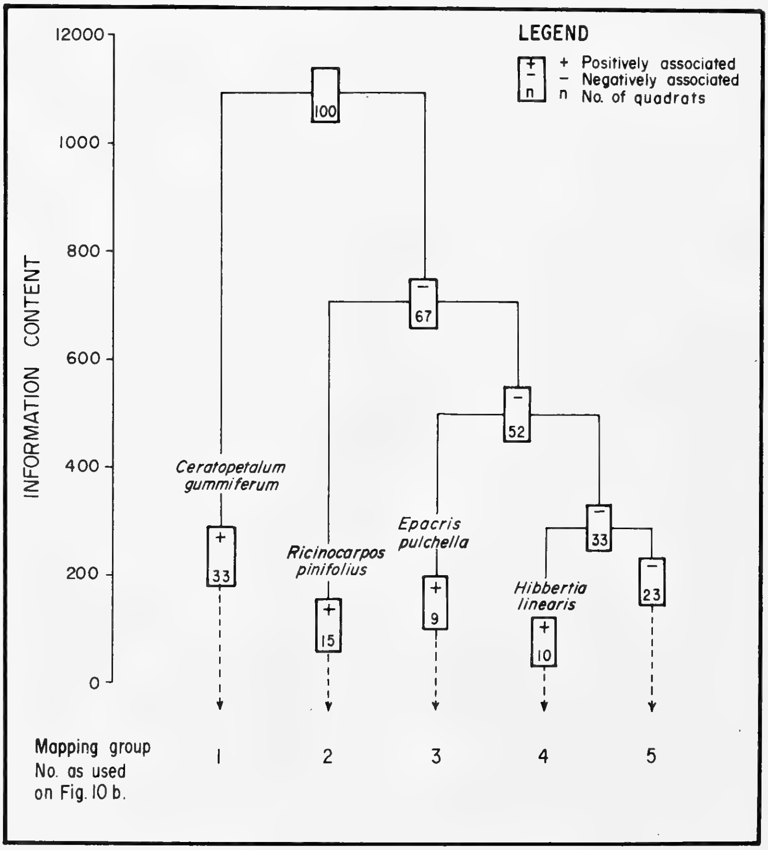


Fig. 8. Site A. Normal association analysis.

these apparent discrepancies disappear. Even the well-defined finger of non-podzol vegetation that intrudes into the podzol on the Site B community map is the intrusion of a single species, *B. marginata*. This species is unimportant in these quadrats.

DISCUSSION

All results, whether those of the exclusiveness calculations, the association analysis or the principal components analysis, showed that there was a difference in the vegetation on the podzol and the non-podzol soils at each site. This difference was less evident at the moister, more sheltered Site B than at the plateau site, Site A. At Site B there were more species common to both podzol and non-podzol soils, and these species were more important than at Site A. The vegetation characteristic of the podzol soil is present to the podzol boundary where it ceases abruptly. At both sites, on the non-podzol soil the vegetation close to the soil junction is dominated by species common to both soils, with many of the non-podzol species being infrequent. Though the two podzol sites differ in topographic terms, the vegetation on both podzols looks remarkably similar. Extensive field reconnaissance within the Sydney Basin has shown that the vegetation on these two sites is typical of most podzols on the sandstone plateaux.

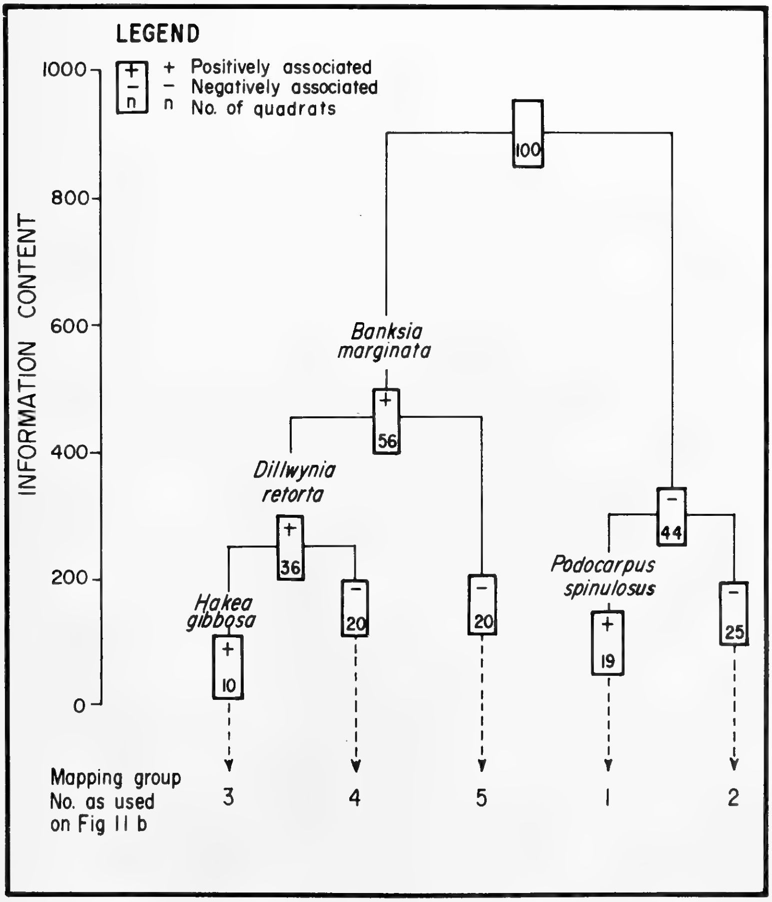


Fig. 9. Site B. Normal association analysis.

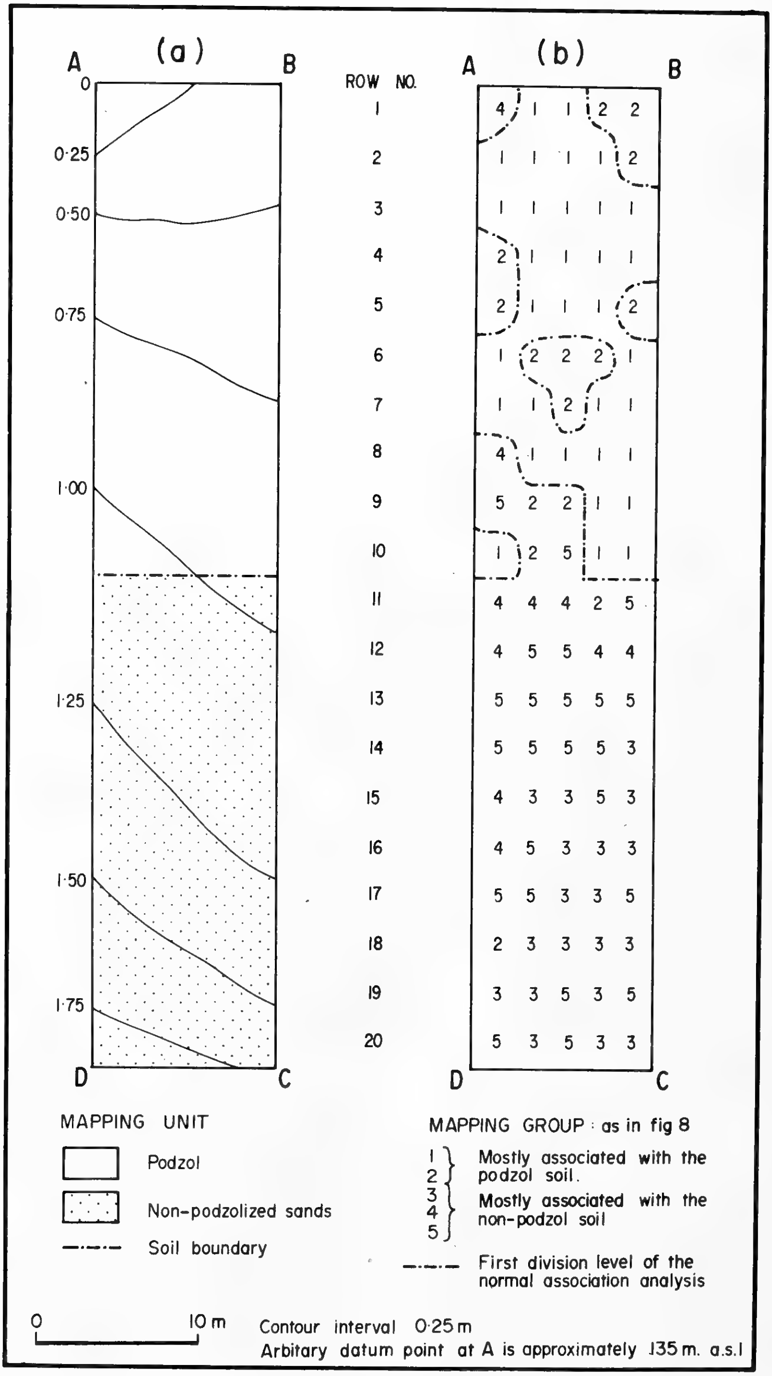
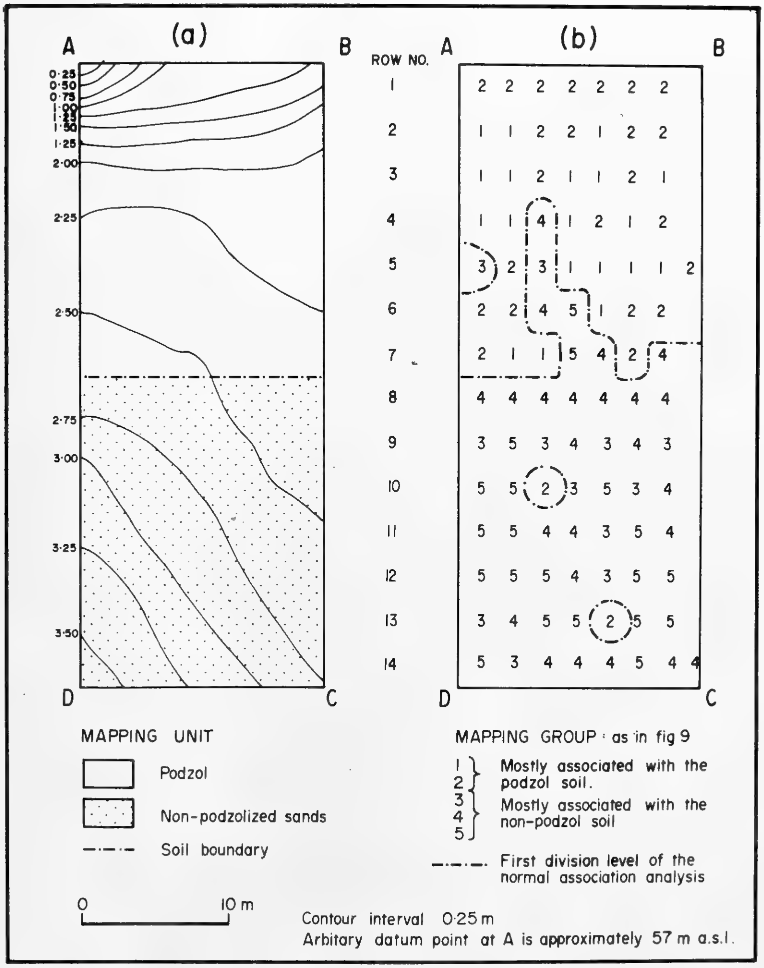


Fig. 10. Site A. (a) Soil and microtopography of the sample grid (Fig. 3a) (b) Vegetation community map.

The podzol vegetation is usually woodland or open-forest and is often taller than the trees on the surrounding soils. The tree species common to both sites, *Angophora costata* and *Eucalyptus gummifera*, are usually important components on sandstone podzols over most of the Sydney region. The third species, although frequently *Eucalyptus piperita*, is less constant. The understorey species restricted to the two podzols, *Ceratopetalum gummiferum, Xylomelum pyriforme, Xanthorrhoea arborea* and to a lesser extent *Ricinocarpos pinifolius* and *Gompholobium latifolium*, are typical podzol species. *Banksia serrata* is often an obvious species on podzols and was present at both sites. Other species may be locally important.

The important species on these podzols are usually plants with a wide habitat range, or are those which occur on the upper and middle gully slopes. *C. gummiferum* thrives in the damper gullies (Rotherham *et al.*, 1975) but it is also found in three situations on and near the plateaux surface. The first is the rocky positions, either along creeks incised a few metres below the immediate plateau surroundings, or on the sheltered sides of rock outcrops. The second situation is the deep sand bodies, most of which have podzol soils, where rock outcrops are noticeably absent. Thirdly, *C.*



ROW NO.								
1	2	2	2	2	2	2	2	
2	1	1	2	2	1	2	2	
3	1	1	2	1	1	2	1	
4	1	1	4	1	2	1	2	
5	3	2	3	1	1	1	1	2
6	2	2	4	5	1	2	2	
7	2	1	1	5	4	2	4	
8	4	4	4	4	4	4	4	
9	3	5	3	4	3	4	3	
10	5	5	2	3	5	3	4	
11	5	5	4	4	3	5	4	
12	5	5	5	4	3	5	5	
13	3	4	5	5	2	5	5	
14	5	3	4	4	4	5	4	4

Fig. 11. Site B. (a) Soil and microtopography of the sample grid (Fig. 5a) (b) Vegetation community map.

gummiferum is sometimes found on more clayey soils, either derived from occasional intercalations of shale, or associated with the boundary between Hawkesbury Sandstone and the overlying Wianamatta shale, such as along Mona Vale Road between the junctions with Forest Way and McCarrs Creek Road (Fig. 1).

On the Hornsby Plateau *X. arborea* and *G. latifolium* are most frequent on upper and middle slopes, while the very common *B. serrata* has a wide habitat range, as do the less common *X. pyriforme* and *R. pinifolius*. Other common species on podzols include the habitat-tolerant *Leptospermum attenuatum* and *Dillwynia retorta* and the slope species *Smilax glyciphylla* and *Platylobium formosum*.

This assemblage of species may also occasionally be found on sand deposits some of which may have a considerable clay component but no development of a podzol profile. In general, however, a combination of topographic situation (low slope) and floristics may be used to locate podzols.

Grevillea species have rarely been recorded on the main body of a podzol. The absence of this genus is one of the most unexpected features, as twenty species with a wide range of habitats occur in the Sydney region (Beadle, Evans and Carolin, 1972). One of these species, *Grevillea linearifolia*, is a very common plant of the gully slopes on the Hornsby Plateau. In this situation it frequently grows with *C. gummiferum*. No *Grevillea* species were recorded on the podzol at Site A, although two species grew on the adjacent soil. At the Site B podzol, *G. linearifolia* and *G. buxifolia* grew only on the steeper slope adjacent to the creek.

Many species common in the heaths and low woodland on the plateau are infrequent on podzols, even though the podzols may immediately adjoin such communities. The very common plateau tree, *Eucalyptus haemastoma*, has rarely been recorded, while shrub species uncommon on the podzol include *Banksia aspleniifolia, Gompholobium grandiflorum, Angophora hispida* and the *Grevillea* species.

Because the podzol vegetation has greatest affinity with the gully slope vegetation and very little with the plateau vegetation, podzols on the plateau are easier to locate than those in the gullies. In plateau areas the extent of the podzol can be roughly mapped by the distribution of the easily observed *C. gummiferum* which is usually the most conspicuous species on these podzols even where it is not common. It is a tall slender plant (average heights of 2.5 m and 3.5 m at Site A and Site B) and stems up to 4 m tall are present on both podzols. On the podzols, *C. gummiferum* is usually multi-stemmed and the dense, light green leaves are often present from near ground level. This tall dense mass contrasts sharply with the sparser, grey-green xeromorphic foliage of most species. Although the average height of vegetation on the podzol and non-podzol at each site was similar (1.5 m and 1.0 m at Site A and 2.5 m at Site B; Tables 2 and 3), the presence of this tall dense mass of *C. gummiferum* foliage usually makes the vegetation on the podzols appear taller than the surrounding vegetation.

On the podzols *R. pinifolius* and *G. latifolium* are fairly inconspicuous, thin-stemmed shrubs rarely more than 2 m tall. *B. serrata* may be a small tree up to 4-5 m tall but the average height of this thick-stemmed species was only 1-1.5 m. *X. arborea* is a fairly obvious member, as individuals with stems up to 2 m tall are often present. *Xylomelum pyriforme* is usually present but is always uncommon.

The podzol vegetation is a fairly stable unit, as all of the six indicator species regenerate from parent plants after fire. *C. gummiferum* often has a clumped distribution as it usually possesses a well-developed lignotuber, especially in fire-prone areas such as the plateau surface. The lignotuber of one plant may be almost as large as the 2 m^2 quadrat used. Small *B. serrata* and *X. pyriforme* regenerate from lignotubers, but larger plants usually regenerate from epicormic buds on the main stem. *R. pinifolius* and perhaps *G. latifolium* regenerate from underground perennating buds and are clumped on a much smaller scale than *C. gummiferum*. *X. arborea* continues growing from its apical meristem and all the trees regenerate from lignotubers or epicormic buds after fire.

This paper unlike that of Enright (1978) does not deal with important general issues such as the genesis of podzol soils, the origin of the characteristic vegetation or the interaction between vegetation and soils. Nevertheless we would like to consider briefly two possible causes of the different vegetation between podzols and non-podzol soils. The different distribution of plants on soils with essential chemical differences is well documented. Thus in the field situation dealt with by Enright (1978) both calcareous and non-calcareous parent materials occurred, with podzols, and hence podzol vegetation, best developed on the non-calcareous aeolian sands. Such a dramatic difference in soil chemistry is not likely at Sites A and B as the acidic parent material of the podzol and non-podzol is all derived from the Hawkesbury Sandstone. However, at Sites A and B there is a difference in soil drainage characteristics between the podzol and the non-podzol. The podzol has a well-aerated and well-drained layer overlying a less pervious pan that may also act as a perched water table. In comparison, the non-podzol is a less well drained soil. This contrast may explain some of the differences in the vegetation between the podzol and the non-podzol.

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APPENDIX I

The soils were mapped as layers and described in terms of field texture, matrix fabric, planar void development, consistency (as defined in Paton, 1978), Munsell colours, pH and nature of the boundaries (as defined in Northcote, 1974). Two "Type Profiles" (Paton, 1978), one of a podzol and the other of a non-podzol, are described from the vegetation sample area at Site B. These soils were also classified into "Great Soil Groups" (Stace *et al.*, 1968) and "Principal Profile Forms" (Northcote, 1974).

There is a sharp boundary of less than 2 m between these two soil types and the intravariation is small.

Type Profile:	Podzol
Great Soil Group:	Podzol
Principal Profile Form:	Uc 2.3, approx. Uc 2.36
Location:	Site B; centre of the podzol half of the sampling grid (Figs. 5 & 11).
Parent Material:	One to 2 m of sand deposits with some cobbles overlying 2 m of *in situ?* altered sandstone.
Vegetation:	Shrubs of *Ceratopetalum gummiferum, Dillwynia retorta, Xanthorrhoea media* and a nearby dead stump of *Eucalyptus gummifera?* and other typical podzol vegetation.
Description:	
2-0 cm (leaf litter)	Leaf litter of the above-mentioned species, especially *Ceratopetalum gummiferum* and *Xanthorrhoea media*; white fungi hyphae connecting many leaves; sharp even to:
0-21 cm pH 5.0-5.5	Organic-rich coarse sand (silky feel); 2.5Y2/1 (dry and moist); single grain sand with minor coherence from the dense root mat; no planar voids; apedal and fragile consistency; abundant charcoal; earthworms in the upper 10 cm, white Scarabaeidae grub in the lower, diffuse wavy to:
21-64 cm (bleached layer) pH 6.0-6.5	Coarse sand; 10YR7/1 (dry), 6/2 (moist); incoherent single grain sand; no planar voids; apedal and very fragile consistency; roots are sparsely distributed and are mainly confined to the upper 15 cm; small patches of fungi hyphae linking individual sand grains in lower 10-20 cm; sharp wavy to:
64-70 cm (organic pan)	Coarse loamy sand; 10YR3/4 (dry), 4/3 (moist); mottled with 10YR2/3 (dry and moist); matrix fabric, weakly coherent, non-uniform and highly porous; planar voids are absent; consistency, apedal and brittle when dry; small patches of fungi hyphae binding individual grains; within and beneath a decaying root (5-7 cm diameter) it is 10YR2/3; sharp irregular to:

70-89 cm (iron pan) pH 6.0	Coarse loamy sand; 10YR 4/4 (dry), 3/4 (moist) with mottles of 10YR 5/6 (dry), 4/6 (moist); matrix fabric, moderately coherent, non-uniform and very porous; no planar voids; consistency, apedal and brittle when dry. Interspersed are mottles of 7.5 YR 5/8 (dry & moist); matrix fabric, very coherent non-uniform and porous with no planar voids in the upper part of the layer but it is very nodular in the lower half; consistency, brittle and very indurated when dry requiring considerable pressure to disrupt. Charcoal throughout often centering the very indurated material; earthworms and termites present:
89-100 cm pH 5.5	Coarse clayey sand; 10YR 5/8 (dry & moist); matrix fabric, moderately coherent, non-uniform; no planar voids; consistency, slightly plastic; some charcoal and few roots.
Type Profile:	Depositional Earth
Great Soil Group:	Earthy Sand
Principal Profile Form:	Gn 2.21 to Um 5.22
Location:	Site B, near centre of the non-podzol half of the sampling grid (Figs 5 & 11).
Parent Material:	Approximately 0.5 m of sand deposits overlying more than 1 m of *in situ?* altered bedrock.
Vegetation:	Small tree of *Persoonia levis* and shrubs of *Banksia marginata, Dillwynia retorta, Leptospermum attenuatum* and *Platysace linearifolia*, and other typical non-podzol vegetation.
Description:	
1.0 to 0 cm	Thin litter layer, mainly of leaves from *Persoonia levis;* sharp even to:
0-8 cm pH 5.0	Coarse sand; 2.5Y 4/2 (dry), 5/2 (moist); highly porous, sand-dominated, non-uniform, fragile matrix fabric, with added but weak coherency due to the organic matter; no planar voids; consistency apedal and very brittle; roots throughout; plenty of coarse charcoal; grub (Scarabaeidae) present; clear, even to:
21-50 cm pH 5.0	Medium sandy loam; 10YR 5/5 (dry and moist); porous, sand-dominated, non-uniform and coherent matrix fabric with indurated nodules 10YR 4/6 (dry and moist) of weakly porous to dense, sand-dominated, non-uniform and very coherent matrix fabric; no planar voids; consistency apedal and brittle; fine charcoal; some white quartz pebbles one to 1.5 cm diameter; few large roots; gradual even to:
50-180 cm pH 5.5-6.0	Clayey sand 10YR 5/8 (dry and moist); moderately porous clay-dominated, non-uniform and coherent matrix fabric; no planar voids; slightly subplastic consistency; occasional white quartz pebble one to 1.5 cm diameter. In lower 1 m (augered) mottled streaks of 7.5 YR 5/8 dry and moist occur.

APPENDIX II

Species mentioned in paper

GYMOSPERMAE
  Podocarpaceae:
    Podocarpus spinulosus (Sm.) R. Br. ex Mirb.
ANGIOSPERMAE
Dicotyledones
  Proteaceae:
    Banksia aspleniifolia Salisb.
    B. ericifolia L.f.
    B. marginata Cav.
    B. robur Cav.
    B. serrata L.f.
    B. spinulosa Sm.
    Conospermum longifolium Sm. ssp. *longifolium*

Grevillea buxifolia (Sm.) R. Br.
G. linearifolia (Cav.) Druce
G. sericea (Sm.) R. Br.
Hakea dactyloides (Gaertn.) Cav.
H. gibbosa Cav.
H. teretifolia (Salisb.) J. Britt.
Lambertia formosa Sm.
Lomatia silaifolia (Sm.) R. Br.
Persoonia lanceolata Andr.
P. levis (Cav.) Domin
P. Unnamed
Petrophile pulchella (Salisb.) Knight
Xylomelum pyriforme Sm.

Dilleniaceae:
Hibbertia linearis DC. var. *obtusifolia*
H. sp.

Euphorbiaceae:
Ricinocarpos pinifolius Desf.

Cunoniaceae:
Ceratopetalum gummiferum Sm.

Mimosaceae:
Acacia terminalis (Salisb.) MacBride
A. myrtifolia (Sm.) Willd.
A. suaveolens (Sm.) Willd.
A. ulicifolia (Salisb.) Court

Papilionaceae:
Bossiaea heterophylla Vent.
Dillwynia retorta (Wendl.) Druce var. *retorta*
Gompholobium grandiflorum Sm.
G. latifolium Sm.
Phyllota phylicoides (Sieb. ex DC.) Benth.
Platylobium formosum Sm.
Pultenaea elliptica Sm.
P. stipularis Sm.

Myrtaceae:
Angophora hispida (Sm.) Blaxell
A. costata (Gaertn.) Druce
Eucalyptus globoidea Blakely
E. gummifera (Gaertn.) Hochr.
E. haemastoma Sm.
E. oblonga DC
E. piperita Sm. ssp. *piperita*
E. sieberi L. Johnson
E. sp.
Kunzea capitata Reichb.
Leptospermum attenuatum Sm.
L. flavescens Sm.
L. squarrosum Sol. ex Gaertn.

Rutaceae:
Eriostemon australasius Pers.
Boronia ledifolia (Vent.) J. Gay
B. pinnata Sm.

Sapindaceae:
Dodonaea triquetra Wendl.

Umbelliferae:
Platysace linearifolia (Cav.) C. Norman

Epacridaceae:
Epacris pulchella Cav.
Epacridaceae sp.
Leucopogon ericoides (Sm.) R. Br.
L. microphyllus R. Br.
Woollsia pungens (Cav.) F. Muell.

Monocotyledones
  Xanthorrhoeaceae:
    Xanthorrhoea arborea R. Br.
    X. media R. Br. ssp *media*
  Cyperaceae:
    Gahnia sieberana Kunth
  Restionaceae:
    Empodisma minus (Hook.f) Johnson & Cutler syn. *Calorophus minor* Hook.f

The species names are those currently used by the Royal Botanic Gardens of N.S.W. (1978).

The Lambert Peninsula, Ku-ring-gai Chase National Park. Physiography and the Distribution of Podzols, Shrublands and Swamps, with Details of the Swamp Vegetation and Sediments

ROBIN A. BUCHANAN

BUCHANAN, R. A. The Lambert Peninsula, Ku-ring-gai Chase National Park. Physiography and the distribution of podzols, shrublands and swamps, with details of the swamp vegetation and sediments. *Proc. Linn. Soc. N.S.W.* 104 (1), (1979) 1980:73-94.

The Lambert Peninsula is asymmetric, with deeply-dissected V-shaped valleys on the western side and on the eastern side extensive areas with low slope (less than 5°). Podzols, shrublands and swamps on the peninsula have been mapped using aerial photographs and ground confirmation. All podzol soils, the majority of swamps and most of the shrublands occur on areas of low slope. Areas of low slope underlain by clayey sandstone (puggy material) and extensive sandstone benches lead to poorly-drained soils and development of moist shrublands. In even less well-drained conditions swamps form, both on valley floors and valley sides. The vegetation of the swamps is divided into four types using the characteristic height and abundance of some of the larger conspicuous species. The anomalous distribution of two of the swamp species, *Banksia robur* and *Gymnoschoenus sphaerocephalus*, on the peninsula is mapped. The iron/organic-rich sediments which have accumulated in swamps to depths varying between a few centimetres and 2 metres are described. The influence of climatic fluctuations on the extent of moist shrublands and swamps is discussed.

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INTRODUCTION

The Lambert Peninsula in Ku-ring-gai Chase National Park, on the northern edge of Sydney (Fig. 1), is an area of great beauty and botanical interest. The scenic attraction of the West Head Lookout at Broken Bay, the numerous walking trails, and the proximity to Sydney create intense pressure on the area. Yet knowledge of the biology of the area is minimal and no detailed vegetation maps or physiographic studies hitherto have been available for the area.

This paper is a first attempt to describe the general physiography of the Peninsula and to map the distribution of shrublands, of swamps, and of plant communities growing on podzolized sand accumulations on the plateau surface. An attempt is made to relate the swamps, the shrublands and the podzol communities to the physiography and geology of the peninsula. Only passing comment is made on the woodlands and forests of the area, and the vegetation on the dykes and on the Triassic Narrabeen Group is not mentioned. This group is only revealed near sea level whereas the gentle undulating plateau surface, broken by steep gullies, has been produced by weathering and erosion of the overlying Hawkesbury Sandstone.

The depositional environment of the Hawkesbury Sandstone is still under debate (Ashley and Duncan, 1977). The sedimentation units are near horizontal on a regional scale, but are commonly cross-bedded. It is an argillaceous iron-rich quartz sandstone, with the grain size commonly medium to coarse (Standard, 1969). The soils have a sandy top soil often overlying a more clayey sub-soil (Gradational Gn, or duplex Dy soils; Northcote, 1971) but in two regional surveys (Walker, 1960; Hamilton, 1976) the soils of this sandstone have been mapped as uniform sandy soils. Shale is infrequent in the Hawkesbury Sandstone sequence but on the eastern surface of the Lambert Peninsula a clayey material is quite widespread. The texture can vary from a clayey sand to clay over short (approximately 1 m) distances, both laterally and vertically, and subsurface layers of these beds are usually weathered to a pliable

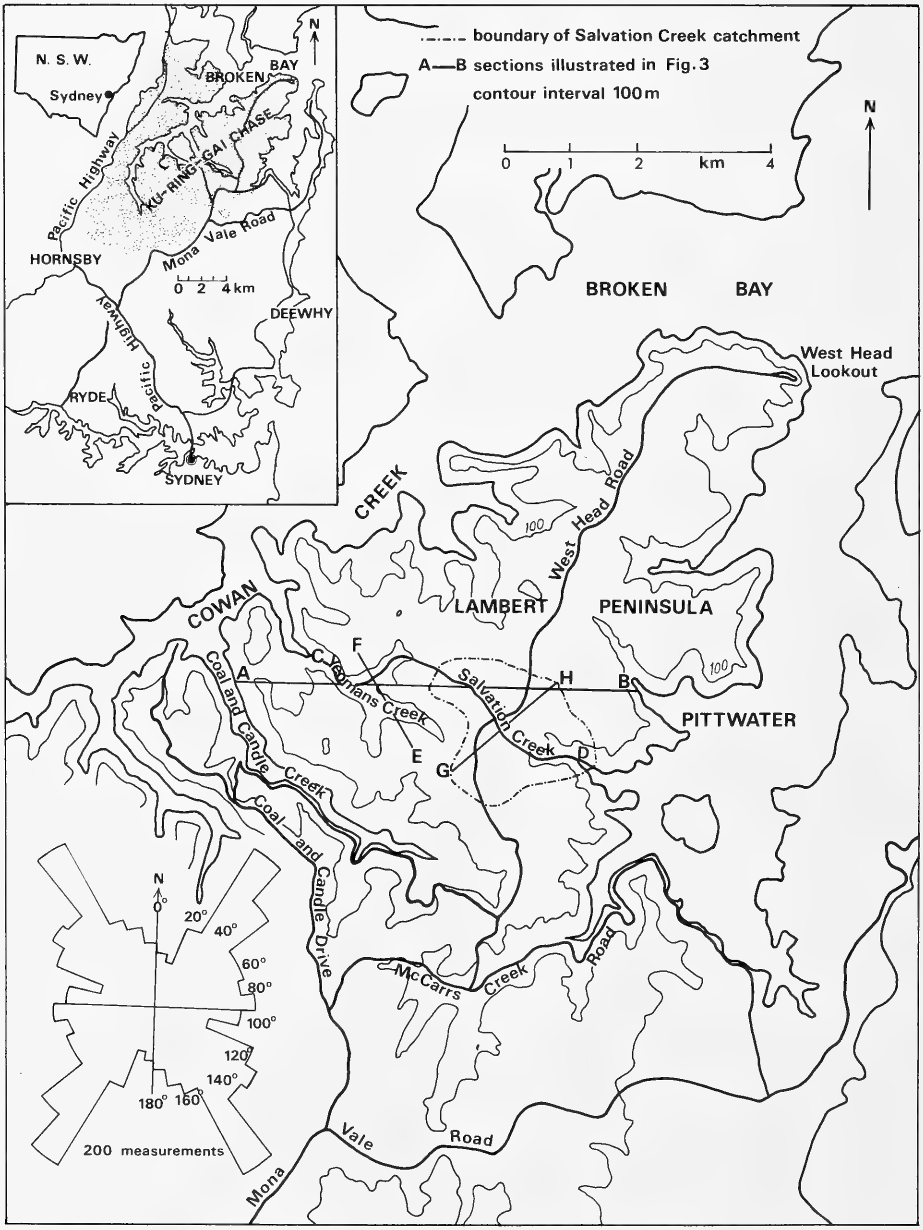

Fig. 1. Location map of the study area and a joint rose from the Salvation Creek catchment.

consistency. It is usually moist; the colour is whitish grey or, in places, mottled red to yellow. It will be referred to as puggy material.

Shale beds in the Hawkesbury Sandstone impede drainage and aid the development of swamps (Davis, 1936; Hannon, 1956; Lamy and Junor, 1965; Holland, 1974). Comparatively level areas and extensive sandstone layers can also cause deficient drainage (Pidgeon, 1938; Lamy and Junor, 1965). The term 'swamp' has long been applied to the wet areas around Sydney (for example by Hamilton, 1915) but more recently in Specht, Roe and Boughton (1974) the term 'fen' has been applied to areas dominated by *Gymnoschoenus sphaerocephalus* in Ku-ring-gai Chase. The traditional word 'swamp' is used here to describe the diverse wetlands on the peninsula.

Holland (1974) divided the swamps of the Blue Mountains (approximately 70 km west of Sydney) into two topographic types, valley-floor and valley-side, but did not name the swamps with both components. Sufficient examples of this type occur on Lambert Peninsula to warrant classifying these as a third group — composite swamps.

Pidgeon (1938) classified the swamps of the Hornsby Plateau, an area which includes Lambert Peninsula, into two vegetative types. One category was the shrub swamps, which are either classified with the driest swamp type or, more generally, grouped with moist shrubland in this paper. Pidgeon (1938) called the second type sedge swamps, and from the species list and description provided, this type covers a wide range of soil moisture. The dominant species listed typify the drier swamps on the peninsula and the large areas (up to approximately 3 ha for a single swamp) of the wetter types on the peninsula only receive a very brief mention as occurring in soaks and drainage channels. The swamps between McCarrs Creek and West Head, which were grouped as sedge swamps by Pidgeon (1938), are subdivided and described as four different swamp types.

METHODS

Aerial photographs (at a scale approx. 1:14 000) were used to locate and map shrublands, swamps and podzols and for measurement of joint orientations. The ease with which features such as vegetation boundaries and joints in rock outcrops can be seen on these photographs varies with the time since a fire. As the vegetation regrows after a fire, the early stages are insufficient to define features, and at later stages dense regrowth may obscure some detail. Aerial photographic interpretation on Lambert Peninsula is easiest approximately ten years after a fire. Identification of features was confirmed by field examination.

The base maps for Figs 1, 4 & 5 were adapted from 1:63 360 Broken Bay sheet and 1:100 000 Sydney sheet 9130. Fig. 2 was compiled from aerial photographs (Cumberland 1970) and N.S.W. 1:25 000 ortho-photomaps Broken Bay, Hornsby, Cowan and Mona Vale. Sections across the peninsula (Fig. 3) were derived from the N.S.W. Department of Lands map, Ku-ring-gai Chase 1:25 000.

All swamp profiles were measured using an Abney Level. After initial samples of subsurface layers were obtained using a two inch auger, a length of steel re-inforcing rod pushed into the ground was generally sufficient to locate sand, puggy material, swamp fill layers and the podzol pan between successive auger holes.

Botanical names are those used in Beadle, Evans and Carolin (1972) except for some recent name changes.

THE SHAPE OF THE PENINSULA

The directions of the western and eastern boundaries of the peninsula, Cowan Creek and Pittwater, and the southern boundary, Coal and Candle Creek (Fig. 1) are

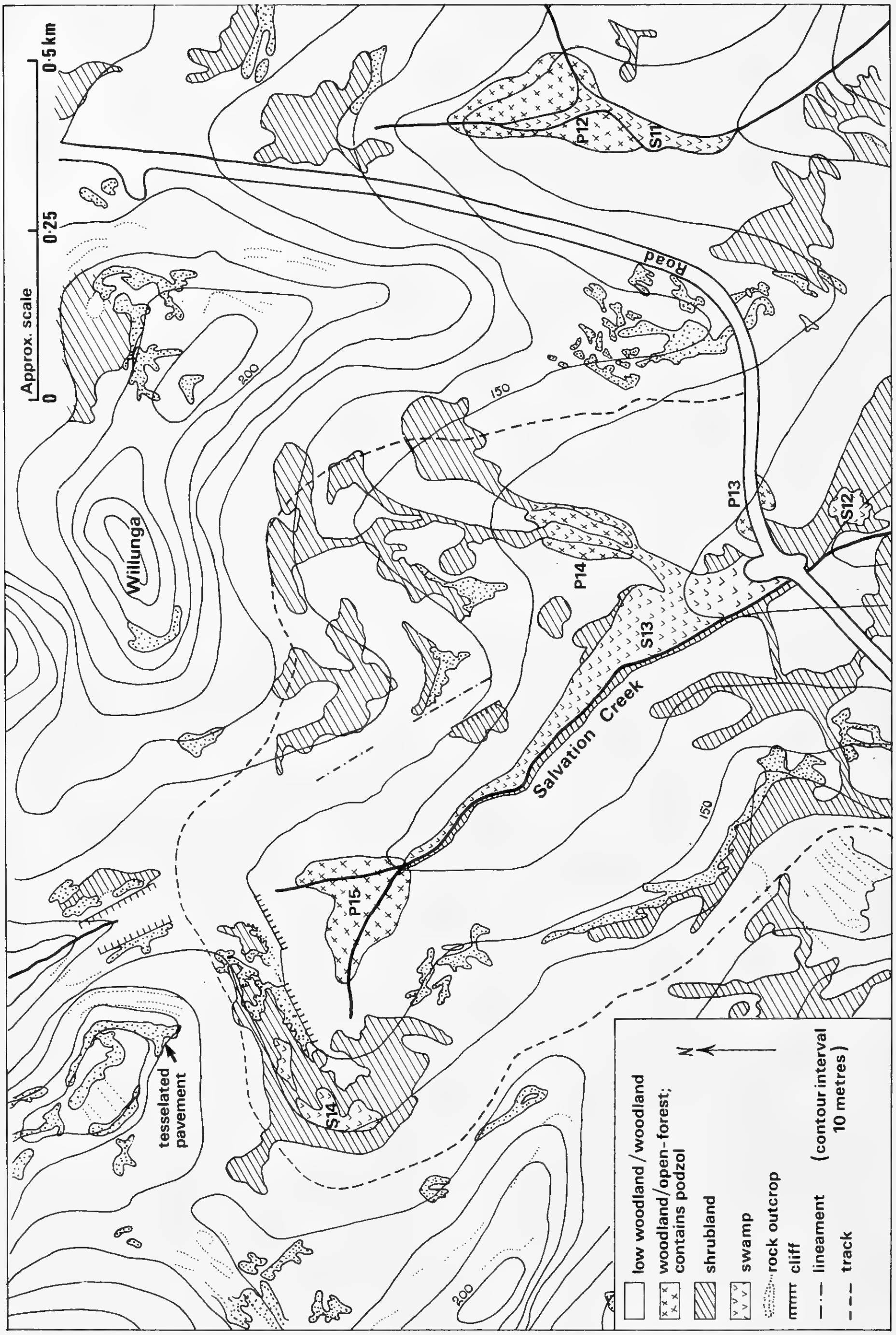

Fig. 2. Map of the upper Salvation Creek catchment.

probably controlled by NE-SW and NW-SE joints respectively, since these boundaries correspond to regional joint orientations (Mabbutt, 1970). Joint-control of cliffs, creeks and swamps, and vegetation boundaries is obvious throughout the peninsula and can be observed in the field and on aerial photographs. The joint rose in Fig. 1 is compiled from measurements made from aerial photographs of the Salvation Creek catchment. Joint measurements from ground survey in this catchment also show predominant NE-SW and NW-SE directions, and many features in the upper Salvation Creek area follow these orientations (Fig. 2). For example, Salvation Creek and the creek draining Swamp 11 both drain SE. The cliffs defining a trench-like valley north of Podzol 15 are orientated NW-SE and are approximately in line with a cliff and a lineament (revealed as a joint and a gap in the tree canopy along different parts of its length) in the Salvation Creek Catchment. The NE-SW orientation is less frequently exploited but one example is the cliffs near Swamp 14.

The peninsula is asymmetric about the divide running approximately N-S (Fig. 4). West of the divide it is deeply dissected by V-shaped valleys but on the eastern side, shallow basin-shaped valleys are present (Fig. 3, section A-B). For example, (Fig. 3, section C-D), the westerly flowing Yeomans Creek has deeply eroded headwaters, a middle course with a gentle slope, followed by a short steep fall to Cowan Creek. The headwaters and middle section of Salvation Creek cross a gentle easterly sloping surface, beyond which the creek falls steeply to Pittwater. Cross sections halfway along

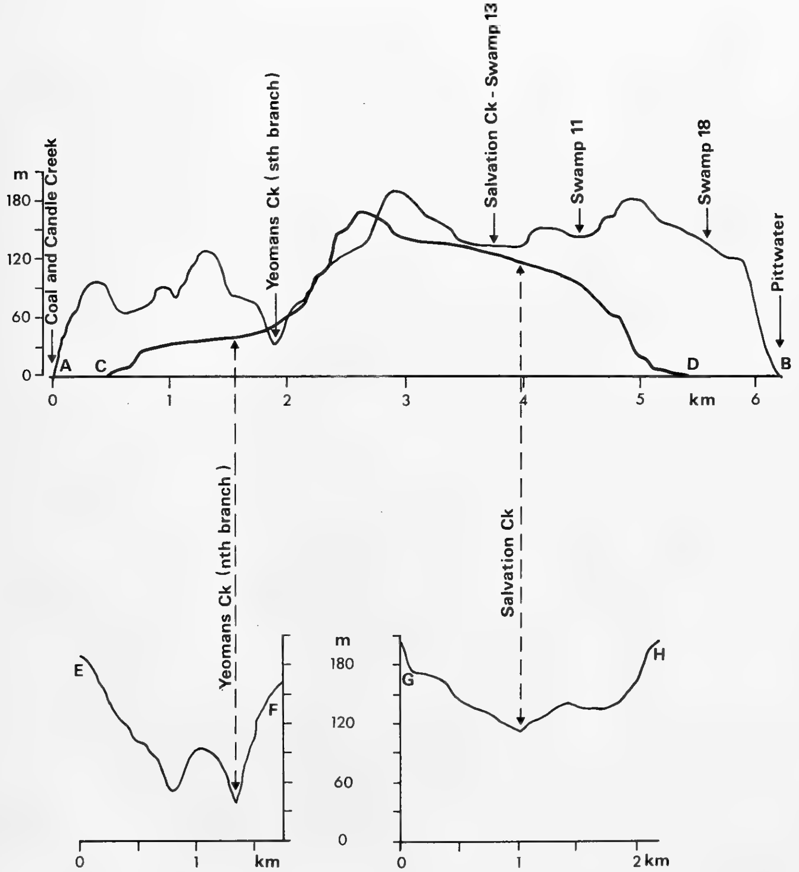

Fig. 3. Topographic sections of the Lambert Peninsula. Sections located on Fig. 1.

these creeks (Fig. 3, sections E-F, G-H) show that the Yeomans Creek valley is steep-sided and narrow, while Salvation Creek occupies a broad valley with gently sloping sides.

Steep slopes (Slope Class 1, slope >15-20°) are virtually restricted to the coastal cliffs and some deep gullies on the eastern half of the peninsula, but on the western side these slopes intrude deeply (Fig. 4). The intermediate slope class (Class 2, 5° to 15° or 20°) covers large areas on both sides of the peninsula, but it is most common on

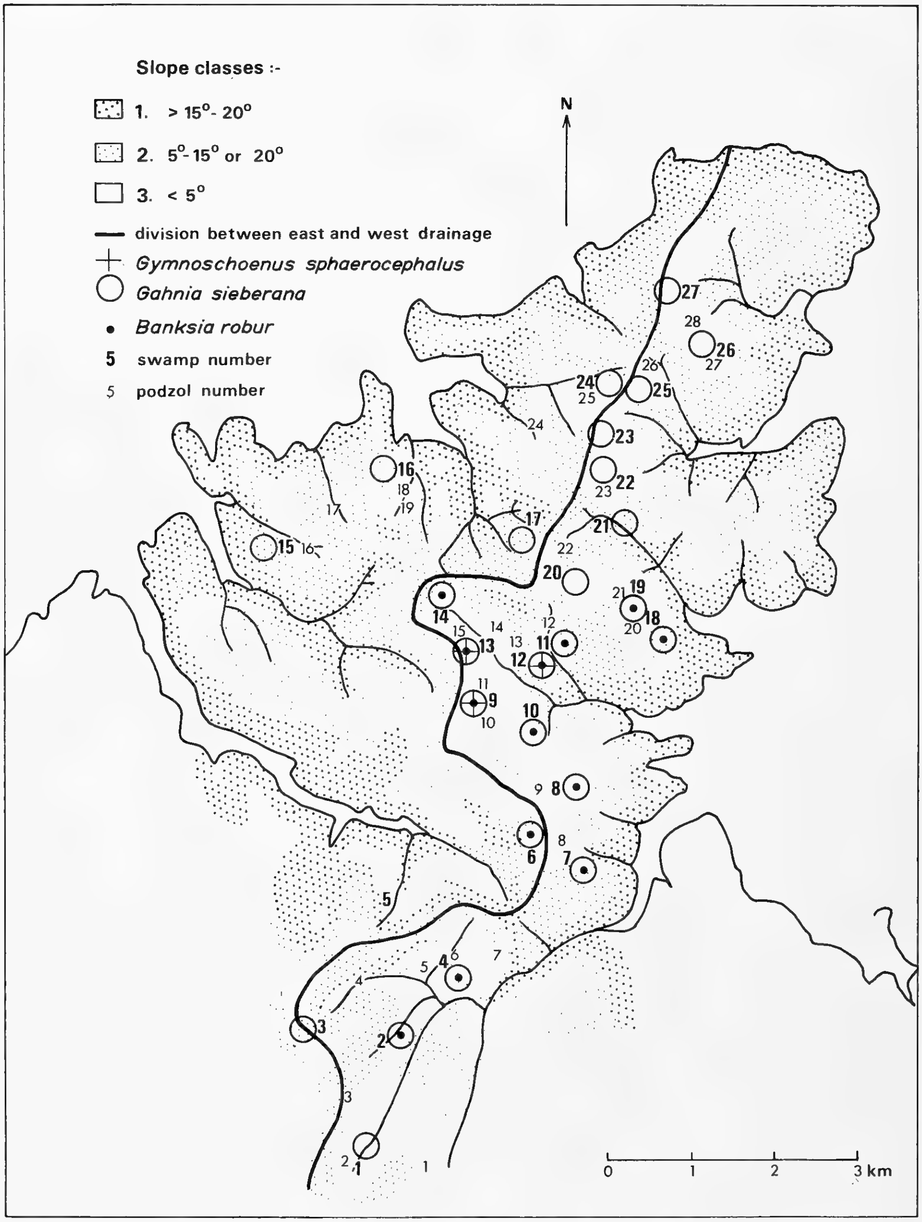

Fig. 4. The distribution of the three slope classes, podzols, swamps and three swamp plants, *Gymnoschoenus sphaerocephalus, Gahnia sieberana* and *Banksia robur*.

the western half. The most gentle slope class (Class 3, <5°) is almost confined to the eastern side, with only very small areas present in the west.

The causes of the asymmetry are not known but the gentle easterly slope of the surface of the Hawkesbury Sandstone and the easterly trend of the cross-beds (Standard, 1969) may be responsible.

PODZOLS

Podzol soils on the sandstone plateaux have only recently been described in detail (Buchanan and Humphreys, 1980) and the vegetation characteristic of these soils was first mentioned in the above paper.

All twenty-eight podzol soils (at grid references listed in Appendix 1) which were found on the peninsula occur in low slope areas (Fig. 4). Only six of these are on the western side and these six occur in isolated small areas with a gentle slope. Podzol soils develop in deep (1-4 m) quartz sand deposits which may cover an area from less than 0.1 ha to approximately 5 ha. These deposits frequently occur near creeks or swamps. The vegetation growing on these soils is very similar throughout the peninsula. The trees are usually taller (open-forest/woodland; Specht, 1970) than the surrounding *Eucalyptus haemastoma* Sm. association of low open-forest/low woodland. They can therefore be identified on aerial photographs with a high degree of confidence using the characteristics of gentle slope and taller vegetation, and in the field, the floristics of the tree and understorey layers aids identification of these soils (Buchanan and Humphreys, 1980).

SHRUBLANDS

The term shrubland has been selected as the clearest description of shrub-dominated areas, although it has been used in vegetation classifications (Specht, 1970; Forster, Campbell, Benson and Moore, 1977) to refer to shrub communities of specific height and density. The shrub-dominated areas on the peninsula fit into many categories in these detailed classifications and the term shrubland in this paper does not imply a specific height or density of shrubs. In a floristic survey of Ku-ring-gai Chase, Outhred, Lainson, Lamb and Outhred (in preparation) classify shrub-dominated areas in a fashion broadly consistent with that adopted by Specht.

The distribution of shrublands does not appear to be influenced by aspect or shelter (Pidgeon, 1938) but rather by soil depth and drainage. Fairly extensive areas of shrubland interspersed with rock outcrops occur on the peninsula, especially at the northern end (Fig. 5). Shrublands develop in these areas as resistant sandstone beds near the surface prevent trees becoming established. However, much of the shrubland is not broken up by rock outcrops and the presence of shrubland in these areas is controlled by a number of factors, all of which result in poorly drained soils. The majority of these moist shrublands have a low surface slope and are most common on the gentle slopes on the eastern side of the peninsula. A puggy material is often present approximately 1 m or less below the surface and it effectively prevents rapid drainage. Extensive sandstone benches also impede drainage and many moist shrublands are perched on benches with the sandstone revealed on the downslope side (Fig. 2). The extremely broken topography of the western half of the peninsula does not allow impeded drainage except on small benches.

On the eastern half, the boundary between shrubland and trees is sometimes ill-defined but it is frequently very sharp and coincides with the change from a poorly-drained to a well-drained soil. Observation during and after torrential rain showed that the surface soil under the trees never became waterlogged but the shrubland soil became waterlogged, and remained so for days. This rapid change in soil drainage may occur over as short a distance as several metres, and matches exactly the tree/shrub boundary. The most spectacular examples have a very obvious change in understorey as well, and are often the result of an abrupt junction between clayey sandstone and sandstone (Fig. 6). An equally sharp shrub and tree boundary, but a more gradual change in the understorey, takes place when the clayey sandstone thins or deepens beneath the trees.

Many of these moist shrubland/tree boundaries obviously occur at joints which mark this change in rock type and involve little or no change in surface topography.

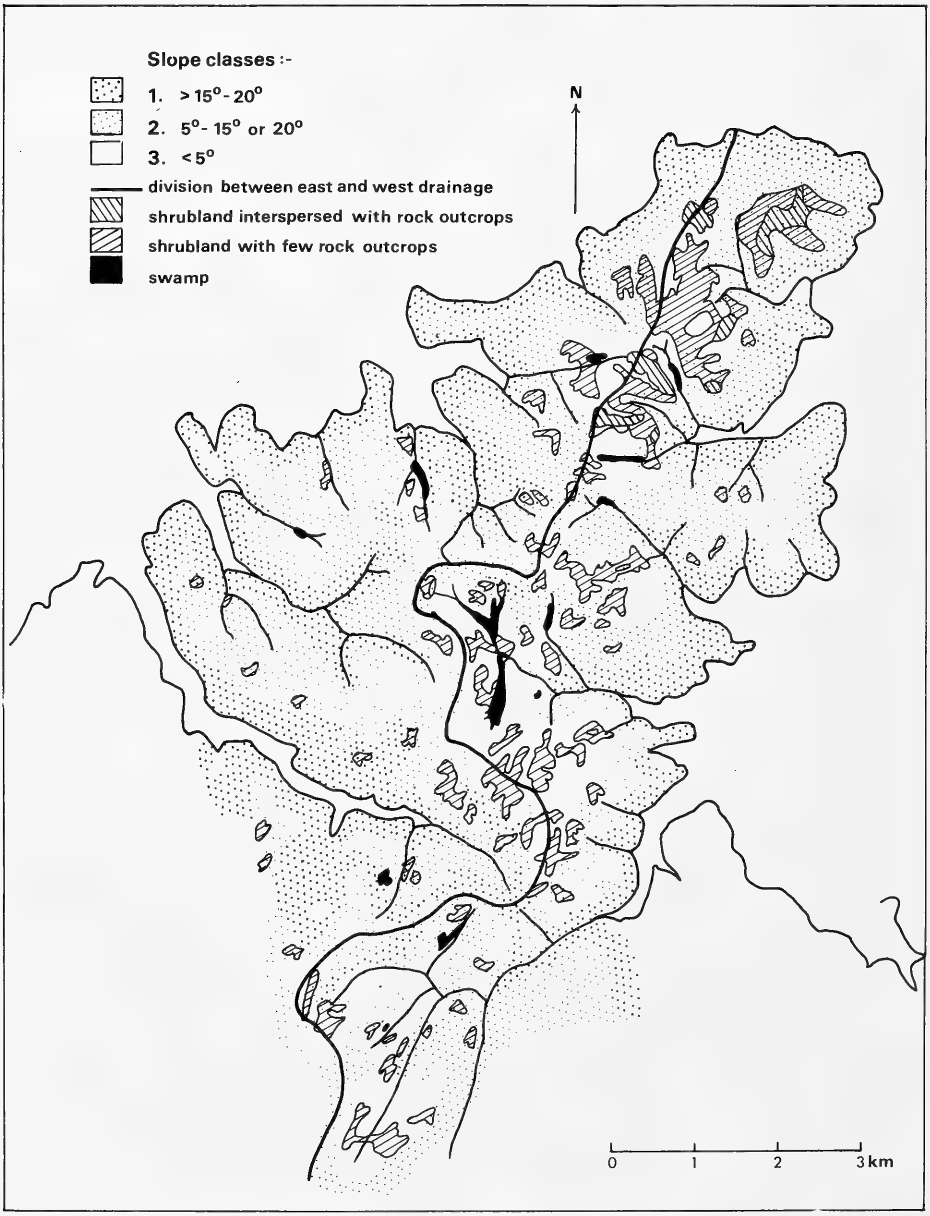

Fig. 5. The distribution of the three slope classes, shrubland and swamps.

Joints which control the direction of cliffs often mark a change in vegetation as well as surface elevation. Fig. 2 shows a clear example of shrubland on a rock shelf and an area covered by trees immediately below the cliff north-west of Podzol 15. Rapid changes in surface and subsurface slope can also cause an abrupt change in soil drainage.

SWAMPS

The distribution of swamps in the West Head to McCarrs Creek area is strongly controlled by lithology and topography. Areas need a fairly constant inflow of water as well as a slow loss of water for swamps to develop. The simplified and generalized longitudinal section of the swamps on the peninsula (Fig. 6) shows the suitable conditions for swamp development.

The first requirement is a gentle slope. Twenty-three of the twenty-seven mapped swamps (grid references listed in Appendix 2) occur in areas with a slope of 5° or less (Fig. 4). Only two of the valley-floor swamps, which form along creeks, occur where the general surrounding slope is greater than 5° (Nos. 17 and 21) but all of the valley-floor swamps and valley-floor elements of composite swamps have a longitudinal slope between 0° and 3°. Some valley-floor swamps are probably situated directly on extensive sandstone benches in these near horizontal segments of the creek beds. Valley-side swamps are frequently perched on rock shelves on the valley slopes and may have a slope of up to 10°.

The second requirement is the presence of the puggy material in the swamp catchment. Water percolating vertically through the overlying sandy soil and sandstone beds will saturate the puggy material and water seeping from it provides a fairly slow and constant supply to the swamps in dry periods. This layer may sometimes continue laterally under readily-draining sandstone beds and, if this is so, the catchment of these puggy layers may be considerably larger than augering indicates. The presence of this puggy material near the surface is indicated by the presence of moist shrubland, and all swamps except No. 15 and the valley-side arm of No. 4 receive drainage from moist shrubland. The swamps may occur immediately

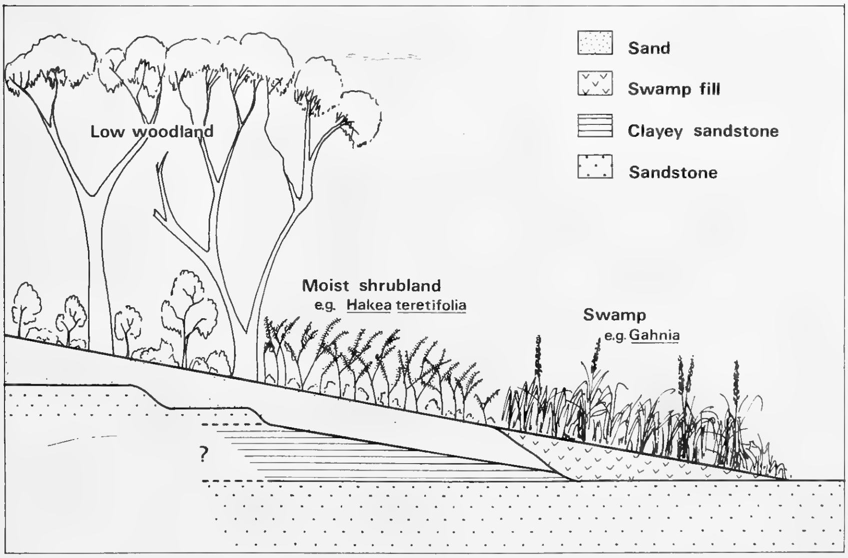

Fig. 6. Simplified and generalized longitudinal section of the swamps on the Lambert Peninsula.

downslope of such areas or they may be connected by a creek. Some swamps are directly underlain by the puggy material.

Physiographic Types

Valley-floor Swamps

Valley-floor swamps are linear, as they form along creeks. They have a cross sectional slope of 0° and a longitudinal slope of 0-3°.

Swamp 21 (Fig. 7a, Fig. 9a) is an example of the simplest type of valley-floor swamp, as there is no zonation between the tall, dense swamp vegetation and the low woodland (*sensu* Specht, 1970) growing on the adjacent steep, rocky slopes. The iron/organic swamp fill is up to 2 m deep and a thick layer of sand is present between the swamp fill and bedrock. The main creek channel is on the least sandy side of the swamp, immediately adjacent to the rocky slope. Swamp 11 (Fig. 7b) is an example of a common valley-floor type. In the area of the section, the gradual slope change along one side of the swamp has allowed a very narrow zone of short swamp vegetation to develop between the tall and dense swamp vegetation and the low woodland. In other places along this border a thin zone of dense *Banksia ericifolia* has developed and such fringes are fairly common on the peninsula. Many valley-floor and composite swamps have a short (0.5-2 m) steep sandy rise along the edge. A podzol soil supporting a distinctive podzol vegetation occurs on these rises (Buchanan and Humphreys, 1980).

Valley-side Swamps

These swamps are very variable but frequently have a fairly steep slope (3-8°) and are sometimes controlled by the underlying rock shelf. Hanging swamps described by Pidgeon (1938) are probably valley-side swamps perched on rock shelves.

Swamp 14 (Fig. 7c) is not controlled by cupping of the underlying rock shelf, as the shelf slopes upward at approximately the same angle as the soil surface, 3°-7°. No creeks drain into this swamp so water levels must be maintained by downslope seepage, and drainage is probably impeded by the relative scarcity of joints in the rock shelf. The vegetation types indicate fairly dry conditions, as only a narrow zone of dense swamp vegetation occurs. Broader zones of short vegetation occur on either side of the wettest area and the usual fringe of mixed vegetation is present along the rock shelf boundary.

Swamp 4 (Fig. 8d, Fig. 9c) is the steepest (slopes up to 14°) in the area and it is the only example of the following type. A cliff 4 m high above a puggy material layer occurs at the upslope edge of the swamp. The presence of tall and dense swamp vegetation at the base of the cliff, as well as the geological relations, indicate that water draining from the overlying sandstone seeps out of the clayey layer at the base of the cliff. Further downslope, drier conditions only enable a swamp with short vegetation to form. Sand washed down the slope has accumulated in irregularities in the bedrock, giving the hillside a smooth rather than terraced profile. The iron/organic fill forms a continuous skin over the sand and rock. On each side this hillside swamp is bordered by well-drained soils carrying a low woodland of *Eucalyptus haemastoma,* and the boundary between swamp and low woodland is remarkably sharp.

Composite Swamps

These swamps consist of a valley-floor element and the bordering gentle (0-3°) hillslope. A decrease in soil moisture and a greater fluctuation in soil moisture occurs from the valley-floor up to the hillslope. The water-table fluctuations are influenced by such features as the surface and bedrock slope, the permanence of the creek, the

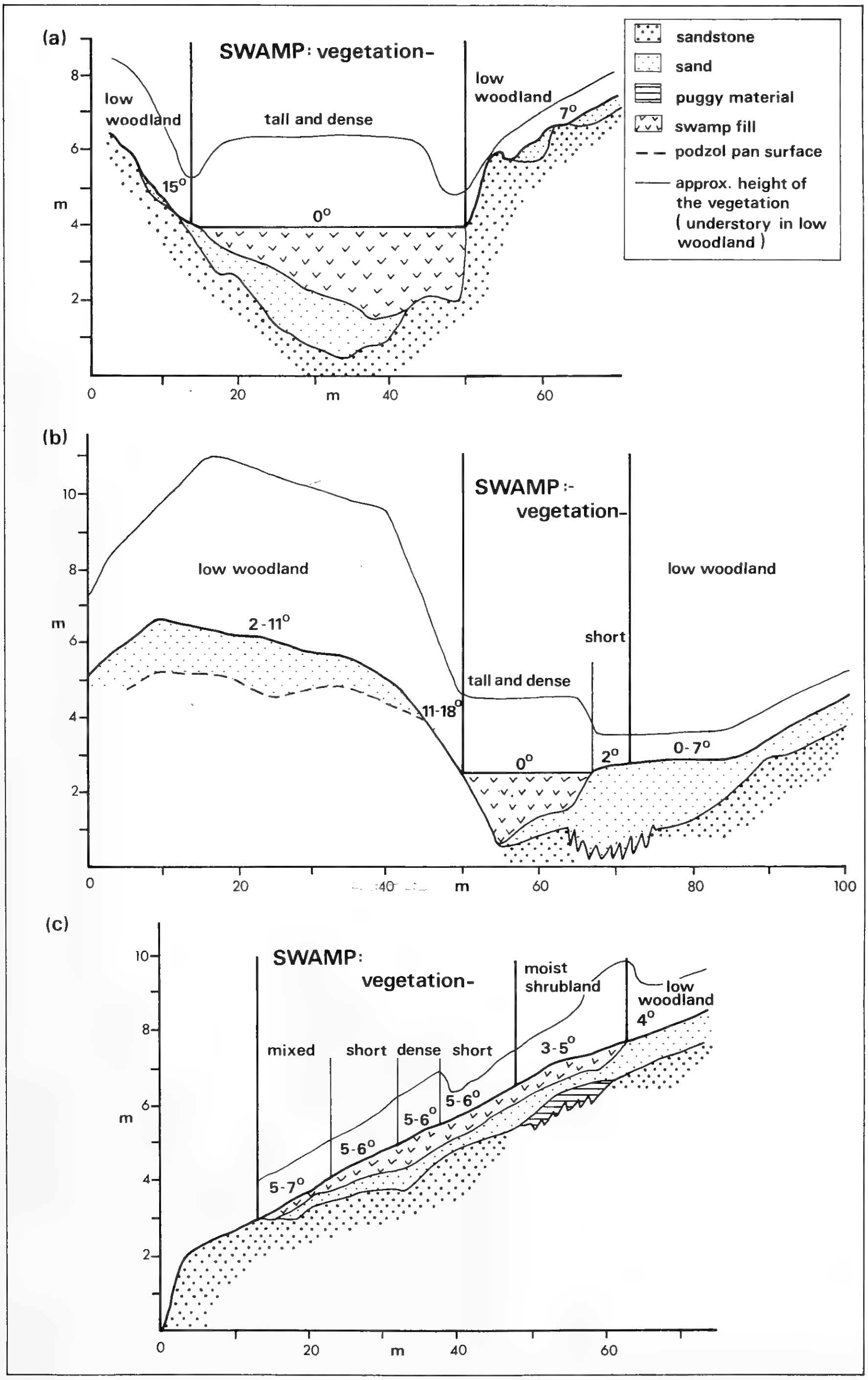

Fig. 7. Swamp sections: a) Swamp 21, valley-floor. b) Swamp 11, valley-floor. c) Swamp 14, valley-side.

distance from the creek, and the depth, thickness and extent of the puggy material. The type and extent of swamp vegetation on the hillslope is therefore very variable.

Swamp 13 (Fig. 8e) shows the zonation up the hillside. As usual, the tall and dense swamp vegetation is present on the valley-floor component. A change in slope from 0° to 2° and the presence of puggy material cause a rapid decrease in vegetation height to an area dominated by *Gymnoschoenus sphaerocephalus*. A gradual but still readily distinguishable change from short to mixed swamp vegetation, then to moist shrubland occurs as the soil becomes progressively drier upslope. At Swamp 13 the zone with mixed vegetation characterized by *Lepidosperma flexuosum* is only a narrow and discontinuous band.

Vegetation Types

Four distinct but intergrading swamp types occur in the Lambert Peninsula area. Listed in order of decreasing soil moisture, they are swamps with 1) tall and dense

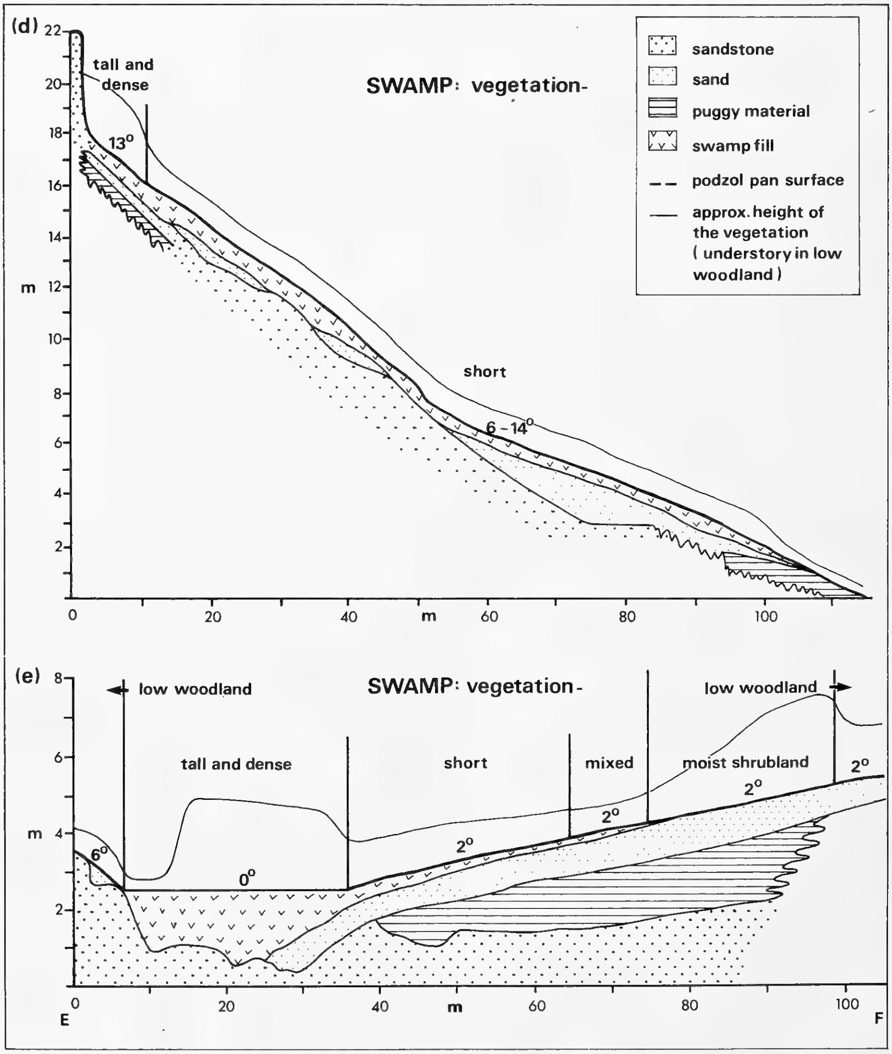

Fig. 8. Swamp sections: d) Swamp 4, valley-side. e) Swamp 13, composite.

vegetation, 2) dense vegetation, 3) short vegetation and 4) mixed vegetation. Moist shrubland is frequently associated with swamps and is included in this section.

Only nine species have been recorded in swamps with tall and dense vegetation but as the swamp type becomes drier, the number of species present becomes greater. This trend is partly reflected in Table 1 where only the most common species are listed.

TABLE 1

List of typical species present in the four swamp types and moist shrubland

	Swamps: vegetation —				Moist
	tall and dense	dense	short	mixed	shrubland
Utricularia cyanea R. Br.	X	X			
Banksia robur Cav.	X	X	X		
Baeckea linifolia Rudge	X	X	X		
Leptospermum juniperinum Sm.	X	X	X		
Aotus ericoides (Vent.) G. Don	X	X	X		
Gleichenia dicarpa R.Br.	X	X	X		
Gahnia sieberana Kunth	X	X	X		
Baumea arthrophylla or sp. aff.	X	X	X		
Empodisma minus (Hook.f) Johnson & Cutler syn. *Calorophus minor* Hook f.	X	X	X	X	X
Lepidosperma forsythii Hamilton		X	X		
L. longitudinale Labill.		X			
Cassytha glabella R.Br.		X	X	X	X
Epacris obtusifolia Sm.		X	X	X	X
Sprengelia incarnata Sm.		X	X	X	X
Banksia ericifolia L.f.		X	X	X	X
Viminaria juncea (Schrad.) Hoffmgg.		X	X	X	
Lepidosperma flexuosum Labill.			X	X	X
L. limicola N. Wakefield			X	X	
Schoenus paludosus (R. Br.) Poir.			X	X	X
Schoenus sp.			X		
Gymnoschoenus sphaerocephalus (R.Br.) Hook.f.			X		
Xanthorrhoea resinosa Pers. ssp. *resinosa*			X	X	X
Leptocarpus tenax (Labill.) R.Br.			X	X	X
Drosera spathulata Labill.			X	X	
D. pelata Sm. ex Willd.			X	X	
Xyris operculata Labill.			X	X	
Lycopodium laterale R.Br.			X		
Baeckea imbricata (Gaertn.) Druce			X	X	X
Leptospermum squarrosum Soland. ex Gaertn.			X	X	X
Bauera rubioides Andr.			X	X	X
Dillwynia floribunda Sm. var. *floribunda*			X	X	X
Hakea teretifolia (Salisb.) J.Britt.			X	X	X
Banksia aspleniifolia Salisb.			X	X	X
Lepyrodia scariosa R.Br.				X	X
Restio complanatus R.Br.				X	
R. fastigiatus R.Br.				X	X
Actinotus minor (Sm.) DC.					X
Angophora hispida (Sm.) Blaxell syn. *Angophora cordifolia* Cav.					X
Kunzea capitata Reichb.					X
Grevillea speciosa (Knight) D. McGillivray syn. *Grevillea punicea* R.Br.					X
Isopogon anethifolius (Salisb.) Knight					X
Petrophile pulchella (Schrad.) R.Br. syn. P. *fucifolia* (Salisb.) Knight					X
Persoonia lanceolata Andr.					X
Epacris pulchella Cav.					X

Two of the plant species which occur in swamps have interesting distributions (Fig. 4). *Banksia robur* occurs only in the southern and eastern corner of the area. Its absence from apparently suitable habitats in the northern swamps is difficult to explain, especially as it occurs immediately north of the peninsula in the Gosford district. The western swamps may be too dry. A very common swamp species in the Blue Mountains and south of Sydney, *Gymnoschoenus sphaerocephalus,* occurs only in the Salvation Creek catchment. Like *B. robur,* its absence from other swamps is unexplained, as apparently suitable habitats occur elsewhere on the peninsula.

Gahnia sieberana, by contrast, occurs in all suitable habitats on the peninsula and only the largest occurrences have been marked on Fig. 4. This bird-dispersed species appears to spread more rapidly than the wind- or water-dispersed *B. robur*, as mature individuals occur in moist places along the verges of the West Head Road.

Because of the anomalous distribution of some major species, the wide range of water tolerance of some species, and the importance of fire frequency on species distribution, it is necessary to divide swamp types on criteria other than species presence or absence. The four swamp types and moist shrubland were divided by the characteristic height and abundance of some of the larger species (Table 2). Swamp species such as *B. robur, Gahnia sieberana, Leptospermum juniperinum* and *Empodisma minus* become shorter and more scattered with a decrease in soil moisture. Species most abundant and vigorous in moist shrubland become progressively shorter and less dense with an increase in soil moisture, for example *Hakea teretifolia, Banksia ericifolia* and *Banksia aspleniifolia*.

The Specht classification (Specht, 1970) is not very suitable for describing the four swamp types. In the swamps in the wetter areas (vegetation tall and dense) species from the families Restionaceae and Cyperaceae combine to form a dense layer but a sparse layer of shrubs emerges above this mass (Fig. 9a). Specht's classification using the projective foliage cover of the tallest stratum has been rejected and the swamps have been classified by the dominant tallest stratum (Beadle and Costin, 1952; Forster, Campbell, Benson and Moore, 1977). Several structural formations in the Specht classification are needed to describe fully the range of swamps with short vegetation, although this type is readily distinguishable in the field.

A description of the four swamp types and of moist shrubland and conditions in which they usually occur is given below.

1. *Swamp: vegetation tall and dense* (Fig. 9a). Classification according to Specht (1970), tall closed-sedgeland.

   The water-table is near or above the surface for most of the year, as this swamp type is closely associated with creeks. The iron/organic fill is fairly free of sand and is 1-3 m deep.

   Gahnia sieberana is often the dominant species but it may be co-dominant with *Empodisma minus*. The dense *G. sieberana* and *E. minus* form a thick layer from the soil up to approximately 2 m. Scattered shrubs of *Leptospermum juniperinum, Baeckea linifolia* and heads of *G. sieberana* 3-4 m tall emerge above the dense layer. *Banksia robur,* if present, is usually 1.5-3.5 m tall and *Aotus ericoides* is usually only 1-1.5 m tall. All shrubs provide support for the weakly twining *E. minus*. The fern *Gleichenia dicarpa* is scattered or dense and up to 1 m tall. The dense *Gahnia sieberana* and *E. minus* may be interrupted by drainage lines where *Baumea arthrophylla* or sp. aff., *E. minus* and the small herb *Utricularia cyanea* are the only vascular plants present.

2. *Swamp: vegetation dense* (Fig. 9b). Classification according to Specht (1970) mid-height closed-herbfield.

   The water-table is less frequently above the surface than for swamps with tall

Fig. 9.
a) Swamp 21 — vegetation tall and dense. Dense *Gahnia sieberana* overtopped by scattered *Leptospermum juniperinum*.
b) Swamp 9 — vegetation dense. Canopy height more even than in (a). Broad leaved shrub is *Banksia robur*. The white zone at the edge of the swamp is *Hakea teretifolia* in flower (moist shrubland).
c) Swamp 4 (valley-side arm) — vegetation short. Rocks in the foreground are part of a 4 m high cliff. There is a sharp swamp/low woodland boundary.
d) Vegetation mixed. *Lepidosperma flexuosum* frequently forms the tallest layer and gives this swamp type a uniform appearance. Scattered *Hakea teretifolia* is visible.

and dense vegetation, as these swamps are associated with less permanent creeks or are at a greater distance from the main creek channel. The iron/organic fill is slightly sandier and is usually 0.5-1.5 m deep. Sand usually occurs between the iron/organic fill and the underlying rock.

E. minus and *Gleichenia dicarpa* frequently form a dense layer from the soil surface to between 0.5-1.0 m. A second but less dense layer composed of *Gahnia sieberana, Baeckea linifolia, L. juniperinum* and *Banksia robur* occurs at 1.5-2.0 m. Drainage channels, with *Baumea arthrophylla* or sp. aff. the commonest species, may be present. Plants from drier areas may be scattered throughout.

3. *Swamp: vegetation short* (Fig. 9c). Classification according to Specht (1970), mid-height closed-herbfield/herbfield, closed-heath/open-heath.

This swamp type frequently occurs on shallow soils with rock less than 1 m below the surface. Such soils provide only a small reservoir of water in dry periods and high water levels are maintained by flooding from drainage lines during wet periods and/or from water in puggy material. The iron/organic fill may be sandy and almost absent or up to 1 m deep, but it is commonly between 0.3-0.6 m deep.

No dominant species occurs in this swamp type, although in individual swamps one or more dominant species may be recognized. As the species composition is so variable, this type is best recognized by the height and abundance of some of the most constant species (Table 2). *Gleichenia dicarpa* may be dense, in dense patches or scattered. The average height of the vegetation is commonly 0.5-1.0 m and it is usually less thick than the vegetation of the two preceding types.

4. *Swamps: vegetation mixed* (Fig. 9d). Classification according to Specht (1970), mid-height herbfield/open-heath.

This swamp type often occurs in shallow sandy soils approximately 0.2-0.5 m deep and it frequently forms a zone between a rock shelf and moist shrubland. Swamps with mixed vegetation are subject to widely fluctuating soil moisture and to drier conditions than other swamps. The iron/organic fill may be reduced to a thin sandy skin or up to 0.3 m deep.

The vegetation is a mixture of species occurring in swamps and moist shrublands. No dominant species occur in this swamp type, but *Lepidosperma flexuosum* frequently forms the tallest layer between 0.75-1.0 m and gives it a characteristic and often uniform appearance. The *L. flexuosum* layer is often only interrupted by a few scattered shrubs, usually *Banksia ericifolia, Banksia*

TABLE 2

Abundance and height of species which characterize swamps with vegetation: 1) tall and dense 2) dense 3) short 4) mixed, and moist shrubland.

	Swamps: vegetation —				Moist shrubland
	tall and dense	dense	short	mixed	
Banksia robur					
Abundance	scattered	scattered	very scattered	—	—
Height (m)	1.5-3.5	1.5-2	<1.5		
Leptospermum juniperinum					
Abundance	scattered	scattered	very scattered	—	—
Height (m)	2.5-4	1.5-2	<1.5		
Gahnia sieberana					
Abundance	dense-scattered	scattered	very scattered	—	—
Height (m)	2-3	1.5-2	<1.5		
Empodisma minus					
Abundance	dense-scattered	dense-scattered	scattered-very scattered	very scattered	very scattered
Height (m)	1-2	0.5-1	0.25-0.75	0.25	0.25
Hakea teretifolia					
Abundance	—	—	very scattered-scattered	scattered	scattered-dense
Height (m)			<1	<1	1-2.5
Banksia ericifolia					
Abundance	—	usually absent	very scattered-scattered	scattered	scattered
Height (m)		1-2	<1	<1	1-2.5
Banksia aspleniifolia					
Abundance	—	—	very scattered-scattered	scattered	scattered
Height (m)			<1	<1	1-1.5

"—" = absent

aspleniifolia, Hakea teretifolia or *Viminaria juncea*. Only one species from the wettest swamp type is sometimes present. *E. minus* is occasionally scattered throughout but is usually less than 0.25 m tall.

5. *Moist shrubland.* Classification according to Specht (1970), open-heath/open scrub and Pidgeon (1938), moist scrub.

   The soil surface is sandy and very little iron or organic material is present. The soil is intermittently moist and puggy material usually occurs under these shrublands.

   The moist shrublands are usually dominated by *Hakea teretifolia* or more rarely by a mixture of *H. teretifolia, Banksia aspleniifolia, B. ericifolia, Persoonia lanceolata* and *Grevillea speciosa*. *H. teretifolia* is usually about 2 m high and fairly dense but it may become shorter and more scattered near the boundary with swamps. An understorey of herbs and shrubs, especially *Bauera rubioides,* may be present but often much of the ground is bare. Occasionally a *Xanthorrhoea resinosa — Banksia aspleniifolia — Bauera rubioides* shrubland occurs. The average height of this type is only 0.5-0.75 m and may be denser than the *H. teretifolia* shrublands. *H. teretifolia,* up to 2 m tall, is often scattered through this second moist shrubland type.

The Swamp Fill

The outlet of valley-floor and composite swamps occurs at a fill/erosion transition zone along the creek profile. In the fill or swamp zone only local and minor erosion takes place. Deposition of the dissolved, dispersed and solid load is partially caused by the decrease in slope, but organisms also decrease the stream competence.

The dense tussocky vegetation in valley-floor swamps probably reduces the water velocity and inhibits erosion of the swamp. Dense *Empodisma minus* and *Baumea arthrophylla* or sp. aff. trap sand and a flocculent, reddish-brown material at the outlets of valley-floor and composite swamps. The resulting barrier forms an efficient dam which frequently has a large pool built up behind it.

A large amount of this flocculent, reddish-brown material occurs in creek channels, semi-permanent pools and in the upper layer of swamp soils. A sample of the flocculent material, and a sample of ferric hydroxide were analysed by atomic absorption spectroscopy. The material from the swamp contained 60% as much iron on a dry weight basis as the sample of ferric hydroxide. Iron bacteria are present and can aid the deposition of iron by oxidizing ferrous compounds to ferric oxide which is deposited in the bacterial sheath (Stevenson, 1967) or by metabolizing the organic molecule with which the iron is complexed (Skerman, 1967). Algae such as *Botryococcus* sp. and *Closterium* sp. are fairly abundant and *Closterium* is often common in boggy, acid waters (Prescott, 1969). This flocculent mass may be approximately 0.5 m deep in valley-floor swamps but on valley-side swamps it may be only a thin skin. No attempt has been made to undertake a detailed study of the microbiology or chemistry of these interesting communities.

As a result of the complex depositional history and an intricate sedimentation pattern, the iron/organic swamp fill may vary over short distances. This fill does however have many characteristic features. It is acid (pH 4.5-5.5) throughout. The upper 0.5 m or less consists of the reddish-brown flocculent mass and plant remains, but with increasing depth the fill becomes firmer and the colour changes to olive-black or black. The smell of hydrogen sulphide also increases with depth. The fill appears to have a high iron and organic content throughout and has a silky feel. The flocculent mass on the surface contains the least amount of sand. Layers with varying sand and gravel content occur throughout, but there is usually a sharp break to an organically-stained sand which sometimes occurs immediately above bedrock. Charcoal is present in the fill. In valley-floor swamps and the valley-floor component of composite swamps the iron/organic fill is usually 1-2 m deep. In valley-side swamps the fill is shallower and more sandy.

Crayfish burrows and the resulting piles of soil are abundant in some swamps. They mix the sediment layers and even contribute to the formation of irregular hummocks.

DISCUSSION

The physiographic asymmetry of the Lambert Peninsula has resulted in an asymmetric distribution of vegetation types. The rugged topography of the western side is not generally suited to the formation of shrublands, swamps or podzols, while the extensive areas with a gentle slope on the eastern side provide suitable conditions. Swamps on the western side are generally drier than those on the eastern side (Table 3). For example, the vegetation of all eastward flowing valley-floor swamps is tall and dense but in the three western valley-floor swamps (Swamps 15, 16 and 17) tall and dense vegetation is absent or unimportant.

TABLE 3

Topographic and vegetation swamp types

	Swamps: vegetation —				Moist
	tall and dense	dense	short	mixed	shrubland
Valley-floor swamps					
1	X				
4	X				
11	X				
15			X		X
16			X		X
17	—				X
21	X				
22	X				
25	X				
26	X				
Valley-side swamps					
2			X		X
3			—	X	X
4			X		
5				X	X
6		X	—	—	X
7			—		X
10	X				X
12			X		X
14		—	X	—	X
20			—	X	X
27			—	X	X
Composite swamps					
8	—	—	X		X
9	—	X	—		X
13	X		—	—	—
18		—	X		X
19	X		—		X
23			X		X
24	X			X	—

"X" = an important component
"—" = present but unimportant

On the gently sloping plateau surface of the peninsula the influence of aspect (varying exposure to the prevailing winds and sunlight) is not as great as Pidgeon (1938) reports for the Hornsby Plateau — an area which includes Lambert Peninsula. She relates the distribution of moist scrub (moist shrubland) to inefficient drainage and rigorous conditions of exposure. However low woodland can grow in more exposed conditions than occur on the plateau surface and extensive areas on the upper, exposed western slopes are indeed covered by this formation. Exposure appears to modify the height and floristics of some of the vegetation units, but the basic pattern of swamp, shrubland and tree covered areas is determined by soil depth and moisture, which are, in turn, controlled by the lithology and micro-topography. Even the structure and floristics of the podzol vegetation are functions of the soil conditions, as the characteristic vegetation of these soils is only slightly altered by the degree of exposure.

The different structural formations are probably very stable, even in terms of millennia, and can thus be considered as climaxes (Beadle and Costin, 1952). Despite this stability, major climatic changes appear to be responsible for swamp development and destruction, and even short term (tens of years) fluctuations can lead to temporary boundary changes. For example, a series of dry years enabled eucalypts (probably *Eucalyptus sieberi* L. Johnson) to become established in the valley-side components of Swamps 13 and 9 and these grew to about 5 m before the water-table rose and killed them.

Fluctuations are however most easily seen on the rock shelf/moist shrubland boundary, as the conditions enabling the development of swamps and moist shrublands on these shelves seem to be more delicately balanced. The dry summer of 1974-75 probably illustrates the conditions which lead to boundary oscillations and in more severe conditions to permanent major changes. During this summer the algal, sand and root mat at the rock boundary cracked vertically and up to 15 cm of the soil fringe lifted 5 cm off the rock surface. When only a thin layer (0.5-1.0 cm) of moss, algae and herb roots covered the rock shelf, shrinkage and cracking of the mat revealed the rock beneath. In moist areas the smooth gelatinous texture of the surface changed to a rough one as the algae and bacteria dried.

Although individuals of only one plant species (mature *Banksia ericifolia*) were noticed dead as a result of this drought, it is not difficult to imagine drier conditions, particularly combined with fire, leading to the removal of the vegetation and shallow soil from rock shelves. As vegetation and micro-organisms die, soil binding would be reduced (Harris, Chesters, Allen and Attoe, 1964) and cracks in the soil would enable fire to burn organic matter well below the surface. Heavy rain or even wind could rapidly remove the resulting loose, unprotected soil. A sequence similar to this probably caused the death of vegetation in vacant gnammas (Twidale, 1975) but a widespread retreat of vegetation from rock surfaces would probably require a catastrophically drier climate than at present.

Heavy rains appear to cause little damage to rock/vegetation boundaries or to swamp vegetation if the vegetation has not been dried out or burnt beforehand. A moister climate than at present and a low fire frequency may result in the vegetation advancing across the bare rock surfaces downslope of moist shrublands.

Formation and destruction of valley-floor swamps may be closely linked with climatic changes. Destruction or scouring of deep channels may occur in the dry periods by a sequence similar to that described for rock shelf vegetation, but the conditions would have to be very dry to scour a whole valley-floor swamp to bedrock. The presence of zones of gravels on bedrock beneath some swamps could be explained either by destruction of the swamp, or by the lateral migration of deep major drainage channels which are sometimes present. Although more detailed stratigraphic studies and dates are needed before any general statements can be confidently made, the valley-floor swamps around Sydney appear to be quite young, with dates from the Blue Mountains (Stockton and Holland, 1974) and south of Sydney (Dury and Langford-Smith, 1968) ranging from 4110 ± 100 years before the present (B.P.) to 17050 ± 600 years B.P. This suggests that deposition occurred in the Holocene and terminal Pleistocene. Geographical and climatic conditions probably favoured swamp development before these dates and the present swamps may be representatives of a cycle of swamps which have built up, been scoured or even destroyed, and subsequently re-formed.

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APPENDIX 1

Podzol grid references (G.R.)

Podzol No.	Map	G.R.
1	Hornsby 9130-1V-S	371716
2	"	366718
3	"	365725
4	"	364739
5	"	373742
6	"	376742
7	Mona Vale 9130-1-S	383742
8	" "	391755
9	" "	389762
10	" "	382768
11	" "	384773
12	" "	389779
13	" "	384778
14	" "	384780
15	Broken Bay 9130-1-N	379783
16	Cowan 9130-IV-N	360792
17	"	365796
18	"	372796
19	"	376796
20	Broken Bay 9130-1-N	399781
21	" "	401787
22	" "	393792
23	" "	399799
24	" "	392805
25	" "	398810
26	" "	406808
27	" "	413812
28	" "	408816

All maps N.S.W. 1:25 000 orthophotomap series

APPENDIX 2

Swamp grid references (G.R.)

Swamp No.	Map	G.R.
1	Hornsby 9130-1V-S	366719
2	"	368732
3	"	360735
4	"	375741
5	"	369750
6	Mona Vale 9130-1-S	386754
7	" "	391753
8	" "	389762
9	" "	384770
10	" "	388771
11	" "	389779
12	" "	385776
13	" "	383779
14	Cowan 9130-IV-N	376783
15	"	359792
16	"	375798
17	Broken Bay 9130-1-N	386794
18	" "	400781
19	" "	411787
20	" "	391789
21	" "	396794
22	" "	399799
23	" "	440806
24	" "	397810
25	" "	406808
26	" "	413812
27	" "	409821

All maps N.S.W. 1:25 000 orthophotomap series

PROCEEDINGS
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VOLUME 104
PART 2

Heat Generation by Siliceous Igneous Rocks of the Basement and its possible influence on Coal Rank in the Sydney Basin, New South Wales

R. A. FACER, A. C. HUTTON and D. J. FROST

FACER, R. A., HUTTON, A. C., & FROST, D. J. Heat generation by siliceous igneous rocks of the basement and its possible influence on coal rank in the Sydney Basin, New South Wales. *Proc. Linn. Soc. N.S.W.* 104 (2), (1979) 1980:95-109.

The Sydney Basin rests unconformably along its northwestern, western and southern margins on rocks of the Lachlan Fold Belt. Devonian and Carboniferous siliceous igneous rocks, which comprise approximately 25% of this basement, have been sampled at 18 sites — from Gulgong in the north to Moruya in the south — for this investigation.

On the basis of chemical data (SiO_2, K_2O and trace elements) here, the Carboniferous rocks can be distinguished from the Devonian rocks. New heat-generation values, based on K-, Th- and U-contents, have been determined for the 18 sites, together with calculations based on published chemical data from 5 localities (including one of the new sites). The new determinations agree with previously-published heat-generation data for the Bathurst batholith and Moruya Tonalite. Heat generation (mean) by the Carboniferous rocks, with the Nelligen Granodiorite included because of its chemical similarities to the other Carboniferous rocks, is relatively high at 2.53 $\mu W/m^3$ (n = 13, s.d. = 0.46 $\mu W/m^3$). Heat generation (mean) by the Devonian rocks is 1.98 $\mu W/m^3$ (n = 9, s.d.=0.39 $\mu W/m^3$).

Variation in heat generation in the basement to the Sydney Basin may be an important influence in the flow of heat through the basin. Together with influences by rocks within the basin, heat generation is a potential long-term influence on rank of the coal in the Permian Illawarra Coal Measures in the western and southern portions of the Sydney basin.

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INTRODUCTION

The northern and northeastern portions of the Sydney Basin consist of a sequence of Carboniferous volcanic rocks which passes up into Permian and then Triassic sequences. Apart from very minor patches of Carboniferous sedimentary rocks, the basal rocks of the Sydney Basin sequence at its western and southern edges are Permian in age, and unconformably overlap Palaeozoic rocks (Fig. 1) of the Lachlan Fold Belt. Included in the basement rocks are siliceous igneous rocks — both extrusive and intrusive (cf. various discussions *in* Packham, 1969).

Heat generation in rocks of the Bathurst batholith is (relatively) high (Bunker *et al.*, 1975; Facer, 1977). Sass *et al.* (1976) showed that heat flow through the Sydney Basin is apparently higher than other areas of eastern Australia, and suggested a possible relation to Tertiary extrusive rocks on the southwestern Sydney Basin. The thermal history of the basin, including heat generation and the timing of thermal events, is an important problem in understanding the rank of coal in the Sydney Basin (cf. Facer *et al.*, 1978). White *et al.* (1974) have noted high heat flow in the rocks of the Lachlan Fold Belt.

This study was carried out to assess the heat generation by siliceous igneous rocks from the basement along the northwestern to southern margin of the Sydney Basin. Data obtained will provide background information for detailed investigation of the

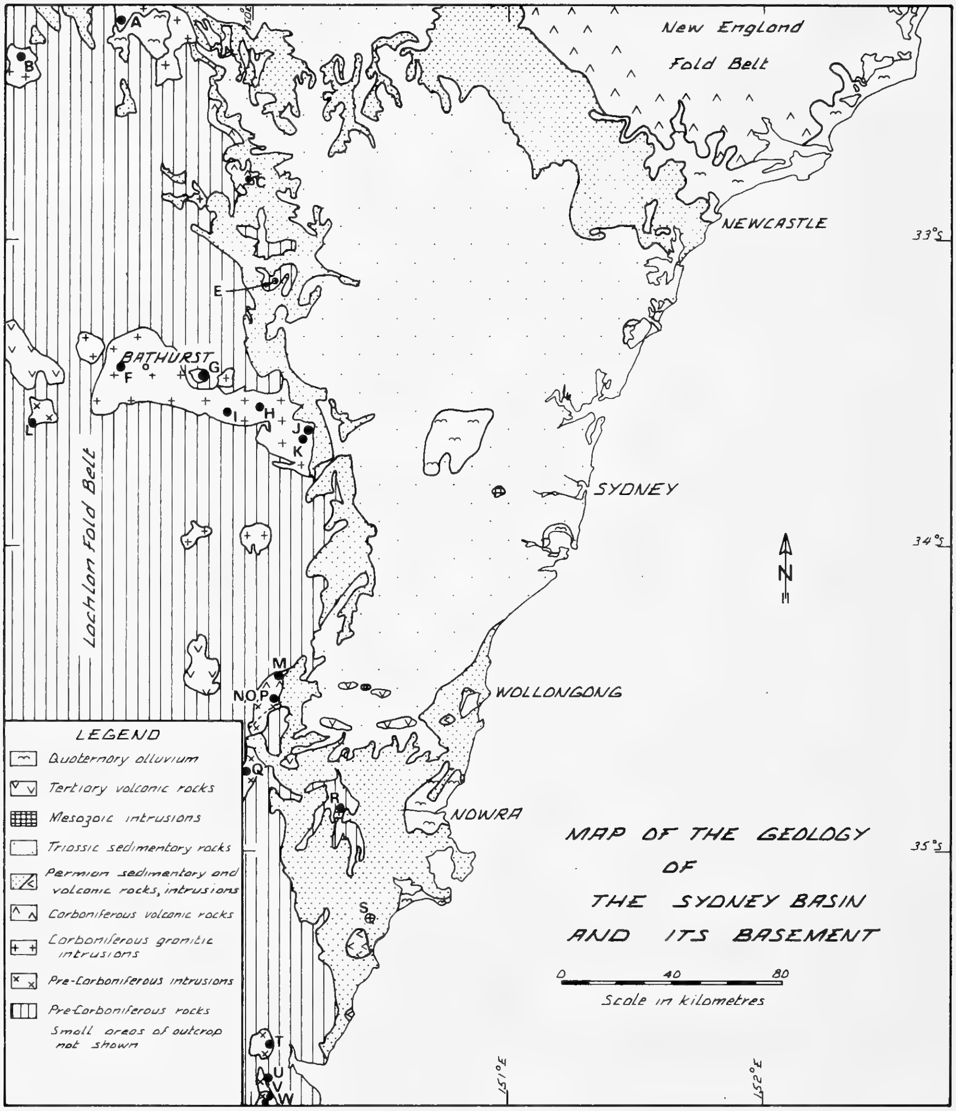

Fig. 1. Map of Sydney Basin

thermal setting of the Sydney Basin — to assist in understanding the rank of the Permian coal (and variations in its rank) within the basin. Samples have been collected from the intrusive and extrusive igneous basement rocks along the northwestern, western and southern edges of the basin. These rocks constitute approximately 25 per cent of the exposed basement. All the major siliceous bodies have been sampled, as well as some of the smaller intrusions or exposures (for example the "windows" of granitic rocks at Yalwal and Gooloo Creek, sites R and S in Fig. 1). Mafic rocks and deeply weathered rocks have not been analysed. Because of present inadequate knowledge on the behaviour of Th and U in metamorphic reactions (Rogers and Adams, 1969*a, b*) the metamorphosed pre-Carboniferous volcanic and sedimentary rocks were not sampled for this phase of the overall investigation.

TABLE 1

Ages of the Sydney Basin basement rocks for which heat generation data are presented herein

Locality (1)	Rock unit	Age(2)	Reference for Age
A	Gulgong Granite	312 My	Evernden and Richards(1962)
B	Wuuluman adamellite	Carb.	Brunker and Rose (1969)
C	Rylstone (dacite) tuff	Carb.	Day (1969)
D	Yeoval batholith	ca 392 My	Gulson and Bofinger (1972)
E	Huntingdale "rhyolite"	Carb. (?Dev.)	Brunker and Rose (1969)
F	Dunkeld adamellite	303 ± 2 My	Facer (1978)
G	Durandal Adamellite	314 ± 6 My	Facer (1976)
H	Sodwalls adamellite	Carb.	Vallance (1969)
I	Carlwood granite	Carb.	Vallance (1969)
J	Hartley adamellite	311 ± 6 My	Evernden and Richards (1962)
K	Hartley granodiorite	(?) 311 My	cf. Rhodes (1969)
L	Carcoar Granite	Dev. (?Carb.)	Brunker and Rose (1969); Vallance (1969)
M	Yerranderie rhyodacite	Dev.	Jones *et al.* (1977)
N	Bindook Porphyry	Dev.	This investigation
O	Jemidee granodiorite	Dev.	This investigation
P	Mandari granodiorite	Dev.	This investigation
Q	Marulan Granite	Dev.	Felton (1974)
R	Bundundah granite	Carb.	Vallance (1969); McIlveen (1975)
S	Gooloo granite	Carb.	McIlveen (1975)
T	Nelligen Granodiorite	Dev.(?) (3)	Chappell and White (1976)
U	Minor intrusions (Moruya)	Dev.	Chappell and White (1976)
V	Moruya batholith	381 ± 3 My	Chappell and White (1976)
W	Moruya tonalite	(?) 381 ± 3 My	Chappell and White (1976)

Notes: (1) Locality — the code corresponds to the localities given in Fig. 1.
(2) Age — the radiometric ages have been recalculated where necessary to correspond to the decay constants given in Steiger and Jager (1977). Recalculations for entries G and J are from Facer (1978). Entry D assumed a mean age before recalculation of 400 My. Errors for entries F (2 values), G(4), J(2), and V and W(3) are standard deviations of the mean recalculated ages. The abbreviations are Dev. (Devonian) and Carb. (Carboniferous).
(3) The age for the Nelligen Granodiorite may be Carboniferous, (based on chemical data.

However, sampling of these rocks for a more complex investigation of K, Th and U distribution has commenced. The mafic phases of the Bathurst batholith comprise only a minor proportion of that complex. Rocks of the Sydney Basin rest on deeply weathered "granite" at unsampled localities, such as the Aaron's Pass granite contact 20 km south of Rylstone (site C in Fig. 1). In such rocks leaching may have redistributed heat-generating elements, especially uranium, and hence the surface material would not give a true value for heat generation. Where possible artificial exposures such as road cuts, blasted sites and drill core were sampled.

Because no published chemical data could be found for many of the newly-

TABLE 2

Chemical analyses of some (igneous) basement rocks along the northwestern to southern margins of the Sydney Basin

Analysis Locality	1 A	2 B	3 B	4 C	5 E	6 F	7 G	8 G	9 H	10 I	11 J	12 L	13 M	14 N	15 N	16 O	17 P	18 Q	19 R	20 R	21 R	22 R	23 S	24 W
Age	C	C	C	C	C(?)	C	C	C	C	C	C	D(?)	D	D	D	D	D	D	C	C	C	C	C	D
Oxide weight percentages																								
SiO_2	68.94	66.91	67.15	64.50	76.49	66.51	68.56	70.81	75.29	74.76	72.21	64.76	67.20	65.58	66.78	67.66	67.84	69.39	74.64	75.02	74.68	76.78	74.41	62.56
TiO_2	0.48	0.54	0.58	0.56	0.18	0.54	0.48	0.19	0.13	0.24	0.35	0.53	0.53	0.63	0.55	0.54	0.53	0.43	0.12	0.14	0.16	0.11	0.11	0.98
Al_2O_3	14.89	15.30	14.59	15.49	12.38	15.53	14.87	16.15	12.97	13.38	13.99	14.72	14.00	15.29	15.50	14.22	14.67	14.88	10.68	12.62	13.15	11.75	13.25	15.94
Fe_2O_3	1.52	0.90	1.37	1.29	0.29	0.96	0.96	1.83	0.18	0.37	0.72	0.26	0.38	1.51	0.98	1.23	0.61	1.17	1.62	0.07	1.04	0.52	0.32	2.85
FeO	1.58	2.02	1.75	1.90	1.37	2.92	2.24		0.90	1.05	1.53	5.07	3.63	3.71	3.53	3.35	2.99	2.10	3.28	2.11	0.68	0.84	1.35	2.96
MnO	0.09	0.05	0.06	0.10	0.02	0.07	0.07	n.d.	0.03	0.04	0.05	0.09	0.07	0.08	0.07	0.07	0.05	0.05	0.30	0.12	0.07	0.06	0.04	0.07
MgO	1.31	1.63	1.77	1.08	0.50	1.98	1.18	0.50	0.42	0.44	0.81	3.19	2.03	2.49	1.91	1.89	1.79	1.06	0.31	0.12	0.09	0.06	0.27	2.68
CaO	2.76	2.62	2.62	3.39	0.23	3.96	2.83	1.32	1.26	1.08	1.78	5.30	1.82	4.47	5.03	4.20	3.48	3.71	0.24	0.55	0.49	0.51	1.07	5.10
Na_2O	3.82	3.89	4.20	3.17	2.95	3.25	3.85	3.21	2.73	3.55	3.29	2.39	3.12	2.12	2.49	2.09	3.42	2.80	1.67	3.10	3.52	3.49	4.30	3.92
K_2O	3.47	4.78	3.94	3.61	4.36	3.44	3.50	4.54	5.46	5.01	4.38	1.99	4.42	2.79	2.88	2.98	2.93	3.46	3.80	4.66	4.84	4.43	3.30	1.79
H_2O^+	n.d.	n.d.	0.84	n.d.	n.d.	n.d.	1.16	-	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.68	n.d.
H_2O^-	n.d.	n.d.	0.23	n.d.	n.d.	n.d.	0.25	-	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.12	n.d.
P_2O_5	0.20	0.25	0.28	0.18	0.05	0.18	0.17	0.12	0.04	0.04	0.12	0.11	0.13	0.15	0.13	0.12	0.15	0.11	0.03	<0.02	<0.02	<0.02	0.04	0.29
CO_2	n.d.	n.d.	0.04	n.d.	n.d.	n.d.	-	-	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
L.O.I.	0.76	0.55	n.d.	4.96	1.46	0.36	n.d.	n.d.	0.74	0.38	0.86	0.95	2.59	1.08	0.27	0.90	0.95	0.82	3.59	1.65	1.02	0.90	n.d.	0.66
TOTAL	99.82	99.44	99.42	100.23	100.28	99.70	100.12	98.67	100.15	100.34	100.09	99.36	99.92	99.90	100.12	99.25	99.41	99.98	100.28	(100.16)	(99.74)	(99.45)	99.26	100.41
S.G.	2.66	(2.68)		2.54	2.65	2.70	(2.67)		2.61	2.61	2.64	2.68	2.75	(2.74)		2.69	2.72	2.68	2.75	2.61	(2.60)		2.62	2.76
Trace elements (ppm)																								
V	61.2	52.0	n.d.	55.3	18.2	97.4	n.d.	n.d.	18.3	10.7	29.0	132.0	65.0	111.	108.	112.	63.2	39.7	18.3	5.8	5.8	5.8	n.d.	105.
Co	9.8	8.0	n.d.	8.3	4.7	13.0	n.d.	n.d.	14.6	4.7	5.7	20.2	12.3	12.0	11.1	14.6	11.8	8.1	9.0	3.3	2.8	1.9	n.d.	18.8
Ni	10.9	17.8	n.d.	6.2	8.9	18.7	n.d.	n.d.	7.3	9.0	8.9	23.8	13.3	15.3	13.7	14.9	16.6	11.9	14.3	12.0	7.9	10.5	n.d.	18.7
Cu	5.1	7.0	n.d.	3.8	2.6	4.3	n.d.	n.d.	2.2	2.6	2.7	25.1	3.8	9.1	10.3	9.3	8.3	6.1	1160.	78.7	14.0	2.2	n.d.	13.6
Zn	61.7	52.0	n.d.	76.8	54.8	59.0	n.d.	n.d.	17.8	36.1	38.0	73.5	74.0	65.8	53.9	50.0	53.0	60.1	1310.	15.8	99.9	26.2	n.d.	75.5
Cd	0.1	<0.1	n.d.	0.15	<0.1	<0.1	n.d.	n.d.	<0.1	(0.15)	0.13	0.1	0.1	<0.1	0.24	<0.1	0.1	0.39	8.6	1.2	0.19	0.1	n.d.	0.1
Pb	12.0	10.3	n.d.	12.4	53.6	59.0	n.d.	n.d.	7.6	15.4	10.4	21.9	13.3	20.6	24.3	21.8	14.6	24.4	1050.0	42.8	16.1	8.0	n.d.	14.0

sampled rocks whole rock analyses were also carried out. These data were also used for comparison between rock bodies.

REGIONAL GEOLOGY

Fig. 1 shows the sites which provided fresh samples for this investigation. In addition, data from an area near Yeoval (32° 45′ S, 148° 40′ E), sampled by Gulson (1972), have been included as site D. Table 1 indicates the ages of the rocks used in this investigation, although no radiometric age data are available for many sites. All the granitic rocks are "massive", and most are of the Bathurst-type association (Vallance, 1969). Similarly the extrusive rocks show evidence of only minor deformation in thin section, although they have been folded with meridional trends. The intrusive rocks have been emplaced into Ordovician to Devonian metamorphosed sedimentary and mafic extrusive rocks of the Lachlan Fold Belt (Packham, 1969).

Outcrops of the Devonian granitic rocks follow the regional meridional trends, although adjacent to the Sydney Basin such trends were apparently not imposed by post-emplacement tectonic activity. The Carboniferous granitic rocks along the Basin margins cut across the trends of the older rocks. Both Devonian and Carboniferous granitic intrusive rocks have mineralogical and chemical affinities with — and thus apparent genetic relationships to — adjacent extrusive rocks, such as near Bullio and Yerranderie (localities M, N, O, P in Fig. 1), and near Rylstone (Day, 1969) (locality C).

Chappell and White (1974, 1976) recognized two types of granitic rocks in the Lachlan Fold Belt. These two types are distinguished using chemical criteria, and have been interpreted to indicate two different types of source material — I-type from igneous material and S-type from sedimentary material (Chappell and White, 1974).

PETROGRAPHIC AND CHEMICAL DATA

New chemical data are presented here for 18 of the localities of Table 1 and Fig. 1, although chemical data have previously been published for some of the sites. Analyses for major oxides and some trace elements are listed in Table 2. Table 3 contains new results of analyses for Th and U for 18 sites, and also summarizes published K, Th and U data for 5 sites.

PETROGRAPHY

Petrographic descriptions for the samples analysed in this investigation are summarized in Appendix 1. The descriptions are based on both thin section and polished section study. The adamellite from Hartley has been described in detail by Joplin (1931), whose data are supplemented by new observations here.

The Gooloo granite (analysis 23 in Table 2) is a small inlier of granite exposed in Gooloo Creek and possibly also in Conjola Creek (McIlveen, 1974; 1975). Roadworks

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TABLE 2 (Continued)

NOTES: The locality code corresponds to Table 1 and Fig. 1. Grid localities are for the (named) 1:250,000 map sheets. Sample numbers refer to the University of Wollongong reference collection. In some cases the specific gravity has been averaged for a locality.
n.d. - not determined. Ages are given as Carboniferous (C) or Devonian (D).
Major oxide analyses (XRF) were by R.H. Flood and S.E. Shaw, except analyses 7 and 8 (I.R. Plimer *in* Facer, 1977, table 2), and 23 (AMDEL).
Trace element analyses (AAS) by A.M. Depers.

1. R7571. Small quarry (several blocks), Dubbo 243001.
2. R6619. Roadworks (several blocks), Dubbo 206988
3. (Anal. 3 supplied by E.R. Phillips) (locality near that for 2).
4. R7585. Roadworks (2 blocks), Dubbo 295946.
5. R7574. Natural outcrop, Sydney 312904.
6. R6631. Road cutting (several blocks), Bathurst 245871.
7. Facer (1977, table 2, 1 and 5) A dash indicates n.d. for one sample.
8. Facer (1977, table 2, 2 and 3) Roadworks and cutting, Bathurst 277866.
9. R6621. Roadworks (2 blocks), Sydney 300857.
10. R6624. "Opera House Quarry", average of two analyses, Bathurst 285850.
11. R6626 and R7578. Roadworks, average of two analyses, Sydney 315855.
12. R6620. Roadworks, Bathurst 213846.
13. R7573. Drill core, 209m depth, Wollongong 321784(approx.).
14. R7235. Pulpit Rock member of Bindook Porphyry, natural outcrop, Wollongong 317757.
15. R7236. Rileys Range member of Bindook Porphyry, natural outcrop, Wollongong 316758.
16. R7237. Natural outcrop, Wollongong 314757.
17. R7238. Natural outcrop, Wollongong 318753.
18. R7575 and R7576, Roadworks, average of two analyses, Goulburn 294696.
19. R6695. Altered vein, natural outcrop, Wollongong 339690.
20. R6697A. At altered vein, natural outcrop, Wollongong 339690.
21. R6697B. 10cm from altered vein, natural outcrop, Wollongong 339690.
22. R6696. 3m from altered vein, natural outcrop, Wollongong 339690.
23. R7581. Roadworks (2 blocks), Ulladulla 344651.
24. R6472. Roadworks (several blocks), Ulladulla 311564.

TABLE 3

Heat generation of some (igneous) basement rocks along the northwestern to southern margins of the Sydney Basin

Locality	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
Age	C	C	C	D	C(?)	C	C	C	C	C	C	D(?)	D	D	D	D	D	C	C	C/D	D	D	D
Chemical data																							
K(%)	2.88	3.62	3.00	3.32	3.62	2.86	3.34	4.53	4.16	3.64	3.00	1.65	3.67	2.35	2.47	2.43	2.87	3.85	2.74	2.91	1.82	1.71	1.49
Th(ppm)	14.2	15.4	18.0	15.4	21.1	13.8	19.2	15.1	18.5	19.5	19.6	13.9	15.6	14.4	14.8	14.1	13.5	15.3	14	15.4	8.8	8.7	13.7
U(ppm)	2.9	2.9	4.8	3.5	3.7	3.3	6.0	4.1	4.4	5.1	4.9	2.8	4.1	3.1	2.9	3.4	2.9	3.0	1.7	5.3	2.0	2.1	2.9
S.G.	2.66	2.68	2.54	2.67*	2.65	2.70	2.67	2.61	2.61	2.64	2.69	2.68	2.75	2.74	2.69	2.72	2.68	2.60	2.62	2.76*	2.76*	2.76*	2.76
Heat generation (Bunker *et al.*, 1975, equation, p.2)																							
10^{-13}cal/cm^{3}sec	4.83	5.24	6.37	5.53	6.63	5.08	7.72	5.98	6.65	7.20	7.08	4.47	6.19	5.02	4.90	5.13	4.75	5.18	3.97	6.76	3.25	3.27	4.60
µW/m^3	2.02	2.19	2.66	2.31	2.77	2.12	3.23	2.50	2.78	3.01	2.96	1.87	2.59	2.10	2.05	2.14	1.99	2.17	1.66	2.83	1.36	1.37	1.92
Heat generation (Rybach, 1976, equation 3, p.311)																							
µW/m^3	1.97	2.13	2.59	2.25	2.70	2.07	3.14	2.44	2.70	2.93	2.88	1.82	2.52	2.04	1.99	2.09	1.93	2.11	1.61	2.76	1.32	1.32	1.87

NOTES: In some cases "rounding" during averaging has been necessary, but care was taken to ensure that cumulative errors did not increase the value of the heat generation. (This rounding was necessary to maintain consistency of significant figures in chemical data.) The chemical information for K is based on Table 2, and on the references given in the listing below. Analyses for Th and U for this investigation were carried out by A. Holland, following the technique of Pollock (1977), except for S (Th by XRF and U by fluorimetry; anal. AMDEL).

* - signifies that the specific gravity is estimated here.

A	Table 2, analysis 1.
B	Table 2, analyses 2 and 3 (Th,U: 1 anal.)
C	Table 2, analysis 4.
D	Gulson (1972, average of table 3: granodiorite, 3 analyses; and table 4 granite, 4 analyses)
E	Table 2, analysis 5.
F	Table 2, analysis 6.
G	Table 2, analyses 7 and 8 (Th and U, 3 analyses).
H	Table 2, analysis 9.
I	Table 2, analysis 10.
J	Table 2, analysis 11.
K	Rhodes (1969 table 3, average, 9 anals).
L	Table 2, analysis 12.
M	Table 2, analysis 13.
N	Table 2, analyses 14 and 15.
O	Table 2, analysis 16.
P	Table 2, analysis 17.
Q	Table 2, analysis 18.
R	Table 2, analyses 21 and 22.
S	Table 2, analysis 23.
T	Griffin *et al.* (1978, table I, analyses MG1 to MG3).
U	Griffin *et al.* (1978, table I, analyses MG5 to MG8, MG15, MG22).
V	Griffin *et al.* (1978, table I, analyses MG9 to MG14).
W	Table 2, analysis 24.

at Gooloo Creek indicate an unconformable relationship between the Gooloo granite and the Sydney Basin. The name Bundundah granite is used here for the "Bundundah Porphyritic Microgranite" referred to by McIlveen (1975, p. 6) and based on mapping of granite in the Bundundah, Yarramunmun, Danjera and Yalwal Creeks area (Towey, 1965; Wall, 1965; Frost, 1977). Like the Gooloo granite the Bundundah granite is overlain by Sydney Basin rocks, but the Devonian sedimentary and volcanic rocks into which it is emplaced are also exposed.

CHEMISTRY

The chemical data in Table 2 indicate that all the rocks analysed are silica-rich, no granites (*sensu lato*) containing less than about 65% SiO_2. The tonalite of analysis 24 is marginally less siliceous than the other rocks, but this analysis is similar to those of Griffin *et al.* (1978, table 1) for the Moruya Tonalite. Allowing for slightly different sample-sites, degree of weathering and techniques, analysis 11 is similar to analyses IX and X of Joplin (1931, p.53).

The Carboniferous rocks are generally more siliceous than the Devonian samples, but detailed comparisons would require more accurate age data. As indicated in Table 1 some sites have not been dated by radiometric techniques — in which case their most likely age is indicated.

Chemical analyses for the Bundundah granite of site R (Table 2, analyses 19 to 22; with petrographic descriptions in Appendix 1) indicate that the distribution of major oxides in the two phases of the granite differs from that in the hydrothermally altered zone in Fe content and oxidation state, Na_2O and Al_2O_3. Co, Cu, Cd and Pb increase markedly towards the altered zone. In addition, Th (23.1 ppm) and U (6.3 ppm) are high in the vein (cf. Table 3, entry R for Th and U content away from the vein). These increases apparently indicate that hydrothermal solutions have introduced trace metals, including Th and U, and hence only analyses 21 and 22 (Table 2) have been used for heat-generation calculations.

HEAT GENERATION

An indication of the generation of heat by the heat-producing elements in rocks is provided by the equation (after Bunker *et al.*, 1975):

Heat Generation

$$= [\,(0.27\text{K}\% + 0.20\text{Th ppm} + 0.73\text{U ppm}) \times \frac{\text{S.G.}}{3.156}\,] \times 0.418\,\mu\text{W/m}^3 \qquad (1)$$

(1 heat-generation unit (HGU)) is 10^{-13} cal/cm³sec = 0.418 μW/m³). Equation 1 is similar to that given by Rybach (1976, equation 3, p.311), who also gave details of the decay processes giving rise to the heat generation. Isotopic equilibrium is assumed when using such an equation.

Values of heat generation obtained using equation 1 (Table 3) average 1.028 times those determined using Rybach's (1976) equation. However, as equation 1 follows the decay data in Rogers and Adams (1969*b*, p.92-B-2), and as much published heat generation information has been published using these decay data comparison will be facilitated by adopting them.

Discussion here will be based on determinations using equation 1. Some of the determinations in Table 3 are for rocks which outcrop beyond the present margin of the basin, but near outliers of Permian sedimentary rocks (such as Wuuluman, site b, cf. Dulhunty, 1964) — or as major rock bodies which may have a significant influence on basement heat generation (such as Carcoar). Table 3 also contains chemical data for sites D, K, T, U and V, for which no calculations of heat generation were published with the data. The information in Table 3 for the Durandal Adamellite is modified from Facer (1977) using additional data.

Bunker *et al.* (1975) have presented heat-generation data for the Bathurst batholith (although the last entry in their table 2-2 should be located at (33° 24′ S, 149° 20′ E), one site in schist from Apsley (33° 34′ S, 149° 34′ E); and one site from the Moruya batholith. The data of Bunker *et al.* (1975) have been converted into heat-generation units using S.G.'s of 2.65 (based on measurements of other samples) for the Bathurst batholith and 2.60 for Apsley schist, and by converting data from Sass *et al.* (1976, p.13) for the Moruya batholith. These recalculated data are:

Bathurst batholith — 3.02 $\mu W/m^3$;
Apsley schist — 2.44 $\mu W/m^3$; and
Moruya batholith — 1.45 $\mu W/m^3$.

Heat-generation values determined by Bunker *et al.* (1975), recalculated here, for the Bathurst batholith agree well with those of the present investigation in Table 4. Similarly, for the Moruya batholith the mean (Table 4) agrees with that of Bunker *et al.* (1975).

Heat generation in the Nelligen Granodiorite (entry T in Table 3) is approximately twice that in the minor intrusions (Table 3, U) adjacent to the main mass of the Moruya Tonalite and the tonalite (Table 3, V and W). Entry U of Table 3 includes data for a "gabbroic diorite" phase of the Mogendoura Granodiorite (Griffin *et al.,* 1978, p.238 and table 1), although exclusion of this mafic phase would only raise the value of the heat generation to 1.57 $\mu W/m^3$ — still only about half that for the Nelligen Granodiorite.

The mean heat generation for all 22 values based on equation 1 (Table 4) is 2.31

TABLE 4

Mean heat generation in siliceous igneous rocks in the basement to the Sydney Basin

Igneous rocks mass or group of rocks	Number of analyses	Heat generation $\mu W/m^3$ mean	s.d.	Entries in Table 3
Bathurst batholith	6	2.77	0.40	F to K
Carboniferous rocks	12	2.51	0.47	A to C, E to K, R and S
Carboniferous rocks and Nelligen Granodiorite	13	2.53	0.46	A to C, E to K, R to T
Moruya batholith	2*	1.41	-	U to W
Devonian rocks	9	1.98	0.39	D, L to Q, U to W
Devonian rocks and Nelligen Granodiorite	10*	2.07	0.46	D, L to Q, T to W
All rocks	22*	2.31	0.51	All
All rocks, except Bathurst batholith	17*	2.13	0.44	A to E, L to W

Note: The entries marked * include a mean value for V and W of 1.46 $\mu W/m^3$.

$\mu W/m^3$ (s.d. = 0.51 $\mu W/m^3$). For the 17 values (V and W combined), after omission of entries F to K, the mean is noticeably lower than the mean for the Bathurst batholith (Table 4), although the two values (2.77 $\mu W/m^3$ s.d. = 0.40 $\mu W/m^3$ and 2.13 $\mu W/m^3$, s.d. =0.44 $\mu W/m^3$) are within 2 s.d.'s.

DISCUSSION

The siliceous igneous rocks forming part (25%) of the basement to the Sydney Basin (Table 1) range from Devonian to Carboniferous in age, with the younger rocks outcropping more to the north and the older (Devonian) rocks more to the south of the Bathurst batholith (Fig. 1). Part of the Yeoval batholith may be as old as Late Silurian (Gulson and Bofinger, 1972).

Table 2 indicates that only three of the rocks for which new chemical data are presented contain less than 65% SiO_2. No distinctive chemical differences were noted between intrusive and extrusive rocks. The Carboniferous rocks, especially those of the Bathurst batholith, tend to be more siliceous and potassic than the Devonian rocks. Similarly the Carboniferous intrusions plot slightly towards the A apex on AFM diagrams.

The granites (*sensu lato*) analysed here fit into the I-type classification of Chappell and White (1974) using the first three criteria of their table. However, analysis 8 of Table 2 for the Durandal Adamellite may represent an S-type rock, notwithstanding that analysis 7 fits the I-type classification. There are no apparent mineralogical differences between these adamellite samples sufficient to explain the chemical differences. Aplites and contact adamellite from this site yield an initial $^{87}Sr/^{86}Sr$ ratio of 0.7051 ± 0.0016 (Facer, 1976) which fits one I-type criterion of Chappell and White (1974, p.173). Entry 8 of Table 2 is an average of analyses of different samples by two analysts (cf. Facer, 1977, Table 2), yet has the apparent S-type characteristic of $Mol[Al_2O_3/(Na_2O + K_2O + CaO)] = 1.28$. One possible explanation is that, by coincidence, the analyses 2 and 3 in table 2 of Facer (1977) each contain minor sedimentary xenolithic material which was not observed in the hand specimen blocks prior to crushing, and which was not intersected by thin (or polished) sections. The Durandal Adamellite does contain xenoliths, although those of sedimentary origin are at least subordinate, most having an apparent igneous origin (cf. Mackay, 1964; Facer, 1977). These xenoliths comprise both igneous country rocks (Mackay, 1964) and fragments of a more granitic nature which could have been stoped from the early-cooled parts of the intrusions — and igneous inclusions, some of which may have been assimilated, would tend to suggest an I-type origin.

Th and U contents are generally lower in the older rocks (Table 3). The other trace elements, despite variations, show no strong trends.

The SiO_2, K_2O, Th and U (and to a lesser extent V, Co, Ni and Cu) trends shown by the new analyses and those of Griffin *et al.* (1978, table 1) indicate that the Nelligen Granodiorite may be Carboniferous, and hence not part of the Moruya batholithic complex (cf. McIlveen, 1974; 1975, p.6). Griffin *et al.* (1978, p.244) used chemical data to suggest (qualitatively) a slightly different source for the Nelligen Granodiorite from that for the main Moruya batholith. Several cluster analysis dendrograms were calculated and indicate that results for the Nelligen Granodiorite tend to cluster with the Carboniferous rocks of this investigation. However, lack of complete discrimination between Devonian and Carboniferous rocks precluded definite inclusion of the Nelligen Granodiorite in the Carboniferous group.

The Th and U contents of the Carboniferous rocks (Table 3) are generally at or above the levels listed by Clark *et al.* (1966, figs 24-6 to 24-9) as means and medians for granodiorites (Th 9.3 ppm, 9.0 ppm respectively; U 2.6 ppm, 2.3 ppm respectively) and siliceous igneous rocks (Th 20 ppm, 16 ppm respectively; U 4.7 ppm, 3.9 ppm respectively). For the older rocks of this investigation the Th and U contents are closer to, or below, these averages. However differences between the present calculated means (Table 4) and those of Clark *et al.* (1966) are not marked.

The overall Th:U ratio (with localities V and W combined as one locality) is 4.52 (s.d. = 1.08), not significantly different from the value of 4.0 suggested in fig. 24-13 of Clark *et al.* (1966), and very close to the mean for granitic rocks of 4.63 (s.d. = 0.85) in table 90-E-1 of Rogers and Adams (1969*a*). For the Bathurst batholith this ratio is 3.85 (s.d. = 0.38). For the Bundundah granite the Th:U ratio ranges from 3.67 (for the vein) to 5.50 (10 cm from the vein), with an overall mean of 4.50 (s.d. = 0.85). As this ratio for other samples in Table 3 extends outside the range for the Bundundah granite the introduction of Th and U along the vein does not influence the ratio.

Reflecting the overall K, Th and U content, the heat generation in the Carboniferous rocks, especially in the Bathurst batholith, is higher than in the older rocks. This heat generation is at or above an "average" value for granitic or siliceous igneous rocks based on the data of Clark *et al.* (1966). Although specific isotopes are responsible for production of heat, the heat generation values are based on *total* K, Th and U content (equation 1). The older rocks do not generate less heat than the Carboniferous rocks only because of greater time for radioactive decay. Disequilibrium in the isotopes of K, Th and U could introduce errors in heat-generation studies, for example in analysis of small samples.

Table 4 summarizes the heat-generation data from Table 3, arranged in various groupings — which indicate higher heat generation by the Carboniferous rocks. Because of the possible uncertainty in the age of the Nelligen Granodiorite, the Nelligen data are included in both Carboniferous and Devonian groups. Inclusion of the Nelligen data in the Carboniferous mean makes little change in that mean. Heat generation by the Nelligen Granodiorite is approximately twice that of the Moruya batholith. Although variation in uranium content strongly influences the magnitude of heat generation (and can be redistributed by weathering) all three elements K, Th and U in the Nelligen Granodiorite are closer in content to the Carboniferous rocks than the Devonian rocks. The further work planned on the distribution of K, Th and U may help in the interpretation of the possibly anomalous place of the Nelligen Granodiorite in the sequence of Devonian and Carboniferous intrusions.

The narrow range in S.G.'s of the rocks of this investigation (Table 3) precludes determination of accurate relationships between heat generation, S.G. and seismic velocity (cf. Rybach, 1976). The possible relationship between (high) heat flow and (low) seismic velocity for the Lachlan Fold Belt, discussed by White *et al.* (1974, p.161), may partly reflect the relatively high heat generation in at least some of the siliceous igneous rocks which make up approximately 25% of the fold belt. As yet heat-generation data for the other rocks of the Lachlan Fold Belt are inadequate for discussion of the relationship between heat generation and seismic velocity. The P velocity of 6.52 km/sec reported by Doyle *et al.* (1966) for the layer under the southern and southwestern Sydney Basin corresponds to a low heat generation of approximately 0.8 μW/m^3 using Rybach's (1976) fig. 2. Thus the relatively "cool" Devonian igneous rocks of this basement may have been emplaced into rocks of even lower heat generation, although the "wedge of a few kilometres of 6 km/sec. material" (Doyle *et al.*, 1966, p. 355) immediately under the basin rocks would correspond to a heat generation of approximately 1.2 μW/m^3.

Comparatively high heat generation in some basement siliceous igneous rocks may contribute to high heat flow (relative to eastern Australia) within the southern portion (but not the extreme southernmost area) of the Sydney Basin (Munroe *et al.*, 1975; Sass *et al.*, 1976, p.15). However, the lack of heat-flow data from levels below the Triassic rocks of the basin, and the low heat-flow value from near Moruya (Sass *et al.*, 1976), make a detailed thermal properties investigation an interesting problem for research of the present type. The Moruya heat flow may be low partly because the Moruya batholith generates low amounts of heat relative to other granitic rocks of the basement. Although such a programme has commenced, more data are required.

It is apparent that a careful study of variation of heat generation in both basement rocks and the Permian basin rocks needs to be integrated with other criteria of thermal history — such as "coal rank" measurements, even on accessory carbonaceous detritus in the basin rocks. Heat flow, which is partly influenced by heat generation, has an important influence on coal, and may be a significant factor in coal rank variation in the Sydney Basin. The heat which has influenced and still may influence the coal rank was, and is, generated by the basement rocks, as well as rocks below the Illawarra Coal Measures (and within the coal-bearing horizons). The rocks below the coal measures are igneous and sedimentary (including volcanoclastic) rocks. As these igneous rocks are potassium-rich they may be significant contributors to the heat generation — but preliminary data indicate that many of the sedimentary rocks below and within the coal measures also generate more heat than the Moruya batholith. A full investigation of the basement rocks and their distribution (using, for example, gravity surveying) is required. This would help in establishing the relative contribution of basement and basal rocks to the thermal history of the coal within the basin. Such an assessment should assist in evaluating the role of the younger (Jurassic and younger) igneous rocks in and on the basin to the heat flow of the basin. Towards the centre (and northern part) of the Sydney Basin the Carboniferous volcanic rocks may be important generators of heat.

CONCLUSIONS

Analyses of siliceous igneous rocks making up approximately 25% of the basement along the northwestern, western and southern margins of the Sydney Basin have revealed chemical differences between Carboniferous and Devonian rocks. Carboniferous rocks, which tend to outcrop in the northern portion of the Lachlan Fold Belt sampled in this investigation, contain higher proportions of SiO_2 and K_2O than the Devonian rocks. Values for Th and U are generally higher in the Carboniferous rocks, being at or above means in tabulations of world-wide data. On the basis of available chemical data the Nelligen Granodiorite shows more similarities to the Carboniferous granitic rocks than to the Devonian Moruya batholith. The Carboniferous and Devonian granitic intrusions are I-type, indicating igneous source material.

Because of the higher proportions of the heat-producing elements K, Th and U, the Carboniferous rocks generate more heat (cf. equation 1) than the Devonian rocks. Values of heat generation have been determined for 18 sites, based on new chemical data. When combined with published chemical data for 5 sites, heat generations at 22 sites (the Moruya batholith is in both groups) are available. The overall mean value for heat generation at these 22 sites is 2.31 $\mu W/m^3$ (s.d. = 0.51 $\mu W/m^3$). For the Carboniferous rocks (Nelligen Granodiorite included) the mean heat generation is 2.53 $\mu W/m^3$ (s.d. = 0.46 $\mu W/m^3$, n = 13), whereas for the Devonian rocks, with the Nelligen Granodiorite (2.83 $\mu W/m^3$) excluded, the mean heat generation is 1.98 $\mu W/m^3$ (s.d. = 0.39 $\mu W/m^3$, n = 9).

The relatively high heat generation in the Carboniferous rocks along the basement margins of the Sydney Basin could influence seismic velocity through the upper crust. It also apparently influences heat flow through the Sydney Basin, which is high for this portion of eastern Australia, and could thus affect the coal rank within the basin. The pre-Carboniferous intrusions which outcrop near or south of 35°S generate less heat than the Carboniferous rocks — and are south of the relatively high heat flow area and coal rank area between Wollongong and Sydney.

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APPENDIX I

PETROGRAPHY OF THE SAMPLES ANALYSED

Samples were collected from localities A to C, E to J, L to S, and W (Fig. 1). (Only the designating letter is used in the following description.) Table 3 contains chemical data, and references to published petrographic descriptions. The petrographic descriptions are generally restricted to the samples analysed, except for the rocks near Bullio (N,O,P) (Hutton, 1977) and Yalwal (R) (Frost, 1977) where more general petrographic descriptions are given based on petrographic studies of several thin and polished sections. References in this Appendix are included in the list following the text of this paper.

A. Sample R7577 is a porphyritic granodiorite from the Gulgong Granite (Matson, 1974), with feldspar phenocrysts up to 15 mm set in a groundmass with an average grainsize of 2 mm. The composition is quartz (29%); perthitic potash feldspar (16%); and albite-rimmed plagioclase (44%), with rim myrmekite; biotite (6%), (α = pale brown, $\beta = \gamma$ = dark brown, with apatite and zircon inclusions); and accessory minerals (2%) — magnetite and sphene. Alteration minerals include clinozoisite, chlorite, epidote and "sericite".

B. The Wuuluman adamellite has been described by Phillips and Carr (1973), being distinctive in containing tabular potash feldspar megacrysts up to 75 mm in length, some of whict exhibit rapakivi textures. (The analytical data correspond to the petrography described by Phillips and Carr, 1973.)

C. Day (1969) has described the tuffaceous rocks which outcrop north and northwest of Rylstone. Sample 7585 is a fawn tuffaceous dacite — close to rhyodacite — with feldspar, quartz and lithic fragments up to 3 mm set in a fine-grained groundmass of partly devitrified glass (58%). As noted by Day (1969, p.179), the 5% clear quartz grains are fractured, and embayed, and some small grains have small acicular "overgrowths". The feldspar crystals are also fractured, and consist of both potash feldspar, 10% (sanidine; Day, 1969) and plagioclase, 21% (altered, possibly about An_{35}), occurring both as large grains and in the groundmass. Minor biotite (α = yellow brown, $\beta = \gamma$ = dark brownish green), hornblende (α = brown, β = brown green, γ = dark green, with apatite inclusions); magnetite, and zircon are also present. Alteration products include "sericite", hematite, chlorite and calcite. The lithic fragments comprise a sufficiently small proportion that they probably do not significantly influence the chemical analysis, especially as they appear to be similar in rock type to the main rock.

E. The porphyritic rhyolite from this site consists of quartz and feldspar grains (3 to 4 mm across) set in a grey-green aphanitic groundmass and has been termed the "Huntingdale Porphyry" (S. Holland, *pers. comm.*, 1977). Clear, fractured, embayed quartz grains (16%) contain inclusions of rutile and tourmaline. The feldspar grains include cloudy perthitic potash feldspar (19%) and strongly sericitized plagioclase (5%). Magnetite comprises less than 1%. The (59%) groundmass, which may include some devitrified glass (although difficult to identify definitely), contains quartz and feldspars. In addition to "sericite" and clay minerals, alteration has produced epidote and calcite.

F to K. These sites are from various granitic phases of the Bathurst batholith. Vallance (1969) has presented a summary of descriptions of rocks of this batholith, which is a composite suite of massive (undeformed) intrusions ranging from granites to relatively minor mafic phases (the latter not having been sampled in this study).

At Dunkeld (F) a grey, even-grained (3 mm) adamellite outcrops, consisting of 25% quartz with rutile inclusions; 25% perthitic potash feldspar and 40% plagioclase (An_{34}), with rim and bulbous myrmekite; 5% strongly pleochroic biotite (α = brown to straw, $\beta = \gamma$ = dark brown) with dark haloes around zircon inclusions; 4% strongly pleochroic hornblende (α = pale brown, β = green, γ = dark greenish brown); and 1% accessory minerals (magnetite, spinel, apatite). Alteration products include "sericite", epidote and chlorite.

Descriptions of the Durandal Adamellite (G) have been given by Mackay (1964) and Facer (1977), and of the granodiorite at Hartley (K) by Rhodes (1969). Joplin (1931, pp.23-27) has described in detail the granite at Hartley (J).

The porphyritic adamellite from Sodwalls (H) consists of 24% quartz, with inclusions of rutile and tourmaline; 46% orthoclase (tabular crystals up to 6 mm in length), with ribbon perthite, and altered to "sericite"; 27% plagioclase (An_{36} to An_{42}), altered to "sericite", epidote and minor calcite; 1% biotite (α = yellow brown, $\beta = \gamma$ = dark greenish brown) with inclusions of zircon; and 1% hornblende (α = greenish brown, β = brown, γ = dark brown); and approximately 1% apatite and magnetite. Both biotite and hornblende are partly chloritized.

The Carlwood granite (I) is pink, coarse and even-grained (average 4 mm). Quartz comprises 36% and is free from inclusions. Perthitic orthoclase comprises 42%, and albite-rimmed plagioclase 19%, with rim myrmekite. Minor biotite (α = pale brown, $\beta = \gamma$ = dark brown), brown to green hornblende and magnetite are also present. Alteration minerals include "sericite", epidote and chlorite.

L. "The Carcoar Granite appears to be discordant" (Vallance, 1969, p.194) with a range in composition which includes granite and quartz diorite. Other Devonian granitic intrusions in the Lachlan Fold Belt are concordant. The sample analysed is a grey, medium-grained (3 mm) granodiorite, and contains 20% clear quartz, 20% perthitic potash feldspar and 45% plagioclase (An_{40} to An_{45}), which may be zoned with sericitized cores. Biotite comprises 10% (α = yellow brown, $\beta = \gamma$ = reddish brown) and twinned hornblende 5% (α = pale brown, β = greenish brown, γ = dark green). Magnetite is accessory. Alteration minerals include "sericite" and epidote, and localized clinozoisite and prehnite.

M. The rhyodacite from Yerranderie is strongly altered, with little of the original phenocrysts remaining. It was sampled from drill core, but field relationships are unknown — except that it appears similar to the Bindook Porphyry (cf. Vallance, 1969, p.194). The feldspar phenocrysts are sericitized, and the mafic phenocrysts altered to chlorite. Quartz is abundant.

N to P. The Bindook Porphyry (N) is dacitic to rhyodacitic, and has been subdivided into two members (Hutton, 1977). It contains phenocrysts of embayed quartz (8%) and plagioclase in a fine-grained groundmass of quartz and orthoclase, with minor biotite and hornblende. The plagioclase phenocrysts (26%) are zoned, with cores of An_{34} to An_{54} and rims of An_{20} to An_{25}. Hornblende (α = pale green, β = green, γ = dark green to brown) phenocrysts comprise 4%; and slightly pleochroic hypersthene, clinopyroxene and biotite are also present. Magnetite, zircon and topaz are accessories. Alteration minerals include "sericite" and epidote in plagioclase cores, and chlorite, clinozoisite and prehnite.

The mineralogy of the granodiorite from locality O is similar to that of the rocks from locality N, except that the plagioclase is more calcic (cores of An_{38} to An_{47}) and hypersthene is absent. This granodiorite is non-porphyritic, with grains averaging 2 to 3 mm across.

The granodiorite of locality P is distinct from that of locality O, being coarse-grained, with elongate hornblende phenocrysts up to 15 mm in length set in an even-grained pale grey groundmass. Quartz comprises 13% of the rock, orthoclase 19% and plagioclase (An_{35} to An_{45} cores, An_{20} rims) 40% – with minor myrmekite. The hornblende (α = pale green, β = green, γ = dark green to brown) comprises 20% and biotite (α = pale brown, β = brown, γ = dark brown) comprises 5%. Accessory minerals include magnetite, zircon and apatite. Alteration includes sericitization of plagioclase, especially cores, and chloritization.

Relationships between the rocks at localities N to P will be discussed in a separate presentation by Hutton (in prep.).

Q. The granodiorite at Bungonia (Marulan Granite) has been described by Kantsler (1973), and is the subject of a separate study by P. F. Carr *et al.* (in prep.). Two samples were analysed in this investigation, each being even- and medium-grained (2 to 3 mm), and each containing quartz, potash feldspar, plagioclase and minor mafic phases. Magnetite is the main opaque phase, and is accompanied by minor hematite and ilmenite.

R. Four samples from the small outcrop of the Bundundah granite were analysed, including a fracture zone of hydrothermal alteration about 0.5 m wide. The granite has two phases – an outer pale fawn porphyritic microgranite, (average grainsize 1 mm) and an inner pink porphyritic granite (average grainsize 4 mm) which contains xenoliths of the fine-grained phase. Aplite dykes and hydrothermally altered fracture zones are common, being subparallel to the outer contact of the porphyritic microgranite. These features indicate that emplacement of these two granitic phases was not quite synchronous. The fine-grained phase contains phenocrysts, up to 10 mm, of quartz in an hypidiomorphic granular groundmass of quartz, microcline, plagioclase and minor biotite, apatite, sphene and hematite after magnetite. Lack of quartz phenocrysts is the only major difference between the porphyritic granite and the fine-grained phase. The overall approximate proportions are quartz: 34%, potash feldspar: 42%, plagioclase: 16%, biotite: 4%, and accessory minerals: 5%. In the alteration zone (centred on a sulphide-rich vein) the quartz and biotite contents remain the same, but most of the feldspar is altered to sericitic micas and epidote, and pyrite and chalcopyrite comprise 5%. Although the alteration vein has sharp contacts, the host granite contains sulphides within 5 cm of the vein.

S. The small inliers of granite in Gooloo and Conjola Creeks are exposed below the Permian Conjola Subgroup of the Sydney Basin. In Gooloo Creek the granite is even- and coarse-grained (5 mm), and, although moderately weathered, is fresher than the outcrop in Conjola Creek (S. H. Hickey, *pers. comm.*). Quartz comprises 4% of the granite. The perthitic potash feldspar is heavily clouded by sericitic alteration, and comprises 62%. Plagioclase (An_{44}) is also altered – to "sericite", clay and calcite – and comprises 27%. Biotite (α = yellow, $\beta = \gamma$ = dark brown) and weakly pleochroic hornblende (brown and green) each comprise 3%. Magnetite and sphene are very minor accessories.

W. One of the phases of the Moruya batholith is the tonalite analysed here. Sample R6472 is a grey, even- and medium-grained (2.5 mm) tonalite which contains xenoliths, although xenolithic material was avoided during preparation for analysis. Quartz comprises 11% of the tonalite and contains rutile inclusions. Potash feldspar (21%) and plagioclase – An_{37} – (53%) are the main constituents, with 9% zircon-bearing biotite (α = yellow brown, β = brown green, γ = dark green brown) and 5% twinned hornblende (α = yellow green, β = green, γ = dark green) being the ferromagnesian minerals. Magnetite, sphene, apatite and zircon make up the accessory minerals. Alteration products include minor "sericite", chlorite and epidote.

Dating of Rocks from the Bungonia District, New South Wales

P. F. CARR, B. G. JONES and A. J. WRIGHT

CARR, P. F., JONES, B. G., & WRIGHT, A. J. Dating of rocks from the Bungonia district, New South Wales. *Proc. Linn. Soc. N.S.W.* 104 (2), (1979) 1980: 111-117.

The lower part of the Bungonia Limestone contains fossils of Ludlovian (late Silurian) age but no age-diagnostic fauna has been identified from the upper part of the formation or from the overlying Tangerang volcanics. The K-Ar radiometric age determination reported in this study from the Tangerang volcanics (399 m.y.) appears to be too low, suggesting radiogenic argon loss. K-Ar radiometric data for rocks from the southern part of the Marulan Batholith yield a mean age of 398 m.y. (early Devonian). Since the Tangerang volcanics overlie the Bungonia Limestone and are intruded by the Marulan Batholith they are probably early Devonian. It is suggested that the Tangerang volcanics are a correlative of the Bindook Porphyry which is also intruded by the Marulan Batholith. The southern part at least of the Bindook Porphyry is therefore probably also early Devonian. Extrusion of the Tangerang volcanics, deformation of the Ordovician to early Devonian strata and intrusion of the Marulan Batholith are considered to have been related to the Bowning Orogeny.

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INTRODUCTION

Bungonia lies approximately 150 km southwest of Sydney near the western margin of the southern Sydney Basin. Rocks in the Bungonia district (Fig. 1) range in age from Ordovician to Devonian with a few erosional remnants of younger sedimentary and volcanic rocks. The Ordovician to Devonian strata were deposited in the eastern part of the Lachlan Fold Belt and have been described or mentioned by many earlier authors (*e.g.* Woolnough, 1909; Naylor, 1935, 1936, 1939, 1950; Packham, 1969; Moore, 1976).

The aim of the present study was to determine the age of the Bungonia Limestone, Tangerang volcanics and Marulan Batholith. This investigation provides new data derived from K-Ar dating and fossils. All radiometric age determinations presented in this study were carried out by S. Lafferty and D. C. Green using facilities at the Department of Geology and Mineralogy, University of Queensland and techniques outlined by Sutherland *et al.* (1973). The K-Ar ages have been calculated using the preferred decay constants of Steiger and Jäger (1977).

PRE-PERMIAN REGIONAL SETTING

The Ordovician sequence consists of multiply-deformed siltstones, cherts and quartzites yielding late Ordovician graptolites at a few localities (Naylor, 1935, 1938). Early Silurian shales and siltstones overlie the Ordovician rocks in a small area 6 km west of Bungonia (Naylor, 1935). East of Bungonia the Ordovician strata are unconformably overlain by, or faulted against, late Silurian limestones and shales (Woolnough, 1909) which contain corals, brachiopods, bryozoans, crinoids, nautiloids, trilobites and graptolites (Moore, 1976; Carr *et al.,* at press). Regionally the late Ordovician and late Silurian strata appear to occupy two asymmetrical meridional synclines reaching as far north as the Wombeyan Caves (Naylor, 1935,

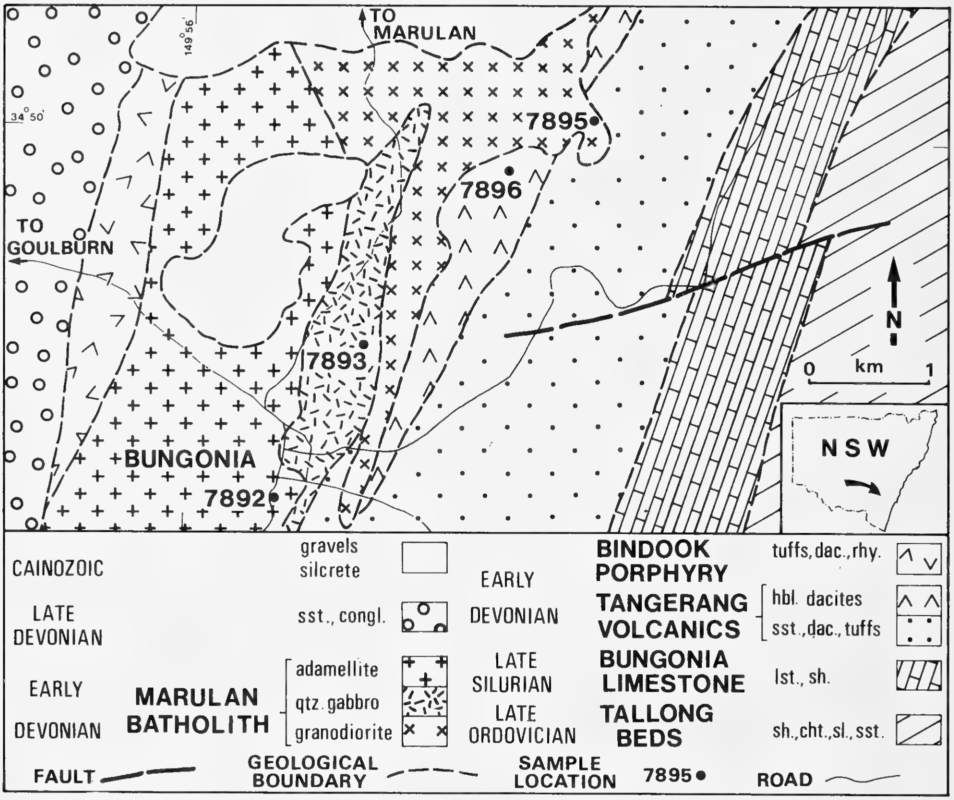

Fig. 1. Locality map and geology of the Bungonia area.

1950) and extending southwards to Windellama (Garretty, 1937) and Bendithera Caves (Packham, 1969). In the South Marulan area Wass and Gould (1969) have shown that the late Silurian limestones and shales are conformably overlain by the Tangerang volcanics which comprise dacites and tuffaceous sedimentary rocks. This sequence is known to extend southwards to Bungonia (Kantsler, 1973; Moore, 1976; Carr *et al.,* at press). Wass and Gould (1969) suggested that the Tangerang volcanics are late Silurian to early Devonian in age. Dacitic and tuffaceous outcrops of the Bindook Porphyry (McElroy and Relph, 1961; Packham, 1969) extend north from Marulan for approximately 70 km to Yerranderie and show many characteristics in common with the Tangerang volcanics. The age of the Bindook Porphyry is known on stratigraphic grounds to be between latest Silurian (Packham, 1969, p.134) and late Devonian (Powell and Edgecombe, 1978).

All the Ordovician and Silurian units have been intruded by the Marulan Batholith (Woolnough, 1909; Osborne, 1949) which is a composite body extending almost continuously from near Bungonia to about 8 km south of Bullio. The batholith contains a variety of rock types including granite, granodiorite and quartz-hypersthene porphyry (Osborne, 1949; Joplin *et al.*, 1952; Osborne and Lovering, 1953).

AGE DETERMINATIONS

Bungonia Limestone. Previous estimates of the age of the Bungonia Limestone, based largely on corals, were middle to late Silurian (Woolnough, 1909; Wass and Gould, 1969). More recently Moore (1976) suggested a late Silurian age based in particular on a graptolite fauna including *Bohemograptus bohemicus tenuis* (locality 1, Appendix I), and shelly fossils including encrinurid and phacopid trilobites and the brachiopod *Plectodonta bipartita* (locality 2, Appendix I). These fossils occur in the lower part of the Bungonia Limestone. Rickards *et al.* (1977, fig. 45), indicated that *B. b. tenuis* is late Ludlovian, ranging from the *leintwardinensis* zone to the *kozlowskii* zone. Conodont data (Pickett, 1972; Dean-Jones, *pers. comm.,* 1978) are in agreement with this late Silurian age. No age-diagnostic fossils have yet been identified from the upper part of the formation. Therefore the lower part of the Bungonia Limestone is late Ludlovian, and the uppermost beds should prove to be either latest Silurian or early Devonian.

Marulan Batholith. The Marulan Batholith intrudes the Bungonia Limestone near South Marulan (Osborne, 1931) and is unconformably overlain by late Devonian sedimentary rocks to the west of Bungonia (Naylor, 1939). Hence on stratigraphic grounds the batholith is younger than late Silurian but older than late Devonian. Evernden and Richards (1962) obtained a Carboniferous age (313 m.y.; recalculated using new constants) for biotite from the batholith and were aware of the anomaly as were Vallance (p.198, *in* Packham, 1969) and O'Reilly (1972). In the present study a biotite separate from each of three different phases of the batholith was dated (Table 1 and Fig. 1). The three age determinations are consistent with the sequence of emplacement demonstrated by field studies (*i.e.* granodiorite (oldest), quartz gabbro, adamellite), although when the errors (Table 1) are considered, there is no significant age difference between the three dates. The mean age for the emplacement of the southern part of the Marulan Batholith is 398 m.y. (early Devonian) which is consistent with its age on the basis of the local stratigraphy.

The age obtained for the southern part of the Marulan Batholith by Evernden and Richards (1962) is inconsistent with the stratigraphy and the ages obtained in the present study. Radiogenic argon was probably lost by the sample.

Tangerang volcanics. The only previous published reference to the age of the Tangerang volcanics is that of Wass and Gould (1969) who suggested a late Silurian to early Devonian age for the toscanites, tuffs and tuffaceous sandstones which appear to overlie the Bungonia Limestone conformably. In the Bungonia area the Tangerang volcanics consist of plane-bedded, cross-bedded or massive lithic to sublithic sandstones (tuffaceous in part) and thick lensoidal dacite and hornblende dacite units. The dacites in the upper part of the Tangerang volcanics contain hornblende phenocrysts which are absent from the lower dacites.

TABLE I

K-Ar data for igneous rocks from the Bungonia area

Sample Number	Rock type	Material dated	Latitude south	Longitude east	K_2O % (av.)	$^{40}Ar^*$ (10^{-5} cc/gm)	% $^{40}Ar^*$	Age (m.y.)
7892	adamellite	biotite	34°51.7'	149°56.5'	6.63	9.413	90.5	393 ± 7
7893	quartz gabbro	biotite	34°50.9'	149°56.9'	7.23	10.313	74.8	395 ± 8
7895	granodiorite	biotite	34°49.9'	149°58.2'	7.05	10.374	94.8	406 ± 7
7896	hornblende dacite	hornblende	34°50.1'	149°57.7'	1.12	1.616	93.4	399 ± 7

$\lambda_\beta = 4.962 \times 10^{-10}$ yr^{-1}; $\lambda_e + \lambda'_e = 0.581 \times 10^{-10}$ yr^{-1}; $^{40}K = 0.01167$ atom %

Errors are taken at the 95% confidence level.

Sample numbers refer to the University of Wollongong rock collection.

Fossils found within this unit (localities 3 and 4, Appendix I) indicate that it was at least partly deposited under marine conditions. However, the fossils, which are poorly preserved bryozoans, crinoid ossicles and rare corals, do not provide a refined age for the unit.

A K-Ar age determination was carried out on a hornblende separate from sample 7896 of the hornblende dacite (Table 1, Appendix II). The age of 399 m.y. is very close to the mean age obtained for the emplacement of the Marulan Batholith *which intrudes the volcanics*. Thus the 399 m.y. date for the Tangerang volcanics is probably too young to represent the age of extrusion of the hornblende dacite, and may result from loss of radiogenic Ar by the hornblende.

On the basis of the K-Ar ages for the Marulan Batholith, the Tangerang volcanics were extruded more than 398 m.y. ago. The maximum age of the formation is provided by the Bungonia Limestone, so the Tangerang volcanics must have been extruded during the early Devonian (or possibly the latest Silurian).

Woolnough (1909), Naylor (1935) and Osborne and Lovering (1953) considered the silicic volcanic rocks in the Marulan area (Tangerang volcanics of Wass and Gould, 1969) to be shallow intrusions and to be intimately associated in time, and possibly comagmatic, with the rocks of the Marulan Batholith. O'Reilly (1972), however, concluded that the Marulan Batholith and the silicic volcanics were 'discrete entities'. The new data show that the volcanics and the rocks of the batholith are indeed closely associated in space and time and a genetic relationship between the two, as suggested by earlier workers, is possible.

Bindook Porphyry. The Bindook Porphyry is a meridionally-trending belt of dacites, rhyolites, crystal and lithic tuffs and hypersthene porphyrites (McElroy and Relph, 1961). At Yerranderie only the upper dacite flows in the Bindook Porphyry contain biotite and hornblende (Joplin *et al.,* 1952). Jones *et al.* (1977) noted the abundance of ash-flow tuffs in the Yerranderie area and suggested that the dacites and tuffs are remnants of an early to middle Devonian volcano. Powell and Edgecombe (1978) concluded that late Devonian strata unconformably overlie the Bindook Porphyry near Yerranderie. O'Reilly (1972) described part of the western margin of the Bindook Porphyry (invalidly named 'Brayton Volcanics' as Brayton limestone [Naylor, 1950] has priority) as a series of extrusive toscanites and dacites and associated tuffs. She assigned (O'Reilly, 1972) a late Silurian to early Devonian age to the unit based on its apparent conformity with the Silurian sequence in the Brayton area, and the contact metamorphic effects where the Bindook Porphyry is intruded by part of the Marulan Batholith (Lockyersleigh adamellite).

It is suggested that the Tangerang volcanics are a correlative of the Bindook Porphyry based on the following:

(1) although the units are separated by intrusions of the Marulan Batholith, the Tangerang volcanics form a possible southerly extension of the Bindook Porphyry;

(2) both occupy a similar stratigraphic position in that at least part of each unit conformably overlies late Silurian limestones (Wass and Gould, 1969; O'Reilly, 1972); and

(3) both are similar, consisting of hypersthene-bearing acid volcanics, with hornblende dacites largely restricted to the upper parts of the sequences.

The suggested correlation of the Bindook Porphyry and Tangerang volcanics implies an early Devonian age (possibly extending to latest Silurian) for at least the southern part of the Bindook Porphyry.

IMPLICATIONS

The new stratigraphic and radiometric data contribute to our understanding of the Bungonia district. The unconformity below the late Devonian strata indicates that there was post-early Devonian folding. In terms of the orogenies recognized in this part of the Lachlan Fold Belt, this phase of folding could represent either the Bowning Orogeny or the Tabberabberan Orogeny. However, the K-Ar ages (mean 398 m.y.) indicate that the southern part of the massive Marulan Batholith was emplaced during the early Devonian. Thus the Bungonia area records the Bowning Orogeny which was responsible for movements occurring at the end of the Silurian and throughout the early Devonian (Packham, 1969). Associated with the orogeny in this area was the extrusion of the Tangerang volcanics, the subsequent folding of the Ordovician to early Devonian strata, and the intrusion of the batholith.

Acid volcanics of early Devonian age — which occur at Yarrangobilly, Canberra, south of Cowra, northwest of Forbes and west of Molong (Packham, 1969) — are possible correlatives of the Bindook Porphyry and Tangerang volcanics, as are the volcanics in the Bowning Group at Bowning (Link and Druce, 1972). In addition to the Marulan Batholith, other large granite and granodiorite batholiths including the Kosciusko Granite, the Murrumbidgee Batholith and the Gunning-Wyangala Batholith were emplaced during the Bowning Orogeny (Packham, 1969).

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APPENDIX I

FOSSIL LOCALITIES

Locality 1. Bungonia Limestone. Ludlovian (late Silurian). Grid reference 715365, Kooringaroo 1:25,000 Series Topographic Map. Fauna includes: trilobites, ? *Encrinurus* and cf. *Phacops crosslei;* brachiopods, *Plectodonta bipartita,* cf. *Visbyella.* Identifications by A. J. Wright.

Locality 2. Bungonia Limestone. Ludlovian (late Silurian). Grid reference 729396, Bungonia 1:25,000 Series Topographic Map. Fauna includes *Bohemograptus bohemicus tenuis.* Identification by G. H. Packham.

Locality 3. Tangerang volcanics. Possibly latest Silurian in part, probably early Devonian. Grid reference 005017, Caoura 1:31,680 Series Topographic Map. Fauna includes indeterminate crinoid ossicles, corals and bryozoans. Identifications by P. F. Carr and B. G. Jones.

Locality 4. Tangerang volcanics. Possibly latest Silurian in part, probably early Devonian. Grid reference 732427, Bungonia 1:25,000 Series Topographic Map. Fauna includes indeterminate corals and crinoid ossicles. Identifications by P. F. Carr and B. G. Jones.

APPENDIX II

Brief descriptions of samples dated by K-Ar method. Sample localities are specified by grid references from the Bungonia 1:25,000 Series Topographic Map.

7892 Medium- to coarse-grained adamellite consisting of K-feldspar, plagioclase, quartz, biotite, hornblende, apatite, zircon, sphene and iron-titanium oxides. Alteration has produced chlorite, sericite, epidote and prehnite. The biotite is slightly chloritized and contains minor prehnite. G.R. 689385.

7893 Medium- to coarse-grained quartz gabbro consisting of plagioclase, augite, biotite, hypersthene, hornblende, iron-titanium oxides, interstitial quartz and minor apatite and K-feldspar. Alteration has produced sericite, carbonate, fibrous amphibole and pyrite. The biotite is slightly chloritized. G.R. 697397.

7895 Medium- to coarse-grained granodiorite consisting of plagioclase, K-feldspar, quartz, biotite, hornblende, iron-titanium oxides, diopside, hypersthene, apatite and zircon. Alteration has produced chlorite, fibrous amphibole, prehnite, epidote and kaolinite. The biotite is slightly chloritized. G.R. 716416.

7896 Porphyritic hornblende dacite with phenocrysts of quartz, hornblende, plagioclase and hypersthene in a very fine-grained groundmass of quartz, plagioclase, K-feldspar, hornblende, biotite, hypersthene and iron-titanium oxides. Alteration has produced chlorite, sericite and kaolinite. The hornblende is slightly chloritized. G.R. 709412.

The Benthos of the Kosciusko Glacial Lakes

B. V. TIMMS

TIMMS, B. V. The benthos of the Kosciusko glacial lakes. *Proc. Linn. Soc. N.S.W.* 104 (2), (1979) 1980: 119-125.

Twenty-one macrobenthic species are recorded with a range of 8 to 12 species per lake. Common species include *Antipodrilus davidis*, the phreatoicid isopod *Metaphreatoicus australis, Chironomus ?oppositus* and *Pisidium tasmanicum*. The latter three species together with an unidentified gammarid amphipod are typical of highland lakes in south-eastern Australia. Relative numbers and distribution in the lakes appear to be influenced by fish predation.

Momentary biomass levels range from 2.4-14.9 g m^{-2} and in some lakes benthic production must be based largely on allochthonous organic matter.

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INTRODUCTION

Blue Lake, near Mt. Kosciusko, was one of the first Australian lakes to be dredged for benthic invertebrates; Hedley took samples from 28m there sometime during 1905/6. Descriptions of three worms (*Antipodrilus davidis, Branchiura pleurotheca* (= *Rhycodrilus coccineus*), *Phreodriloides notabilis*) and two endemic molluscs (*Glacidorbis hedleyi, Glacipisium kosciusko*) were subsequently published (Benham, 1907 and Iredale, 1943, respectively). There have been few further investigations on Blue Lake and the other nearby lakes (Cootapatamba, Albina and Club) despite their being the only glacial lakes in mainland Australia, and the highest in altitude (1890m, 2070m, 1920m, 1950m, respectively) in all Australia. Information is available on their physiography (Dulhunty, 1945), water chemistry (Williams, Walker and Brand, 1970), phytoplankton (Powell, 1970), zooplankton (Bayly, 1970) and on some other invertebrate inhabitants (e.g. Ball, 1977; Hynes and Hynes, 1975).

The present paper is concerned with the composition, diversity and standing crops of the benthic invertebrates of the lakes. Only the herpobenthos was sampled and attention was focused on macro-invertebrates. This paper is one of a series on the benthos of Australian lakes, aspects of which have recently been reviewed by Martin and Timms (1978), and Timms (in press).

METHODS

The lakes were visited during February 7-11, 1976. Sampling stations were chosen in each lake to represent the area and depth range as adequately as possible. In Blue Lake there were 7 stations at roughly 4m depth intervals from 1 to 26m. There were 8 stations in Lake Albina, 4 in each basin. Five stations were used in Cootapatamba but only two in the small Club Lake.

At each site quadruplicate samples were collected with a Birge Ekman grab of 200 cm^2 gape and sieved through mesh of aperture 0.4 mm. The organisms retained were sorted alive in the field and then preserved in 70% alcohol. This results in up to a 10% weight loss (Weiderholm and Erikson, 1977). In the laboratory the number of individuals of each species and the wet biomass of each taxonomic group were determined for each sample. In the preparation of samples for weighing, excess external water was blotted and the shells of molluscs removed beforehand. A mean weighted biomass was calculated for each lake by integration using bathymetric charts given in Dulhunty (1945).

Samples of the substrate were taken from the deepest station in each lake and stored at 5°C before drying. Then they were analysed for organic matter by % loss on ignition at 550°C and for %C and %N by the CSIRO Microanalytical Service.

SOME PHYSICOCHEMICAL FEATURES OF THE LAKES

The water of all four lakes is very fresh (salinity < 3 ppm) with a pH near 6 (Williams, Walker and Brand, 1970). Their water is transparent (eg. Secchi disc depth of *ca* 6m in Blue Lake). Seasonal temperature regimes are unknown, but all four freeze over for several months during winter; Blue Lake was stratified (11°C at surface and 8°C at 12m), Albina was weakly stratified while the two shallow lakes, Lake Cootapatama and Club Lake, were isothermal when visited in February. Thus at least two of the Kosciusko glacial lakes are of the warm thereimictic type (see Bayly & Williams, 1973) while Blue Lake is possibly dimictic and as such would be the only known example of this type on mainland Australia, though examples occur in highland Tasmania (P. Tyler, personal communication). There were no indications of hypolimnetic oxygen deficiencies in Blue or Albina.

TABLE 1

Some chemical characteristics of the lake muds

Lakes	Sample depth (m)	Organic Matter %	Carbon %	Nitrogen %	C/N ratio
Blue	26	12.1	5.21	0.56	9.30
Club	2	7.1	2.44	0.36	6.77
Albina	8.5	23.1	11.59	0.80	14.48
Cootapatamba	3	16.5	6.49	0.73	8.89

Bottom substrates were largely sandy-grit to sandy-mud in Lake Cootapatamba (except at stations > 2m) and at stations <1m in Club Lake and Lake Albina, and <5m in Blue Lake. In the latter visible organic detritus was particularly obvious in the 8 and 12m stations. Deeper stations in all lakes were of fine organic mud. Muds from the deepest stations in each lake had organic matter contents ranging from 7.1 - 23.1%, carbon contents 2.4 - 11.6% and nitrogen levels 0.36 - 0.80% (Table 1). Carbon/nitrogen ratios are <10 in Blue Lake, Club Lake and Lake Cootapatamba, but in Lake Albina the ratio is much higher (14.5) indicating considerable input of allochthonous organic matter (Hansen, 1959). The source of at least some of this could well be septic effluent from Albina Hut.

RESULTS

(a) *Blue Lake.* Twelve macrobenthic species were recorded from Blue Lake; the dominants were *Antipodrilus davidis, Chironomus ?oppositus* and *Glacipisidium kosciusko* (Table 2). At least two mesobenthic species — the ostracod *Candonocypris* n. sp. and the mite *Oxus australicus* Lundblad live associated with the bottom.

Number of species, abundance and biomass were greatest in the sub-littoral (Table 2). Despite the lake being relatively deep, there were no species restricted to the profundal, the common species there being the dominants. Mean weighted biomass was 12.3 g m^{-2}, with chironomids the most important contributor (63%) and oligochaetes next (25%).

TABLE 2

Blue Lake benthos — species present, their abundance (as individuals m^{-2}) and biomass with depth.

Species	1m	4m	8m	12m	16m	20m	26m
unidentified large nematode	—	—	11	—	—	—	—
Antipodrilus davidis Tubificidae n. gen.	177	499	1232	965	810	1209	477
Metaphreatoicus australis	—	11	399	11	11	—	—
Procladius sp.	—	11	78	33	11	11	33
Polypedilum nr *tonnoiri*	—	—	11	22	—	—	—
Chironomus ?oppositus	1132	3274	3951	3152	3340	2642	2120
Tasmanophebia nigrescens	—	11	—	—	—	—	—
Ramrheithrus dubitans	11	22	—	—	11	—	—
unidentified tipulid larva	22	—	—	—	—	—	—
Glacidorbis hedleyi	—	11	—	—	—	—	—
Glacipisium kosciusko	44	1100	1643	1798	739	480	242
Total Numbers (individual m^{-2})	1386	4939	7325	5981	4922	4342	2872
Total Biomass ($g\ m^{-2}$)	3.67	14.72	23.49	14.40	11.49	12.17	7.05

(b) *Club Lake*. Eight macrobenthic (Table 3) and three mesobenthic species (*Candonocypris* n. sp., the cladoceran *Biapertura affinis* and the copepod *Macrocyclops albidus*) were noted in the 8 grabs. *Chironomus ?oppositus* was dominant while *Pisidium tasmanicum* and unidentified turbellarian were common.

Mean weighted biomass was 2.4 g m^{-2} with chironomids the most significant contributor (60%).

TABLE 3

Club Lake benthos — species present, their abundance (as individuals m^{-2}) and biomass with depth.

Species	1m	2m
unidentified green turbellarian	855	355
unidentified large nematode	66	177
Antipodrilus davidis	344	89
Metaphreatoicus australis	—	11
Procladius sp.	33	111
Chironomus ?oppositus	1432	4074
Glacidorbis hedleyi	11	—
Pisidium tasmanicum	455	333
Total Numbers (as individual m^{-2})	3196	5150
Total Biomass (as $g\ m^{-2}$)	2.30	3.12

(c) *Lake Albina*. Both basins yielded nine species (Table 4). There were no significant differences in distribution patterns between the basins or at different depths. The phreatoicid isopod *Metaphreatoicus australis* and *Pisidium tasmanicum* were dominant, while *Antipodrilus davidis, Procladius villosimanus* and *Tanytarsus paskervillensis* were relatively important.

Isopods were the main contributor (91%) to the mean weighted biomass of 14.9 g m^{-2}.

(d) *Lake Cootapatamba*. Ten macrobenthic species and *Candonocypris* n. sp., were noted in the 20 grabs (Table 5). The dominant species numerically was *Antipodrilus davidis;* it and other common species including *Metaphreatoicus australis* and *Pisidium tasmanicum* occurred at all depths sampled.

TABLE 4

Lake Albina benthos — species present, their abundance (as individuals m^{-2}) and biomass with depth.

	South Basin				North Basin			
Species	0.5m	1m	2m	3.5m	3m	5m	6.5m	8.5m
Spathula truculenta	11	33	—	—	11	33	22	55
Antipodrilus davidis	22	11	311	644	344	455	888	533
unidentified gammarid amphipod	11	—	—	—	11	11	710	67
Metaphreatoicus australis	722	2387	1199	1265	444	533	1276	1210
Procladius villosimanus	56	244	400	588	211	211	255	233
Tanytarsus paskervillensis	—	11	200	544	322	11	11	33
Chironomus ?oppositus	—	—	44	56	33	66	122	89
Glacidorbis hedleyi	—	—	22	—	22	—	—	55
Pisidium tasmanicum	33	599	737	333	732	866	2309	3109
Total Numbers (individual m^{-2})	855	3285	2913	3430	2130	2186	5593	5384
Total Biomass (g m^{-2})	9.92	30.64	12.72	21.66	7.33	9.02	36.98	26.70

TABLE 5

Lake Cootapatamba benthos — species present, their abundance (as individuals m^{-2}) and biomass with depth.

Species	0.5m	1m	1.5m	2.2m	3m
unidentified green turbellarian	—	11	—	—	—
Antipodrilus davidis Tubificidae n. gen. *Dero furcatus*	1565	3052	577	1121	133
unidentified gammarid amphipod	477	55	155	78	67
Metaphreatoicus australis	388	178	311	444	200
Procladius villosimanus	—	—	11	33	56
Tanytarsus sp.	—	100	122	400	200
Chironomus ?oppositus	—	—	—	11	—
Austreithrus sp.	11	—	—	—	—
Pisidium tasmanicum	144	325	335	389	267
Total Numbers (individual m^{-2})	2585	3721	1511	2476	923
Total Biomass (g m^{-2})	10.37	9.13	10.33	9.77	5.64

Mean weighted biomass was 9.5 g m^{-2}, with isopods the most important (71%) and oligochaetes next (21%).

DISCUSSION

(a) *Community Structure*. Twenty-one macrobenthic species were collected from the four lakes, with a range of 8 to 12 in each (Table 6). Typically each lake contained a turbellarian, an oligochaete, an isopod, two to three chironomids including *Chironomus ?oppositus,* a snail and a sphaerid bivalve. This low diversity is typical of lakes in Australia (Timms, in press) but it is even less than "average" (cf. mean of 16.6 species in 16 lakes in lowland of south-eastern Australia and 21.3 in 7 Tasmanian lakes — Timms, 1978). Possible reasons for the general situation are given in Timms (in press), while in the case of the Kosciusko lakes, factors such as physicochemical harshness and small size (and hence high homogeneity) could restrict diversity further.

Most species listed in Tables 2-6 have been recorded from the area before, many as stream dwellers, e.g. the crustaceans, mayfly and caddisflies. In that the

TABLE 6

Presence and relative abundance of macrobenthic species in the Kosciusko Lakes. (Key: + + + + = very common, + + + = common, + + = present; and + = uncommon).

Species	Blue Lake	Club Lake	Lake Albina	Lake Cootapatamba
Platyhelminthes				
Spathula truculenta Ball			+	
unidentified green turbellarian		+ + +		+
Nematoda				
unidentified large nematode	+	+ +		
Oligochaeta				
Antipodrilus davidis	+ + +	+ +	+ + +	+ + + +
Tubificidae n. gen.				
Dero furcatus (Müller)				
Crustacea				
Metaphreatoicus australis	+	+	+ + + +	+ + +
unidentified gammarid amphipod			+ +	+ +
Insecta: Ephemeroptera				
Tasmanophlebia nigrescens Till.	+			
Insecta: Trichoptera				
Austrheithrus dubitans Mos.				+
Ramrheithrus sp.	+			
Insecta: Diptera				
Procladius villosimanus Kieffer			+ + +	+
Procladius sp.	+	+ +		
Tanytarsus paskervillensis Glover			+ +	
Tanytarsus sp.				+ +
Polypedilium nr. *tonnoiri* Freeman	+			
Chironomus ?oppositus Walker	+ + + +	+ + + +	+ +	+
unidentified tipulid larva	+			
Mollusca				
Glacidorbis hedleyi Iredale	+	+	+	
Glacipisium kosciusko Iredale	+ + +			
Pisidium tasmanicum Ten. Wood		+ + +	+ + +	+ +

inadequately described *Glacipisium kosciusko* appears to be synonymous with *Pisidium tasmanicum*, the presence of the latter is not new. Two notable absences are Benham's worms, *Rhycodrilus coccineus* and *Phreodriloides notabilis* which must be uncommon and easily overlooked or no longer present.

At least three new species have been found — a tubificid worm, a candonocyprid ostracod, and a gammarid amphipod. They are to be described in due course by the appropriate taxonomists (see acknowledgements).

Although there is a core of species common to all lakes, there is a marked difference in the distribution and relative abundance of some species between Blue and Club Lakes in which the mountain minnow *Galaxias findlayi* is common and Lakes Albina and Cootapatamba which lack fish (Table 6). To illustrate, *Chironomus ?oppositus* is abundant, *Metaphreatoicus australis* uncommon and the gammarid amphipod not present in the benthos of Blue and Club Lakes, while in Lakes Albina and Cootapatamba, *Chironomus ?oppositus* is uncommon, *Metaphraetoicus australis* very common and the amphipod is present. A continuing study on the littoral fauna of the lakes (Timms, unpublished) is revealing other differences in the distribution and relative numbers of invertebrates and tadpoles in the two lake groups, while Hebert (1977) notes the absence of the large planktonic cladoceran, *Daphnia nivalis* (syn. *D. alpina*) from the two lakes with fish. It seems then, that predation by fish is an important determinant of community structure in these lakes, as it is some lakes elsewhere (eg. Tuunainen, 1970).

(b) *Zoogeography.* Of the species identified only a few (e.g. *Procladius villosimanus, Antipodrilus davidis*) are common components of benthic communities of Australian lakes. Five species, *Metaphreatoicus australis, Tasmanophlebia nigrescens, Austrheithrus dubitans, Spathula truculenta,* and *Glacidorbis hedleyi* are restricted to the highlands of south-eastern Australia. There appear to be no endemic species, unless the undescribed or unidentified species are.

All the dominant species (*Metaphreatoicus australis, Chironomus ?oppositus, Pisidium tasmanicum*) and many of the common ones belong to a group important in Lake Tarli Karng (the only other deep lake in the highlands of southeast mainland Australia; Timms, 1974) and in the highland Tasmanian lakes investigated by Timms (1978). This reinforces the biographical relationships between the highland areas of south-eastern Australia noted for other communities.

(c) *Biomass.* Taken that the mean biomass figures for the lakes are not annual means, but momentary values, and that the figures for Lakes Cootapatamba and Albina may be elevated due to lack of fish predation (by up to a factor of 2 — Kajak, 1972) the figures for all lakes except Club are unexpectedly high for lakes which on other criteria (e.g. water chemistry, sparse phytoplankton) appear oligotrophic. It seems this is because benthic production is based largely on allochthonous organic matter input (cf. Bretschko, 1975).

Although no data are available on organic matter input, particulate input must be significant at least in Blue Lake and Lake Albina where partly decomposed leaves and twigs were commonly recovered from samples; additionally in Lake Albina, the septic effluent from Albina Hut probably adds organic matter. Percent organic matter is greatest in Lake Albina mud where the C/N ratio indicates considerable input of allochthonous matter and least in Club Lake where the flushing of the lake prevents any accumulation. Mean biomass figures apparently reflect the levels of organic matter in the four lakes (Table 7). However the correlation is not statistically significant ($r = 0.840$ $P = 0.05$). By comparison, some other lakes at high altitudes in southeastern Australia e.g. Lakes St. Clair, Dobson, Tarli Karng (Timms, 1974, 1978) also have considerable allochthonous organic matter input and associated higher benthic standing crops than expected on other criteria.

The dominant contributors to biomass in each lake are surface feeding detritivores — *Metaphreatoicus australis* in Lakes Cootapatamba and Albina and *Chironomus ?oppositus* in Blue and Club Lakes. Oligochaetes and molluscs (almost

TABLE 7

Percentage contribution to total biomass by species according to eight taxonomic groupings.

Parameter	Cootapatamba	Albina	Club	Blue
% organic matter in mud	16.5	23.1	7.1	12.1
Mean Standing Crop (g/m^2)	9.48	14.87	2.44	12.31
% contribution to biomass				
Planarians	0.1	0.1	12.2	
Oligochaetes	20.5	3.5	14.2	24.5
Phreatoicids	70.6	91.3	0.4	4.0
Amphipods	6.4	1.1		
Chironomids	0.4	2.7	59.7	62.9
Snails		0.1		0.1
Bivalves	1.8	1.2	12.9	7.8
Others	0.2		0.6	0.7

entirely of sphaerid bivalves) are relatively important in at least two lakes (Table 7). It is the importance of *Chironomus ?oppositus*, crustaceans and sphaerid bivalves which characterize the Kosciusko glacial lakes, separating them from lakes of lowland eastern Australia where these taxa are absent or unimportant (Timms, in press) and even from highland Tasmanian lakes, where although *Chironomus ?oppositus* and crustaceans are often important, sphaerid bivalves usually are not (Timms, 1978).

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Living Australian Schizasterid Echinoids

K. J. McNAMARA and G. M. PHILIP

McNamara, K. J., & Philip, G. M. Living Australian schizasterid echinoids. *Proc. Linn. Soc. N.S.W.* 104 (2), (1979) 1980:127-146.

Seven schizasterid echinoid species are recognized from Australian waters. Four of these *Schizaster (Ova) myorensis, S. (Ova) portjacksonensis, S. (Schizaster)* sp. A and *S. (Schizaster)* sp. B are new. The ontogenetic development of *S. (Ova) myorensis* is described and discussed. *Schizaster* is re-interpreted and emended. *Diploporaster* Mortensen 1951 is considered a synonym of *S. (Ova)* Gray 1825; and *Hypselaster* H. L. Clark 1917 a synonym of *Proraster* Lambert 1895.

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INTRODUCTION

The living irregular echinoids of Australia are poorly known. Since H. L. Clark's (1921, 1932, 1938, 1946) monographs, description of Australian echinoid faunas has been in abeyance. Moreover, Clark dealt largely with a few, poorly localized museum specimens. Detailed taxonomic and ecological work on the irregular echinoids is urgently needed. This paper aims to rectify the situation to a small degree by describing the schizasterid echinoids of Australia. They comprise three genera: *Schizaster, Proraster* and *Moira*. Previously (H. L. Clark, 1921, 1932, 1946; Mortensen, 1951; Endean, 1961) the only species of *Schizaster* to have been recorded from Australian waters was *S. lacunosus* (Linnaeus). We propose to show that a further four species of this genus are present, and that the distribution of *S. lacunosus* is much more restricted than hitherto considered.

Two species of *Ova,* a subgenus of *Schizaster,* are described: one from Moreton Bay, Queensland, based on relatively large, well-localized collections made by Dr. R. Endean and by Professor W. Stephenson of the University of Queensland; the other is based on two specimens collected from Port Jackson, N.S.W. and housed in the Australian Museum. In the past, species of *Schizaster* have been described on the basis of small numbers of specimens. The large collection of the Moreton Bay species has allowed a detailed description and enabled us to study both intraspecific variation within adults of the same population, and the ontogenetic development of the species. Two new species of *Schizaster* (s. s.) from northern Queensland are described. As each is known only from a single, incomplete test, open nomenclature is employed. In the light of this paper it is to be hoped that more collections will be made of the species to allow them to be named formally. In addition, H. L. Clark's (1938) "*Hypselaster dolosus*" from Western Australia is discussed and re-interpreted.

Species of *Schizaster* occur as far as 35°S on the eastern coast of Australia, but only as far south as 21° on the west. *Moira* occurs around the entire Australian coastline. *Proraster* is confined to warm seas although again extending further south on the east (27°S) than on the west (18°S).

SYSTEMATIC DESCRIPTIONS

Family SCHIZASTERIDAE Lambert, 1905

According to Mortensen (1951) and Fischer (1966) representatives of the family Schizasteridae possess both peripetalous and lateroanal fascioles. However, a number do not possess both fascioles. In *Proraster* the lateroanal fasciole may be incomplete or absent. The genus *Abatus*, which Mortensen (1951, pp. 250-251) placed in the Schizasteridae, possesses a lateroanal fasciole in the juvenile stage, but this is lost in adults. *Amphipneustes* lacks both peripetalous and lateroanal fascioles, yet is also included with Mortensen's and Fischer's Schizasteridae. In *Brisaster* the lateroanal fasciole may be reduced or lost in the adult (Mortensen, 1951, p. 280). Both *Tripylus* and *Parabrissus* possess an incomplete lateroanal fasciole; in *Parabrissus* the lateroanal fasciole is "not observed" (Mortensen, 1951, p. 348).

The work of Kermack (1954) and Nichols (1959) suggests that fascioles are not such an important taxonomic feature of spatangoids as has hitherto been considered. The genera included within Mortensen's and Fischer's Schizasteridae can be separated into groups based on a combination of morphological characters. As is discussed in more detail elsewhere (McNamara and Philip, 1980) we prefer to describe as schizasterid echinoids genera with the gross test features of *Schizaster*, *i.e.* the genera *Brisaster* Gray 1855, *Kina* Henderson 1975, *Moira* Agassiz 1872 (= *Moiropsis* Agassiz 1881), *Proraster* Lambert 1895 (= *Hypselaster* H. L. Clark 1917) and *Schizaster* Agassiz 1838 with subgenera *Dipneustes* Arnaud 1891, *Paraster* Pomel 1869, and *Ova* Gray 1825 (= *Diploporaster* Mortensen 1951). The term is therefore used in a much more restricted sense than either Mortensen (1951) or Fisher (1966). Our current revision of other fossil and living spatangoids should allow formal recognition of the group as a separate family.

Genus *SCHIZASTER* Agassiz 1836

Type Species. Schizaster studeri Agassiz 1836, p. 185; by subsequent designation of the Thirteenth International Congress of Zoology in Paris; opinion 209, 1948 (*Bull. Zool. Nomenclature* London, vol. 4, p. 527).

Emended diagnosis. Apical system located posteriorly of centre; with two to four genital pores. Ambulacrum III and anterior notch shallow to deep and with pore pairs arranged in single or double rows. Anterior petals at least twice length of posterior petals. Peripetalous and lateroanal fascioles both present and complete.

Remarks. A number of schizasterid genera have, in the past, been distinguished largely on the number of genital pores. For instance, *Schizaster* was characterized by Mortensen (1951) as possessing two genital pores, *Brisaster* three and *Paraster* four. Likewise *Diploporaster* was considered to be generically distinct from *Ova* as it possessed four genital pores, whereas *Ova* was considered to have only two; though why *Diploporaster* should have gained generic rank (Fischer, 1966) whereas *Ova* was regarded as a subgenus of *Schizaster* is unclear. Likewise *Paraster* has sometimes been considered to be only a subgenus of *Schizaster* (Kier, 1957; Henderson, 1975).

Pomel (1869) proposed *Paraster* as a genus for species previously referred to *Schizaster* which possessed four genital pores. However, whether the type species of *Schizaster, S. studeri,* has two or four genital pores remains uncertain. Cotteau (1886, p. 36) thought it had four, though Mortensen (1951, p. 287), thought it had but two. Accordingly, Mortensen characterized *Schizaster* as possessing two genital pores and *Paraster* as having four, irrespective he said, of whether or not the *S. studeri* was found to include specimens with four genital pores. Henderson (1975, p. 14) believed that *S. studeri* would "probably prove to have four gonopores" but employed *Schizaster* for species with only two.

Mortensen considered the number of genital pores to be of generic importance, even though he noted that *Abatus phillipi* Loven may equally often have two or four. Lambert and Thiéry (1924) did not use the number of genital pores as a generic character. Likewise Duncan and Sladen (1882), Currie (1925) and Cooke (1942) have considered this feature to be of only specific importance. Kier (1957) "for the sake of convenience" referred species with four genital pores to the subgenus *Paraster,* even though he noted intraspecific variation in the number of genital pores in many echinoids. More recently both Chesher (1966) and Kier (1975) have reverted to regarding forms with four genital pores as generically distinct from those with two.

The growth and development of *S. (Ova) myorensis* sp. nov. shows that at the onset of sexual maturity the posterior pair of genital pores appears first, followed, in most cases, by one of the anterior pair, then the other. However, in some specimens either one, or both, of the anterior pair may fail to develop. Consequently, most members of the population studied possess four genital pores, about 14% have three, and a similar percentage produced only two; these specimens are all large adults.

We believe, however, that it is useful to distinguish *Paraster* as a morphological subgenus of *Schizaster*, but not on the basis of the number of genital pores. Based on the morphology of the respective type species, *Paraster* is employed for species which differ from typical species of *Schizaster* s. s. in having a shallower ambulacrum III, a more circular test, a less posteriorly-situated apical system, and straighter anterior ambulacral petals which diverge more strongly. The pore pairs in ambulacrum III are set more transversely in *Schizaster* s. s. The evolutionary relationship of the subgenera is discussed elsewhere (McNamara and Philip, 1980).

Key to the Australian schizasterid genera

1.	Lateroanal fasciole rudimentary or absent	*Proraster*
	Lateroanal fasciole entire	2.
2.	Pore-pairs in ambulacrum III in irregular double series	*Schizaster (Ova)*
	Pore-pairs in ambulacrum III in regular single series	3.
3.	Petals broad and open	*Schizaster (Schizaster)*
	Petals narrow and very deep	*Moira*

Key to the Australian species of *Schizaster*

1.	Pore-pairs in ambulacrum III in irregular double series	2.
	Pore-pairs in ambulacrum III in regular single series	3.
2.	Four genital pores and relatively long posterior petals	*S. (Ova) myorensis*
	Two genital pores and relatively short posterior petals	*S. (Ova) portjacksonensis*
3.	Paired petals narrow, anterior pair weakly flexed distally; labrum short and broad	*S. (Schizaster)* sp. nov. B
	Paired petals broad	4.
4.	Anterior petals strongly flexed distally	*S. (Schizaster)* sp. nov. A
	Anterior petals not flexed distally	*S. (Schizaster) lacunosus*

Subgenus *SCHIZASTER* Agassiz 1836

Diagnosis. Pore pairs in ambulacrum III arranged in regular single series in both juvenile and adult stages.

Schizaster (Schizaster) lacunosus (Linnaeus 1758)

(Fig. 1)

Material and locality. A single, complete specimen (WAM 1488.75) dredged from a depth of 4-5 m outside Norbill Bay, Rosemary Island, Dampier Archipelago, Western Australia and an incomplete specimen (MCZ 6066) from the lee of Turtle Island at 8 fathoms, collected on the Great Barrier Reef Expedition 1928-29.

Description. Test length of W.A. specimen 23.5 mm; test broad, maximum width 87.5% test length, and high, maximum height 65.4% test length. Apical system with

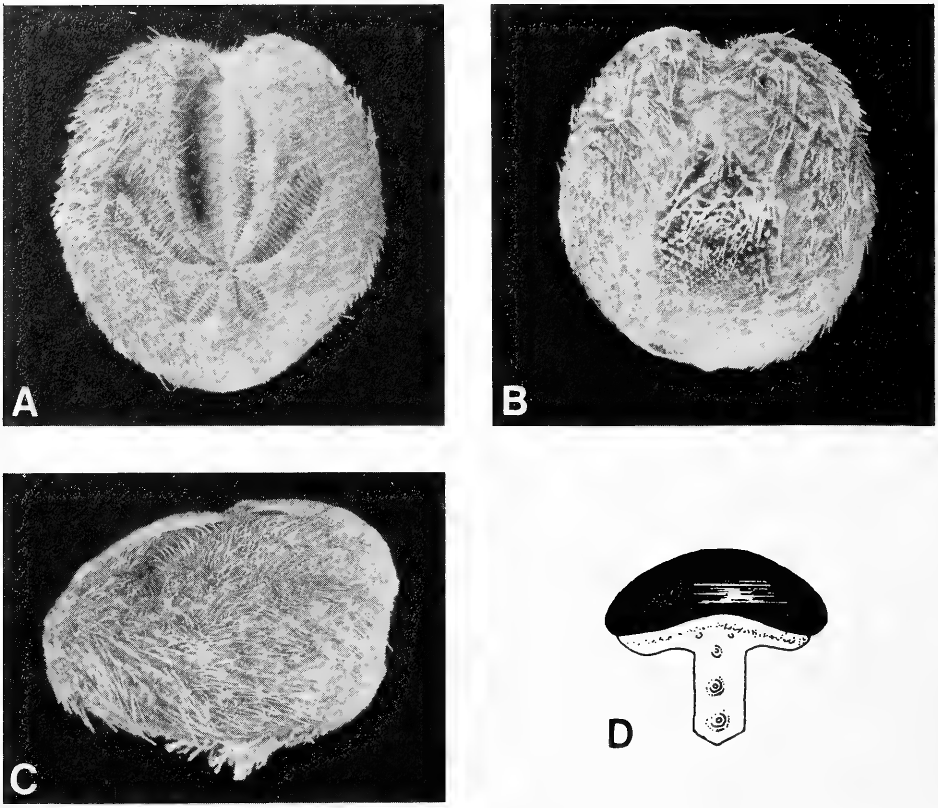


Fig. 1. Schizaster (Schizaster) lacunosus (Linnaeus 1758) WAM 1488.75, from Norbill Bay, Rosemary Island, Dampier Archipelago, Western Australia. **A**, aboral view; **B**, adoral view; **C**, lateral view; all x2. **D**, labrum of *Schizaster (Schizaster) lacunosus* (Linnaeus 1758) WAM 1488.75. x7.

two genital pores, situated 57.5% test length from anterior margin. Ambulacrum III broad and deep, with 29 pore pairs arranged in single series. Anterior notch broad and moderately indented. Anterior petals progressively widen adapically, reaching a maximum width of 11.5% test length; not reflexed distally; diverging at approximately 85°. Posterior petals broad and short, one third length of anterior petals. Interambulacra 2 and 3 forming keels adapically. Peripetalous fasciole broad and extending to 9% test length from apical system in interambulacrum 1. Lateroanal fasciole narrow and passing 11% test length below periproct.

Plastron narrow, occupying 46% width of test. Labrum very narrow and long posteriorly (Fig. 1D); anteriorly acuminate medially and projecting sharply anteroventrally; anterior of labrum situated 17% test length from anterior margin of test. Peristome wide, 22.5% test length.

Discussion. This species has previously been recorded in Australian waters from Madge Reefs, Thursday Island, Queensland (Clark, 1921, p. 153) and from Turtle Isles in the Great Barrier Reef (Clark, 1932, p. 219). The record from Madge Reefs (MCZ 4147) comprises two broken specimens, neither of which is *S. (Schizaster) lacunosus,* one being an indeterminate species of *S. (Ova)*, the other being *Proraster jukesii.* The Turtle Island specimen is, however, confirmed as being *S. (Schizaster) lacunosus,* and consequently represents the only known example of this species from eastern Australia.

H. L. Clark (1946, p. 368) considered that *S. lacunosus* was absent from Western Australia, being replaced by *"Hypselaster dolosus"*. The specimen of *S. (Schizaster) lacunosus* from Rosemary Island extends the known range of *S. (Schizaster) lacunosus* from the Japan and China seas (Mortensen, 1951, p. 303) to Western Australia. A. M. Clarke and Rowe (1971, p. 149) question the accuracy of Mortensen's (1951, p. 303) record of *S. (Schizaster) lacunosus* from the Maldives; thus the species is probably restricted to the western Pacific region and Queensland. The specimen from Natal, South Africa referred to *S. (Schizaster) lacunosus* by Mortensen (1951, p. 303, Pl. 21, figs 5, 6) differs from typical specimens of *S. (Schizaster) lacunosus* in its more posteriorly located apical system, relatively shorter petals, less anteriorly divergent petals and longer ambulacrum III.

Schizaster (Schizaster) sp. nov. A.

(Figs 2A-C, 3A)

Material and locality. A single specimen, QM G2178, from North Keppel Island, Queensland.

Diagnosis. Test moderately depressed, with deep, but broad anterior notch; test vertically truncated posteriorly. Apical system posteriorly located about two-thirds test length from anterior; bears four genital pores. Ambulacrum III deep and broad, with steep sides. Anterior petals broad and strongly curved; posterior petals short and broad. Labrum long and narrow.

Description. Test is large (test length 63.5 mm); width of test 88% its length; test height 58.5% test length. Test highest posterior to apical system at keel of interambulacrum V (Fig. 2C). Posterior face of test almost vertical. Apical system ethmolytic, depressed, with four genital pores, posterior pair being much larger than anterior pair. Ambulacrum III long, deep and wide (13.3% test length); pore pairs arranged in a single row. Outer pores elongate and larger than inner pores. Anterior notch broad and deep. Interambulacra II and III form sharp, high keels. Anterior petals strongly flexuous and broad (Fig. 2A), being 10.5% test length wide and bearing pore pairs which are subcircular, widely spaced and conjugate; 38 pairs are

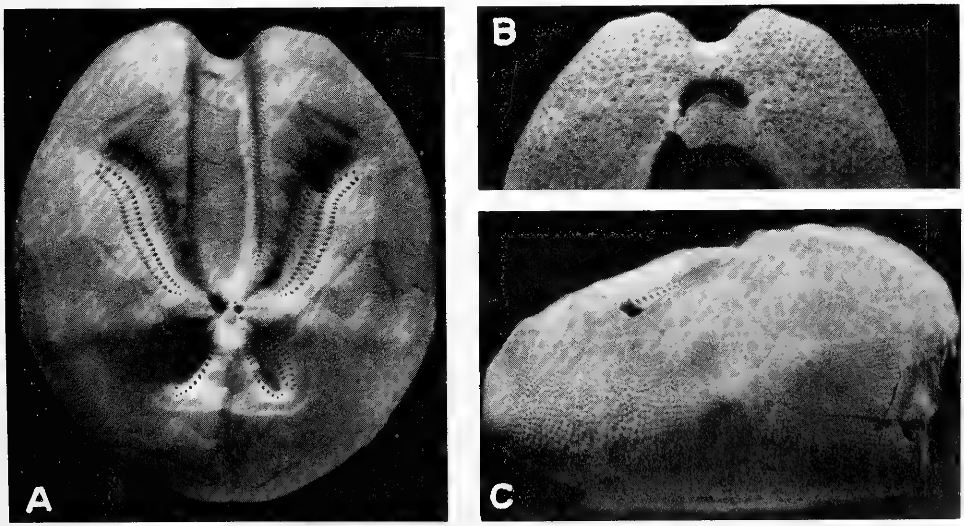


Fig. 2. Schizaster (Schizaster) sp. nov. A, QM G2178, from North Keppel Island, Queensland; **A**, aboral view; **B**, adoral view of anterior part of test; **C**, lateral view; all x1.

present. Posterior petals moderately long (occupying 16.5% test length) and broad, bearing 23 pore pairs.

Peripetalous fasciole transverse posteriorly; in form like that of *S. (Ova) myorensis.* Lateroanal fasciole extends in a straight line across posterolateral part of test, extending close to ambitus posteriorly. Peristome hardly sunken; anterior tip of labrum set 17.5% test length from anterior and projecting anteriorly. Labrum with anterior rim poorly developed; medially acuminate; posteriorly long, narrow and parallel-sided (Fig. 3A); covered by small tubercles anteriorly and by larger ones posteriorly. Plastron incompletely known, but thought to have been rather narrow, width being approximately 70% of the length.

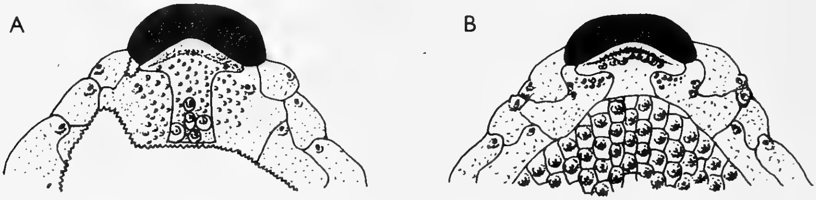


Fig. 3. Labrum and adjoining ambulacral plates of, A, *Schizaster (Schizaster)* sp. nov. A, QM G2178, from North Keppel Island, Queensland, x2. **B**, *Schizaster (Schizaster)* sp. nov. B, QM G12092, from Stone Island, Edgecumbe Bay, Queensland, x2.

Discussion. S. (Schizaster) sp. nov. A compares closely with the specimen from South African waters figured by Mortensen (1951, Pl. 21, figs 5, 6) and referred by him to *S. (Schizaster) lacunosus* (see above). However, it differs in possessing a more parallel-sided ambulacrum III, more strongly reflexed anterior petals, and by its possession of an anterior pair of genital pores, in addition to the large posterior pair. *S. (Schizaster)* sp. nov. A differs from *S. lacunosus* in possessing a greater number of genital pores, more distally reflexed and less divergent anterior petals, deeper anterior notch and broader labrum. *S. (Schizaster) edwardsi* Cotteau, from the Gulf of New Guinea (Mortensen, 1951, Pl. 21, figs 1-4, ?11-13) is similar to the Queensland species, but has only two genital pores, a more posteriorly positioned peristome and a constricted labrum.

Schizaster (Schizaster) sp. nov. B
(Figs 3B, 4A-D)

Material and locality. A single specimen QM G12092 collected by Dr. E. Frankel from the spit at the southern end of Stone Island, Edgecumbe Bay, Queensland.

Diagnosis. Paired petals narrow, anterior pair relatively straight; posterior pair long, half length of anterior pair. Anterior notch deep and narrow. Apical system only slightly posterior of centre, with four genital pores. Labrum very short and broad, projecting only weakly anteriorly; anterior rim poorly developed.

Discussion. S. (Schizaster) sp. nov. B differs from *S. (Schizaster)* sp. nov. A in possessing straighter, narrower anterior petals; longer (22.2% test length compared with 16.4%), narrower posterior petals; a more centrally located apical system; a shorter, broader labrum (Fig. 3B); and a broader plastron. The lateroanal fasciole follows the contours of the test more closely in *S. (Schizaster)* sp. nov. B initially, before it bends through 90° close to the posterior of the test to run ventrally and pass below and close to the periproct.

S. (Schizaster) sp. nov. B can be distinguished from *S. (Schizaster) lacunosus* by its apical system, which bears four genital pores, unlike *S. (Schizaster) lacunosus* which only has two. Although broken, the apical system of *S. (Schizaster)* sp. nov. B

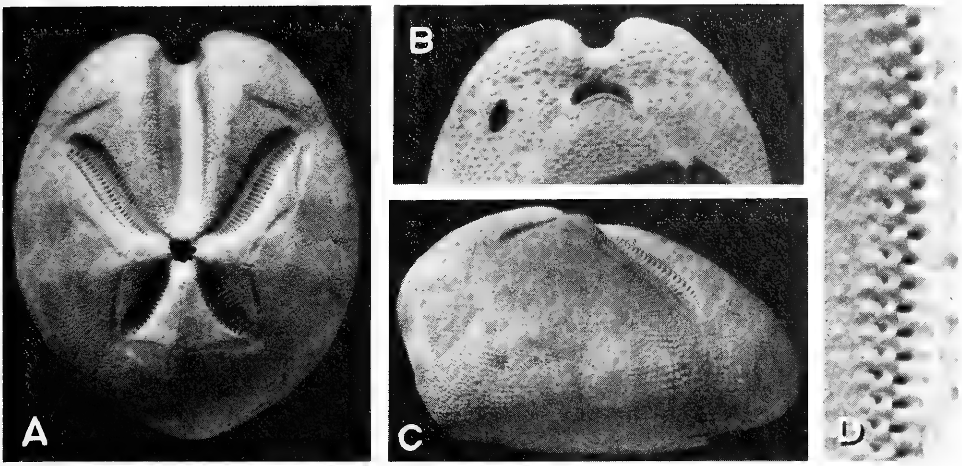


Fig. 4. Schizaster (Schizaster) sp. nov. B, QM G12092 from Stone Island, Edgecumbe Bay, Queensland; **A**, aboral view; **B**, adoral view of anterior part of test; **C**, lateral view; all x1; **D**, pore pairs of ambulacrum III, x8.

shows the outer part of a large posterior pore and a smaller anterior pore, indicating the possession of four genital pores. *S. (Schizaster)* sp. nov. B can further be distinguished by its narrower paired petals and deeper anterior notch, longer posterior petals, more distally reflexed anterior petals and broader labrum.

Subgenus *OVA* Gray 1825

Emended diagnosis. Species of *Schizaster* with pore pairs in ambulacrum III arranged in irregular double series in adult stage.

Remarks. H. L. Clark (1917, 1925) resurrected Gray's (1825) *Ova* for *Spatangus canaliferus* Lamarck 1816. Although Mortensen (1951, p. 308) recognized that the nature of the poriferous tract of ambulacrum III precluded placing *canaliferus* in *Schizaster,* he preferred to regard *Ova* as a subgenus of *Schizaster,* a course followed by Fischer (1966, p. U569). Within the various *Schizaster*-like forms from eastern Australia, the pores form either a distinct single series or a very irregular double series. The juvenile stage of *Ova* possesses a single row of pores, like *S. (Schizaster);* the irregular double row develops with growth in the adult stage of *Ova,* but remains single in *Schizaster.* Mortensen and Fischer are herein followed in regarding *Ova* as a subgenus of *Schizaster,* as its single differentiating character only appears in the adult stage.

The number of genital pores is thought not to be a generic characteristic of the Schizasteridae; likewise the nature of the pore pairs is thought to be of less than generic significance.

Schizaster (Ova) myorensis sp. nov.
(Figs 5A-E, 7A-C, 8A-C, 9A)

1961 *Schizaster lacunosus* Linnaeus; Endean, p. 294

1978 *Schizaster lacunosus* Linnaeus; Stephenson *et al.,* p. 207.

Holotype. QM G12063 from Myora, Moreton Bay, Queensland.

Paratypes. QM G3870-1, 11826-8, 12064-6, 12094, 12428-45 from Myora, Moreton Bay, Queensland, QM G11826-8, 12065-6, 12446-8 from Middle Banks, Moreton Bay, Queensland and QM G3809 from Dunwich, Moreton Bay, Queensland.

Material and localities. Forty one specimens are available for this study, ranging in size from a test length of 7.0 mm to 71.2mm; only twenty eight were undamaged and could be measured. Six of the specimens were in a pre-adult stage, the remainder are adults. Thirty of the specimens were collected by Dr. R. Endean in 1960 from sandy mud near the "Black Beacon" at Myora in Moreton Bay. Dr. Endean (pers. comm. 26.9.78) informs us that the specimens were dug from burrows, which extended to 10 cm below the surface of the intertidal flat, approximately L.W.N. to L.W.S. One specimen was found burrowing in muddy sand at L.W.N. at Dunwich in Moreton Bay. Nine specimens were collected by Professor W. Stephenson in 1972 from sites 34, 43, and 51 on Middle Bank, Moreton Bay (Stephenson *et al.,* 1978, Fig. 2). Professor Stephenson (pers. comm. 19.9.78) informs us that site 34 was at a depth of 11±2 fathoms; sites 43 and 51 at 15±2 fathoms. The depth of burial of the specimens is not known. This species forms part of the *Schizaster — Nucula — Prionospio* community of Stephenson *et al.* (1978, p. 199). This community occurs in the south-western part of Middle Banks, where the sediment has the highest mud content found in the area (16% mud and 76% fine sand).

Diagnosis. Anterior ambulacral petals long and flexuous; posterior petals long. Interambulacra strongly keeled adapically. Apical system with two to four genital pores. Peristome situated well back from anterior of test. Labrum projects strongly forward; moderately broad and parallel-sided posteriorly.

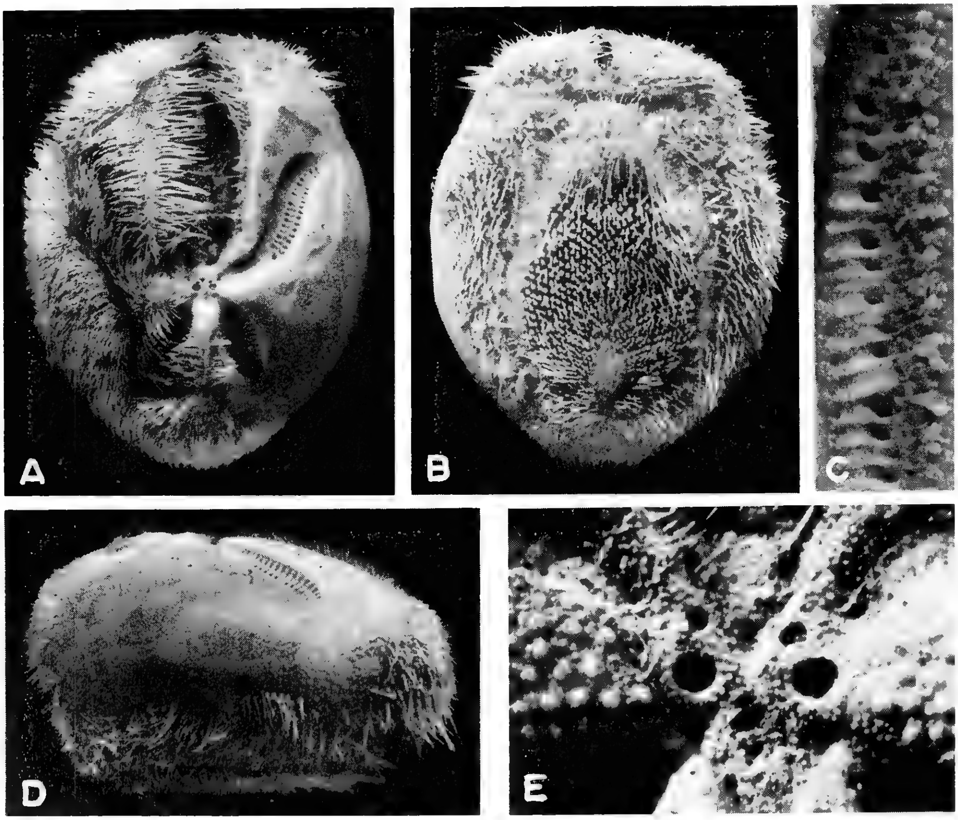


Fig. 5. Schizaster (Ova) myorensis sp. nov. **A, B, D,** aboral, adoral and lateral views, respectively, of holotype, QM G12063 from Myora, Moreton Bay; all x1; **C,** irregular double pore pairs of ambulacrum III, QM G12094, paratype, from Myora, Moreton Bay, x7. **E,** apical system of QM G3809, paratype, from Dunwich, Moreton Bay, x8.

Description. The test, which reaches a maximum known test length of 71.2 mm, is very variable in shape. Although being always longer than broad, there is up to 15% variation, width of test varying in adults between 74% and 91% of test length (Fig. 6B). Similarly maximum height of test varies, being between 53% and 63% of test length in adults (Fig. 6A). Widest part of test is at half test length; highest part of test is posterior to apical system, at about 25% test length from posterior. Aboral surface declines anteriorly at 15°. Posteriorly keeled interambulacrum V overhangs periproct. Anteriorly a deep notch is present in test. Apical system is depressed and set posterior of centre, between 55% and 62% of test length from anterior; ethmolytic. Of thirty five adult specimens studied, twenty six possess four genital pores, four had produced only three, while five specimens have only two. Posterior pair of genital pores are larger and more widely spaced than anterior pair. Smaller anterior pair may be set close to, and conjoined with, the posterior pair (Fig. 5E). Madreporite long, extending past posterior oculars. Ocular plates are triangular.

Ambulacrum III is long, deep and wide. From apical system it declines steeply anteriorly initially and progressively widens; it reaches its maximum width (12% to 20% of test length) and maximum depth at mid-length; rises gently and constricts a little anteriorly to deep anterior notch; it is sunken to peristome. Slightly obliquely orientated pore pairs are arranged in an irregular double series (Fig. 5C). The outer pores of the series are tear-shaped. The outermost pore is large, whilst its partner is small and shallow. Both are surrounded by a narrow, raised rim. Pores are conjugate but separated by a swollen interporal partition. The inner pore pairs of the double series are smaller than outer pores; they are equidimensional. Ambulacral plates often occluded in region of poriferous zone. Pore pairs form a single series abapically close to where peripetalous fasciole meets ambulacrum III. Anterior to this there are only four single pores to peristome. Funnel-building tube feet not fully developed close to apical system; fully developed tube feet densely concentrated toward the peripetalous fasciole and bearing discs which carry approximately twenty papillae.

Ambulacra II and IV aborally petaloid, sunken, long and sinuous, being reflexed distally. They occupy a length of between 40% and 46% of test length (measured in a straight line from apical system to abapical extremity of petal). Number of pore pairs variable, ranging from 33 to 47 in adults from 40 mm to 60 mm test length, respectively. Pore pairs transverse to axis of petal; conjugate; each pore separated by width equal to diameter of three pores. Pores contain simple respiratory tube feet. Interporiferous zone equal in width to that of poriferous zone. Petals overhung adapically by interambulacra. Width of petals 8% to 13% of test length; angle of divergence approximately 80°; distance between abapical extremities 48% to 58% test length.

Ambulacra I and V aborally petaloid, sunken, straight and up to one-half length of anterior paired petals. They occupy a length of between 16% and 23% of test length in adults. Number of pore pairs ranges between 19 and 27 in specimens of test length 40 mm to 60 mm, respectively. Form of pore pairs like those of anterior paired petals. Petal width varies between 7% and 11% of test length. They diverge posteriorly at approximately 75%. Distance between abapical extremities of petals is 25% to 35% of test length.

Peripetalous fasciole runs transversely between posterior petals, thickening at petal extremities and running forward exsagittally until in line with apical system, before bending outward toward extremities of anterior petals. Between anterior and posterior petals fasciole constricts three times: at outward flexure near apical system; where fasciole joined by lateroanal fasciole at about mid-test length; and midway between those two points. These constrictions occur in the centre of interambulacral

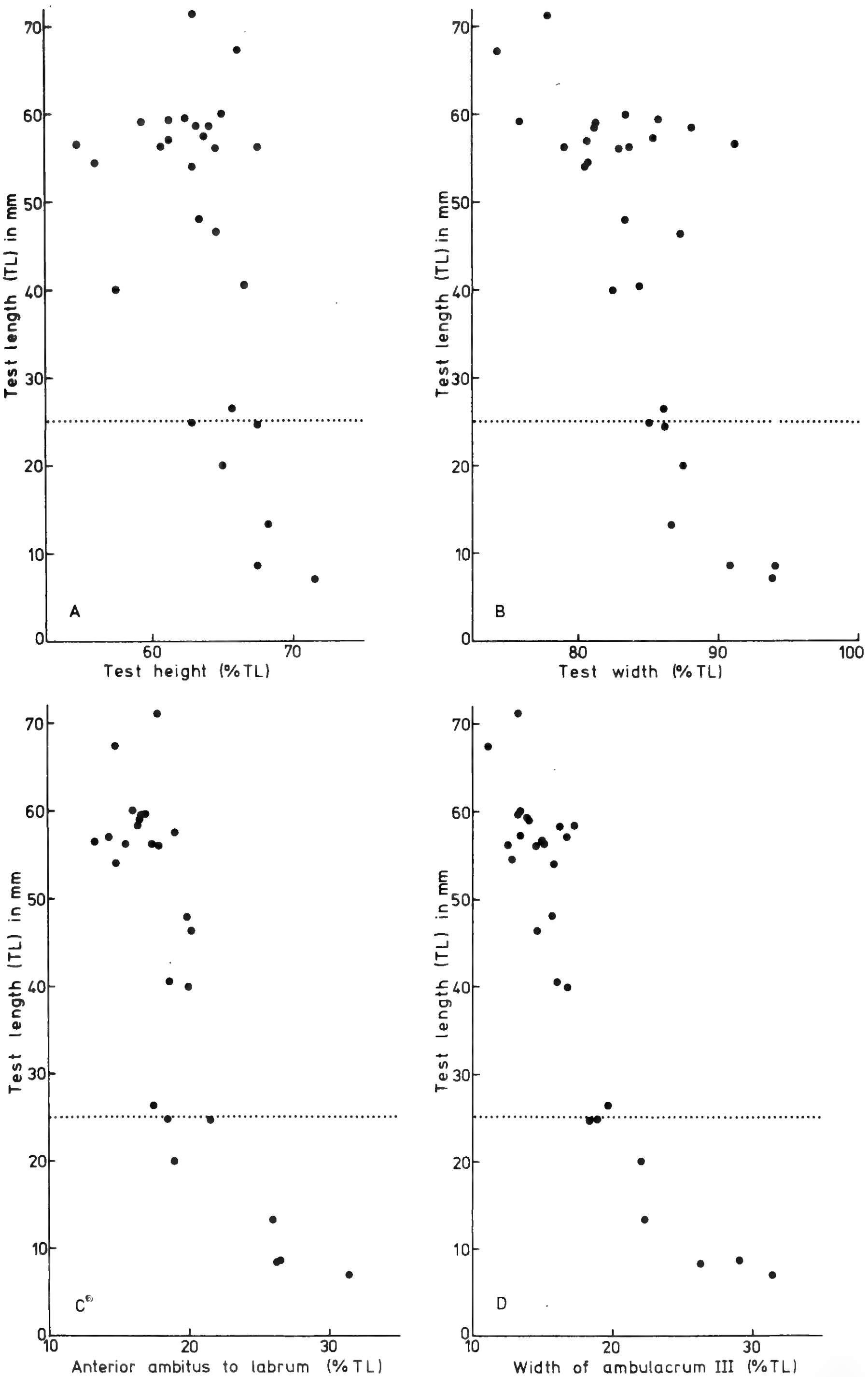


Fig. 6. Plots of test length against test height (**A**), test width (**B**), sagittal length from anterior ambitus to labrum (**C**) and width of ambulacrum III (**D**) of *Schizaster (Ova) myorensis* sp. nov. expressed as percentages of test length; broken line represents test length at attainment of sexual maturity.

plates where plates form a raised point (Fig. 5A); all interambulacral plates are similarly raised centrally. Peripetalous fasciole runs forward from anterior petals at about 45° before curving more strongly forward close to its junction with ambulacrum III, which it meets at 12% test length from anterior of test. One specimen (QM G3809) has a curious posterior extension of the peripetalous fasciole extending sagitally posterior from between the posterior petals for 10% test length.

Lateroanal fasciole narrower than peripetalous and of more constant width. From peripetalous fasciole it extends abaxially posteriorly at 30° to an exsagittal line; close to ambitus it recurves sharply and runs straight toward periproct. On meeting posterior petals it bends to run far below periproct, close to adoral surface. Area between periproct and lowest part of lateroanal fasciole forms a shallow depression.

Peristome oval and slightly sunken; situated anteriorly, anterior tip of labrum 13% to 19% test length from anterior of test in adults. Peristomial girdle is composed of four large, pentagonal plates anteriorly, interdigitating with three shorter plates posteriorly. Laterally there are many small plates. Anteriorly labrum strongly curved and projects forward strongly; bounded by thick rim which degenerates laterally. Labrum (Fig. 9A) as long as broad, posterior extension being rectangular and more than twice as long as broad. Labrum carries large tubercles medially; these decrease in size anteriorly and laterally. Labrum does not extend beyond first adjacent ambulacral plate. Oral tube feet are arranged in a phyllode; eight are borne in each of ambulacra II and IV. Ambulacra I and V each bear nine; pores single within phyllode. Posteriorly eight tube feet occur in ambulacra I and V below periproct. Plastron oval and broad, maximum width being three-quarters length. Plastron tubercles are regularly arranged in curving rows which extend postero-laterally adaxially at a high angle anteriorly, and at a progressively smaller angle posteriorly.

Within anterior and posterior paired ambulacra, and scattered on the surface of interambulacra, are globiferous pedicellariae (Fig. 7A). They consist of three, cylindrical, gently curving valves which are narrowest distally where they bear eight very small denticles; gradually widen toward base initially; at half length broaden strongly to become four times wider at base than at tip; skeletal material dense. Within ambulacra I and V on adoral surface, quadridentate pedicellariae (Fig. 7B) are common. They occur rarely within the ambulacra on the aboral surface. The four, almost straight, valves are broad basally, but rapidly narrow to one-fifth this width at a little over one-third valve length. For the most part the valve is parallel-sided, but restricted broadening occurs near mid-length and distally, the tips being spatulate. Valves are strongly denticulate marginally from median thickening close to spatulate tip. Around margin of spatulate tip, very small, densely packed denticles are present. These probably serve to hold valves tightly together. The skeletal structure of this pedicellaria is an open meshwork, much in contrast to the dense structure of the globiferous pedicellariae. Within ambulacrum III on aboral surface, rostrate pedicellariae (Fig. 7C) occur on upper sides of ambulacral walls. Valves are similar in size to those of the quadridentate pedicellariae, and basally are of similar form. However, the rostrate valves lack the median thickening, are strongly curved distally and do not possess denticulate margins.

Ontogeny. The smallest known specimen is one of test length 7.0 mm (Fig. 8A-C). Other specimens are known of test lengths 8.4 mm, 8.6 mm and 12.5 mm. The onset of maturity is taken as being indicated by the opening of the genital pores. A specimen 20.0 mm test length has just the posterior pair of pores open. In a specimen 24.8 mm test length a third pore is just open, whilst specimens 24.6 mm and 26.5 mm test length have all four pores open. Thus it would appear that the genital pores had opened by a test length of approximately 25 mm in length, although, as noted above,

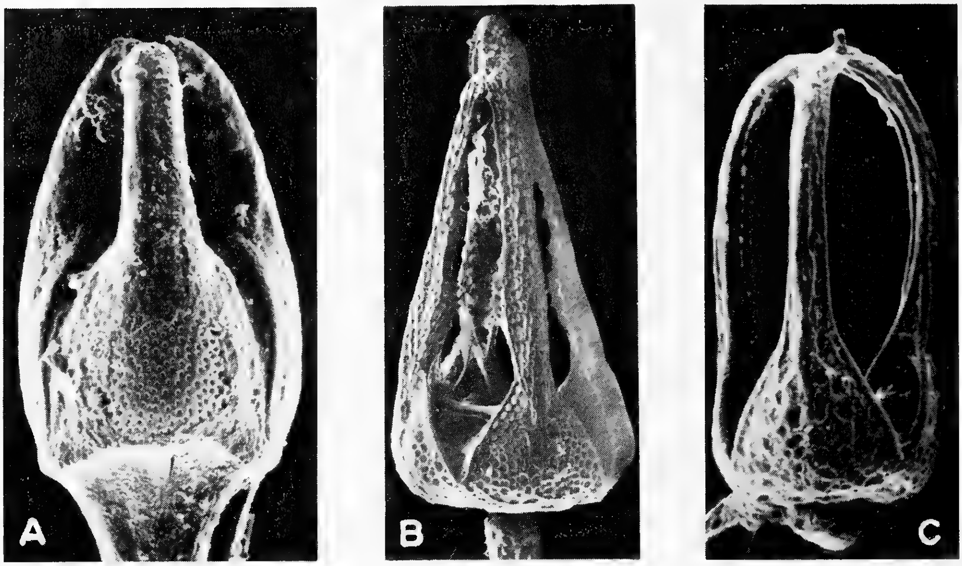


Fig. 7. Pedicellariae of *Schizaster (Ova) myorensis* sp. nov., QM G12064, paratype, from Myora, Moreton Bay: **A,** globiferous, x65; **B,** quadridentate, x100; **C,** rostrate, x100.

nine adult specimens, ranging in test length between 48.0 mm and 58.5 mm have not formed all four genital pores.

The proportions of many morphological features differ between juveniles and adults, and may show negative, normal or positive allometry. In juveniles ambulacrum III is relatively very wide aborally, being up to 31.5% of the test length. It shows negative allometry with growth of the test, becoming relatively narrower, such that it is only between 12% and 20% of the test length in adults (Fig. 6D). The widths of the paired ambulacra remain virtually constant relative to growth of the test. The test itself shows a small change in shape with growth (Fig. 6A, B), juveniles being higher and broader than adults, i.e. it becomes less spherical with growth.

The paired petals change both in shape and orientation with growth. The width between the anterior petals is almost 60% of the test length in juveniles, but decreases to between 46% and 58% in adults. Greater change occurs in the disposition of the posterior petals. In juveniles the width between the extremities of the petals may be as little as 15.5% of the test length, whereas in adults it may range up to 35%, although can be as low as 25%. The anterior petals become more sinuous with growth, juveniles lacking the distal reflexion. The number of pore pairs appears to increase progressively with growth at a constant rate. The peristome is proportionately wider in juveniles, being as much as 22.5% of the test length; in adults it varies between 11% and 16%, illustrating negative allometry with growth of the test (Figs 5A, 8A). The periproct grows with normal allometry. The peristome also moves forward with growth, the anterior of the labrum being up to 31.5% of the test length from the anterior in juveniles, but only 13% to 19% in adults (Fig. 6C). This change is also due, in part, to an increase in anterior projection of the labrum over the peristome. During growth the apical system moves relatively closer to the posterior (Figs 5A, 8A). The increased sinuosity with growth of the anterior paired petals may indicate increased rate of production of ambulacral plates in adults. This is also evident in ambulacrum III. In juveniles the pore pairs occur in a single row. However, in young adults, i.e. those below test length of 40 mm, the pore pairs start to form a more

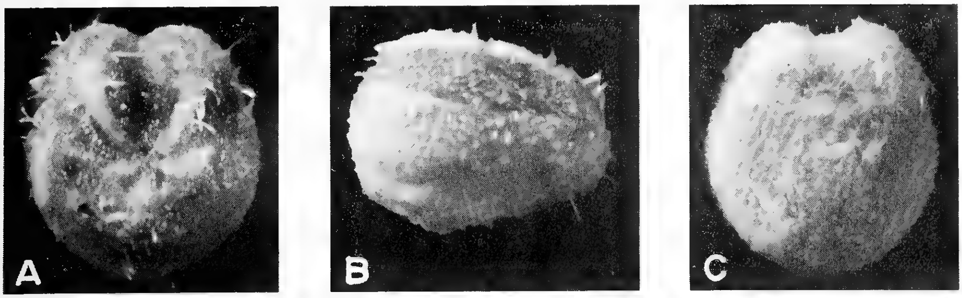


Fig. 8. Juvenile *Schizaster (Ova) myorensis* sp. nov., QM G12066, from Middle Bank, Moreton Bay; **A**, aboral view; **B**, lateral view; **C**, adoral view; all x5.

irregular series, such that in larger adults 60 mm test length, two irregular rows are discernible (Fig. 5C). Occlusion of plates also occurs in adults, probably so that more ambulacral plates could fit into the length of ambulacrum III.

The only observable change in the form of the fascioles is a relative increase in width of the peripetalous fasciole. The lateroanal fasciole, which is similar in width to the peripetalous in juveniles, but narrower in adults, shows negative allometry with growth of the test in comparison with the peripetalous fasciole. This suggests that the lateroanal fasciole assumed greater importance in juveniles than the peripetalous fasciole; but that with growth this situation is reversed.

Fig. 6 shows the more rapid morphological changes which occur up to a test length of less than 25 mm; this corresponds with the opening of the genital pores suggesting onset of sexual maturity.

Discussion. The specimens described here as *S. (Ova) myorensis* were originally assigned to *S. (Schizaster) lacunosus* (Linnaeus) by Endean (1961) and by Stephenson *et al.* (1978). Indeed, in the past it seems to have been common practice to call any *Schizaster*-like form from eastern Australia *'Schizaster lacunosus'* (Clark, 1921, 1932, 1946; Mortensen, 1951). *S. (Schizaster) lacunosus* is best restricted to the specimens from Japan and the southern Pacific, as discussed by Mortensen (1951, pp. 300-303) and the Australian specimens mentioned above. *S. (Schizaster) lacunosus* is more circular in outline than other Australian species. It possesses single rows of pore pairs in ambulacrum III which is not as deep as that of *S. (Ova) myorensis.* It also has shorter, straighter petals and a much narrower labrum.

S. (Ova) myorensis is morphologically closest to *S. (Ova) savignyi* (Fourtau, 1904, pp. 436-439, Pl. 1, figs 4-5) from the Red Sea. Both possess four genital pores in addition to the irregular double row of pore pairs in ambulacrum III. *S. (Ova) myorensis* can, however, be distinguished by the possession of longer paired petals with more pore pairs. According to Fourtau (1904, p. 437) a specimen of *S. (Ova) savignyi* of test length 53.5 mm possesses 33 pore pairs in each of the anterior petals, and 17 in each of the posterior pair. In a Moreton Bay specimen of comparable test length there are 40 pore pairs anteriorly and 23 posteriorly. The longer petals of *S. (Ova) myorensis* result in a different fasciole pattern; the anterolateral branch of the peripetalous fasciole is more transversely orientated in *S. (Ova) myorensis,* whilst the posterolateral is more nearly exsagittal. The section of the peripetalous fasciole which links the posterior petals is virtually transverse in *S. (Ova) myorensis,* but posteriorly convex in *S. (Ova) savignyi.* Ambulacrum III appears to be a little wider in *S. (Ova) myorensis* than in the illustrated specimens of *S. (Ova) savignyi* (Fourtau, 1904, Pl. 1, fig 4; Koehler, 1914, Pl. 8, fig. 13). Mortensen (1951, p. 242) says that the double row of pore pairs in ambulacrum III appears in *S. (Ova) savignyi* in specimens only 20 mm test length, this specimen possessing four genital pores. *S. (Ova) myorensis* does not attain all its adult number of genital pores until 25 mm test length, and in specimens of this length the pore pairs in ambulacrum III form a single row. In a specimen of *S. (Ova) myorensis* of test length 40 mm the poriferous zone has just started to form an irregular double series. Mortensen also noted how the keels of interambulacra II and III overhang ambulacrum III in *S. (Ova) savignyi,* so as to almost cover the poriferous zone when viewed from above; the same keels in *S. (Ova) myorensis* do not overhang to the same extent, the poriferous zones being completely visible. In contrast to Koehler's figured specimen, *S. (Ova) myorensis* possesses far more strongly keeled interambulacra aborally. In addition, the peristome is more anteriorly placed in *S. (Ova) savignyi,* whilst the anterior part of the labrum is much less prominent than in *S. (Ova) myorensis.* Posteriorly the labrum of *S. (Ova) savignyi* appears narrower than that of *S. (Ova) myorensis.* The posterior pair of genital pores appear relatively much smaller in *S. (Ova) savignyi* than in *S. (Ova) myorensis,* and are more widely spaced (Koehler, 1914, Pl. 8, fig. 6). In contrast to Koehler's specimen, the interambulacra of *S. (Ova) myorensis* are far more strongly keeled adapically.

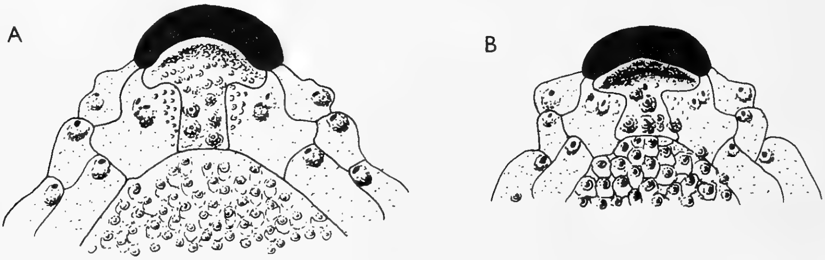


Fig. 9. Labrum and adjoining ambulacral plates of, **A**, *Schizaster (Ova) myorensis* sp. nov. QM G3809, paratype, from Dunwich, Moreton Bay, x2.5. **B**, *Schizaster (Ova) portjacksonensis* sp. nov., AM J1732, holotype, from Port Jackson, N.S.W., x2.

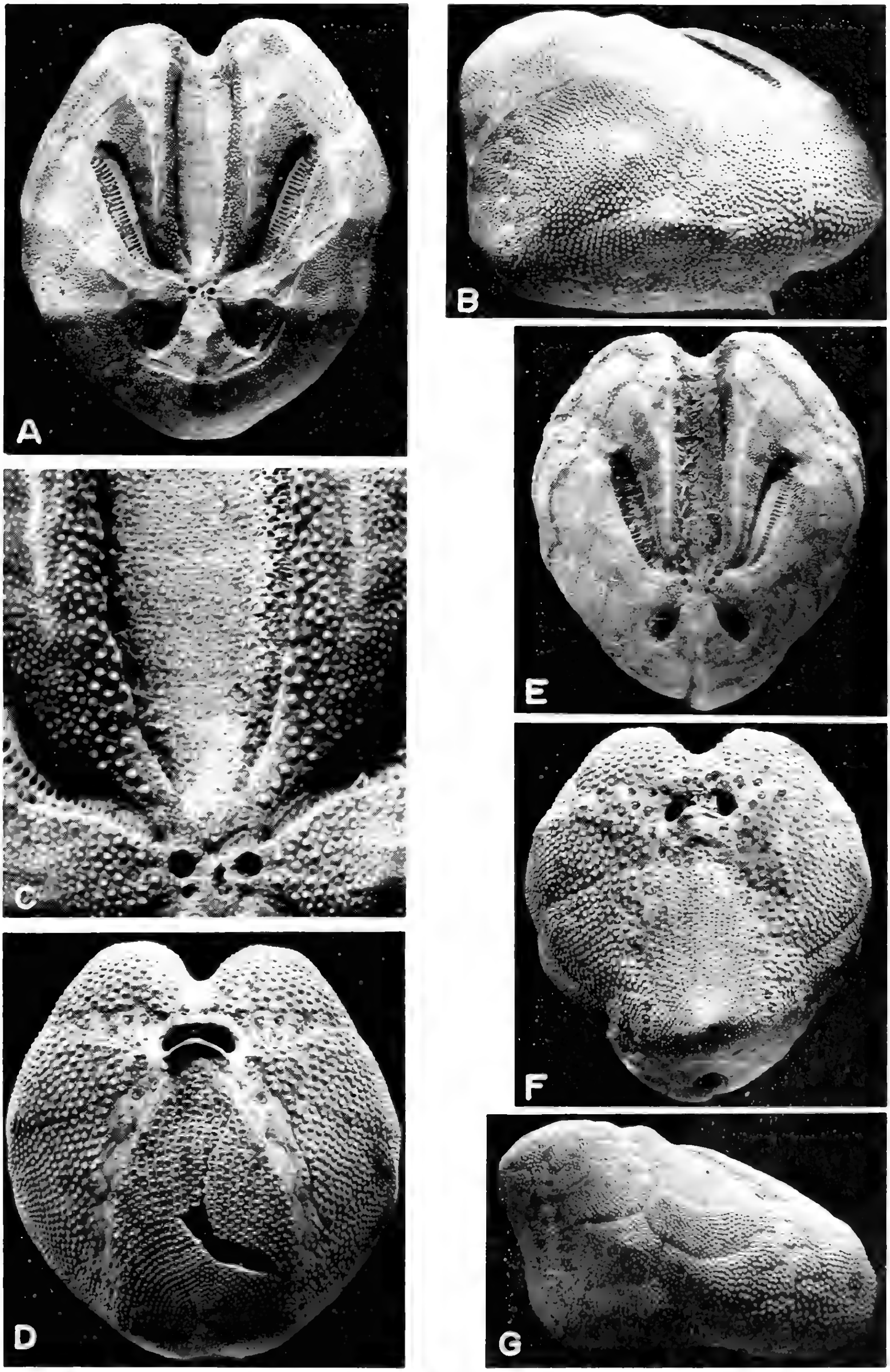
S. (Ova) canaliferus from the Mediterranean, differs from *S. (Ova) myorensis* in the following characters: straighter anterior petals; shorter posterior petals; only two genital pores; smaller outer pores in ambulacrum III; broader labrum which has a more pronounced anterior rim; and a narrower plastron. *S. (Ova) barbatus* (Mortensen, 1951), known from a single specimen from Tanzania, has straighter anterior petals and shorter, more divergent posterior petals than *S. (Ova) myorensis.* The test of *S. (Ova) barbatus* (Mortensen, 1951, Pl. 25, figs 1-3) is also much flatter than that of *S. (Ova) myorensis.* Comparison with *S. (Ova) portjacksonensis* is made in discussion of that species.

Schizaster (Ova) portjacksonensis sp. nov.
(Figs 9B, 10A-G)

Type specimens. Holotype: AM J1732; *paratype:* AM J1731; both collected from 'Port Jackson' and now housed in The Australian Museum. Information on the label gives the depth at which the specimens were collected as 7 fathoms. These are the only known specimens.

Diagnosis. Short, broad, widely spaced posterior petals. Apical system with two genital pores. Anteriorly labrum projects strongly ventrally; it is short, constricted medially. Tubercles on adoral surface densely packed.

Fig. 10. Schizaster (Ova) portjacksonensis sp. nov. from Port Jackson, N.S.W.; **A**, aboral view; **B**, lateral view; **C**, apical region, x3.5; **D**, adoral view, of AM J1737, holotype. **E**, aboral view; **F**, adoral view; **G**, lateral view of AM J1731, paratype. All x1 except where otherwise stated.


A
B
C
D
E
F
G

Discussion. *S. (Ova) portjacksonensis* is morphologically most similar to *S. (Ova) canaliferus*. Both share a strongly inflated test and similar aboral morphology. However, *S. (Ova) portjacksonensis* has a more posteriorly placed apical system (varying between 56.5% and 59.1% of the test length from the anterior, whilst in *S. (Ova) canaliferus* it varies only between 50.8% and 53.7%). The posterior petals diverge more strongly in *S. (Ova) portjacksonensis* than in *S. (Ova) canaliferus,* though not reaching the depth of *S. (Ova) myorensis*. *S. (Ova) portjacksonensis* can be more easily distinguished from *S. (Ova) canaliferus* by the morphology of the adoral surface of the test. The plastron of *S. (Ova) portjacksonensis* is broader than in *S. (Ova) canaliferus* (0.83 the length compared with 0.68). The labrum of *S. (Ova) portjacksonensis* (Fig. 9B) anteriorly projects more strongly ventrally and is medially acuminate; posteriorly the labrum is constricted medially, unlike *S. (Ova) canaliferus* in which it is parallel-sided. It is proportionately shorter in *S. (Ova) portjacksonensis*. The adoral tubercles are more dense in *S. (Ova) portjacksonensis* than in either *S. (Ova) canaliferus* or *S. (Ova) myorensis*.

S. (Ova) portjacksonensis possesses a more inflated test than *S. (Ova) myorensis*; its paired petals are shorter, the anterior pair being less flexuous anterolaterally. *S. (Ova) myorensis* possesses more genital pores than *S. (Ova) portjacksonensis* and has a deeper ambulacrum III. The interambulacra do not form such prominent keels adapically in *S. (Ova) portjacksonensis*. The labrum projects ventrally (Fig. 10B), not anteriorly as in *S. (Ova) myorensis,* and is medially constricted, unlike *S. (Ova) myorensis* which is parallel-sided. The adoral tubercles of *S. (Ova) portjacksonensis,* in addition to being more densely packed than in *S. (Ova) myorensis,* are larger; this is also true of the aboral surface. The few spines preserved in the ambulacra of *S. (Ova) portjacksonensis* are like those of *S. (Ova) myorensis*.

The paratype of *S. (Ova) portjacksonensis* (Fig. 10E-G) possesses a much less inflated test than the holotype. However, this variation comes within the limits of variation in test shape displayed by *S. (Ova) myorensis*. This paratype is a

TABLE 1

Dimensions (in mm) of typical specimens of the four new Australian species of *Schizaster* discriminated in this paper. In brackets the various parameters are given as a percentage of test length.

	S. (Ova) myorensis QM G12063 (holotype)		*S. (Ova) portjacksonensis* AM J1732 (holotype)		*S. (Schizaster)* sp. nov. A QM G2178		*S. (Schizaster)* sp. nov. B QM G12092	
Test length	57.0		60.5		64.0		54.0	
Test width	46.0	(81.0)	54.0	(88.5)	56.0	(87.5)	46.5	(86.0)
Test height	35.0	(61.5)	43.0	(71.0)	38.0	(59.5)	33.0	(61.0)
Length apical system to anterior	33.0	(58.0)	35.0	(58.0)	37.5	(58.5)	30.0	(55.5)
Width amb. III	9.5	(16.5)	8.7	(14.5)	8.5	(13.5)	6.5	(12.0)
Width amb. I/V	4.7	(8.0)	4.4	(7.5)	4.5	(7.0)	4.0	(7.5)
Width amb.II/IV	5.3	(9.5)	5.0	(8.5)	6.0	(9.5)	4.3	(8.0)
Width ant. paired petals	30.7	(54.0)	32.0	(53.0)	33.0	(51.5)	30.0	(55.5)
Width post. paired petals	15.5	(27.0)	15.4	(25.5)	16.0	(25.0)	16.3	(30.0)
Length amb. II/IV		(36.5)		(41.0)		(37.5)		(37.0)
Length amb. I/V	11.7	(20.5)	9.2	(15.2)	10.5	(16.5)	12.0	(22.0)
Width peristome	9.0	(16.0)	9.4	(15.5)	7.5	(11.5)	7.0	(13.0)
Diameter periproct	6.3	(11.0)	8.4	(14.0)	8.5	(est)	8.8	(16.5)
Length labrum to ant.	8.2	(14.5)	11.4	(19.0)	11.2	(17.5)	10.0	(18.5)
No. genital pores	four		two		four		four	
Nature of pore pairs in amb. III	double		double		single		single	

teratological specimen. The adoral surface is malformed and the labrum is grossly misshapen (Fig. 10F). A singular feature is the presence of tuberculation on the periplastronal area. This region is virtually free of tuberculation in the holotype (Fig. 10D).

Genus *PRORASTER* Lambert 1895
[= *Hypselaster* Clark 1917]

Type species. Schizaster atavus Arnaud *in* Cotteau 1883, p. 13.
Remarks. Mortensen (1951, p. 228) characterized *Proraster* by its possession of a deep ambulacrum III, with deep anterior notch in the test; a peripetalous fasciole, but not lateroanal fasciole; and four genital pores. On the basis of this definition *Proraster* differs from *Schizaster* only in its lack of a lateroanal fasciole. The genus *Hypselaster* is here considered to be synonymous with *Proraster,* as the lateroanal fasciole is rudimentary or lacking. Mortensen (1951, p. 312) noted that *Hypselaster* is "an unsatisfactorily limited genus". He further observed that the lateroanal fasciole may be present in a rudimentary form or be entirely absent: yet he gave the main character of *Hypselaster* as the presence of a rudimentary fasciole. Five specimens in the Australian Museum collection (AM J6625) collected by H. L. Clark from Roebuck Bay, Broome, Western Australia, lack the lateroanal fasciole entirely, while one specimen shows a small segment ventro-lateral of the periproct. It straddles the junction of two interambulacral plates, indicating that it appeared in maturity and did not degenerate to this condition.

H. L. Clark (1917) also characterized *Hypselaster* by the possession of only two genital pores: *Proraster* has four. This difference is not considered to be sufficient to merit generic separation. Lambert's *Proraster* ranges from the Cenomanian to Senonian, whilst species referred to *Hypselaster* by H. L. Clark (1917) and Mortensen (1951) are all living species. Mortensen (1951, p. 313) tentatively placed *H. perplexus* Arnold and Clark (1927) in *Hypselaster;* this species is from the Eocene (?) of Jamaica.

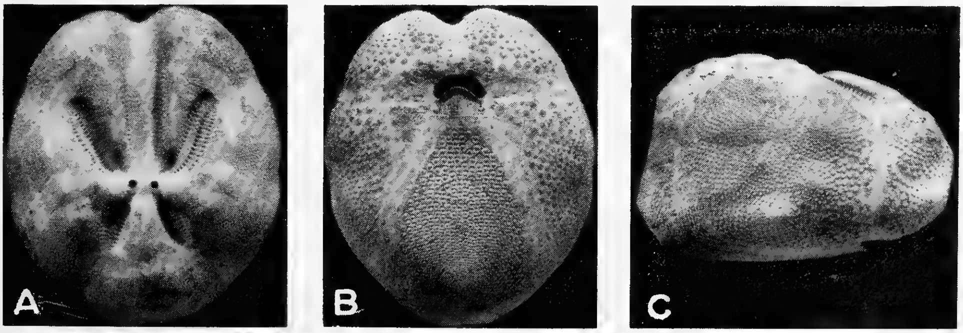


Fig. 11. Proraster jukesii (Gray 1851), AM J6625, from Roebuck Bay, Broome, Western Australia: **A**, aboral view; **B**, adoral view; **C**, lateral view, all x1.

Proraster jukesii (Gray 1851)
(Figs 11A-C, 12A)

1851 *Schizaster jukesii* Gray, p. 133
1855 *Schizaster jukesii* Gray, p. 61, Pl. 3, fig. 4
1925 *Hypselaster fragilis* Clark, p. 208, Pl. 11, figs 1-3
1938 *Hypselaster dolosus* Clark, p. 430, Pl. 28, figs 4-7
1946 *Hypselaster dolosus* Clark; Clark, p. 367
1951 *Hypselaster dolosus* Clark; Mortensen, pp. 319-320, Pl. 32, fig. 6

1951 *Hypselaster jukesii* (Gray) ; Mortensen, pp. 315-319, Pl. 22, figs 14-17, Pl. 52, figs 2, 9, 21, 22

1961 *Hypselaster jukesii* (Gray) ; Endean, p. 294

1972 *Hypselaster jukesii* (Gray) ; A. M. Clarke & Rowe, p. 167, footnote 16.

Type specimen. The specimen figured by Gray (1855, Pl. 3, fig. 4) and identified and figured by Mortensen (1951, p. 318, Pl. 22, figs 15-17) and in the collections of the British Museum (Natural History). It is from "Cape York".

Localities. Mortensen (1951, p. 316) gave the geographic range of *P. jukesii* as "from the Torres Strait region to the Queensland coast (Bowen)". H. L. Clark's "*H. dolosus*" was based on specimens from Broome and Augustus Island, Western Australia. Six specimens studied in this paper were collected by Clark from tidal falts at Roebuck Bay, Broome. Endean (1961, p. 294) records two specimens from Myora, Moreton Bay and four from Dunwich, Moreton Bay. These were taken at L.W.N. from sand flats.

Remarks. H. L. Clark (1946, p. 367) distinguished his Western Australian specimens from those from eastern Australia by the position of the apical system, which he considered to be slightly posterior of centre in the Western Australian form *P. "dolosus"* but anterior of centre in *P. jukesii*, and by differences in petaloid area and shape of the valve of the globiferous pedicellariae. Mortensen (1951, p. 318) further suggested that *P. "dolosus"* has narrower posterior paired petals than *P. jukesii.* A. M. Clarke and Rowe (1971, p. 167, footnote 16) have pointed out that neither of these supposed differences in test character is borne out by Mortensen's (1951, Pl. 22) illustrations of the species. We therefore follow these authors in placing *dolosus* in synonymy with *jukesii.*

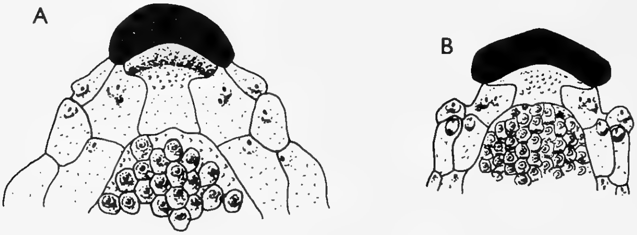


Fig. 12. Labrum and adjoining ambulacral plates of, A, *Proraster jukesii* (Gray 1851), AM J6625, from Roebuck Bay, Broome, Western Australia, x2.5; **B**, *Moira lethe* Mortensen 1930, QM G12093, from Moreton Bay, Queensland.

Globiferous pedicellariae are not common in *P. jukesii.* A Western Australian specimen shows the pedicellariae to have two teeth at the distal end as is typical. However, in comparison with Mortensen's illustration (Pl. 52, fig. 21) of a globiferous pedicellaria of *P. jukesii,* the Western Australian specimen has valves which are relatively longer. However, this is judged to be insufficient grounds to warrant the separation of the two forms as different species.

Genus *MOIRA* Agassiz 1872

Type species. Spatangus atropos Lamarck 1816, p. 32. By subsequent designation of the International Commission of Zoological Nomenclature; Opinion 209, 1948.

Moira lethe Mortensen 1930
(Figs 12B, 13A-D)

1926 *Moira stygia* Lütken, Clark, p. 191

1930 *Moira lethe* Mortensen, p. 392, Pl. 3, figs 1-4

1938 *Moira stygia* Lütken, Clark, p. 432

1946 *Moira stygia* Lütken, Clark, p. 369

1951 *Moira lethe* Mortensen; Mortensen, pp. 334-335, Pl. 19, figs 12, 18, 22; Pl. 55, figs 12, 24.

Localities. Mortensen (1951, pp. 334-335) records this species from Bowen, Queensland; "Liverpool, (!) N.S.W."; Broome, Western Australia; and South Australia. Specimens have also been found by one of us (K. J. McN.) on the eastern side of Bribie Island, Queensland and at Myora, Moreton Bay, Queensland. It is also known from Albany, Western Australia and from Port Phillip Bay, Victoria (A. M. Clarke, 1966, p. 292).

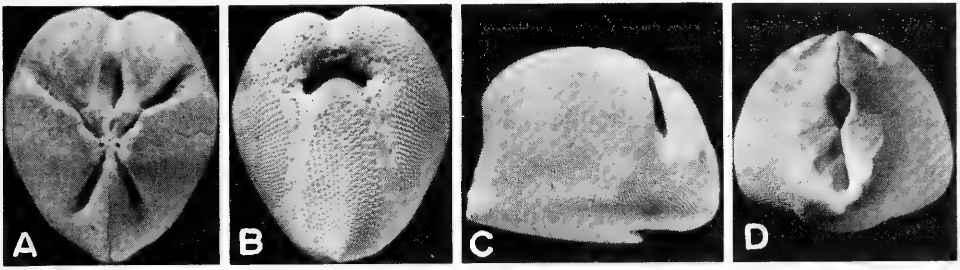


Fig. 13. Moira lethe Mortensen 1930, QM G12092, from Moreton Bay, Queensland; **A**, aboral view; **B**, adoral view; **C**, lateral view; **D**, posterior view; all x1.

As noted by Mortensen (1951, p. 334) this species is most similar to *M. stygia*, from which it can be distinguished by the deep, sagittal depression between the periproct and lowest part of the lateroanal fasciole (Fig. 13D), and by its shorter labrum (Fig. 12B).

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Cirral Activity and Feeding in the Lepadomorph Barnacle *Lepas pectinata* Spengler (Cirripedia)

D. T. ANDERSON

ANDERSON, D. T. Cirral activity and feeding in the lepadomorph barnacle *Lepas pectinata* Spengler (Cirripedia). *Proc. Linn. Soc. N.S.W.* 104 (2), (1979) 1980: 147-159.

Among the lepadids, *L. pectinata* shows extreme adaptation to neustonic life, as a small species inhabiting fragile, ephemeral objects at or near the water surface. In addition to feeding by cirral extension on small macroplankton, *L. pectinata* employs rhythmic cirral beating in continuous feeding on microplankton. The form and setation of the cirri and mouthparts are adapted to these dual modes of feeding. The rhythmic cirral activity of *L. pectinata* is in the opposite mode to that of balanoids, the cirri being held extended between beats, and is similar in general to that of *Verruca stroemia*. All three patterns of cirral activity have evolved independently, those of *L. pectinata* and *V. stroemia* being convergent, associated with feeding on microplankton.

Other features of adaptation of *L. pectinata* to its mode of life are discussed. They include, in addition to continuous versatile feeding on small food organisms in the top few centimetres of the water, a rapid growth rate, onset of sexual maturity and reproduction at a small size, insensitivity of the cirri to light, water movements or contact stimulation, production of specialized flotatory nauplii, settlement of cyprids gregariously on planktonic objects and a precocious post-settlement metamorphosis.

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INTRODUCTION

Although lepadid barnacles are well known taxonomically (Darwin, 1851; Nilsson-Cantell, 1921; Stubbings, 1963; Zullo, 1963; Utinomi, 1968; Newman, 1972; Arnaud, 1973; Foster, 1978), only a few scattered reports have been given of their feeding activities. In general, these place emphasis on prolonged cirral extension and macrophagy (Gruvel, 1893; Howard and Scott, 1959; Patel, 1959; Bieri, 1966; Crisp, 1967; Jones, 1968; Lockwood, 1968; Cheng and Lewin, 1976), with some intimation of cooperative feeding on larger prey. The obvious and prolonged extension of the cirri in *Lepas* species is also attested by the many photographs in elementary textbooks and popular accounts of marine animals, showing *Lepas* with its cirri fully exposed. No other cirripede behaves so readily in this way. *Lepas* is often said to be a generalized thoracican genus, but all aspects of its biology are indicative of specialization for a neustonic mode of life. This specialization is nowhere more evident that in the small *L. pectinata* of tropical and warm temperate waters, a species whose cirral activity and feeding have hitherto been undescribed.

L. pectinata preferentially attaches to a variety of small, fragile floating objects such as cuttle bones, feathers, sargassum, pumice and tar (Darwin, 1851; Horn, Teal and Backus, 1970; Lang, 1979). The present paper analyses the cirral activity of *L. pectinata* in relation to cirral and mouthpart anatomy and offers some comparisons with feeding in other species of the genus in the same neustonic habitat.

MATERIALS AND METHODS

Living specimens of *L. pectinata* attached to a cuttlefish shell were collected by Mr M. J. Moran at Cape Banks, Botany Bay, N.S.W. in October, 1978. The animals were maintained in an aerated aquarium tank at the University of Sydney. Cinematographic records of cirral activity and details of anatomical structure were obtained by methods described in previous papers (Anderson, 1978, 1980a). Anatomical details were determined from specimens preserved in 5% formalin in sea water, dissected, and examined by both bright field and dark field microscopy of unstained material. Records of cirral movements were made by cinephotomacrography, using Kodak Ektachrome 160 super 8 mm film, and analysed using a Eumig R2000 analysing projector. No food was provided for the living *L. pectinata* during the two weeks that they were kept alive in the tank, but the water was renewed every three days. After 10 days in the tank, some of the animals released large numbers of nauplius larvae, on which the captive population proceeded to feed. It was notable, however, that the level and pattern of activity was no greater when nauplii were present than it had been in the absence of obvious food organisms. Since all of the animals in the tank retained their vigour throughout the two weeks of observation, it was presumed that they were able to feed microphagously on naturally occurring microscopic organisms in the water. As will be shown below, the cirral and mouthpart morphology, the mode of cirral activity and the gut contents bear out the fact that *L. pectinata* is both a microphagous and macrophagous feeder in the neuston.

OBSERVATIONS

General External Anatomy. The general external anatomy of *L. pectinata* is well known (Darwin, 1851; Foster, 1978) and only certain aspects will be emphasized here. The species is the smallest in the genus *Lepas*, with individuals rarely exceeding 12 mm in length. The grey-coloured capitular plates (Fig. 1A) are thin and deeply cupped, with closely approximated margins. The distinctive ridging on the plates and

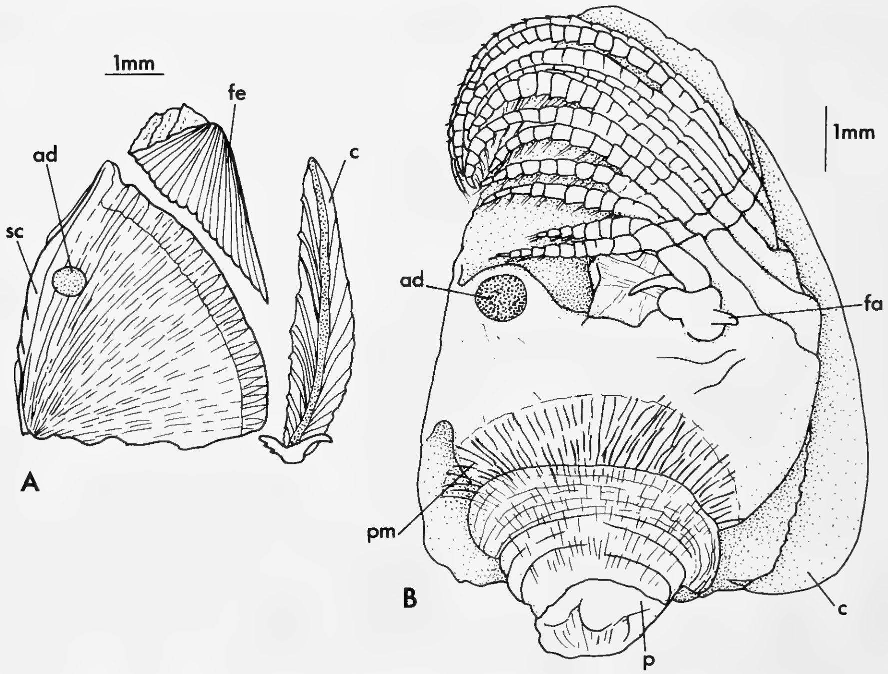

Fig. 1. A. — The carapace plates of *L. pectinata*; interior view of the left scutum, left tergum and carina. B. — *L. pectinata,* viewed from the right side, with the right valve removed. *ad,* adductor scutorum; *c,* carina; *fa,* filamentary appendage; *p,* peduncle; *pm,* peduncular muscle; *sc,* scutum; *te,* tergum.

the positions of the umbones reveal the specialized growth pattern which yields the globose, lightweight valves. The capitulum is also large relative to the peduncle, which is short (Fig. 1B), cone shaped, thin walled and muscular. The yellowish covering of the peduncle is irregularly annulated but otherwise smooth and not setose. Longitudinal muscle strands are conspicuous beneath the peduncular cuticle in preserved specimens, fanning out into the mantle beneath the basal margin of the scutum of each side (Fig. 1B).

Within the capitular valves, the body of the animal is relatively large, almost completely filling the mantle cavity when in the retracted position with the cirri curled (Fig. 1B). The prosoma is swollen and thin walled, with the musculature and other internal organs clearly visible through the cuticle. The oral cone is large and the thorax well developed. The cirri are of moderate length, but strongly formed for the size of the animal. The first pair is set quite close to the second pair on either side of the posterior end of the oral cone (see also Fig. 4A).

In contrast to the relatively large size of the body, the adductor scutorum muscle is quite small (Figs 1A and 1B). It lies close to the occludent margins of the scuta, approximately at the midpoint of the length of these margins. The aperture, which lies apical to the adductor scutorum, thus occupies only the apical half of the rostral surface of the capitulum (Fig. 4B). When extended, the body and limb bases of the animal fill the aperture. When withdrawn, the coiled limbs are only just confined within the aperture. As will be shown below, the large body, small adductor, small aperture and restricted mantle cavity of *L. pectinata* are associated with a mode of life in which the animal spends most of its time with the body and limbs extended in the water and only occasionally retracts within the shell. The contrast between the bold exposure of the limbs in living *L. pectinata* and the fugitive retreat of most barnacles into the mantle cavity at the slightest provocation is perhaps the most striking indication of the adaptation of *L. pectinata* to a highly specialized mode of neustonic life.

Anatomy of the Cirri. As in all species of *Lepas,* cirrus I in *L. pectinata* shows substantial modification as a maxilliped. Cirrus II is partially modified anatomically for this function and the remaining cirri (III-VI) show a more generalized form. In the following description, setal directions refer to the position of the limbs when the animal is withdrawn into the mantle cavity as in Fig. 1B.

Cirrus I (Figs 2A and 2B) has moderately short, subequal rami, the exopod having 11 or 12 podomeres, the endopod 9. Apart from the terminal few, the podomeres of both rami are short and broad. Setation is sparse on the lateral surfaces, being confined to a few setae on the distal margins of the podomeres, but dense on the median surfaces of both rami. On the exopod, the median setae of the distal five podomeres arise at the distal margins of the podomeres, point distally and are simple setae. On the remaining podomeres, dense brushes of long, thin, serrate setae arise from the posteromedian surfaces and point posterodistally. On the endopod, dense brushes of similar long, thin serrate setae arise from the median surfaces of the podomeres and point anteriorly, intermeshing with the median setae of the exopod. Little setation occurs on the protopod except for a bunch of long, distally directed setae distally on the median surface.

Cirrus II (Figs 2C and 2D) has longer, more cylindrical rami than cirrus I, the exopod and endopod being almost equal in length, with 12 and 14 podomeres respectively. As in cirrus I, lateral setation is sparse and median setation dense, especially on the proximal half of each ramus. These median setae are a mixture of simple and serrate, long, thin setae all pointing anteriorly and overlapping with the median setae of cirrus I.

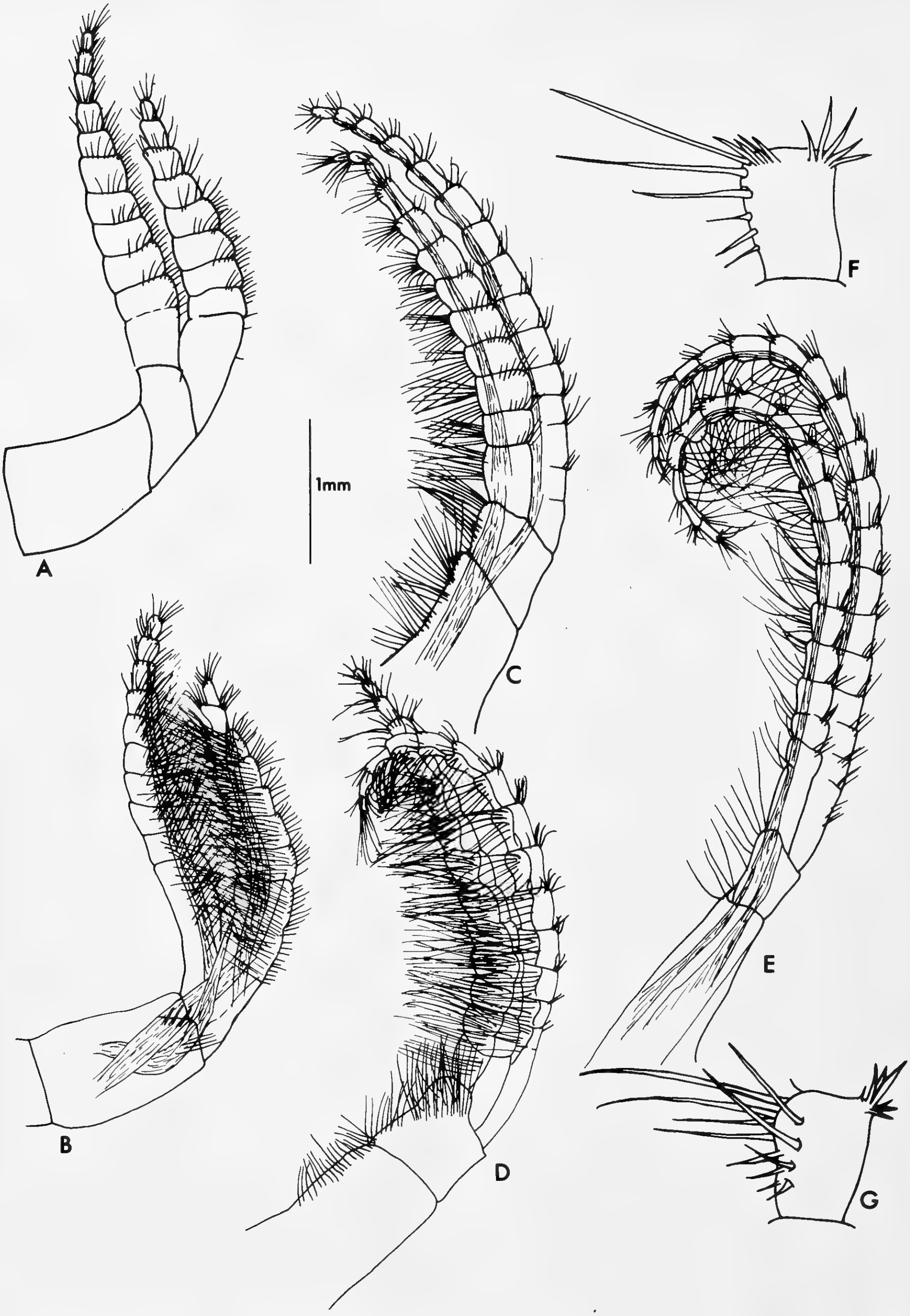

Fig. 2. L. pectinata. A. — Cirrus I, right lateral view. B. — Cirrus I, left, median view. C. — Cirrus II, right, lateral view. D. — cirrus II, left, median view. E. — Cirrus III, right, lateral view. F. — Podomere 10 of exopod of right cirrus III, lateral view. G. — Podomere 10 of exopod of left cirrus III, median view.

The remaining cirri, III-VI, all have long cylindrical rami. Podomere numbers for the exopod and endopod are 18/20, 19/21 and 22/19 respectively (Figs 2E and 3A). Each podomere carries 6 pairs of setae anteriorly, the distal 3 pairs being long (Figs 2F and 2G), and a group of short setae posteriorly on the distal margin. Most of the setae are simple, but serrate setae occur amongst them on the more proximal podomeres of the limbs. The long anterior setae of cirri III-VI are about 0.75 mm in length, but when the cirral rami are spread in the extended position shown in Fig. 4, the setae do not meet across the spaces between the distal parts of the rami.

Anatomy of the Mouthparts. The oral cone of *L. pectinata* (Fig. 3B) is large and prominent. The bullate labrum is densely setose around the entrance of the preoral cavity, the setation being continued along the posteromedian margins of the mandibular palps (Fig. 3D). Mandibles, maxillules and maxillae are in the usual array, but their masticatory margins show prominent setation and only moderate

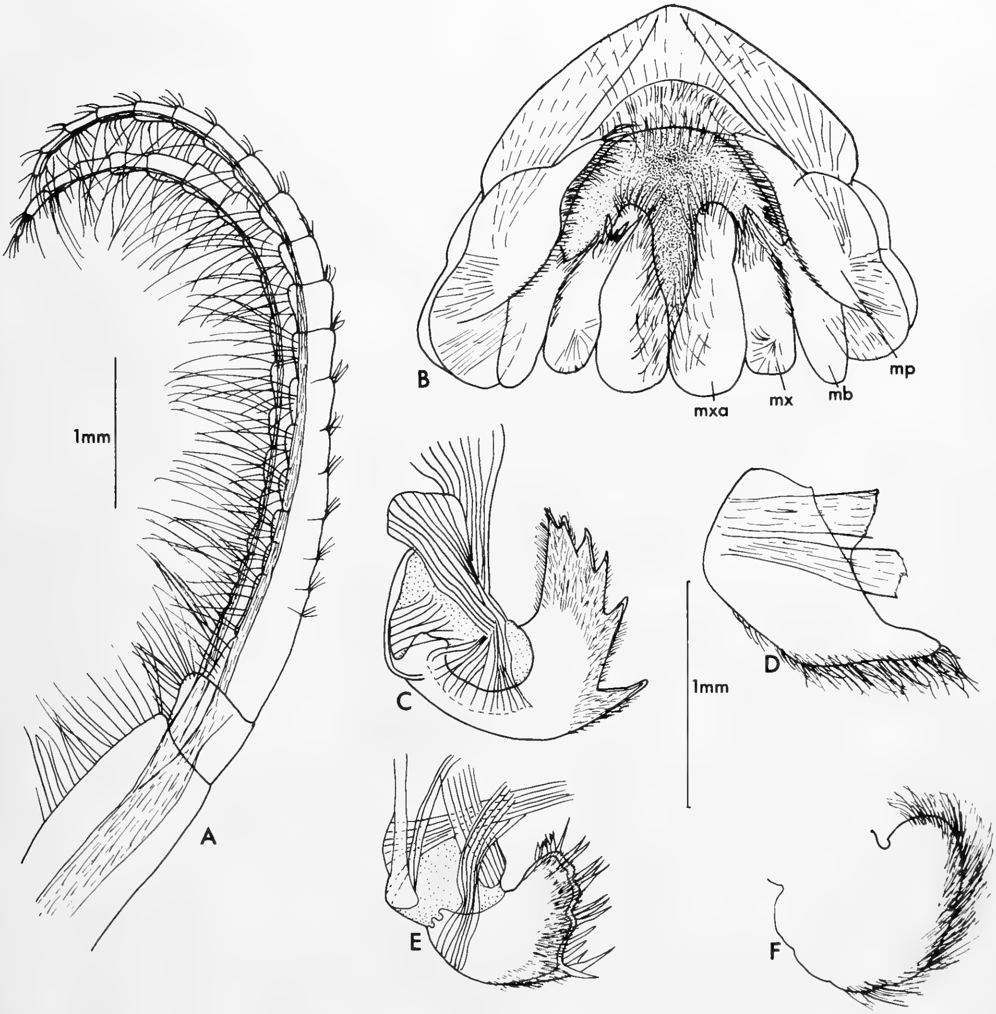

Fig. 3. L. pectinata. A. — Cirrus IV, left median view. B. — Oral cone, posterior view. C. — Right mandible, lateral view. D. — Right mandibular palp, lateral view. E. — Right maxillule, lateral view. F. — Right maxilla, lateral view. *mb,* mandible; *mp,* mandibular palp; *mx,* maxillule; *mxa*, maxilla.

spination. The mandible (Fig. 3C) has 5 teeth, but the incisor tooth is modest and the molar process is small. The maxillule (Fig. 3E) shows only vestigial stepping of the margin, small cutting blades on the lateral angle and short spines on the median angle. The maxilla (Fig. 3F) is a convex lobe with many fine, anteriorly directed setae on the free margin. These mouthparts, while retaining the capacity for maceration of small prey, are also indicative of an ability to retain and process fine particulate food (compare *Semibalanus balanoides* and *Verruca stroemia*; Stubbings, 1975; Anderson, 1980a).

Cirral Activity. The most striking feature of the cirral activity of *L. pectinata* is that the animals are active continuously. The group of individuals observed in the present study showed no break in activity during two weeks. Even in the brief periods when the animals were removed from the aquarium in order to change the water, cirral exposure and movements of the peduncle continued. Activity was maintained in all conditions of illumination, being unaffected by bright light, darkness, or changes of illumination. No shadow reflex could be elicited. Activity was unaffected by water

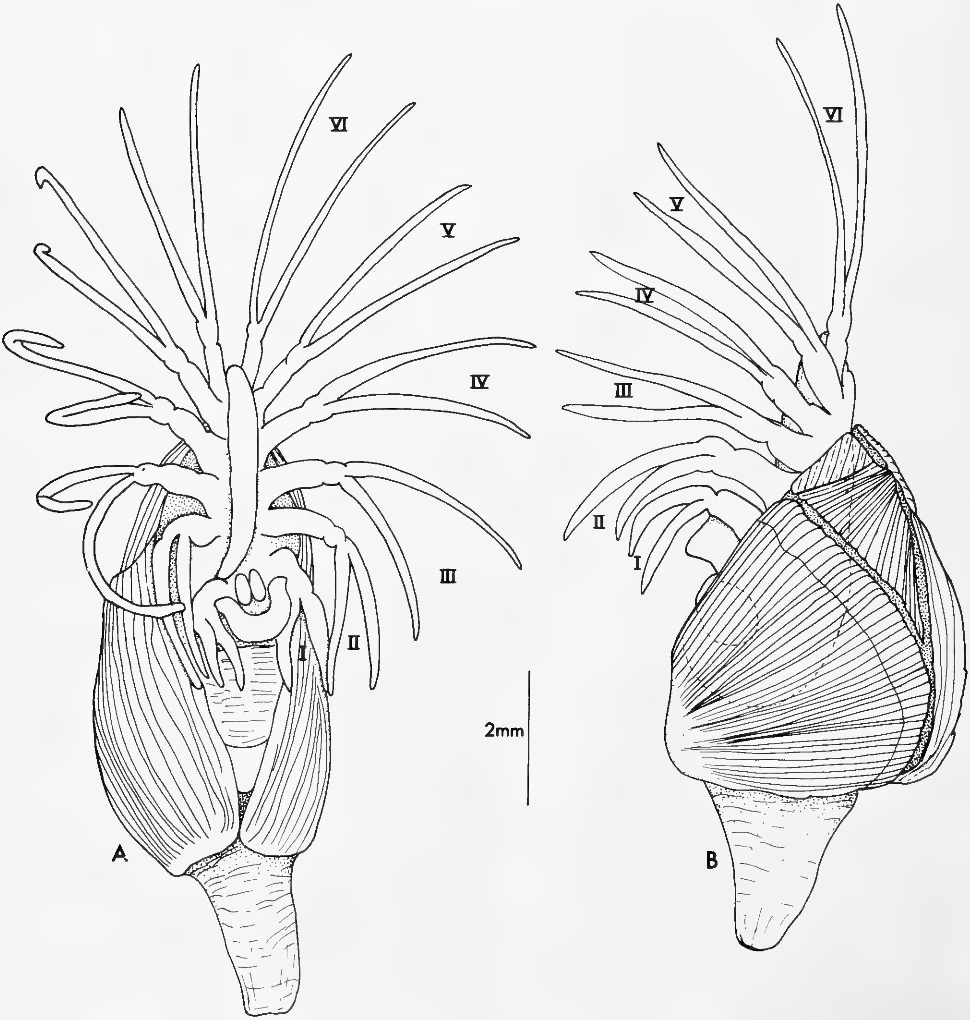

Fig. 4. *L. pectinata,* with cirri fully extended. A. — Ventral view. B. — Lateral view.

movements or by reversing the orientation of the animals relative to the water surface. Animals attached on both sides of the cuttle bone and around its margin continued their activity regardless of orientation. Activity was also unaffected by contact with the water surface. Submerged individuals swept the water with their cirri. Individuals at the water surface swept the surface, with some cirral rami projecting above the surface.

A sharp percussive vibration of the aquarium caused the animals to react by sudden withdrawal into the shell, but only momentarily. The shell valves reopened and the cirri emerged again in a few seconds. In general, the activity of *L. pectinata* at or just under the water surface is one of continuous feeding and low sensitivity to environmental disturbance.

The activity expressed by the animals involves two elements. One is swaying of the capitulum on the short peduncle, both from side to side and back and forth, slowly swinging the extended cirral net about in the water. This swaying action tends to be self sustaining within a group of individuals, in that movement of one causes contact with adjacent animals and elicits movement by them.

The second and more vigorous element of activity in *L. pectinata* is rhythmic cirral extension and withdrawal. The extended position is the normal one for this species. In it, the body is straightened and protruded through the aperture to the level of the oral cone (Fig. 4). Cirri IV-VI stand upright as a fan at the carinal end of the aperture, with cirrus III adjacently upright on either side in a carinolateral position.

Fig. 5. A - E. — Representative cirral positions during a typical sequence of limb extension and withdrawal in *L. pectinata*, seen in lateral view. The total sequence occupies 1.28 s.

A. — Position at the beginning of the sequence
B. — 0.28 s from the beginning of the sequence
C. — 0.5 s
D. — 0.72 s
E. — 0.94 s
F. — 1.28 s

Cirrus II on either side has its rami directed forwards above the oral cone, and cirrus I similarly projects forwards on either side of the oral cone.

From the extended position, the animal makes a regular movement (Fig. 5) of withdrawal of the cirri followed by extension. In the withdrawal movement, the body swings downwards and forwards on the axis of the adductor muscle. The first two pairs of cirri are drawn down into the mantle cavity. Cirri III-VI are folded together and curled forwards, but not completely withdrawn into the mantle cavity. After a short pause, the cirri and body are extended again. The long cirri first uncurl, then extend and spread, accompanied by unfolding and protrusion of cirrus I and II on either side.

Frame by frame analysis of cinematographic records (Fig. 6) shows that the timing of the withdrawal-extension sequence varies little among individuals. At 22 - 23°C,, observations of 3 individuals performing a total of 70 beats gave an average cirral withdrawal time of 0.28 - 0.30 s, followed by a pause of 0.17 - 0.37 s and a cirral protrusion time of 0.36 - 0.40 s. The slight difference in duration between withdrawal and extension of the cirri reflects, as is usual with thoracican barnacles, the faster muscular contraction and slower hydraulic action of the two movements. The range of variation in the duration of the pause with the cirri withdrawn is correlated with the rate of cirral beating in different individuals. At higher rates of beat, the pause in the withdrawn position is of shorter duration, but it was not observed to be greater than 0.37 s even when the rate of beat was markedly slow.

The factors determining the rate of beat are obscure. General observation showed that adjacent individuals in the group under study exhibited different rates of beat. Counts were made for 11 individuals recorded simultaneously on film. The number of beats performed per 10 s by these animals were 0.2, 0.8, 1.7, 2.0, 2.4, 4.75, 5.0, 5.0, 5.9, 7.25 and 7.6 respectively. The range was thus from one beat every 50 s to one every 1.3 s, with corresponding intervals of cirral extension of 49 s and 0.6 s respectively, slight differences in timing being evident from beat to beat. The two

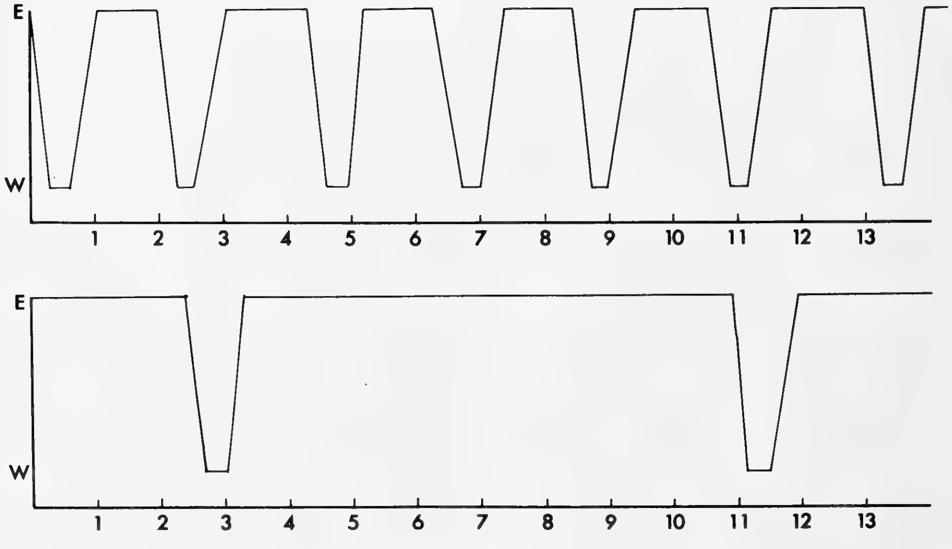

Fig. 6. Record of cirral extension and withdrawal in two individuals of *L. pectinata* in still water at 22-23°C. Vertical axis: E. limbs extended, W. limbs withdrawn. A. — An individual beating at 5 per 10 s. B. — An individual beating at 1.7 per 10 s.

examples given in Fig. 6 show rates of 5.0 and 1.7 beats per 10 s, with average interbeat durations of 1.3 s and 8.4 s respectively.

In spite of these variations in the rate of beat, the withdrawal - extension action is the same in all individuals. On withdrawal, the cirri curl down through the water, collecting suspended particulate matter. During the pause before re-extension, the coiled cirri show movements indicative of cleaning off by the maxillipeds and mouthparts. The cirri are then extended again, preparatory to the next sweep.

When the cirri were extended in water containing nauplii, individual cirral rami were seen to curl forwards and down to be cleaned off by apposition of the second pair of cirri. These limbs were then bent downwards between the first pair of cirri, rubbed together and drawn back. Finally, the endopods of the first pair of cirri were brought together in the midline above the mouthparts and rubbed one upon the other. By this means, the small captured prey are presumably transferred to the mouthparts for ingestion.

Contact of the extended cirri with a larger object such as the end of a pencil elicited a strong grasping action by all the cirri together. *L. pectinata* appears to be able to feed by the capture of larger prey, as well as on small prey and particulate matter.

In order to determine the food intake resulting from these movements, the gut contents of five of the captive individuals were examined. Three categories of food were found in abundance, phytoplankton, nauplii and fragments of adult exuviae. It can be concluded that *L. pectinata* is able to feed, by its rhythmic cirral action, its individual ramal action and the grasping closure of the cirral net, on microplankton and small macroplankton. Little or no selective discrimination of food intake appears to occur, and feeding is continuous at or just below the water surface day and night, irrespective of water movements.

Discussion

Feeding in Lepadids. Prior to the present study, information on cirral activity in *Lepas* was available for *L. anatifera* (Gruvel, 1893; Southward, 1957; Howard and Scott, 1959; Crisp and Southward, 1961; Crisp, 1967), *L. anserifera,* (Bieri, 1966; Jones, 1968), *L. fascicularis* (Crisp, 1967; Cheng and Lewin, 1976) and *L. pacifica* (Cheng and Lewin, 1976). All accounts emphasize a number of common features of lepadid cirral activity. The cirri are held extended for long periods in either still or moving water and are swept through the water by vigorous muscular contractions of the peduncle. On contact with animal food and the stimulus of certain amino-acids and ions (Crisp, 1967), the cirri make two types of response. If the prey is small, contacting a single cirrus, the contacted cirrus curls down, capturing the prey and conveying it to the maxillipeds, thence to the mouthparts. If the prey is large, the cirral net curls as a whole to grasp the food and hold it against the mouthparts. Large prey grasped in this way may be held for up to two hours before the remains are released.

As the present study has shown, *L. pectinata* retains these two feeding responses in spite of its small adult size. The responses are basically like those of scalpellids (Batham, 1946; Barnes and Reese, 1959; Howard and Scott, 1959) but are associated in lepadids with a number of specializations related to the floating neustonic habit. These include prolonged cirral extension in still water, active sweeping by peduncular contractions, and insensitivity to illuminations, water movements or contact stimulation, all of which combine to result in the vigorous capture of small or large planktonic prey. These feeding adaptations are further combined with lightweight, globose capitular valves, a specialized growth pattern, fast rates of growth (Darwin, 1851; Annandale, 1909b; Evans, 1958; Skerman, 1958), rapid attainment of sexual maturity, flotatory specializations during naupliar development (Bainbridge and Roskell, 1966; Lang, 1979), planktonic searching for floating substrata by cyprids, highly gregarious settlement and, in *L. pectinata* (personal observation), a precocious development of the adult organization post-settlement. An account of the latter phenomenon will be given elsewhere. Without doubt, lepadids are highly specialized among the Lepadomorpha for the catch-as-catch-can inhabitation of floating objects in an opportunistic manner.

The carnivorous propensities of lepadids in this environment are well documented in direct observations on their feeding habits. Howard and Scott (1959) fed *L. anatifera* on *Artemia* and *Tigriopus*, and observed polychaetes, amphipods, carids, gastropods, bivalves and pycnogonids in the guts of field-collected specimens. Patel (1959) and Crisp (1976) fed the same species on pieces of *Mytilus* tissue, which were grasped by the cirral net and engulfed in the manner first described by Gruvel (1893). Bieri (1966) and Jones (1968) have shown that *L. anserifera* is even more active as a carnivore, feeding on whole *Vellela*, pieces of *Physalia* tentacle and pieces of fish and squid. Bieri gave evidence that this species can feed cooperatively, passing a *Vellela* from one individual to the next. *L. fascicularis* has also been observed to eat *Vellela* (Bieri, 1966) and pieces of *Mytilus* tissue (Crisp, 1967). In the natural habitat, it is clear that macrozooplankton is the major food source for the larger *Lepas* species.

Anatomical descriptions of the mouthparts of *L. anatifera, L. anserifera* and *L. fascicularis* support this conclusion. The comparative anatomy of the cirri and mouthparts further indicates a similar diet of macrozooplankton for other lepadids of the same oceanic habitat, *L. testudinata, L. australis, L. pacifica, Conchoderma virgatum* and *C. auritum* (e.g. Hoek, 1907; Nilsson-Cantell, 1921; Petriconi, 1969; Foster, 1978). Powerful mandibles with strong cutting teeth and a prominent molar process, heavily built maxillules with a large cutting spine on the lateral angle, a sequence of setose steps along the cutting edge and a group of strong spines in the median angle, and a strong spinose development of the maxillae, are features of these species. *L. pectinata* retains these features on a smaller scale, but the cutting masticatory processes of the mouthparts are relatively reduced and the mouthparts, mandibular palps and labrum carry many fine setae. This is indicative of an ability to collect and ingest particulate material gathered by the cirri, a fact confirmed by analysis of gut contents. *L. pectinata* feeds on small macroplankton by the usual two lepadid methods, but also takes in substantial quantities of microplankton.

Rhythmic Cirral Activity in ***L. pectinata.*** It is in connection with particulate feeding that the rhythmic cirral activity of *L. pectinata* can be interpreted. Little reference has been made to such activity in other lepadid species. It has been mentioned as occurring occasionally in *L. anatifera* at a maximum rate of 2.85 contractions per 10 seconds (Southward, 1957) but the pattern and significance of the activity were not described. In *L. anatifera*, the rami of cirrus I and the exopod of cirrus II carry dense setation on the median surface, arranged in a pattern similar to that of *L. pectinata*, but there is no evidence that *L. anatifera* feeds on particulate material. The maxilliped specialization in this species appears to be related to a grasping function.

In *L. pectinata*, in which every individual maintains a rhythm of cirral contractions, albeit at a wide range of rates among individuals (from 1 per 50 s to 1 per 1.3 s in the present study), the cirral movements gather particulate material from the water and transfer it to the maxillipeds. In addition to the rami of cirrus I and the exopod of cirrus II, the endopod of cirrus II in *L. pectinata* carries dense, anteriorly pointing setation. Rhythmic feeding on microplankton can therefore be recognized as a third feeding mechanism in this species, with correlated setose arrangements on the mouthparts and two pairs of maxillipeds. The continuous performance of this rhythmic activity, the amount of microscopic material in the gut and the ability of *L. pectinata* to remain active and healthy in water containing no macroplankton, confirm the importance of particulate feeding in this species.

The pattern of rhythmic cirral activity is also different from that well known for various balanomorph species. In particular, the timing is reversed as compared with balanids, the cirri being held extended between beats, with only a brief pause in the contracted position during each beat. In balanids, the cirri are held in the contracted position between beats, with little or no pause in the extended position (Crisp and Southward, 1961; Anderson, 1980b). There is also no indication in *L. pectinata* that the rhythmic cirral activity drives a current of water through the mantle cavity, as it does in balanids. Indeed, there is very little free space for such a current in the mantle cavity of *L. pectinata,* though some movement of water across the vascularized internal surfaces of the mantle valves must occur at each beat.

A comparison of the timing of events between the rhythms of *L. pectinata* and a representative balanoid, *Balanus balanus,* emphasizes this contrast and also reveals certain functional constraints in the cirripede cirral mechanism. *B. balanus* shows rhythmic extension and withdrawal at a rate of 2-5 beats per 10 seconds (Crisp and Southward, 1961). The average duration of the pause between beats, with the cirri withdrawn, is 0.8 - 1.74 s. During each beat, cirral extension takes 0.75 - 1.25 s and is immediately followed by a faster withdrawal, taking 0.5 - 1.0 s.

In *L. pectinata*, the cirri may be held extended up to 50 s between beats, but rates of 4-5 beats per 10 seconds are frequently observed. At this comparable rate, cirral extension in 0.38 - 0.40 is followed by a pause of 1.0 - 1.3 s with the cirri extended. Cirral withdrawal in 0.28 - 0.30 s is then followed by a pause of 0.17 - 0.28 s before the cirri are extended again. In both species, cirral extension is slower than cirral withdrawal, a function of the similar hydraulic and muscular mechanisms involved in both cases. Other than this common factor, the rhythms of the two species are performed in entirely different ways. Extension and withdrawal are both faster in *L. pectinata* than *B. balanus.* Between extension and withdrawal, the cirri are held in the mantle cavity for a much shorter time in *L. pectinata* than in *B. balanus.* Following each extension, the cirri are held extended in *L. pectinata* for a period equal to or longer than the duration of a beat. In *B. balanus,* there is no pause in the extended mode. These differences indicate that the rhythmic cirral beating of *L. pectinata* has evolved independently of that of balanoids, lending further support to the view that it is a special feature of *L. pectinata* among lepadids.

The recent description and analysis (Anderson, 1980a) of rhythmic cirral activity in the verrucid *V. stroemia*, again evolved independently of balanoid beating, provides a further opportunity for comparison with *L. pectinata.* In this comparison, the similarities are much greater. *V. stroemia,* like *L. pectinata*, performs rhythmic cirral beating at 4-9 beats per 10 seconds, with the cirri held extended between beats. In each beat, the average duration of the withdrawal movement is 0.34 s, little different from that of *L. pectinata,* and of the extension movement 0.57 s, intermediate between *L. pectinata* and *B. balanus.* The average duration of the pause between beats with the cirri extended is 0.90 s in *V. stroemia,* slightly less than in *L. pectinata.* On the other hand, there is no pause with the cirri in the withdrawn position in *V. ,stroemia.* Once withdrawn, they are immediately extended again. Another unique feature of the rhythmic cirral action of *V. stroemia* is that the long, posterior cirri do not curl forwards during the withdrawal movement.

Thus in spite of the general similarity of the rhythmic cirral action of *V. stroemia* and *L. pectinata*, the two patterns of action differ fundamentally in the lack of a pause in the withdrawn position in *V. stroemia* and in the lack of cirral bending. The maxillipeds also spread and close in different ways in the two species. Since all phylogenetic considerations point to the independent evolution of these rhythmic actions as specialized features of these species within their genera, the differences between them are not surprising. What is more remarkable is the convergent similarity that they show as modifications of the prolonged cirral extension with captorial feeding characteristic of lepadids and verrucids respectively. *L. pectinata* and *V. stroemia* are both small species adapted to unusual habitats as compared with other members of each genus. *L. pectinata* preferentially inhabits ephemeral objects at the water surface. *V. stroemia* is a shallow water species. Both retain captorial feeding on small macroplankton, but both also feed on microplankton. Both have finely setose mouthparts and maxillipeds. Both capture their microplankton by a rhythmic cirral action in which the cirri are held extended between beats. In view of this convergent evolution of similar rhythmic cirral activity in a lepadomorph and a verrucomorph, the possibility of convergent evolution of the balanoid pattern of rhythmic cirral activity on more than one occasion in the Balanomorpha must not be overlooked.

ACKNOWLEDGEMENTS

This investigation forms part of a study supported by the Australian Research Grants Committee and the University of Sydney. I wish to thank Mr M. J. Moran for the provision of animals and my wife, Joanne, for technical assistance.

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THE LINNEAN SOCIETY OF NEW SOUTH WALES

RECORD OF THE ANNUAL GENERAL MEETING, 1979

The one hundred and fourth Annual General Meeting was held in the Science Centre, 35 Clarence Street, Sydney on Wednesday, 28th March 1979 at 7.30p.m.

The President, Mr J. T. Waterhouse, occupied the Chair. The minutes of the one hundred and third Annual General Meeting 29th March 1978 were read and confirmed.

REPORT ON THE AFFAIRS OF THE SOCIETY FOR THE YEAR 1978-9

Publications

Following advice in February 1978 from the Australasian Medical Publishing Company, our printer since 1925, that other commitments would prevent its handling the *Proceedings* beyond vol. 102, part 3, the Society was faced with an urgent need to find another printer. At this time also, we were seeking ways of improving the format of our *Proceedings* as well as reducing the burdensome costs of editing and printing.

To give effect to our plans, Professor T. G. Vallance has taken over as Honorary Editor from Part 1 of Volume 103 and the changes forecast in last year's Annual Report are being implemented. We are considerably in Professor Vallance's debt. We are pleased to report that manuscripts are coming in at a steady rate and copy is now in the hands of our new printers, Southwood Press Pty Limited, of Marrickville.

Volume 102, Part 3 of the *Proceedings* was published on July 5th.

Membership

During the year, 10 new members were elected to the Society, 6 resigned and one died. At 1st March, 1979 the membership was made up of 258 Ordinary Members, 26 Life Members and 6 Corresponding Members, making a total of 289.

Council noted with regret the death in May of Mr H. K. Judd. Howard Judd was elected to the Society in 1960. At the time of his election he had just taken on the position of Custodian and Ranger of the Minnamurra Falls Forest Reserve, Jamberoo, a relict pocket of rain forest in the Illawarra that he himself had been the prime initiator in having conserved. Although this reserve is small it is extremely important floristically as a sample of the once more-widespread southern rain-forests, and natural historians will be forever indebted to Howard Judd for its conservation. He was by training a marine wireless operator and for some time was in charge of an army training school in this field. He became an amateur natural historian not only well-informed on his premier interest, the botany of rain-forests, but also knowledgeable on the local fauna and geology. Many of us have found him an enthusiastic and valued guide in the Jamberoo area and his loss will indeed be felt.

In September, Emeritus Professor I. A. Watson was elected to Corresponding Membership of the Society in recognition of his distinguished contribution to Science and to the Society over many years.

Council had decided to recognize a new category of membership to be known as "Associate Membership", suitable for students and others who do not wish to be full members. Associate Members would be invited to participate in all activities and benefits of the Society except voting and receiving the *Proceedings,* and would be liable for a smaller fee than full members ($4.00 in 1979).

Meetings

Our activities during the year included one Special General Meeting of Members to discuss the Society's financial position and relationship with Science House Pty Ltd, three Ordinary General Meetings and three Field Excursions. None of these meetings was as well attended as we should have liked, but all were very rewarding for those who did come.

At the first of the Ordinary General Meetings in May, Dr D. H. Ashton of the School of Botany at Melbourne University spoke about "The Vegetation of Chile". In June at a joint meeting with the Australian Museum Society, Professor Gordon Craig, James Hutton Professor of Geology at the University of Edinburgh, gave an address on "The Lost Illustrations of James Hutton for *The Theory of the Earth* (1795)".

On September 3rd a Field Day was held at the Kurnell Peninsula to visit the aboriginal middens and examine the vegetation and the mud flats. In October a Field Day was held at Agnes Banks to examine the Castlereagh State Forest and the effects of sand mining. Another Field Trip visited Lake Illawarra in November to explore problems involved in the management of the lake.

More recently, on 14th March, 1979, we joined the Australian Systematic Botany Society to hear an address by Mr H. B. Carter (Hons. Banksian Archivist, British Museum (Nat. Hist.)) on "Sir Joseph Banks".

Newsletter

The LINN SOC NEWS has continued to be printed quarterly, giving details of coming meetings, reports of resolutions from the Council meetings and other items of interest to members.

Linnean Macleay Fellowship

Mrs Jennifer Anderson completed her third and final year as a Linnean Macleay Fellow at the University of New South Wales, studying the biology of two species of Australian Coccinellidae, *Scymnodes lividigaster* (Mulsant) and *Lepthothea galbula* (Mulsant). During the year her experimental studies of the reproductive and diapause physiology of *L. galbula* and an ecological programme involving population monitoring, determination of voltinism, sex ratios and seasonal developmental cycles in both species, was completed. She is now a tutor in the School of Zoology, University of New South Wales, and writing her PhD thesis.

Miss B. D. Porter is the Linnean Macleay Fellow for 1979. She is carrying out her research in the School of Biological Sciences at the University of New South Wales on the subject "The Structure and Function of Macropodid Salivary Glands".

Linnean Macleay Lectureship in Microbiology

This appointment continues to be held by Dr K. Y. Cho. The research work this year concerns mainly the use of agricultural waste for the cultivation of edible fungi. Cotton seed hull has been found suitable for the cultivation of *Vovariella volvacea, Pleurotus ostreatus, Lentinus edodes, Pholiota nameko* and *Flammulina velutipes*. Similar studies will be extended to other edible fungi.

The study of the antegenecity of the outer and inner membranes of *Azotabacter vinelandii* is still in progress.

Staff Appointments

Mrs Pauline Mills was appointed the Society's Librarian on May 22nd following the resignation of Mrs Buttigieg.

Office

The Society's office is on the 6th floor of the Science Centre. The Librarian is in attendance on Mondays and Wednesdays from 9 a.m. until 1 p.m. and the Secretary all day on Tuesdays. The office is closed on Thursdays and Fridays.

The Society's telephone number is 290 1612.

Science Centre

Professor N. G. Stephenson gave a detailed report on the Science Centre which was printed in full in Newsletter No. 13 issued in June 1979.

Library

Since the appointment of Mrs Pauline Mills the library has functioned normally.

FINANCIAL REPORT

This report was given by the Honorary Assistant Treasurer, Dr F. W. E. Rowe, in the absence overseas of the Honorary Treasurer, Dr D. A. Adamson.

Following the resignation of Dr Vickery as Honorary Treasurer in August, Council appointed a Finance Committee consisting of Dr D. Adamson, Honorary Treasurer, with Drs F. W. E. Rowe and A. Ritchie assisting.

The apparently healthier situation of the Society at the end of 1978 — with a credit balance of $2224, compared with the 1977 deficiency of $3516 — was the result of unusual factors and belies the true situation.

Invested funds in the General Account have risen marginally to $94,175 from which we derived interest of $9,864. The remainder of our investments (totalling $403,004) is tied up in the loans to Science House Pty. Ltd. It still appears unlikely that we will receive any financial return from this source in the foreseeable future.

Many of the expenditure items differed little from those of the previous year and will not be dealt with individually.

Council continued to supplement the Linnean Macleay Fellowship Grant until the completion, in December, of Mrs J. Anderson's term.

The 1978 costs for cleaning and office rent considerably exceeded those of 1977 mainly because the former represented the first payment for a full year.

Because of the problems encountered with the *Proceedings* following the printer's abrupt termination of its long-standing association with the Society, issue of the *Proceedings* has been severely delayed. 1978 printing costs were only $2287 compared with $10,573 for 1977 for printing and illustrations. The Society can expect, therefore, to face severe financial problems when the cost of publishing the overdue issues and those of the following volume fall in the same financial year. We expect these costs to exceed $10,000. By a decision of Council referees' fees were discontinued.

The delay in publishing the *Proceedings* has also had an effect on the costs of postage and of reprints which were smaller than usual during 1978.

Secretarial services cost $10,632 ($11,090 for 1977) which still included payment for editing work undertaken by Science House prior to the Council's decision to appoint an Honorary Editor.

Total expenditure for the year 1978 was $24,310 ($31,911 for 1977).

Total income for 1978 in the General Account was $26,534 ($28,395 for 1977).

The main sources of income for the General account fall into several categories:

(a) Membership subscriptions
(b) Subscriptions to *Proceedings*
(c) Interest on General Account investments
(d) Transfer of surplus income from the Fellowships Account
(e) Donations to the *Proceedings*
(f) Sales of sets of the *Proceedings,* back issues, etc.
(g) Sale of valuable assets, e.g., Gould *Humming Birds* volumes.

Of these (a) and (b) are unlikely to rise markedly; there is some scope for reinvestment of maturing funds at higher interest rates (c) and (d); (e) is likely to be minimal. This leaves (f) sale of *Proceedings* — these are "once only" items but if potential buyers for sets can be located they may also be expected to subscribe to future *Proceedings*. (g) Since Landsdowne Press has made facsimiles from other sources do we need to keep this item?

The financial situation can also be improved by reduction of expenditure and the main categories where this might be achieved appear to be

(a) the library — by relocation and reducing the costs of servicing it.
(b) secretarial services currently carried out by Science House Pty. Ltd.

Failing some determined action during the next 12 months the Linnean Society will be compelled to draw on investments as they mature instead of reinvesting them, a short-sighted and short-term policy which would solve nothing.

In the Fellowships Account total investments of $129,861 produced an interest income of $10,726. $3,199 of this went to the Fellow during 1978 leaving $7,527 to be transferred to the General Account. This was similar to the situation in 1977.

The Bacteriology Account involving total investments of $36,900 received interest of $2,398 (similar to 1977), allowing $2,400 to be donated to the University of Sydney towards the salary of the Linnean Macleay Lecturer in Microbiology.

The Scientific Research Fund has been augmented by interest of $2,121 and by donations of $2,000 during 1978 bringing the balance to $21,895.

Following the presentation of the Honorary Treasurer's report and discussion a motion that the audited balance sheets for 1978 he adopted was passed unanimously by the members present.

PRESIDENTIAL ADDRESS

The President, Mr J. T. Waterhouse, delivered an address entitled "The Phylogenetic significance of Dracaena-type growth in Monocotyledons", which he illustrated with slides. The Presidential Address will be published in full in a future issue of the *Proceedings*.

DECLARATION OF ELECTIONS

As the number of nominations did not exceed the number of vacancies on the Council, no election was necessary. The Chairman declared the following members duly elected:

President: Dr A. Ritchie
Members of Council: Dr H. A. Martin, Mr E. J. Selby, Dr A. Ritchie, Dr J. W. Vickery, Mr J. T. Waterhouse and Dr A. J. T. Wright.
Auditors: W. Sinclair & Co.

Mr Waterhouse introduced Dr A. Ritchie as the President for 1979 and invited him to take the Chair.

Dr Ritchie called on Professor D. J. Anderson to propose a vote of thanks to Mr Waterhouse for his Presidential Address and for his work for the Society during the year. This was carried by acclamation.

Dr Ritchie expressed appreciation of the retiring President's meticulous chairmanship of Council meetings during a difficult year. He also expressed appreciation of Dr Vickery's work as Honorary Treasurer from 1971 until last August when she resigned and the Finance Committee was appointed.

LINNEAN SOCIETY OF NEW SOUTH WALES

GENERAL ACCOUNT

Balance Sheet as at 31st December, 1978

1977 $		$
	Accumulated Funds —	
	Balance, 1st January, 1978	500,402.85
	Add Surplus for the year	2,224.11
500,403	Balance, 31st December, 1978	502,626.96
	Reserves —	
1,143	Bookbinding	1,142.66
	Science House Pty Limited —	
236	Donations held	3.00
—	Sundry creditors	157.50
$501,782		$503,930.12

1977 $			$	$
	Fixed Assets —			
	Furniture, Fixtures & Fittings — At Cost		1,670.91	
1,423	*Less* Depreciation written off		354.63	1,316.28
	Office Machines — At Cost		2,021.33	
495	*Less* Depreciation written off		602.33	1,419.00
	Investment — At Cost —			
1	Share — Science House Pty Limited			1.00
1,919	Total Fixed Assets			2,736.28
	Investments —			
	Deposits —			
410	N.S.W. Permanent Building Society		1,475.66	
36,700	Australian Resources Development Corp.		36,700.00	
—	Australian Resources Development Bank		9,300.00	
1,000	Commonwealth Loans — At Cost		1,000.00	
	Debentures — At Cost			
20,000	C.B.F.C. Limited	20,000.00		
	Add Interest Accrued	1,150.00		
			21,150.00	
—	Esanda Limited		1,800.00	
22,100	Metropolitan Water, Sewerage & Drainage Board		10,000.00	
12,750	Mutual Acceptance Limited		12,750.00	
92,960	Total Investments			94,175.66
	Current Assets —			
	Loans — Science House Pty Limited —			
400,000	Science Centre Account		400,000.00	
3005	Management Account		3004.60	
311	Sundry Debtors		608.20	
40	Linnean Macleay Fellowships Account		48.16	
35	Cash on Hand		—	
3,512	Cash at Bank		3,357.22	
406,903	Total Current Assets			407,018.18
$501,782				$503,930.12

LINNEAN SOCIETY OF NEW SOUTH WALES

Income and Expenditure Account for the Twelve Months Ended 31st December, 1978

1977	EXPENDITURE		1977	INCOME		
$		$	$		$	$
450	Audit Fees	450.00		Subscriptions —		
66	Cleaning	198.00	928	Members	1,484.00	
203	Depreciation	220.05	5,047	Proceedings	6,197.06	
410	General Expenses	237.97	5,975			7,681.06
600	Fellowship Grant	600.00				
1,417	Illustrations	—		Proceedings — Printing Costs —		
33	Insurance	25.15	26	Donations received		1,100.00
250	Legal Expenses	109.05	34	Insurance Refund		—
140	Library	144.04	8,903	Interest Received		9,863.92
266	Light and Power	172.96		Fellowships Account —		
1,201	Postages	993.05	7,413	Surplus Income for the year		
9,157	Proceedings — Printing Costs	2,287.07		ended 31st December, 1978		7,527.05
317	Printing and Stationery	515.93	6	Donations Received		7.50
70	Referees Fees	—	789	Reprint Sales		327.34
117	Repairs and Maintenance	9.75	5,249	Sales		27.00
1,273	Reprints	593.10	28,395	Total Income		26,533.87
216	Room Hire	290.00				
4,133	Salaries	5,702.24	3,516	Deficiency for year		—
314	Science House Rent	961.80				
11,090	Secretarial Services	10,632.33				
188	Telephone	167.27				
31,911	Total Expenditure	24,309.76				
	Surplus for Year					
	Transferred to Accumulated Funds	2,224.11				
$31,911		$26,533.87	$31,911			$26,533.87

AUDITORS' REPORT

We have audited the books and records of the Linnean Society of New South Wales for the twelve months ended 31st December, 1978 and are of the opinion that the above Balance Sheet and accompanying Income and Expenditure Account correctly sets forth the position of the financial affairs as at 31st December, 1978, according to the explanations given to us and as disclosed by the books of the Society.

W. SINCLAIR & CO.,
Chartered Accountants
Registered under the Public Accountants Registration Act, 1945,
as amended.

DATED at Sydney this fifteenth day of March, 1979.

F. W. E. ROWE,
Hon. Assistant Treasurer.
15th March, 1979.

LINNEAN SOCIETY OF NEW SOUTH WALES

LINNEAN MACLEAY FELLOWSHIPS ACCOUNT

Balance Sheet as at 31st December, 1978

1977 $		$	$
	Accumulated Funds—		
	Balance, 1st January, 1978—		
	Amount Bequeathed by Sir William Macleay	70,000.00	
	Transfers from Income Account	59,873.10	
	Increase in Value of Assets	272.02	
			130,145.12
	Less adjustment of transfers to general account in respect of interest received		318.69
129,826	Balance, 31st December, 1978		129,826.43
	General Account—		
40	Interest not transferred		48.16
$129,866			$129,874.59

1977 $		$
	Fixed Assets—	
46,200	Commonwealth Loans — At Cost	46,200.00
13,500	Australian Savings Bond — At Cost	13,500.00
	Debentures — At Cost—	
200	British Petroleum Company of Australia Ltd	200.00
1,000	Electricity Commission of New South Wales	1,000.00
—	Esanda Limited	4,200.00
1,263	F.N.C.B. — Waltons Corporation Limited	1,262.90
13,000	Metropolitan Water, Sewerage & Drainage Board	8,500.00
13,250	Mutual Acceptance Limited	13,250.00
6,000	Telecom Australia	6,000
	Deposits—	
35,400	Australian Resources Development Bank	35,700.00
40	Permanent of Australia Building Society Ltd	48.16
129,853	Total Investments	129,861.06
	Current Assets—	
13	Cash at Bank	13.53
$129,866		$129,874.59

Income and Expenditure Account for the Twelve Months Ended 31st December, 1978

1977 $		$
3,200	Salary of Linnean Macleay Fellow	3,199.92
7,250	Surplus for the year transferred to General Account	7,527.05
$10,450		$10,726.97

1977 $		$
10,450	Interest Received	10,726.97
$10,450		$10,726.97

AUDITORS' REPORT

We have audited the books and records of the Linnean Society of New South Wales for the twelve months ended 31st December 1978 and are of the opinion that the above Balance Sheet and accompanying Income and Expenditure Account correctly sets forth the position of the financial affairs of the Linnean Macleay Fellowships Account as at 31st December, 1978, according to the explanations given to us and as disclosed by the books of the Society.

W. SINCLAIR & CO.
Chartered Accountants
Registered under the Public Accountants Registration Act 1945,
as amended.

DATED at Sydney this Fifteenth day of March, 1979.

F. W. E. ROWE,
Hon. Assistant Treasurer.
15th March, 1979.

LINNEAN SOCIETY OF NEW SOUTH WALES

BACTERIOLOGY ACCOUNT

Balance Sheet as at 31st December, 1978

1977 $		$	$	1977 $		$
	Accumulated Funds—				Investments—	
	Balance, 31st December, 1978—			26,900	Commonwealth Loans — At Cost	26,900.00
	Amount bequeathed by Sir William Macleay	24,000.00		1,600	Australian Savings Bonds — At Cost	1,600.00
36,900	Transfers from Income Account etc.	12,900.00	36,900.00		Australian Resources Development Bank	
				8,000	Transferable Deposits — At Cost	8,000.00
	Macleay Lecturer in Microbiology Reserve—				Debentures—	
	Balance, 1st January, 1978	2,564.70		200	British Petroleum Company of Australia Ltd.	200.00
2,565	*Less* Deficiency for Year	1.40	2,563.30		Metropolitan Water, Sewerage & Drainage	
	Balance, 31st December, 1978			200	Board — At Cost	200.00
				36,900		36,900.00
					Current Assets—	
				2,565	Cash at Bank	2,563.30
$39,465			$39,463.30	$39,465		$39,463.30

Income and Expenditure Account for the Twelve Months Ended 31st December, 1978

1977 $			1977 $		$
2,500	University of Sydney — Salary of Lecturer	2,400.00	2,398	Interest Received	2,398.60
			102	Deficiency for Year	1.40
$2,500		$2,400.00	$2,500		$2,400.00

AUDITORS' REPORT

We have audited the books and records of the Linnean Society of New South Wales for the twelve months ended 31st December 1978 and are of the opinion that the above Balance Sheet and accompanying Income and Expenditure Account correctly sets forth the position of the financial affairs of the Bacteriology Account as at 31st December, 1978, according to the explanations given to us and as disclosed by the Books of the Society.

W. SINCLAIR & CO.
Chartered Accountants
Registered under the Public Accountants Registration Act, 1945,
as amended.

DATED at Sydney this Fifteenth day of March, 1979.

F. W. E. ROWE,
Hon. Assistant Treasurer.
15th March, 1979.

LINNEAN SOCIETY OF NEW SOUTH WALES

SCIENTIFIC RESEARCH FUND ACCOUNT

Balance Sheet as at 31st December, 1978

19776 $		$	$
	Accumulated Funds —		
	Balance, 1st January, 1978	17,773.62	
	Interest Received	2,121.36	
	Donations Received	2,000.00	
17,774	Balance, 31st December, 1978		21,894.98
$17,774			$21,894.98

1977 $		$
	Investments —	
	Debentures — At Cost —	
1,800	Australian Guarantee Corporation Ltd	1,800.00
3,600	Beneficial Finance Corporation Ltd	3,600.00
1,200	British Petroleum Company of Australia Ltd	1,200.00
2,700	Commercial & General Acceptance Limited	2,700.00
3,100	Finance Corporation of Australia Ltd	3,100.00
1,021	F.N.C.B. — Waltons Corporation Limited	1,021.00
1,900	General Credits Ltd.	1,900.00
1,200	Citicorp Aust. Ltd.	3,300.00
1,200	Mutual Acceptance Limited	3,200.00
17,721		21,821.00
	Current Assets —	
53	Cash at Bank	73.98
$17,774		$21,894.98

AUDITORS' REPORT

We have audited the books and records of the Linnean Society of New South Wales for the twelve months ended 31st December, 1978 and are of the opinion that the above Balance Sheet correctly sets forth the position of the financial affairs of the Scientific Research Fund Account as at 31st December, 1978 according to the explanations given to us and as disclosed by the Books of the Society.

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Papers should be written in clear, concise English. The *Style Manual for Authors and Printers of Australian Government Publications* (Second Edition, 1972) is a useful guide. Spelling should conform to that preferred by the *Oxford English Dictionary*.

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2. A concise Abstract, complete in not more than 200 words, indicating the scope of the paper. Authors should adopt the lay-out used in this issue of the *Proceedings*, including details of postal address but leaving spaces for editorial insertions.
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4. Acknowledgements, if any.
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   BULLOUGH, W. S., 1939. — A study of the reproductive cycle of the minnow in relation to the environment. *Proc. zool. Soc. Lond.,* Ser. A, 109: 79-108.

   Titles of periodicals should be abbreviated as in the *World List of Scientific Periodicals.* If more than one work by the same author published in the same year is cited, use a, b, etc., after the year in both text and list of references. Titles of books should be quoted in full together with the place of publication, the name of the publisher and the edition if other than the first.

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PROCEEDINGS of LINNEAN SOCIETY OF NEW SOUTH WALES
VOLUME 104

Issued 21 July 1980

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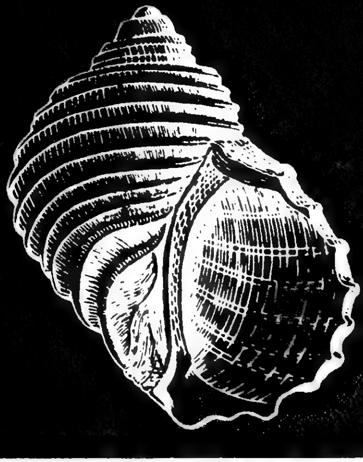
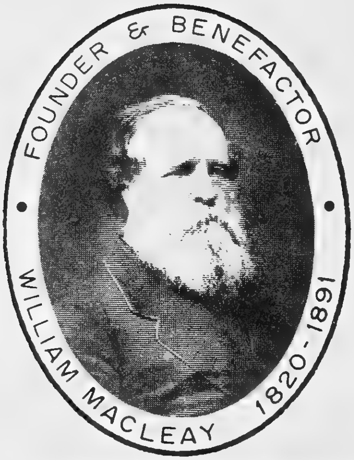


NATURAL HISTORY IN ALL ITS BRANCHES

THE LINNEAN SOCIETY OF NEW SOUTH WALES



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[1] appointed 23 May 1979

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[3] appointed 21 November 1979

[4] resigned 23 May 1979

[5] resigned 24 October 1979

[6] deceased 29 May 1979

Cover motif: *Fossarus sydneyensis* Hedley
Balmoral Beach, Sydney
(*Proc. Linn. Soc. N.S.W.* 35, 1900: 89)

PROCEEDINGS
of the
LINNEAN SOCIETY
of
NEW SOUTH WALES

VOLUME 104
NUMBER 3

Sporobolomycetaceae from Indooroopilly (Australia) and from Port Moresby (Papua New Guinea)

DOROTHY E. SHAW and E. GWENDA CARTLEDGE

SHAW, D. E., & CARTLEDGE, E. G. Sporobolomycetaceae from Indooroopilly (Australia) and from Port Moresby (Papua New Guinea). *Proc. Linn. Soc. N.S.W.* 104 (3), (1979) 1980:161-170.

Sporobolomycetaceae were isolated following the spore fall method from 60 out of 89 mainly healthy, undamaged, samples from 51 of 58 plant species at Indooroopilly near Brisbane, Australia, and from 21 out of 66 samples from 21 of 51 plant species from eight sites around Port Moresby in Papua New Guinea. At Indooroopilly, positive records involved *Sporobolomyces* (58.3%), *Tilletiopsis* (38.1%) and *Bullera* (3.6%), and at the Port Moresby sites, *Tilletiopsis* (78.3%) and *Sporobolomyces* (21.7%), no *Bullera* being recorded. At Indooroopilly, some plant species were consistently positive with many colonies while five species were negative in two tests. In the Port Moresby area, ratios of positive to negative samples were 1: 1.4, 1: 3.2 and 1: 8.0 for three foliage zones (below 1 m, between 1 and 2 m and over 2 m, a.g.l., respectively); 1: 7.0 and 1: 0.2 for coastal versus inland sites, and 1: 1.8 and 1: 17.0 for sites with and without rain in the 24 h preceding sampling. Eighty isolates altogether from the temperate and tropical locations were lodged with Dr J. Fell, U.S.A., for biochemical studies and species identification.

Dorothy E. Shaw, C/- Plant Pathology, Department of Primary Industries, Meiers Road, Indooroopilly, Australia 4068 and E. Gwenda Cartledge, 39 Greenways Road, Glen Waverley, Australia 3150 (both formerly, *Department of Primary Industry, Konedobu, Papua New Guinea*); *manuscript received 14 June 1979, accepted in revised form 20 February 1980.*

INTRODUCTION

Since the study of Derx (1930), Sporobolomycetaceae have been recorded on various plants in different parts of the world by workers including Nyland (1948, 1949, 1950); Tubaki (1952a, b; 1958); Last (1955 a, b; 1970); di Menna (1959); Brady (1960); Last and Deighton (1965); Hogg and Hudson (1966); Pady (1974) and Pugh and Lindsey (1975), and they have also been isolated from other situations (Phaff, 1971; Lindsey, 1976). Dickinson (1976) stated that although the majority of phylloplane studies have been carried out in temperate regions and on agricultural crops, the few studies which have been published on tropical plants suggest that many phylloplane fungi (which include the Sporobolomycetaceae) are cosmopolitan in their distribution.

In January 1976, the spore fall method of Derx (1930) was used as a qualitative measure to determine whether members of the Sporobolomycetaceae were occurring on samples of plants from Indooroopilly, near Brisbane, a temperate site at 27°28′ S latitude, and from around Port Moresby in Papua New Guinea (P.N.G.), a tropical area at 9° 27′ S latitude.

MATERIALS AND METHODS

The average annual rainfall for Brisbane is 1158 mm with 60% occurring from December to April inclusive; average relative humidity for 0900 and 1500 h is 66% and 54% respectively, and mean annual temperature is 20.5°C, with average maximum and minimum of 25.4° and 15.5°C respectively.

The average annual rainfall for Port Moresby is 1197 mm with 76% occurring from December to April inclusive; average relative humidity for 0900 and 1500 h is 77% and 67% respectively; mean annual temperature is 26.9°C with average maximum and minimum of 31.0° and 22.6°C respectively.

At Indooroopilly

One sample was taken at random from within the first 30 cm of foliage above ground level (a.g.l.) from each of 58 herbaceous and tree ornamentals, weeds, crop and pasture species* growing within an area of 0.5 ha about 20 km in direct line from the coast. Each sample consisted of a piece of healthy, undamaged leaf, or a small leaf, or phyllode, or several strap-like leaves, according to the plant species.

Following the procedure of Derx (1930), samples were attached to the underside of Petri dish lids by adhesive tape at each end to expose an area of the adaxial surface of approximately 10 mm² for each species, and held over potato dextrose agar (PDA) in the bottom of the dishes for three to four days at 25°C. Colonies were then counted, or scored as 'many' if confluent. No attempt was made to express the number of colonies quantitatively per cm² of plant tissue because of the variability of the samples. Colonies on the plates, and isolates from the colonies, were examined for colour, 'haloing' by ejected ballistospores, type and size of spores, presence or absence of budding, mycelium and clamp connexions.

Eighteen plant species negative in the first screening were retested a second time with fresh samples. Some of the repeat tests were carried out with the sample on one half of the lid and a fresh sample from *Bidens pilosa* L. or *Erigeron floribundus* (H. B. and K.) Schultz (two species chosen at random from those whose samples gave 'many' colonies) on the other half for comparison. Two other species negative twice were retested using insect-damaged material. One other species (*Rhychelytrum repens* (Willd.) C. E. Hubbard) was sampled twice without and twice with rust (*Puccinia levis* (Sacc. and Bizz.) Magn. var. *tricholaenae* (H. Syd. and P. Syd.) Ramachar and Cumm.).

Around Port Moresby

Samples were taken from 51 plant species* at eight sites around Port Moresby: five sites near the coast and three further inland at 7, 15 and 31 km in direct line from the coast, with the last site on a plateau at about 600 m altitude.

The sampling procedure differed slightly from that used at Indooroopilly. At two sites near the city, second samples were taken after rain when the first samples proved negative. In a few other cases, a second (and in two more cases, a third) sample was taken at another site or at another foliage height or both. The height a.g.l. of each sample was measured, and these are grouped arbitrarily into three foliage zones as (1) under 1 m, (2) between 1 and 2 m, and (3) over 2 m a.g.l. The method of isolation followed the spore fall procedure of Derx (1930) as given in the previous section, except that quantities of colonies were not assessed.

The meteorological data given previously apply to Site 6. Although no accurate figures are available for other sites, the five near the coast are generally slightly drier and warmer, and the other two inland sites slightly wetter and cooler, than Site 6. Rain was known to have fallen at all sites during the 24 h preceding sampling except at two coastal sites when the first screening followed a dry 24 h, and at Site 7, where no information was available.

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*A complete list of species is available for any interested reader.

RESULTS

At Indooroopilly

Sixty (67.4%) out of the 89 samples, involving 51 (87.9%) out of 58 plant species, yielded Sporobolomycetaceae (Table 1, a and b).

Three (5.2%) of the plant species sampled (*Lantana montevidensis* Briz., *Trifolium repens* L. and *Wahlenbergia caryophylloides* B. Carolin) yielded three genera of the Sporobolomycetaceae, namely *Sporobolomyces, Tilletiopsis* and *Bullera*. One of the species was scored as having 'many' colonies of *Tilletiopsis.*

TABLE 1

Summary of the number and percentage of samples and sampled plant species at Indooroopilly and around Port Moresby positive and negative for various genera of the Sporobolomycetaceae

Item as under	*Indooroopilly*		*Around Port Moresby*	
	No.	%	*No.*	%
a Samples positive	60	67.4	21	31.8
Samples negative	29	32.6	45	68.2
Total samples	89	100	66	100
b Plant species positive	51	87.9	21	41.2
Plant species negative	7	12.1	30	58.8
Total plant species	58	100	51	100
c Plant species with genera:				
Sporobolomyces, Tilletiopsis and *Bullera*	3	5.2	0	0
Sporobolomyces, and *Tilletiopsis*	27	46.5	23	3.9
Sporobolomyces only	19	32.8	3	5.9
Tilletiopsis only	2	3.4	16	31.4
None	7	12.1	30	58.8
	58	100	51	100
d Total records of genera, separately:				
Sporobolomyces	49	58.3	5	21.7
Tilletiopsis	32	38.1	18	78.3
Bullera	3	3.6	0	0
	84	100	23	100

Twenty-seven (46.5%) of the plant species sampled yielded two genera, *Sporobolomyces* and *Tilletiopsis.* Of these species, seven were scored with 'many' colonies of both *Sporobolomyces* and *Tilletiopsis.* These included *Bidens pilosa* and *Erigeron floribundus* which were consistently positive with 'many' colonies of both genera in six and four successive samplings respectively. Five other plant species yielded only *Sporobolomyces,* one with 'many' colonies. Two (3.4%) of the species yielded only *Tilletiopsis,* one with 'many' colonies.

Eleven of the plant species included above did not yield any Sporobolomycetaceae in their first tests, and were resampled, the second tests proving positive in all except two, viz., *Acacia podalyriifolia* A. Cunn. ex G. Don and *Eucalyptus* sp. A third sample from each of these two species deliberately selected with insect damage proved positive. The two healthy samples of *Rhynchelytrum repens* were negative and the two rusted samples positive.

Seven (12.1%) of the plant species (*?Astridia* sp., *Chlorophytum capense* (L.) Kuntze, *Crotalaria mucronata* Desv., *Ctenanthe oppenheimeriana* Schum., *Hakea gibbosa* (Sm.) Cav., *Macroptylium lathyroides* (L.) Urb and *Pinus* sp.) did not yield any Sporobolomycetaceae when tested twice.

The above figures are summarized in Table 1, c. Total records of the genera taken separately are *Sporobolomyces* 49 (58.3%), *Tilletiopsis* 32 (38.1%) and *Bullera* 3 (3.6%) (Table 1, d).

The specific identities of the *Sporobolomyces* isolates were not determined as facilities for the biochemical studies were not available.

The isolates of *Tilletiopsis* had ballistospores with length before germination of 4.5-10.5 μm; on the medium used (PDA) the colonies were at first white and glistening, then 'frosted', turning deep ivory in colour and still later deep tan; all the isolates produced tan pigment in the medium. The isolates are tentatively ascribed to *T. minor* Nyland.

The size of the ballistospores of the *Bullera* isolates falls into the '*B. alba*' group, but as it was not possible to carry out nitrogen assimilation tests, it is not known, for example, whether some or all were *B. alba* (Hanna) Derx, which does not assimilate nitrate, or *B. tsugae* Phaff and Do Carmo-Souza, which does (Phaff, 1971).

Although colonies were carefully checked for the presence of clamp connexions, none was noted, so that in this preliminary survey no species of *Sporidiobolus* or *Itersonilia* were recorded.

Thirty-four isolates, consisting of one isolate of *Bullera,* 10 of *Tilletiopsis* and 20 of *Sporobolomyces,* as well as three isolates which were non-ejecting and are perhaps true yeasts, were lodged in 1976 with Dr J. Fell, U.S.A., for biochemical studies and species identification, the results of which will be published separately.

Around Port Moresby

Sixty-six samples were taken from 51 herbaceous and tree species. No sample yielded three genera of the Sporobolomycetaceae as at Indooroopilly. Twenty-one (31.8%) out of the 66 samples, involving 21 (41.2%) of 51 plant species, yielded Sporobolomycetaceae (Table 1, a and b).

Two (3.9%) of the plant species sampled yielded both *Sporobolomyces* and *Tilletiopsis:* three (5.9%) only *Sporobolomyces* and 16 (31.4%) only *Tilletiopsis.* Thirty (58.8%)* of the species sampled did not yield any Sporobolomycetaceae at all, even the six tested twice.

The results are summarized in Table 1, c. Total records of the genera taken separately are *Tilletiopsis* 18 (78.3%) and *Sporobolomyces* 5 (21.7%) (Table 1, d).

TABLE 2

Number, percentage and ratio of samples positive and negative for Sporobolomycetaceae from three foliage zones sampled around Port Moresby

Foliage zones	Samples								
	Total		Yielding Sporobolomycetaceae (positive)		Not yielding Sporobolomycetaceae (negative)		Positive	Negative	
m (a.g.l.)	No.	%	No.	%	No.	%	%	%	Ratio
Below 1	36	54.5	15	22.7	21	31.8	41.7	58.3	1:1.4
Between 1 and 2	21	31.9	5	7.6	16	24.3	23.8	76.2	1:3.2
Over 2	9	13.6	1	1.5	8	12.1	11.1	88.9	1:8.0
Total	66	100	21	31.8	45	68.2			

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*A complete list of species is available for any interested reader.

Thirty-six (54.5%) of the samples came from the foliage zone below 1 m, 21 (31.9%) from between 1 and 2 m and 9 (13.6%) from the zone over 2 m a.g.l. The ratio of positives (yielding Sporobolomycetaceae) to negatives in the three zones is 1:1.4, 1:3.2 and 1:8.0 respectively (Table 2).

Only 28.6% of the positive samples came from the five coastal sites, whereas 71.4% came from the three inland sites. The percentages of positives to negatives in the coastal area are 12.5% and 87.5%, giving a ratio of 1:7.0, compared with 83.7% and 16.7% for the inland area, giving a ratio of 1:0.2 (Table 3).

TABLE 3

Number and percentage of samples positive for Sporobolomycetaceae at eight sites in two areas around Port Moresby and ratio of positives to negatives

Location	Samples								
	Per site			Per area					
	Total	Positive for Sporobolomycetaceae		Total	Total positive		Positive	Negative	
	No.	No.	%	No.	No.	%	%	%	Ratio
Coastal area				48	6	28.6	12.5	87.5	1:7.0
Site 1	18	2	9.5						
" 2	12	1	4.8						
" 3	6	0	0						
" 4	6	1	4.8						
" 5	6	2	9.5						
Inland area				18	15	71.4	83.3	16.7	1:0.2
Site 6	6	6	28.6						
" 7	6	5	23.8						
" 8	6	4	19.0						
	66	21	100.0	66	21	100.0			

Some samples at Sites 1 and 2 had been collected when no rain had fallen in the previous 24 h, and others after rain had fallen during this period. The figures for these sites were one positive sample against 17 negatives without rain, giving a ratio of 1:17, compared with two positives against 10 negatives after rain, giving a ratio of 1:5. The figure for all sites (except Site 7 where no rainfall information was available) was one positive against 17 negatives without rain, a ratio of 1:17, compared with 15 positives against 27 negatives with rain, a ratio of 1:1.8 (Table 4).

The specific identities of the *Sporobolomyces* isolates were not determined as facilities for the biochemical studies were not available.

The *Tilletiopsis* isolates were all at first white and glistening, then 'frosted', turning deep ivory in colour and still later deep tan. The lengths of the isolates mainly fell into the *T. minor* range, although eight of the 45 isolates measured had lengths over 12.5 μm and appeared nearer to *T. washingtonensis* Nyland; some widths were wider than those recorded for this species. Therefore all isolates are ascribed to *Tilletiopsis* sp. until further study.

Forty-six isolates, consisting of nine isolates of *Sporobolomyces,* 36 of *Tilletiopsis* from the present study, and one isolate of *T. minor* isolated previously by Shaw (unpublished) were lodged in 1976 with Dr J. Fell, U.S.A., for biochemical studies and species identification, the results of which will be published separately.

TABLE 4

Number and ratio of samples positive and negative for Sporobolomycetaceae with and without rain during the 24 h prior to collection around Port Moresby

Rainfall during 24 h prior to collection	Samples		
	Positive	Negative	Positive : Negative
	No	No	Ratio
No rain, sites 1 and 2	1	17	1:17.0
Rain, sites 1 and 2	2	10	1: 5.0
Rain, all sites (except Site 7*)	15	27	1: 1.8

*No rainfall information available.

DISCUSSION

The results of the studies in the two regions (as discussed in detail below) support the suggestion that members of the Sporobolomycetaceae are cosmopolitan in distribution.

Locality occurrence

As shown in Table 1, a and b, 67.4% of the samples at Indooroopilly were positive for Sporobolomycetaceae, and 31.8% of the samples were positive around Port Moresby; 87.9% of the plant species sampled at the former location were positive and 41.2% positive around Port Moresby. These figures for occurrence even from mainly healthy, undamaged samples indicate that members of the family are fairly common at the tropical location (Port Moresby) and common at the temperate site (Indooroopilly).

Relative abundance of genera and temperature relations

Last and Deighton (1965) stated that *Sporobolomyces* is the best known genus of the Sporobolomycetaceae. Nyland (1950), Gandy (1966) and Flannigan and Campbell (1977) reported that *Sporobolomyces* predominated over *Tilletiopsis*. Last (1955a), however, found that *Tilletiopsis*, when present, decreased the number of colonies of *Sporobolomyces*. From studies with spore traps in England, Last (1955b) found a predominance of *Sporobolomyces* per m^3 of air compared with *Tilletiopsis*, the position being reversed a month later, and Gregory and Sreeramulu (1958) found that numbers of *Sporobolomyces* reached a maximum of about one million per m^3, about six times the peak concentration of *Tilletiopsis*.

Last (1955a) recorded *T. minor* only in the warmer months of his study in England. In controlled experiments, the number of colonies of *S. roseus* reached a maximum about 20°C. Pady (1974) isolated *Sporobolomyces* throughout the year in Kansas, *Bullera* in autumn, winter and spring, and *Tilletiopsis* only in summer; *T. minor* was the only species to produce well at 27°C. Derx (1930) reported that some species of *Sporobolomyces* had no growth at 30°C while others had some growth sometimes or were positive. Dickinson (1976) concluded that *Tilletiopsis* appeared to require a higher temperature for growth than *Sporobolomyces*.

Species of *Bullera* have been recorded very occasionally, as summarized by Phaff (1971), and since then mentioned by various authors including di Menna (1971), Davenport (1976) and Dickinson (1976). Derx (1930) found that the maximum temperature of *B. alba* was 27°C and Phaff (1971) reported that *B. alba* gave no growth at 30°C.

The lower temperature at Indooroopilly may have accounted for the predominance of *Sporobolomyces* (58.3%) over *Tilletiopsis* (38.1%) and for the occurrence of *Bullera* (3.6%) at that site, while the higher temperature at Port Moresby may have contributed to the predominance of *Tilletiopsis* (78.3%) over *Sporobolomyces* (21.7%) and *Bullera* (0%) in that area (Table 1, d). Whether a reversal of genus dominance occurs at higher altitudes (up to 4500 m) in P.N.G. has still to be determined.

'Hosts'

Last and Deighton (1965) and di Menna (1971) considered that colonizers of leaf surfaces (including Sporobolomycetaceae) were not host specific. Gandy (1966), however, found that *Itersonilia perplexans* Derx occurred on some live and dead parts of some host and non-host species, but not on some other parts or some other species. It was rarely isolated from the hirsute leaves of a derivative of *Chrysanthemum morifolium,* but was commonly found on glabrous leaves of three other *Chrysanthemum* species. Last (1970) found that numbers of *Tilletiopsis* colonies isolated from leaves of three herbs usually greatly exceeded those of *Sporobolomyces,* but the latter was usually more abundant on three deciduous tree species. Lamb and Brown (1970) isolated 10 times more colonies of *S. roseus* from leaves of *Paspalum dilatatum* than from *Salix babylonica,* and none at all from *Eucalyptus stellulata.* Davenport (1976) recorded *S. roseus* from certain parts of apple flowers and fruit but not from other parts, and Dennis (1976) isolated *S. roseus* from freshly harvested fruit of *Rubus idaeus* and *R. ulmifolius* whereas none was recovered from the fruit of *Fragaria ananassa.*

At Indooroopilly, although 87.9% of the plant species tested yielded Sporobolomycetaceae, including two species consistently positive in six and four tests each, 12.1% of the plant species were negative even when tested twice (Fig. 1, b). The limited number of repetitions precludes the drawing of any definite conclusions from the results. However, in view of the slight evidence presented, it is suggested that undamaged leaves of some species may be less acceptable habitats than others to even epiphytic phylloplane inhabitants such as the Sporobolomycetaceae. A similar opinion has already been expressed by Lamb and Brown (1970), Dickinson (1976) and Irvine *et al.* (1978).

As yet, little information has accumulated in the literature on recovery or non-recovery of Sporobolomycetaceae from various plant species or parts of plants. In some cases where samples have been drawn from many hosts, the species names have not been published, no doubt because of space restrictions. It would seem that many more data are required from repeated screenings in order to determine consistent negatives. If confirmed, they could then be investigated in detail to determine the cause or causes of the inhospitality. This might involve aspects of gross morphology and structure orientation (affecting, for example, the deposition and liberation of propagules); glabrosity or hairiness and presence of glands and stomates; microscopic topography and surface wax crystals; nutrient status or inhibitory activity of leachates and possibly other factors intrinsic to the host. In colonization studies, methods apart from spore fall may need to be considered (Bashi and Fokkema, 1976).

State of the host

Derx (1930) considered that the Sporobolomycetaceae belong to the microflora which are nourished principally by exudations on plants produced by atmospheric or traumatic causes. Some workers have obtained the greatest number of colonies from actively growing leaves (Ruscoe, 1971), from leaves soon after unfolding and persisting for 18 months (Hog and Hudson, 1966), from living and dead leaves (Last, 1955a; Gandy, 1966; Collins, 1976). Brady (1960) found that species of *Tilletiopsis* were present on most leaves checked whether or not these were attacked by *Entyloma,* but Last and Deighton (1965), Pady (1974) and Last (1970) reported increase in numbers after fungal infection, leaf nematodes, mites and other damage. Burg (1974) suggested that *Sporobolomyces* only becomes established on *Phragmites australis* following honey dew deposition, but Dickinson (1976) reported growth on undamaged and unpolluted leaves of this host.

In the present study, Sporobolomycetaceae were obtained from healthy, undamaged leaves of many plants. However, insect damaged leaves of *Acacia podalyriifolia* and *Eucalyptus* sp., and rusted leaves of *Rhynchelytrum repens* yielded colonies whereas healthy, undamaged ones did not, so that the former groups apparently afforded a more favourable habitat for sporulation than did the latter.

Height of samples

Last (1955a) found that the greatest concentration of *Sporobolomyces* spores in the air over wheat in England was near ground level. Lamb and Brown (1970) conceded that closeness to the ground may have contributed to the larger number of colonies of *S. roseus* isolated from a host sampled at 30 cm compared with two other hosts sampled at 2 m a.g.l.

The ratios of samples positive to negative for Sporobolomycetaceae in the Port Moresby study were 1:1.4 for the foliage zone below 1 m, 1:3.2 for the zone between 1 and 2 m, and 1:8.0 for the zone over 2 m a.g.l. (Table 2). While different plants were sampled in each zone, these figures indicate that the largest numbers of Sporobolomycetaceae were probably occurring in the lowest zone. Various factors may have been responsible for this, particularly humidity, which was probably highest in the zone closest to the ground.

Coastal versus inland sites

Pugh and Lindsey (1975) found that cell numbers of *Sporobolomyces* from plants growing in maritime areas were lower than those of inland plants and was caused by relatively high salt concentrations on leaf surfaces due to deposition and evaporation of salt spray.

The ratio of samples positive for Sporobolomycetaceae to negative for the five coastal sites around Port Moresby was 1:7.0 whereas the ratio for the three more inland sites was 1:0.2 (Table 3). Salt deposition may have had some part in reducing the populations on leaves at the coastal sites. These latter, however, are also in a drier and warmer zone than the sites further inland, and this may also have contributed to the reduction in numbers of their positive samples.

Rainfall and humidity

Various workers have discussed rainfall and humidity in relation to the Sporobolomycetaceae. Last (1955a) concluded that in wheat the spread of *Sporobolomyces* was probably restricted until the crop became dense enough to raise the humidity. Last (1955b) also found a tremendous increase in the number of spores per m^3 over cereal crops on a rainy day compared with a dry day. Zoberi (1964) reported that the rate of ballistospore discharge of *S. roseus* fell immediately on transfer from high to low humidity but recovered on return to relatively damp air, if the exposure to dry conditions was not too prolonged. Pugh and Lindsey (1975) reported that populations of *Sporobolomyces* on leaves of *Halimione portulacoides* were removed by tidal washing and a similar effect was also obtained by washing leaves in the laboratory. Bashi and Fokkema (1977), however, found no evidence that rain could be either beneficial to yeast populations by providing free water or disadvantageous by washing cells from the leaves, although continuous rain may leach nutrients. *Sporobolomyces* could only profit from the nutrients if exposed to relative humidities of at least 90% during part of the day. Flannigan and Campbell (1977), however, noted increase in numbers of *S. roseus* populations on wheat despite dry weather, perhaps influenced by increased nutrient availability from ageing organs or pollen grains deposited on the surface. Dickinson and O'Donnell (1977) supported the suggestion that humidity is a prime factor in determining the extent of leaf colonization.

At Port Moresby, fewer samples were positive when collected after a dry 24 h (positives to negatives 1:17) than after rain at the same two sites (1:5) or at all sites (1:1.8) (Table 4). The last ratio may reflect higher annual rainfall at two of the sites, as well as rainfall during the 24 h prior to collection.

Possible interactions with other microorganisms

Di Menna (1962) recorded *S. roseus* as sensitive to some bacterial species from soil, to soil *Streptomyces* and a few soil fungi, while Smith (1967) found that isolates of *Bacillus subtilis* and *Streptomyces* from natural soil were antagonistic to *I. pastinacae*.

A protostelid, *Protostelium mycophaga* var. *major* Olive, was found parasitizing *Sporobolomyces* sp. isolated from *Solanum nodiflorum* Jacq. at Indooroopilly (Shaw and Olive, 1977). However, it is not known whether the Indooroopilly samples differed from the Port Moresby samples regarding type and quantity of other phylloplane resident or transient microorganisms, or other objects such as pollen (Fokkema, 1976) which may have also contributed to the difference in numbers of colonies obtained between the temperate and tropical sites.

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A Preliminary Report on the late Cainozoic Geology and Fossil Fauna of Bow, New South Wales

C. G. SKILBECK

SKILBECK, C. G. A preliminary report on the late Cainozoic geology and fossil fauna of Bow, New South Wales. *Proc. Linn. Soc. N.S.W.* 104 (3), (1979) 1980:171-181.

Fossil marsupials collected from Bow, New South Wales, since 1966 are here examined and identified for the first time. These fossils occur in unconsolidated riverine conglomerates that overlie Liverpool Range basalts of early Janjukian age. The fossil deposits are estimated to be about 4.5 million years old (early Pliocene). A comparison of species recovered from Bow with those of other Australian Tertiary mammal faunas indicates affinities with both the Bluff Downs and Chinchilla local faunas of Queensland.

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INTRODUCTION

Excavations during relocation of the Merriwa-Cassilis Road at the site of the new bridge across Bow Creek led to a road cutting exposure (grid reference 323033 on 1:250,000 Geological Sheet for Singleton (No. S1-56-1), New South Wales, New South Wales Department of Mines, Sydney) of sediments containing a fossil mammal fauna. Although discovered in 1964, the palaeontological significance of this site remained unknown until 1966 when a local council gardener gathered surface specimens and forwarded them to the Australian Museum. The site was visited by J. A. Mahoney, of the University of Sydney, several times during 1966 at which time further specimens were collected. Between 1967 and 1970 a local banker, E. W. McDonald, made extensive collections at the site and donated these to the Australian Museum. A group that included A. Ritchie, of the Australian Museum, visited Bow in 1975 and with the aid of council earthmoving equipment collected further material. Further surface material was collected during research for the present study. Continued investigation of the site is being conducted by M. Archer of the University of New South Wales.

GEOLOGICAL SETTING

Bow is situated approximately 12 kilometres west of Merriwa on the Merriwa-Cassilis Road (Fig. 1). It lies on the 'Merriwa Plateau', a geomorphological subdivision of the Hunter Valley on the southern slopes of the Liverpool Ranges (Galloway, 1963b).

Galloway, in his geomorphological study of the Hunter Valley (1963a, 1963b, 1967) concluded that the recent drainage pattern has been determined primarily by lithology and secondarily by the structure of Palaeozoic and Mesozoic rocks which crop out in the valley. The effects of widespread Tertiary volcanism have been considerable. The pre-Cainozoic geology of the Hunter Valley has been recorded by Packham *et al.* (1969); Branagan, Herbert and Langford-Smith (1976) and

Galloway (1963a). The only recently published investigation of the Tertiary basalts of the Liverpool Ranges is that of Galloway (1967) who looked at the occurrence of the basalt and its effects on subsequent geomorphology. A detailed investigation of the petrology and geochemistry of these basalts is at present being undertaken by R. Schön of the University of Sydney.

GEOLOGY OF THE BASALT

Great flows of basalt were extruded over much of the Hunter Valley during the middle Tertiary (Galloway, 1967). These volcanics were erupted from two separate shield volcanoes and yield potassium/argon dates of 33.7 ± 1.4 million years (lower Janjukian) and 39.0 ± 1.4 million years (middle Aldigan) for the western and eastern provinces respectively (Wellman *et al.,* 1969). These dates are further supported by those of Wellman and McDougall (1974). The remnants of this volcanic episode are manifest as the present Liverpool Ranges. The geology of the basalt is of particular importance in the development of Bow Creek since basalt forms its basement and provided a unique source of its sediment.

Perpendicular jointing planes and the platy texture of weathered basalt which crops out around Bow indicate that the flows there dip slightly to the south. These near horizontal flows indicate a highly liquid lava capable of widespread occurrence. Petrologically, the basalts that crop out in the vicinity of Bow are olivine basalts. The texture is highly fluidal and amygdales occur in some flows. Although more than one flow can be recognized at Bow, a single volcanic episode is thought to have been their origin. The evidence for this single episode is the narrow range of modal compositions of six basalt samples from different stratigraphic levels. These compositions were derived by thin section point count.

POST-BASALTIC DEVELOPMENT

Since the termination of basalt eruption, the Hunter Valley has been subject to almost continual erosion. Removal of vast quantities of basalt and underlying sediments in some places has produced the lower-relief areas of the valley. Minor erosion in the thicker basalt areas has resulted in a remoulding of the geomorphology without any great topographical changes. The 'Merriwa Plateau' is an example of the latter part of this range of topographical expressions. Deep dissection of the basalt has not occurred; erosion has resulted in broad shallow valleys that are typified by the formation of alluvial terraces.

THE GEOMORPHOLOGICAL DEVELOPMENT OF BOW CREEK

The late Cainozoic deposition at Bow occurred in a depression, now occupied by a laterally restricted, slightly meandering stream. The earliest fluvial sediments in the Bow Creek Valley, deposited subsequent to the cessation of volcanism, have been partially eroded by the modern creek to form characteristic fluvial terraces. In some places, the terrace bank and/or river bed is defined by renewed incision of the basalt basement.

Terrace delineation, within the scope of this report, has only been tentatively attempted for the Bow Creek Valley (Fig. 1). It is based on altitude correlations of plane table mapping data. Based on the definition of a terrace as an 'abandoned flood plain' (Leopold, Wolman and Miller, 1964) for the section of Bow Creek studied, four terraces are recognizable. An active flood plain with an associated low discharge level bench is also recognized.

The abandonment of a flood plain can occur by three methods (Warner, 1972).

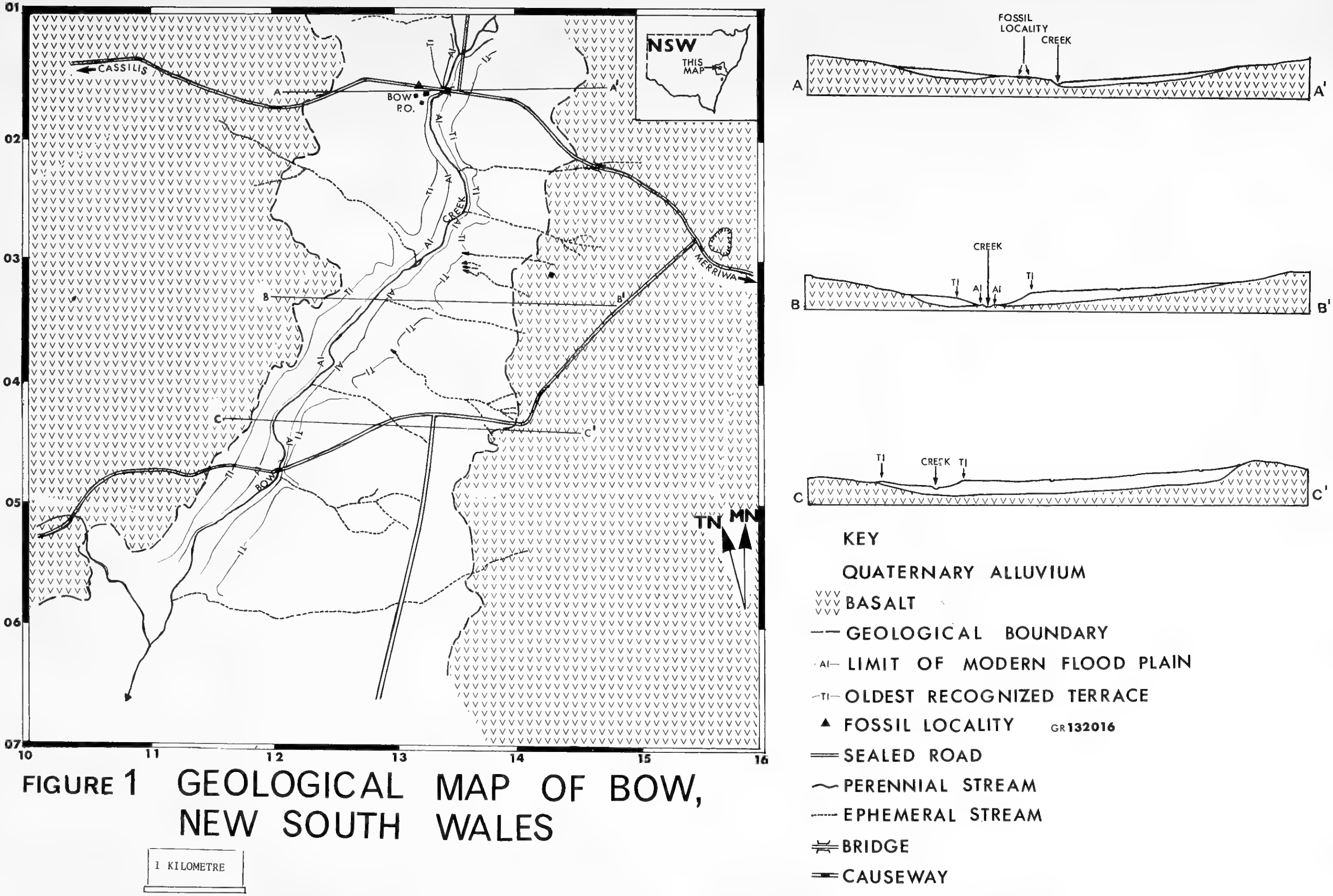
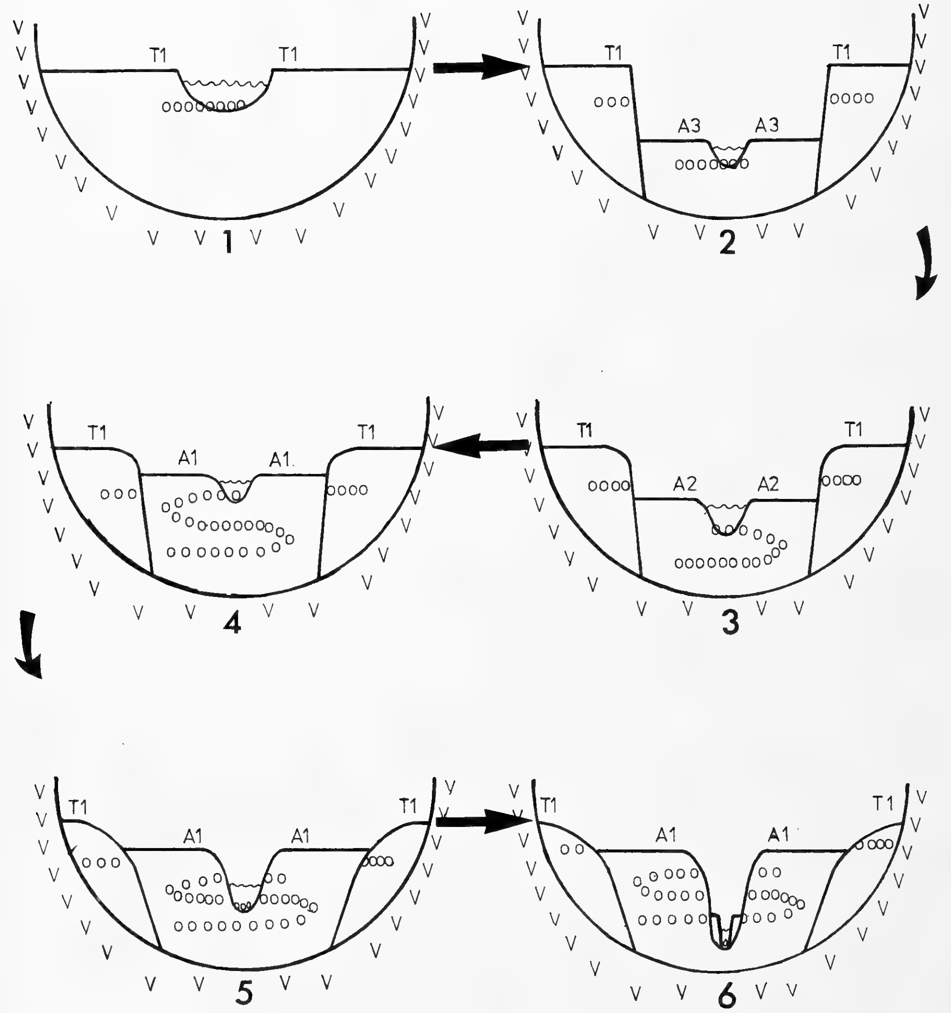


FIGURE 1 GEOLOGICAL MAP OF BOW, NEW SOUTH WALES

A combination of these three can be shown to have occurred at Bow (Fig. 2). The modern flood plain — designated A_1 — was formed by overlapping at least two previous flood plains during higher discharge levels or positive base level movements. This overlapping was caused by aggradation. These terraces — designated A_2 and A_3 — have a vertical stratigraphic relationship with the A_1 terrace and thus do not appear on Fig. 1. An older terrace, designated T_1, is probably representative of a Pleistocene terrace no older than sixty thousand years (Warner, pers. comm.). It has been formed by the inset method (shown in Fig. 2), presumably accompanying a fall in the base level associated with the onset of glaciation. Poor preservation is due to weathering



KEY: [vvv] Basalt basement. [ooo] Channel lag conglomerate.
▭ Point bar and overbank deposits.

Fig. 2. IDEALIZED DEVELOPMENT OF FLUVIAL GEOMORPHOLOGY ASSOCIATED WITH BOW CREEK.
1. Original flood plain; **2.** Inset of A3 flood plain inside abandoned T1 flood plain; **3.** Overlapping abandonment of A3 flood plain by A2 flood plain during river migration; **4.** Overlapping abandonment of A2 flood plain by A1 flood plain; **5.** Renewed incision by river; **6.** Present geomorphology. Incision has exposed older channel lag and flood plain sediments. Low discharge-level benches formed.

and the development of a soil cover. In some places, complete erosion of older fluvial deposits has resulted in renewed lateral incision of the basalt basement.

The contemporary river regime is represented by the stream and its associated depositional and erosional activities. Deposition occurs on meander points, as lag in the channel and in times of flood, on the flood plain. Erosion occurs on the concave meander bank and where basement is exposed. Down-cutting through the older flood plains would indicate that erosion is the present dominant force.

Channel sediment consists almost exclusively of well rounded pebbles and cobbles of basalt. The roundness of these pebbles is not indicative of transport mechanisms or distance, but is rather a feature of initial spheroidal weathering. Evidence for this can be seen in the basalts exposed in the road cutting below Bow Post Office (grid ref. 132016, Fig. 1).

THE FOSSIL DEPOSITS AND THEIR RELATIONSHIP TO THE DEVELOPMENT OF BOW CREEK

The deposits containing fragments of the fossil vertebrates crop out adjacent to Bow Post Office and occur within a slightly elevated region of weathered basalt. They occur as residual deposits (Warner, 1972, p. 10, fig. 3c), above the T_1 terrace. Outcrop in this road cutting is particularly sparse due to slumping and subsequent council efforts to reduce erosion by planting 'pig face' (*Carpobrotus aequilaterus*). A section of the southern bank of the road cutting is given in Fig. 3.

The fossiliferous sediment is riverine and in section it is confined to channels, slightly convergent to the south with the modern creek. These channels may represent Pliocene perennial streams that did not develop laterally or that resulted from incised formation. However, evidence presented later does not favour the presence of a permanent body of water. The most probable interpretation of these sediments is that they represent ephemeral gully facies deposits.

THE BOW FAUNAL ASSEMBLAGE

The classification used herein follows those listed by Moore (ed.) (1957) for the Gastropoda and Bivalvia, Webb *et al.* (1975) for the Malacostraca, Romer (1971) for

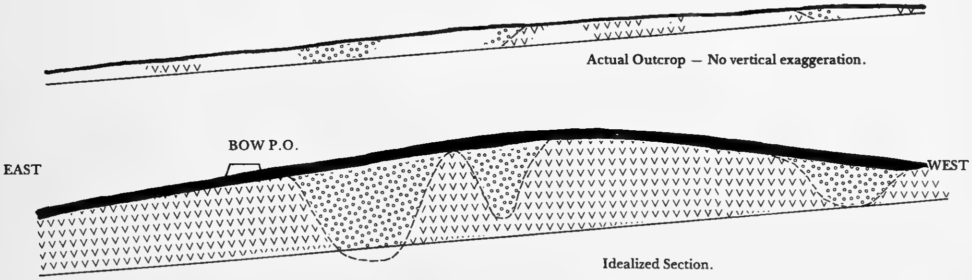


Figure 3. ROAD CUTTING SECTION (SOUTHERN EXPOSURE)
Map reference 132016 (figure 1).

Horizontal scale ▭ Vertical X100.
100m
Average slope of bank 41°.
KEY:

V Basalt, weathered (in situ)

o Fossiliferous conglomerates, basalts weathered by transport.

■ Soil profile.

the Reptilia and Mahoney and Ride (1975) for the Marsupialia. Dental notation follows that used by Archer (1978). The sample number prefix 'F' denotes Australian Museum fossil specimens, while 'QF' applies to Queensland Museum fossil specimens. All measurements are in millimetres. The Bow fossil material, registered at the Australian Museum, can be summarized as follows:

BIVALVIA
  HYRIINAE Ortman, 1911
    Hydridella sp. cf. *H. australis* (Lamarck)
  CORBICULIDAE Gray 1847
    Corbicula sp.

GASTROPODA
  PLANORBIDAE Dybowski, 1903
    Physastra sp.
  BITHYNIIDAE
    Gabbia sp. cf. *G. australis*, Tryon

MALACOSTRACA
  DECAPODA Latreille, 1802
    BRACHIURA Latreille
      Family indet.

REPTILIA
  ANAPSIDA
    CHELONIA
      Family indet.

MAMMALIA
  METATHERIA
    MARSUPICARNIVORA
      DASYURIDAE Waterhouse, 1838
        Dasyurus sp.
    DIPROTODONTA
      VOMBATIDAE Iredale and Troughton, 1934
        Phascolonus sp.

    THYLACOLEONIDAE Gill, 1872
        Thylacoleo crassidentatus Bartholomai, 1962

    DIPROTODONTIDAE Gill, 1872
      PALORCHESTINAE Tate, 1948
        Palorchestes sp. cf. *P. parvus* De Vis, 1895
      NOTOTHERIINAE Stirton, Woodburne and Plane, 1967
        Genus indet.

    MACROPODIDAE Owen, 1839
      POTOROINAE Trouessart, 1898
        Propleopus sp.
      MACROPODINAE Thomas, 1888
        Macropus (Osphranter) sp. cf. *M. (Osphranter) woodsi* Bartholomai, 1975
        Protemnodon chinchillaensis Bartholomai, 1973
        Troposodon sp. cf. *T. bluffensis* Bartholomai, 1978
        Genus indet.
      STHENURINAE Glauert, 1926
        Sthenurus sp.

The Bow fossil material consists largely of broken limb fragments with very rare and always disassociated dentary and maxillary fragments. Recovery of fossil speciments is also difficult because of the clayey matrix of the sediment. Even after several washings the fossils are often still coated with fine sediment.

DISCUSSION OF THE BOW FAUNAL ELEMENTS

BIVALVIA and GASTROPODA

Several entire and fragmentary shells have been recovered from the Bow fossil deposits. They also occur in the terrace deposits associated with the modern Bow Creek. Identification was made by Dr P. Colman of the Australian Museum.

MALACOSTRACA

Specimen F60120 represents brachiuran gastroliths.

REPTILIA

Fragments of tortoise shells (e.g. F60119) were among the most common fossils recovered. They cannot at present be referred to any particular genus although they do apparently represent relatively small chelonians.

MAMMALIA

MARSUPICARNIVORA

DASYURIDAE

Dasyurus sp.

One specimen (F60112), a left dentary with M_{2-4}, represents a species of *Dasyurus*. In molar morphology it resembles *D. viverrinus, D. geoffroii* (*in* Smith, 1972) and *D. dunmalli* (Bartholomai, 1971). The last named is known from the Pliocene Chinchilla Sand of Queensland and is distinguished by the presence of a single rooted P_3. *D. viverrinus* and *D. geoffroii* are both only known from Pleistocene and modern deposits. The Bow *Dasyurus* is of the same size as all three of the above species, larger than *D. hallucatus* and smaller than *D. maculatus*. It also differs in molar morphology from the last two.

Without information about the presence or absence of a P_3 the Bow specimen cannot be identified.

DIPROTODONTA

VOMBATIDAE

Phascolonus sp.

One specimen F59587 appears to represent a fragment of an upper incisor of a species of *Phascolonus*. Two species are known, *P. gigas* from the Pleistocene (and possibly Pliocene) and *P. lemleyi* from the Pliocene (Archer *in* Archer and Wade, 1976). At present lower incisors are required to distinguish the species and for this reason the Bow specimen cannot be more precisely assigned.

THYLACOLEONIDAE

Thylacoleo crassidentatus Bartholomai, 1962

This species is represented in the Bow fauna by F59593, a partial left mandibular ramus with roots of M_2, alveoli for the posterior molar (s), and an incomplete posterior root for P_3. F59594, a left P_3; and F59569, an incomplete right P_3. Four genera and nine species of thylacoleonids have been named. Of these, four species, *Mylodon australis, Thylacopardus australis, Thylacoleo oweni* and *Thylacoleo robustus* are generally considered to be synonyms of *Thylacoleo carnifex*. The status of the Pleistocene species of *Thylacoleo* is in doubt but a recent review by Archer (in preparation) suggests that on the basis of dental structure alone, all but one named Pleistocene species appear indistinguishable from *T. carnifex*. The only exception is *T. hilli* Pledge, which because of its very small size cannot be referred to any other known species. The age of *T. hilli* is unknown, while *T. crassidentatus* is Pliocene.

The Bow thylacoleonid is not attributable to the genus *Wakaleo,* because of the more generalized structure of the cheektooth of species of *Wakaleo,* particularly the P_3. Further, in *Wakaleo* the ratio of length of P_3 to M_2 is less than 1.5 (Clemens and Plane, 1974). In the Bow thylacoleonid this ratio is 2.8 which is in close accord with specimens of species of *Thylacoleo.*

Bartholomai (1962) described *Thylacoleo crassidentatus* from the Pliocene Chinchilla fauna. He indicates that the most specifically useful diagnostic feature was the structure of P_3. This tooth is much broader in *T. crassidentatus* than it is in *T. carnifex,* particularly above the posterior root and the longitudinal convexity is much better developed in *T. crassidentatus* than it is in *T. carnifex.* These features in F59594 and F59569 compare well only with *T. crassidentatus.* The second lower molar in *T. crassidentatus,* although variably developed, is commonly proportionately larger than it is in *T. carnifex* and the alveolus is partially divided in the former by a vertical ridge on the lateral wall (F59593 has the alveolus completely divided).

Thylacoleo crassidentatus and *T. carnifex* appear to have had very similar dimensions, but it has been shown above that they have very distinct dental morphologies. The Bow thylacoleonid can only be referred to *T. crassidentatus.*

DIPROTODONTIDAE

PALORCHESTINAE

? *Palorchestes* sp. cf. *P. parvus* DeVis, 1895

A single, isolated right M_2, F59595, recovered from Bow appears to represent a species of *Palorchestes.* Although the crown of this tooth is worn, it can definitely be placed in the subfamily. Woods (1958) described *Palorchestes parvus* as a smaller and more lightly built species than *P. azael.* The lower molars are morphologically similar, but the upper molars are distinct in detail. Upper molars are as yet unavailable from Bow and thus identification has been based on less diagnostically unique characters. The dimensions of the Bow palorchestid, 20.8 x 12.8 (M_3 length x width) place it within the range of *P. parvus* (Woods, 1958). However, the generic identification remains tentative because M_3 is not particularly diagnostic. It is even possible that it could represent *P. painei* which is otherwise only known from the Miocene Alcoota fauna of the Northern Territory (Woodburne, 1967).

The age range of *Palorchestes parvus* is in some doubt. The Chinchilla fauna and its component of *P. parvus* are commonly regarded to be Pliocene in age (Archer and Bartholomai, 1978). However, Bartholomai (1977) has also reported this species from the Pleistocene Gore Cement Mills fauna of southeastern Queensland.

NOTOTHERIINAE

Several upper molars and a single incisor are referable to this subfamily. The characteristic 'V'-shaped transverse valleys (Stirton *et al.,* 1967) are best represented in F59596 and F59597. However, the most diagnostic tooth for both subfamilial and generic identification is P_3, and as yet, this tooth is unavailable from Bow. Molar structure alone has not enabled generic determination. Six nototheriine genera are currently recognized of which the generic status of '*Euowenia*' is in doubt (Archer *in* Archer and Wade, 1976).

MACROPODIDAE

POTOROINAE

Propleopus sp.

A single, incomplete mandibular ramus recovered from Bow is referable to a small species of the genus *Propleopus*. It is referred to by Bartholomai (1972, p. 15, para. 4). A paper on this specimen is in preparation by J. A. Mahoney and W. D. L. Ride.

MACROPODINAE

Macropus (Osphranter) sp. cf. *M. (Osphranter) woodsi* Bartholomai, 1975

This macropodid is represented by many specimens (e.g. F59548 dentary and F59536 maxillary). Although definitely referable to the subgenus *Osphranter* (as described by Bartholomai, 1975) the Bow species differs from all members of the subgenus currently recognized. The anterior cingulum of *M. (Osphranter) altus* exhibits recurvature and the shape of the talonid is variable. *M. (Osphranter) ferragus* has differentially rotated lophids in the lower molars and *M. (Osphranter) pan* has accessory links in the talonid basin (Bartholomai, 1975). The Bow *Osphranter* is most comparable to *M. (Osphranter) woodsi* except that the Bow specimens are smaller than the average Chinchilla speciments described by Bartholomai (1975).

Protemnodon chinchillaensis Bartholomai, 1973

This Pliocene species is represented by F59530, a left maxillary fragment with M^{2-5}; F59533, a left maxillary fragment with P^3–M^3; and F59540, an M^5. Although the Bow material is very limited this material appears to be referable to *Protemnodon chinchillaensis*. This identification is based mainly on the morphology of P^4 (P^3 of Bartholomai 1973) which is proportionately very elongate, high crowned and has a very low lingual cingulum. *Protemnodon chinchillaensis* is the smallest member of the genus yet recovered in Australia and it is also a morphologically distinct species, having low cheektooth crown heights with more accessory ridging (Bartholomai, 1973). All these features are present in the small Bow sample.

Troposodon sp. cf. *T. bluffensis* Bartholomai, 1978

Numerous dentary specimens (e.g. F60108) represent a small species of *Troposodon*. In size and morphology it is clearly distinct from *T. minor* and *T. kentii*. It compares best with *T. bluffensis* described recently by Bartholomai (1978) from the Pliocene Bluff Downs fauna of northeastern Queensland. Positive identification must await a more complete analysis of the as yet unassessed isolated upper molars from the Bow site. In addition, the isolated P_3 referred by Bartholomai to *T. bluffensis* differs sufficiently from that tooth in a Bow dentary (F60108) to advise caution in referring the Bow material to this otherwise Queensland taxon.

Genus indet.

Several specimens (e.g. F59603) are not clearly referable to any known genus. They represent a form that exhibits some affinity with species of *Wallabia, Troposodon* and to a lesser extent, even *Dorcopsis*. At present it seems best to leave it unallocated at the generic level until more material has been collected.

STHENURINAE

Sthenurus sp.

A single tooth appears to represent a right lower molar of a species of *Sthenurus*. In size it approximates with some of the *S. (Sthenurus)* species such as *S. (Sthenurus)* *atlas* but in morphology it suggests similarities to species of the subgenus *Simosthenurus*. More specimens must be found before it can be allocated confidently to a particular species.

THE AGE OF THE BOW FAUNA

Although the Bow faunal deposits occur in association with basalts (see above), an erosional hiatus of indeterminate span separates the basalts from the fossiliferous sediments. As a result, the estimate of Pliocene age for the Bow fauna is based on a faunal comparison with the Chinchilla and Bluff Downs faunas. The Bluff Downs fauna lies immediately below a basalt dated at about four and a half million years B.P. (Archer and Wade, 1976). Comparison of the Bluff Downs fauna with the Chinchilla fauna suggests a four to four and a half million year date for the Chinchilla fauna. Presence in the Bow fauna of *Protemnodon chinchillaensis* (Chinchilla), *Troposodon* sp. cf. *T. bluffensis* (Bluff Downs), *Macropus (Osphranter) woodsi* (Chinchilla), *Thylacoleo crassidentatus* (Chinchilla) and *Palorchestes* sp. cf. *P. parvus* (Chinchilla), and the apparent absence of forms only known from younger or older faunas, suggests that the Bow fauna is early to middle Pliocene in age.

THE PALAEOENVIRONMENT

While assessment of the palaeoenvironment is subject to the problems of extrapolation from the habitat requirements of related modern animals, some comment can be made in the light of evidence now available. Fish and crocodile remains are absent, to date, from the Bow deposits. These animals require a permanent aquatic habitat. An ephemeral body of water is indicated by freshwater invertebrate and tortoise remains. Tortoises can migrate subaerially and the invertebrates can invade the habitat temporarily from perennial streams.

The majority of marsupial species so far identified from the Bow fauna are essentially browsing herbivores, such as *Troposodon* sp., *Protemnodon chinchillaensis, Palorchestes parvus* and *Sthenurus* sp. The apparent lack of many aboreal marsupials is probably the result of a sampling bias because most of the aboreal species are fairly small animals and, as yet, no sieving has been attempted at the site. The presence of *Thylacoleo crassidentatus* also may indicate that more work will reveal an aboreal component in the fauna because it may be inferred that this carnivore could have been aboreal (Wells and Nichol, 1977).

ACKNOWLEDGEMENTS

The work presented in this paper resulted from the author's honours research at the University of Sydney during 1977. Special thanks are given to Mr Jack Mahoney for his suggestion of the topic and his supervision and encouragement throughout its duration. Gratitude is expressed to Dr Michael Archer of the University of New South Wales who assisted greatly in the preparation of this paper with his criticism of the content and identifications as well as in the drafting. Professor David Branagan assisted with the geology and also read the manuscript. Dr Alex Ritchie and Dr Phillip Colman of the Australian Museum allowed access to fossil collections and laboratory facilities and Dr Colman also identified the Invertebrate material. Finally, thanks are extended to Professor Graeme Philip of the Department of Geology and Geophysics at the University of Sydney for providing research facilities.

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The genus *Raillietia* Trouessart in Australia (Acari: Dermanyssidae)

ROBERT DOMROW

DOMROW, R. The genus *Raillietia* Trouessart in Australia (Acari: Dermanyssidae). *Proc. Linn. Soc. N.S.W.* 104 (3), (1979) 1980: 183-193.

Raillietia, confined to the auditory meatus of mammals, is represented in Australia by three species. Supplementary descriptive notes are given for *R. australis* Domrow from a wombat, *Vombatus ursinus* (Shaw) (Marsupialia: Vombatidae) and *R. auris* (Leidy) from the cow, *Bos taurus* Linnaeus (Artiodactyla: Bovidae). *R. manfredi,* n. sp., is figured and described from the goat, *Capra hircus* Linnaeus (Bovidae: Caprinae). A key to the females of the five known species is given.

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INTRODUCTION

Three species of *Raillietia* Trouessart are now known to occur in the ears of native and introduced mammals in Australia. The descriptions are completed of the somewhat atypical *R. australis* Domrow, both known series of which are from a marsupial, and of the widespread *R. auris* (Leidy), a cause of *otitis media* in cattle (Domrow, 1963; Ladds *et al.,* 1972). A new species (*R. manfredi*) from the goat is yet another of the parasitic mites found only recently on domesticated animals [*e.g. Trixacarus caviae* Fain, Hovell and Hyatt, 1972 (Sarcoptidae) from the guinea-pig, and *Lynxacarus radovskyi* Tenorio, 1974 (Listrophoridae) from the cat].

The two other known species (*R. hopkinsi* Radford, 1938 and *R. whartoni* Potter and Johnston, 1978, both from African bovids) are beyond the scope of this paper, as is the genus *Rhodacantha* Domrow, 1979* from the ears of Australian dasyurid marsupials.

The term 'holotrichous' refers to the setal condition in typical free-living dermanyssids (Evans and Till, 1965; Evans, 1969). The hosts' names are given after Simpson (1945) and Ride (1970).

Depositories are abbreviated: ANIC, Australian National Insect Collection, CSIRO, Canberra; BMNH, British Museum (Natural History), London; QIMR, Queensland Institute of Medical Research, Brisbane; RVL, Regional Veterinary Laboratory, Wollongbar.

Genus *RAILLIETIA* Trouessart

Raillietia Trouessart, 1902: 1335. Type-species *Gamasus auris* Leidy.

The larval structures described below support Radovsky's (1969) placement of the Raillietiinae in the Halarachninae. Evans and Till (1966) gave an extended diagnosis for *Raillietia*; additional characters may be culled from Zumpt and Till's (1961) key.

Key to females of *Raillietia*

Based in part on original descriptions.

1. Dorsal shield with 19 and 15 pairs of setae on

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*In this paper, read seta for setae at line 51, page 118; and $Z_{2,4}$ for $Z_{2\text{-}4}$ at line 6, page 121.

podonotal and opisthonotal portions, respectively. Trochanter I and femora I, III holotrichous. Tibia I with seta pv_2 added. From a vombatid (Marsupialia) .... *australis*
Dorsal shield with 10 and at most seven pairs of setae on podonotal and opisthonotal portions, respectively. Trochanter I and femora I, III unideficient. Tibia I with seta pv_2 added or not. From bovids (Artiodactyla) 2

2\. Dorsal shield with 17 pairs of setae. Tibiae hypertrichous. From a caprine .... *manfredi*
Dorsal shield with at most 15 pairs of setae. Tibiae at most holotrichous. From bovids 3

3\. Dorsal shield with at least 13 pairs of setae. Tibia IV holotrichous. From species of *Kobus* Smith 4
Dorsal shield with 12 pairs of setae. Tibia IV unideficient. From *Bos* Linnaeus .... *auris*

4\. Dorsal shield with 15 pairs of setae. Genital setae on margin of genital shield. Setae on tarsus II normal .... *hopkinsi*
Dorsal shield with 13 pairs of setae. Genital setae free of margin of genital shield. Setae ad_{2-4} on tarsus II hypertrophied .... *whartoni*

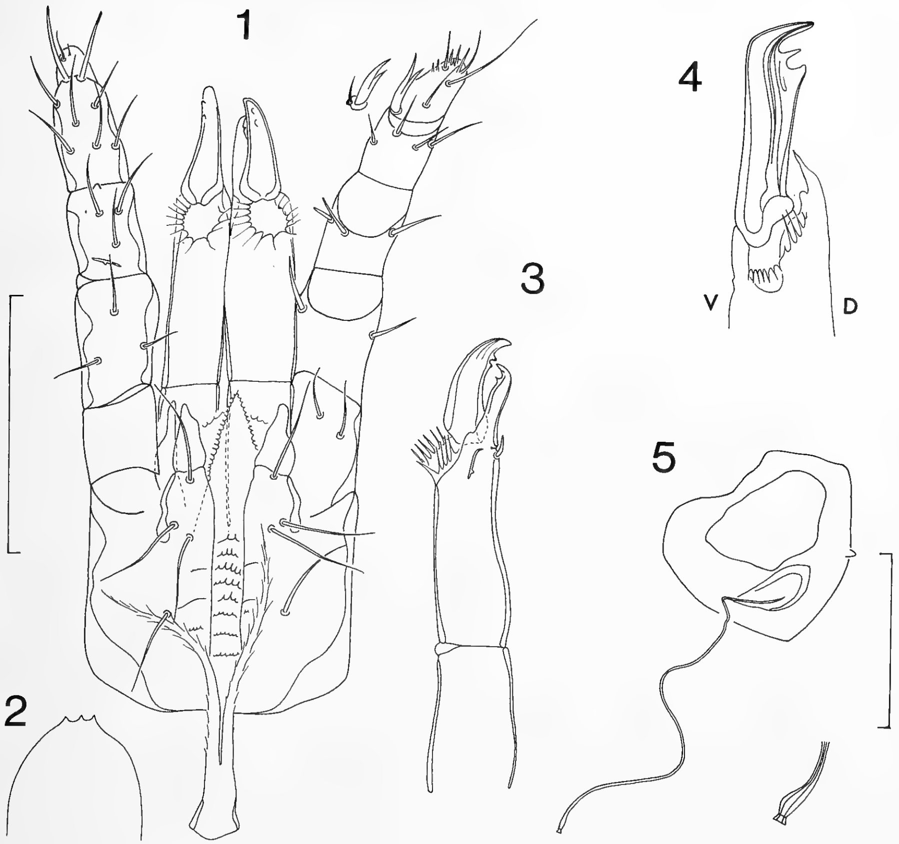
Raillietia australis Domrow
(Figs 13-14)

Raillietia australis Domrow, 1961: 75; 1973: 79.

Types. Holotype ♀ and one paratype ♀, in ears of common wombat, *Vombatus ursinus* (Shaw) (Marsupialia: Vombatidae), Brindabella Road, A.C.T.-N.S.W. border, 24.v.1960, J. H. Calaby. Holotype in ANIC, paratype in BMNH (both reexamined).

Other material. One ♀, *V. ursinus,* near Taggerty, Vic., 26.vii.1971, R. C. H. Shepherd. In QIMR (reexamined).

Female. Add to original description [Potter and Johnston's (1978) setal counts for dorsal shield and tibia I are wrong]: Chelicerae, although still dorsoventrally orientated, now seen to be very similar to those of *Mesolaelaps* Hirst (see Tenorio and Radovsky, 1974); 270 μm long overall, shaft 45 μm in diameter, with digits occupying 27% of total length; middle segment with distinct dorsal setule and lyriform pore (external lyriform pore not detected), and ventral corona; fixed digit with pilus dentilis short and stiff, outwardly directed, set between tip of digit (shaped to receive tip of movable digit) and single low tooth placed well beyond midlength of digit; movable digit subequal to fixed digit, 70-75 μm long, with two low teeth placed just beyond midlength. Epistome lobate, with lightly serrate margin not reaching far beyond level of palpal trochanters; disc with extensive dendritic pattern. Labial cornicles 'not very strong' *cf.,* say, the predatory *Hypoaspis* Canestrini, but actually well sclerotized; internal malae a single triangle with fringed margin barely exceeding tips of labial cornicles; epipharynx minutely ciliated around marginal strip, longitudinally striate in midline; salivary stylets present; anteromedial extension [see Evans and Loots (1972, 1975); this is 'labrum' of Gorirossi Bourdeau (1956)] of



Figs 1-5. Raillietia manfredi. **1.** Capitulum ♀, ventral (true right palp dorsal). **2.** Epistome ♀. **3.** Chelicera ♀, external. **4.** Cheliceral digits ♂, ventrointernal. **5.** Coxa III and insemination apparatus ♀, dorsal. Scales ≙ 100μm.

subcheliceral shelf distinct, with tip variable [holotype with two blunt points, paratype with three blunt points ending at same level, cf. *Mesolaelaps bandicoota* (Womersley, 1956) and *M. australiensis* (Hirst) as figured by Tenorio and Radovsky (1974)]. Palpi holotrichous: trochanter 2, femur 5, genu 6 (al_{1-2} spatulate, al_2 absent on one side of paratype), tibia 14 (including two dorsodistal rods), tarsus 4 (plus terminal cluster of rods). All capitular setae, except the very shortest, barbulate along shaft (true also of setae on idiosoma and legs).

Dorsal shield [Fig. 28 in Domrow (1961) represents paratype] 700-770 μm long, 310-340 μm wide, ratio length/width 2.26-2.30, distinctly granulate (except on muscle insertions), hypotrichous, probably with 34 pairs of setae in normal specimens; podonotal portion with 19 pairs (s_2 absent on both sides of paratype and on one side of holotype, but present on both sides of Taggerty specimen) compared to normal 22 (i.e. lacking z_3, s_1 and r_4 — if setae acquired at protonymphal, rather than at deutonymphal, stage are taken as more likely to be represented in a reduced species); opisthonotal portion with 15 pairs (S_3 absent on both sides of holotype, and S_4 on one side of Taggerty specimen) compared to normal 17 (i.e. lacking intercalary px_{2-3}).

Undivided portion of tritosternal laciniae lightly spiculate. Sternal shield of paratype with seta st_1 absent on one side. Insemination apparatus not detected. Metapodal shields in two pairs just behind basifemora IV, inner pair equalling accessory genital shieldlets in size, outer pair rather larger. Anterior portion of peritrematalia originally figured in dorsoventral orientation [Fig. 27 in Domrow (1961) represents holotype], but actually more flared, though free of vertex of dorsal shield.

Leg setation holotrichous, with one exception: tibia I with fourth ventral seta (pv_2) added, i.e. 2-3/2.3/2.2 rather than 2-3/2.3/1-2 (pv_{1-2} absent on one side of paratype). Tarsus I with dorsodistal sensory islet occupying 20% of length of segment. *Notes.* It may be that this morphologically and zoogeographically distinct species (see key above) should be transferred from *Raillietia* (Halarachninae) to some laelapine genus near *Mesolaelaps* and *Rhodacantha,* whose hosts are also largely Australian marsupials rather than Old World artiodactyls. That is to say, in a complex so morphologically reduced and so little collected, the presence of seta pv_2 on tibia I, once believed peculiar to these two Australian genera but now known also to occur in *Raillietia,* may as well be an adaptation to a habitat merely shared by unrelated lines as an indication of real relationships.

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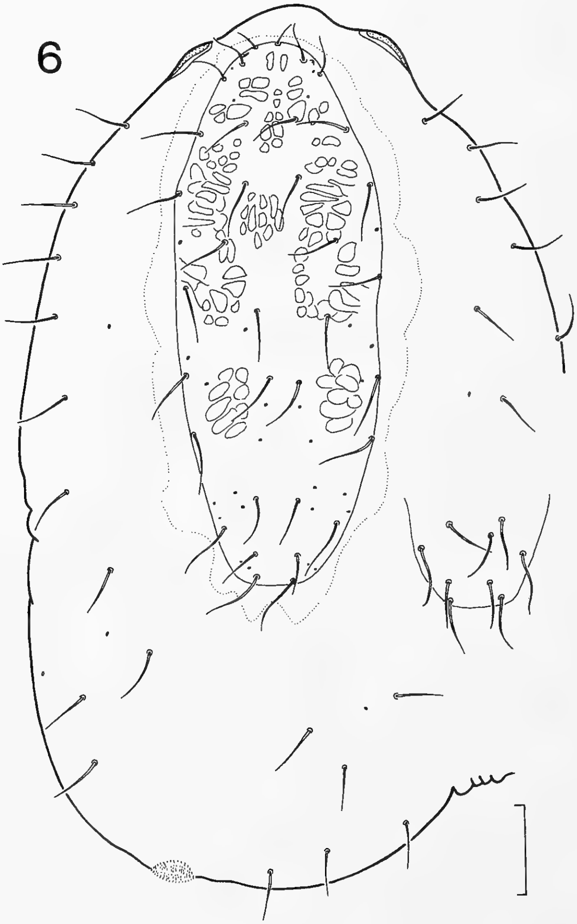


Fig. 6. Raillietia manfredi ♀. Idiosoma, dorsal. Scale = 100μm.

Raillietia auris (Leidy)

Gamasus auris Leidy, 1872: 138.

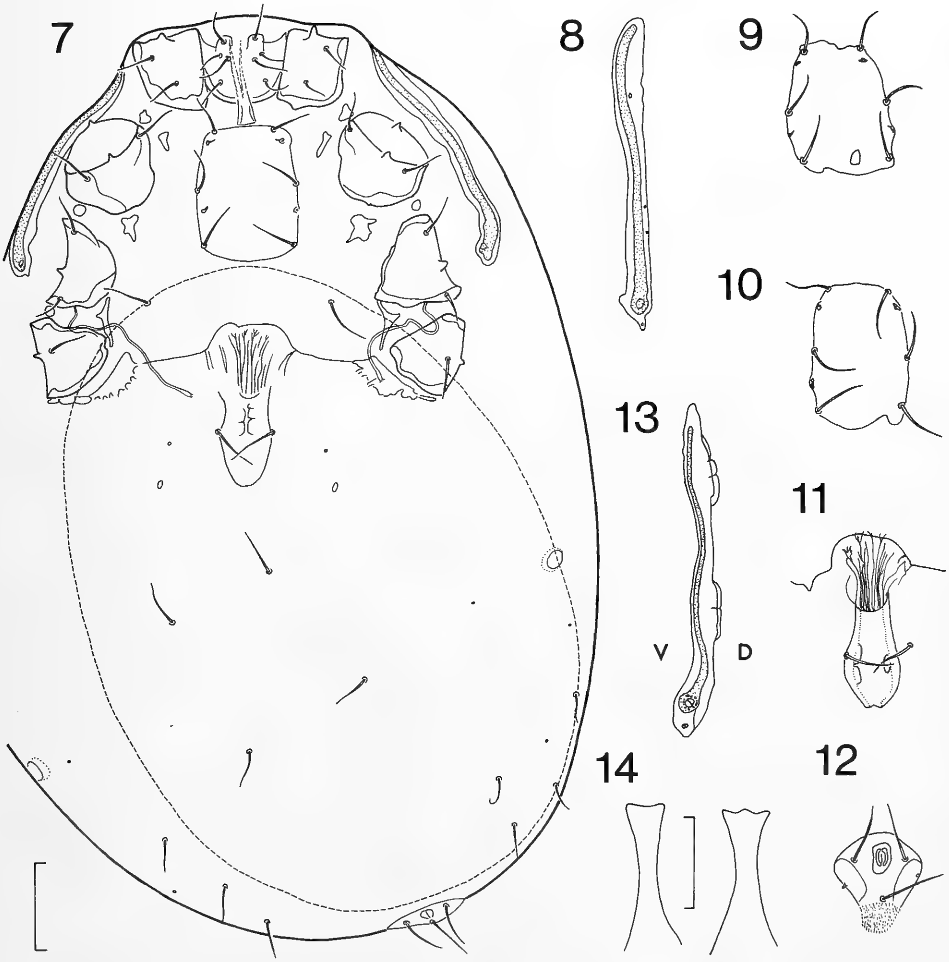
Raillietia auris: Freund, 1910: 313; Tzimbal and Litvishko, 1955: 1229.

Material. Eight ♀♀, middle ear of domestic cattle, *Bos taurus* Linnaeus (Artiodactyla: Bovidae), Townsville, Qld, 11.v.1972, D. B. Copeman. In QIMR.

Female. Palpal trochanter-genu holotrichous, tibia bideficient (12, including two dorsodistal rods).

Insemination apparatus as in *R. manfredi.*

Legs with following deviations from holotrichous condition — hypotrichous: trochanter I 1-0/3-1 (*d* lacking), femur I 2-5/3-2 (one *pv* lacking), femur III 1-3/1-0 (*pl* lacking), tibia IV 2-4/2-1 (pl_2 lacking); hypertrichous: genu IV 2-5/1-2 (pl_2 added). Tarsus I with dorsodistal sensory islet occupying 25% of length of segment.



Figs 7-14. Raillietia spp. (**7-12,** *R. manfredi* ♀; **13-14,** *R. australis* ♀). **7.** Idiosoma, ventral. **8.** Peritrematalia. **9-10.** Sternal shield, variants. **11.** Genital shield, variant. **12.** Anal shield. **13.** Peritrematalia. **14.** Anteromedial extension of subcheliceral shelf, variants. Scale = 100 μm, except for *Fig. 14* (25 μm).

Raillietia manfredi, n. sp.

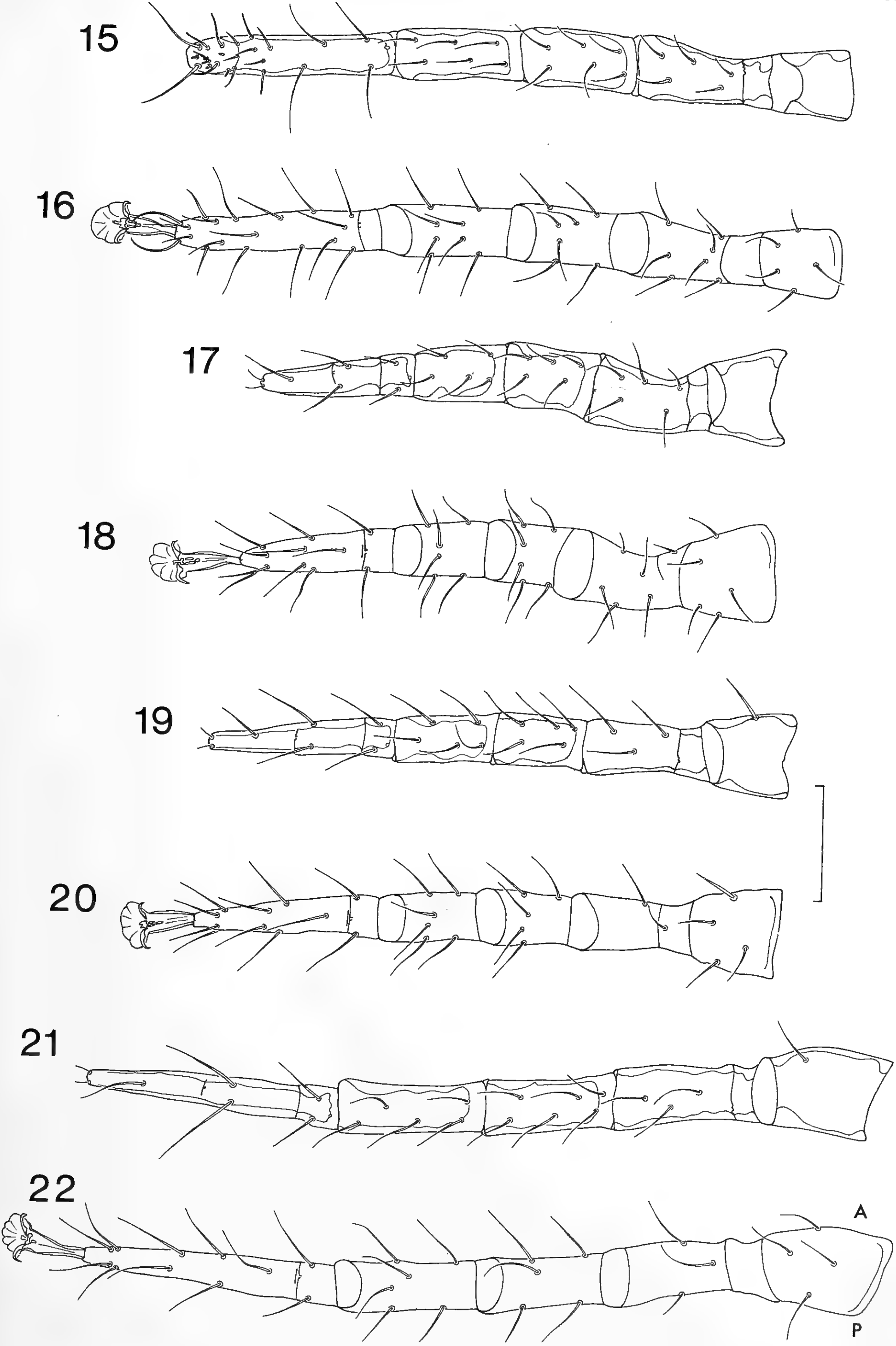
(Figs 1-12, 15-28)

Types. Holotype ♀, allotype ♂ and five paratype ♀♀, auditory meatus of domestic goat, *Capra hircus* Linnaeus (Artiodactyla: Bovidae), Lismore, N.S.W., vi.1978, R. W. Cook. Six paratype ♀♀ and one paratype ♂, auditory meatus of *C. hircus,* Byron Bay Lighthouse, N.S.W., vi.1978, R.W.C. One morphotype larva, auditory meatus of *C. hircus,* Tuncester, near Lismore, 17.viii.1979, R.W.C. In ANIC (holotype, allotype and morphotype); BMNH, QIMR, RVL (paratypes).

Female. Chelicerae 175 μm long overall, with digits occupying 26% of total length; middle segment with distinct dorsal setule, dorsal and external lyriform pores, and ventral corona; fixed digit with only one distinct denticle in addition to tip, pilus dentilis apparently absent; movable digit 45 μm long, with two external denticles at level of tip of fixed partner. Epistome hyaline, in shape of inverted U, barely reaching level of bases of palpal femora, with two or three small serrations distally. Basis capituli wider than long, with a few short lines of denticles in addition to eight stronger rows in deutosternum; setae *c* simple, slender, exceeding sides of basis (often broken off short, as are all setae on body and appendages, except the shortest). Hypostome with setae h_{1-3} subequal to *c*; cornicles not heavily sclerotized, but distinct (albeit somewhat irregular in outline); internal malae not clear; epipharynx as in *R. australis*; salivary stylets present; anteromedial extension of subcheliceral shelf not clearly seen (cf. *R. australis* above). Palpi strong; genu with lyriform pore dorsally, tarsus with bifid claw (*n.b.:* small seta immediately above claw is also tarsal); trochanter-genu holotrichous (al_1 on genu spatulate), tibia bideficient (two dorsodistal rods included), tarsus discrete, with usual few simple setae and terminal cluster of rods.

Idiosoma saccate, size unavailable because of rupture during mounting procedure. Dorsal shield 585-640 μm long, 230-255 μm wide (ratio L/B 2.51), poorly demarcated from investing strip of sclerotized cuticle, sides subparallel, ends broadly rounded; surface heavily marked by muscle insertions, otherwise granulate, with about 15 pairs of pores (anteriormost pair lyriform); podonotal portion hypotrichous, with 10 pairs of setae; opisthonotal portion hypotrichous, with seven pairs of setae (one *J* seta doubled on one side of one specimen). Dorsal cuticle largely hyaline, with about 12 pairs of setae and a few paired pores.

Tritosternum fully formed, with ciliated laciniae just exceeding insertions of setae h_3 on capitulum. Presternal striae absent. Sternal shield longer than wide, with somewhat irregular margins (one specimen with small submedian fenestration at level of setae st_3); surface minutely granulate, provided submarginally with three pairs of setae (st_{1-3}) and two pairs of pores (p_{1-2}, p_2 absent on one side of one specimen). Metasternal setae (*mst*) free in cuticle, without associated pores (p_3) or shields. Genital shield small, drop-shaped; surface granulate, marked by muscle insertions, and with one pair of setae (*g*) touching on margins (well free of margin on one side of one specimen), but associated two pores and shieldlets free in cuticle; operculum shallow, but rayed, supported by two strong genital apodemes. Insemination apparatus visible as convoluted adductor canals arising from sclerotized prominences on posterior margins of coxae III. Ovum very large, 760-800 μm long, 540-565 μm wide, some containing fully developed larva. Anal shield terminal in engorged specimens, with cribrum encroaching onto dorsum; surface weakly granulate, with pair of pores laterally; anus and adanal setae (*aa*) well forward, postanal seta (*pa*) subequal to *aa*. Irregular endopodal and exopodal shieldlets present between and behind coxae. Metapodal shields present, but largely subcuticular. Ventral cuticle with about six pairs of setae and a few paired pores. Stigmata provided with stout

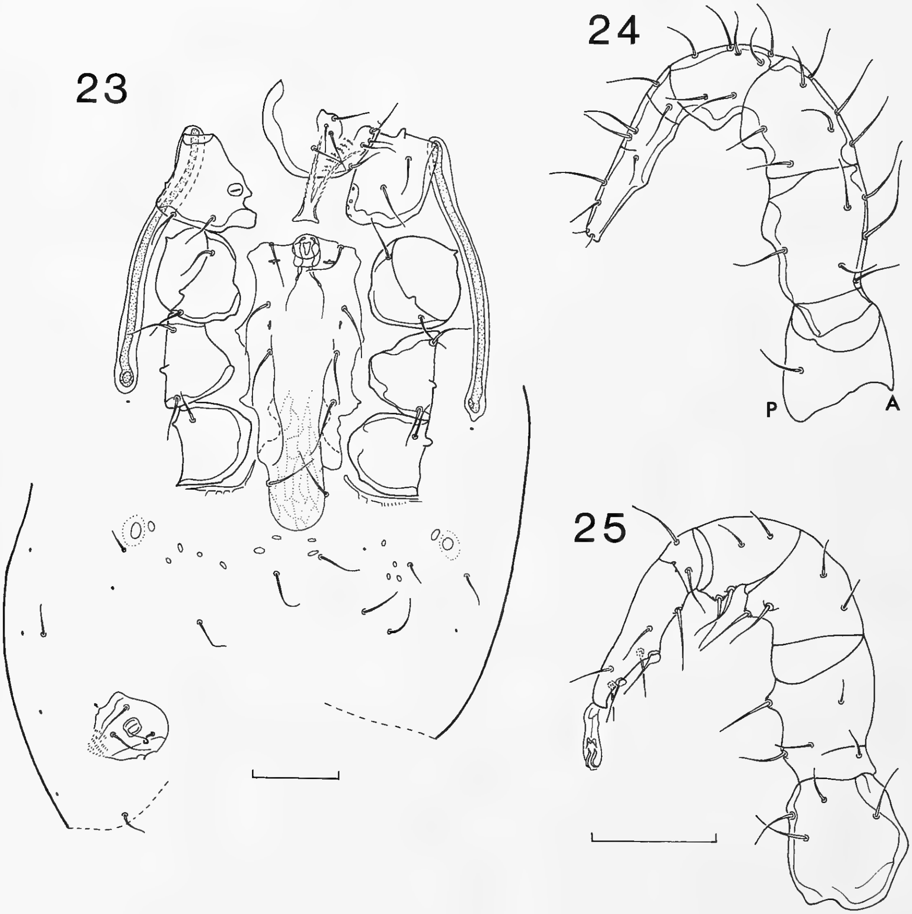


Figs 15-22. Raillietia manfredi ♀, legs. **15-16.** I, dorsal, and ventral and lateral setation. **17-22.** II-IV, same presentation as I. Scale = 100 μm.

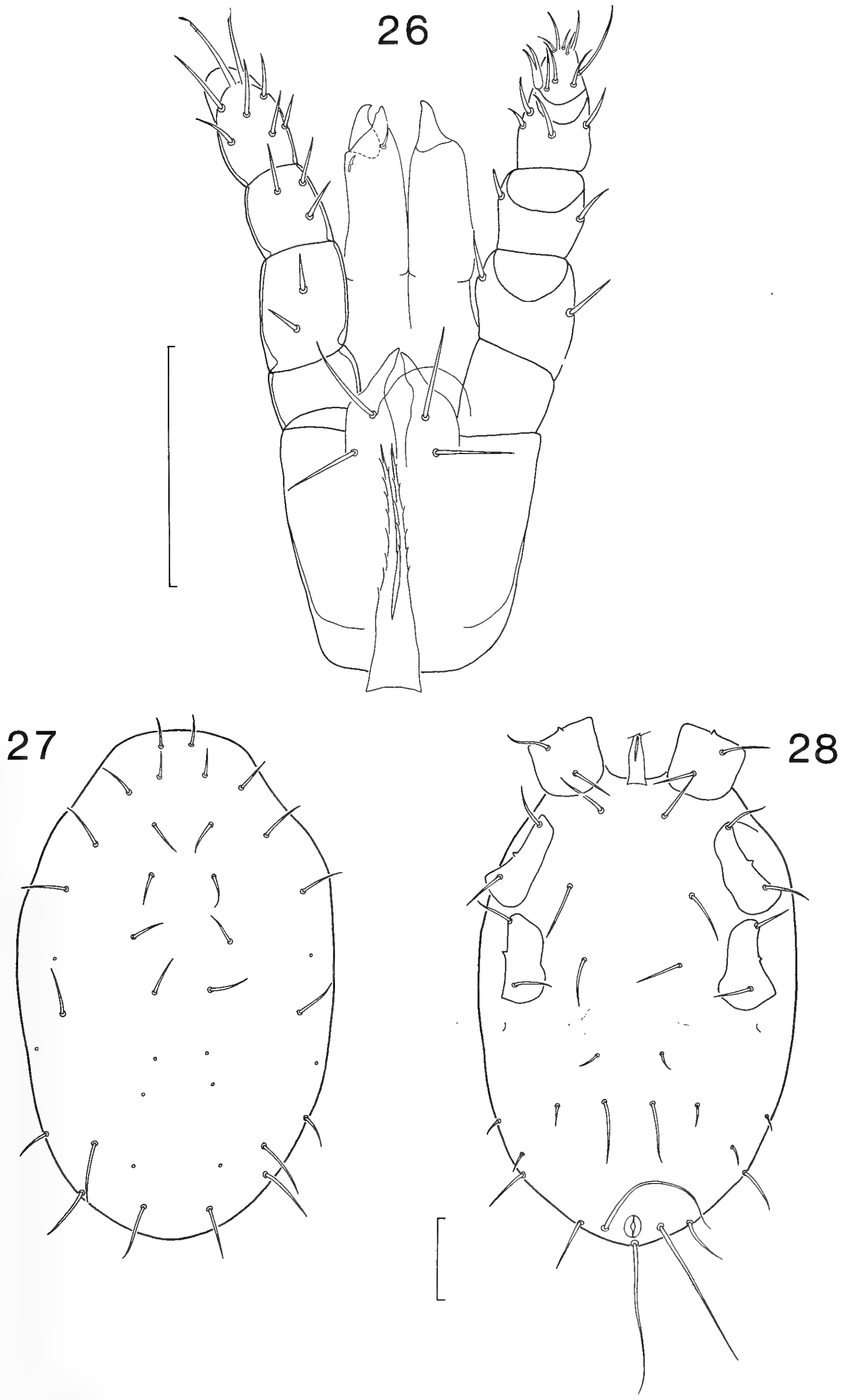
peritremes that, while largely ventral, turn finally dorsad onto humeral promontories; peritrematal shields anteriorly slightly expanded mesad, but free of dorsal shield and, posteriorly, of expodal shields IV.

Legs slender, with following deviations from holotrichous condition — hypotrichous: trochanter I 1-0/3-1 (*d* lacking), femora I 2-3/1.2/2-2 (one *pv* lacking), III 1-2/1.1/0-0 (*pl* lacking); hypertrichous: genua III 2-3/1.2/1-1 (ad_3 added; individual variation: pl_2 at times also added), IV 2-3/1.3/0-2 (ad_3 and pl_2 added); tibiae I 2-3/2.3/2-2 (pv_2 added), II-IV 2-2/1.3/1-2 (II with pd_3 added; III with ad_2, pd_3 and pl_2 added; IV with ad_2 added). Femora-genua I-II without any *d* seta unduly strengthened. Tarsus I with dorsodistal sensory islet occupying 25% of length of segment. Coxa II without spinose anterodorsal process in addition to usual two condyles. Ambulacra with two claws and pulvillus.

Male. Capitulum as in ♀, except for slightly stronger setae on palpal trochanter-tibia and secondary sexual characteristics of chelicerae. Shafts thicker and more heavily sclerotized, but proportions unavailable because of foreshortening; fixed digit



Figs 23-25. Raillietia manfredi ♂. **23.** Idiosoma, ventral. **24-25.** Leg II, dorsal and posterolateral, and ventral and anterolateral setation. Scales = 100 μm.



Figs 26-28. Raillietia manfredi larva. **26.** Capitulum, ventral (true right chelicera and palp dorsal). **27-28.** Idiosoma, dorsal and ventral. Scales = 100 μm.

obsolescent, but dorsal setule and at least external lyriform pore present; spermatodactyl strongly bidentate, apart from tip, *ca* 85 μm long.

Idiosoma saccate, of uncertain size. Dorsum as in ♀, except that dorsal shield is wider, 605-615 μm long, 260-265 μm wide (ratio L/B 2.33) (seta J_1 doubled on one side of one specimen).

Sternogenital shield with cornua slight, genital aperture in midanterior margin; strongly sclerotized laterally between coxae III-IV, otherwise granulate, except for weak reticulations on genital portion; with five pairs of setae and two pairs of pores as in ♀ (one *mst* seta absent on one side of one specimen). Venter otherwise essentially as in ♀.

Legs with same setational formulae as in ♀, with some individual variation: one specimen with femur III 1-2/1.2/0-0 (pd_2 added, *pl* lacking) on one side and tibia I 2-3/2.3/1-2 (holotrichous) on both sides. Legs I, III-IV slender, II incrassate, with pv_{1-2} on femur, *av* and *pv* on genu-tibia, and (to varying extent) av_{1-3} on tarsus strengthened and set on prominences (av_{1-2} on tarsus also strongly inflated basally).

Nymphs. Unknown.

Larva. Chelicerae 100 μm long overall, with digits occupying 25% of total length; middle segment with dorsal setule and external lyriform pore, but dorsal pore and corona not detected; digits edentate, pilus dentilis apparently absent. Epistome as in ♀, but margin almost smooth. Basis capituli as long as its maximum width, deutosternal details not clear. Hypostome with setae h_{1-2} subequal; cornicles pale, but distinct; other hypostomatal structures not clear. Palpi strong, genu without lyriform pore dorsally, tarsus with bifid claw; trochanter-tibia holotrichous (al_1 on genu slightly spatulate), tarsus much as in ♀.

Idiosoma ovate, 650 μm long, 405 μm wide. No distinct shield evident, but dorsum with at least five pairs of pores; podonotal portion holotrichous, with 10 pairs of setae; opisthonotal portion hypotrichous, with four pairs of setae.

Tritosternum fully formed. No distinct shields evident on venter. Setae st_{1-3} subequal. Setae *aa* flanking anus, only slightly shorter than *pa*, with strong tendency to elongation as in other halarachnine larvae, e.g. *Halarachne* Allman and *Orthohalarachne* Newell (see Domrow, 1962, 1974). Ventral cuticle with three pairs of lateral setae in addition to usual three pairs of midventrals and pair flanking anal complex; with metapodal traces and duct-like structures seen in *Orthohalarachne*.

Legs holotrichous, otherwise much as in ♀.

Notes. This is the first species of *Raillietia* to be described from a caprine rather than a bovine member of the family Bovidae.

ACKNOWLEDGEMENTS

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Structural Relationships across the Lambian Unconformity in the Hervey Range-Parkes Area, N.S.W.

C. McA. Powell, C. L. Fergusson and A. J. Williams

Powell, C. McA., Fergusson, C. L., & Williams, A. J. Structural relationships across the Lambian Unconformity in the Hervey Range-Parkes area, N.S.W. *Proc. Linn. Soc. N.S.W.* 104 (3), (1979) 1980:195-210.

Detailed mapping of the structural relationships in four areas on the flanks of the Hervey and Parkes Synclines shows that the angular discordance between ?Silurian and Lower Devonian rocks and the overlying Hervey Group is very low in the north and increases southward. Comparison of the structural style of the Hervey and Parkes synclines with synclines in rocks of similar facies from other areas in the northern Lachlan Fold Belt shows that the latest Devonian to Early Carboniferous folding is less intense in the Hervey Range-Parkes area than in the eastern Lachlan Fold Belt, but more marked than the gentle warping further west. Mid-Devonian folds in the Hervey Range-Parkes area, if present, were open to gentle, and trended north-northeast.

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INTRODUCTION

The Lambian Unconformity (Powell and Edgecombe, 1978, p. 166) in the northern Lachlan Fold Belt separates an upper well-bedded, quartzose, terrestrial to shallow-marine succession of sandstone and conglomerate from a lower succession that varies from graded-bedded sandstone and shale to massive silicic volcaniclastics and granitic rocks. The lower parts of the quartzose upper succession, variously known as the Lambie, Catombal, Hervey, Cocoparra and Mulga Downs Groups in the northern Lachlan Fold Belt (Conolly, 1965, 1969) range in age from latest Early or early Middle Devonian in the basal Mulga Downs Group (Ritchie, 1973) to Late Devonian in the lower marine part of the Lambie Group (Roberts *et al.,* 1972). The upper parts of the succession may well extend into the earliest Carboniferous. The underlying rocks vary in age depending on the lacuna across the unconformity; in places, they are Early Devonian and elsewhere are as old as Ordovician.

The structural relationships across the Lambian Unconformity have been mapped to determine the relative importance of deformations before, and after, deposition of the quartzose succession (Powell and Edgecombe, 1978; Powell and Fergusson, 1979a,b). By considering areas where the underlying rocks are no older than earliest Devonian, or, if older, where they can be shown to be conformable into the earliest Devonian, the relative importance of mid-Devonian and latest Devonian to Early Carboniferous deformation across the Lachlan Fold Belt may be compared.

Mechanically, the upper quartzose succession is less ductile, and has a higher ductility contrast, than most of the underlying rocks, with the exception of areas of granite and multiply-deformed volcanics that may act as rigid masses in subsequent deformations (e.g. the Ordovician Sofala Volcanics, Powell *et al.,* 1978). The

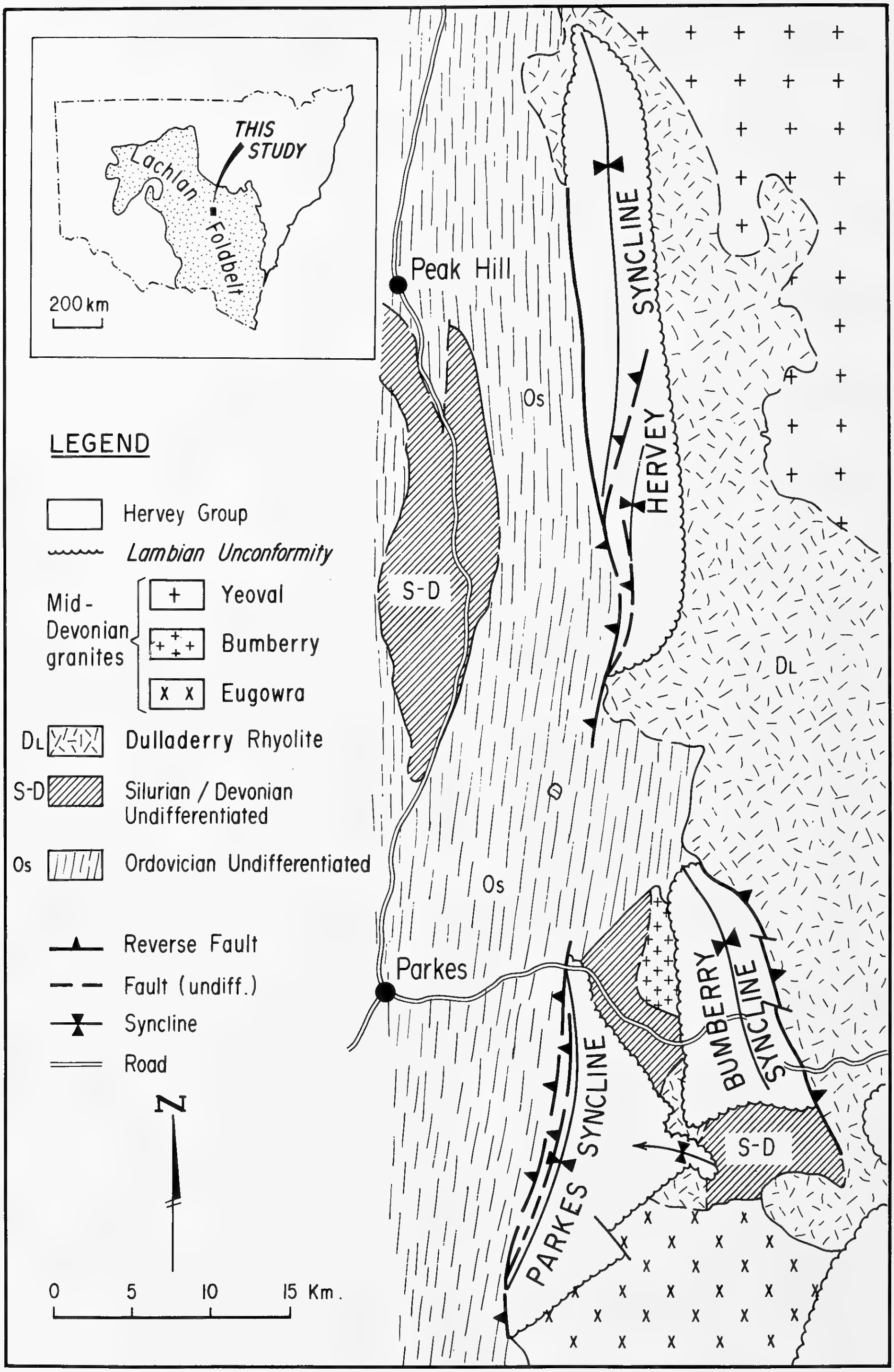

Fig. 1. **Structural setting of the Parkes and Hervey Synclines.**

quartzose succession can thus be expected to deform into cylindrical concentric folds by layer-parallel slip while the underlying rocks may deform in several ways including forming conical folds with the same general trend but varying vertex angles depending on the pre-fold attitude of the beds (Haman, 1961; Ross and McGlynn, 1963; Stauffer, 1964; Ramsay, 1967).

In this paper, the relationship of structures across the Lambian Unconformity is described from the Hervey and Parkes Synclines in the central-northern Lachlan Fold Belt (Fig. 1). The broad stratigraphy of the quartzose succession was described by Conolly (1965), and the southern part of the area has been mapped in greater detail by Williams (1975).

GEOLOGICAL SETTING

The oldest rocks known in the region (Fig. 1) are Ordovician, consisting of thinly-bedded quartzose sandstones and slates of flyschoid aspect which overlie andesites, limestones and interbedded marls west of Parkes (Packham, 1969). This sequence is overlain unconformably (?) by an Upper Silurian (?) to Lower Devonian succession of lithic sandstones and shales, with interbedded massive to foliated, porphyritic, silicic volcanic rocks. In the mapped area, two units of the Upper Silurian (?) to Lower Devonian succession occur, the Dulladerry Rhyolite and an informal unit of shales and interbedded feldsparlithic graded sandstone, the 'Moura beds'. The 'Moura beds' are typically olive grey silts and shales in which sporadic influxes of coarse detritus have produced thick sandstone units. Flute marks on the base of 6 sandstone units indicate an average direction of flow towards 355°, and the mean of 5 occurrences of tool marks on the soles of sandstone beds gives a line of current 018° or 198°. Outcrops on the eastern side of the Parkes Syncline indicate that the Dulladerry Rhyolite and the 'Moura beds' are either interbedded or in fault contact. Further east (GR 1493 8838, Bathurst 1:250,000 geological sheet) marine sediments conformable below the Dulladerry Rhyolite have yielded fossils of Early Devonian, probably late Lochkovian age (Pickett, 1979).

The 'Moura beds' are intruded by the Eugowra and Bumberry Granites and associated rhyolite dykes. The relationship of the Dulladerry Rhyolite to the Eugowra Granite is not clear, because although both occur in close proximity on the southeastern side of the Parkes Syncline, the contact relationships are not exposed. The Dulladerry Rhyolite, which includes a variety of rocks ranging from lenticle tuff, banded rhyolite, basalt and water-laid clastics to porphyry, may well be the surface equivalent of the subjacent contemporaneous granite. All these rocks are overlain by the Hervey Group which can be subdivided (Conolly, 1965) into a thin, lower, arkosic to lithic unit of sandstone, siltstone and red mudstone (Beargamil Sub-Group), a thick, middle, cyclic sequence of cross-bedded quartzite, minor conglomerate, and interbedded red siltstones and shales (Nangar Sub-Group), and an upper thick unit of red siltstones and mudstones (Cookamidgera Sub-Group). The relative stratigraphic order (legend, Fig. 1) is consistent with the 1:250,000 Narromine and Forbes geological maps (Brunker, 1967, 1968). No relative ages have yet been established between the Yeoval, Bumberry and Eugowra Granites.

The Ordovician rocks are in contact with the Hervey Group along the western limbs of the two synclines, separated by high-angle reverse faults. On other limbs of these synclines the Hervey Group rests unconformably on various older rocks, the angular discordance (described below) increasing southward. The regional structure trends meridionally, but there are folds, faults and airphoto lineaments trending obliquely.

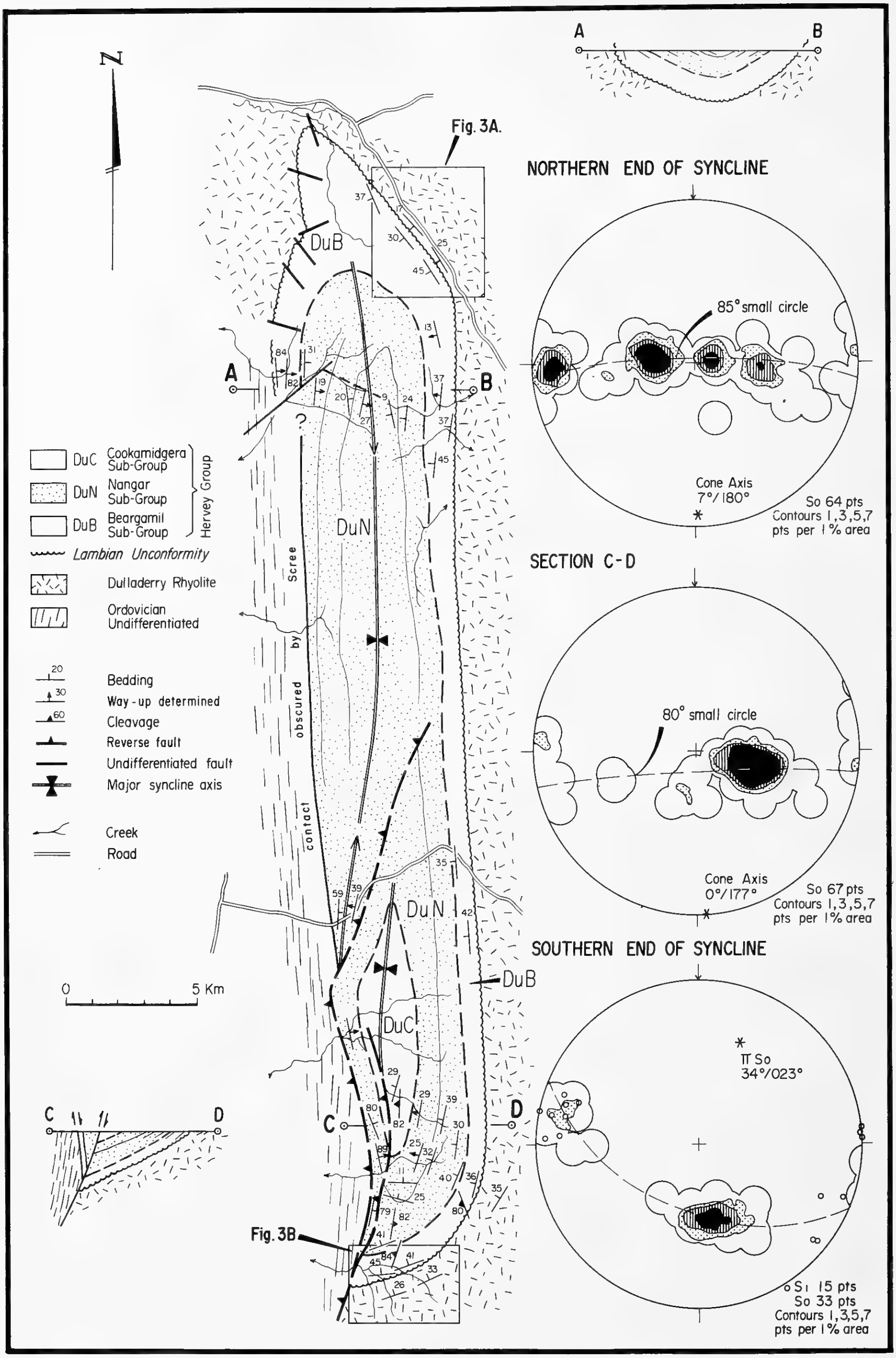

Fig. 2. Structure of the Hervey Syncline. Geological contacts plotted on enlarged air-photo mosaic base. A-B and C-D are natural-scale cross sections.

STRUCTURE

Hervey Syncline

The Hervey Syncline consists of two en-echelon synclines separated by a north-northeasterly trending fault that cuts obliquely across the meridional trend (Fig. 2). Conolly (1965, p. 47) considered the fault to be normal with the southeastern side down-thrown, but there is no conclusive evidence of which way the fault dips. In Fig. 2, the fault is depicted as a continuation of the high-angle reverse fault along the western margin of the southernmost syncline.

Profiles through the Hervey Syncline vary from open in the north (interlimb angles of 105° and 130° for Conolly's (1965) fig. 7, sections A-B and C-D respectively, but 60° if the nearly vertical beds on the western part of our section A-B, Fig. 2, are taken into account) to close in the south (interlimb angles of 56° for section E-F, Conolly (1965, fig. 7), and 61° in our section C-D, Fig. 2). There is no cleavage in the

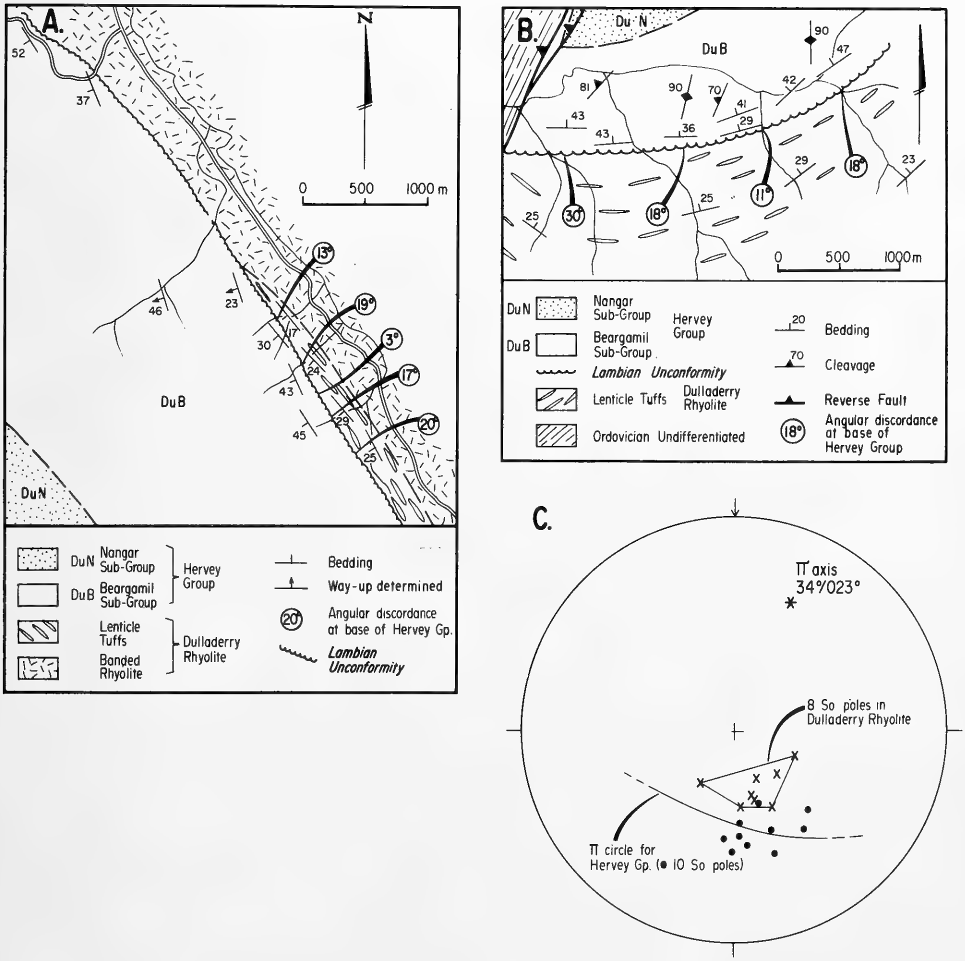

Fig. 3. **A.** Detail of structural relationships across the Lambian Unconformity at the northern end of the Hervey Syncline. **B.** Detail of structural relationships across the Lambian Unconformity at the southern end of the Hervey Syncline. **C.** Stereogram of bedding poles in the Dulladerry Rhyolite and adjacent Hervey Group from the area in **B.** π-circle for Hervey Group is extrapolated from Fig. 2.

Hervey Syncline except at the southern end where a statistically planar, anastomosing, disjunctive cleavage (Powell, 1979) spaced at cm-scale and parallel to the steep, westerly-dipping fault bounding the western limb, pervades the quartzites and conglomerates.

Equal-area stereograms of bedding poles from the Hervey Group along sections A-B and C-D give small-circle patterns that correspond closer to conical patterns (stereograms in Fig. 2) than to cylindrical distributions. The cone axes are nearly horizontal, and in both cases the cone apex points southward. This relationship can be explained in both areas by the tightening of the fold profile southward. In the northern section the fold profile tightens towards the middle of the syncline, culminating in the displacement on the north-northeasterly trending fault. In the southern section, the fold profile tightens towards the south of the fold as increasing displacement is taken up on the flanking high-angle reverse fault. In the southern part of the Hervey Syncline a wedge of Nangar Sub-Group lies between two splays of the western bounding fault, and the bedding in this wedge gradually steepens southward until it is vertical. The extreme southern end of the syncline, where there is the platy, disjunctive cleavage, plunges appreciably more steeply (34° towards 023°) than other parts of the fold. Because of the lack of a regional axial-surface cleavage, the orientation of the axial plane can be approximated only by inspection of the attitude of the fold limbs which dip more steeply (60° to 90°) on the west than on the east (35° to 45°). The axial plane is thus probably inclined steeply west at between 70° and 75°.

The orientation of bedding in the rocks below the Lambian Unconformity has been determined in two areas, at the northern and southern ends of the syncline. Elsewhere, outcrop is poor or bedding is absent in the Dulladerry Rhyolite. In the northern area (Fig. 3A), a band of lenticle tuff (Fig. 4) overlies banded rhyolite, and

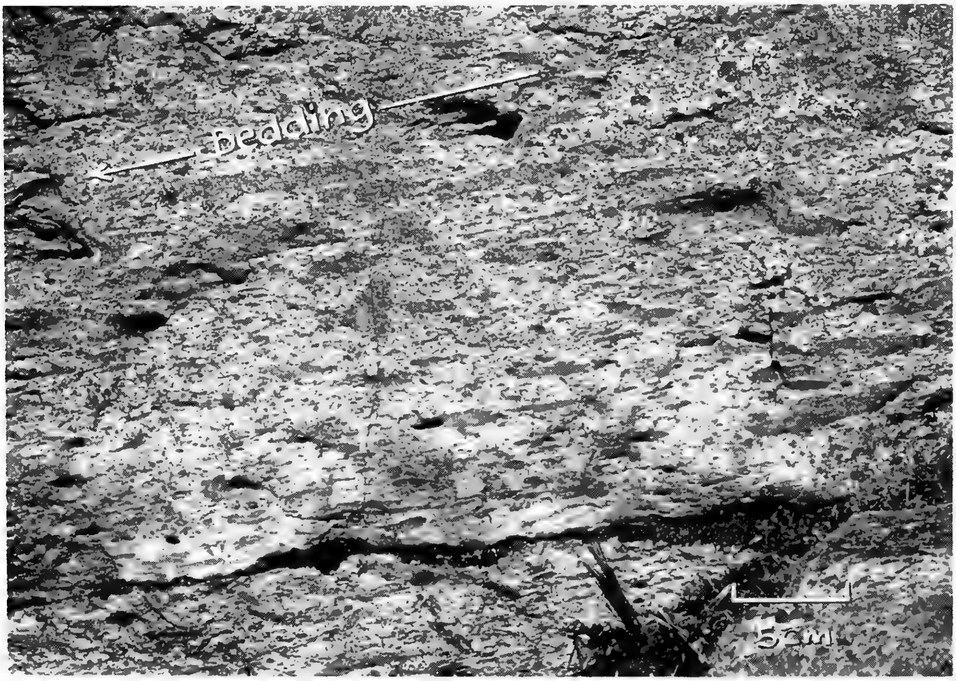

Fig. 4. Lenticle tuff immediately below the Lambian Unconformity at northern end of Hervey Syncline (Fig. 3A).

the outcrop pattern shows a low-angle erosional truncation of the lenticle tuff by the Hervey Group. Five bedding couplets across the Lambian Unconformity give an angular discordance ranging from 3° to 20°, with a mean of 14°, which, considering the inherent inaccuracies (Powell and Edgecombe, 1978, fig. 2), is a very low-angle truncation.

Another band of lenticle tuff in the Dulladerry Rhyolite at the southern end of the Hervey Syncline allowed us to determine four more angular discordances across the Lambian Unconformity (Fig. 3B), with a range of 11° to 30° and a mean of 19°. These individual calculations of the magnitude of the angular discordance agree well with the average angular separation shown by the cluster of eight bedding poles from the lenticle tuff in the Dulladerry Rhyolite as compared with the π-circle distribution of the immediately adjacent basal Hervey Group (Fig. 3C).

Parkes Syncline

The Parkes Syncline has a triangular plan shape with the longest side trending meridionally (Fig. 5). The structure is markedly asymmetric, with steep to locally overturned dips in the western limb. A system of high-angle reverse faults is parallel to, and truncates part of, the western limb, as in the Hervey Syncline. The eastern limb has moderate to gentle westerly dips (commonly 20° to 49°) though in the northern end dips steepen to more than 80°. A gentle synclinal, crossfold near Mt. Bolton plunges shallowly to the west-northwest.

Latitudinal profiles through the Parkes Syncline vary from close to tight (interlimb angles of 24° and 66° in our sections A-B and C-D, Fig. 5, respectively, and of 66° in Conolly, 1965, fig. 9), with the thickness of the western limb attenuated by movement on high-angle reverse faults dipping westward. The axial surface dips steeply westward, but its precise attitude cannot be determined from bedding data alone. Equal-area stereograms of bedding poles from the northern and southern ends of the syncline reflect the curved, inward-plunging fold axis which, at the northern end, plunges steeply (60° towards 170°). A meridional profile across the shallowly west-northwesterly plunging cross-fold at Mt. Bolton is gentle (interlimb angle around 130°). There is no axial-surface cleavage.

The rocks below the Hervey Group across the Lambian Unconformity include the well-bedded 'Moura beds', the massive Dulladerry Rhyolite and the Eugowra Granite on which the Hervey Group rests nonconformably. The best exposure across the Lambian Unconformity occurs in the Mt. Bolton area (Fig. 6) where, in at least one outcrop, the contact is exposed (Fig. 7). The structure of this area has been mapped in detail, and as well as 16 separate calculations of the angular discordance (Fig. 8A; range from 26° to 97°, with a mean of 42°), the gross structure of the 'Moura beds' has been outlined by walking out several prominent lithic sandstone units (Fig. 6).

Equal-area stereograms of bedding poles in the Mt. Bolton area reflect divergent fold axes across the unconformity (Fig. 9). Bedding in the Hervey Group defines a gentle fold plunging 8° towards 287° (Fig. 9A), whereas bedding in the immediate underlying 'Moura beds' lies on a 70°-small circle about a cone axis plunging 55° towards 001° (Fig. 9B). The trend of the cone axis is parallel to the regional meridional structure, and the 70°-small circle is probably caused by the dip the 'Moura beds' had before the Hervey Group was deposited. The reason for the steep plunge of the cone axis, however, is not clear.

There is no cleavage parallel to the meridional cone axis, but a local cleavage trending 070° to 080° is developed in the Hervey Group (as a platy to anastomosing disjunctive cleavage, spaced at the cm-scale) and in the 'Moura beds' (as an anastomosing, reticulate cleavage in mudstones) around Mt. Bolton at the eastern end

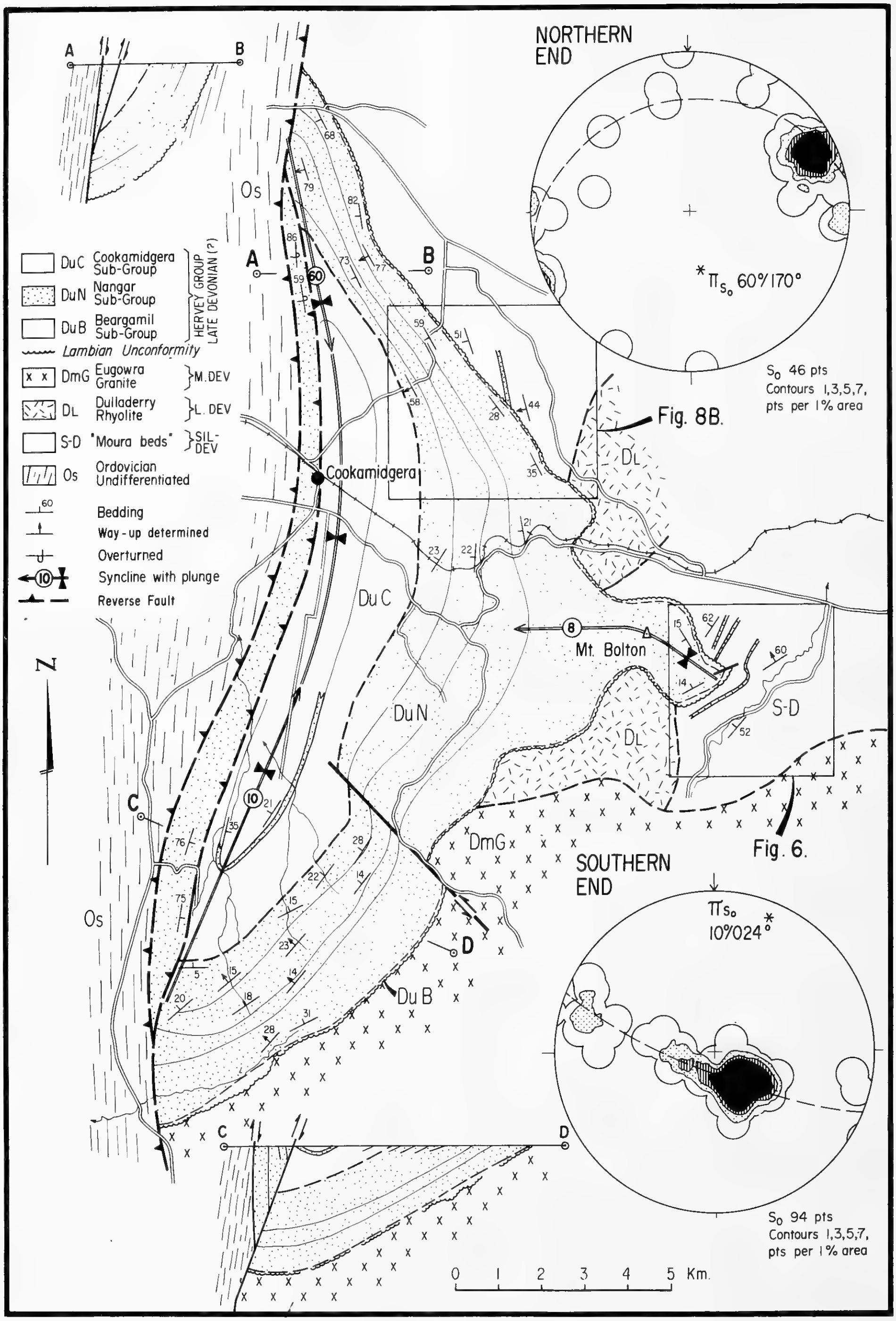

Fig. 5. Structure of the Parkes Syncline. Geological contacts plotted on enlarged air-photo mosaic base. A-B and C-D are natural-scale cross sections.

of the Parkes Syncline. In this area, there are a number of small faults (one offsets the trace of the Lambian Unconformity in Fig. 6) and mesoscopic folds with the same east-northeasterly trend — a direction also approximately parallel to the outcrop trace of rhyolite dykes probably related to the Eugowra Granite. These east-northeasterly trending structures occur only in a 500-metre wide zone, and are superimposed on the regional meridional folds.

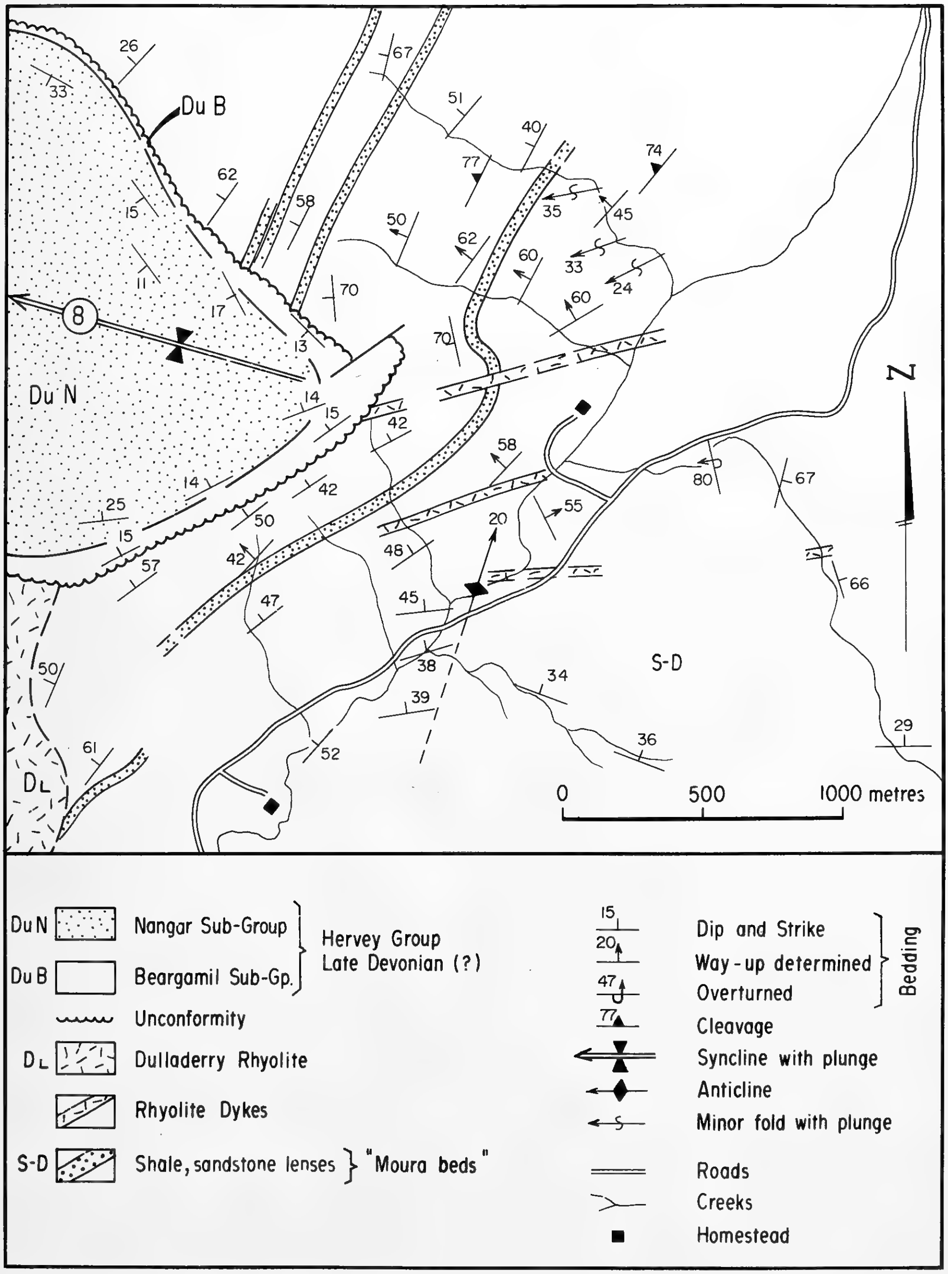

Fig. 6. Detailed structure of the Mt. Bolton area, at the eastern end of the Parkes Syncline.

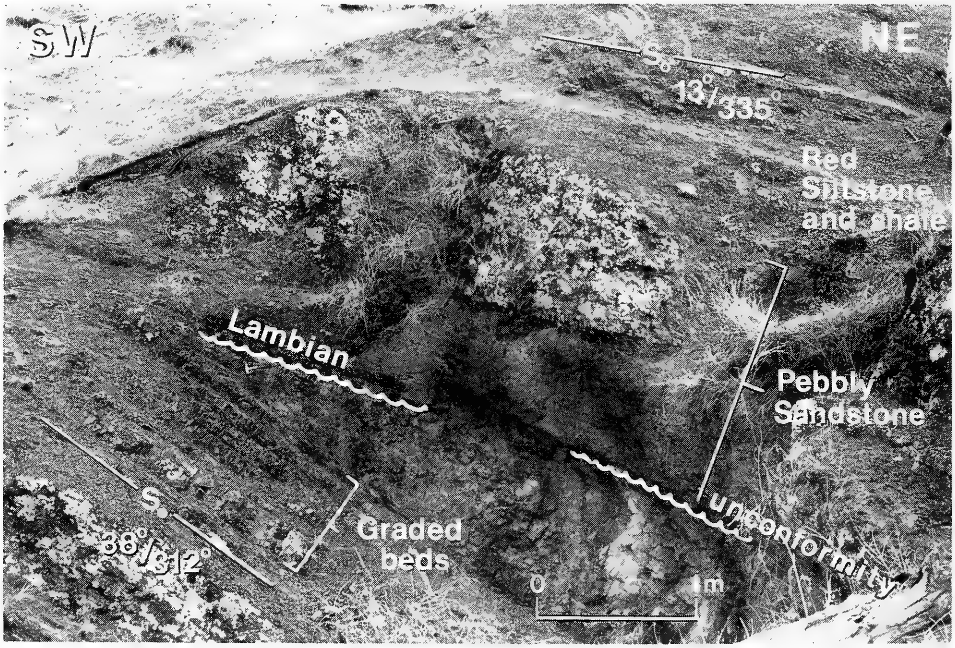

Fig. 7. Lambian Unconformity exposed on the southeastern side of Mt. Bolton (location in Fig. 8A). The underlying beds dip 38° towards 312° and the overlying beds dip 13° towards 335°.

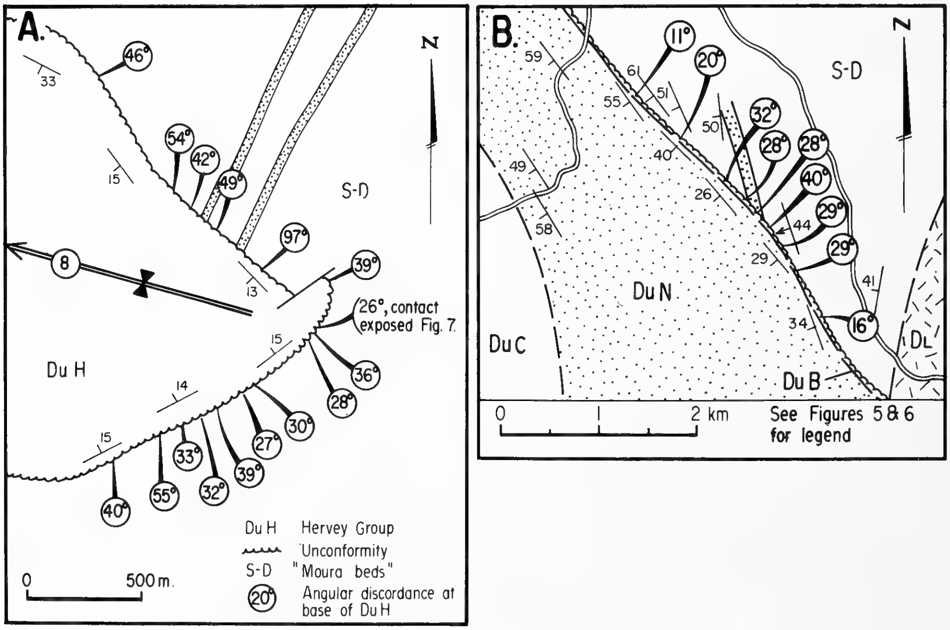

Fig. 8. **A.** Angular discordances across the Lambian Unconformity in the Mt. Bolton area (Fig. 6). **B.** Detail of structural relationships across the Lambian Unconformity on the northeastern flank of the Parkes Syncline (location in Fig. 5).

The structure of the underlying beds was also determined on the northeastern flank of the Parkes Syncline (Fig. 8B). In this area, nine bedding couplets across the Lambian Unconformity give an angular discordance ranging from 11° to 40° with a mean of 26°. A sandstone bed striking more northerly than the Hervey Group can be traced in the 'Moura beds' up to the Lambian Unconformity. A fault offset in the trace of the Lambian Unconformity on the southeastern flank of the Parkes Syncline (Fig. 5) suggests some brittle deformation of the Eugowra Granite after deposition of the Hervey Group.

DISCUSSION

Mid-Devonian bedding orientations

The bedding orientations in the 'Moura beds' and Dulladerry Rhyolite were restored stereographically to their presumed disposition prior to deposition of the Hervey Group using the local fold axes (method in Powell *et al.,* 1978). The resulting stereogram suggests a sub-horizontal pre-Hervey Group fold axis trending north-northeasterly (Fig. 10). No mid-Devonian fold hinges have been found so that the restored mid-Devonian bedding orientations may have been formed equally as much by simple tilting about a north-northeast axis as by regular folding about the same axis. The average pre-Hervey Group orientation of the beds in the Mt. Bolton area is a dip of between 40° and 60° towards 308°. This orientation is approximately 70° oblique to the later regional, sub-horizontal, meridional fold axis which may account for the 70° small-circle distribution of the bedding poles (Fig. 9B).

Angular discordance across the Lambian Unconformity

The 34 calculations of the angular discordance across the Lambian Unconformity in the Parkes-Hervey Ranges area appear to show a trend of increasing discordance southward (Fig. 11). Most of the discordances at the northern end of the Hervey Syncline are low enough to be caused by imprecision in the method of estimating the magnitude of the angular discordance (Powell and Edgecombe, 1978, fig. 2), but there does appear to be a gradual truncation of the 100 m thick lenticle-tuff horizon over more than 1.5 km along strike. The possibility of facies change over this distance, however, cannot be ruled out. The angular discordance at the northern end of the Hervey Syncline is thus very low, and possibly the Lambian Unconformity there is a paraconformity.

In the Mt. Bolton area, angular discordances around 40° are common. Present data do not permit us to determine whether the increase in angular discordance near Mt. Bolton is local, caused by tilting during mid-Devonian intrusion of the Eugowra Granite, or whether it is part of a regional trend of mid-Devonian angular discordance across the Lambian Unconformity increasing southward as noted in the eastern Lachlan Fold Belt (Powell and Edgecombe, 1978; Powell and Fergusson, 1979a,b). Angular discordances north of Bathurst are less than 30°, but increase southward along the Cookbundoon Synclinorium to exceed 90° locally, near Taralga. To the northwest, in the Cobar area, the contact between the Mulga Downs Group and the underlying Amphitheatre Group is essentially conformable, with only small areas of angular discordance that can be related to slumping and local folding in the underlying rocks (Glen, 1978, 1979). Such a pattern of mid-Devonian angular discordances increasing southwards in the Lachlan Fold Belt might be expected if there was an area of major mid-Devonian deformation in southern New South Wales and Victoria dying out northwards.

Another possibility exists if the 'Moura beds' are older than the Late Silurian to

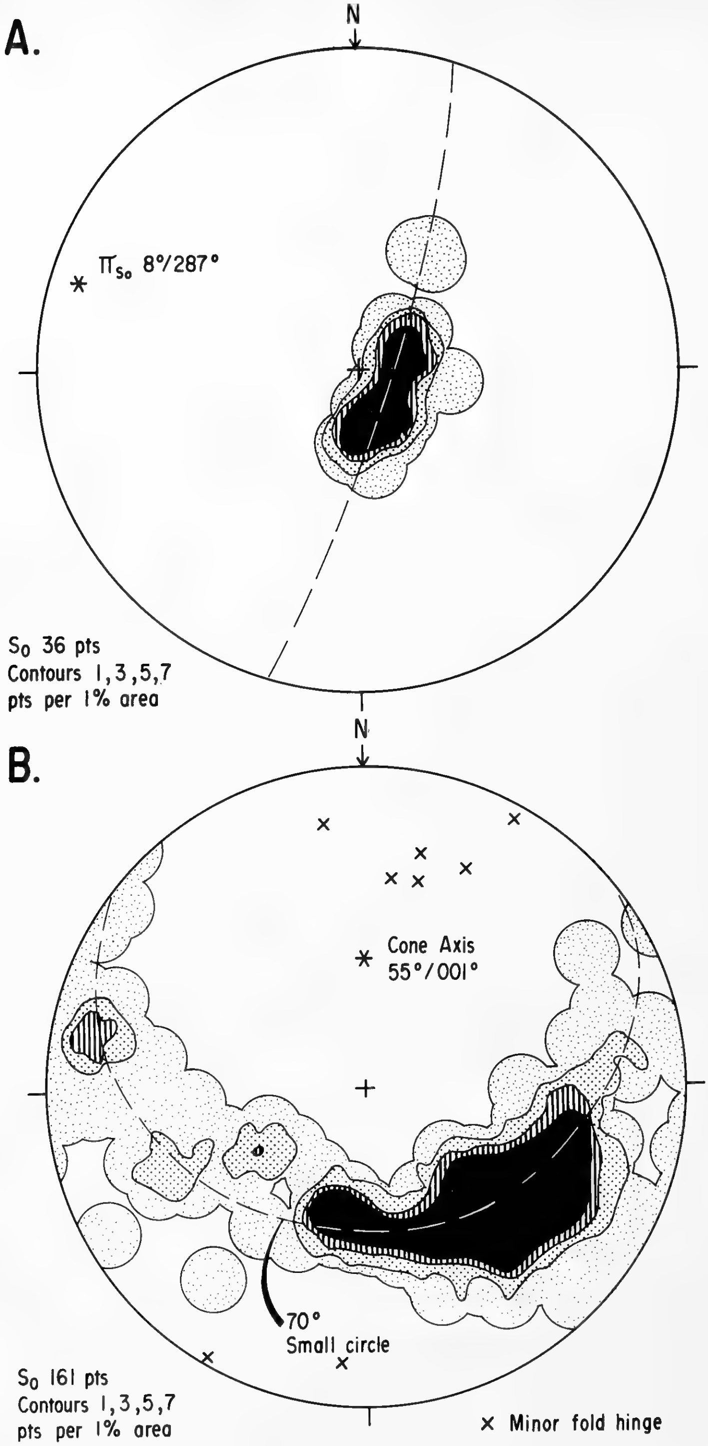

Fig. 9. **A.** Equal-area stereogram of bedding poles in the Hervey Group in the Mt. Bolton area (Fig. 6). **B.** Equal-area stereogram of bedding poles in the Moura beds in the Mt. Bolton area (Fig. 6).

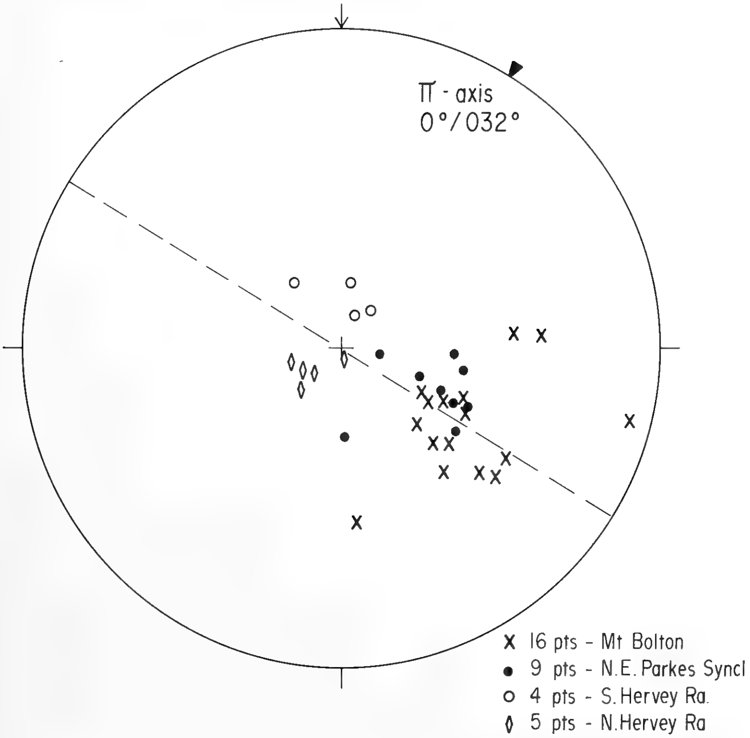

Fig. 10. Equal-area stereogram of mid-Devonian bedding orientations from the Hervey Range-Parkes area, after the overlying Hervey Group has been restored to horizontal stereographically using the procedure outlined in Powell *et al.* (1978).

Early Devonian age we have inferred, because then the angular discordance at Mt. Bolton may have been caused by movements older than mid-Devonian. In either case, the mid-Devonian deformation in the Parkes area was mild, and, if any folds developed, they were gentle to open in profile and trended north-northeast. No cleavage developed during the mid-Devonian deformation in the Parkes area.

Comparison of the post-Hervey Group deformation in the Parkes area with other areas

The structural style of the Hervey Group in the Parkes area is, in many ways, transitional between the relatively intense deformation in equivalent rocks in the northeastern Lachlan Fold Belt (Powell *et al.,* 1977; Powell and Edgecombe, 1978; Powell and Fergusson, 1979a) and the mild warping in equivalent rocks in the western part of the fold belt (Table 1, cf. Burns and Embleton, 1976). The meridional fold trends are quite well-defined in the Parkes area, although some oblique trends do occur (e.g. Mt. Bolton area). The fold profiles have interlimb angles in places as close as 60° — more open than the tight to isoclinal folds in the northeastern Lachlan Fold Belt, but much tighter than the gentle warps of the Cobar area. Axial surfaces are either upright or inclined steeply west, an orientation common in the northeastern Lachlan Fold Belt where there is a tendency for axial surfaces to dip more shallowly westward in the extreme east (Crook and Powell, 1976, fig. 7-4). In common with the northeastern Lachlan Fold Belt, the western limbs of synclines are commonly sheared out by high-angle reverse faults, although in the Bumberry Syncline (Fig. 1) a reverse

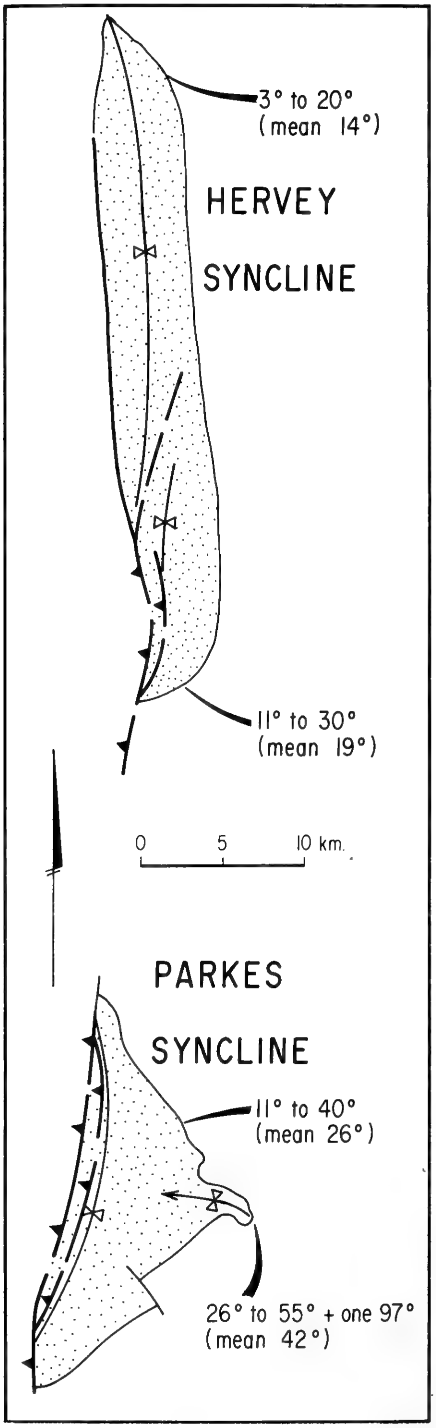

Fig. 11. Range and mean of mid-Devonian angular discordances across the Lambian Unconformity from the four areas in the Hervey Range-Parkes area.

TABLE 1

Comparison of structural style across the northern Lachlan Fold Belt in the Hervey Group and equivalent facies

	Western area (Cobar)	Central area (Parkes)	Eastern area (Molong-Turon River)
Fold trends	Variable, with an overall north-northwesterly azimuth.	Grossly meridional with some oblique trends.	Strongly meridional trends.
Fold shape	Gently folded, centroclinal structures (domes, basins, noses and saddles).	Open to closely folded synclinal structures with rare anticlines.	Tight to isoclinally folded synclines.
Axial surface and fold symmetry.	Upright and symmetrical.	Upright to inclined steeply (70°) westward. Commonly asymmetrical with western limb sheared out.	Overturned to inclined, usually westward, at angles decreasing to 55° in the east.
Cleavage	Absent	Virtually absent, developed locally in areas of presumed high strain.	Widespread slaty type in pelitic units, with disjunctive, platy to anastomosing cleavage in conglomerates and sandstones in some places.

fault occurs on the eastern limb. Cleavage is virtually absent from the Parkes Syncline westward, but is quite well developed in the Murga area some 20 km east. In the northeastern Lachlan Fold belt, slaty cleavage is developed in pelitic units, and a platy to anastomosing, disjunctive cleavage, spaced at the cm-scale, is common in conglomerates and some sandstones.

These combined features suggest a westward dying-out of the latest Devonian to Early Carboniferous deformation in the northeastern Lachlan Fold Belt (Powell *et al.*, 1977). One possible explanation for this westward (also southwards) decrease in deformational intensity may be the different states of consolidation of the substrate on which the Lambie and equivalent facies rested during the later deformation. In the Parkes area, Early or Middle Devonian granites would have acted as rigid, or at least less ductile, bodies in comparison with the well-bedded flyschoid rocks of the northeastern Lachlan Fold Belt. It is possible that fractures which developed in the Parkes area prior to the deposition of the Hervey Group propagated upward during the later meridional deformation, thereby controlling local fold orientations. It is also possible that ductility contrast between the mid-Devonian granites and the surrounding flyschoid rocks produced strain heterogeneities that controlled the trends of local folds. Further work is required to test such hypotheses.

ACKNOWLEDGEMENTS

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A new Early Devonian tabulate coral from the Mount Frome Limestone, near Mudgee, New South Wales

A. J. WRIGHT and R. A. FLORY

WRIGHT, A. J., & FLORY, R. A. A new Early Devonian tabulate coral from the Mount Frome Limestone, near Mudgee, New South Wales. *Proc. Linn. Soc. N.S.W.* 104 (3), (1979) 1980:211-219.

Holacanthopora clarkei sp. nov. is described from late Early Devonian beds of the Mount Frome Limestone, near Mudgee, New South Wales, Australia. The species and genus are referred here to the Micheliniidae (Favositoidea, Tabulata). Difficulties encountered in comparing genera of this family, as a result of mode of preservation and uncertainty concerning the significance of the various growth forms, are discussed.

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INTRODUCTION

Although our appreciation of the stratigraphic value of Devonian tabulate corals has increased markedly in the last two decades, there are still major gaps in our knowledge. Large-celled forms such as that described here are a case in point.

Hill and Jell (1970) make a most valuable contribution to our knowledge of a number of problematical tabulate coral genera and families, including the large-celled forms. In particular they raise the question of characteristic favositid and syringoporoid features. This is a matter of some concern with large-celled material, and is briefly discussed below. We hope that this paper will focus attention on the evolution of at least some Middle and Late Palaeozoic tabulate corals — especially the large-celled forms similar to *Michelinia*.

MATERIAL AND STRATIGRAPHY

Holacanthopora clarkei sp. nov. is a relatively large-celled, wholly cerioid tabulate coral known only from the Mount Frome Limestone (Wright, 1966) at Mount Frome near Mudgee, New South Wales, Australia (Fig. 1). The most recent estimates of the age of this formation (Philip, 1974; Pickett, 1978), based on conodonts, indicate that the Early-Middle Devonian boundary occurs in the limestone. The boundary is probably above the highest occurrence of *H. clarkei,* which occurs in the interval 36-108m (Fig. 2) and thus appears to be wholly Early Devonian.

All six known specimens of this species are transported but only slightly abraded coralla. The stratigraphically lowest specimens (USGD 85218, AMu 60130) occur in otherwise poorly fossiliferous calcarenites (Fig. 2). Three specimens (AMu 60129, USGD 85219, AMu 60131) from an intermediate stratigraphic position (Fig. 2) occur with a varied macrofauna in a crinoidal calcarenite. The single specimen (USGD 85220) from the highest level (Fig. 2) occurs in a richly fossiliferous calcarenite.

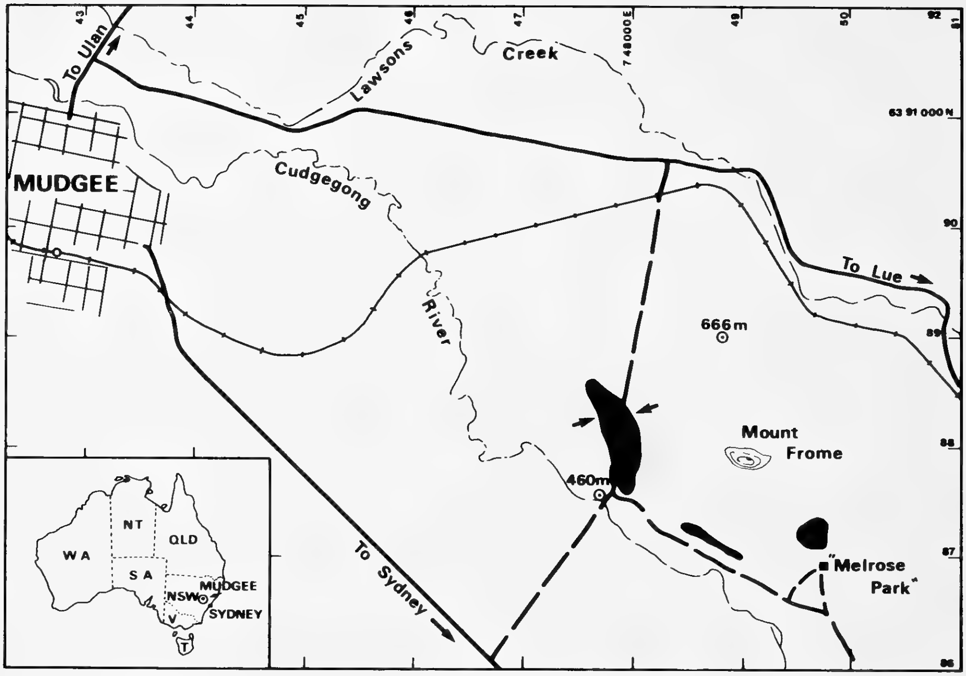

Fig. 1. Map showing main outcrops of Mount Frome Limestone. Base from Mudgee 1:100,000 topographic sheet 8832 (1st ed.). Grid lines 1000m intervals. Approximate location of measured section shown by arrows.

SYSTEMATIC PALAEONTOLOGY

Superfamily FAVOSITOIDEA
(*nom. transl.* Hill and Jell 1970)

Family MICHELINIIDAE Waagen and Wentzel 1886
(*nom. transl.* Sokolov 1950)

Remarks. Typified by *Michelinia,* this family is characterized by cerioid or fasciculate colonies of relatively large-celled tabulate corals with flat (or nearly so) calical floors, mural pores and usually prominent septa. The taxomic significance of acanthine septa as developed in *Holacanthopora* (but mostly not in *Michelinia* — see below) is uncertain, so Holacanthoporinae Le Maître is possibly of family status but nevertheless is provisionally considered here a junior subjective synonym of the Micheliniidae. However, the genera are retained as separate forms. Sokolov (1962) placed *Holacanthopora* in the Beaumontiinae, separate from the Micheliniinae. Hill and Jell (1970, p. 184-185) have suggested that *Pseudoroemeria* (see below), *Troedssonites* and *Syringoporinus* represent a new subfamily, possibly within the Syringoporidae. As there is some similarity between *Pseudoroemeria* and *Holacanthopora,* the new species may therefore belong in such a new subfamily. Le Maître (1959) included *Holacanthopora* and *Maurenia* in the Holacanthoporinae.

A major problem in this group of tabulate corals concerns the taxonomic significance of the growth form. This problem is aggravated by the various types of preservation. Although the two factors are intertwined, it is possible to delineate some resultant problems. Many taxa in this group are notoriously variable in growth form. For instance, *Holacanthopora,* as presently understood, includes both cerioid and

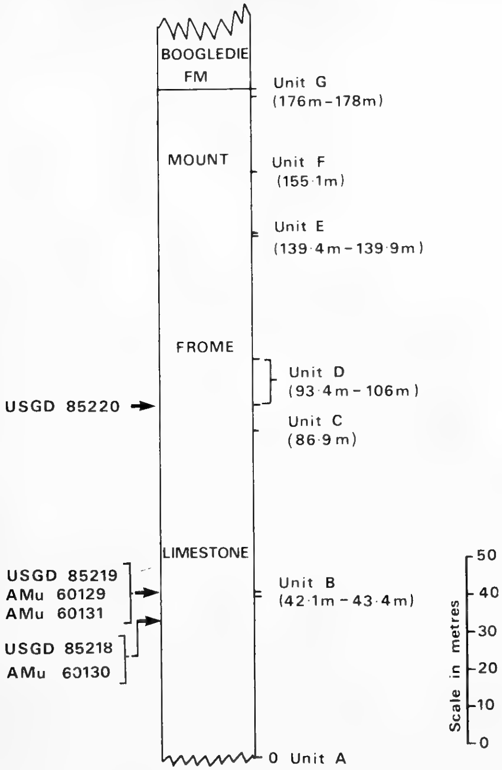

Fig. 2. Stratigraphic section through the Mount Frome Limestone showing location of specimens and informal faunal subdivisions of the Limestone.

fasciculate species which should possibly be separated on the basis of growth form at the generic level. However, it is also possible that genus-level taxa in this group ought to include a wide variety of growth forms as many species-level taxa [e.g. *P. (Pleurodictyum) cylindricum* (Michelin): Stumm, 1964, pl. 71, figs 1-5] are themselves quite variable. In particular, it is far from clear whether flattened colonies are generically distinct from more upright colonies approaching hemispherical form. Jones (1944) has discussed the problems generated by differing preservation in relation to *Michelinia* and *Pleurodictyum.* Many *Pleurodictyum,* such as are common in the Rhenish facies, occur as moulds and are discoidal colonies; these seem distinct from erect forms such as *Pleurodictyum bifidum* Jones, 1944 and many of the forms described by Stumm (1964), especially those which are many-celled colonies.

The problems created by varied preservation take on two main aspects. Firstly we have the matter of comparison of observed overall shape of the corallum; secondly there is the problem of comparison of detailed structures, often obscured by silicification and largely absent in moulds (e.g. septal microstructure). We believe these are separate problems as their results are felt at different taxonomic levels.

The problem of preservation is an acute problem exemplified by the contrast between 'typical' Rhenish *Pleurodictyum* (almost always preserved as moulds) and the abundant North American materials (e.g. Stumm, 1964) (generally calcareous or silicified). One result is considerable doubt as to the generic and subgeneric status of the *Pleurodictyum problematicum* Goldfuss (and *Pleurodictyum megastoma* McCoy) group compared with larger colonial forms such as *P. bifidum* Jones, 1944, *P. (Pleurodictyum) maximum* (Troost) and some other forms described by Stumm (1964). It may be that mould material referred to *Procteria* by Plusquellec (1965) and *Cleistopora* by Plusquellec (1966) will be eventually referred to *Pleurodictyum* when the importance of fine morphological features can be evaluated. Some unfortunate results of poor and good preservation might finally be noted. Concerning the former, the literature is replete with instances of probably indeterminate, broadly 'favositid' material preserved as moulds and referred (we believe erroneously in many cases) to *Pleurodictyum*. Conversely, well-preserved calcareous material described as a new tetracoral genus *Araiostrotion* (Guo, 1965) is probably a *Pleurodictyum* (see also Weyer, 1973).

Subfamily Holacanthoporinae Le Maître, 1957

Holacanthopora Le Maître, 1954, p. 1668

Type Species. Michelinia (Ethmoplax) fascialis Le Maître, 1952, p. 80, pl. 4, figs 3-6.
Diagnosis. Large-celled fasciculate and cerioid Tabulata with abundant acanthine septa; tabular floors weakly convex to weakly concave; mural pores located at or near wall junctions (new diagnosis).
Remarks. In addition to the type species, Le Maître (1959) also placed in this genus *H. gracilis* Le Maître, 1954 (*nom. nud.*) and *H. irregularis* Le Maître, 1957 (*nom. nud.*). The genus ranges from Emsian to Givetian (Le Maître, 1959 p. 147). *H. irregularis* is known from the Emsian (Le Maître, 1959, p. 203) and *H. fascialis* is known from the early Couvinian (Le Maître, 1952, 1954, 1959). *H. gracilis* ranges from the early Couvinian to early Givetian (Le Maître, 1959, p. 203).

Michelinia and *Holacanthopora* differ as the former lacks acanthine septa. Only in *Michelinia varia* Pickett (1967, p. 34) have '. . . very short septal spines . . .' been described, projecting into the lumen; it remains to be seen whether truly acanthine septa are widespread in European *Michelinia*.

Some similarities may be noted between *Holacanthopora* and *Pseudoroemeria* Chekhovich, 1960. The type species, *P. atbashiensis* Chekhovich, 1960, is partly cerioid and has mostly horizontal or oblique tabulae which Hill and Jell (1970, p. 185) consider favositoid. *P. pulchra* (Dubatolov, 1969, pl. X, figs 2a-b; 1971, pl. 5, figs 1a-b) has thickened walls (as in *Roemeripora*) and prominent mural pores which profoundly affect the tabulae. In this latter feature the Russian species differs markedly from the North African and Australian species.

Holacanthopora clarkei Wright & Flory, sp. nov.

Fig. 3A-F; Fig. 4A

Diagnosis. Wholly cerioid *Holacanthopora* with corallites up to 6.5 mm in diameter; up to about 10 acanthine septa on each wall; calical floors more or less horizontal, consisting of globose tabulae.
Etymology. The species is named after Rev. W. B. Clarke who was apparently the first to record the Devonian age of the limestones at Mount Frome (Clarke, 1878, p. 16),

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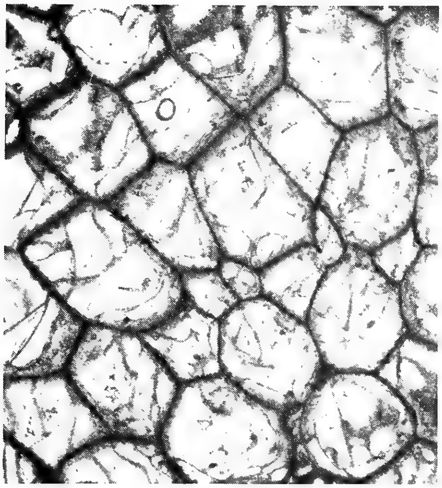
Fig. 3. Holacanthopora clarkei Wright & Flory, sp. nov. Mount Frome Limestone, Early Devonian, near Mudgee, New South Wales. **A, B, C,** holotype USGD 85218; **A,** transverse section, x2.5. **B,** longitudinal section, x1.5. **C,** longitudinal section showing mural pores, x4. **D,** AMu 60131, longitudinal section, x2. **E, F,** USGD 85219; **E,** transverse section, x2.5. **F,** longitudinal section, x3.5. Both **E** and **F** show the abundant septal spines.

Specimens bearing USGD are in the collections of the Department of Geology and Geophysics, University of Sydney; AMu denotes specimens in the Australian Museum collections.



A

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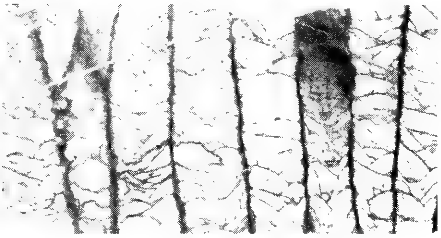

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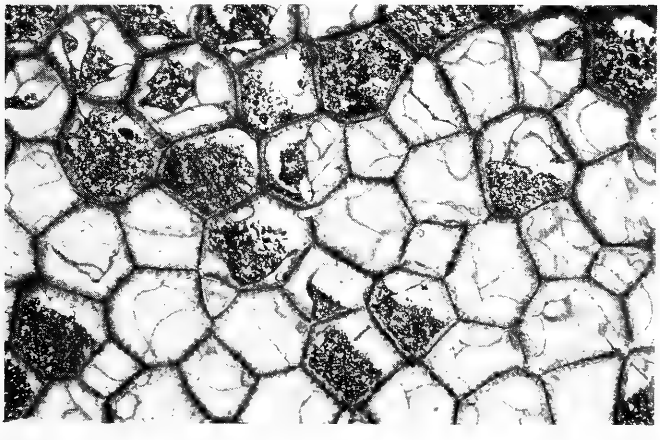
F



E

probably based on fossils (especially *Calceola*) collected by Professor A. M. Thomson (Taylor, 1879).

Material. 6 specimens, whose stratigraphic distribution is shown in Fig. 2. Holotype USGD 85218 (slides WW 190-191); paratypes USGD 85220 (slides W 220-221-222); USGD 85219 (slides W 497-498); AMu 60131 (slides WW 1-5 inclusive); AMu 60129 (slide WW 192); AMu 60130 (slides WW 193-194), all from the Mount Frome Limestone.

Description. Colony cerioid, approximately spherical and up to at least 12 cm in diameter. Even at colony rim, corallites polygonal, although walls often curved; corallites up to 6.5 mm in maximum diagonal diameter. Walls up to 0.8 mm in total thickness with thin dark median structure (presumably primary) which bifurcates in places but elsewhere has beaded, discontinuous appearance (presumably recrystallization). Stereozone contains up to 10 (usually about 7) septa on each wall. Mural pores about 0.5 mm in diameter mostly located at or near wall junctions; their vertical arrangement apparently in single series. Calices about 5 mm in depth, with subhorizontal floors. Increase intermural (Fig. 4A), at junctions of 3 or more corallites.

At inner edge, stereozone denticulate, with short (up to 1 mm in length) septa with rounded or angular axial ends in transverse section which are weakly distally concave and distally inclined at low angle. Septa contain slender holacanths set in lamellar calcite and extend to median axial structure of wall. Longitudinal sections show acanthine septa (Fig. 3F).

Tabular floors weakly convex to weakly depressed (with no sign of syrinx), formed by weakly convex to weakly concave, subhorizontal to gently inclined incomplete plates (tabellae). Spacing often up to 1 mm. Rarely septal spines on these plates.

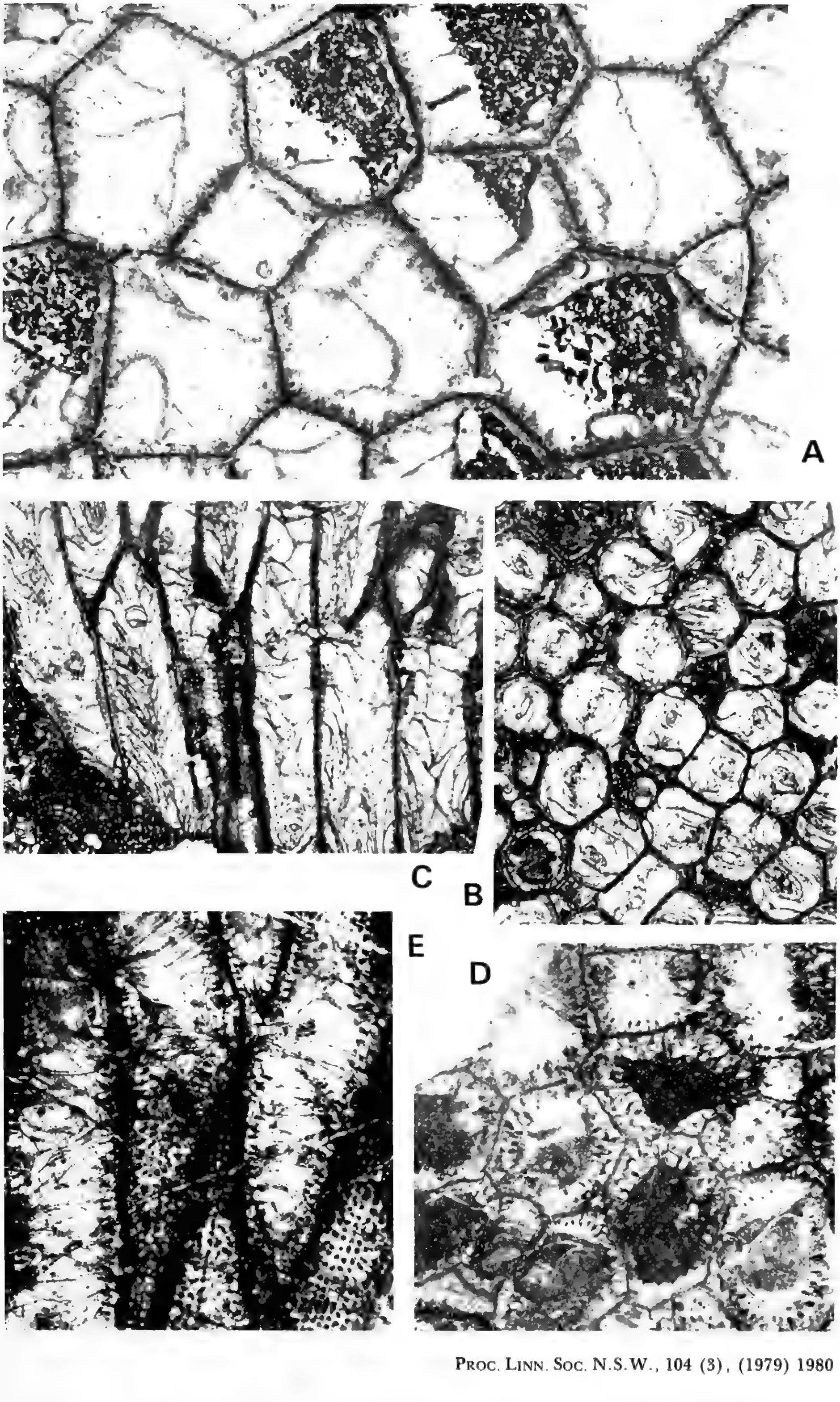
Comparisons. Le Maître (1957, 1959) assigns three species to *Holacanthopora, viz. H. fascialis* Le Maître, 1952; *H. irregularis* Le Maître, 1957 (*nom. nud.*) and *H. gracilis* Le Maître, 1954 (*nom. nud.*).

Of the three Northern Hemisphere species placed in this genus, only *H. fascialis* can be usefully compared (and then only in its size and internal morphology) with *H. clarkei*. A major difference is that, whereas *clarkei* is cerioid, *fascialis* is fasciculate (Le Maître, 1952, p. 80). In addition, corallite increase in *clarkei* is intermural but in *fascialis* is lateral. Le Maître (1957) states that *H. gracilis* and *H. irregularis* are cerioid species. In *gracilis* the colony diameter is 7 mm (Le Maître, 1954, p. 1668) and in *irregularis* the corallite diameter is 4 mm (Le Maître, 1957).

Some general similarity with *Michelinia* is evident, but *Holacanthopora* is distinguished from *Michelinia* in possessing acanthine septa (see above). Devonian tabulate corals from many parts of the world have been assigned to *Michelinia,* but these reports probably require reassessment; a noteworthy occurrence in this regard is the cerioid *M. transitoria* (Knod, 1908) from the Lower Devonian of Bolivia (Barthel and Barth, 1972). Sokolov (1962, p. 226) gives the range of the genus as Lower, Middle and Upper Devonian as well as Carboniferous.

Remarks. The only similarly large-celled cerioid tabulate coral common in earlier Devonian limestones in New South Wales is *Roemeripora progenitor* (Chapman)

Fig. 4. **A,** *Holacanthopora clarkei* Wright & Flory, sp. nov. Mount Frome Limestone, Early Devonian, near Mudgee, New South Wales; USGD 85219, transverse section, x6, showing wall structure, septal spines and mural pores. **B, C,** *Roemeripora progenitor* (Chapman), USGD 88216, Jesse Limestone, Limekilns, New South Wales, Early Devonian; **B,** transverse section, x3. **C,** longitudinal section, x3. **D, E,** *Pleurodictyum bifidum* Jones, holotype USGD 6251, 'Garra Beds', near Wellington, New South Wales, Early Devonian; **D,** transverse section, x5. **E,** longitudinal section, x5.


A
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(Hill and Jell, 1970), clearly a roemeriporid (syringoporid) (Fig. 4B-C). Despite the similar wall structure, the nature of the tabulae argues against any phylogenetic relationship between *progenitor* and *clarkei.* The rare *Pleurodictyum bifidum* Jones, 1944, from New South Wales differs from *H. clarkei* in possessing distant, complete and flattish tabulae (Fig. 4D-E), but probably should be placed in *Holacanthopora* and could be ancestral to *clarkei;* both species have abundant septal spines.

ACKNOWLEDGEMENTS

This work is part of a continuing study of Devonian biostratigraphy generously supported by ARGC grants to A. J. Wright.

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VOLUME 104
NUMBER 4

A new species of the *ulysses* group, genus *Haemolaelaps* Berlese (Acari: Dermanyssidae)

ROBERT DOMROW

DOMROW, R. A new species of the *ulysses* group, genus *Haemolaelaps* Berlese (Acari: Dermanyssidae). *Proc. Linn. Soc. N.S.W.* 104 (4), (1979) 1980:221-227.

Haemolaelaps sisyphus, n. sp., a much reduced member of the Australian *ulysses* group, is figured and described from the nasal passages of the brush-tailed possum, *Trichosurus vulpecula* (Kerr) (Marsupialia: Phalangeridae), in New South Wales. A key to the eight known species is given.

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The distinctive new species of *Haemolaelaps* Berlese now described is the eighth member of the peculiarly Australian *ulysses* group, the history and host relationships of which can be gleaned from the following key. Two further references are Domrow (1979, 1981). In brief, four of the species (those with seta pl_2 added on genu IV, as often in *Haemolaelaps*) are from non-petaurid hosts, while the holotrichous four (those lacking pl_2) are all from petaurids. The latter four comprise two pairs, each pair from a non-gliding host and its gliding equivalent (Ride, 1970).

Terminology is after Evans and Till (1965), except for tarsi II-IV (Evans, 1969), the word 'holotrichous' referring to the setal condition in free-living dermanyssids. Measurements are in micrometres.

Genus *HAEMOLAELAPS* Berlese

Haemolaelaps Berlese, 1910: 261. Type-species *Laelaps (Haemolaelaps) marsupialis* Berlese.

Key to females of species of *ulysses* group, *Haemolaelaps*

1. Genu IV with seta pl_2 added (if pl_2 lacking, pd_3 also lacking). From non-petaurids 2
   Genu IV holotrichous (pd_3 present). From petaurids 5
2. Dorsal shield with setae z_3. Sternal shield with distinct cornua between coxae I-II. Metapodal shields enlarged. From *Rattus fuscipes* (Waterhouse) (Rodentia: Muridae) .... *laertes* Domrow, 1972a
   Dorsal shield lacking setae z_3. Sternal shield without exaggerated cornua. Metapodal shields normal 3
3. Dorsal shield with minute setae; holotrichous at J_4 (and elsewhere, except at z_3). From *Antechinus flavipes* (Waterhouse) and *A. stuartii* Macleay (Marsupialia: Dasyuridae) .... *telemachus* Domrow, 1964

Dorsal shield with normal setae; hypertrichous at J_4 (if holotrichous, both podonotal and opisthonotal portions markedly hypotrichous elsewhere) 4

4\. Palpal tibia holotrichous. Dorsal shield hypertrichous at J_4; podonotal portion holotrichous, except at z_3; opisthonotal portion with px_{2-3}. Genu IV with pl_2 added; tibia IV holotrichous. From *Trichosurus caninus* (Ogilby) (Marsupialia: Phalangeridae) .... *penelope* Domrow, 1964

Palpal tibia bideficient. Dorsal shield holotrichous at J_4; podonotal portion markedly hypotrichous; opisthonotal portion lacking px_{2-3}. Genu IV lacking pd_3; tibia IV lacking pd_3 and pl_2. From *Trichosurus vulpecula* (Kerr) (Marsupialia: Phalangeridae) .... *sisyphus,* n. sp.

5\. Dorsal shield with setae z_3 6

Dorsal shield lacking setae z_3 7

6\. Dorsal shield hypertrichous at J_4. Coxae II-III with seta *av* simple. From *Gymnobelideus leadbeateri* McCoy (Marsupialia: Petauridae) .... *anticlea* Domrow, 1972b

Dorsal shield holotrichous at J_4. Coxae II-III with seta *av* blade-like. From *Petaurus breviceps* Waterhouse and *P. norfolcensis* (Kerr) (Marsupialia: Petauridae) .... *calypso* Domrow, 1966

7\. Sternal shield with anterior margin eroded outside setae st_1. Terminal pair of ventral setae barely half as long as anal shield. From *Pseudocheirus peregrinus* (Boddaert) (Marsupialia: Petauridae) .... *ulysses* Domrow, 1961

Sternal shield with anterior margin not eroded outside setae st_1. Terminal pair of ventral setae as long as anal shield. From *Schoinobates volans* (Kerr) (Marsupialia: Petauridae) .... *ulixes* Domrow, 1972a

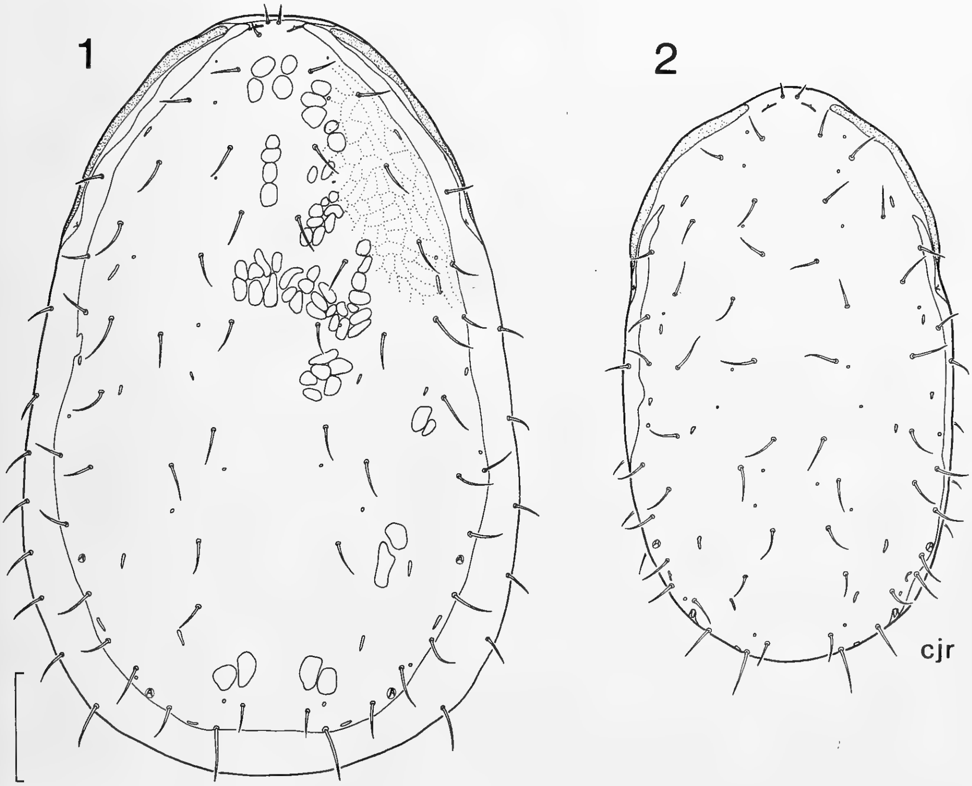
Haemolaelaps sisyphus, n. sp.

(Figs 1-14)

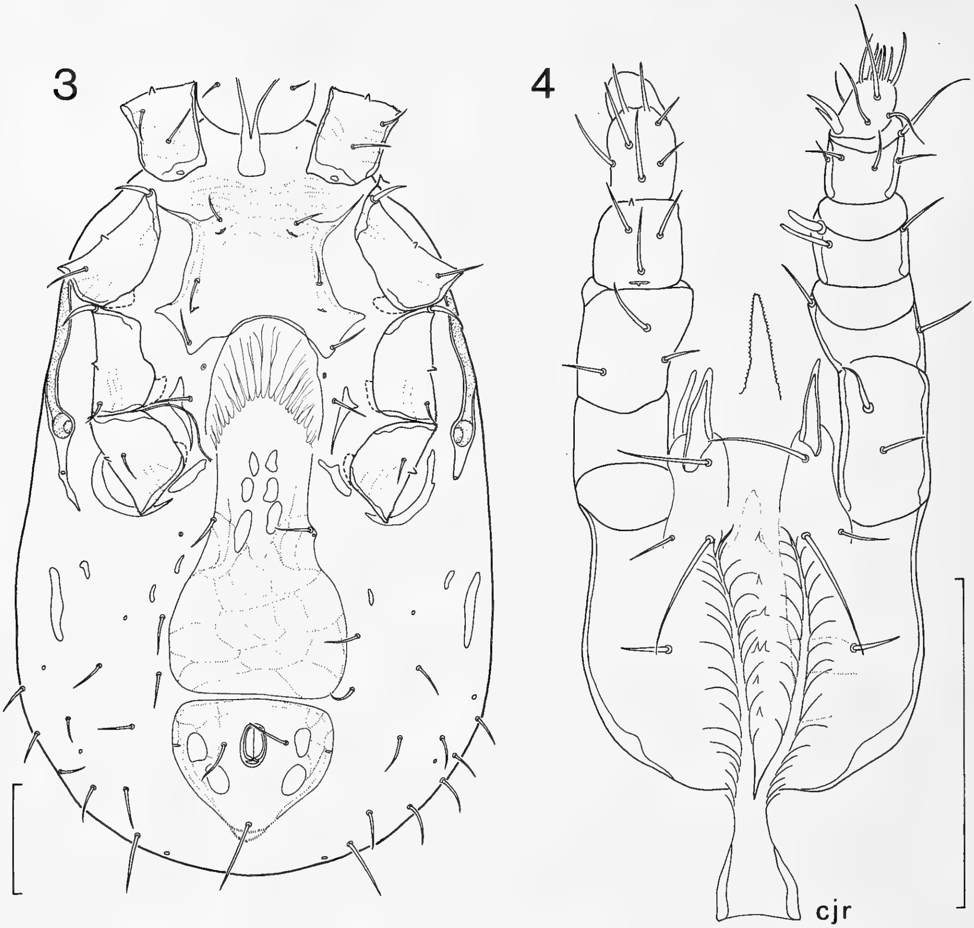
Material. Holotype ♀, allotype ♂, five paratype ♀♀ and two paratype ♂♂, nasal passages of a brush-tailed possum, *Trichosurus vulpecula* (Kerr) (Marsupialia: Phalangeridae), Timbillica State Forest, N.S.W., 26.iii.1979, D. M. Spratt and P. Haycock. Holotype, allotype and one paratype ♀ in Australian National Insect Collection, CSIRO, Canberra; remainder in my institute.

Female. Basis capituli (Fig. 4) slightly wider than long, with setae *c* short, failing to reach either deutosternum or sides of basis; deutosternal denticles six, mostly single (occasionally double, rarely triple). Hypostome with $h_3 > h_1 > h_2$, h_3 slightly exceeding sides of basis; cornicles well sclerotized; internal malae with ciliations almost as long as inner edge of cornicles, but not clearly seen; epipharynx spiculate; salivary stylets almost reaching tips of cornicles; anteromedial extension of subcheliceral shelf present (as it is in all members of group), short, hastate. Epistome (Fig. 8) reaching apices of palpal femora, pointed, with a few serrations and submarginal dendritic pattern. Palpal trochanter-genu holotrichous (2.5.6); trochanter with v_2 only slightly expanded basally; genu with al_{1-2} spatulate, dorsobasal pore present; tibia bideficient (12, including two dorsodistal rods); tarsus with a few slender ventral setae and terminal cluster of rods (figured diagrammatically), claw bifid. Chelicerae (Fig. 9) 190 long overall, with stout, strongly sclerotized shafts 35 in diameter (in dorsoventral view); basal segment 65 long; dorsal setule short (length not available because of refraction of light), not inflated basally, dorsal and external pores both present; coronal ciliations short; fixed digit with two denticles, divided tip and short, setiform pilus dentilis; movable digit 50 long, occupying 26% of overall length, with two denticles and simple tip.

Idiosoma a little broader posteriorly, but not expanded more than in Fig. 1 even when fed or gravid. Dorsal shield similarly wider posteriorly, 655-665 long, 385-405 wide (maximum); surface lightly reticulate, with paired muscle insertions and all 22 pairs of pores (lyriform behind setae j_1, distinctively sclerotized near Z_3 and S_5); podonotal portion hypotrichous, with 14 pairs of setae (excluding r_3, always present, but on cuticle) compared to usual 22 (i.e. $z_{1,3}$, s_{1-3} and $r_{2,4}$ lacking — actually, only on one side of one specimen, left-hand side of Fig. 1, is entire complement of 14 present; all other counts are 13 or 12, due to absence of j_2, right-hand side of Fig. 1, or z_6, or both); opisthonotal portion also hypotrichous, with 14 pairs, left-hand side of Fig. 1,



Figs 1-2. Haemolaelaps sisyphus, idiosoma, dorsal. 1. ♀. 2. ♂. (All scales = 100 μm).



Figs 3-4. Haemolaelaps sisyphus ♀. 3. Idiosoma, ventral. 4. Capitulum, ventral (true right palp dorsal).

compared to usual 17 (i.e. S_1 and px_{2-3} lacking; S_3 absent on one side of one specimen and J_4 on one side of another two, right-hand side of Fig. 1). Dorsal cuticle continuous posteriorly, with about eight pairs of setae (including r_3).

Tritosternal base unarmed (Fig. 3), laciniae well ciliated. Sternal shield 105-110 long in midline, 130-135 wide at setae st_2; anterior margin flatly convex, merged almost imperceptibly with presternal striae; posterior margin irregularly concave; surface reticulate only anterolaterally, with two pairs of lyriform pores; setae st_{1-3} short, subequal. Metasternal shields not taking in setae *mst* (of which one is absent on one side of four specimens) and associated pores. Genital shield 145-160 long behind setae *g*, 145-175 wide (maximum); expanded and sharply truncate behind coxae IV; surface reticulate, with paired muscle insertions and leaving genital pores free in cuticle (though not on right-hand side of Fig. 3); setae *g* short; operculum reaching over posterior margin of sternal shield, rayed and supported by apodemes between coxae IV; insemination apparatus visible only as pale, narrow adductor canals running in from between coxae III-IV. Anal shield 125-130 long (including cribrum), 140-145 wide, only narrowly separated from genital shield; surface reticulate, with paired muscle insertions and two pores on margin; anus set forward of centre, flanked by setae *aa* and followed by longer *pa*. Metapodal shields in two elongate elements, outer one much the larger. Ventral cuticle with one or two pairs of shieldlets flanking genital shield, some paired pores and about 11 pairs of setae of increasing length posteriorly (including two pairs flanking genital shield). Peritremes reaching forward almost to anterior margins of coxae I; peritrematal shields fused very narrowly to vertex of dorsal shield, with two narrow expansions (the more posterior with a pore) along dorsal margins and variably free posteriorly of crescentic exopodal shields IV.

Legs slender, but II a little thicker; holotrichous, with two exceptions: genu IV lacking pd_3, tibia IV lacking pd_3 and pl_2 (Figs 13-14). Seta *av* on coxae II-III somewhat expanded; ad_1 on femora I-IV strengthened and bifid at very tip, but other *d* setae on femora (and genua) undistinguished; pd_3 on tarsus IV not long and outstanding. Individual variations noted once (twice for genu IV) include unideficiencies: pd_3 on genu I, *av* on genua III-IV and ad_3 on tarsus IV; and doubled setae: ad_1 on femur III (anterior seta normal, bifid, posterior seta short, simple, each in its own alveolus) and pl_4 on tarsus IV (setae subequal, in contiguous alveoli). Dorsodistal sensory islet on tarsus I (Figs 11-12) including a forked seta and occupying 19% of length (of the seatae on this segment, four distals and two laterals are longer, and one middorsal long and outstanding, cf. *H.* n.sp. Domrow, 1981). Coxae II with anterodorsal process small; II-IV with posterointernal apodemes. All tarsi with stalked ambulacrum and two claws.

Male. As ♀, except as follows. Deutosternum at times with seven denticles. Seta v_2 on palpal trochanter not expanded basally. Chelicerae (Fig. 10) 165-170 long overall; setule, pores and corona not seen clearly; fixed and movable digits with one denticle and simple tip; spermatodactyl 55 long, occupying 32% of overall length, sharply upcurved at tip.

Dorsal shield fuller, 520-525 long, 280-290 wide (maximum); podonotal portion hypotrichous, with 14 pairs of setae (though not same 14 pairs as in ♀ since r_3, always present, is on shield, except on one side of one specimen, and z_6 is lacking — notwithstanding this, the regularity with which one or both z_6 are absent in ♀ suggests this signature will also be found in ♂ when more material becomes available) compared to usual 22 (actually, only on one side of two specimens is entire complement of 14 present; all other counts are 13 or 12, due to absence of j_2, left-hand side of Fig. 2, or j_2 and r_3 in one case or r_5 in another, right-hand side of Fig. 2); opisthonotal portion also hypotrichous, with 14 pairs compared to usual 17. Dorsal cuticle interrupted posteriorly, with about four setae to each side.

Holoventral shield (Fig. 5) with genital aperture on convex anterior margin; 445-450 long overall, 155-175 wide behind coxae IV where ventral portion is irregularly expanded to usurp two (in one case, Fig. 6, one plus an alveolar remnant too imperfect ever to have housed a seta) or three pairs of ventral setae (one specimen with one *mst* seta, another with both *mst* and one *g* absent, Fig. 7). Metapodal shields likewise irregular, the larger divided posteriorly on one side of one specimen. Ventral cuticle with about five pairs of setae of increasing length posteriorly. Peritrematal shields fused broadly, *via* more anterior of two expansions of their dorsal margins, to dorsal shield.

Individual variations in leg setation (all unideficiences) even more common than in ♀: *pl* on femur IV, *av* on genu III and av_2 on tibia I (all noted once); *av* on trochanter I and ad_3 on femur I (on same side of one specimen); and *av* on genu IV (on both sides of two specimens).

Etymology. Named after Sisyphus, said to have been Ulysses' father.

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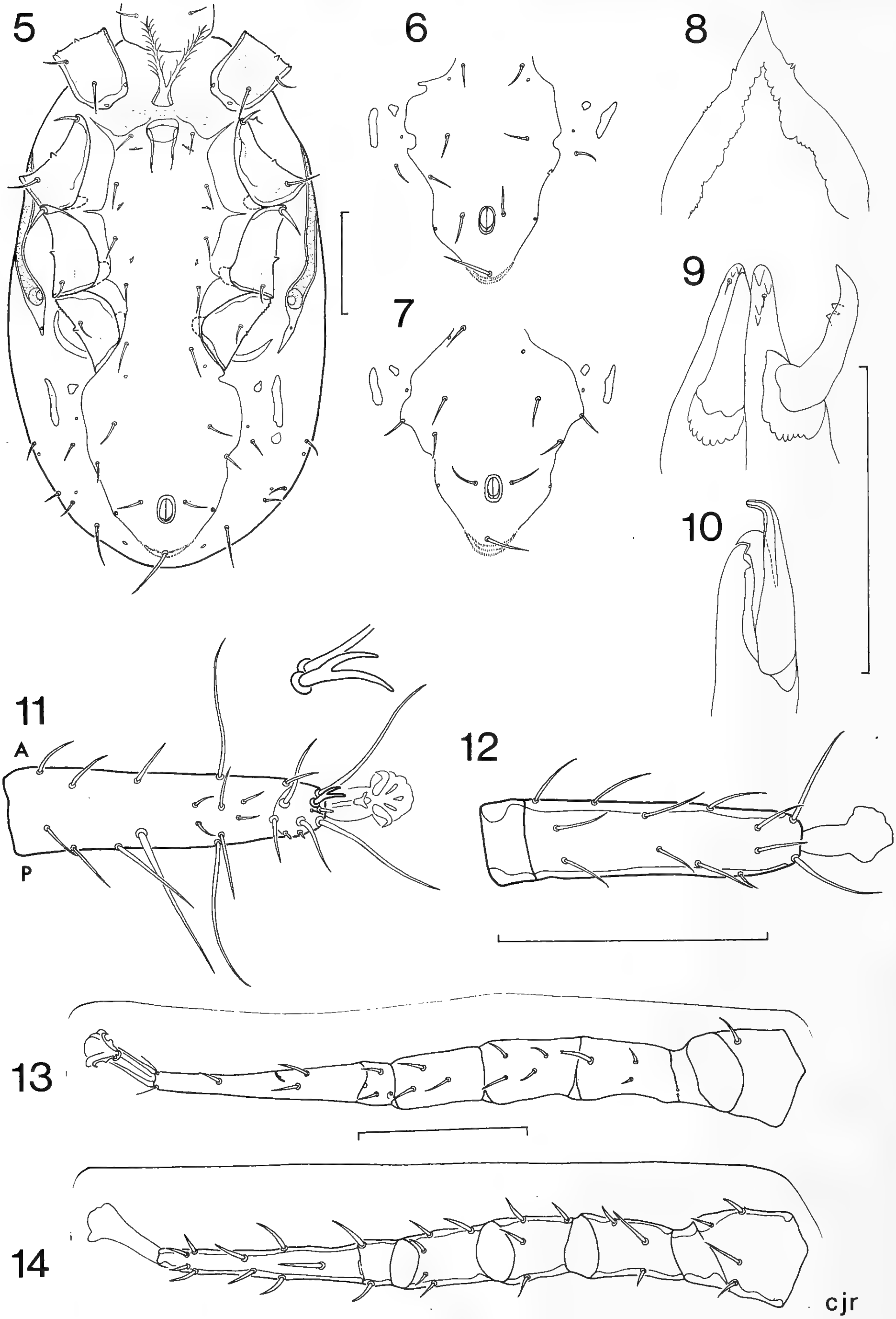

Figs 5-14. Haemolaelaps sisyphus. **5.** Idiosoma ♂, ventral. **6-7.** Variants of ventrianal portion of holoventral shield ♂. **8.** Epistome ♀. **9.** Cheliceral digits ♀, ventral. **10.** Cheliceral digits ♂, ventral. **11-12.** Trochanter-tarsus IV ♀, dorsal and ventral. **13-14.** Tarsus I ♀, dorsal and ventral.

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The Geology of the Bungonia District, New South Wales

P. F. CARR, B. G. JONES, A. J. KANTSLER, P. S. MOORE
and A. C. COOK.

CARR, P. F., JONES, B. G., KANTSLER, A. J., MOORE, P.S. & COOK, A. C. The geology of the Bungonia district, New South Wales. *Proc. Linn. Soc. N.S.W.* 104 (4), (1979) 1980:229-244.

Detailed geological mapping has provided stratigraphic and structural evidence for reinterpreting the geological history of the Bungonia area in the eastern Lachlan Fold Belt, New South Wales. The oldest rocks consist of a Late Ordovician distal flysch sequence (Tallong Beds) which shows isoclinal folding. The Tallong Beds are unconformably overlain by the Late Silurian shallow marine limestone — shale sequence of the Bungonia Limestone. Carbonate deposition ceased in the Late Silurian or Early Devonian when deposition of the Tangerang volcanics commenced. The latter sequence consists of lensoidal dacite flows interbedded with shallow marine volcaniclastic and tuffaceous sedimentary rocks. Emplacement of the southern part of the Marulan Batholith in the Early Devonian was probably coincident with a phase of broad folding. Erosional remnants of Permian and post-Permian sedimentary and volcanic rocks overlie parts of the older sequence.

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INTRODUCTION

The area mapped at Bungonia (Fig. 1) abuts the western margin of the southern Sydney Basin and includes a sequence of Ordovician to Devonian sedimentary and volcanic rocks. This sequence occurs in the eastern part of the Lachlan Fold Belt and has been intruded by the Marulan Batholith. Erosional remnants of younger sedimentary and volcanic rocks overlie part of the area.

The first detailed geological study of the Bungonia area was carried out by Woolnough (1909) and further references to the regional geology were made by Naylor (1935, 1936, 1939, 1950) and Garretty (1937). Aspects of the limestones were studied by Carne and Jones (1919), Pratt (1964), Ellis *et al.* (1972) and Pickett (1972), and descriptions of the Marulan Batholith were published by Osborne (1931, 1949) and Osborne and Lovering (1953). The district has been the subject of several unpublished honours theses.

The aim of the present study was to remap the area from Bungonia Gorge to Inverary Park (Fig. 1) to elucidate the stratigraphy, structure and tectonic development of the region.

TALLONG BEDS

Distribution and Petrography. The Ordovician Tallong Beds (Wass and Gould, 1969) are well exposed along the Shoalhaven River between Tallong and Bungonia, and form part of a much larger meridional belt of Ordovician rocks extending southwards to the coast between Bermagui and Tathra (Packham, 1969; Crook *et al.,* 1973).

In the Bungonia area, the Tallong Beds consist of micaceous, fine-grained, quartz-rich sandstone with shale, slate, siltstone, phyllite and chert interbeds (Table

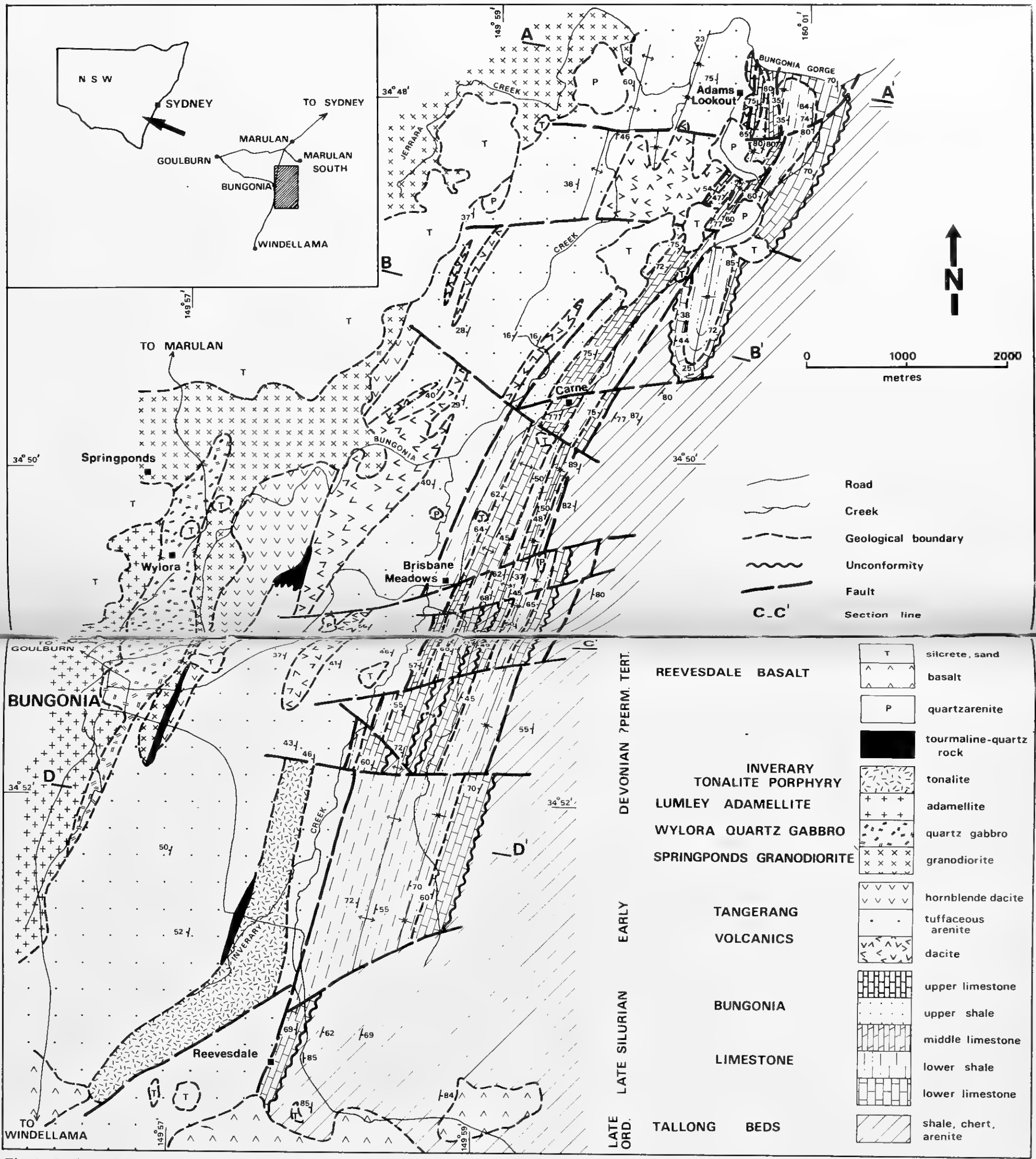

Fig. 1. Geology of the Bungonia area, New South Wales.

TABLE 1

Petrography of the Tallong Beds

Rock Type	Composition	Other Features
Quartz-rich arenite	Fine-grained, poorly to moderately sorted, immature sublitharenite. Quartz (to 80%), feldspar (0-5%), sandstone and chert rock fragments (7%), muscovite (0-5%); minor epidote, amphibole, biotite, chlorite; rare zircon, rutile, tourmaline and iron-titanium oxides. Framework grains subangular to subrounded. Matrix (5-20%) of sericite, clay, quartz and carbonaceous material. Minor quartz cement and secondary chlorite.	Most prominent in northeast. Massive to flat bedded. Symmetrical and asymmetrical ripples. Bouma sequences include erosional base, sole marks, load casts, flame structures, graded beds, ripple cross-beds and small slumps. Arenite interbedded with siltstone and shale in 0.1-1m units. Generally show medium to large scale isoclinal folds.
Carbonaceous shale and slate	Very fine-grained quartz, muscovite, chlorite, clay, pyrite (to 15%) and organic matter (>10%). Reflectivity of graptolites in the range $\bar{R}_o$max 8.35% to 10.01%.	Occur as interbeds in arenite or as massive shale with lenses of chert, siltstone and very fine grained sandstone. Abundant graptolites. Some small isoclinal folds.
Non-carbonaceous siltstone, shale, slate and phyllite	Well sorted siltstone with quartz (75-95%); minor sodic plagioclase, chert, muscovite; rare biotite, pyrite and hematite. Remaining lithologies very fine grained with quartz, sericite and clay. Slate and phyllite have mica and chlorite (to 30%) defining bedding plane cleavage.	Most prominent in south and east. Lithologies interbedded. Tops of Bouma sequences common. Ripple cross-beds. Some chert lenses. Show small and large scale isoclinal folds.
Chert	Microcrystalline quartz; minor sericite, clay; rare graphite and iron-titanium oxides.	Occurs as interbeds in sandstone and shale. Some secondary chert.

1). An axial plane cleavage is weakly to moderately developed. The stratigraphy of the Tallong Beds is poorly resolved because of faulting and isoclinal folding with meridional axes (Fig. 2).

Environment of Deposition. Sandy units in the Tallong Beds typically exhibit Bouma sequences and a variety of sedimentary structures characteristic of deposition from turbidity currents (Table 1). A thick, predominantly graded-bedded sandstone containing only minor argillaceous interbeds crops out in the northeast of the study area and is interpreted as proximal flysch. Sequences comprising thin alternations of sandstone and slate probably represent distal flysch, whereas the extensive, uniformly

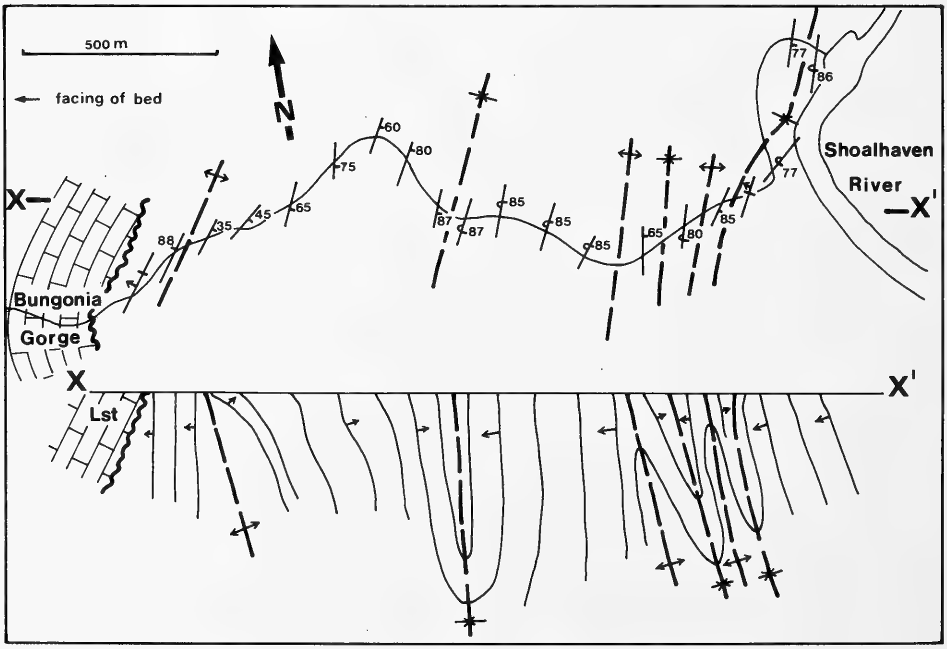

Fig. 2. Structure of Tallong Beds exposed along the lower portion of Bungonia Creek.

thin-bedded, black slate — chert association indicates deposition under moderately quiet water with reducing conditions at the sediment-water interface. A low initial Eh in the black slate facies would favour the preservation of abundant organic matter, including graptolites, and lead to the development of early diagenetic pyrite.

The quartz-rich arenite — slate — chert association conforms to the greywacke — slate suite of Packham (1969) and Unit B of Crook *et al.* (1973) and Scheibner (1973). The source of the sediment was to the south and southwest (current direction to 030° assuming simplest structural interpretation) and may have come from the Canberra-Molong Volcanic Rise and possibly a distant continental mass.

Fauna and Age. The carbonaceous black slates of the Tallong Beds contain graptolite faunas of Late Ordovician age (Sherrard 1949, 1954, 1962; Sherwin, 1972). Ten new Late Ordovician graptolite localities have been recorded in the Bungonia area but most of these have poorly preserved faunas because of surface weathering.

ORDOVICIAN-SILURIAN BOUNDARY

Considerable disagreement has existed over the nature of the boundary between the Tallong Beds and the overlying Bungonia Limestone. A marked angular discordance between the two formations in Bungonia Creek was described as an angular unconformity by Woolnough (1909) and Osborne (1949). However, Naylor (1950) attributed the angular discordance entirely to faulting and suggested that the Bungonia Limestone has a disconformable relationship with the Late Ordovician sequence. Gould (1966), Baker (1971) and Kantsler (1973) have indicated that the isoclinally folded Late Ordovician sequence was deformed at least once prior to the deposition of the Bungonia Limestone and have suggested a faulted contact. Counsell (1973) considered the boundary to be an unconformity and this has been confirmed by the present study.

The base of the Bungonia Limestone between Bungonia Gorge and the southern nose of the plunging syncline northeast of Carne (Fig. 1) is a sharply defined slightly undulating plane which shows no evidence of faulting. This syncline accounts for the very extensive limestone outcrops in the lower part of Bungonia Gorge. Rare clasts of shale from the Tallong Beds occur in the basal 2 m of the limestone just south of Bungonia Creek. Furthermore, the presence of Ordovician graptolitic shale in the core of a small anticline south of Brisbane Meadows is additional evidence for the unconformable nature of the basal contact. In the central part of the area (Fig. 1) the eastern contact of the Bungonia Limestone is faulted.

BUNGONIA LIMESTONE

The Bungonia Limestone was first described by Woolnough (1909), named by Carne and Jones (1919) and has subsequently been mentioned by several authors. It is subdivided here into five informal units (lower limestone, lower shale, middle limestone, upper shale and upper limestone) which are not of uniform lateral extent. The three limestone units are composed of five interdigitating lithotypes whereas the lower and upper shales are composed of four lithotypes (Table 2).

Lower Limestone. The lower limestone forms the basal unit of the formation except on the western limb of the syncline northeast of Carne where it is underlain by a thin lensoidal fossiliferous sandstone. The lower limestone varies in thickness from 280 m in the north and south, to 90 m northeast of Carne (Fig. 1). Either the original depositional surface was undulating or the transition from limestone to shale was controlled by localized terrigenous sediment input.

TABLE 2

Petrography of the Bungonia Limestone

Unit	Rock Type	Composition	Other features	Fauna
LOWER AND UPPER SHALE	Shale	Illite, chlorite; some sericite, muscovite, biotite, quartz, brown organic matter and fossil fragments. Some shale calcareous or siliceous. Reflectivity of organic matter in the range $\bar{R}_o$max 2.7% to 6.7%.	Poorly bedded.	Bryozoans, graptolites, trilobites, brachiopods, nautiloids, gastropods and crinoid ossicles.
	Siltstone	Quartz; minor feldspar; rare rock fragments, organic matter, pyrite, zircon, tourmaline and muscovite. Matrix of illite and chlorite. Some siltstone calcareous with fossil fragments.	Poorly to moderately bedded.	Crinoid ossicles.
	Sandstone-sublitharenite	Fine-grained and immature. Subrounded quartz; minor feldspar, chert and lithic fragments, muscovite, biotite, zircon and iron-titanium oxides. Matrix of sericite. Very minor calcite and quartz cement.	Laminated and ripple cross-bedded. Graded bedding.	Crinoid ossicles and corals.
	Chert	Microcrystalline quartz. Some silty chert.	Thin beds.	Crinoid ossicles, corals, brachiopods and bryozoans.
LOWER, MIDDLE AND UPPER LIMESTONE	Biosparudite	Rounded fossil fragments (to 35cm) and some angular to subangular limestone intraclasts (to 20cm). Clasts mainly 5-10cm. Minor detrital quartz and clay. Spar calcite cement.	Massive and biostromes.	Brachipods, crinoid ossicles, corals, stromatoporoids and stromatolites.
	Biosparite	Fossil fragments (approximately 15%) and rounded intraclasts <1mm (to 5%). Poorly washed. Spar calcite cement. No terrigenous material.	5-25cm thick beds interbedded with thin micritic layers.	Brachiopods, corals, crinoid ossicles and bryozoans.
	Biomicrite	Some fossil fragments and pellets. Micrite matrix (30-70%), locally recrystallized to microspar. Minor spar calcite cement. Terrigenous clay locally present.	Beds to 2m. Some fossils abraded. Most abundant lithology (40-70%) in lower and middle limestone.	Brachiopods, corals, stromatoporoids and crinoid ossicles. Some articulated brachiopods with geopetal structures.
	Fossiliferous micrite	Approximately 90-95% micrite. Minor fossil fragments (to 5%).	Thinly bedded, interbedded with biosparite.	Brachiopods, crinoid ossicles and bryozoans.
	Algal micrite	Alternating beds of micrite and carbonaceous micrite. Some clay on bedding planes.	Thin (<0.5mm) lenticular carbonaceous laminae.	
BASAL SAND-STONE	Sandstone-sublitharenite	Medium-grained quartz with some chert, phyllite, fossil fragments and muscovite. Immature to submature. Matrix of sericite, clay and minor calcite.	Poorly bedded.	Crinoid ossicles and brachiopods.

North of Brisbane Meadows the lower limestone contains a prominent basal conglomerate with variable proportions of angular intraclasts and abundant rounded fossil fragments. This basal biosparudite is overlain and replaced laterally by biosparites which show progressively fewer signs of reworking at stratigraphically higher levels. The basal lower limestone is characterized by the presence of large pentamerid brachiopods. Bryozoans, crinoids and corals become more abundant, brachiopods smaller and stromatolites less common from the base to the top of the unit. Also the limestone becomes more micritic, less fossiliferous and darker towards the top. Thinly interbedded micrite and biosparite occur higher in the sequence and pass upwards into wavy laminated algal limestone with thin lenses of marl.

Lower Shale. The thickness of the lower shale varies from 300 m in the northern and southern portions of the study area to 120 m around Carne and Brisbane Meadows (Fig. 1). North of Brisbane Meadows, the lower shale is sparsely fossiliferous (mainly crinoid ossicles). It includes a basal marl overlain by poorly to moderately bedded siltstone and very fine-grained sandstone which passes into thinly bedded siliceous shale. Thin (<20 cm) interbeds of graded sandstone containing angular clasts (up to 5 cm) of shale, limestone and fossil fragments, occur within the siliceous shale near the top of the unit.

The poorly bedded lower shale east and south of Brisbane Meadows contains minor siltstone and chert, and several faunal assemblages including brachiopods, trilobites, graptolites, gastropods, nautiloids and crinoids (Moore, 1976; Carr *et al.*, 1980).

A thin (20 cm) fossiliferous chert occurring 20 to 50 m above the base of the lower shale in the southern part of the area and in the syncline northeast of Carne is a useful marker horizon.

Middle Limestone. The middle limestone is thickest (250 m) around Carne and thins northwards to about 110 m and southwards to 60 m. North of Carne, the unit is composed of massive fossiliferous micrite with some biosparite, marl and shale interbeds. The base of the limestone is characterized by an abundance of corals and bryozoans; the middle by crinoids, bryozoans, corals, brachiopods and stromatoporoids whereas the upper part is dominated by bryozoans and stromatolites. Bioturbation and geopetal structures are present throughout.

South of Carne, the middle limestone has well-developed flaggy bedding with biomicrite and biosparite interbedded with micrite and fossiliferous micrite. Small lenses of biosparudite are also present. Fossils include corals, brachiopods, crinoids and bryozoans. Burrowing is evident in some of the micritic limestone and thinly laminated algal micrite is also present, especially towards the top of the unit.

Upper Shale. The upper shale varies from 50 m to 110 m thick and is only recognized in the northern part of the study area (Fig. 1). The sequence is composed of poorly bedded calcareous, siliceous and sandy shale, siltstone, chert and very fine-grained sandstone. Fossils are generally more common than in the lower shale although their distribution is sporadic. The fauna comprises fenestellid bryozoans, crinoids, brachiopods (including lingulids), bivalves, trilobites and corals.

Upper Limestone. The upper limestone occurs only in the northern part of the district (Fig. 1) and its thickness decreases southwards from 100 m to 50 m. The limestone consists of moderately bedded, sparsely fossiliferous micrite with interbeds of finely laminated algal micrite and lenses of calcareous and siliceous siltstone.

Environment of Deposition. The Bungonia Limestone is a shallow water sequence of biostromal limestone and marine shale deposited on the southern extension of the Capertee Rise. The thickest sequence occurs near Bungonia Gorge. Southwards the formation becomes thinner and more shaly.

In the lower limestone the presence of biosparudite with randomly oriented fragmented fossils indicates wave-induced erosion of a slightly elevated biostrome. A decrease in the amount of reworking in laterally equivalent and stratigraphically higher horizons is indicated by an increase in the abundance of lime-mud. Thick beds of micrite indicate a lack of current activity and imply a rapid rate of precipitation of the carbonate ooze.

The lateral and vertical alternation of high and low energy facies probably represents fluctuations from biostromal shoal to marine lagoonal environments. Restricted circulation in such marine lagoons (Youngs, 1978) leads to poor oxygenation, thereby severely retarding the growth of biostromes, and inducing the deposition of dark micritic limestone.

Wavy-laminated algal limestone with rare domal stromatolites, and micritic limestone rich in stromatoporoids are present in the south. A quiet subtidal environment of deposition is envisaged as the flat-lying algal mats show no sign of desiccation or brecciation (cf. Moore, 1979).

The limestone units pass laterally and vertically into poorly bedded, calcareous and fossiliferous shale. The association of lingulid brachiopods with bryozoans and trilobites in the shale units suggests a shallow water, marine environment. Preservation of graptolites implies a calm environment of deposition. The widespread chert bed may represent a period of very slow deposition on a current swept sea floor. Other evidence of periodic current activity is provided by the presence of thin sandy lenses and concentrations of crinoid ossicles on bedding planes. Graded sandstone beds near the top of the lower shale represent thin proximal turbidite deposits which accumulated in the relatively shallow water depositional basin.

Age. The faunal assemblage in the lower shale indicates that the lower part of the

TABLE 3

Petrography of the Tangerang volcanics

Unit	Rock Type	Composition	Other features
SEDIMENTARY UNITS	Crystal tuff	Coarse- to very coarse-grained (to 5mm), poorly sorted and immature. Very angular to subangular quartz, plagioclase (andesine), iron-titanium oxides; minor chert and volcanic fragments. Chert and chlorite matrix. Secondary sericite, chlorite, clay and calcite.	Poorly to massive bedded. Few thin graded beds. Rare solitary corals and crinoid ossicles.
	Coarse arenite (arkose to feldspathic litharenite)	Very coarse- to medium-grained, very poorly sorted and immature. Angular to subangular quartz (volcanic origin, to 5mm), plagioclase (andesine, 12-47%) fresh and altered to sericite; chlorite, epidote and calcite. Angular intraclasts to 10cm, few granules and pebbles—volcanic fragments (devitrified to chlorite and chert), dacite; few quartz sandstone, quartzite and siltstone. Accessory ilmenite, leucoxene and zircon. Matrix of chert, chlorite, sericite and clay. Cement includes quartz, calcite, secondary amphibole and pyrite.	Dominant lithology in north. Poorly to massive bedded. Some chert breccia. Thin lensoidal conglomerate layers. Rare crinoid ossicles. Calcite cement most abundant in north.
	Fine arenite (quartzarenite, sublitharenite and litharenite)	Poorly to moderately sorted and immature. Very angular to well rounded quartz and minor weathered feldspar (<5%). Rock fragments include siltstone, shale, chert and dacite. Accessory iron-titanium oxides, zircon, tourmaline, anatase and sphene. Matrix of sericite, clay; minor chert and calcite. Cements include quartz and rare calcite especially in the north.	Most abundant lithology in south (approximately 75%). Flat laminated to lenticular beds. Small to medium tabular and trough cross-beds mainly <15cm, few to 1m. Small slumps. Cut and fill structures. Some chert and shale interbeds. Rare bryozoans, corals and crinoid ossicles.
	Chert and shale	Very fine-grained chert, chloritic chert and shale. Shales include detrital quartz, mica and clay.	Thin beds. Massive to poorly bedded, some with undulose laminae. Cherty shale more abundant in south and at top of formation.
EASTERN DACITES	Porphyritic dacite	Phenocrysts of embayed quartz and greenish plagioclase (An_{50-45}). Very fine-grained groundmass of quartz, plagioclase, K-feldspar and minor hornblende, biotite, hypersthene and iron-titanium oxides.	Extensively altered — devitrification of volcanic glass gives abundant chlorite, sericite and kaolinite.
WESTERN HORNBLENDE DACITE	Porphyritic hornblende dacite	Phenocrysts of embayed quartz, hornblende, plagioclase (An_{52-47}) and hypersthene. Groundmass and accessories as above.	As above.

Bungonia Limestone is Late Ludlovian (Carr *et al.*, 1980), which is in agreement with earlier age determinations by Pickett (1967, 1972).

BUNGONIA LIMESTONE-TANGERANG VOLCANICS BOUNDARY

The boundary between the Bungonia Limestone and the Tangerang volcanics is not exposed in the study area. Although the limestone and volcanics have similar dips, the contact between the units south of Adams Lookout is probably faulted since the basal unit of the Tangerang volcanics overlies several different units of the Bungonia Limestone (Fig. 1). In the Marulan South area the equivalent boundary is considered conformable (Wass and Gould, 1969).

TANGERANG VOLCANICS

The sequence of igneous and volcanogenic sedimentary rocks which overlies the Bungonia Limestone can be equated with the Tangerang volcanics (Wass and Gould, 1969) in the Marulan South region. In the Bungonia area these rocks can be subdivided into (i) the eastern dacites which are interbedded with tuff, tuffaceous to quartzose arenite and shale; and (ii) the western hornblende dacite.

Eastern Dacites. The eastern dacites (Table 3) crop out as elongate lenses parallel to the regional strike in the central and northern parts of the study area.

Sedimentary rocks interbedded with the eastern dacites show a wide range in grain-size and mineralogical composition but characteristically contain angular grains of plagioclase, β-quartz and volcanic rock fragments in a chloritic and cherty matrix. The rocks are texturally and mineralogically immature and the mineralogical composition is strongly grain-size dependent. They grade from very coarse-grained, poorly-sorted crystal tuff and tuffaceous sandstone to well-sorted, fine-grained quartz-rich arenite with minor cherty shale (Table 3, Fig. 3). The arenite tends to become finer and more quartz-rich towards the south.

Western Hornblende Dacite. The hornblende dacite (Table 3) of the Tangerang

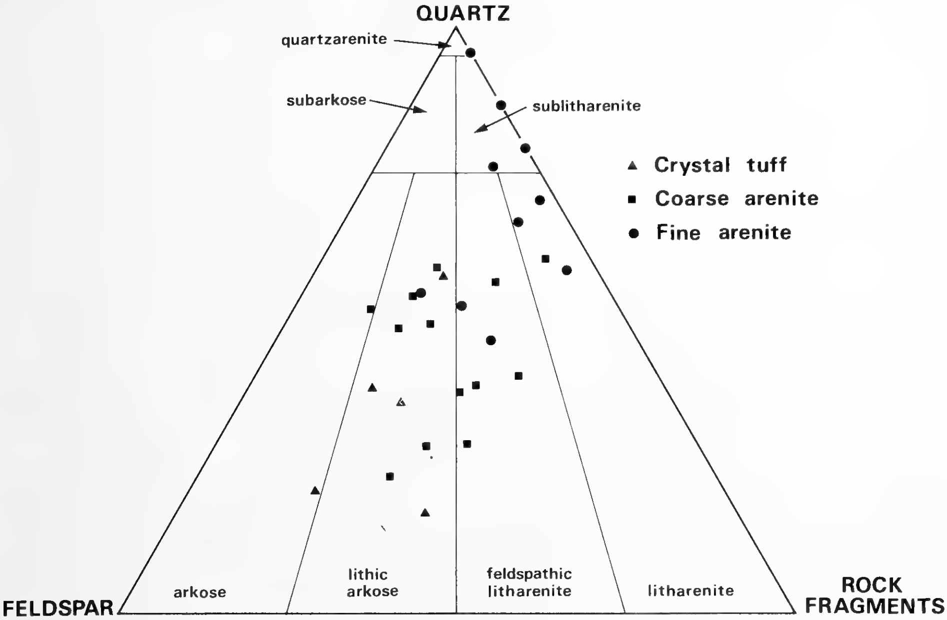

Fig. 3. Mineralogical composition and classification of sedimentary units of the Tangerang volcanics.

volcanics is restricted to the central-western portion of the study area (Fig. 1).

Thickness. Preserved thicknesses of the Tangerang volcanics in the Bungonia area vary from 450 m in the north to 1600 m in the south. The original thickness is indeterminate because the western margin of the formation is an intrusive contact with the Marulan Batholith.

Mode of Emplacement of Igneous Rocks. The dacites and hornblende dacite within the Tangerang volcanics are considered extrusive in origin. The reasons are as follows:

(i) the eastern dacites occur as a series of lensoidal bodies parallel to the regional strike;

(ii) there is no evidence of contact metamorphism along the margins of the igneous rocks;

(iii) possible pillow structures occur at the base of a thin dacite north of Carne;

(iv) microscopic flow-layering is present in some dacites;

(v) β-quartz occurs in all units;

(vi) the dacites are interbedded with tuff and tuffaceous sedimentary units; and

(vii) some of the very fine-grained cherty groundmass of the sedimentary rocks probably originated from devitrification of volcanic glass.

Fauna and Age. Sporadic occurrences of crinoid ossicles, bryozoans and solitary corals have been found in sedimentary units in the lower and middle parts of the Tangerang volcanics but the poorly preserved fossils do not permit an accurate age determination. In the Bungonia area, the Tangerang volcanics are Early Devonian (possibly latest Silurian) in age based on faunas from the Bungonia Limestone and K-Ar dating of the southern part of the Marulan Batholith (Carr *et al.*, 1980).

Environment of Deposition. The Tangerang volcanics represent an accumulation of shallow marine, flat- and cross-bedded arenite interbedded with submarine dacitic lavas and associated pyroclastic rocks. Devitrification of volcanic glass and primary precipitation of silica from marine waters supersaturated by volcanic emanations could account for the high proportion of chert in much of the tuffaceous arenite.

A dacitic volcanic source must have been located to the north of Bungonia since the proportion of dacite and volcanic detritus in the Tangerang volcanics decreases south of the township. At the same time a sedimentary source, probably an exposed block of the Tallong Beds, was contributing fine-grained quartzose detritus to the depositional area.

MARULAN BATHOLITH

The Marulan Batholith is a composite body which crops out east and northeast of Goulburn and includes granite, granodiorite, contaminated and hybrid rocks (Woolnough, 1909; Osborne, 1949; Osborne and Lovering, 1953). O'Reilly (1972) considered that the 'hybrid zones' of Osborne and Lovering (1953) correspond to zones of progressive metamorphism of silicic volcanics intruded by magmas forming the batholith complex. Four separate phases of the batholith have been mapped in the Bungonia area (Fig. 1) and K-Ar dating of three of these phases indicates an Early Devonian age of emplacement (Carr *et al.,* 1980).

Springponds Granodiorite (new name). The Springponds Granodiorite crops out extensively in the Bungonia area and is named after the property Springponds (type locality GR701407 — Bungonia 1:25,000 Topographic Sheet).

The rock is holocrystalline, medium- to coarse-grained with a hypidiomorphic granular texture. It contains plagioclase, K-feldspar, quartz, hornblende, biotite and iron-titanium oxides with minor amounts of diopside, hypersthene, chlorite, uralite, prehnite, epidote, apatite, zircon and kaolinite. Plagioclase shows normal and oscillatory zoning from andesine (An_{48}) to oligoclase (An_{22}). The K-feldspar is perthitic and extensively kaolinized.

Wylora Quartz Gabbro (new name). The Wylora Quartz Gabbro has an elongate outcrop to the north and east of Bungonia township and is named after the property Wylora (type locality GR695394 — Bungonia 1: 25,000 Topographic Sheet).

The quartz gabbro is a holocrystalline, medium- to coarse-grained rock with a hypidiomorphic granular texture. Plagioclase, augite, biotite, hornblende, hypersthene, iron-titanium oxides, interstitial quartz and accessory apatite occur in addition to traces of K-feldspar, sericite, carbonate, fibrous amphibole, prehnite and pyrite. The plagioclase shows normal and oscillatory zoning from cores of bytownite (An_{87}) to rims of labradorite (An_{53}).

Lumley Adamellite (new name). The Lumley Adamellite crops out to the south and west of the township of Bungonia and is named after Lumley Creek (type locality GR689385 — Bungonia 1: 25,000 Topographic Sheet).

The adamellite is holocrystalline, medium- to coarse-grained with an allotriomorphic granular texture. Primary minerals are K-feldspar, plagioclase, quartz, biotite, hornblende, apatite, zircon, sphene and iron-titanium oxides. Alteration has produced chlorite, sericite, epidote and prehnite. The K-feldspar is microperthite and the plagioclase is zoned from andesine (An_{35}) to oligoclase (An_{23}).

Inverary Tonalite (new name). Brunker and Offenberg (1968) mapped a number of porphyritic tonalite intrusions on the southeastern portion of the Goulburn 1: 250,000 Geological Sheet. The northernmost tonalite intrusion crops out southeast of Bungonia and is dissected by and named after Inverary Creek (type locality GR711380 — Bungonia 1: 25,000 topographic Sheet).

The eastern contact between the intrusion and the Tangerang volcanics is sharp and dips towards the west at approximately 45° (Fig. 4D). The tonalite is holocrystalline and porphyritic with phenocrysts of plagioclase and subordinate hornblende, biotite and quartz in a fine-grained groundmass of plagioclase, quartz, biotite, hornblende, iron-titanium oxides and minor apatite and zircon. Extensive secondary alteration has produced chlorite, sericite, sphene and leucoxene.

Tourmaline-Quartz Rock. Three separate outcrops of tourmaline-quartz rock have been mapped in the Tangerang volcanics (Fig. 1). Two of the outcrops occur at the margins of intrusions whereas the northern outcrop does not have any obvious field relationship with intrusions. The rocks consist of fine-grained ferrian tourmaline and quartz with minor secondary hematite.

CONTACT METAMORPHISM

The Marulan Batholith has produced a narrow (<200 m) aureole within the Tangerang volcanics which is recognized by a slight recrystallization of the dacite groundmass. Contact metamorphism has produced the mineral assemblage albite-epidote-chlorite-actinolite typical of the albite-epidote hornfels facies. At some localities within 10 m of the intrusions the metamorphic grade reaches the hornblende hornfels facies. O'Reilly (1972) has described similar grades of contact metamorphism of silicic volcanic and associated sedimentary rocks around the Marulan Batholith in an area 15 km northwest of Marulan.

METAMORPHISM OF ORGANIC COMPONENTS

Reflectance measurements on coalified graptolites from the Tallong Beds in Bungonia Creek (Table 1) indicate a metamorphic grade equivalent to the lower greenschist facies (chlorite zone). In contrast, vitrinite-like organic matter from the lower shale of the Bungonia Limestone (Table 2) is considered to represent a regional metamorphic grade equivalent to the upper zeolite facies. The differences in metamorphic grade between the Tallong Beds and the Bungonia Limestone could indicate that the Tallong Beds underwent low grade regional metamorphism prior to the deposition of the Bungonia Limestone. Alternatively the Tallong Beds may have been affected by contact metamorphism from a buried intrusion of the Marulan Batholith, although there is no evidence of this in the topographically equivalent portion of the Bungonia Limestone.

?PERMIAN SEDIMENTARY ROCKS

Small outliers of ?Permian quartzarenite unconformably overlie the Bungonia Limestone and Tangerang volcanics and are commonly silicified or ferruginized. Some are cross-stratified (mean foreset azimuth to 340°). The arenite is typically medium- to coarse-grained, poorly sorted and consists of subangular to rounded quartz, lithic chert and rare sericitized K-feldspar, iron-titanium oxides and zircon. Quartz overgrowths and chert cement are present. Some of the arenite contains subrounded to well-rounded pebbles of quartz and quartzite. These outliers are tentatively correlated with the Permian sequence of the Sydney Basin. They are lithologically similar to a fossiliferous Permian outlier at Marulan South described by Wass and Gould (1969).

REEVESDALE BASALT *(new name)*

The northernmost flow of the Late Eocene Nerriga Province (Wellman and McDougall, 1974) crops out to the south of Bungonia (Fig. 1) and is named after the property Reevesdale (type locality GR720336 — Bungonia 1: 25,000 Topographic Sheet). Maximum thickness is approximately 8 m but the original thickness and extent are unknown. The rock is an alkali olivine basalt consisting of a fine- to medium-grained assemblage of plagioclase (An_{62-48}), olivine, titaniferous augite, iron-titanium oxides and accessory apatite.

DYKES

Numerous basalt and dolerite dykes occur in the Bungonia area but are too thin to be shown in Fig. 1. The dykes are medium- to fine-grained, have an ophitic texture and consist of plagioclase (An_{65-60}), titaniferous augite, serpentine pseudomorphs after olivine, iron-titanium oxides and minor apatite. The rocks are extensively altered with the development of abundant serpentine, calcite and chlorite. The age of the dykes is uncertain but their emplacement may be related to the extrusion of the Eocene Reevesdale Basalt.

TERTIARY SEDIMENTARY ROCKS

Poorly-consolidated quartz sandstone and minor conglomerate occur sporadically beneath the Reevesdale Basalt. The age of most other surficial sediments cannot be defined except for the occurrence of *Cinnamomum* spp. leaves (Tertiary) in a ferruginous sandstone southeast of Adams Lookout (Pratt, 1964). Only the major ?Tertiary deposits are shown in Figure 1 and they consist of poorly-consolidated sand, gravel, ferruginous shale and manganiferous grit.

PEDOGENIC DEPOSITS

(i) Ferruginous surficial deposits, laterite and ferricrete occur as isolated patches over much of the study area. Iron (and manganese) oxides replace the matrix and minerals of the host rock to a variable degree. Ferruginous shale breccias also occur, especially along fault planes.

(ii) Deep red bauxite with a pisolitic texture formed by intense weathering of the Eocene basalt in the Reevesdale area.

(iii) Silcrete occurs on many low hills and ridges throughout the area. It consists of angular to rounded quartz grains with pitted or etched grain boundaries set in a cherty matrix. The silcrete is underlain by a pallid or mottled zone which suggests an origin due to deep weathering (cf. Hutton *et al.,* 1972). The silcrete in this area has been described in detail by Callander (1978).

(iv) Kaolinite deposits of variable quality occur beneath the silcrete.

STRUCTURAL HISTORY

Schematic geological cross-sections which show the major structural features of the Bungonia area are given in Figure 4.

Folding. Two scales of folding have been recognized in the Tallong Beds. Large scale isoclinal folds (F_1) have been mapped in the almost continuous exposures along the lower reaches of Bungonia Creek (Fig. 2). Shale which occurs between the more competent sandstone and chert units shows medium- to small-scale isoclinal folding. These smaller folds are generally not persistent along strike and the fold axes plunge gently (approx. 15°) towards the north-northeast. The shale beds show crenulation cleavage and a marked thickening in many of the fold hinges. Axial planes of the smaller folds have similar orientations to those of the larger folds, suggesting that all these folds were produced concurrently.

Open, gently-plunging concentric folds (F_2) occur in the Bungonia Limestone and the northeastern part of the Tangerang volcanics (Figs 1 and 4). The limestone beds and the Tangerang volcanics act as competent units whereas the interbedded shale is more deformed, shows the development of a weak bedding-plane cleavage and thickening along fold hinges. The meridional F_2 axial planes dip east at approximately 70°. The Tangerang volcanics south of Carne show consistent westerly dips between 35° and 55°.

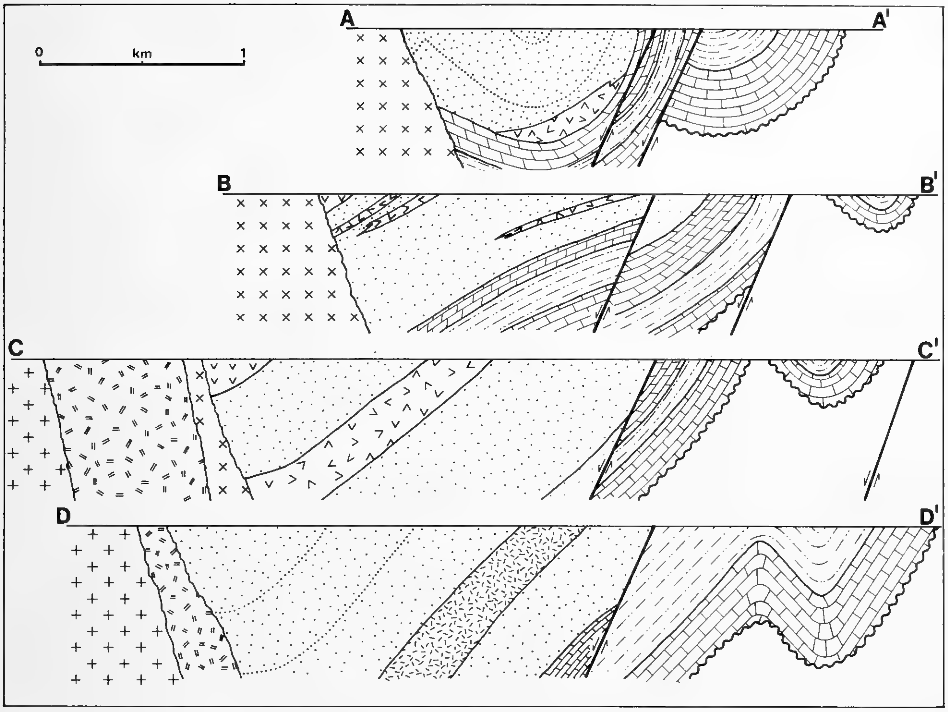

Fig. 4. Idealized geological sections for the Bungonia region. Locations of sections are indicated on Fig. 1.

Between the eastern edge of the Bungonia Limestone and the Shoalhaven River, the mesoscopic F_1 folds in the Tallong Beds are generally symmetrical with almost vertical axial planes, whereas east of the river they become asymmetrical with axial planes dipping at a moderate angle to the east (Baker, 1971). Thus, the Tallong Beds in the study area could represent the eastern limb of a broad F_2 syncline.

Late Devonian strata which crop out about 1 km west of the study area in Lumley Creek and near Oak Valley homestead dip at approximately 15° to 20° towards the west and unconformably overlie more steeply dipping Early Devonian rocks. This post-Devonian tilting could explain the steep easterly dips of the F_2 axial planes.

Faulting. The Bungonia Limestone is cut by two major normal strike faults which both dip 65° to 70° west (Figs 1 and 4). These faults are exposed in Bungonia Gorge as 1 to 3 m wide crush zones. The eastern fault is clearly recognizable from the northern side of Bungonia Gorge by a 30° discordance in dip within the Bungonia Limestone. The strike faults were later cut by a series of oblique faults which show lateral, vertical and slight rotational movement. Only the major faults are indicated in Figure 1.

DISCUSSION

During the Late Ordovician deep marine, quartz-greywacke distal flysch spread throughout the southern Lachlan Geosyncline south and east of Yass (unit B of Crook *et al.*, 1973). The Tallong Beds at Bungonia form a northward extension of this facies and accumulated on the Monaro Slope and Basin near the subduction zone on the eastern edge of the Lachlan Pre-Cratonic Province. The F_1 fold style in the Bungonia area is similar to the isoclinal recumbent folding produced by the Benambran Orogeny in the southeastern part of the Lachlan Fold Belt (Late Bolindian to Late

Llandoverian; Stauffer and Rickard, 1966; Crook *et al.,* 1973). At the time of deposition of the basal part of the Bungonia Limestone (Late Silurian) the axial planes of the F_1 folds probably dipped towards the west at 30°.

The Bungonia region remained deeply submerged after the Benambran Orogeny. Early Silurian graptolitic distal flysch strata (Jerrara Series of Naylor, 1935; 1936; 1950) 6 km west of Bungonia appear to be faulted against the Late Ordovician sequence. The Early Silurian strata show upright isoclinal folding (Naylor, 1936) probably resulting from the Wenlockian Quidongan Orogeny (Crook *et al.,* 1973) but there is no evidence of this fold style at Bungonia. The Quidongan Orogeny encompassed a major period of uplift in the Quidong-Canberra region (Crook *et al.,* 1973) which is extended to the Bungonia area to account for the change from distal flysch facies in the Early Silurian to a shallow marine environment in the Late Silurian. The Quidongan Orogeny also led to the formation of the Capertee Rise and the Hill End Trough by splitting off from the Molong Volcanic Rise (Scheibner, 1973). Deformation and uplift of Late Ordovician (Powell and Fergusson, 1979) and Late Ordovician to Early Silurian (Powell *et al.,* 1976) sequences prior to Late Silurian deposition has also been recognized in the Cookbundoon Syncline 60 km northwest of Bungonia.

The southern part of the Capertee Rise was submerged during the Late Ludlovian and the shallow marine Bungonia Limestone was deposited unconformably on the Tallong Beds. Limestone deposition alternated with periods of greater input of fine-grained clastic detritus and was terminated by eruption of calc-alkaline acid volcanics on the Bungonia portion of the Capertee Volcanic Arch in the earliest Devonian or latest Silurian (Carr *et al.,* 1980). Volcanic activity was presumably related to the high level intrusion of orogenic granitic rocks. Scheibner (1973) implied that these magmas were associated with a zone of secondary subduction. The phase of F_2 folding almost certainly accompanied the east-west compression associated with the intrusion of the southern part of the Marulan Batholith in the Early Devonian and is therefore associated with the Bowning Orogeny. At the close of this phase of folding, the axial planes of the F_1 folds probably would have dipped west at a high angle (about 75°).

Northwest of Bungonia in the Murruin Creek area of the Cookbundoon Syncline, Powell *et al.* (1976, figs 4 and 5) have noted a low angle unconformity between Late Silurian strata and Early to ?Middle Devonian sandstone and conglomerate. Further south in the Taralga area a post-Late Silurian pre-Late Devonian fold episode produced upright open folds (Powell and Fergusson, 1979, fig. 7). The folding in the latter area is similar in style to the phase of F_2 folding at Bungonia and could therefore be related to the Early Devonian Bowning Orogeny rather than a Middle Devonian event as suggested by Powell and Fergusson (1979).

The age of the faulting in the Bungonia area is difficult to ascertain but at least some of the faults are younger than the F_2 folding and may be related to a tensional phase of the Bowning Orogeny. Most of the oblique faults post-date the strike faults.

The effects of the Bowning Orogeny increase in intensity south and west of the Bungonia area towards Wyangala, Breadalbane, Tarago and Bowning (Packham, 1969, 1978). The Ordovician to middle-Early Devonian stratigraphic succession and deformational history of the Tarago area (Felton and Huleatt, 1977; Gilligan *et al.,* 1979) is similar to that of the Bungonia area some 70 km to the northeast although the open fold style produced during the Bowning Orogeny at Tarago has an associated axial plane slaty cleavage.

Cratonization of the Lachlan Fold Belt occurred during the Mid-Devonian Tabberabberan Orogeny (Scheibner, 1973) but there is little or no evidence of this orogenic episode in the Bungonia area. From studies in the northeastern part of the Lachlan Fold Belt, Powell and Edgecombe (1978) concluded that uplift, tilting and erosion occurred during the Middle Devonian but that there was no evidence of an intense orogenic episode beneath the Late Devonian Lambie and Catombal Groups.

The Bungonia region was covered by shallow marine and terrestrial sediments of the Late Devonian Lambian Transitional Province. The folding of these beds must have occurred between the latest Devonian and Middle Permian and is probably related to the Carboniferous Kanimblan Orogeny.

The sequence of deformational events recorded at Bungonia therefore can be related to the widespread orogenic episodes recognized in the southeastern Lachlan Fold Belt (e.g. Packham, 1969, 1978). The intrusion of the Early Devonian Marulan Batholith across the F_2 fold structures in the Late Silurian to earliest Devonian strata precludes the possibility that all the deformation occurred as a single latest Devonian to Early Carboniferous regional deformational phase as suggested by Powell *et al.* (1976).

Remnants of flat-lying Middle Permian (Wass and Gould, 1969) Sydney Basin sedimentary rocks and Cainozoic volcanic rocks, sediments and pedogenic deposits complete the regional history.

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New Records of Zygnemaphyceae and Oedogoniophyceae (Chlorophyta) from northern New South Wales

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SKINNER, S. New records of Zygnemaphyceae and Oedogoniophyceae (Chlorophyta) from northern New South Wales. *Proc. Linn. Soc. N.S.W.* 104 (4), (1979) 1980:245-263.

Records are given of 70 taxa from the Zygnemaphyceae and 9 taxa, including a new species *Oedogonium wissmanii* sp. nov., from the Oedogoniophyceae from collections of freshwater algae made in 1974. Most collections were made in the New England Tableland with two from the Clarence River Valley. They constitute the first report on the algal flora of northeastern New South Wales since Playfair's (1914, 1915) records of algae from Lismore and the Richmond River.

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INTRODUCTION

Papers on freshwater algae from Australia have been few and, with the exception of Playfair's various papers, scattered in coverage, both of the collections and the algae. Most of the earliest records, which record algae from Tasmania and Victoria, contain no illustrations, few descriptions and no authorities for the names. There are also papers by Nordstedt (1887, 1888) and Raciborski (1892) derived from collections made by scientific travellers to Australia and New Zealand. Bailey (1893, 1895, 1898) gave much information on the Queensland algal flora including desmids and *Oedogonium* species. These papers are little more than compilations from the papers of the various authorities including Borge (1897, 1911), Schmidle (1896) and Moebius (1892, 1894) to whom Bailey sent specimens for determination.

Hardy (1904, 1905, 1906, 1913), with the help of G. S. West, produced a series of checklists of freshwater algae, excluding diatoms, for Victoria which included original drawings and descriptions by West. West himself (1905, 1909) described the algal flora of the Yan Yean reservoir on the Yarra River, near Melbourne.

Playfair, in a series of papers from 1907 to 1923, described the freshwater algal and animalcules of the Sydney and Lismore districts. He made numerous descriptions and illustrations of many desmids and allied algae but made almost no reference to Oedogoniophyceae. Although his concepts of the limits of species, especially desmids, were broad (Playfair, 1910, 1911), nevertheless he described and named numerous morphological varieties within his species which have led to subsequent nomenclatural difficulties for more recent collectors. His *Supplement* I (1917) to Maiden and Betche's *Census of New South Wales Plants* is marred by a complete lack of localities for taxa listed.

Prescott and Scott examined collections of desmids from South Australia (Prescott and Scott, 1952) and collections of freshwater algae from Arnhem Land made by the American-Australian Expedition 1948 (Scott and Prescott, 1958) which contain many new taxa. Croasdale has since completed the desmid records from the latter collections (Croasdale and Scott, 1976). More recently Tyler, in Tasmania, has led an upsurge in interest in freshwater algal (Tyler 1970; Thomasson and Tyler, 1971) with a return to the problem of polymorphism in desmid species (Ling and Tyler, 1972, 1974, 1976).

DESCRIPTION OF THE AREA OF COLLECTION

The geography and geology of the northeastern quarter of New South Wales are rather complex. The tablelands, which rise to 1600 m, consist largely of a much faulted granitic batholith and associated metamorphic rocks. Much of the area shows traces of extensive volcanic capping during the Tertiary. The Clarence River system, draining the northeast of the tableland and following the escarpment for about half the river's length, traverses a sedimentary basin of Jurassic to Cretaceous age in its run to the sea.

In the tablelands the water bodies are shallow lagoons or weed-choked but swiftly flowing streams; on the coastal plain, billabongs and lagoons frequently occur in association with the middle river. Both the coastal and montane shallow lagoons (Baldersleigh Lagoon; Dangar's Lagoon, Uralla; the Mother of Ducks Lagoon system, Guyra; and the swamp billabong at Deep Creek, near Baryulgil on the Clarence) are species-rich, as are the various creeks and small rivers. The richest algal floras have developed in the swamps and sluggish creeks of old mining sites especially where the country rock is granitic (gold mines on the Ann River, Backwater; the tin mines on Majors Ck, Howell near Tinga). Comparable floristic variety is found in the alpine bogs near Round Mountain and Point Lookout. The deeper bodies of water, on basalt-derived sediments (Llangothlin Lagoon system) are species-poor, although often highly productive.

Author citations, except for a few more recently published taxa, have been limited to the author's name and date of publication only. The major references used have been Krieger (1937-1944) and Krieger and Gerloff (1962-1969) for the desmids, Kolkwitz and Krieger (1944) and Randhawa (1959) for the filamentous Zygnemaphyceae, and Tiffany (1930) and Gauthier-Lièvre (1963-1964) for the Oedogoniophyceae. Further references for species are mostly restricted to those published on Australian collections. L = length of cell; W = width of cell; WM = median width; WP = polar width; T = thickness; I = isthmus; D = diameter of zygospore.

The higher order classification used here follows Růžička (1979) for the desmids, with the orders and families arranged to follow Mix (1972) who based her rearrangement on the wall ultrastructure common to each group. The name Zygnemaphyceae of Round (1971) is preferred to Conjugatophyceae of Fott (1959) as it incorporates the name of the type genus and family. The filamentous taxa are classified according to the families designated by Randhawa (1959), and the ordinal status of the Mesotaeniales is retained.

Specimens have been deposited in the Herbarium of the Botany Department, University of New England.

Type material of *Oedogonium wissmanii* sp. nov. is stored at the National Herbarium, Royal Botanical Gardens, Sydney.

ZYGNEMAPHYCEAE

ZYGNEMALES

Mougeotiaceae: Although vegetative and reproductive filaments of taxa in this family were often encountered in collections, no fully mature zygospores were found.

Zygnemaceae:

Zygnema coeruleum Czurda 1932. Kolkwitz and Krieger, 1941: 227, figs 237, 238. Gauthier-Lièvre, 1965: 50, pl. 12, fig. 6. Randhawa, 1959: 227, fig. 163, a, b.

Cells L/B 3-4, 20-25 µm in diameter, wall ends lenticular. Zygospores 30-35 µm in diameter, mesospore wall blue with ellipsoid depressions forming a pattern over the surface.

Majors Creek, Howell near Tinga (*Garrard*, July 1974).

Spirogyra submaxima Transeau 1914. Kolkwitz and Krieger, 1941: 141, figs 637, 638.

Individual filaments discernible with the naked eye, or low magnification. Cells large, L/B 2-3(−5), 80-120 µm wide, end wall lenticular, chloroplasts 7-10, each with 1 to 2 turns. Conjugation scalariform; conjugation tube of two cups, median to cells; receiving cells all in one filament; zygospore round to slightly ovoid in outline, mesospore smooth, golden brown; diameter 90-115 µm.

Gwydir River, Bundarra, with zygospores (*Schneider,* March 1974); Aberfoyle River (*Skinner*, March 1974); Falconers Creek, Guyra (*Skinner* Dec. 1974); Mother of Ducks Lagoon, Guyra (*Skinner,* Dec. 1974).

Spirogyra westii Transeau 1934. Kolkwitz and Krieger, 1941: 381, fig. 558, 559. Gauthier-Lièvre, 1965: 167, pl. 63, fig. A, a-á. Randhawa, 1959: 310, fig. 279.

Cells narrow, 20-25 µm wide, L/B 4-5, end wall lenticular; chloroplast single, with 4-7 turns, with numerous pyrenoids. Conjugation scalariform; conjugation tube of two cups, towards one end of both donor and receiver cells, a little more terminally in the slightly inflated receiving cell, all receiving cells in the one filament. Zygospore ellipsoid, 65-70 x 30-35 µm, suture line median, mesospores golden brown.

Majors Creek, Howell, near Tinga (*Garrard,* April-July 1974); Sandy Creek, near the dog-gate, Armidale-Dorrigo Road (*Skinner,* Dec. 1974).

Sirocladiaceae:

Sirogonium sticticum (Eng. Bot.) Kützing 1849. Bailey, 1898: 10, pl. 4. Gauthier-Lièvre, 1965: 186, pl. 72, B, b-é. Randhawa, 1959: 424, pl. 508 (after Jao). Schmidle, 1896: 303.

Spirogyra stictica (Eng. Bot.) Wille. Kolkwitz and Krieger 1941: 429. L 130-160 µm; W 60-65 µm; D 65 x 70 µm.

Aberfoyle River (*Skinner,* March, July, Oct. 1974); Falconers Ck; (*Skinner,* Dec. 1974); Little Guyra Lagoon (*Skinner,* Dec. 1974); Cooney Ck, near Hillgrove (*Skinner,* Dec. 1974).

MESOTAENIALES

Mesotaeniaceae:

Spirotaenia condensata Bréb. in Ralfs 1848. Krieger, 1937: 181, pl. 2, fig. 1. L 160-165 µm; W 22-25 µm.

Backwater (*Wissman*, Feb. 1974); Baldersleigh, near Kingston (*Wissman,* Oct. 1974); Howell, near Tinga (*Garrard,* July 1974).

Spirotaenia obscura Ralfs 1848. Krieger 1937: 180, pl. 1, fig. 5, 6.

Playfair 1907: 170, pl. 3, fig. 2.

This taxon was found in pairs in gelatinous sheaths, otherwise it agrees with Krieger (1937). L. 75-80 µm; WM 10 µm; WP 5-7 µm.

Fig. 1, 1.

Sandy Ck, near the dog-gate, Armidale-Dorrigo Road (*Skinner,* Dec. 1974).

Netrium digitus var. *lamellosum* (Bréb.) Grønblad 1920. Krieger, 1937: 219, pl. 7, fig. 6.

Netrium lamellosum Krieger, 1932: 158, pl. 3, fig. 5.

A form which differs from *N. digitus* var. *digitus* by having straight cell walls in the middle of the cell; very common. L 200-350 μm; WM 75-85 μm; WP 30 μm.

Backwater (*Skinner,* March 1974); Baldersleigh (*Wissman,* Oct. 1974); Bullock Ck, Point Lookout (*Skinner,* Dec. 1974); Cooney Ck, near Hillgrove (*Skinner,* Dec. 1974); Deep Ck, near Baryulgil, swamp (*Skinner,* Nov. 1974).

Netrium digitus var. *rhomboideum* Grønblad 1920. Krieger, 1937: 218, pl. 7, fig. 5.

A variety which is smaller and more rhomboidal than the type. L 150-170 μm; WM 30-35 μm; WP 20-25 μm.

Backwater, fen (*Skinner,* March, Dec. 1974); Llangothlin Lagoon (*Skinner,* Sept. 1974); Majors Ck, Howell (*Garrard,* June 1974; *Wissman,* August 1974).

Gonatozygaceae:

Gonatozygon monotaenium var. *pilosellum* Norst. 1886. Scott and Prescott, 1958: 22, fig. 3.14. Playfair, 1915: 317.

Gonatozygon kinahanii var. *monotaenium* Playfair, 1912: 506, pl. 54, fig. 4. L 140-150 μm; WM 10 μm; WP 12 μm.

Dumaresq Creek, University of New England, Armidale (*Skinner,* Feb. 1974).

Genicularia spirotaenia de Bary 1858.

With two spiral, ribbon-like chloroplasts; cells often bent or curved. L 200-230 μm; W 12 μm.

Howell, near Tinga (*Garrard,* April 1974); Sandy Creek, near the dog-gate, Armidale-Dorrigo Road (*Skinner,* Dec. 1974).

Peniaceae:

Penium cylindrus (Ehrenb.) Brébisson in Ralfs 1848. Krieger, 1937: 234, pl. 9, fig. 9-12. Scott and Prescott, 1958: 22, pl. 1, fig. 20; 1961: 9, pl. 1, fig. 11.

Cells with 3-5 or more sutures; L 20-45 μm; W 6-8 μm.

Backwater, swamp (*Skinner,* March, June, Dec. 1974).

Penium margaritaceum (Ehrenb.) Bréb. in Ralfs 1848. Krieger 1937: 230, pl. 10, figs 2-4.

I 150-190 μm; W 20 μm.

Styx River state forest, soakage pool (*Skinner* and *Wissman,* Feb. 1974); Dumaresq Ck, U.N.E., Armidale (*Skinner,* Feb. 1974).

Penium phymatosporum Nordst. 1876. Krieger, 1937: pl. 11, figs 14-17.

Small cells with smooth walls, L/B 3, 7-10 μm in diameter. Zygospore irregularly mamillate, D 20-30 μm.

Fig. 1, 2.

Baldersleigh, near Kingston, lagoon (*Wissman,* Oct. 1974).

Penium spirostriolatum Barker 1869. Krieger, 1937: 227, pl. 9, figs 1-6.

Playfair, 1908: 607, pl. 11, fig. 5; 1910: 490, pl. 13, fig. 24.

I 140-160 μm; W 10-15 μm.

Backwater (*Wissman,* Feb. 1974; *Skinner,* March 1974); Little Styx River, Point Lookout (*Skinner* and *Wissman,* Feb. 1974); Howell (*Garrard,* April-July 1974); Bullock Ck, Point Lookout, bog (*Skinner,* Dec. 1974).

Closteriaceae:

Closterium cuspidatum Bailey in Ralfs 1848.

Spinoclosterium curvatum Bernard, 1909: 31, pl. 2, fig. 35.

Spinoclosterium cuspidatum (Bail.) Hirano. Scott and Prescott, 1958: 24, pl. 1, fig. 17.

Spinoclosterium curvatum var. *spinosa* Prescott, 1940: 99.

L 200-230 μm WM 40 μm; WP 15 μm.

Backwater, swamp (*Skinner,* March, June 1974).

Closterium ehrenbergii Menegh. 1840. Krieger, 1937: 285, pl. 17, fig. 1. pl. 18, fig. 1. Bailey, 1893: 42. Hardy, 1905: 66. Moebius, 1892: 441. Prescott and Scott, 1952: 56. Playfair, 1914: 100.

L 200-250 μm; W max 45 μm.

Little Styx River, Point Lookout, bog (*Skinner* and *Wissman,* Feb. 1974).

Closterium idiosporum West and West 1900. Krieger, 1937: 271, pl. 15, fig. 1, 2.

L 150-160 μm; MW 15 μm.

Zygospore ovoid, densely papillose with a brown mesopore, held tightly between the four semicells, D 20 x 45 μm.

Fig. 1, 3a, b.

Sandy Ck, near the dog-gate, Armidale-Dorrigo Road (*Skinner,* Dec. 1974).

Closterium kutzingii Bréb. 1856. Krieger, 1937: 351, pl. 32, fig. 8, 9. Bailey, 1893: 42, 1898: 33. Hardy, 1905: 66; 1906: 41. Moebius, 1892: 441. Prescott and Scott, 1952: 57, pl. 1, fig. 8. Schmidle, 1896: 304. Scott and Prescott, 1958: 23, pl. 1, fig. 14. Thomasson, 1973: 392. West, 1909: 14.

A very variable species; L 180-250 μm; WM 8-20 μm.

Backwater (*Wissman,* Feb. 1974; *Skinner,* March, June 1974); Round Mountain, drain in bog (*Wissman,* Nov. 1974); Deep Ck, near Baruylgil, swamp (*Skinner,* Nov. 1974).

Closterium libellula var. *interruptum* (West and West) Donat 1926. Krieger, 1937: 256, pl. 12, fig. 6. Scott and Prescott, 1958: 24, pl. 1, fig. 6.

As noted by Scott and Prescott (1958), this species has distinctive terminal vacuoles with gypsum statoliths, thus distinguishing it from either *Penium* or *Netrium.* L 145-170 μm; WM 20-25 μm.

Styx River state forest, soakage pool (*Skinner* and *Wissman,* Feb. 1974); Backwater, fen (*Skinner,* March, Dec. 1974); Majors Ck, Howell near Tinga (*Garrard,* June 1974); Mother of Ducks Lagoon, Guyra (*Skinner,* Dec. 1974); Sandy Ck, near the dog-gate, Armidale-Dorrigo Road (*Skinner,* Dec. 1974); Bullock Ck, Point Lookout, bog (*Skinner,* Dec. 1974).

Closterium lunula (Müll.) Nitzsch 1817. Krieger, 1937: 301, pl. 21, fig. 1, pl. 22, fig. 1. Hardy, 1906: 36.

Closterium lunula forma *giganteum* (Bernard) Playfair, 1908: 605, pl. 11, fig.2.

This very large species is often readily visible to the naked eye.

L 800-1100 μm; W 90-120 μm.

Little Styx River, bog (*Skinner* and *Wissman,* Feb. 1974); Backwater (*Wissman,* Feb. 1974; *Skinner,* March 1974); Aberfoyle River (*Skinner,* June 1974); Llangothlin Lagoon (*Skinner,* Sept. 1974); Sandy Ck, near the dog-gate, Armidale-Dorrigo Road (*Skinner,* Dec. 1974); Cooney Ck, near Hillgrove (*Skinner,* Dec. 1974).

Closterium moniliferum (de Bary) Ehrenb. 1838. Krieger, 1937: 289, pl. 18, figs 6, 7.

L 180-230 μml W: max 40 μm.

Llangothlin Lagoon (*Skinner,* Sept. 1974); Dangars Lagoon, Uralla (*Skinner,* Dec. 1974); Pyes Ck, near Tenterfield (*Skinner,* Jan. 1975).

Closterium nematoides Joshua 1886. Krieger, 1937: 370, pl. 37, fig. 2. Croasdale and Scott, 1976: 508, pl. 1, fig. 7. Scott and Prescott, 1958: 24, pl. 1, fig. 12.

L 80-110 μm; WM 20-25 μm.

Little Styx River, bog (*Skinner* and *Wissman,* Feb. 1974); Dumaresq Ck, U.N.E., Armidale (*Skinner,* March 1974); Majors Ck, Howell (*Garrard,* May 1974); Round Mountain, drain in bog (*Wissman,* Nov. 1974); Baldersleigh near Kingston, swamp (*Wissman,* Oct. 1974); Bullock Ck, Point Lookout (*Skinner,* Dec. 1974).

DESMIDIACEAE

Gronbladia neglecta (Racib.) Teiling 1952. Scott and Prescott, 1961: 122, pl. 61, fig. 7.

Cells L/B 4-6, W 15-20 μm, forming very long chains. Zygospore, present in March sample, irregular cruciform, D 80-85 μm.

Fig. 1, **4.**

Backwater, swamp (*Skinner,* March, June, Dec. 1974).

Hyalotheca dissiliens (Sm.) Brébisson in Ralfs 1844. Bailey, 1893: 38, pl. 12, fig. 28; 1895: 37; 1898: 12. Borge, 1911: 203. Hardy, 1905: 70. Moebius, 1892: 439. Prescott and Scott, 1952: 68.

End view of cell circular; cell wall of ten with fine plications; L 14-18 μm W 15 μm; Diameter of cell 15 μm. Zygospore ovoid, D 50 x 35 μm.

Backwater (*Wissman,* Feb. 1974); Aberfoyle River (*Skinner,* June 1974); Round Mountain (*Wissman,* Nov. 1974); Deep Ck, near Baryulgil, swamp, with zygospores (*Skinner,* Dec. 1974).

Hyalotheca hians Nordstedt 1888, Bailey, 1898: 12, pl. 5, fig. 1a, b.

End view of cell oval, with two antipodal peaks; walls smooth, with a central invagination; L 20-25 μm; W 20-25 μm; Diameter of cell 25 μm.

Backwater (*Skinner,* March 1974); Howell (*Garrard,* June 1974).

Hyalotheca mucosa (Dillw.) Ehrenberg 1840. Scott and Prescott, 1958: 69, pl. 1, fig. 19.

Cells cylindrical, with double rings of fine plications towards either end; L 15-25 μm; W 15 μm.

Backwater (*Skinner,* June 1974); Sandy Ck, near the dog-gate, Armidale-Dorrigo Road (*Skinner,* Dec. 1974); Cooney Ck, near Hillgrove (*Skinner,* Dec. 1974).

Phymatodocis nordstedtiana Wolle 1884. Scott and Prescott, 1961: 123, pl. 61, fig. 9, 10.

L 25-30 μmum; W 30-40 μm; I 25 μm.

Backwater, swamp (*Skinner,* March, Dec. 1974); Round Mountain, drain in bog (*Wissman,* Oct. 1974); Bullock Ck, Point Lookout, fen (*Skinner,* Dec. 1974.

Desmidium baileyi (Ralfs) Nordstedt 1880. Prescott and Scott, 1952: 68, pl. 3, fig. 14. Schmidle, 1896: 303.

This form, which is similar to the South Australian form, is very like that of Rich (1932, fig. 17C), but shows arms linking across the sinus, and is more squared off at the corners of the cell. L 25 μm; W 30 μm.

Fig. 1, **6.**

Backwater (*Skinner,* March, June 1974).

Desmidium suboccidentale Scott and Prescott, 1958: 70, pl. 21, fig. 9, 1961: 125, pl. 63, fig. 7.

Cells a little larger than Northern Territory form, with greater constriction of the lateral lobes, otherwise similar; L 17-20 μm; W 20-30 μm; I 15-20 μm.

Fig. 1, **5a, b.**

Backwater, fen (*Skinner,* June, Dec. 1974).

Desmidium swartzii C. Agardh 1824. Scott and Prescott, 1958: 70, pl. 21, fig. 18. Hardy, 1905: 71. Thomasson, 1973: 392. West, 1909: 16.

Some chains of cells very long indeed, and this species may occur as the dominant photosynthetic organism at a site. The form from Baryulgil is less

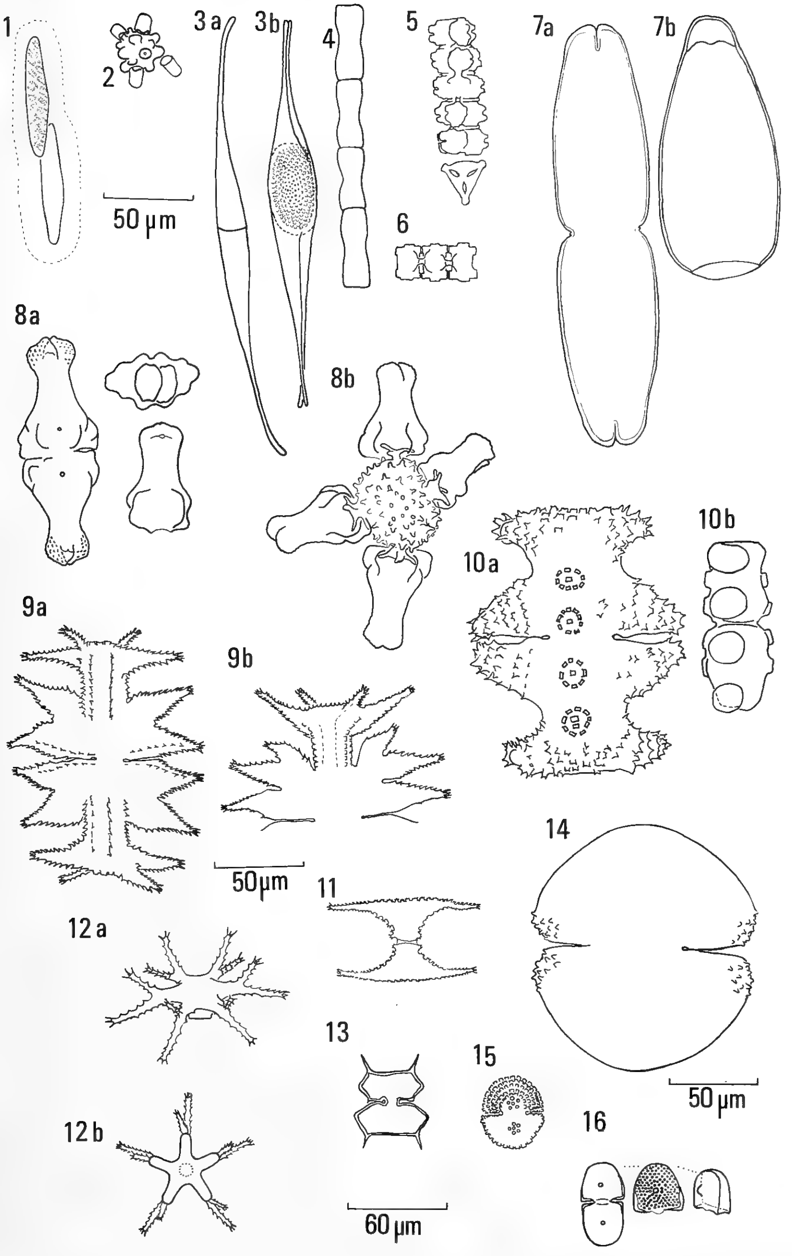

Fig. 1. **1,** *Spirotaenia obscura,* Sandy Ck; **2,** *Penium phymatosporum,* Baldersleigh, swamp; **3a, b,** *Closterium idiosporum,* Sandy Ck; **4,** *Gronbladia neglecta,* Backwater, swamp; **5,** *Desmidium suboccidentale,* Backwater, fen; **6,** *D. baileyi,* Backwater, swamp; **7a, b,** *Tetmemorus brebissonii,* Baldersleigh, swamp; **8a, b,** *Euastrum longicolle* var. *capitatum,* Backwater, fen; **9,** *Micrasterias mahabuleshwarensis,* (a) Bullock Ck, Point Lookout; (b) Cooney Ck; **10a, b,** *M. tropica* var. *indivisa,* Baldersleigh, swamp; **11,** *Staurastrum bicorne,* Backwater, swamp; **12a, b,** *S. sexangulare,* Deep Ck, Baryulgil swamp; **13,** *Xanthidium inchoactum,* Backwater, swamp; **14,** *Cosmarium askenasyi,* Bullock Ck, Point Lookout; **15,** *C. botrytis,* Dumaresq Ck, Armidale; **16,** *C. rotundum,* Baldersleigh, swamp.
50 µm scale, for **1**; **2**; **3a, b**; **5**; **6**; **9a, b**; **11**; **14**; **15**.
60 µm scale, for **4**; **7**; **8a, b**; **10a, b**; **12a, b**; **13**; **16**.

ornate than usual, the Round Mountain form is very large.
L 15-25 μm; W 30-50 μm; I 35-45 μm.
Round Mountain (*Wissman,* Oct. 1974); Sandy Ck, near the dog-gate, Armidale-Dorrigo Road (*Skinner,* Dec. 1974); Deep Ck, near Baryulgil, swamp (*Skinner,* Nov. 1974).

Tetmemorus brebissonii (Meneghini) Ralfs 1844. Krieger, 1937: 452, pl. 54, fig. 1-5. Bailey, 1893: 43. Prescott and Scott, 1952: 58. Scott and Prescott, 1958: 28.
A very large form, L 230-300 μm; WM 50-70 μm; WP 20-25 μm; I 30-45 μm; from Baldersleigh and Mother of Ducks Lagoon (compare with a similar sized form of Prescott and Scott (1952), from Mt. Compass, South Australia), and, more commonly, a smaller form, L 90-110 μm; WM 20-30 μm; I 10 μm.
Fig. 1, **7a, b.**
Backwater (*Skinner,* March, June, Dec. 1974); Baldersleigh, near Kingston, swamp, both forms (*Wissman,* Sept. 1974); Round Mountain, drain in bog (*Wissman,* Oct. 1974); Bullock Ck, Point Lookout (*Skinner,* Dec. 1974); Mother of Ducks Lagoon, Guyra, large form (*Skinner,* Dec. 1974).

Tetmemorus granulatus (Bréb.). Ralfs 1844. Krieger, 1937: 458, pl. 55, fig. 1-5. Schmidle, 1896: 304.
L 70-80 μm; WM 14-18 μm; WP 10 μm.
Baldersleigh, near Kingston, swamp (*Wissman,* Sept. 1974).

Tetmemorus laevis (Kützing) Ralfs 1844. Krieger, 1937: 455, pl. 54, fig. 9-12. Prescott and Scott, 1952w: 58.
L. 75-85 μm; WM 25-30 μm; WP 20 μm; I 22 μm
Styx River state forest, soakage pool (*Skinner* and *Wissman,* Feb. 1974).

Pleurotaenium nodosum (Bailey) Lundell 1871. Krieger, 1937: 436, pl. 47, fig. 1. Bailey, 1893: 44. Hardy, 1905: 66.
Docidium nodosum Bailey 1898: 30, pl. 16, fig. 12.
L 200-360 μm; WM 55-65 μm; WP 20-28 μm; I 30-35 μm.
Backwater, fen (*Skinner,* June 1974); Round Mountain, drain in bog (*Wissman,* Oct. 1974); Bullock Ck, Point Lookout, bog (*Skinner,* Dec. 1974).

Pleurotaenium ovatum var. *tumidum* (Maskell) G. S. West *in* Hardy, 1906; 21. G. S. West, 1909: 54, pl. 6, fig. 9. Krieger, 1937: 435: pl. 50, fig. 2, 3.
L 200-250 μm; WM 100-120 μm; WP 30-35 μm; I 55 μm. Bailey (1893, 1895) may also be discussing this taxon, as Moebius' (1892) variety appears to be a variation from the Queensland form rather than the type.
Bullock Ck, Point Lookout, bog (*Skinner,* Dec. 1974).

Pleurotaenium verrucosum (Bailey) Lundell 1871. Krieger, 1937: 438, pl. 51, fig. 13. This form has pointed coronal teeth, perhaps agreeing more fully with var. *bulbosum* Krieger, 1937: 439, pl. 51, fig. 5.
L 300-350 μm; WM 35-40 μm; WP 20-25 μm; I 31-35 μm.
Deep Ck, Baryulgil, swamp (*Skinner*, Nov. 1974).

Triploceras gracile Bailey 1851. Krieger, 1937: 442, pl. 52, fig. 1-7. Bailey, 1893: 44, fig. 36, 1895: 38. Hardy, 1905: 66. Schmidle, 1896: 304.
A number of varieties of this plastic species have been described (Prescott and Scott, 1952; Scott and Prescott, 1958; Thomasson, 1973) for Australian specimens. Although the specimens collected in the present survey showed some variation, they are treated as members of one variable taxon here.
L 350-415 μm; W 30-40 μm; I 30-35 μm. Zygospore with 14 several times furcate spines, mesospore brown, D 60-75 μm.
Backwater (Skinner, March, June (with zygospores), Dec. 1974); Round Mountain (*Wissman,* Oct. 1974); Bullock Ck, Point Lookout (*Skinner,* Dec.

1974); Cooney Ck, near Hillgrove (*Skinner,* Dec. 1974); Deep Ck, near Baryulgil swamp (*Skinner,* Nov. 1974).

Euastrum longicolle var. *australicum* Playfair, 1907: 172, pl. 3, fig. 6. Krieger, 1937; 494, pl. 61, fig. 1.

L 120 μm; WM 70 μm; WP 35 μm; I 15 μm.

Baldersleigh, near Kingston, swamp (*Wissman,* Sept. 1974).

Euastrum longicolle var. *capitatum* West and West 1902. Krieger, 1937: 494, pl. 60, fig. 11. Croasdale and Scott, 1976: 518, pl. 4, figs 1, 2. Scott and Prescott, 1958: 36, pl. 4, fig. 3.

L 100-110 μm; WM 50 μm; WP 30-33 μm; I 15 μm. Zygospore spherical to ovoid, mesospores red brown, spines simple and coarse, with four pointed anvil shaped spines holding the empty semicells to the spore, D 50-65 μm. This zygospore with its anvil spines does not agree fully with Croasdale and Scott (1976).

Fig. 1, **8a, b, c.**

Backwater, fen (*Skinner,* March, June, Dec. 1974), spores present in all samples).

Euastrum spinulosum var. *inermis* Nordstedt 1888. Krieger, 1937: 635, pl. 93, fig. 8-10.

L 60 μm; W 55 μm; I 12 μm.

Howell, near Tinga (*Garrard,* June 1974); Baldersleigh, near Kingston, swamp (*Wissman,* Sept. 1974); Bullock Ck, Point Lookout (*Skinner,* Dec. 1974).

Euastrum turneri W. West. 1893. forma.

L 35-40 μm; WM 25-30 μm; WP 20-22 μm; I 9-11 μm.

Backwater (*Wissman,* Feb. 1974; *Skinner,* March, June, Dec. 1974); Baldersleigh, near Kingston (*Wissman,* Sept. 1974); Round Mountain (*Wissman,* Oct. 1974); Mummulgum, Bruxner Highway (*Wissman,* Nov. 1974); Cooney Ck, near Hillgrove (*Skinner,* Dec. 1974).

Micrasterias alata Wallich 1890. Scott and Prescott, 1958: 339, pl. 7, fig. 1, 2; Croasdale and Scott, 1976: 522, pl. 7, fig. 8. Tyler, 1970: 219, fig. 18, A, B.

L 145-155 μm; W 150-165 μm; I 25 μm.

Deep Ck, Baryulgil, swamp (*Skinner,* Nov. 1974); Cooney Ck, near Hillgrove (*Skinner,* Dec. 1974).

Micrasterias anomala Turner 1893. Scott and Prescott, 1958: 39, pl. 10, fig. 2; 1961: 46, pl. 19, fig. 1-3. Tyler, 1970: 219, fig. 23.

Xanthidium bifurcatum Borge 1897: 16. Bailey, 1898: 19, pl. 14, 5a-c, 6a-c. Scott and Prescott, 1958: 56, pl. 10, fig. 3.

Xanthidium pulcherrimum Playfair, 1907: 180, pl. 4, fig. 10.

Xanthidium gloriosum G. S. West *in* Hardy, 1906: 19. Playfair, 1908: 620.

This very large desmid was found in two collections, only once in the Backwater collection. The form found fits Playfair's description (Playfair, 1907) and plate, although somewhat larger. The differences between the various specimens in the literature have been delimited by each author. Until this taxon (or complex) can be studied in culture the nomenclature will remain uncertain.

L 290-310 μm; WM 165 μm; WP 60 μm; I 45 μm.

Backwater, swamp (*Skinner,* June 1974); Bullock Ck, Point Lookout (*Skinner,* Dec. 1974).

Micrasterias jenneri Ralfs 1848. Tyler, 1970: 224, fig. 28, B, C.

L 200-320 μm; W 100-120 μm; I 35 μm.

Backwater (*Skinner,* March 1974); Baldersleigh, near Kingston (*Wissman,* Sept. 1974); Sandy Ck, near the dog-gate, Armidale-Dorrigo Road (*Skinner,* Dec. 1974).

Micrasterias mahabuleshwarensis Hobson 1863: Tyler, 1970: 216, fig. 11-15, 17. Bailey, 1895: 42, pl. X, fig. 14. Borge, 1911: 203. Playfair, 1915: 330.

Tyler (1970) shows in his fig. 17 the range of variation in this taxon, in south eastern Australia, from forma 'typica' to forma 'Wallichii', and both ends of this range have been found among the northern tablelands specimens. The records of other forms and varieties [var. *reducta* West *in* Hardy, 1905, Scott and Prescott, 1958, var. *ampullacea* (Mask.) Nordst. fa. *australiensis* Prescott and Scott, 1952] may also prove to be forms of this graded series.

Fig. 1, **9a, b.**

forma 'typica'

Bullock Ck, Point Lookout (*Skinner,* Dec. 1974); Sandy Ck near the dog-gate, Armidale-Dorrigo Road (*Skinner,* Dec. 1974); Yellow Gap, Guyra-Mt. Mitchell Road, swamp (*Skinner,* March 1974).

forma 'Wallichii'

Cooney Ck, near Hillgrove (*Skinner,* Dec. 1974).

Micrasterias moebii (Borge) West and West 1894. Scott and Prescott, 1958: 41, pl. 8, fig. 5, 6.

Euastrum turgidum var. *moebii* (W. and G. S. West) Playfair, 1915: 329.

L 90-100 μm; WM 90 μm; I 55 μm.

Dumaresq Ck, U.N.E., Armidale (*Skinner,* Feb. 1974); Backwater (*Wissman* Feb. 1974): Mummulgum, Bruxner Highway, swamp (*Wissman,* Nov. 1974).

Micrasterias thomasiana var. *notata* (Nordst.) Grφnblad 1920. Tyler, 1970: 225, fig. 29, A-C. Prescott and Scott, 1952: 60, pl. 4, fig. 3.

The northern tablelands form of this species is without much ornamentation, like Tyler (1970), fig. A. & C.

L 200-250 μm; W 165-180 μm I 50 μm.

Backwater (*Wissman,* Feb. 1974; *Skinner*, March 1974); Baldersleigh (*Wissman,* Sept. 1974); Oakey River Hydroelectricity Dam, near Jeogla (*Skinner,* Feb. 1974).

Micrasterias tropica var. *indivisa* (Nordst.) Eichl. and Rac. 1893. Tyler, 1970: 219, fig. 18 C, D.

The form of this taxon from the northern tablelands differs from those figured by Tyler (1970) in the possession of two (not just a single) circular raised processes on each face of each semi-cell, one below the other.

L 90-120 μm; MW 80-90 μm; WP 70 μm; I 50-55 μm.

Zygospore (in Baldersleigh sample) spherical with a mixture of simple and bifurcated spines, randomly distributed, mesospore brown, D 65-70 μm.

Fig. 1, **10a, b.**

Baldersleigh, near Kingston, with zygospore (*Wissman,* Sept. 1974); Round Mountain (*Wissman,* Oct. 1974); Cooney Ck, near Hillgrove (*Skinner,* Dec. 1974); Bullock Ck, Point Lookout (*Skinner,* Dec. 1974); Sandy Ck, near the dog-gate, Armidale-Dorrigo Road (*Skinner,* Dec. 1974).

Staurastrum bicorne Hauptfl. 1888. forma

L 50 μm; W 60 μm; I 15 μm.

Fig. 1, **11.**

Backwater (*Skinner,* March, June 1974); Deep Ck, near Baruylgil, swamp (*Skinner,* Nov. 1974).

Staurastrum dickiei Ralfs 1848. Prescott, 1940: 91, pl. 2, fig. 8, 9. Hardy, 1905: 69.

L 60-65 μm; W 60-65 μm; I 8 μm.

Backwater (*Wissman,* Feb. 1974); Round Mountain (*Wissman,* Oct. 1974);

Deep Ck, near Baryulgil (*Skinner,* Nov. 1974); Cooney Ck, near Hillgrove. (*Skinner,* Dec. 1974); Dangar's Lagoon, Uralla (*Skinner,* Dec. 1974).

Staurastrum longispinum (Bailey) Archer.

L 80 μm; W 100-110 mm; I 35 μm.

Backwater, swamp (*Wissman,* Feb. 1974; *Skinner,* March, June 1974); Bullock Ck, Point Lookout (*Skinner,* Dec. 1974).

Staurastrum pinnatum Turner 1892.

L 30 μm; W 50 μm; I 23 μm.

Deek Ck, Baryulgil, swamp (*Skinner,* Nov. 1974); Cooney Ck, near Hillgrove (*Skinner,* Dec. 1974).

Staurastrum sagittarium Nordstedt 1887. Thomasson, 1973: 393, pl. 32, figs 7, 8. Hardy, 1905: 69. Moebius, 1892: 446, fig. 18. Prescott and Scott, 1952: 67, fig. 5, 5. Schmidle, 1896: 312. Scott and Prescott, 1958: 65, pl. 18, figs 3, 4.

L 40-45 μm; W 60 μm; I 30 μm.

Backwater (*Skinner,* June 1974).

Staurastrum sexangulare Lundell, 1871. Thomasson, 1973: 387, pl. 34, fig. 1. Hardy, 1905: 69. Playfair, 1907: 185, pl. 5, fig. 11.

An ornate form; not as simple as Scott and Prescott (1958), pl. 18, fig. 1, occasional five-armed form found. Thomasson (1973) comments on the variety of forms displayed by this taxon.

L 40-42 μm; W 60-65 μm; radius (top view) 65-70 μm; I 30 μm.

Fig. 1, **12 a, b.**

Backwater (*Skinner,* March, June 1974); Majors Ck, Howell, near Tinga (*Garrard,* June 1974); Deep Ck, near Baryulgil, swamp (*Skinner,* Nov. 1974).

Xanthidium hastiferum Turner 1892. Thomasson, 1973: 387, pl. 34, 7. Hardy, 1905: 68, 41. West, 1909: 15.

L 75-80 μm; W 65 μm; I 25 μm.

Backwater (*Skinner,* June 1974); Bullock Ck, Point Lookout, bog (*Skinner,* Dec. 1974).

Xanthidium inchoactum Nordstedt 1887. Playfair, 1915: 330, pl. 42, fig. 9a.

Form very close to *β mamillatum* described by Playfair (1908), except that the triangular processes at either end of the sinus may be missing in one semicell.

L 30-35 μm; W 35-40 μm; I 12-15 μm.

Fig. 1, **13.**

Backwater (*Skinner,* March 1974).

Xanthidium octonarium var. *cornutum* Playfair, 1908: 620, pl. 12, fig. 7. Thomasson, 1973: pl. 33, fig. 7, 9.

L 70 μm; W 50 μm; I 20 μm.

Backwater (*Skinner,* March 1974); Majors Ck, Howell, near Tinga (*Garrard,* April-June 1974); Baldersleigh (*Wissman,* Sept. 1974).

Cosmarium amplum Nordstedt 1888. Bailey, 1898: 29, pl. 4, fig. 2a-d. Schmidle, 1896: 309.

L 95-105 μm; W 65-80 μm; I 25-29 μm; T 45-50 μm.

Fig. 2, **1.**

Baldersleigh, near Kingston, swamp (*Wissman,* Sept. 1974).

Cosmarium askenasyi Schmidle 1895. Bailey, 1898: pl. 15, fig. 9a, b. Scott and Prescott, 1961: 54, pl. 23, fig. 4.

Cosmarium species Moebius in Bailey, 1895: 40, pl. 10, fig. 20.

Cosmarium askenasyi var. *crateriforme* Playfair, 1915: 327, pl. 42, fig. 6.

This form is similar to but not quite as wide as fa. *latum* of Scott and Prescott (1958).

L 135-145 μm; W 120-130 μm; I 55 μm.
Fig. 1, **14.**
Bullock Ck, Point Lookout, bog (*Skinner,* Dec. 1974).

Cosmarium botrytis (Bory) Meneghini 1840. Bailey, 1898: 28, pl. 6, fig. 13, a-g.
L 35-50 μm; W 35-45 μm; I 12-20 μm.
Fig. 1, **15.**
Dumaresq Ck, U.N.E., Armidale (*Skinner,* Feb. 1974); Baldersleigh, near Kingston, swamp (*Wissman,* Sept. 1974); Bullock Ck, Point Lookout, bog (*Skinner,* Dec. 1974).

Cosmarium denticulatum Borge 1897. Bailey, 1898: 21, pl. 15, fig. 5a-c. Scott and Prescott, 1958: 45, pl. 13, fig.4.
L 150-175 μm; W 70-80 μm; I 55 μm.
Dumaresq Ck, U.N.E., Armidale (*Skinner,* Feb. 1974); Major's Ck, Howell, near Tinga (*Garrard,* June 1974); Backwater, swamp (*Skinner,* June 1974); Round Mountain, drain in bog (*Wissman,* Oct. 1974); Mummulgum, Bruxner Highway (*Wissman,* Nov. 1974); Bullock Ck, Point Lookout, bog (*Skinner,* Dec. 1974).

Cosmarium dentiferum Corda 1839. Playfair, 1914: 104, pl. 3, fig. 18. Prescott and Scott, 1952: 60, pl. 4, fig. 7.
L 80 μm; W 80 μm; I 20 μm.
Sandy Ck, near the dog-gate, Armidale-Dorrigo Road (*Skinner,* Dec. 1974).

Cosmarium glyptodermum West and West. Playfair, 1908: 619.
L 110-125 μm; W 50-70 μm; I 20-25 μm.
Fig. 2, **2.**
Baldersleigh, near Kingston, swamp (*Wissman,* Sept. 1974).

Cosmarium lundellii Delp. 1877. Borge, 1911: 200, pl. 2, fig. 3. Scott and Prescott, 1958: 47, pl. 12, fig. 19.
L 120-130 μm; W 90-95 μm; I 4-5 μm.
Fig. 2, **3.**
Backwater (*Wissman,* Feb. 1974; *Skinner,* June 1974).

Cosmarium magnificum Nordstedt 1887. Playfair, 1914: 104.
L 100-110 μm; W 85-96 μm; I 35 μm. Zygospore with simple spines, D 80 μm.
This form shows some of the pits described by Scott and Prescott (1961), but is not quite as highly ornamented.
Fig. 2, **4.**
Backwater, swamp, with spores (*Skinner,* March, July 1974); Deep Ck, near Baryulgil, swamp (*Skinner,* Nov. 1974); Bullock Ck, Point Lookout, bog (*Skinner,* Dec. 1974).

Cosmarium obsoletum (Hautzsch.) Reinsch 1867; Scott and Prescott, 1958: 47, pl. 12, fig. 17. Bailey, 1893: 47. Borge, 1911: 200; Hardy, 1905: 68. Moebius, 1892: 444. West, 1909: 14.
L 40-60 μm; W 50-60 μm; I 40 μm. Zygospore with simple spines, D 65 μm.
Dumaresq Ck, U.N.E., Armidale (*Skinner,* Feb. 1974); Backwater [*Wissman,* Feb. 1974; *Skinner,* March, June (with spores), Dec. 1974]; Llangothlin Lagoon (*Skinner,* Sept. 1974); Deep Ck, near Baryulgil, swamp (*Skinner,* Nov. 1974); Cooney Ck, near Hillgrove (*Skinner,* Dec. 1974); Dangars Lagoon, Uralla (*Skinner,* Dec. 1974).

Cosmarium rotundum Prescott and Scott, 1952: 64, pl. 3, fig. 6.
Form similar to the type, but somewhat smaller.
L 40-50 μm; AW 25-30 μm; T 15 μm; I 10 μm.
Fig. 1, **16.**

Baldersleigh, near Kingston, swamp (*Wissman,* Sept. 1974).

Cosmarium spirale (Playfair) Krieger and Gerloff 1962.

Cosmarium stenonotum var. *spirale* Playfair, 1908: 618, pl. 13, fig. 20.

The degree of spiral of the semi-cell and the disposition of the semi-cells to each other are very variable.

L 60-65 μm; W 25-30 μm; T 12-18 μm; I 10-12 μm.

Fig. 2, **5a, b, c, d.**

Backwater, fen (*Skinner,* March, June, Dec. 1974); Bullock Ck, Point Lookout (*Skinner,* Dec. 1974).

Cosmarium striolatum var. *nordstedtii* (Moebius) Krieger, 1932: 186, pl. 12, fig. 2. Grönblad and Croasdale, 1971: 17, fig. 112, 113.

Pleurotaeniopsis tesselata (Delp.) De Toni var. *nordstedtii* Moebius 1892: 443, fig. 16. Bailey 1893: 45, fig. 40. Schmidle 1896: 305 [as *Cosmarium (Pleurotaeniopsis) tessellata* (Delp.) De Toni var. *nordstedtii*].

L 90-110 μm; W 50-70 μm; T 240-50 μm; I 30-35 μm. Similar to *C. lagerheimianum* (Turn.) Scott and Prescott (F1961), but spines not as pronounced.

Fig. 2, **6.**

Backwater (*Skinner,* March, June, Dec. 1974); Bullock Ck, Point Lookout, bog (*Skinner,* Dec. 1974).

Onychonema filiforme (Ehreb.) Roy and Bisset 1848. Playfair, 1915: 332, pl. 41, fig. 20.

L 8-10 μm; I 1-1.5 μm.

Backwater (*Skinner,* March 1974); Deep Ck, Baryulgil, swamp (*Skinner,* Nov. 1974).

Playfair (1915) commented that there were low numbers of desmids in his Richmond River collections. He had records of 116 desmid taxa from lagoons and semipermanent pools in the Lismore area, and a further 56 taxa from the Richmond River, but he (1914, 1915) described very few of these, with comments on the presence of a few more. (His note on the conspecificity of *Closterium ehrenbergii* and *C. moniliformis* was all too brief).

Comparison of the desmid floras of the New England Tableland and Clarence River system with Playfair's Richmond River district collections is rather difficult in the absence of complete records. There are only nine taxa recorded above which also appear in Playfair's (1914, 1915) papers. To be fair to Playfair, some recent collections from the Clarence, e.g. the Mummulgum collection, did have a predominance of diatoms, euglenoids and bluegreen algae. The Baryulgil collection, by contrast, contained a wide variety of algae, including numerous desmid taxa.

OEDOGONIOPHYCEAE

OEDOGONIALES

Oedogoniaceae:

Bulbochaete elatior Pringsheim 1858. Tiffany, 1930: 32, pl. 1, fig. 1. Bailey, 1893: 16, pl. 4, fig. 7. Gauthier-Lièvre, 1964: 237, pl. 25, fig. A. Gemeinhardt, 1939: 373, fig. 459. Moebius, 1892: 428, fig. 8.

Cells medium-sized, L/B 4-6, W 14-18 μm, gyandrosporous and nannandrous, androsporangia epigynous, one or two celled, dwarf males, stipe and one cell only, on supporting cell; oogonia closely fitting the oospores, supporting cell with a basal division, oospore depressed subquandrangular globose, 30-35 μm in diameter, smooth walled. This form approaches fa. *pumila* Hirn (Gauthier-Lièvre 1964, 238, pl. 25, fig. C). Scott and Prescott (1958) show a form closer to

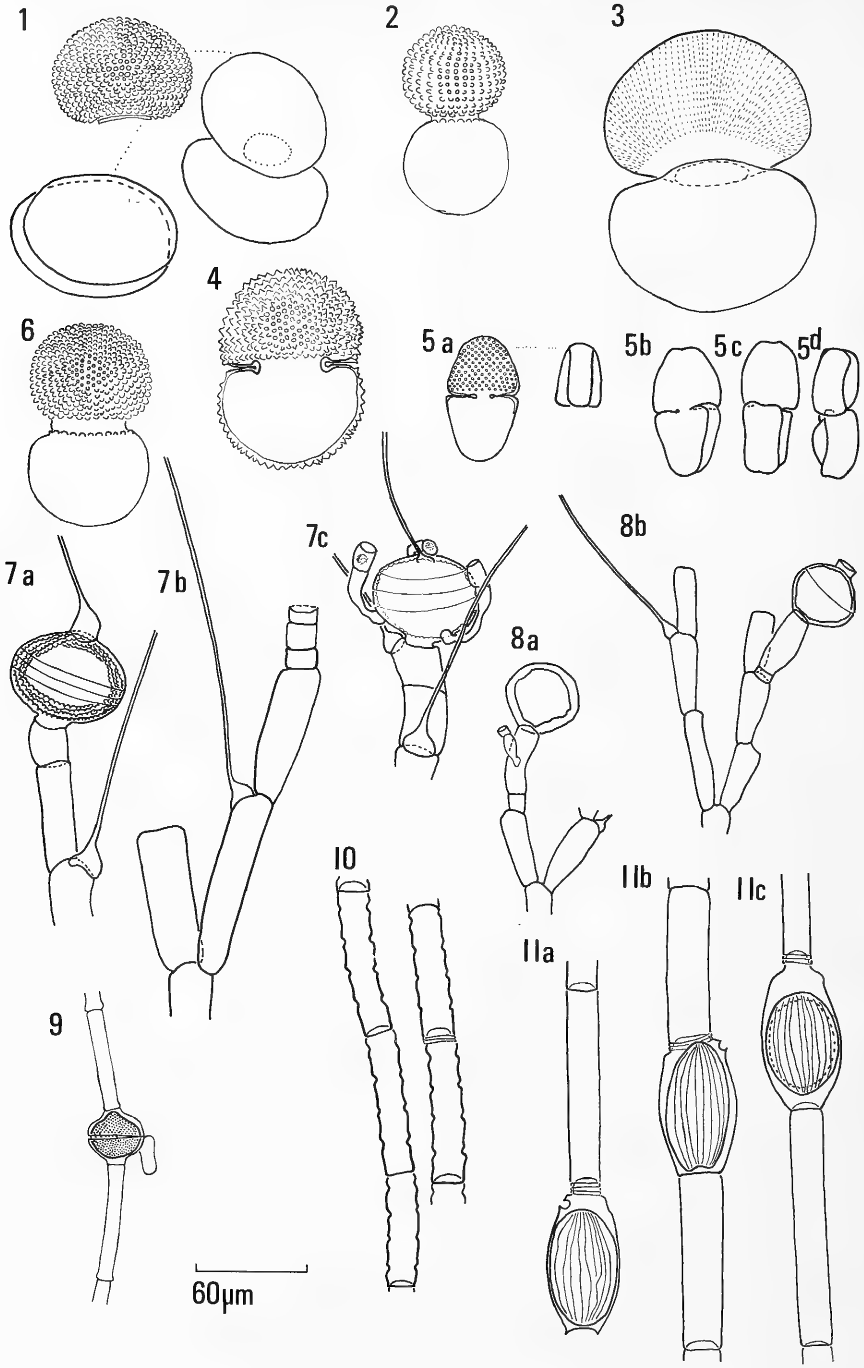

Fig. 2. **1,** *Cosmarium amplum,* Baldersleigh, swamp; **2,** *C. glyptodermum,* Baldersleigh, swamp; **3,** *C. lundellii,* Backwater, swamp; **4,** *C. magnificum,* Backwater, swamp; **5a-d,** *C. spirale,* Backwater, fen; **6,** *C. striolatum* var. *nordstedtii,* Bullock Ck, Point Lookout; **7a-c,** *Bulbochaete gigantea,* Bullock Ck, Point Lookout; **8a, b,** *B. elatior,* Bullock Ck, Point Lookout; **9,** *Oedogonium areschougii,* Backwater, swamp; **10,** *O. undulatum,* Baldersleigh, swamp; **11a-c,** *O. boscii,* Yellow Gap, swamp.

var. *scrobiculata* Tiffany.

Fig. 2, **8a, b.**

Bullock Ck, Point Lookout, bog (*Skinner,* Dec. 1974).

Bulbochaete gigantea Pringsheim 1858. Tiffany, 1930. 38, pl. 5, figs 35, 36. Gauthier-Lièvre, 1964: 248, pl. 239, fig. 44, c-g. Gemeinhardt, 1939: 386, fig. 475.

Cells large, L/B 4-6, W 20-25 μm; idioandrosporous and nannandrous, androsporangia on separate plants in this collection, 1-5 celled, terminal or subterminal on branch, 15 x 15 μm; dwarf males epigynous, 3 celled; oogonium subglobular, terminal, L/B 0.8-1, W 45-50 μm, supporting cell division median or slightly above, oospore filling oogonium reticulate scrobiculate. This form differs slightly from that described by Tiffany (1930).

Fig. 2, **7a, b, c.**

Bullock Ck, Point Lookout, bog (*Skinner,* Dec. 1974).

Oedogonium areschougii Wittrock 1870. forma. Tiffany, 1930: 140, pl. 53, fig. 500. Gauthier-Lièvre, 1964: 450, pl. 98, fig. 161, a-e. Gemeinhardt, 1939: 383, fig. 327.

Cells small and narrow with a distinct basal capitulum, L/B 10-15, W 5-8 μm; nannandrous (androsporangia not observed), dwarf males one celled, bean shaped epigynous; oogonium compressed globose, opening by a central suture, 18-22 μm in diameter; oospore not quite filling the oogonium, brown, wall papillose, 16-20 μm in diameter.

Fig. 2, **9.**

Backwater, hanging swamp (*Skinner,* March, June, Dec. 1974).

Oedogonium boscii (Le Clerc) Wittrock 1874. Tiffany, 1930: 91, pl. 26, fig. 225-226. Gauthier-Lièvre, 1964: 319, pl. 50, fig. 82, a-d. Gemeinhardt, 1939: 149, fig. 151.

Cells moderately large, cylindrical L/B 3-10, W 15-18 μm; only oogonia found in collection; pore superior, oogonium single (in groups separated by two or three vegetative cells), oblong ellipsoid, L/B 1½-2, W 36-40 μm, oospore ellipsoid striate, light brown, not filling oogonium longitudinally, L/B 1-1½, W 35-38 μm.

Fig. 2, **11a, b, c.**

Yellow Gap, Guyra-Mt. Mitchell Road, swamp (*Skinner,* June 1974).

Oedogonium bourellyanum Villeret, 1951: 39, fig. 3. Gauthier-Lièvre, 1964: 280.

Cells moderately large, cylindrical, L/B 5-7, W 12-18 μm; gynandrosporous, nannandrous, androsporangium up to 8-celled each cell 15-20 μm long; dwarf males large, 55-60 μm long, three-celled (stipe and two sporangial cells), on supporting cell of oogonium, numerous; oogonia one or two together inflated, constricted at the superior suture, cap projecting to upper vegetative cell, L/B 1-1½, W 57-62 μm, supporting cell elongate cup-shaped cospore the shape of the oogonium, but not quite filling it, 55-60 μm wide. The form found in the Yellow Gap collection differs from the type being narrower in width of vegetative cells, the position of the oogonium, intercalary in this form, not terminal, and the oogonium shows an invagination at the suture. This taxon keys to *O. mirandrium* in Tiffany (1930), but is altogether larger and has multicellular dwarf males.

Fig. 3, **1a, b, c.**

Oedogonium capilliforme Kützing 1853. Tiffany, 1930: 81, pl. 19, fig. 172-173. Gauthier-Lièvre, 1964: 307, pl. 44, fig. 72a, pl. 47, fig. 72, a-c. Gemeinhardt, 1939: 149, fig. 51.

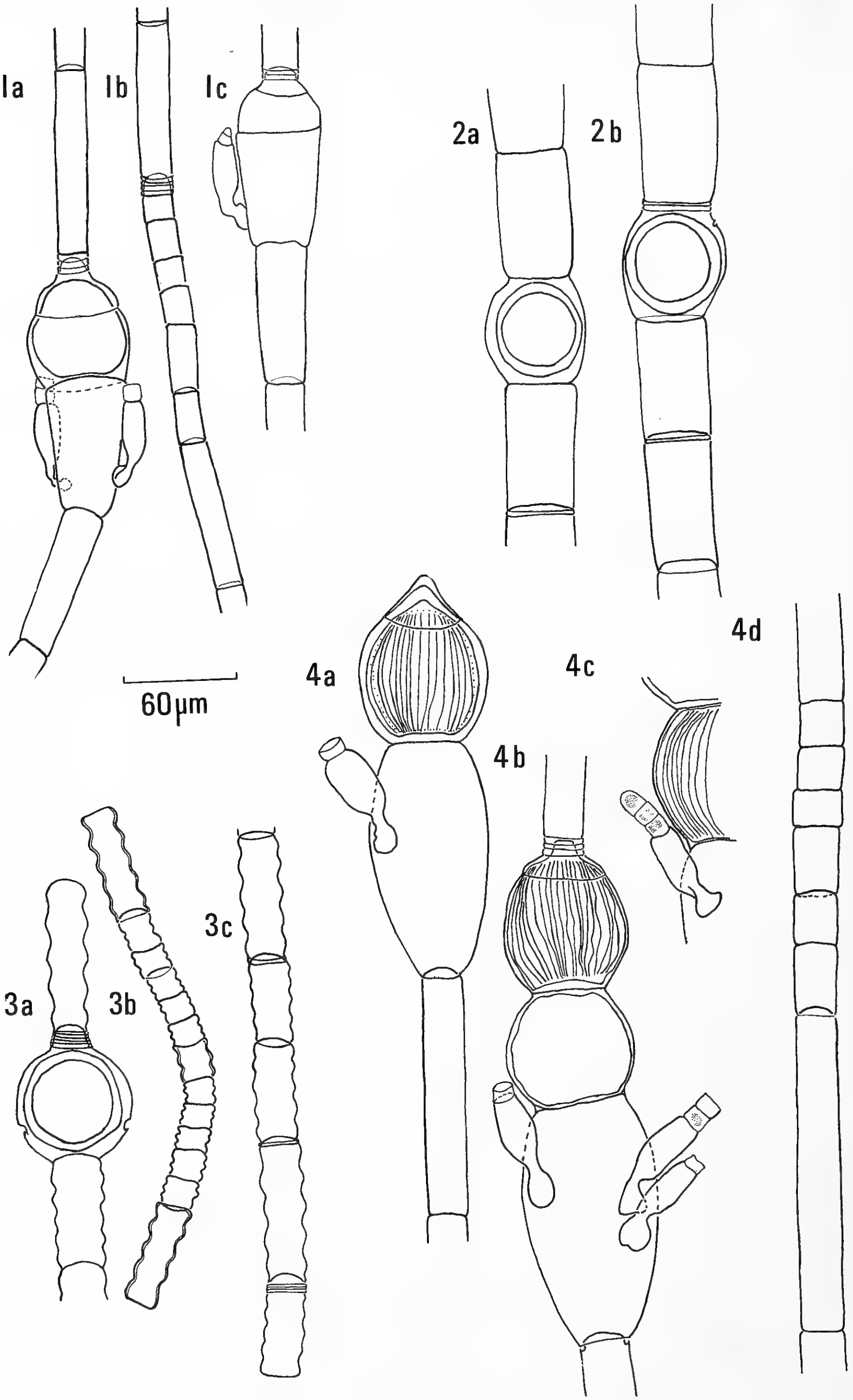

Fig. 3. **1a-c,** *Oedogonium bourrellyanum,* Yellow Gap, swamp; **2a, b,** *O. capilliforme,* Cooney Ck; **3a-c,** *O. wissmanii,* Bullock Ck, Point Lookout, bog; **4a-d,** *O. wolleanum,* Bullock Ck, Point Lookout, bog.

Cells large, cylindrical, L/B 2-5, W 30-40μm; androsporangia not observed with certainty, one or two celled among vegetative cells; oogonia inflated cylindrical, only slightly wider than vegetative cells L/B 1-1½, W 40-48 μm, opening by a superior pore; oospores spherical, golden brown, smooth walled, almost filling the oogonium, 40-45 μm wide.

Fig. 3, **2a, b.**

Cooney Creek, near Hillgrove (*Skinner,* Dec. 1974).

Oedogonium undulatum (Brébisson) A. Braun 1854. Tiffany, 1930: 118, pl. 42, fig. 407. Gauthier-Lièvre, 1964: 466, pl. 103, fig. 171f. Gemeinhardt, 1939: 222, fig. 250. Moebius, 1892: 429, fig. 9a-c.

A form similar to that described by Moebius in Bailey (1895), and described as var. *moebiusii* Schmidle (1896: 297, pl. 9, fig. 1) and accepted by Playfair (1917), with flattened undulations, cells moderately narrow, L/B 4-6, W 12-15 μm; attached oogonia few in collection, mostly broken.

Fig. 2, **10.**

Baldersleigh, near Kingston, swamp (*Wissman,* Sept. 1974).

Oedogonium wolleanum Wittrock 1878. Tiffany, 1930: 135, pl. 50, fig. 479, Gauthier-Lièvre, 1964: 353, pl. 64, fig. 104a-c. Gemeinhardt, 1939: 267, fig. 310.

A very large species; cells moderately large, L/B 6-10, W 20-25 μm; idioandrosporous, nannandrous; androsporangium 8-12 (16) celled; dwarf males numerous on a supporting cell, 4 celled (3 + stipe), 70-90 μm long, W 15-20 μm in the stipe; oogonia solitary to three celled, with a terminal dome, suture superior, supporting cell elongate cupshaped, maximum width 60-65 μm, oospores filling the oogonium, striated, golden brown, 65-75 μm wide. This form should also be compared with *O. striatum* Tiffany (1930) (*O. wolleanum* var. *insigne* Nordst.) in Gemeinhardt (1939).

Fig. 3, **4a-d.**

Bullock Creek, Point Lookout, bog (*Skinner,* Dec. 1974).

Oedogonium wissmanii sp. nov.

Diagnosis: Paries cellulae undulata 4 undis cellulae, L/B 3-6, 23-30 μm late; idioandrosporous sine nannandroecio, androsporangium 4-7 cellulare duobus undis cellulae, L/B 1; oogonium globosum, sutura inframedia, 55-60 μm oogonium globosum, sutura inframedia, 55-60 μm diametro; oospora globosa laevis, 48-53 μm diametro.

Iconotypus: Fig. 3, **3a, b, c.**

Cells moderately large, walls undulate, with 4 undulations per cell, L/B 3-6, W 23-50 μm; idioandrosporous, androsporangium four- to seven-celled, with two undulations per cell, L/B 1; oogonium globose, with a terminal dome, suture wide and inframedian, 55-60 μm wide, oospore globose, smooth walled, not filling the oogonium, 48-53 μm.

Iconotype: Fig. 3, **3a, b, c.**

Bullock Creek, Point Lookout, bog (*Skinner,* Dec. 1974).

Named for Hans Wissman, who collected many samples of freshwater algae for the author and suggested other sites for collecting. Differs from *O. undulatum* in size, lacking dwarf male plants, and in having undulate walls on the androsporangial cells. Type material stored at National Herbarium, Royal Botanical Gardens, Sydney.

Some records of the occurrence of Oedogoniophyceae, seven taxa in *Oedogonium* and two taxa in *Bulbochaete,* in New South Wales appear in Playfair (1917) but without localities. This class is not well documented for

Australia, but two taxa from the present collections are also recorded from Queensland by Moebius (1892).

SUMMARY

The desmid flora of north-eastern New South Wales, as presently known, has many species in common with both the Indo-Malay-northern Australia and temperate Australia-New Zealand floras of Krieger (1932). *Gronbladia neglecta, Desmidium suboccidentale, Phymatodocis nordstedtiana, Euastrum longicolle* formae, *Cosmarium askenaskiyi* and *C. denticulatum* are species common to the Indo-Malayan flora and this region. Most other taxa are common throughout the world. Many species, e.g. *Staurastrum sexangulare,* which reaches its greatest diversity of form in Indonesia (Scott and Prescott, 1961), are found throughout Australia and New Zealand. Much further research is needed before the interrelations between these tropical and temperate floras are clearly documented. The flora of the north-eastern New South Wales may prove to be part of the interface between the two floras as the climate and ecological variables are present in this region.

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*Not seen by author.

Darwin and *Diprotodon:* The Wellington Caves Fossils and the Law of Succession

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DUGAN, K. G. Darwin and *Diprotodon:* the Wellington Caves fossils and the law of succession. *Proc. Linn. Soc. N.S.W.* 104 (4), (1979) 1980: 265-272.

Fossil evidence from the Wellington Caves of New South Wales contributed to the overthrow of the theory of special creation and promoted the development of Darwinian theory. The law of succession, which notes the close affinities between recently extinct and living species, was first established on the basis of the Wellington Caves fossils. This law provided a powerful argument in favour of evolution and first attracted Darwin's attention to the problem of the origin of species.

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INTRODUCTION

In the early decades of the nineteenth century Australia was sparsely settled and its colonists had little time to devote to scientific investigation. Palaeontological discoveries were rare and the colonists themselves lacked the scientific expertise necessary to interpret their significance. But the Australian fossil evidence provided European biologists with the key to a fundamental law of distribution and contributed to the development of a new theoretical framework, Darwinian evolution.

The exploration of the Wellington Caves of New South Wales in 1830 led to the first major discovery of mammalian fossils in Australia. The caves aroused a great deal of interest and speculation in Europe because they provided the first evidence of past geographic distribution of mammals in Australia, a continent known for its biological peculiarities. The Wellington fossils challenged some of the treasured assumptions of the Scriptural geologists, particularly belief in the universal Deluge, and thus raised uncomfortable doubts regarding the literal truth of the Bible. More significantly, the fact that the recently extinct Australian mammals were marsupials and thus clearly related to the living mammals of Australia led to the formulation of the 'law of the succession of types', a generalization of fundamental importance in the development of evolutionary theory.

Colonist George Ranken first discovered the fossil remains of the Wellington Caves (Lane and Richards, 1963) and brought them to the attention of the Surveyor-General of New South Wales, Thomas Livingstone Mitchell, who conducted further explorations. Mitchell was particularly interested in cave fossils because he wished to show that the diluvial geology of William Buckland applied in Australia as well as in Europe (Foster, 1936). In *Reliquiae Diluvianae* (1824) Buckland had argued that the recent fossilized remains of large extinct mammals in European caves revealed the action of a universal deluge. These inhabitants of the antediluvian world were, he claimed, destroyed by a world-wide flood. Buckland's views, supportive of the literal truth of *Genesis,* were widely adopted in Australia where conservative religious beliefs predominated in scientific circles.

Colonist John Dunmore Lang first announced the Wellington discovery (Lang, 1830), interpreting the fossils in the context of traditional Christian belief as proof of the literal truth of Scripture and evidence of the wisdom and foresight of the Creator. Lang, a Presbyterian clergyman with an amateur interest in geology, was eager to show that the facts of science were not in conflict with the Mosaic account of creation and the Deluge (Lang, 1846, 1951).

He noted that many of the cave animals were extinct or at least were no longer to be found in New South Wales. Lang adopted Buckland's theory, attributing their extinction to natural catastrophe, a catastrophe which did not materially change the external appearance of the country, i.e., a flood.

He concluded:

> While this very interesting discovery supplies us, therefore, with another convincing proof of the reality and universality of the deluge, it supplies us also with a powerful motive of gratitude to Divine providence for that long-forgotten visitation. For if this territory were over-run with such beasts of prey as the antediluvian inhabitants of the cave at Wellington Valley, it would not have been so eligible a place for the residence of man as it actually is. The tiger or hyaena would have been a much more formidable enemy of the Bathurst settler than the despicable native dog, though indeed they would certainly have afforded a much nobler game to the gentlemeu [sic] of the Bathurst Hunt. And if the huge rhinoceros had inhabited the lagoons of Hunter's River, it might have been a much more serious work to displace him than to shoot the pelican or emu. [Lang, 1830]

Just as Lang and other colonists sought to explain the huge fossils in a manner consistent with their Christian beliefs, so the Aborigines explained them within their own frame of reference. The Aborigines of Eastern Australia were very fearful of the bunyip, a legendary aquatic monster inhabiting deep waterholes and roaming the billabongs at night. Confronted with the fossil remains of gigantic animals, Aborigines often identified these as the remains of the bunyip (Barrett, 1946). As one colonist observed:

> It may not be amiss to state that all the Natives throughout these Northern Districts have a tradition relative to a very large animal having at one time existed in the large Creeks & Rivers & by many it is said that such animals now exist & several of the Fossil bones which I have at various times shown to them they have ascribed to them. Whether such animals as those to which they refer be yet living is a matter of doubt, but their fear of them is certainly not the less & their dread of bathing in the very large waterholes is well known — [Isaac, 1845]

J. W. Gregory, Professor of Geology at the University of Melbourne (later at the University of Glasgow), suggested that Aboriginal legends of gigantic monsters might be based upon a knowledge of the living *Diprotodon* (Gregory, 1906, p. 7).

Lang's theory was published in Europe (Lang, 1831) but European biologists were quick to offer an alternative explanation. Examples of the Wellington Caves fossils were sent to Robert Jameson, Professor of Natural History at Edinburgh University, for identification by European experts. Jameson forwarded them to William Clift, Conservator of the Hunterian Museum, who identified the remains of dasyurids, wombats, and kangaroos (Clift, 1831). All the bones belonged to marsupials of the Australian type with one apparent exception. Lang had suggested that a large thigh bone found in the caves belonged to an Irish elk, rhino, or elephant (Lang, 1830). Clift compared it to the thigh of an ox or hippo (Clift, 1831), and William Pentland claimed that it represented the remains of an elephant (Pentland, 1831). From these data, Jameson observed that Australia, like Europe, was formerly populated with gigantic animals which have since become extinct. Moreover, he argued that the cause of extinction was the same in Europe and Australia, but he did not identify this cause as the Biblical flood. Most significantly, he concluded "[t]hat New Holland was, at a former period, distinguished from the other parts of the world, by the same peculiarities in the organization of its animals, which so strikingly characterize it at the present day" (Jameson, 1831).

This conclusion challenged catastrophist theories. Georges Cuvier, of the Muséum d'Histoire Naturelle in Paris, had developed methods of comparative anatomy which had enabled palaeontologists to reconstruct the skeletons of animals from the fragmentary remains preserved in the fossil record. A vast array of fantastic creatures, now extinct, had been revealed for the first time to an astonished public. Cuvier believed that past geological changes had been sudden and violent, thus causing the extinction of whole populations of plants and animals. These had been replaced by new, unrelated species, either by migration or (as many of Cuvier's followers, including Buckland, believed) by a succession of miraculous, divine creations. Catastrophist theory necessarily ruled out evolution because rapid, violent changes did not allow the necessary continuity of generations and because a comparatively limited age of the earth did not allow adequate time for gradual evolutionary change. Cuvier was recognized as the foremost naturalist of his day, and the full weight of his formidable reputation was solidly opposed to evolution (Coleman, 1964). The full significance of the Wellington Caves discoveries was not recognized until after Cuvier's death in 1832.

The fossils raised uncomfortable doubts about catastrophism and special creation. If all the plants and animals of the Tertiary were destroyed by a universal deluge and subsequently replaced by a specially created, entirely new set of plants and animals, why should there be any continuity between existing species and recently extinct species? In fact, from the principle of adaptation of organisms to their environment one would expect that organic changes would accompany drastic changes in the physical environment. The discontinuities of fossil distribution provided Buckland with the major evidence in support of his theory. European caves contained the fossil remains of tropical species like hyaenas and elephants which no longer survived in Europe. Buckland concluded that these animals had been destroyed by a world-wide flood and expected to find evidence of similar discontinuous distribution on other continents.

The Wellington fossils, however, suggested quite the opposite conclusion. Some of the species found in the caves were still living in Australia, and most European scientists were struck with the similarities between the extinct and living species rather than with the differences. Pentland, for example, observed:

> with a single exception, all the genera to which these fossils are referable, are now found inhabiting the Australasian Continent, a remarkable coincidence with the fossil animals of the same geological epoch in Europe, where, with few exceptions, the animals which have been found in what have been called Diluvial Deposits, belong to genera still inhabiting our countries. [Pentland, 1832]

This fact was taken to cast doubt on Buckland's diluvialist theories. In 1833 Mitchell wrote to George Ranken concerning the significance of their discovery at Wellington:

> I understand Buckland's nose is put completely out of joint by the bones from Australia, their not being those of lions and hyenas is, I find, a fact which is considered in England to entirely upset his theory. And I have now heard from the best authority that the fact of their fossil bones belonging to animals similar to those now existing has worked a great change in all their learned speculating on such subjects at home. [Ranken, 1916, p. 29]

The discovery that the peculiarities of the living Australian flora and fauna were reflected in the fossil species as well suggested that the laws of geographic distribution which currently confine particular groups of animals within particular geographic regions applied in the recent geologic past as well.

The Wellington discoveries, coupled with Darwin's observations in South America, led him to formulate the law of the succession of types. This law provided important evidence in favour of evolution and, indeed, turned Darwin's attention towards the problem of the origin of species (De Beer, 1968, pp. 79-80; Eiseley, 1961, pp. 161-166; Himmelfarb, 1962, pp. 108-113).

Darwin is credited with developing the law in 1837 as a result of his fossil discoveries in South America. Finding the remains of giant mammals related to sloths, llamas and armadilloes, he noted that these extinct mammals are now represented by smaller animals, also confined to South America, which display the same peculiarities of anatomy as their larger predecessors (C. Darwin, 1838). Subsequently, Darwin (1839, pp. 209-210) wrote:

> The most important result of this discovery, is the confirmation of the law that existing animals have a close relationship in form with extinct species . . . The law of the succession of types, although subject to some remarkable exceptions, must possess the highest interest to every philosophical naturalist, and was first clearly observed in regard to Australia, where fossil remains of a large and extinct species of Kangaroo and other marsupial animals were discovered buried in a cave. In America the most marked change among the mammalia has been the loss of several species of Mastodon, of an elephant, and of the horse . . . If Buffon had known of these gigantic armadilloes, llamas, great rodents, and lost pachydermata, he would have said with a greater semblance of truth, that the creative force in America had lost its vigour, rather than that it had never possessed such powers.

Contemplating the Wellington fossils, Thomas Mitchell offered a similar suggestion with regard to the waning power of Australian nature:

> It is consolatory here to find that Australia did once support herbivorous animals of such magnitude — and that an animal so well provided for a country of burning woods and fallen timber — by its young = [sic] protecting pouch and saltatory powers has always belonged to Australia — although the curious gradation of species — and the diminutive character of existing classes seem to indicate the energies of animal nature here to be on the wane — unless indeed this is a wise provision of providence for the introduction of those other large animals by man's agency — which have been found better suited to his wants. [Mitchell, 1843]

The influence of the Australian fossils on the development of the law of the succession of types has not been generally emphasized. Historians have tended to stress instead the importance of Darwin's own South American experiences. Darwin himself, as he tried to reconstruct the development of his ideas in retrospect, recalled the importance of the South American observations. He wrote in his Journal:

> In July [1837] opened first note book on "Transmutation of Species" — Had been greatly struck from about Month of previous March on character of S. American fossils — & species on Galapagos Archipelago. These facts origin (especially latter) of all my views. [C. Darwin, 1959, p. 7]

However, as historian Camille Limoges points out, it is doubtful if Darwin could have developed a comprehensive generalization on the basis of a single South American example (Limoges, 1970, pp. 17-18). The significance of the discovery is unclear until one recognizes that it is true for other parts of the world as well. In fact, Darwin himself cited Clift's work on the Wellington fossils as evidence for the law of succession (C. Darwin, 1859, p. 339). Clift's work was also cited favourably in Lyell's *Principles of Geology* (Lyell, 1833, p. 144), which Darwin had studied while on the *Beagle*. In 1831 E. W. Brayley suggested the possibility of such a correlation in distribution (Brayley, 1831), but the Wellington Caves provided the first and most dramatic evidence for the law.

In 1844 Richard Owen developed a similar law, again based on the Wellington find. Owen, Britain's leading comparative anatomist and palaeontologist, was intensely interested in Australian natural history and developed an extensive correspondence with observers in Australia (Moyal, 1976). Owen classified the vertebrate fossils Darwin had collected on the voyage of the Beagle (C. Darwin, 1840) and provided a description of the Wellington fossils for Mitchell's *Three Expeditions into the interior of Eastern Australia* (Mitchell, 1838). Owen cited the Australian fossils as evidence

> that, with extinct as with existing Mammalia, particular forms were assigned to particular provinces, and, what is still more interesting and suggestive, that *the same forms were restricted to the same provinces at a former geological period as they are at the present day*. [Owen, 1845]

This generalization was frequently repeated in Owen's publications and, together with his work on Darwin's 'Beagle' fossils, formed the basis of his claim to priority in formulating the law of succession. Although Darwin readily acknowledged that Owen had extended the law to apply to the Old World, Owen's attempt to claim credit for the law irritated him. In a letter to Lyell in 1859, he complained:

> Why I gave [in the *Origin*] in some detail references to my own work is that Owen (not the first occasion with respect to myself and others) quietly ignores my having ever generalised on the subject, and makes a great fuss on more than one occasion at having discovered the law of succession . . . Long before Owen published I had in MS. worked out the succession of types in the Old World . . . [F. Darwin and Seward, 1903, I, p. 133]

As further research provided additional evidence for the law of succession, it became an accepted rule of geographic distribution. The close relationship between existing species and recently extinct species strongly suggested an evolutionary connection. Such a connection was, of course, denied by the anti-evolutionists, but they could offer no satisfactory alternative explanation.

Although the discovery at Wellington Caves led to the formulation of the law of succession, it also offered a major exception to it, the alleged Australian elephant. Naturalists wished to show a close affinity between existing species and recently extinct species. Reports of a large Australian placental violated this rule.

Thomas Mitchell had already questioned the identification. He wrote to Ranken in 1831, 'They find most of them [the Wellington Caves fossils] to be wombats and kangaroos, but Cuvier calls your large bone an elephant's. The London surgeons, however, seemed puzzled about it, and I have doubts . . .' (Ranken, 1916, p. 25).

In 1838 Owen resolved the problem by identifying the large Wellington fossil as a new species, *Diprotodon optatum,* a giant, wombat-like marsupial (Mitchell, 1838, 1, p. xix; 2, pp. 362-363). But this was not the end of claims that proboscideans once roamed the Australian bush. In 1843 Owen identified a fossil from the Darling Downs as a *Dinotherium,* an extinct placental pachyderm (Owen, 1843a, 1843b). The following year he corrected this error, noting that some of these bones, too, belonged to *Diprotodon*. At the same time, however, he identified a fossil tooth, ostensibly from Australia, as that of a *Mastodon* (Owen, 1844). This tooth, which the Polish explorer Strzelecki claimed to have acquired from an Australian Aborigine, served as the basis for later accounts of mastodons in Australia. These false identifications and conflicting reports caused a great deal of confusion. Explorer Ludwig Leichhardt (1855) questioned whether there was sufficient evidence to prove this dramatic exception to a well-established rule of geographic distribution. Nevertheless, in Europe, as in Australia, the former existence of an Australian placental pachyderm was generally accepted.

For evolutionists, it was important to get the mastodon out of Australia. Darwinists wished to explain the unique character of the Australian fauna as a result of isolation and natural selection. They claimed that Australia had at an early geological period become separated from the rest of the world by vast oceans. Marsupials, isolated from competition with placentals, evolved to fill a variety of ecological niches. One might account for the presence of placental rodents by Darwin's mechanisms of chance dispersal but these were hardly sufficient to account for the migration of the huge mastodons.

The Australian mastodon remained an anomaly until 1863 when the British palaeontologist Hugh Falconer challenged its existence. Falconer agreed that Strzelecki's tooth belonged to a mastodon, but noted that it appeared to belong to a South American species. Since claims for the existence of mastodons in Australia rested solely on this isolated example, Falconer concluded there must be an error respecting the origin of the fossil (Falconer, 1863). Owen quietly abandoned his claim. Darwin rejoiced in the overthrow of the mastodon, writing to Falconer in November, 1862, 'I never did or could believe in him' (F. Darwin and Seward, 1903, I, p. 211). In 1882, Owen made one final attempt to revive the Australian proboscidean (Owen, 1882), but he was unsuccessful.

The law of succession, once firmly established, provided a powerful argument in favour of evolution. If one adopts the theory that new species develop from preexisting ones by a process of descent with modification, then it is absolutely necessary that there be a continuity between existing species and recently extinct species. Moreover, the opposing theories of the anti-evolutionists failed to explain this continuity.

The special creationists emphasized the perfect adaptation of animals to their environment, and they attributed this adaptation to God's benevolent design. Yet, as Darwin pointed out, such theories were insufficient to account for the South American and Australian observations. He noted that the animals of Australia are very different from those of South America, even though parts of each continent share a similar climate. Therefore, one could not account for the dissimilarities between South American and Australian animals solely on the basis of adaptation to different environments. At the same time, one could not explain the similarities between living and recently extinct animals on the same continent solely as a result of adaptation to similar environments, because geological change should presumably be accompanied by organic change. Darwin claimed that only a theory of evolution could adequately explain these facts:

> On the theory of descent with modification, the great law of the long enduring, but not immutable, succession of the same types within the same areas, is at once explained; for the inhabitants of each quarter of the world will obviously tend to leave in that quarter, during the next succeeding period of time, closely allied though in some degree modified descendants. If the inhabitants of one continent formerly differed greatly from those of another continent, so will their modified descendants still differ in nearly the same manner and degree. [C. Darwin, 1859, p. 340)

The law of succession not only provided important evidence in support of evolution, it also played a role in convincing Darwin of the validity of evolution. He wrote to Lyell in 1859, 'In fact, this law, with the Galapagos distribution, first turned my mind on the origin of species' (F. Darwin and Seward, 1903, I, p. 133).

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*The ascription to William Pentland is almost certainly an error given currency by Robert Jameson, editor of the *Edinburgh New Philosophical Journal.* W. A. S. Sarjeant and J. B. Delair (*Bull. Brit. Mus. (Nat. Hist.)* , hist. series, 6(7), 1980, p. 319) assign the work to Joseph Barclay Pentland [1797-1873]. *Note added by T. G. Vallance.*

Rock Units, Structure and Metamorphism of the Port Macquarie Block, eastern New England Fold Belt

EVAN C. LEITCH

LEITCH, E. C. Rock units, structure and metamorphism of the Port Macquarie Block, eastern New England Fold Belt. *Proc. Linn. Soc. N.S.W.* 104 (4), (1979) 1980:273-292.

The presence of syn- and late-orogenic rocks, relationships between recrystallization and imposed structures, and contrasts between units separated by large faults, has allowed reconstruction of a detailed structural and metamorphic history of the Port Macquarie Block.

Three units of stratified rocks are recognized: the Watonga Formation mainly composed of chert and slate of pre-Devonian age, the Middle Palaeozoic Touchwood Formation consisting of volcanogenic clastic sedimentary rocks and andesite, and the Thrumster Slate comprising slate and meta-sandstone of Early Permian (?) age. These units have been intruded by dolerite dykes collectively grouped in the Karikeree Metadolerite, by serpentinite bodies, and by felsic dykes, and are unconformably overlain by Early Triassic conglomerate of the Camden Haven Group.

The Watonga Formation and Thrumster Slate together with early members of the Karikeree Metadolerite were cleaved and recrystallized under greenschist facies conditions at an early stage during Late Permian orogenesis. Later dolerite bodies emplaced in the cleaved rocks are massive but also show greenschist facies mineral assemblages. Touchwood Formation rocks and associated Karikeree Metadolerite dykes lack cleavage and suffered only burial metamorphism, under prehnite-pumpellyite metagreywacke facies conditions. They were brought into contact with the more intensely deformed rocks by transcurrent movements along a system of northnorthwest-trending faults that slice the block. Subsequently serpentinite masses rose along some of these fractures as well as along a somewhat younger northwest striking fault. Isolated glaucophane schist blocks in soil at one locality have probably weathered out of a serpentinite lens.

A small thermal high in which static recrystallization produced biotite post-dates most deformation and may be associated with a buried intrusive body. Here the serpentinite contains antigorite, in contrast with the chrysotile-lizardite serpentinites elsewhere in the block, and is associated with lenses of talc and chlorite-tremolite rocks.

Fault movements continued into post-Early Triassic times, juxtaposing Camden Haven rocks and both serpentinite and earlier Palaeozoic rocks.

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INTRODUCTION

The meridional trend of major tectonic units that characterizes most of the Tasman Orogenic Zone cannot be recognized in the eastern part of the New England Fold Belt. Instead, stratified rocks of diverse facies, structural history, and metamorphic character, are juxtaposed across a complex series of faults that divide the region into irregular blocks, of which the 150 km^2 Port Macquarie Block is the smallest (Fig. 1; Leitch, 1974). The only accessible contact of this block with other Palaeozoic rocks is on its west, where it abuts Carboniferous and Early Permian sedimentary rocks of the Hastings Block along the Cowarra Fault. To the south the block is faulted against Early Triassic strata of the Lorne Basin, and to the north it disappears beneath Quaternary sediment. The eastern edge of the block lies beyond the coastline except perhaps north of Tacking Point where coastline and a northwest-bounding fault may coincide.

No systematic account of the nature of the block has been published previously, although Voisey (1939) described some of the constituent rocks. Carne (1896), Quodling (1964) and Barron, Scheibner and Slansky (1976) have provided data concerning serpentinite and associated rocks that occur along the coast north of Tacking Point, and in view of these reports, and forthcoming accounts by Samuels (*in prep.*) and Leitch (*in press*) the geology of this complex zone is not treated here.

Recent investigations by the author confirm the distinctive character of the Port Macquarie Block but indicate that it is more geologically diverse than has previously been recognized. Northnortheast-trending faults divide the predominantly Palaeozoic mass into domains of differing rock sequences, structural character, and metamorphic history, and its unity derives principally from a persistent structural grain and the presence in each domain of members of a suite of metadolerites.

ROCK UNITS

Most of the Palaeozoic rocks of the Port Macquarie Block are placed in lithostratigraphic units of formational status that are defined here for the first time. Distribution of the various units is shown on Fig. 1.

Watonga Formation

The Watonga Formation comprises abundant chert and slate, uncommon meta-sandstone, and rare metabasalt, found east of the Lake Innes Fault. The name is derived from Watonga Rock (932171*) designated the type locality for the unit. Irregular folds and numerous faults throughout the formation prevent designation of a meaningful type section.

Chert is typically thin-bedded with stratification defined by colour changes and the presence of thin slate beds and argillaceous partings. Massive chert found particularly adjacent to faults and in some fold hinges has resulted, at least in part, from intense deformation and partial recrystallization of originally thin-bedded units, for in some mesoscopic folds massive chert in the hinge area passes into stratified material in the fold limbs. The cherts are composed of anhedral interlocking quartz grains 0.01-0.02 mm across cut by several generations of quartz veins; traces of radiolaria remain in some samples. A few small mica flakes are scattered through the rocks, which contain tiny hematite grains that impart a progressively more intense red colour as their amount increases. At several localities (876144, 837095) hematite has been concentrated sufficiently to yield impure ironstone intercalations in the cherts. Slate forms units up to several tens of metres thick. It ranges from green chloritic quartz-poor varieties to dark grey micaceous types in which discontinuous quartz segregations occur parallel to cleavage. Stratification is indicated by colour changes and thin fine-grained meta-sandstone laminae. The rocks are texturally reconstituted, detrital relics are absent and cleavage is defined by parallel phyllosilicate films. Meta-sandstone is interstratified with slate at 873140. Little primary structure is preserved and relic detrital grains of plagioclase and less abundant quartz are scattered through a groundmass rich in white mica.

Exposures of igneous rocks of the Watonga Formation (904197, 904191, 905185) are extremely weathered; abundant chloritic material suggests a mafic composition, and relic textural features indicated fine to medium grainsize.

Although no stratigraphic divisions have been recognized within the formation several chert-dominated units each probably originally in excess of 100 m thick, are shown on Fig. 1. It is unclear whether the units comprise different stratigraphic levels,

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*Localities are specified by 6-digit grid references read from 1: 25,000 sheets Port Macquarie and Grants Head (1st edition, 9434-I-N and 9435-II-S) published by the New South Wales Department of Lands.

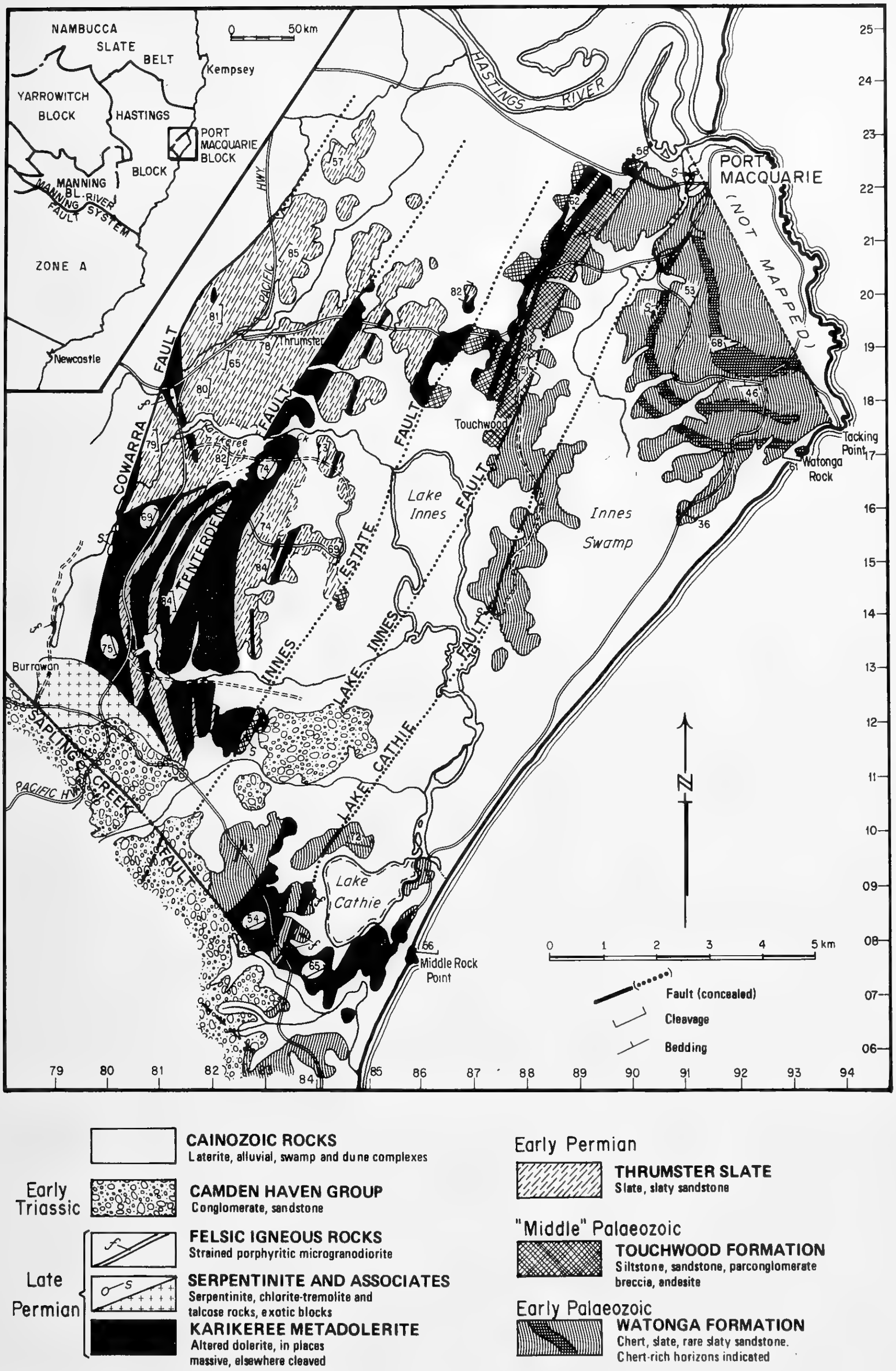


Fig. 1. Geological map of the Port Macquarie Block. (Note an arrow head on the bedding symbol denotes direction of younging.)

or whether they are tectonically repeated slices of the same horizon. The western contacts of two of the units are exposed (913207, 905197). At the first locality thin-bedded chert adjoins slate along a near vertical surface slightly oblique to the overall attitude of stratification in the chert and along which small weathered lenses of serpentinous material are found. Relationships at the second locality are less clear, but again an abrupt boundary is indicated. Several small serpentinite pods occur some 30-50 m to the west of the contact, elongate parallel to it. At both localities isolated blocks of chert several metres long are imbedded in the slates and, especially at 905197, the structure of the slates is characterized by sudden along-strike changes, irregular sheared contacts and abrupt changes in degree of deformation. It is possible that many chert contacts in the Watonga Formation are complex shears that have largely remained unrecognized because of poor exposure. Elsewhere in the unit disruption is suggested by the presence of blocks of chert floating in clay (904191), and steeply-dipping chert zones 2-20 m wide alternating with clay zones 1-50 m wide across contacts oblique to stratification (905185).

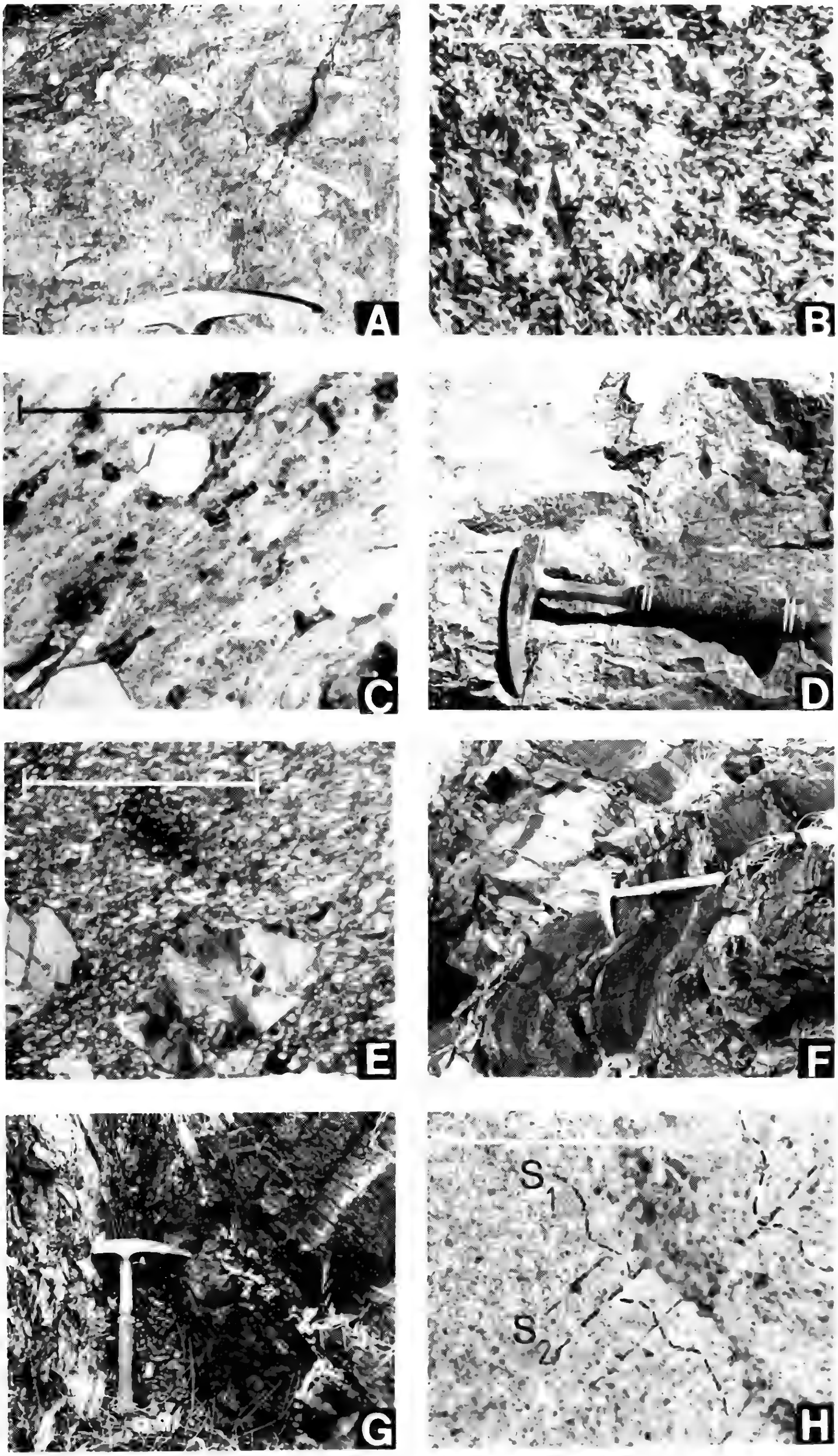
Biostratigraphically useful fossils have not been found in the unit and its age is uncertain. It is intruded by Late Permian metadolerite in the south and is lithologically similar to the Woolomin Beds as defined by Crook (1961) which are of pre-Devonian age (Leitch and Cawood, 1980). Interbedded meta-sandstone and slate at 873140 may belong to a different (? younger) sequence from the rocks further east, for they occur close to the Lake Cathie Fault and are not clearly interstratified with chert-slate sequences typical of the Watonga Formation.

Touchwood Formation

The name Touchwood Formation, derived from the property of that name (877177), is applied to a sequence of siltstone, sandstone, paraconglomerate, basalt breccia and andesite that lies between the Lake Innes and Innes Estate faults north of Lake Innes. Two small areas further south that lack outcrop are mapped as Touchwood Formation by extrapolation (Fig. 1). Neither top nor bottom of the unit is exposed, but it forms a west-younging sequence at least 600 m thick of which the upper 250 m comprises andesite. Typical epiclastic rocks of the formation are exposed in a 40 m section in an old quarry in western Port Macquarie (889224), which is designated the type section.

Siltstone, dark grey to black in colour with a subconchoidal fracture, lacks primary structures apart from horizontal lamination defined by changes in colour and grain size; it characteristically occurs in beds less than 0.1 m thick interstratified with sandstone. The latter are indurated, grey, feldspatholithic rocks containing abundant volcanic debris that form units ranging in thickness from 0.01 to 1.0 m. Many beds are simply graded, a few show small-scale cross lamination, intraformational siltstone clasts are widespread, but the base of beds is usually planar. Paraconglomerate is

Fig. 2. **A.** Paraconglomerate of the Touchwood Formation with fragments of limestone (white), siltstone and volcanic rock fragments (889224). **B.** Andesite from the upper part of the Touchwood Formation (882205). Scale bar = 2 mm. Crossed polars. **C.** Scattered quartz and plagioclase grains in a micaceous groundmass. Meta-sandstone of the Thrumster Slate (824171). Scale bar = 2 mm. Crossed polars. **D.** Highly porphyritic Karikeree Metadolerite (beneath hammer head) in contact with Touchwood Formation rocks (beneath handle) (889224). **E.** Mylonitic groundmass containing strained and fractured relic quartz and plagioclase phenocrysts. From felsic dyke adjacent to Lake Cathie fault (838087). Scale bar = 2 mm. Crossed polars. **F.** Rounded folds affecting S_1 with incipient axial plane crenulation. Slates of Watonga Formation (873140). **G.** Tremolite-chlorite rocks to left of hammer contain small folds with axial plane cleavage dipping vertically and parallel to the contact of these rocks with cleaved slates to the right of hammer. Cleavage within the slates is oblique to the contact. Margin of Lake Innes mass (873140). **H.** Lenticular biotite aggregate cutting across crenulations in S_1 and their associated axial surface structure (S_2). Same locality as F. Scale bar = 0.8 mm. Plane polarized light.


A
B
C
D
E
F
G
S_1
S_2
H

composed of subrounded clasts of limestone, basalt, and andesite, and angular siltstone and interbedded sandstone-siltstone fragments similar to adjacent finer-grained rocks, set in a poorly sorted feldspatholithic sandstone matrix (Fig. 2A). Most conglomerate-grade material is in the size range 0.02-0.1 m diameter, but includes infrequent clasts of limestone up to 0.6 m and bedded sedimentary rocks up to 1.5 m. Clast to matrix ratio is about 1:2. Paraconglomerate forms beds ranging in thickness from 1.5-20+m. Internally the rocks are massive, although there is some preferred orientation of the long axes of clasts parallel to bedding, and in a thick bed at the base of the type section local concentrations of limestone pebbles are found. The top 1 m of this bed is graded from granule conglomerate to sandstone.

All of the clastic rocks are characterized by their quartz-poor character and volcanic provenance. Lithic volcanic debris ranges from basalt to dacite with basalt and andesite dominant. Plagioclase is the most common detrital mineral, quartz is rare, and clinopyroxene is nearly always present in at least accessory amounts.

A massive volcanic breccia horizon at least 50 m thick intercalated between bedded sandstone and siltstone below and coarse sandstone above, is exposed in an abandoned quarry (876183). The rock is composed of vesicular basalt fragments 5-50 mm in diameter together with a few larger clasts (up to 0.1 m) of bedded sedimentary rocks comparable with those underlying the breccia, set in a coarse ill-sorted sandstone matrix. A coarse basalt breccia lacking sedimentary fragments occurs on the north side of the Hastings River (915252).

Poorly exposed andesitic (keratophyric) rocks comprise the upper part of the formation. They are slightly porphyritic rocks, in which small phenocrysts of altered plagioclase occur scattered through a groundmass of aligned plagioclase laths and secondary minerals replacing intersertal glass (Fig. 2B). In contrast to the basaltic rocks clinopyroxene is absent.

Tabulate and rugose corals occur in limestone blocks in the thick paraconglomerate of the type section but these are too altered to allow specific identification. Attempts to obtain conodonts from the limestone blocks were unsuccessful.

Thrumster Slate

Slate, meta-sandstone, and meta-granule conglomerate that outcrop between the Innes Estate and Cowarra faults are termed Thrumster Slate, after the parish of Thrumster in the northwestern part of the Port Macquarie Block. Scattered exposures along Lake Innes Drive (817171 to 824171) comprise the type section. Here, as elsewhere, outcrops are discontinuous and usually deeply weathered, and an estimated thickness of 650 m for this section, which provides a minimum for the unit, assumes no structural repetition of rocks and ignores tectonic thinning attendant upon cleavage formation. The stratigraphic limits of the Thrumster Slate have not been observed and no internal stratigraphy has been recognized.

Slate, the dominant rock type, is of dark blue-grey to black colour when unweathered and has a distinct micaceous sheen. A single planar cleavage is ubiquitous and in some outcrops stratification is indicated by thin beds of poorly cleaved siliceous slate, and fine-grained meta-sandstone laminae. The slate is almost totally recrystallized with cleavage resulting from the parallel growth of white mica films that separate similarly aligned lenses of small quartz and albite grains. Coarse meta-sandstone and granule meta-conglomerate occur together in intervals several tens of metres thick accompanied by little finer-grained material. Individual beds are often simply graded and contain rip-up clasts of siltstone, some over 1 m long. These rocks are dominated by detrital quartz, with lesser relic detrital grains of plagioclase and felsic volcanic rock fragments scattered through a groundmass of white mica (Fig. 2C).

No fossils have been found in the slate and the only signs of organic activity are faecal pellets found at one locality (830497). The unit closely resembles rocks of the Nambucca Slate Belt and on this basis is tentatively assigned an Early Permian age (Runnegar, 1970).

Karikeree Metadolerite

Altered dolerite bodies emplaced within all three stratified Palaeozoic units are grouped in the Karikeree Metadolerite, named from Karikeree Creek that cuts several of the bodies along its course across the western part of the block. Outcrops along Lake Innes Drive (832168 to 827160) constitute the type section.

The doleritic rocks are holocrystalline, of medium grain-size, and at least incipiently altered. Some are crammed with plagioclase phenocrysts up to 20 mm long (Fig. 2D) or contain large clinopyroxene plates, but most are approximately equigranular. Those relatively rich in clinopyroxene have an ophitic texture, whereas more felsic varieties tend to be hypidiomorphic-granular aggregates of equant clinopyroxene grains and plagioclase laths. Plagioclase of intermediate composition was the most common magmatic phase. Although it has been partially replaced by albite, relic labradorite, sometimes normally zoned, occurs in a number of specimens and even some quite highly reconstituted rocks retain feldspar of this composition. Magmatic calcic clinopyroxene is preserved in many metadolerites; colourless, very pale green and distinctly pink varieties are found in different rocks. Coarsely crystalline brown hornblende found in several metadolerites, either as discrete grains or mantling clinopyroxene, is a late-magmatic phase. Apatite rods and angular irregular opaque oxide grains are also magmatic relics.

The alteration of dolerite ranges from incipient to complete. Albite, actinolite, chlorite, epidote and sphene are widespread secondary phases, white mica, clinozoisite, calcite and quartz are less widespread, and garnet is rare. Pseudomorphous replacement characterizes the massive metadolerites, but foliated bodies show a marked preferred orientation of secondary phases and the start of metamorphic differentiation. Planar zones of an exclusively metamorphic character up to a metre wide and containing restricted mineral assemblages, usually dominated by epidote, mark sites of extensive metasomatic alteration and were probably major hydrothermal passageways during metamorphism.

Chemical composition and C.I.P.W. norms for a selection of metadolerites are given in Table 1. On present composition three samples, those with normative nepheline, would be considered alkalic, six samples are olivine-hypersthene normative, and one sample quartz normative and hence apparently tholeiitic. However the norm of the latter is much affected by a high Fe_2O_3/FeO ratio (0.58) and when recalculated for a value of 0.20, normative quartz virtually disappears ($qz = 0.01$). As expected porphyritic samples contain high normative plagioclase and ophitic rocks have relatively large amounts of normative pyroxene plus olivine.

The total alkali versus silica relationship (Fig. 3A, Macdonald and Katsura, 1964) would indicate that both tholeiitic and alkalic rocks are present, with a tendency for more highly metamorphosed rocks to appear more tholeiitic. However, when plotted on Miyashiro's (1975) Na_2O/K_2O versus $Na_2O + K_2O$ diagram some samples fall outside the field occupied by fresh volcanic rocks and the others occur in tholeiitic rather than alkali basalt fields (Fig. 3B). Changes in the amount of Na_2O and K_2O during metamorphism are indicated, and the magmatic affinities of the metadolerites cannot be unambiguously determined from their major element composition.

TABLE 1

Chemical Data

	1	2	3	4	5	6	7	8	9	10
SiO_2	49.09	48.13	47.99	47.90	47.75	47.01	46.92	47.04	46.94	44.83
TiO_2	1.69	2.97	2.66	2.46	1.54	1.99	1.29	2.19	2.98	2.29
Al_2O_3	18.73	14.36	14.73	14.16	18.53	15.05	15.81	14.90	14.61	13.37
Fe_2O_3	0.84	2.28	2.34	1.56	1.72	1.63	1.30	4.29	4.99	3.14
FeO	7.69	10.86	9.97	10.68	7.22	8.98	7.50	7.79	8.54	9.32
MnO	0.15	0.23	0.21	0.23	0.16	0.19	0.16	0.22	0.23	0.20
MgO	5.31	5.46	5.75	6.65	6.16	7.44	9.08	7.16	6.20	11.76
CaO	10.38	8.76	8.50	9.90	11.84	10.48	10.20	9.84	9.29	7.97
Na_2O	3.90	3.27	4.01	3.13	2.42	3.74	3.77	2.92	2.51	1.68
K_2O	0.26	0.39	0.16	0.12	0.09	0.08	0.14	0.50	0.32	0.06
H_2O^+	2.08	2.39	3.88	2.85	2.49	3.85	3.41	2.82	2.79	5.63
H_2O^-	0.09	0.16	0.14	0.12	0.12	0.13	0.18	0.14	0.14	0.39
P_2O_5	0.19	0.32	0.27	0.25	0.18	0.20	0.11	0.20	0.30	0.25
Total	100.40	99.58	100.61	100.01	100.22	100.77	99.87	100.01	99.84	100.89

C.I.P.W. NORMS

(anhydrous)

qz									3.25	
or	1.56	2.38	0.98	0.73	0.54	0.49	0.86	3.04	1.95	0.37
ab	31.68	28.51	35.13	27.29	20.98	27.30	24.67	25.46	21.92	14.98
an	33.43	24.07	22.49	24.99	40.40	24.85	26.80	26.87	28.54	30.32
ne	1.04					2.92	4.59			
di	14.57	15.35	15.92	19.73	15.13	22.46	20.22	17.80	13.72	7.74
hy		17.71	5.88	11.37	13.74			10.66	16.59	30.72
ol	12.76	1.98	10.20	8.14	3.22	15.15	18.09	4.99		5.87
mt	1.24	3.41	3.51	2.33	2.55	2.44	1.96	6.41	7.46	4.80
il	3.27	5.81	5.23	4.81	3.00	3.90	2.54	4.28	5.84	4.58
ap	0.46	0.78	0.66	0.61	0.44	0.49	0.27	0.49	0.73	0.62
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

1 — 57518 Little-altered porphyritic dolerite (898224)
2 — 57519 Moderately altered metadolerite (812163).
3 — 57520 Moderately altered metadolerite (811160).
4 — 57521 Moderately altered ophitic metadolerite (815140).
5 — 57522 Moderately altered porphyritic metadolerite (817137).
6 — 57523 Little-altered ophitic dolerite (812183).
7 — 57524 Moderately altered ophitic metadolerite (834153).
8 — 57525 Moderately altered metadolerite (858077).
9 — 57526 Moderately altered ophitic metadolerite (826083).
10 — 57527 Highly altered metadolerite (832168).

Analyses by X-ray fluorescence spectrometry except for FeO (titrimetry), H_2O (gravimetry). R. Beck, analyst.

The metadolerite masses comprise mainly tabular bodies that range in width from 1 m to more than 30 m. Many of the larger masses shown on Fig. 1 are composite, formed of several parallel bodies often separated by thin (1-10 m) screens of country rock. Where intrusive relationships have been determined the massive, little altered and sometimes porphyritic bodies post-date more altered foliated dykes. The latter tend to lie parallel to cleavage in adjacent rocks, whereas the former though

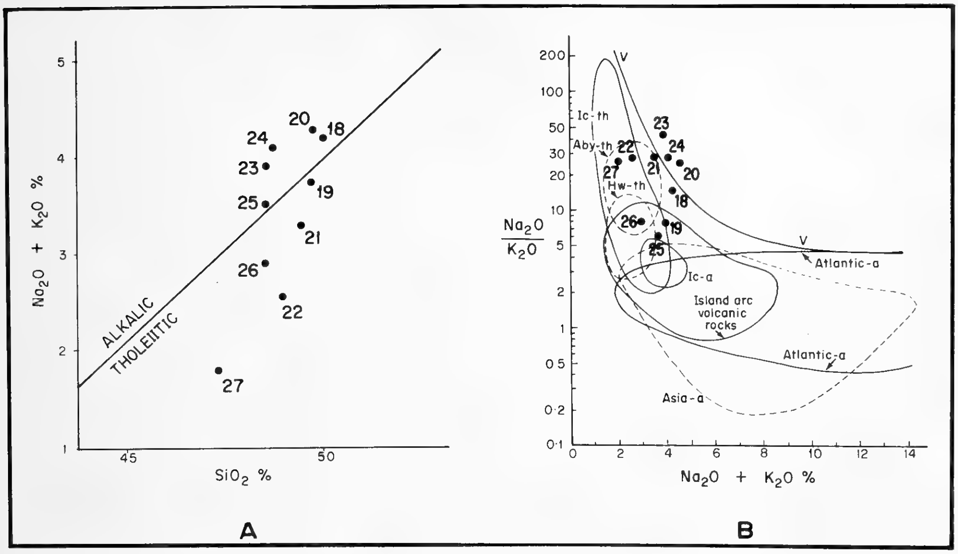


Fig. 3. **A.** SiO_2 versus $Na_2O + K_2O$ for Karikeree Metadolerite. Alkalic-tholeiitic division from Macdonald and Katsura (1964). **B.** Na_2O / K_2O versus $Na_2O + K_2O$ for Karikeree Metadolerite with fields of Cainozoic volcanic rocks indicated (after Miyashiro, 1975). Abyssal tholeiites (Aby-th), Hawaiian tholeiites (Hw-th), Icelandic tholeiites (Ic-th), Icelandic alkalic rocks (Ic-a), alkalic rocks from other Atlantic Islands (Atlantic-a) and from eastern Asia (Asia-a), and common arc volcanic rocks. Numbers are last two digits of University of Sydney numbers indicated on Table 1.

maintaining this orientation in places elsewhere cut obliquely across structural surfaces in the surrounding formations. Cleavage within the metadolerites is variably developed; some bodies are uniformly cleaved, others contain narrow zones of enhanced cleavage, and some otherwise massive dykes have narrow cleaved margins. Contact effects adjacent to the bodies are restricted to a zone from 0.1 to 0.4 m wide wherein the country rocks have been partially silicified and cleavage is less conspicuous.

Karikeree Metadolerite intrudes the Early Permian(?) Thrumster Slate and is truncated by the Late Permian Burrawan serpentinite. The rocks were emplaced during and perhaps immediately after orogenesis, and a Late Permian age is favoured.

Serpentinite bodies and related rocks

Serpentinite bodies occur both within and at the margin of the Port Macquarie Block. The largest mass is that at the southwest corner of the block in the parish of Burrawan, here referred to as the Burrawan serpentinite. A lens of tremolite-chlorite rock containing talc-rich areas and serpentinite blocks on the eastern shore of Lake Innes (873140) is referred to as the Lake Innes mass. Small serpentinite lenses occur along the Cowarra Fault (153800, 157801) and in quarries near Port Macquarie (913207, 905197). Serpentinite mapped in the vicinity of the Lake Cathie Road (827083) and on the Pacific Highway (811160) by Brunker, Offenberg and Cameron (1970) were not located; only outcrops of Karikeree Metadolerite were found at these localities.

Both massive and schistose serpentinite are present, the former variety being more common in the Burrawan mass and the latter forming the bulk of the smaller bodies. In the schistose rocks several generations of structural surfaces can be recognized, with the earliest and dominant often folded and overprinted by an axial surface cleavage and, in some outcrops, a later discrete spaced cleavage. Massive serpentinite comprises dark, subconchoidally-fracturing material containing bastite pseudomorphs. It occurs in blocks up to a metre in maximum dimension separated by schistose material that in places is only a selvedge a few centimetres wide, but elsewhere forms a matrix in which individual blocks are separated by distances as great as their maximum dimension.

Clinochrysotile is the dominant serpentine mineral in most bodies. Massive serpentinite also contains lizardite which probably constitutes the bastite pseudomorphs (Wicks and Whittaker, 1977) that are scattered through the mesh-textured groundmass. Progressive deformation and destruction of bastite in increasingly more schistose material is accompanied by a decrease in the amount of lizardite and the appearance of orthochrysotile. Brucite is present in small amounts and magnetite is widespread in all chrysotile serpentinites. No relics of pre-serpentinization minerals remain apart from irregular rounded chromite grains.

Serpentinite blocks in the Lake Innes mass are composed of a bladed mat of small crystals forming a groundmass and partially replacing strained bastite crystals. Antigorite is the only serpentine phase identified in these rocks, which also contain small amounts of talc.

Magnesite is present as a weathering product of the serpentinites, and chalcedonic silica occurs in the southern part of the Burrawan body.

Tectonic inclusions that are scattered throughout the Burrawan serpentinite are mostly chert identical with that in the Watonga Formation, and highly altered dolerite and amphibolite, in which prehnite is a common phase. Inclusions of massive siltstone similar to that in the Hastings Block are restricted to the western part of this body.

Several blocks of glaucophane schist up to a metre long are associated with metadolerite and a highly foliated quartz-albite rock, along the trace of the Innes Estate Fault (826117). None of this material is *in situ,* but it is almost certainly of local derivation. The blocks are probably tectonic inclusions weathered out of a recessive serpentinite lens.

The serpentinite bodies are intrusive with respect to the stratified Palaeozoic rocks and the Karikeree Metadolerite, and have been emplaced as cold masses along faults. Voisey (1939) reported that the Burrawan serpentinite is unconformably overlain by Triassic strata, and although I have not located an exposure of this contact, his interpretation is accepted and a Late Permian age for emplacement of the body favoured. However, movement on the Sapling Creek Fault subsequent to deposition of the Triassic rocks has locally brought these into tectonic contact with the serpentinite (Fig. 1). Along this section the southern margin of the mass is silicified, probably as a result of these late movements.

Felsic dykes

Two narrow felsic dykes have been mapped within the Port Macquarie Block, one trending just west of north adjacent to the Pacific Highway (813183-814177), and the other striking northeast west of Lake Cathie (833076-839090). The rocks of both bodies are strained and altered. Their general composition is granodioritic, with quartz and plagioclase the dominant constituents; potassic feldspar is uncommon and primary mafic minerals are not preserved.

The Lake Cathie body, which lies adjacent to the Lake Cathie Fault, has been converted to a blastomylonite; plagioclase and quartz phenocrysts remain in a fine groundmass of albite grains, highly strained and marginally recrystallized elongate quartz grains, and slightly wavy white mica films (Fig. 2E). The phenocrysts have been fractured, bent, and rotated during deformation as is indicated by the disruption of twin lamellae in formerly contiguous fragments of feldspar. That they were originally igneous is indicated by relic magmatic embayments preserved in some quartz grains.

The igneous texture of the Pacific Highway dyke is clearer; rare plagioclase microphenocrysts and graphically intergrown quartz-feldspar clots are scattered through a granular quartz-feldspar groundmass. Both quartz and plagioclase crystals are strained, the rock is crossed by quartz-albite veins, and secondary pyrite and chlorite are present.

The Pacific Highway body intrudes Karikeree Metadolerite and hence is probably of post-Early Permian age. Because of its similar composition a similar age is suggested for the Lake Cathie body. Both dykes were emplaced prior to the end of fault movements which probably continued into post-Early Triassic times (Leitch and Bocking, *in press*).

Camden Haven Group

Quartzose coarse clastic rocks of the Early Triassic Camden Haven Group, previously only recognized south of the Sapling Creek Fault, also occur in the southern part of the Port Macquarie Block where they are believed to unconformably overlie Palaeozoic units (Fig. 1). Both the prominent scarp-forming chert conglomerate termed the Laurieton Conglomerate by Pratt and Herbert (1973), and an older lithic conglomerate unit (Leitch and Bocking, *in press*) have been recognized.

Tertiary and Quaternary rocks

Very deep weathered zones, laterite, and extensive Quaternary alluvial, swamp, and dune complexes mask much of the Palaeozoic basement. A metre-wide camptonite dyke cutting Karikeree Metadolerite at Middle Rock Point (857076) probably belongs to the Tertiary alkaline province more voluminously represented west and southwest of the Port Macquarie Block (McDougall and Wilkinson, 1967).

STRUCTURE

Faults

The structure of the Port Macquarie Block is dominated by a set of northnortheast-striking faults which juxtapose stratified rocks belonging to different formations and of contrasting metamorphic grade and structural character. Large but unestablished strike-slip movements are indicated, for no relationship exists between metamorphic grade and the age of rock units, a relationship which might be anticipated if vertical movements had led to the exposure of different levels of a stratified sequence. Major fault surfaces have not been seen, but steep dips are suggested by approximately straight fault traces, the vertical attitude of serpentinite bodies emplaced along the faults, and the steep inclination of small-scale shear fractures within the Block.

The *Cowarra Fault* bounds the Block to the northwest, its position marked by an abrupt change in rock types, from uncleaved conglomerate sandstone and siltstone of the Hastings Block to metadolerite and slate. Small serpentinite lenses occur along the southern part of the fault and further north (819202) highly irregular folds in the Thrumster Slate indicate its proximity. A sliver of Hastings Block rocks is surrounded by slate where the fault cuts the Pacific Highway (832212), suggesting the fracture here is of more complex structure than elsewhere.

The presence of the *Tenterden Fault* is inferred from the distribution of Thrumster Slate and Karikeree Metadolerite south of Karikeree Creek. The *Innes Estate Fault* marks the western limit of the Touchwood Formation and is a major structural and metamorphic discontinuity: cleavage, ubiquitous in pelitic rocks west of the fault, is absent on its eastern side, and metamorphic grade changes from greenschist in the west to prehnite-pumpellyite in the east. Close to its trace Thrumster Slate shows numerous kink bands and associated less regular small folds.

The eastern extent of the Touchwood Formation is determined by the *Lake Innes Fault* east of which cleaved rocks of greenschist grade are again found. Pits from which lateritic iron was once quarried (876173, 894212 and 896215) occur along the trace of the fault and Harrison (1955) recorded serpentinite, not now visible, in the pit at the last locality. The *Lake Cathie Fault* is mapped on the basis of the presence and shape of the Lake Innes serpentinite mass, the abrupt termination of a prominent hematite chert horizon in the Watonga Formation northwest of Lake Cathie, and the mylonitic structure of the granodiorite dyke west of Lake Cathie. The northern continuation of the fault passes through a body of serpentinite in the grounds of the Catholic Church in Port Macquarie (913223).

In the south the Cowarra and Tenterden faults abut the Burrawan serpentinite and the three fractures situated further east are cut off by the northwest striking *Sapling Creek Fault*. This structure brings Palaeozoic rocks in the northeast in contact with Triassic strata to the southwest. A small mass of serpentinite, mapped by Leitch and Bocking (*in press*) at 813046 (see their fig. 1), possibly marks the position of the Cowarra Fault south of the Sapling Creek Fault (Fig. 1), suggesting sinistral strike-slip movement of about 4 km on the latter.

Structural domains

The major northnortheast faults bound domains of differing structural character (Fig. 4). Within these domains bedding (S_0) and slaty cleavage (S_1) are the dominant surfaces, the latter forming the axial surface to folds in the former (B_0^1). A lineation produced by the intersection of the two surfaces (L (0x1)) is occasionally discernible. The internal structure of the domains is discussed below.

Domain I: S_1, the dominant structural surface in Domain I, occurring both in the Thrumster Slate and in early members of the Karikeree Metadolerite, parallels the axial surface of small, rather angular tight to isoclinal folds in S_0, but is unaffected by later mesoscopic structures apart from kink-bands and less regular folds close to the Innes Estate Fault. The stereographic projection of poles to S_1 (Fig. 4A) shows a slightly elongate point maximum suggesting an average orientation of 015/75/W but with slight flexure about an axis plunging approximately 75 to 196, a flexure also indicated by the curve of metadolerite bodies in the southwest of the domain (Fig. 1).

Stratification is not common in this domain and is most readily observed where it is at a high angle to S_1. Hence in spite of the narrow hinges and near-parallel limbs of mesoscopic B_0^1 structures, the distribution of S_0 differs from that of S_1 (Fig. 4B). Insufficient readings are available to allow a detailed study of the geometry of this surface, and the absence of mappable marker horizons and a dearth of younging structures inhibit recognition of major B_0^1 folds. Most mesoscopic B_0^1 folds and L (0x1) lineations plunge very steeply (Fig. 4B) and probably maintain a coherence because of the steep plunge of the axis about which S_1 flexure occurred. The two readings that plunge moderately southwest come from within 1 km of the Burrawan serpentinite and may have been rotated during emplacement of this mass. S_1 in this area strikes west of north and may also have been so affected.

Domain II: S_0 in the Touchwood Formation strikes approximately northeast and dips about the vertical, younging consistently northwest (Fig. 4C). No mesoscopic folds are present and cleavage is absent both from these rocks and Karikeree Metadolerite dykes emplaced within them.

Domain III: S_1, the only widely developed structural marker in the rocks of domain III, has an average strike of about northeast and generally dips at a moderate angle northwest (Fig. 4D). Slate and meta-sandstone adjacent to the Lake Innes mass

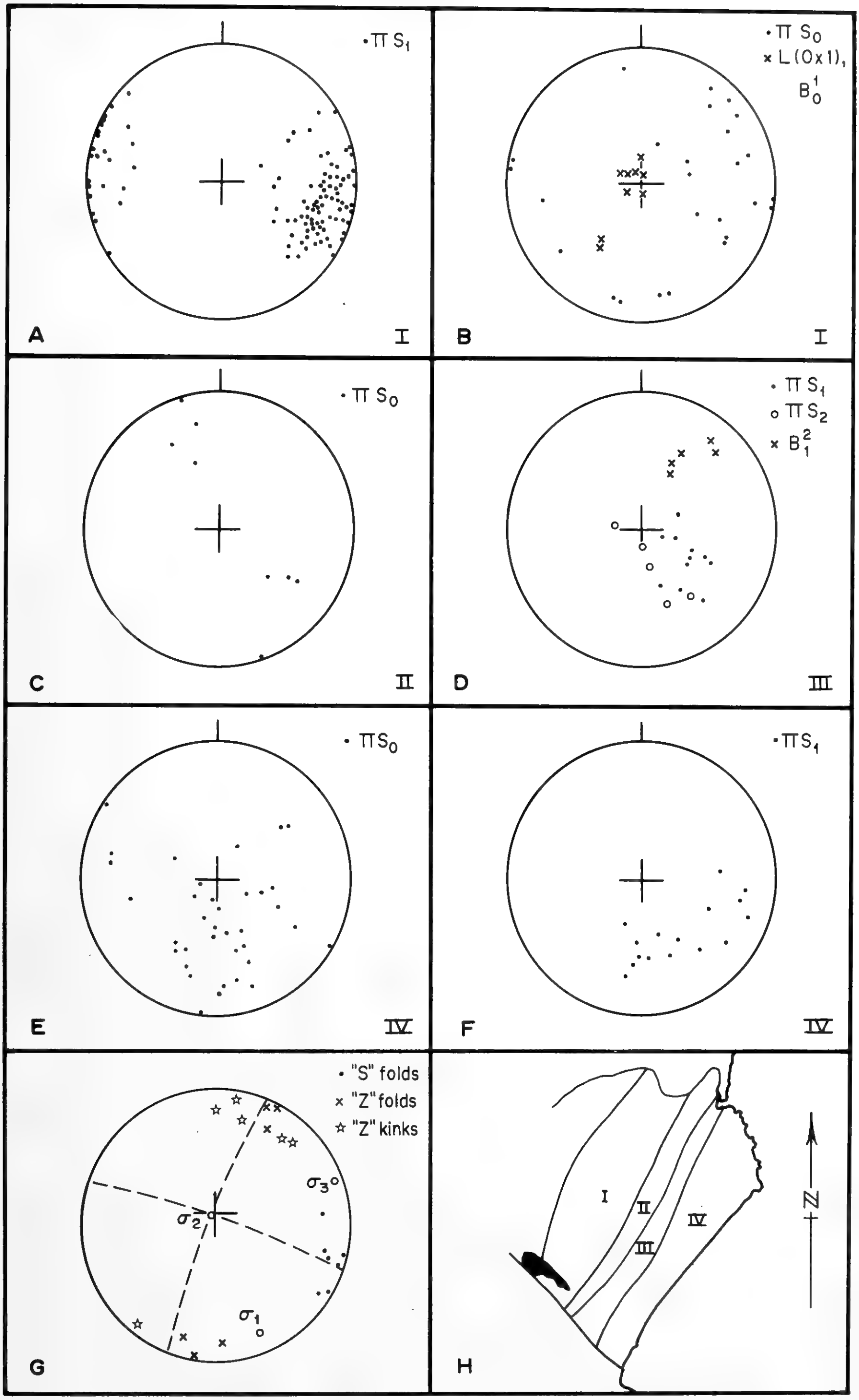


Fig. 4. Structural data for the Port Macquarie Block. Plots are equal angle stereographic projections and roman numerals refer to the domains indicated in H. See text for detailed descriptions.

are unique in the Port Macquarie Block in showing small-scale rounded folds in S_1 with an axial surface crenulation cleavage (Fig. 2F). However dispersion of S_1 overall in domain III is not related to structures of this generation which lack a consistent orientation and appear to have been affected by later movement (Fig. 4D).

Domain IV: A diversity of styles and a wide range in orientations suggest that several generations of mesoscopic folds are present in bedded cherts in the northern part of domain IV, but their analysis is hampered by the absence of axial surface structures and clear overprinting relationships. Some folds are extremely intricate convoluted structures possibly formed before complete lithification of the rocks, others have hinge zones in which bedding is partially obscured by recrystallization and close jointing, and appear to be of significantly later origin. The distribution of poles to S_0 (Fig. 4E) clearly indicates a complex overall geometry for this surface.

Observations of slaty cleavage in domain IV although limited in number, suggest that it is less complexly deformed than S_0, and poles to S_1 occupy a broad partial girdle that indicates flexure about an axis plunging approximately 60 to 335 (Fig. 4F). This deformation appears on a megascopic scale in the progressive change in the strike of S_1 in the southern part of the domain, from near north-south close to the Lake Cathie Fault to east-west at Middle Rock Point. It has also probably resulted in the flexure of the chert-rich units south of Port Macquarie (Fig. 1).

Slates at Watonga Rock show a prominent set of small conjugate folds that are probably related to faulting, and imply a near horizontal principal compressive stress trending northnorthwest (Fig. 4G). Kink bands from domain I close to the Innes Estate Fault are of similar orientation to Z-shaped folds at Watonga Rock and show the same vergence.

Serpentinites and associated rocks: No systematic study of the internal structure of the serpentinites and their associates has been attempted but scattered observations indicate that the structure within these masses are largely independent of those in the surrounding rocks. The earliest surface identified is frequently folded, usually about steeply plunging axes. In the Lake Innes mass the axial surface of the folds is parallel to the contact of the lens with surround rocks, but is oblique to S_1 in these rocks (Fig. 2G). The mesoscopic folds affecting S_1 in the country rocks here have also affected the margin of the mass, and keel-like lenses of talc-rich material have been partially folded into adjacent slates.

Structural correlation: The presence of Karikeree Metadolerite with a single cleavage coincident with that in adjacent rock units in domains I, III and IV suggests S_1 developed in post-Early Permian times, and is of comparable age in each domain. These domains have a similar deformation history, with cleavage formation followed by broad large-scale warping about moderate-steeply plunging axes and only local development of post-S_1 mesoscopic features, suggesting their structure evolved in closely related circumstances. By contrast domain II lacks imposed penetrative structures or obvious folds, and was probably brought into association with the other domains as a result of large fault movements late in the history of deformation.

METAMORPHISM

All Palaeozoic rocks of the Port Macquarie Block are at least incipiently altered, and many show the effects of pervasive metamorphism. Differences betwen the rocks of domain II and those of the remainder of the block indicated by structural characters, are also reflected in their metamorphic grade and style. Other domains contain greenschist facies assemblages and most rocks have a strong preferred orientation of metamorphic phases, but the rocks of domain II are of subgreenschist grade and new minerals have grown pseudomorphously or in irregular replacement patches and veins. These two groups of rocks are discussed separately below, as are the products of a late thermal event that affected a small area east of Lake Innes, and glaucophane schist blocks associated with the Innes Estate Fault.

Metamorphism in domain II

All domain II rocks retain their original texture and much of their pre-metamorphic mineralogy; secondary minerals are patchily developed and there is abundant evidence of incomplete replacement. Rocks of the Touchwood Formation have developed a range of low-grade metamorphic assemblages including:

(i) albite — chlorite — epidote — prehnite — pumpellyite
(ii) albite — chlorite — epidote — prehnite
(iii) albite — chlorite — actinolite — prehnite
(iv) albite — chlorite — epidote
(v) albite — chlorite — actinolite — epidote

In addition sphene is a ubiquitous metamorphic phase, calcite is frequently encountered but only in small amounts, quartz has crystallized during metamorphism in some rocks and in others is present as a relic phase showing no sign of alteration, and white mica is a common but minor secondary mineral. There is little control of metamorphic mineralogy by rock type, although white mica is restricted to epiclastic rocks and (iv) characterizes the andesites of the formation.

Assemblages (i), (ii) and (iii) are all characteristic of the prehnite-pumpellyite metagreywacke facies, with (iii) suggesting the rocks were subjected to conditions close to those at the upper limit of this facies (Coombs, Horodyski and Naylor, 1970). Neither (iv) nor (v) is restricted to a particular facies, but both confirm the low grade of alteration. Assemblage (v) is probably more typical of greenschist facies metamorphism than lower grade facies, especially in rocks reconstituted under conditions of low fCO_2 as are indicated for the Touchwood Formation. Specimens showing this assemblage are known only from the southern part of the main outcrop of domain II rocks, and it is possible that they fall within the Lake Innes thermal high (see below) and hence have been affected by a second metamorphic event.

Karikeree Metadolerite from domain II contains the secondary mineral asemblage:

(albite) — chlorite — actinolite — sphene — white mica — calcite

and is noteworthy for the preservation of most magmatic calcic plagioclase, alteration of which is restricted to narrow irregular veins filled by albite, and the crystallization of tiny white mica flakes. The secondary mineral assemblage is not specific as to grade but is consistent with that indicated by the Touchwood Formation. The retention of plagioclase (and also calcic clinopyroxene) has meant that components necessary for the formation of calcium aluminosilicate minerals were not released in these rocks.

Regional metamorphism in domains I, III and IV

Stratified rocks of domains I, III and IV show the imprint of a regional metamorphic event that also affected members of the Karikeree Metadolerite in these domains. There is little evidence for variation in metamorphic grade throughout the rocks, although the metadolerite bodies show a range in degree of reconstitution and fabric development which suggests some were introduced at only a late stage during metamorphism. Pelitic and psammitic rocks show typical sub-biotite grade mineral assemblages of the type quartz — albite — white mica — (chlorite) — (epidote) whereas chert has reconstituted to assemblages including quartz — white mica — hematite, quartz — stilpnomelane — hematite and quartz — chlorite — stilpnomelane — hematite.

Metamorphic assemblages recognized in the Karikeree Metadolerite are:

(i) albite — actinolite — chlorite — epidote — sphene — (white mica) — (quartz) — (calcite)
(ii) actinolite — chlorite — epidote — sphene — white mica — (quartz) — (calcite)
(iii) albite — actinolite — epidote — sphene — (quartz)
(iv) albite — chlorite — epidote — sphene
(v) albite — chlorite — quartz
(vi) epidote — garnet — calcite

Of a total of 31 specimens examined, 18 contained assemblage (i), 5 contained (ii), 4 contained (iii)), 2 contained (iv), 1 contained (v) and 1 contained (vi). Assemblages (i) and (ii) include the least altered and texturally restructured metadolerites but there is no systematic difference in degree of alteration between the two assemblages. In particular the failure of albite to form at the expense of calcic plagioclase in (ii) is not related to an overall low degree of alteration. Rocks characterized by (ii) contain abundant epidote, and it is likely that the absence of albite is related to a very high Ca^{2+}/Na^{+} ratio in the local fluid phase during metamorphism, which both enhanced the stability of calcic plagioclase relative to albite, and supplied the calcium necessary for epidote crystallization. The ubiquitous presence of small amounts of white mica in assemblage (ii) rocks is possibly a result of the failure of albite to form. Small amounts of potassium in the rocks, that could have been accommodated in albite had it formed, instead gave rise to a potassic phase. It is noteworthy that white mica occurs in all rocks of assemblage (ii) but occurs in only 3 of the assemblage (i) samples, in each of which much magmatic calcic plagioclase remains and albite is present in only small amounts. White mica also occurs in all domain II metadolerites which are characterized by little or no albite.

Assemblages (iii) - (vi) occur in highly altered rocks believed to have suffered metasomatic changes involving increase in Ca ((iii) and (vi)), relative increase in Al (iv), and loss of Ca (v).

The mineral assemblages found in domains I, III and IV indicate regional metamorphism took place under low greenschist facies conditions. Neither prehnite nor pumpellyite is present and biotite has not formed in the pelitic or psammitic rocks. Assemblage (i) in the Karikeree Metadolerite is typical of the lower part of the greenschist facies. Similar assemblages occur a little to the north of the Port Macquarie Block in the Nambucca Slate Belt (Leitch, 1976a).

The Lakes Innes thermal high

Rocks that outcrop in the southern part of the promontory separating Lake Innes from Innes Swamp show the impress of a static thermal metamorphic event on the earlier regional metamorphic fabric. Mineral assemblages identified in stratified rocks here are:

(i) quartz — albite — white mica — biotite — chlorite — epidote — tourmaline
(ii) quartz — albite — white mica — chlorite — epidote
(iii) quartz — hematite — (white mica) — (chlorite) — (garnet)

Assemblage (i) is confined to pelitic rocks, (ii) typifies psammites and (iii) occurs in metamorphosed chert. The pelitic and psammitic rocks are those of domain III that possess both S_1 and a crenulation cleavage S_2 axial plane to folds in S_1. Textural relationships indicate that the assemblages are the result of recrystallization both during the formation of S_1 and S_2, as well as subsequent to the development of the latter surface. S_1 is defined by the parallel orientation of white mica and chlorite flakes which are bent and have polygonized in the hinges of the post-S_1 folds. Some white mica has grown along S_2 in pelitic rocks and irregular patches of chlorite are concentrated in the hinge zone of microfolds in psammites.

Biotite in the pelites is pleochroic in drab shades of green and brown. It occurs in decussate aggregates cutting across S_1 and S_2 (Fig. 2H), and in randomly oriented grains concentrated along chlorite-rich layers parallel to S_1. Biotite is nowhere deformed and it clearly has formed subsequent to the development of S_2. Tourmaline also crystallized in these rocks after deformation, for prisms of this phase grow across S_1 and S_2 but are neither bent nor fractured.

In addition to the presence of small amounts of garnet in some samples, a somewhat higher metamorphic grade for the cherts of this area compared with those elsewhere in the Block is indicated by their coarser grain size. Cherts in the Lake Innes thermal high have average quartz grain diameter of about 0.05 mm compared with 0.01-0.02 mm elsewhere.

Additional evidence for a late-stage thermal metamorphism in this region is furnished by the serpentinite in the Lakes Innes mass. Although emplacement of these rocks post-dated regional metamorphism, blocks within the mass are composed of antigorite, rather than lizardite and chrysotile that characterize the other serpentinite bodies of the Port Macquarie Block. Antigorite serpentinites are generally considered to result from alteration at significantly higher temperatures than are lizardite-chrysotile serpentinites (e.g. Coleman, 1971) and the antigorite has probably resulted from the metamorphism of lizardite-chrysotile material during late-stage heating. Talc-rich lenses on the margins of this mass, and widespread tremolite-chlorite rocks, probably also result from reactions during the thermal event.

Post-tectonic metamorphic highs similar to that at Lake Innes occur elsewhere in the New England Fold Belt (e.g. Gunthorpe, 1970; Leitch, 1972; Korsch, 1978), in places associated with abundant silicic dykes suggesting a subjacent granite pluton. Although no dykes have been discovered at Lake Innes a buried plutonic body is considered to be the most likely heat source. Late stage crystallization of tourmaline might be construed as evidence of boron addition to the rocks from a granite body, but the amount of tourmaline present is not large, and the required boron may have been inherited from the precursor sedimentary parents of the metamorphic rocks (cf. Reed, 1958).

Glaucophane schist blocks

The glaucophane schist blocks along the Innes Estate Fault consist of dark blue fine-grained, schistose rock characterized by the presence of lavender blue to colourless amphibole prisms. The amphibole forms a nematoblastic mat enclosing lenses and clots of fine-grained chlorite and pumpellyite, and tabular clinozoisite crystals. Small murky sphene grains are concentrated along fine seams roughly parallel to cleavage. Calcic clinopyroxene crystals, fractured and partially replaced by glaucophane, are pre-metamorphic relics. The rocks are cut by veins of glaucophane and clinozoisite and by later irregular calcite or calcite-albite patches. The metamorphic mineralogy, and the presence of relic calcic clinopyroxene suggests the schists were derived from basic igneous rocks.

The metamorphic mineral assemblage in these rocks, glaucophane — chlorite — clinozoisite — pumpellyite — sphene — calcite — (albite) is that characteristic of rocks transitional between greenschist and blueschist facies. Absence of lawsonite, jadeite and aragonite indicates metamorphic pressures not greatly above those attained in the greenschist facies, and the presence of pumpellyite suggests relatively low temperatures, less than those of the greenschist facies.

The relationship between the metamorphism giving rise to the glaucophane schists and that responsible for the greenschist facies rocks of the Port Macquarie block is not known. Schistosity in the glaucophanitic rocks is strongly crenulated, perhaps indicating a more complex deformation history than that suffered by the greenschist facies rocks. Although it has been suggested that the blocks are tectonic inclusions within a serpentinite lens (p. 282), an origin as accidental fragments derived from beneath the associated greenschist rocks appears unlikely.

GEOLOGICAL HISTORY

Three phases can be recognized in the geological development of the Port Macquarie Block: a pre-orogenic phase during which the stratified Palaeozoic rocks accumulated, an orogenic phase that commenced with the onset of penetrative deformation and regional metamorphism of many of the stratified rocks and ended with the juxtaposition of the various fault slices that comprise the block, and a late-orogenic phase with faulting on a more restricted scale, probably involving mainly vertical movements and perhaps associated with local plutonic igneous activity.

Pre-orogenic phase

The Watonga Formation is a member of an Early Palaeozoic chert-siliceous argillite-basalt association, widely distributed in the southern part of the New England Fold Belt, and believed to comprise mostly ocean-floor deposits scraped from downgoing lithosphere at a consuming plate margin (Leitch, 1974). The dominance of fine-grained terrigenous detritus, the absence of limestone or massive sandstone, and the presence of widespread bedded radiolarian chert, accord with a deep marine depositional environment. Progressive detachment of the rocks from basaltic ocean floor along a system of imbricate thrust faults could give rise to the repetition of beds suggested by the several chert units, and the disrupted character of the formation with occasional basic igneous intercalations would be anticipated in the rocks of a subduction zone.

The Touchwood Formation clearly belongs to a quite different setting, having accumulated close to a volcanic region comprising rocks ranging from basalt to dacite, but in which subsilicic material was most common. Clastic sedimentary rocks of the formation are mostly turbidite and debris-flow deposits, suggesting accumulation in a relatively steep-sided basin fed by material swept from unstable shelf or delta-front environments. The oligomictic nature of some volcanic-derived units indicates rapid remobilization of debris the initial accumulation of which may have closely followed eruption. Coralline limestone blocks in some paraconglomerates suggest erosion of newly-deposited shelf material and channelling of the basin floor is indicated by abundant intraformational siltstone fragments in many of the coarser rocks. Lateral migration of volcanic activity gave rise to the thick andesite mass that caps the exposed sedimentary sequence.

The parent material of the Thrumster Slate accumulated in a region dominated by siltstone deposition but into which coarse clastic debris derived from silicic volcanic rocks was periodically carried by turbidity currents. The Slate is closely related to the Watonga Formation in its orogenic history, and it is possible that it accumulated in a basin developed on Watonga rocks.

All three formations can be envisaged as fragments of a Palaeozoic active margin. Subduction zone rocks of the Watonga Formation formed a basement for the Thrumster Slate that accumulated either in a slope basin on the accreting face of the zone, or, more likely in view of the probable age difference between the two units, in the outer part of an evolved fore-arc basin above the subsiding older part of the subduction zone. Touchwood rocks are representative of the magmatic arc — inner fore-arc basin realm that were juxtaposed with the other rocks by transcurrent faulting that sliced the margin obliquely at a late stage in orogenesis.

Orogenic phase

Orogenesis affected the Port Macquarie Block in the Late Permian, in the interval between deposition of the Thrumster Slate and the Camden Haven Group. The earliest and most intense deformation, and accompanying greenschist facies metamorphism, affected the Thrumster Slate, the Watonga Formation and the oldest members of the Karikeree Metadolerite. It resulted in the production of near-isoclinal steeply plunging folds and a steeply dipping slaty cleavage. Emplacement of dolerite dykes continued through this period and the presence of little-deformed dykes showing greenschist facies metamorphism suggests that elevated temperatures continued for a period after the relaxation of pervasive stresses.

This relaxation may have followed inception of movement on the northnorthwest-trending faults. Although little control is available, contrasts across the Cowarra, Innes Estate and Lake Innes faults point to large amounts of transcurrent displacement, most of which was completed before emplacement of the serpentinite masses. Thus the Burrawan body truncates several of these fractures and was probably emplaced during movement on the Sapling Creek Fault. By this time temperatures had fallen to sub-greenschist values as indicated by the presence of chrysotile and lizardite and the replacement of plagioclase by prehnite in dolerite blocks. The conditions under which mobilization of the serpentinite bodies occurred are unclear, but it is likely that their rise was initiated under relatively low temperatures and perhaps was accompanied by some re-equilibration of the surrounding metamorphic rocks producing glaucophane schists.

Local folding and the formation of crenulation cleavage post-dated emplacement of the Lake Innes mass indicating minor coherent deformation took place later in orogenic history.

Late-orogenic phase

Although the main orogenic phase was relatively short-lived, structural adjustments continued until after deposition of the Camden Haven Group. Vertical movement on the Sapling Creek Fault disrupted these strata and several faults with northnortheast trends have affected Camden Haven rocks northwest of Grants Head. Abrupt changes in the thickness of formations within the Camden Haven Group take place across northnortheast-trending faults in the Palaeozoic rocks suggesting fault control of sedimentation in the Early Triassic (Leitch and Bocking, *in press*). Emplacement of Triassic granitic rocks elsewhere in the eastern part of the New England Fold Belt was accompanied by vertical faulting (Leitch, 1976b), and the inferred plutonic mass beneath the Lake Innes thermal high was possibly intruded at this time. Further south in the Lorne Basin several large granitic plutons yield Late Triassic K-Ar ages (McDougall and Wellman, 1976). It is unclear whether the felsic dykes of the Port Macquarie block are related to this activity, and owe their strained character to proximity to faults on which there was significant late movement or whether they are representatives of an earlier episode of granitic magmatism.

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LINNEAN SOCIETY OF NEW SOUTH WALES
PRESIDENTIAL ADDRESSES PRINTED IN THE *PROCEEDINGS*
1926-79

Compiled by T. G. VALLANCE
Honorary Editor

The convention that a retiring president deliver an address on a subject of his or her interest and expertise was introduced to the Linnean Society of New South Wales by its founding president, Sir William Macleay, at the first annual general meeting, early in 1876. Macleay's example has been followed and refined by most of his successors. It is a convention that seems to have arisen in the nineteenth century as scientific societies came to elect to presiding office, members who were active in science. The Linnean Society of London, founded in 1788, waited until 1854 and the presidency of Thomas Bell before receiving a scientific anniversary address. Bell's predecessors, if they attended the anniversary meetings, had been content to report on the society's affairs and read obituaries of deceased Fellows. An earlier model is the Geological Society of London (founded 1807), of which W. J. Stephens — by all accounts the sponsor of our name, the Linnean Society of New South Wales — was a Fellow. The Geological Society takes pride in a series of printed scientific discourses reaching back to that of W. H. Fitton in 1828. Both these innovative presidents, Bell and Fitton, incidentally, had links with Australia and the Macleay family.

The record of the first fifty years of the Linnean Society of New South Wales, compiled by the then Secretary A. B. Walkom and published as a pamphlet in 1925, contains details of early presidents and other officers. It was once hoped to issue a sequel to celebrate our centenary session (1974-5) but the scheme fell victim to the financial problems that have beset the Society during the past decade and show no sign of abating. Some of the information gathered for that sequel, however, ought not be lost and as opportunity offers will be put on record in the *Proceedings*. A key to the Memorial Series appeared recently (*Proc*. 103, 1979: 133-4). It is followed now by summary details of presidential addresses printed since 1925. Many of these works have lasting value, as fine examples of scientific exposition and as important statements of original observation, penetrating discussion or historical record. Collectively, they mark significant contributions to science, and not just Australian science, offered in the name of the Linnean Society of New South Wales.

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[†] The text printed is an expanded paper, with Dr L. A. S. Johnson as joint-author, related to Dr Briggs' Presidential Address.

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