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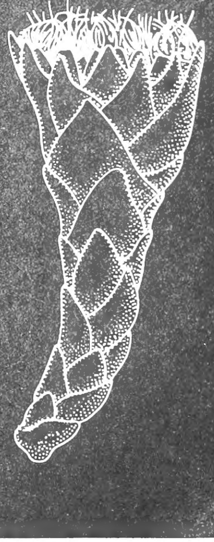
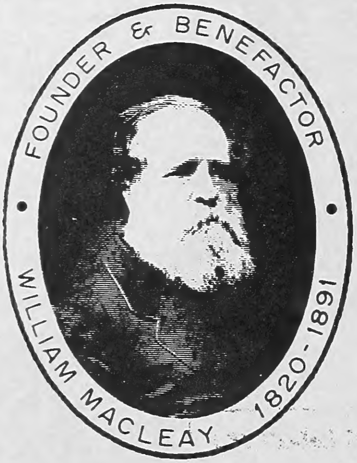


NATURAL HISTORY IN ALL ITS BRANCHES

THE LINNEAN SOCIETY OF NEW SOUTH WALES



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Cover motif: Capitulum of withered flowers of the orchid described by H. M. R. Rupp as *Cryptanthemis Slateri*, n.g. et sp. Adapted by Len Hay from *Proc. Linn. Soc. N.S.W.* 57, 1932, p. 60 (fig. 1).

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The Petrology and Geochemistry of Quartzofeldspathic Gneisses, Broken Hill Mines Area, Broken Hill, New South Wales

BRYAN E. CHENHALL and EVAN R. PHILLIPS

CHENHALL, B. E., & PHILLIPS, E. R. The petrology and geochemistry of quartzofeldspathic gneisses, Broken Hill mines area, Broken Hill, New South Wales. *Proc. Linn. Soc. N.S.W.* 108 (1), (1984) 1985: 1-21.

Two composite, elongate bodies consisting predominantly of quartzofeldspathic gneiss and quartzofeldspathic rocks, together with subordinate volumes of interlayered 'amphibolite/basic granulite' and pegmatite crop out on both the western and eastern sides of the Broken Hill orebody. The compositional diversity present in both bodies is consistent with their origin as a composite pile of volcanic and sedimentary rocks. Initial granulite facies metamorphism of the bodies was overprinted by a greenschist to amphibolite facies retrograde event localized in and adjacent to retrograde schist zones. Three major types of quartzofeldspathic gneiss are defined and described. Granulite facies assemblages and microstructures are largely preserved throughout these gneissic types. Nevertheless, most representative samples are 'polymetamorphic' for they display intergranular/intragranular microstructures and compositional readjustments between biotite and garnet consistent with lower ($<600°C$) metamorphic temperatures. Microstructures in which various morphological types of microperthite are spatially associated with myrmekite appear to have evolved by an exsolution mechanism. Compositional shifts of garnet and biotite towards more Mg-rich endmember compositions with prograde metamorphism, are overprinted by retrograde reactions involving shift in garnet and biotite compositions towards more Fe- and Mg-rich species respectively. Retrograde garnet and biotite compositions are preserved in garnet rims and in domains adjacent to garnet-biotite interfaces. The metastable persistence of orthoclase throughout quartzofeldspathic gneisses is attributed to a 'dry' cooling history where water activity (a_{H_2O}) <1.

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INTRODUCTION

Quartzofeldspathic gneiss is the name given to distinctive light cream to mid-grey, foliated rocks containing quartz, feldspar (sodic plagioclase and/or K-feldspar) and biotite as essential minerals, with almandine and sillimanite as additional phases in some samples. Such rocks are abundant and widespread throughout the Broken Hill Block of the Willyama Complex (Stillwell, 1922; Binns, 1962, 1964) being exposed in western New South Wales and eastern South Australia (Fig. 1**A**).

Within the Broken Hill mines area, surface exposures and numerous diamond drill intersections delineate two major bodies of quartzofeldspathic gneiss cropping out as elongate bodies for about 30km along each side of the main Broken Hill orebody (Fig. 1**B**). Carruthers and Pratten (1961) named these rocks the upper granite gneiss (west) and the lower granite gneiss (east) and suggested that they represent the upper and lower units in a stratigraphic succession termed the mine sequence. However, recent detailed work by Laing *et al.* (1978) indicates that the two quartzofeldspathic gneiss bodies are probably stratigraphic equivalents in a tightly-folded sequence. Throughout this paper we have simply used the names western quartzofeldspathic and eastern quartzofeldspathic gneiss when referring to the two bodies.

Previous work indicated that the western and eastern quartzofeldspathic gneisses are somewhat different in field appearance but that there are no consistent mineralogical or chemical criteria to distinguish between them (Johnson and Klingner, 1975). On petrological and geochemical grounds, three major types of quartzofeldspathic gneiss are defined in this study. Two of these types are present in the eastern body. The aims of this work are to describe and compare the petrographic, mineralogical and geochemical characteristics of these gneisses and to discuss the nature of their parent material prior to regional metamorphism.

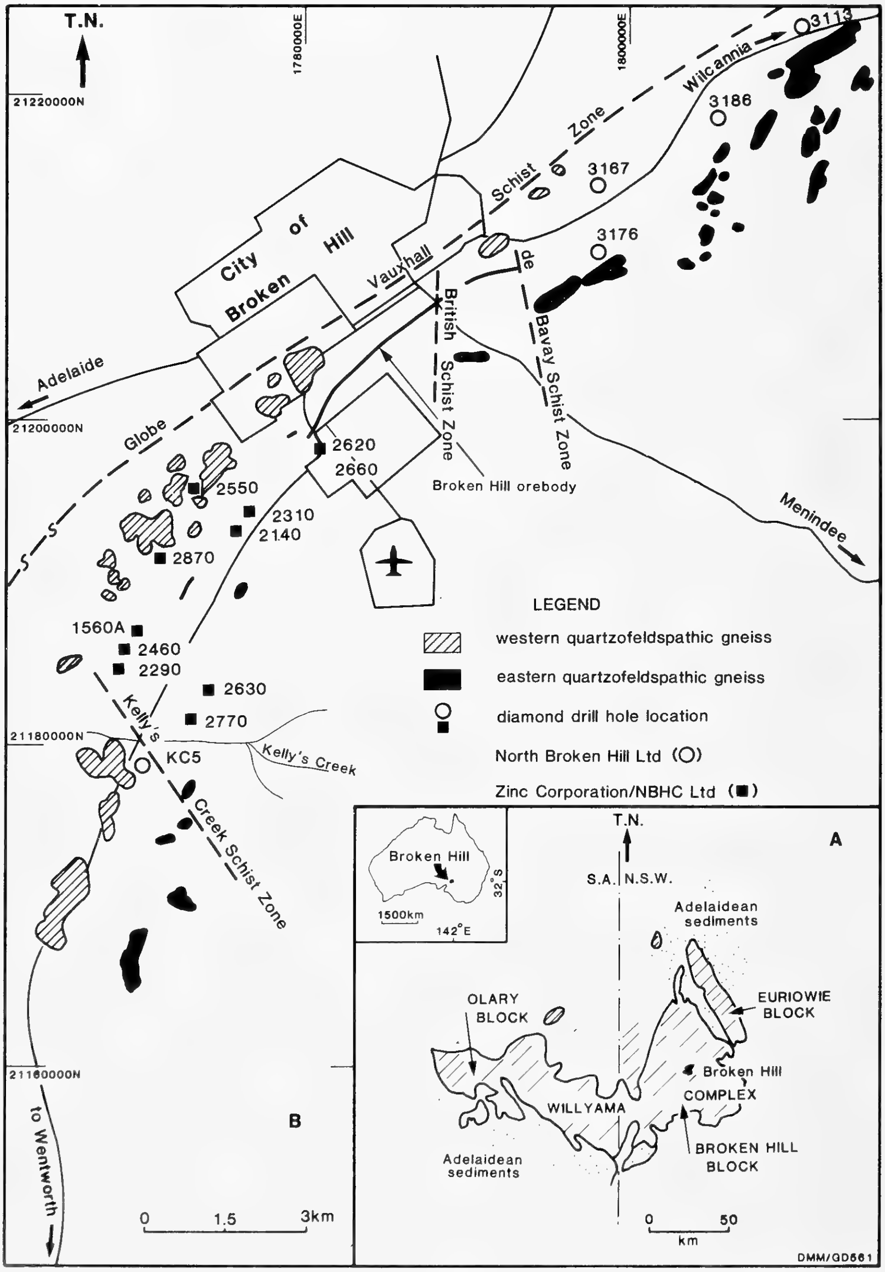

Fig. 1. The distribution of rocks of the Willyama Complex in New South Wales and South Australia (**A**) together with details of the outcrop distribution (**B**) of the western and eastern quartzofeldspathic gneiss in the Broken Hill mines area (adapted from the AIMM geological map of Broken Hill, 1968).

STRUCTURAL AND METAMORPHIC SETTING OF THE WESTERN AND EASTERN QUARTZOFELDSPATHIC GNEISSES

Since the early part of the twentieth century there have been numerous attempts to interpret the structure of the Broken Hill orebody and enclosing rocks (e.g. Andrews, 1922; King and O'Driscoll, 1953; Carruthers and Pratten, 1961; Hobbs, 1966). Quite recently, however, Laing *et al.* (1978) and Laing (1980) have published a detailed reinterpretation of the macroscopic structure in the Broken Hill mines area. These workers suggest that the orebody lies in an antiformal structure (Broken Hill Antiform) between two synforms, the Hanging Wall Synform and Broken Hill Synform, which respectively contain the western and eastern quartzofeldspathic gneisses (Laing, 1980: fig. 4.5). These folds represent macroscopic F2 structures superimposed on a 'stratigraphic succession' which had previously been inverted (Laing, 1980). The western and eastern quartzofeldspathic gneisses are thus regarded as being equivalent stratigraphic units and, because of the inverted attitude of the succession, represent metamorphic Suite 3, the oldest rocks exposed in the Broken Hill mines area. The Broken Hill antiform contains stratigraphically younger rocks of the 'mine sequence' (Suite 4) including sillimanite schist and gneiss, psammitic schist, Potosi gneiss and amphibolite/hornblende-pyroxene granulite together with bodies of Pb-Zn sulphides and lode horizon rocks (see Johnson and Klingner, 1975).

Metamorphic studies by Binns (1962, 1964) show that rocks of the Willyama Complex have undergone initial prograde regional metamorphism under conditions ranging from the amphibolite to granulite facies. Metamorphic grade, in general, increases from northwest to southeast across the orebody (Binns, 1964; Chenhall, 1976; Plimer, 1976; Phillips, 1980). Phillips (1980) has estimated peak metamorphic temperatures in the vicinity of the Broken Hill mines area to have been $< 810°C$ with water activity (a_{H_2O}) estimates (from metapelite data) in the range 0.5 - 0.6. Scott, Both and Kissin (1976) suggested a pressure range of 7.8 - 8.3 kb based on coexisting sphalerite-pyrrhotite pairs from the main orebody although Phillips (1980) has concluded that a more realistic estimate of the upper pressure limit of regional metamorphism in the Broken Hill Block is around 6 kb. This prograde metamorphic event has been dated at 1640 ± 40 m.y. and 1695 ± 21 m.y. by Pidgeon (1967) and Shaw (1968) respectively.

Later retrograde metamorphism along essentially planar zones, termed retrograde schist zones (Vernon, 1969; Vernon and Ransom, 1971) has locally converted the original coarse schistose or gneissic fabric to a finer one in which the mineral assemblages are characteristic of the amphibolite facies (Vernon, 1969; Chenhall, 1973). Additionally, less intense, widespread pseudomorphous retrogression has more or less modified the prograde rocks outside these zones (Vernon, 1969; Chenhall, 1973).

WESTERN QUARTZOFELDSPATHIC GNEISS

The western quartzofeldspathic gneiss is a composite mass consisting largely of quartzofeldspathic gneisses with subordinate amounts of 'amphibolite/basic granulite', metapelite and relatively abundant bodies of pegmatite which are generally concordant with the gneissic foliation. Quartzofeldspathic gneiss / 'amphibolite / basic granulite' contacts are generally sharp and no discernible mineralogical gradation is evident between the two rock types. Samples of 'amphibolite/basic granulite' collected at the contacts with quartzofeldspathic gneisses commonly display a schistose fabric and appear to have retrogressed to assemblages dominated by biotite or by biotite, hornblende, quartz and plagioclase.

Retrogression is by no means confined to the basic gneisses at these contacts. Detailed petrographic studies show that many samples of quartzofeldspathic gneiss have been mildly to moderately affected by retrograde metamorphism. Microstructures indicative of retrograde readjustments include recrystallization of coarse prograde quartz, feldspar and biotite, the replacement of almandine by biotite and of K-feldspar by aggregates of sericite and muscovite. Only those gneisses with a coarse prograde microstructure and showing little or no development of minerals of retrograde origin are described in detail below.

The quartzofeldspathic gneisses of the western mass range from mid grey, moderately well-foliated biotite gneiss to pale grey to cream quartz- and/or feldspar-rich varieties including finer grained aplitic phases together with rare barium feldspar-bearing variants (Mawson and Segnit, 1946). In the quartz-feldspar rich rocks and in some very coarse gneisses, the fabric is represented by a crude biotite lineation rather than a foliation.

The most common type of mid-grey biotite gneiss is medium (1mm) to coarse (2cm) grained and is characterized by a wavy and rather irregular gneissic foliation defined by discontinuous biotite clusters. Gneisses possessing these characteristics are present in most surface outcrops to the south of Broken Hill and are especially well represented in cores from DDH 2550 and DDH 2870 drilled to the south of the city (Fig. 1**B**). Most samples are relatively even grained but locally they are observed to contain numerous megacrysts of K-feldspar. Where developed, ovoid K-feldspar megacrysts ($<$1cm in size) and xenoblastic almandine porphyroblasts show a preferred dimensional orientation parallel to the foliation.

TABLE 1

Modal ranges for the western and eastern quartzofeldspathic gneisses

	Western Gneiss				Eastern Gneiss							
					Type 1				Type 2			
	>5% K-feld		<5% K-feld		> 5% K-feld		< 5% K-feld		>5% K-feld		<5% K-feld	
	range min.	max.	range min.	max.	range min.	max.	range min.	max.	range min.	max	range min.	max.
% Quartz	30	49	34	53	30	50	33	49	34	46	30	50
Plagioclase	14	31	15	48	1	34	25	44	17	28	17	44
Microperthite	7	42	0	4	13	48	0	5	15	16	2	5
Biotite	3	35	3	20	4	17	7	29	7	16	7	19
Garnet	0	19	0	20	0	3	0	8	0	10	0	22
Opaques/Muscovite	1.1	9	6	6	0	6	1	6	1	6	0	2.4
Sillimanite	0	4.4	0	2								
Number of Samples	28		20		23		10		2		10	

Source: Stone, 1973: Pemberton, 1977.

Two mineralogically distinct subtypes of the typical mid grey gneiss have been recognized in thin section. One subtype is free from or low in K-feldspar ($<$5% by mode) and the other contains significant amounts of this mineral. Modal ranges for these rocks are presented in Table 1. The field relationships between these two subtypes are difficult to discern since the rocks have similar physical appearance in handspecimen. However, modal data obtained from cores sampled at intervals of 30cm or less appear to indicate that the two subtypes can exhibit an interlayered relationship. Furthermore, both subtypes appear to be represented in most outcrops and diamond drill cores. Thin sections of both variants are seen to consist of xenoblasts of quartz, clear unzoned twinned plagioclase (composition An_{30}-An_{42}) and subidioblastic, strongly pleochroic (α = pale straw, $\beta = \gamma$ = dark chestnut or red-brown) biotite. Quartz and plagioclase grains are approximately equal in size (1-2mm) and form granoblastic aggregates. Some plagioclase crystals show the development of antiperthitic intergrowths. Biotite flakes (0.5-2mm in size) tend to be grouped together forming discontinuous, flattened folia up to 1cm in length. In most samples the biotite flakes are rimmed with distinctive, thin coronas of very fine ($<$0.1mm) ilmenite granules. Fine (0.1mm) needles of ilmenite are concentrated in the biotite {001} cleavages.

K-feldspar, where present in modal amounts exceeding 5%, occurs as untwinned xenoblasts, commonly coarser (up to 2cm) than the adjacent quartz and plagioclase grains. X-ray diffraction studies indicate that the K-feldspar is orthoclase. Most K-feldspar crystals are microperthitic, the dominant morphological forms being patch and film microperthite. Rim myrmekite is sporadically developed along the margins of the orthoclase crystals in many rocks and intergranular myrmekite is common. Approximately sixty percent of both the K-feldspar-free and K-feldspar-bearing gneiss contain sillimanite as wavy irregular trains of prisms, as patches of fine stumpy prisms or as fibrolite mats, all of which are intergrown with biotite folia. Almandine is present in most rocks and occurs either as coarse (up to 1cm) elongate, cracked xenoblasts containing lobate inclusions of quartz and biotite and needles of sillimanite, or as smaller (1-2mm) grains partly rimmed by biotite. Fine (0.1-0.5mm) needles of sillimanite are common as inclusions in almandine and these define an internal lineation subparallel to that defined by the coarser sillimanite rods associated with the biotite folia. Fine grained (0.05-0.2mm) biotite (which is optically indistinguishable from that forming the folia) is commonly dispersed along the cracks in the almandine xenoblasts along with minor amounts of fine grained (0.05-0.1mm) green biotite (electron probe identification) and sericitic muscovite.

EASTERN QUARTZOFELDSPATHIC GNEISS

Detailed field observation and logging of diamond drill cores together indicate that the eastern quartzofeldspathic gneiss is also a composite body consisting mostly of quartzofeldspathic gneiss with subordinate volumes of 'amphibolite/basic granulite', metapelite and pegmatite. Layers of 'amphibolite/basic granulite' (from 30cm to 30m in thickness) are more abundant within and are almost continuously developed along both western and eastern margins of the quartzofeldspathic rocks composing this body. Quartzofeldspathic gneisses in the eastern mass display considerable lithological diversity, ranging from quartz- and/or feldspar-rich, generally poorly-foliated types, including finer aplitic phases and rare anorthositic variants (Chenhall *et al.,* 1977), through to well-foliated varieties containing more than 10% modal biotite. Retrograde features similar to those given in relation to the western quartzofeldspathic gneiss are widespread and are not considered below.

Two major types of quartzofeldspathic gneiss are present. The first type is represented in the bold outcrops to the northeast of the de Bavay Schist Zone and also in scattered outcrops to the south of Broken Hill near the Kelly's Creek Schist Zone. This gneissic type cannot be traced continuously along strike owing to poor exposure to the south of Broken Hill (Fig. **1B**). Type 1 gneisses occur in diamond drill holes 2620, 2660, 2310 and 2140. The second type is restricted in occurrence to isolated outcrops southwest of the de Bavay Schist Zone. This gneiss has not been observed in the Kelly's Creek area but it is well represented in diamond drill holes 1560A, 2630 and 2770. Gneisses having type 2 characteristics are also present in DDH 2620, 2660, 2310 and 2140.

The structural relationship between the two types of gneiss is uncertain for they have not been observed together in outcrop. Information from diamond drill cores tends to indicate that, with respect to the type 1 gneisses, the type 2 gneisses occupy a structurally higher (that is stratigraphically lower) position in the Broken Hill Antiform.

Type 1

Samples of the gneiss range from cream (surface exposures) to mid-grey (subsurface) and commonly display a well-developed almost platy foliation defined by nearly continuous biotite folia. Both K-feldspar-free and K-feldspar-bearing rocks are well represented in this type (Table 1) and are irregularly distributed throughout single outcrops and individual diamond drill hole cores. In thin sections the rocks are seen to consist of granoblastic aggregates of medium grained (0.5-1.5mm) xenoblasts of quartz and essentially unzoned twinned plagioclase having a composition range $An_{15}-An_{28}$. Pleochroic (α = pale straw, $\beta = \gamma$ = deep red-brown or chestnut) subidioblastic biotite flakes (containing fine, ilmenite needles) averaging 0.5-1mm in size define the foliation in these rocks. Where present, most K-feldspar grains occur as xenoblasts similar in size to those of quartz and plagioclase. The K-feldspar crystals are either untwinned or display twinning ranging from a shadowy, crosshatching through to a well-defined tartan pattern. X-ray diffraction studies indicate that most of the K-feldspar is orthoclase, although there is some broadening (but no discernible splitting) of the 131 peak in grains displaying shadowy twinning. Grains with tartan twinning are intermediate microcline. Two morphological types of microperthite occur in the K-feldspar grains. In one type the sodic plagioclase forms 'beads' associated with fine film perthite and the rocks contain rim and intergranular albite but no myrmekite. In the other type, regular film perthites are observed in close spatial arrangement with rim and intergranular myrmekite (An_{15}-An_{17}) and distinctive, thin albite rims are developed along the margins of adjacent plagioclase crystals.

Almandine is an uncommon mineral in gneisses northeast of the de Bavay Schist Zone but locally becomes more abundant in rocks southwest of this zone. Where present, the almandine either occurs as equidimensional cracked xenoblastic (up to 1cm in size) porphyroblasts or as finer (0.2-2mm) xenoblastic grains. Garnet grains are commonly mantled by and their cracks infilled with fine grained (0.1mm) biotite of similar pleochroic scheme to that forming the folia in the gneisses. Minor green biotite and very pale green 'phengite' also occur in cracks in the garnet.

Type 2

Specimens of this mid-grey type are characterized by a moderately developed irregular and wavy foliation defined by discontinuous aggregates of biotite. Modal ranges for this gneiss are given in Table 1. In thin section, xenoblastic quartz, plagioclase and in some samples untwinned K-feldspar (orthoclase) commonly range from 0.2mm up to 1.5mm in size. Rarely, xenoblasts of quartz and plagioclase may reach 3mm in length. Plagioclase occurs as unzoned, twinned crystals, albite and pericline twins predominating over Carlsbad twins. Compositions of plagioclases range from An_{34} to An_{60} with typical compositions in the range An_{40} to An_{45}. Pleochroic (α = pale straw, $\beta = \gamma$ = deep red brown or dark brown) subidioblastic to xenoblastic biotite, ranging from 0.2mm up to 1mm in length, occurs as discontinuous clusters (up to 3mm in length) sparsely dispersed throughout the quartz-feldspar matrix. Needles and granules of ilmenite occur as inclusions in most biotite grains and coronas of fine (<0.05mm) ilmenite granules are sporadically developed along their margins. Almandine is a common mineral in this type of the eastern gneiss. Garnet usually forms as sub-spherical to irregular, lobate, xenoblastic porphyroblasts ranging from 3mm up to 1cm in size. Crystals of almandine are sparsely poikiloblastic, common inclusions being biotite and quartz. Rare, very fine (<0.05mm) needles of sillimanite are present in almandines from some samples of this type. Fractures in the garnet xenoblasts commonly contain fine brown biotite and minor green biotite and sericitic muscovite.

CHEMICAL DATA

Sample Selection Procedure

Two criteria have been adopted for sample selection in this study. First, as indicated above, the chosen samples have their prograde mineralogy and microstructure largely preserved and are free from, or have low ($<6\%$) modal percentages of, minerals of retrograde character such as muscovite. It is to be noted that many samples of both gneisses fail to meet the requirements of this criterion and have been rejected. Second, only those rocks which are typical of a particular field exposure or diamond drill core log have been analysed.

One disadvantage of this second criterion is that it makes no allowance for some of the compositional diversity present in both gneissic masses. Nevertheless this method of selection has been used since it offers a means of chemical comparison between samples from both the eastern and western quartzofeldspathic gneiss.

Whole Rock Data

Tables 2 and 3 list major and trace element data for typical samples of the western and eastern quartzofeldspathic gneisses respectively. Sample localities are presented in an Appendix. Mean oxide and trace element compositions, together with standard deviations have been calculated and are presented for the data of Tables 2 and 3. Three analyses of quartz- and feldspar-rich rocks constituting minor layers in the eastern quartzofeldspathic gneiss are also given in Table 3. These are included to illustrate some of the compositional diversity generally to be expected throughout quartzofeldspathic gneisses in the Broken Hill mines area.

Tables 2 and 3 also give an indication of the within-type compositional ranges present in the three main gneissic groups defined in this study. These tables show that there are considerable differences in composition between type 1 of the eastern gneiss (where SiO_2 is generally $>70\%$, $Al_2O_3<15\%$, calculated total iron as FeO $<5\%$ and TiO_2 $<0.5\%$ by weight) and the other two gneisses (where SiO_2 is generally $<70\%$, Al_2O_3 $>15\%$, FeO $>5\%$ and TiO_2 $>0.5\%$ by weight) which are seen to be chemically similar. Figs 2**a**, 2**b** and 2**c** show that Al_2O_3, total iron as FeO and TiO_2 contents are linearly related to SiO_2 composition, type 1 gneisses being distinguished from the other rocks on the basis of lower Al_2O_3/SiO_2, FeO/SiO_2 and TiO_2/SiO_2. Moreover, these plots show small scatter about the pooled sample ($n = 37$) regression lines and indicate that respectively 69%, 79% and 85% of the variation (calculated as $100r^2$ where r is the correlation coefficient) in Al_2O_3, FeO and TiO_2 is explained by the variation in SiO_2. A pooled sample is used since the regression coefficients obtained by least squares fitting of individual groups have similar magnitudes. Chemical plots of FeO/Al_2O_3, (Fig. 2**d**) and Na_2O/CaO (Fig. 3**a**) show considerable scatter; the degree of scattering and small within-group sample size tending to obscure systematic relationships (based on a regression model) between these oxides. However, type 1 rocks generally have lower FeO/Al_2O_3 compared with the other gneisses. Fig. 3**a** indicates that type 2 gneisses have higher CaO/Na_2O compared with samples of the western quartzofeldspathic gneiss and this chemical attribute is reflected in the compositional range of their plagioclases, An_{30}-An_{42} and An_{34}-An_{60} respectively.

All gneissic groups show considerable variation with respect to their K_2O, Na_2O and

TABLE 2

Chemical data for the western quartzofeldspathic gneiss

K – feldspar bearing gneisses

Specimen Number	2908	2926	2913	4150	2916	4154	4162
SiO_2	75.25	67.91	67.52	67.33	67.18	71.61	65.96
TiO_2	.15	.62	.60	.69	.69	.24	.73
Al_2O_3	13.26	15.36	15.41	14.88	15.41	16.25	16.83
Fe_2O_3	.02	.53	.78	.08	.25	.17	1.23
FeO	1.28	4.27	4.53	6.07	4.61	1.83	4.61
MnO	.02	.06	.07	.10	.04	.02	.10
MgO	.24	.92	1.08	1.08	1.05	.40	1.47
CaO	.51	1.55	1.60	1.77	1.91	.84	1.11
Na_2O	2.34	2.91	2.33	2.42	2.89	2.80	.79
K_2O	5.30	4.18	4.46	3.93	4.54	5.72	4.76
P_2O_5	.11	.11	.12	.15	.12	.14	.70
L.O.I.	1.90	1.39	1.07	.88	1.05	.79	2.00
FeO (total)	1.30	4.75	5.23	6.14	4.83	1.98	5.72
Mol. Al_2O_3/(K_2O + CaO + Na_2O)	1.26	1.27	1.33	1.30	1.17	1.32	1.93
TOTAL	99.57	99.81	99.57	99.38	99.74	100.81	99.89
Y	26	85	63	68	80	50	68
Sr	89	178	113	117	78	89	115
Zr	67	385	238	268	273	124	284
Nb	11	28	19	25	24	18	–
Rb	307	159	212	221	248	275	233
Th	9	39	22	24	24	16	25
Pb	68	60	27	29	26	26	43

K – feldspar deficient gneisses

	4409	2903	2835	4171	4151	4152	4153	2902	2897	2858	$\overline{X}$	S
SiO_2	65.25	69.23	66.12	68.27	68.01	70.21	69.33	67.00	67.57	66.11	68.23	2.43
TiO_2	.87	.54	.16	.63	.69	.64	.62	.67	.65	.62	.61	.17
Al_2O_3	15.53	14.95	16.39	15.51	15.79	14.48	15.72	15.63	16.00	16.18	15.48	.78
Fe_2O_3	.75	.17	.58	.24	.34	.31	.25	.64	.34	.42	.42	.31
FeO	6.49	4.52	4.92	3.35	3.63	6.32	2.49	3.89	4.88	5.61	4.31	1.47
MnO	.12	.08	.03	.02	.03	.05	.03	.03	.06	.12	.06	.04
MgO	1.38	.87	1.02	.92	.95	1.03	.96	1.08	1.29	1.20	1.00	.31
CaO	3.67	3.00	1.22	2.35	3.13	2.66	3.34	3.23	3.07	2.02	2.18	.97
Na_2O	2.88	3.66	1.74	3.08	3.55	3.11	4.42	4.31	3.18	3.28	2.94	.86
K_2O	1.58	1.33	4.76	4.47	2.54	1.60	1.37	1.93	1.50	2.77	3.34	1.56
P_2O_5	.13	.13	.12	.15	.11	.15	.16	.17	.14	.11	.17	.14
L.O.I.	.27	1.27	1.90	.23	.36	.72	.67	1.07	1.30	1.53	1.08	.55
FeO (total)	7.16	4.67	5.44	3.57	3.94	6.60	2.71	4.47	5.19	5.99		
Mol. Al_2O_3/(K_2O + CaO + Na_2O)	1.18	1.16	1.55	1.09	1.11	1.24	1.06	1.04	1.29	1.34		
TOTAL	98.12	99.75	99.66	99.22	99.14	99.28	99.36	99.65	99.98	99.97		
Y	90	86	89	49	53	56	64	60	64	69	66	17
Sr	308	416	145	268	152	273	566	351	454	143	227	147
Zr	229	351	400	244	270	237	245	266	273	253	259	80
Nb	26	30	31	22	41	25	30	23	23	20	25	7
Rb	90	65	215	201	155	96	89	66	90	156	169	77
Th	–	31	43	49	–	22	30	24	23	23	27	10
Pb	–	39	30	32	–	25	30	18	20	61	36	16

Analysts. S.E. Shaw, R.H. Flood and B.E. Chenhall.

Locality information given in Appendix 1.

TABLE 3

Chemical data for the eastern quartzofeldspathic gneiss

	TYPE 1 GNEISSES												
	K – feldspar bearing gneisses								K – feldspar deficient gneisses				
Sample	4119	2931	2851	2928	4120	4205	4194	4196	4392	4396	2932	$\bar{X}$	S
SiO_2	73 08	73 94	72.50	73.41	73.40	73.59	71.22	72.79	70.99	70.04	71.36	72.01	1.45
TiO_2	.39	14	31	.15	.26	.23	.48	.45	.50	.57	.48	.42	.14
Al_2O_3	13.45	13.41	13.44	13.60	13.44	14.08	12.91	13.09	14.97	14.28	14.23	13.80	.79
Fe_2O_3	.71	.02	.05	.04	.21	.42	.63	.54	.88	.90	.50	.60	.27
FeO	2.56	1.57	2 80	1 75	1.94	1.58	3.54	2.16	2.80	3.45	2.67	2.58	.81
MnO	.04	01	.02	.01	.04	.03	.06	.02	.12	.05	.04	.05	.04
MgO	.60	.34	44	.36	.56	.46	.84	.61	.89	.92	.83	.71	.19
CaO	1.07	.70	1.43	.61	.92	.67	1.49	1.42	2.90	2.30	2.74	1.62	.84
Na_2O	2.06	3.23	3 21	3.68	2.30	3.23	2.39	2.85	1.50	1.06	4.01	2.22	.81
K_2O	4.86	5.20	4.56	5.42	5.56	4.52	4.34	4.58	1.99	3.94	1.96	4.16	1.19
P_2O_5	15	20	16	.20	.18	.15	.15	.08	.10	.11	.16	.13	.04
L.O.I.	.50	.92	.97	.68	1.27	1.09	1.13	.64	2.06	1.98	.96		
FeO (total)	3.35	1.59	2.86	1.79	2.17	2.05	4.24	2.76	3.78	4.45	3.23		
Mol Al_2O_3/(K_2O + CaO + Na_2O)	1.27	1.19	1.05	1.04	1.17	1.23	1.14	1.07	1.51	1.40	1.04		
TOTAL	99.47	99.78	99.89	99.85	100.08	100.05	99.18	99.23	99.79	99.70	99.94		
Y	58	46	51	48	43	41	90	71	49	69	57	56	15
Sr	175	84	103	55	114	63	117	73	327	151	260	138	86
Zr	181	68	142	81	118	82	202	172	172	195	187	145	50
Nb	18	11	24	13	23	17	17	14	–	–	18	17	4
Rb	314	430	337	525	359	442	149	275	115	143	134	293	142
Th	17	13	15	11	15	11	14	15	23	27	22	17	5
Pb	13	15	18	13	17	19	21	15	10	13	11	15	3

	TYPE 2 GNEISSES													
	K – feld bearing gneisses	K – feldspar deficient gneisses										Quartz and feldspar rich minor rock types		
	2862	4124	4189	4138	4384	4386	4139	4128	4129	$\bar{X}$	S	4142	4127	4199
SiO_2	68.89	65.57	65.27	66.26	68.30	68.47	66.72	63.46	65.47	66.49	1.79	83.15	81.20	73.57
TiO_2	.47	.62	.75	.72	.58	.67	.66	.86	.82	.68	.12	.28	.44	.72
Al_2O_3	14.48	16.79	15.64	15.34	15.04	16.32	16.30	16.08	16.52	15.83	.76	8.77	9.93	12.05
Fe_2O_3	.26	.21	.62	.53	.85	1.24	.91	.88	.74	.69	.33	.54	.04	.24
FeO	4.63	5.85	6.19	6.66	4.40	3.40	4.50	6.56	5.16	5.26	1.12	2.08	2.20	2.77
MnO	.05	.15	.25	.09	.08	.09	.10	.14	.10	.12	.06	.09	.02	.05
MgO	.98	1.22	1.14	1.31	1.08	1.14	1.15	1.47	1.47	1.22	.17	.62	.85	1.10
CaO	2.40	3.18	4.09	2.41	2.63	1.92	2.72	2.87	4.08	2.92	.74	2.35	3.10	.73
Na_2O	2.78	2.59	1.95	2.71	1.24	1.65	.96	1.14	3.16	2.02	.82	.38	1.30	.10
K_2O	3.84	2.71	1.95	3.04	3.00	2.79	3.07	3.29	1.65	2.82	.67	.36	.84	6.78
P_2O_5	.12	.08	.16	.14	.09	.10	.11	.10	.05	.11	.03	.01	.04	.01
L.O.I.	1.08	1.62	1.29	.81	2.32	1.81	2.40	2.66	1.14			.72	.62	1.76
FeO (total)	4.92	6.08	6.88	7.25	5.34	4.78	5.51	7.54	5.98			2.68	2.24	3.04
Mol. Al_2O_3/(K_2O + CaO + Na_2O)	1.11	1.29	1.23	1.26	1.49	1.77	1.66	1.51	1.15			1.66	1.14	1.35
TOTAL	99 98	100.59	99 30	100.02	99.77	99 77	99.77	99 72	100.36			99.41	100.58	100.05
Y	137	68	103	69	38	64	45	79	73	75	30	19		6
Sr	188	206	253	105	153	164	137	146	218	174	46	225		183
Zr	155	208	214	211	182	271	172	230	271	213	40	195		13
Nb	11	10	19	20	–	–	–	–	20	16	5	–		–
Rb	191	115	119	175	159	139	138	149	121	145	26	13		261
Th	20	19	22	19	23	27	25	30	36	25	6	10		20
Pb	33	27	80	22	31	23	25	30	21	32	18	15		31

Analysts S E Shaw R H Flood and B.E Chenhall

Major element analyses for rocks 4119, 2931, 2851, 2928 and 2932 are given in Chenhall et al. (1977). Data not available for 4123

Locality information given in Appendix 1

CaO contents and consequently dispersions (indicated by the magnitude of the standard deviation) about their respective oxide means are relatively large. Fig. 3**b** shows that Na_2O plus CaO contents are linearly related to K_2O composition, although there is considerable scatter (with $r = -0.64$) about the pooled sample regression line. Compositional contrasts in $K_2O/(Na_2O + CaO)$ are most clearly indicated in Fig. 3**b** for samples of the western quartzofeldspathic gneiss, but a similar range of composition is evident among samples of the other gneisses. These compositional differences are reflected in an inverse relationship between modal K-feldspar and plagioclase contents (Table 1). Most gneisses have molar proportions of $Al_2O_3/(K_2O + Na_2O + CaO)$ in excess of 1.1. As far as can be ascertained, there is no relationship between the magnitude of this molar ratio and the abundance of modal sillimanite in the gneisses.

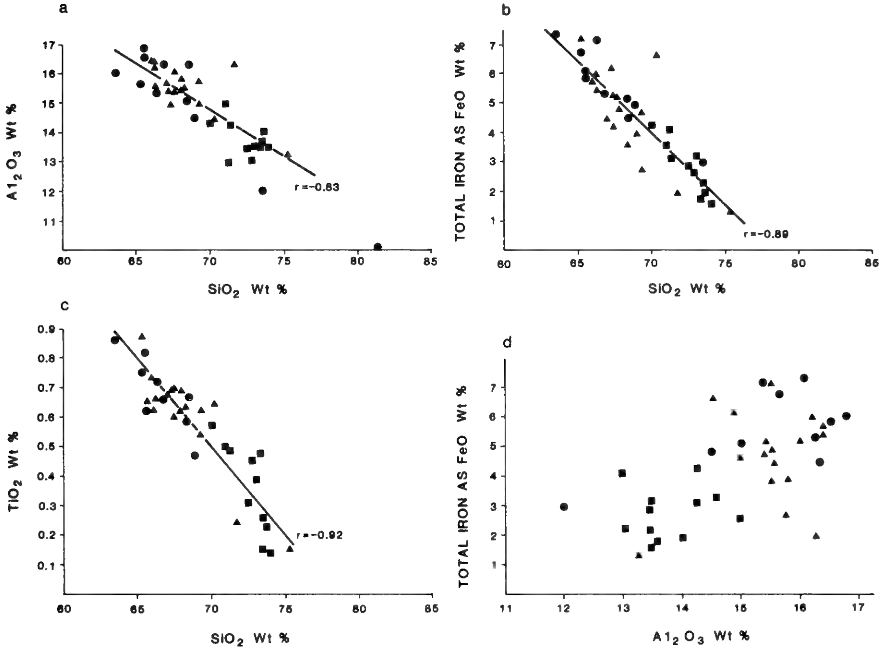

Fig. 2. Chemical plots of Al_2O_3 vs SiO_2 (**a**), FeO vs SiO_2 (**b**), TiO_2 vs SiO_2 (**c**), and FeO vs Al_2O_3 (**d**) for typical western quartzofeldspathic gneiss (▲) and types 1 (■) and 2 (•) of the eastern quartzofeldspathic gneiss.

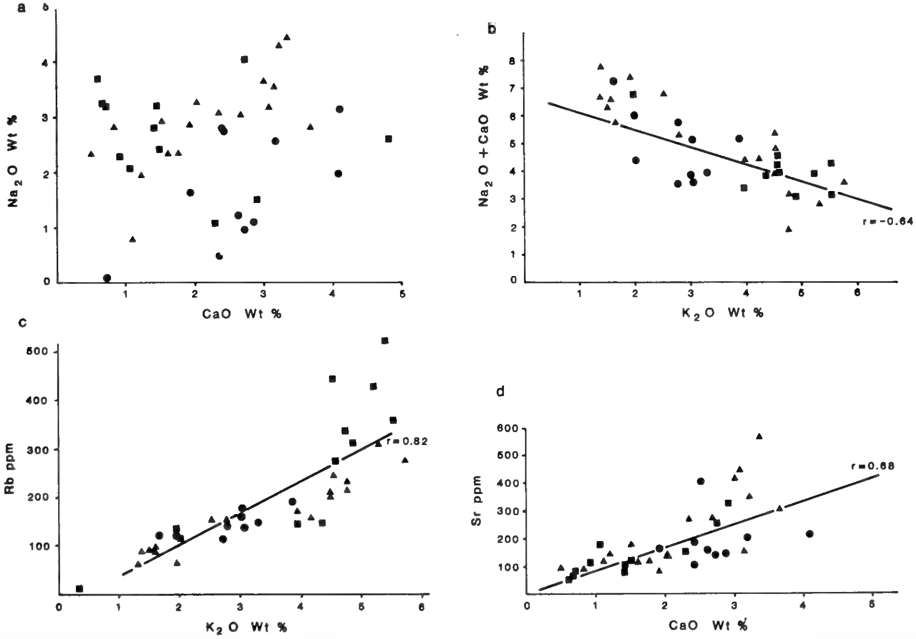

Fig. 3. Chemical plots of Na_2O vs CaO(**a**), (Na_2O + CaO) vs K_2O(**b**), Rb vs K_2O(**c**) and Sr vs CaO(**d**) for typical western quartzofeldspathic gneiss (▲) and types 1 (■) and 2 (•) of the eastern quartzofeldspathic gneiss.

All groups of gneisses display a wide range of chemical composition with respect to the more abundant trace elements Zr, Y, Sr and Rb. Figs 3**c** and 3**d** demonstrate that Rb

TABLE 4

Plagioclase and K-feldspar analyses

Plagioclase

	2908	2926	2913	4162	2931	2851	2928	4127	4196
SiO_2	63.75	62.92	61.55	59.84	64.30	62.59	64.17	59.26	61.94
TiO_2									
Al_2O_3	23.34	23.92	24.36	24.18	22.73	23.81	22.57	26.33	24.02
FeO (total iron)									
MnO									
MgO									
CaO	4.08	5.12	5.64	5.82	2.31	4.85	3.29	7.71	5.33
Na_2O	9.06	8.82	8.31	7.64	9.98	9.17	10.15	6.93	8.17
K_2O	.26	.27	.30	.30	.18	.23	.25	.17	.22
TOTALS	100.49	101.05	100.16	97.78	99.50	100.65	100.43	100.40	99.68
	Number of ions on the basis of 32 0								
Si	11.20	11.04	10.91	10.86	11.36	11.03	11.30	10.53	11.00
Al^{iv}	.80	.96	1.09	1.14	.64	.97	.70	1.47	1.00
Al^{vi}	4.04	3.99	4.01	4.04	4.10	3.98	3.98	4.04	4.03
Ca	.77	.96	1.07	1.13	.44	.92	.62	1.47	1.01
Na	3.09	3.00	2.86	2.69	3.42	3.13	3.46	2.39	2.81
K	.06	.06	.07	.07	.04	.05	.06	.04	.05
	Mol %								
Or	1.49	1.50	1.70	1.79	1.04	1.26	1.36	.99	1.29
Ab	78.88	74.58	71.49	69.12	87.74	76.41	83.66	61.31	72.56
An	19.63	23.92	26.81	29.10	11.22	22.33	14.99	37.70	26.16

K – feldspar

	2908	2926	2913	4162	2931	2851	2928	4127	4196
SiO_2	65.19	64.83	64.84	63.82	63.25	64.28	63.81	63.93	64.76
TiO_2									
Al_2O_3	19.21	18.47	18.74	18.61	18.77	18.91	19.11	19.42	18.77
FeO (total iron)									
MnO									
MgO									
CaO	.04		.08		.12	.08	.18	.22	.25
Na_2O	1.90	1.14	1.67	1.69	1.51	1.25	2.04	1.96	2.09
K_2O	14.63	15.42	14.44	14.18	15.77	15.49	14.22	14.20	13.73
TOTALS	100.97	99.86	99.77	98.30	99.42	100.02	99.36	99.73	99.60
Si	11.88	11.97	11.94	11.93	11.81	11.88	11.83	11.79	11.93
Al^{iv}	.12	.03	.06	.07	.19	.12	.17	.21	.07
Al^{vi}	4.01	4.00	4.01	4.03	3.96	4.00	4.00	4.02	4.00
Ca	.01		.02		.02	.02	.04	.04	.05
Na	.67	.41	.60	.61	.55	.45	.73	.70	.75
K	3.40	3.63	3.39	3.38	3.76	3.65	3.36	3.34	3.23
Or	83.36	89.90	84.72	84.67	86.81	88.73	81.39	81.78	80.22
Ab	16.45	10.10	14.89	15.34	12.63	10.88	17.75	17.16	18.56
An	.19		.39		.56	.39	.87	1.06	1.23

Analysts: E.R. Phillips and B.E. Chenhall.

and Sr contents are linearly related to K_2O and CaO compositions with 67% and 46% of the variation in Rb and Sr being accounted for by variation in K_2O and CaO respectively. Plots of K_2O/Sr, CaO/Rb and Na_2O/Rb are also essentially linear but these have negative slopes. Throughout all gneisses increase in Zr composition is generally accompanied by an increase in Y.

Phase Data

Chemical data for plagioclase and K-feldspar are presented in Table 4. Generally, there is good agreement between the compositions of plagioclase determined by optical

TABLE 5

Almandine and biotite analyses

	Almandine															
	4150^1	4150^2	4150^3	4151^1	4151^2	4151^3	4152^1	4152^2	4162^1	4162^2	4162^3	4128^1	4128^2	4128^3	4196^1	4196^2
SiO_2	37.19	37.12	37.48	37.41	36.94	37.49	37.23	37.61	36.68	36.64	36.64	36.99	37.35	37.31	36.55	36.60
TiO_2																
Al_2O_3	21.35	21.39	21.50	20.66	20.65	20.90	21.30	21.68	21.09	20.99	21.15	20.80	21.05	20.87	20.91	21.04
FeO (total iron)	37.41	36.94	38.00	37.87	38.07	38.71	35.98	35.77	38.70	38.37	38.82	35.97	35.41	36.68	38.38	37.46
MnO	1.20	1.07	1.11	.61	.80	.83	.67	.69	.85	.68	.63	1.89	1.37	2.13	1.34	1.41
MgO	3.16	3.54	2.75	2.11	2.28	2.01	4.09	4.72	2.64	2.85	2.48	2.12	3.31	2.09	2.07	2.74
CaO	1.00	.86	.93	.84	.81	.82	.98	.88	.95	.89	.99	2.08	1.89	1.64	1.26	1.33
Na_2O																
K_2O																
TOTALS	101.31	100.92	101.77	99.50	99.55	100.76	100.25	101.35	100.91	100.42	100.71	99.85	100.38	100.72	100.51	100.58
	Number of ions on the basis of 12 0															
Si	2.97	2.97	2.98	3.04	3.01	3.02	2.98	2.97	2.96	2.97	2.96	3.00	2.99	3.00	2.97	2.96
Al^{iv}	.03	.03	.02				.02	.03	.04	.03	.04		.01		.03	.04
Al^{vi}	1.98	1.98	2.00	1.98	1.98	1.99	1.99	1.99	1.97	1.97	1.97	1.99	1.98	1.98	1.97	1.96
Ti																
Fe^{2+}	2.50	2.47	2.53	2.58	2.60	2.61	2.41	2.36	2.61	2.60	2.62	2.44	2.37	2.47	2.61	2.53
Mn	.08	.07	.07	.04	.06	.06	.05	.05	.06	.05	.04	.13	.09	.15	.09	.10
Mg	.38	.42	.33	.26	.28	.24	.49	.56	.32	.34	.30	.26	.40	.25	.25	.33
Ca	.09	.07	.08	.07	.07	.07	.08	.07	.08	.08	.09	.18	.16	.14	.11	.12
Na																
K																

	Biotite											
	4150^4	4150^5	4151^4	4151^5	4152^4	4162^4	4162^5	4128^4	4128^5	4196^4	4196^5
SiO_2	35.34	36.65	35.41	36.38	35.59	35.51	35.00	35.53	35.42	35.24	34.74
TiO_2	2.71	1.87	2.90	2.59	3.36	3.12	2.19	2.38	1.54	3.05	2.08
Al_2O_3	17.30	18.50	17.46	18.77	17.36	18.35	18.86	17.71	18.07	17.87	17.82
FeO (total iron)	20.52	17.43	20.78	19.55	19.97	21.04	20.06	21.88	21.66	23.57	23.41
MnO											
MgO	8.56	11.13	8.43	8.68	9.08	8.50	9.15	8.09	9.10	6.30	7.06
CaO											
Na_2O	.23	.36				.30	.35			.48	.47
K_2O	9.38	9.88	9.70	9.54	9.51	9.68	9.63	9.54	9.35	9.49	8.82
TOTALS	94.04	95.82	94.68	95.51	95.69	96.50	95.24	95.13	95.14	96.00	94.40
	Number of ions on the basis of 220										
Si	5.50	5.50	5.48	5.51	5.43	5.39	5.36	5.49	5.46	5.45	5.45
Al^{iv}	2.50	2.50	2.52	2.49	2.57	2.61	2.64	2.51	2.54	2.55	2.55
Al^{vi}	.67	.77	.66	.86	.64	.67	.77	.72	.74	.71	.74
Ti	.32	.21	.34	.30	.39	.36	.25	.28	.18	.35	.25
Fe^{2+}	2.67	2.19	2.69	2.48	2.55	2.67	2.57	2.83	2.79	3.05	3.07
Mn											
Mg	1.98	2.49	1.94	1.96	2.06	1.92	2.09	1.86	2.09	1.45	1.65
Ca											
Na	.07	.10				.09				.14	.14
K	1.86	1.89	1.91	1.84	1.91	1.88	1.88	1.88	1.84	1.87	1.76

Analyst. B.E. Chenhall

1 rim domain, 2 core domain, 3 garnet composition adjacent to secondary biotite,
4 coarse matrix biotite, 5 secondary biotite adjacent to garnet (3) or garnet rim (1)

and electron microprobe techniques. Moreover, the plagioclase is optically and chemically homogeneous. Bulk microperthite compositions appearing in Table 4 have been obtained by averaging microprobe spot analyses, although some integrated compositions were determined using a defocused (40 μm) electron beam. This technique gave reproducible results on K-feldspars containing fine albite lamellae. The bulk perthite sodium contents are typically less than 2.5% (wt) Na_2O. Sodium contents have generally been found to be lower in the rim domains and higher in the central domains of the larger microperthite crystals.

Table 5 lists compositional data for coexisting garnet and biotite. Garnet compositions were obtained by averaging electron microprobe spot analyses of rim and core areas and domains adjacent to secondary biotite occupying fractures in garnet. All the analysed garnets are iron almandines containing significant molecular pyrope with lesser amounts of spessartine and grossular component. Table 5 shows that MgO/FeO in the rims of garnets is lower relative to their cores and that MgO/FeO is even lower in garnet adjacent to secondary biotite. Electron microprobe rim-rim traverses across four garnet grains are presented in Fig. 4. These profiles demonstrate that a strong inverse relationship exists between the Mg and Fe contents measured across the grains, whereas Ca and Mn are relatively evenly distributed throughout these almandines.

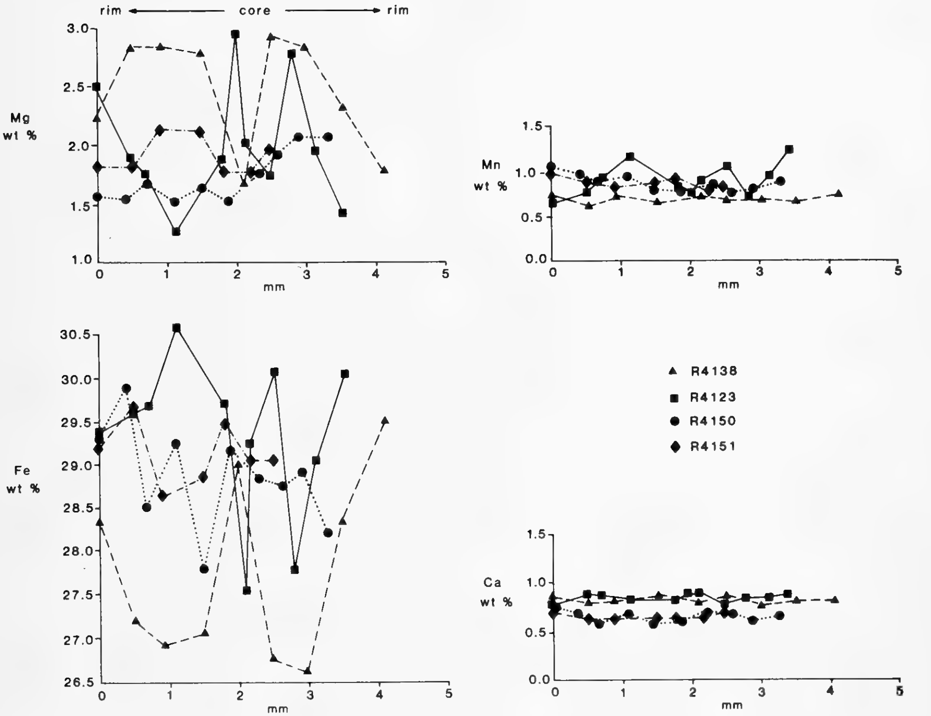

Fig. 4. Illustrates the rim to core compositional variation observed in almandines from quartzofeldspathic gneisses. Specimen numbers refer to rocks housed in the Department of Geology, University of Wollongong.

Electron microprobe traverses across coarse biotite forming the foliation in these gneisses show that these grains are homogeneous with respect to their FeO, MgO and TiO_2 compositions. Coarse biotites have lower MgO/FeO and higher TiO_2 compared with the finer secondary fracture-filling biotites.

DISCUSSION

The most characteristic microstructural association common to K-feldspar-bearing samples of both the western and eastern quartzofeldspathic gneisses is one in which various morphological forms of microperthite are consistently observed in close spatial arrangement with domains containing myrmekite, myrmekite plus albite or albite alone. Some idea of the diverse relationships displayed by minerals in this association is afforded by rocks within type 1 of the eastern gneiss where two distinctive microstructural subtypes can be recognized. In the first of these, coarse bead and fine film perthite (containing a considerable amount of plagioclase) are associated with myrmekite-free areas containing rim and intergranular albite; whereas in the second subtype, sparse film perthites are developed with either rim myrmekite (An_{15}-An_{17}) and albite or with intergranular myrmekite and albite (see also Phillips and Stone, 1974). Petrographic observations indicate that the bead perthites have higher Na_2O contents compared with the sparse film perthites and, together with the microstructural differences noted above and range in the structural state of the K-feldspar from orthoclase to intermediate microcline, lend credence to the contention that these gneisses have undergone a relatively complex metamorphic history.

Perthites are usually thought to represent the products of exsolution during cooling (Smith, 1974) with the regularity and preferred orientation of the sodic plagioclase lamellae providing strong evidence in support of this interpretation (Yund and Ackermand, 1979). Phillips, Ransom and Vernon (1972) have proposed that myrmekite in quartzofeldspathic ('Potosi') gneiss from the mine sequence (Suite 4) has a polygenetic origin, most being produced by an exsolution mechanism whereas minor amounts of myrmekite originated from retrograde decomposition of K-feldspar with the concomitant production of muscovite. An exsolution process may also account for the development of rim and intergranular myrmekite and albite throughout most of the eastern and western quartzofeldspathic gneisses. A retrograde reaction model cannot adequately explain the observed microstructural relationships between the felsic phases, since muscovite is absent from or is present only in small amounts in these gneisses and furthermore, muscovite where present has no consistent microstructural association with either myrmekite or albite. Sodium-depleted rim domains in K-feldspar are possibly produced by exsolving sodium in the form of myrmekite and rim albite. Alternative diffusion or reaction mechanisms involving loss of sodium to the matrix plagioclase (Bohlen and Essene, 1977) do not offer a satisfactory explanation for the sodium-depleted domains in K-feldspar. These models cannot account for the essentially homogeneous nature of plagioclase throughout all domains in the rocks nor can they explain the presence of intergranular myrmekite and albite in plagioclase-free domains between adjacent K-feldspars.

Grainsize coarsening of microperthite lamellae due to reduction of interfacial free energy between phases in the intergrowths (Yund and Ackermand, 1979) and variation in the original bulk perthite composition are other factors which may control the morphology of microperthites in quartzofeldspathic gneisses at Broken Hill. Intergranular/intragranular diffusion rates are probably accelerated in the presence of an aqueous phase (Yund and Ackermand, 1979; Parsons, 1978) leading to the development of coarse, incoherent microperthite intergrowths. However, we cannot convincingly demonstrate that the diverse microperthites described above originate due to variations in the concentration or activity of a fluid phase because the host gneisses appear to have largely cooled under conditions where either the concentration or activity of volatiles or P_{H2O} was low. Variation in bulk microperthite composition is presumably related to differences in 'peak' metamorphic temperature but the bulk K-feldspar compositions appearing in Table 4 do not preserve a true record of the thermal history of the quartzofeldspathic gneisses. 'Peak' metamorphic temperatures may be estimated using a plagioclase—K-feldspar geothermometer (Stormer, 1975) assuming initial equilibrium between coexisting feldspars and provided that the microperthite analyses are integrated to give original bulk K-feldspar compositions (Bohlen and Essene, 1977). This procedure cannot be successfully applied to the gneisses in this study. Coexisting microperthite-plagioclase compositions yield unrealistically low (usually $<600°C$) estimates of 'peak' metamorphic temperature primarily because at least part of the sodic component is lost in the form of myrmekite and albite. Furthermore, little significance can be attached to the derived temperature estimates since the intergranular microstructures probably represent disequilibrium between the felsic phases of the rocks.

Orthoclase is the common K-feldspar phase throughout the bulk of the western and eastern quartzofeldspathic gneisses and its persistence in these rocks could well be related to their cooling histories (see also Guidotti, Herd and Tuttle, 1973). However, it is generally assumed that the very slow cooling rates which accompany regional metamorphism should serve to promote increased Al/Si ordering of K-feldspar leading to the production of microcline, provided of course that diffusion rates are sufficiently high over the cooling interval where microcline is stable. Parsons (1978) has clearly demonstrated that increased ordering in K-feldspar can be related to higher local activities or concentrations of volatile phases. These could provide some samples with faster rates of diffusion resulting in the development of more ordered feldspar lattices.

The persistence of orthoclase thus may be attributable to low activities or concentrations of water and consequently imply 'dry' cooling histories for the gneisses at Broken Hill. Such a proposal is supported by the water activity data obtained by Phillips (1980) for metapelites (a_{H_2O} = 0.5-0.6) in the Broken Hill mines area. One further comment seems warranted here. Wright (1967) has estimated the upper stability limit of maximum microcline to be $375 \pm 50°C$. Elsewhere in this study it is suggested that temperatures controlling the effective Mg/Fe exchange between almandine and fine grained (secondary) biotite lie above this estimate (at $> 450°C$). Thus it may be tentatively suggested that orthoclase could persist in 'dry' rocks if very low diffusion rates prevailed during the final stages of cooling. Intermediate microcline locally present in the eastern gneiss, could evolve due to an increase in volatile activity or concentration associated with prograde metamorphism, but this notion is not supported by the relatively constant nature of water activity estimates for any given locality in the Broken Hill district (Phillips, 1980). Alternatively, increased ordering of the K-feldspar lattice could be promoted by the onset of retrogression where water activities or P_{H_2O} were probably much higher (Chenhall, 1973).

Thus our findings regarding the evolution of these microstructures remain essentially qualitative. However, we do believe that different degrees of exsolution during cooling (under conditions where a low concentration or activity of a volatile phase prevailed) can offer a plausible explanation for the development of these microstructures and the disordered nature of the K-feldspar in the gneisses. Further, we suggest that later retrograde metamorphism could serve to modify further the microstructures that we have described.

Although there is chemical evidence for the homogenization of matrix biotite and almandine compositions (for example the central portion of profile R 4138, Fig. 4) during prograde metamorphism, the microstructures of coexisting biotite and garnet, together with the observed compositional differences of biotite-garnet domains (Table 5 and Fig. 4) are highly suggestive of a retrograde reaction relationship involving the partial decomposition of almandine to form biotite. Compositional heterogeneity in garnet can generally be interpreted in terms of growth fractionation, diffusion exchange or diffusion reaction models (Loomis, 1975). Several authors (e.g. Evans and Guidotti, 1966; Hollister, 1969) have demonstrated that the compositional variation preserved in garnet can suggest reactions which took place between these garnets and the matrix phases of the rock. For example, Hollister (1969) attributed increase in Ti and Mn in the rims of garnet to the decomposition of matrix ilmenite. Elemental distribution profiles (Fig. 4) and Table 5 show that Ca and Mn are fairly evenly distributed throughout garnet with Ti values (Table 5) below the limits of detection of the microprobe. Thus it may be reasonably concluded on the basis of this and on textural grounds that the matrix phases, ilmenite and plagioclase, containing these components have not reacted to produce either garnet or biotite. The asymmetric nature of and the pronounced 'sawtooth' configuration of the Mg-Fe profiles are related to the spatial arrangement of garnet and biotite, higher Mg/Fe in almandine characterizing those domains in which biotite is not in contact with or found immediately adjacent to garnet (see also Tracy, Robinson and Thompson, 1976: 767-768). These observations suggest that the relationship between the two ferromagnesian phases may be best modelled according to a diffusion exchange reaction of the form:

$$\begin{array}{lcl} Mg_3Al_2(SiO_4)_3 + KFe_3AlSi_3O_{10}(OH)_2 & = & Fe_3Al_2(SiO_4)_3 + KMg_3AlSi_3O_{10}(OH)_2 \quad \ldots(1) \\ \text{Mg in garnet} + \text{Fe in biotite} & = & \text{Fe in garnet} + \text{Mg in biotite} \end{array}$$

However, it is apparent from petrographic observations and from the Ti contents of biotites that the model is probably more complex and also involves the production of a low Ti biotite together with small volumes of a Ti-rich phase (ilmenite). Reactions of this type are currently being investigated by one of us (BEC).

Compositions of coexisting almandine and biotite offer a potentially useful means of estimating temperatures of formation of metamorphic rocks provided either that the garnets are homogeneous or that their heterogeneous nature can be fully taken into account. For chemically-zoned garnets, substantial errors in temperature estimates arise where significant compositional shifts in Mg/Fe of biotite have taken place during garnet growth (Tracy, Robinson and Thompson, 1976: 768). Noting the compositional complexity displayed by garnets in this study, it appears most unwise to calculate temperatures following the compositional models proposed by these workers. Instead, we have calculated temperatures at 5kb pressure (based on equation 7 of Ferry and Spear, 1978) from the Mg/Fe values of biotite and garnet grain contacts assuming that these phases are in local equilibrium. These yield values in the range 450-580°C. Clearly these estimates give no indication of 'peak' prograde metamorphic temperatures but they seem useful in that they assist in placing constraints on the temperature interval over which interdiffusion was effective in distributing Fe and Mg between biotite and garnet.

Compositional data for Fe-Mg biotite and almandine in metapelitic gneisses, and in particular, the compositional shift of these phases towards more Mg-rich end members (Phillips, 1980) provide direct evidence for an increase in prograde metamorphic temperatures from northwest to southeast across the Broken Hill Block. This grade increase is also reflected in rocks containing biotite and garnet occurring immediately to the northwest and southeast of the Broken Hill orebody (Plimer, 1976).

In the western and eastern quartzofeldspathic gneisses, compositional shifts of the ferromagnesian phases towards more Mg-rich end members in response to increasing temperature, are generally overprinted by the retrograde compositional adjustments noted above. However, the data of Fig. 4 (profiles R 4123 and 4138) suggest that at least garnet Mg contents tend to be higher in type 2 eastern quartzofeldspathic gneisses occurring to the east and southsoutheast of the orebody.

Furthermore, our studies and those of previous workers (Stone, 1973; Pemberton, 1977) have drawn attention to the widespread occurrence of generally small (0-4%) modal amounts of sillimanite in rocks from the western quartzofeldspathic gneiss and to the virtual absence of this phase in rocks of the eastern mass. The distribution pattern of sillimanite in these quartzofeldspathic rocks is somewhat elusive. However, differences in bulk rock composition, for example in molar $\mathrm{Al_2O_3/(K_2O + Na_2O + CaO)}$ cannot completely account for this pattern since rocks with similar chemistry are represented in both rock suites. A possible explanation for the absence of sillimanite in samples of the eastern gneiss is that during prograde metamorphism this phase (or equivalent component) was consumed according to a reaction of the form:

$$\begin{array}{l} \mathrm{K(MgFe)_3AlSi_3O_{10}(OH)_2} + \mathrm{Al_2SiO_5} + \mathrm{2SiO_2} = \\ \text{biotite} + \text{sillimanite} + \text{2 quartz} = \\ \qquad\qquad \mathrm{(MgFe)_3Al_2(SiO_4)_3} + \mathrm{KAlSi_3O_8} + \mathrm{H_2O} \qquad \ldots (2) \\ \qquad\qquad \text{almandine} + \text{K-feldspar} + \text{water} \end{array}$$

which represents bivariant equilibrium for fixed activity of water at any given pressure.

Thus the compositional data for coexisting ferromagnesian phases and the absence of sillimanite in the eastern quartzofeldspathic gneiss appear to be compatible with sliding of bivariant reactions (equation 2) to their higher entropy side at elevated temperatures.

The pre-metamorphic nature of the quartzofeldspathic gneisses at Broken Hill is subject to some conjecture. Previously, workers have suggested that some or all of these rocks may represent metamorphosed igneous rocks (Binns, 1964) or metamorphosed sediments (Stillwell, 1922). However, it is clear that within the gneisses described above, original microstructures which could possibly unambiguously resolve the nature of their parent material are not preserved due to complete recrystallization at high metamorphic temperatures. Preliminary work by Wall, Etheridge and Hobbs (1976), Stevens *et al.* (1980) and the unpublished work of Shaw together tend to indicate a general chemical link between the quartzofeldspathic gneisses and volcanic (or igneous) precursors. Thus it seems appropriate in this study to compare the chemical compositions of the analysed gneisses with those of commonly-occurring igneous and sedimentary rocks and to suggest likely parent materials for them on this basis.

Apart from several examples, the compositional data for the major variety of the western quartzofeldspathic gneiss (Table 2) and type 2 of the eastern gneiss (Table 3) appear to be consistent with their derivation from pre-existing igneous rocks chemically akin to rhyodacite or dacite. The average major element composition of these gneisses is close to Nockolds' (1954) average rhyodacite or plutonic equivalent. Exceptions to this generalization are manifested in the lower mean CaO, $\mathrm{Na_2O}$ and slightly higher total iron (FeO) values of both gneisses and also by the higher average $\mathrm{SiO_2}$ value for the major type of western quartzofeldspathic gneiss. Type 1 eastern gneiss samples (Table 3) are chemically distinct from the other gneisses and are similar in composition to rhyolites or their intrusive equivalents, with the average composition of this gneissic type closely matching Nockolds' (1954) average rhyolite composition.

Chemical variation diagrams (Figs 2 and 3) indicate that there is generally linear compositional variation between selected major oxides and major oxides-trace elements throughout the three major varieties of quartzofeldspathic gneiss. Some interoxide plots, notably $\mathrm{Al_2O_3/FeO}$ and $\mathrm{K_2O/(Na_2O + CaO)}$, show much more scatter. Chayes (1971) has fully described and discussed the statistical limitations inherent to geochemical interpretation of variation diagrams where the data consist of ratios or percentages. These limitations notwithstanding, we believe that the linear variation displayed by various combinations of oxides and trace elements is better explained in terms of a pre-metamorphic igneous source material rather than by materials having composite or mixed (volcano-sedimentary) parentage. Variation in some oxides notably alkalis and calcium may reflect the original variability of parent material compositions or may be related to pre-metamorphic alteration (Wall, Etheridge and Hobbs, 1976) or to transfer of chemical components during retrogression. The last suggestion is not favoured since lower temperature microstructural and chemical adjustments appear to have taken place on the intergranular or intragranular scale and thus there seems little reason to account for the variation in this manner. It appears unlikely that the quartzofeldspathic gneisses could have undergone extensive pre-metamorphic alteration because this process could reasonably be expected to result in more complex interelemental distributions throughout them.

Representative samples of 'amphibolite/basic granulite' interlayered with the quartzofeldspathic rocks have been interpreted as the metamorphosed derivatives of highly fractionated tholeiitic rocks (Plimer, 1975; Stevens, 1978). Indeed, Stevens *et al.* (1980) suggest that the close spatial association and chemical characteristics of these contrasted rock types are consistent with several pre-metamorphic pulses of paired acid-basic vulcanism. Other rock types occurring throughout the western and eastern quartzofeldspathic gneiss have compositions (e.g., Table 3: analyses 4142, 4127, 4199) which are considered to be atypical of igneous parent material. We tentatively suggest that these rocks represent metamorphosed examples of quartzofeldspathic sediments.

Thus our data suggest a link between the three main types of quartzofeldspathic gneiss that we have studied and acid igneous precursors. Furthermore, the lithological, mineralogical and chemical diversity observed by us and by other workers throughout the western and eastern quartzofeldspathic gneiss seems consistent with the interpretation that both of these bodies represent a composite pile of metamorphosed volcanic rocks and interlayered sediments.

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APPENDIX

Locality Information for the Representative Samples of Quartzofeldspathic Gneiss

Western Quartzofeldspathic Gneiss

(a) Quartz + plagioclase + K-feldspar + biotite ± almandine ± sillimanite gneisses

number	locality
2908	D.D.H. 3176; 118m below collar
2926	g.r. 1779000E 21203500N
2913	D.D.H. 2550; 203m below collar
4150, 2916	D.D.H. 2870; 435m and 533m below collar respectively
4154	D.D.H. 2460; 589m below collar
4162	D.D.H. 2290; 1042m below collar

(b) Quartz + plagioclase + biotite ± K-feldspar ± almandine ± sillimanite gneisses

number	locality
4409	D.D.H. 3167; 1211m below collar
2903	g.r. 1792000E 21210000N
2835	g.r. 1793000E 21211000N
4171	D.D.H. 2550; 777m below collar
4151	D.D.H. 2870; 625m below collar
4152, 4153	D.D.H. 2460; 411m and 476m below collar respectively
2902	g.r. 1860000E 21178000N
2897	g.r. 1769000E 21175700N
2858	D.D.H. KC5; 322m below collar

Eastern Quartzofeldspathic Gneiss
Type 1 Gneisses

(a) Quartz + plagioclase + K-feldspar + biotite ± almandine gneisses

number	locality
4119	g.r. 1811800E 21223600N
2931	g.r. 1801250E 21209000N
2851	D.D.H. 3113; 188m below collar
2928	g.r. 1804500E 21207000N
4120	g.r. 1811800E 21223600N
4205	g.r. 1810000E 21200000N
4194	g.r. 1777000E 21176000N
4196	g.r. 1765000E 21175000N

(b) Quartz + plagioclase + biotite ± K-feldspar ± almandine gneisses

number	locality
4392, 4396	D.D.H. 3186; 313m and 543m below collar respectively
2932	g.r. 1809000E 21221000N

Type 2 Gneisses

(a) Quartz + plagioclase + K-feldspar + biotite ± almandine gneisses

number	locality
2862	g.r. 1792000E 212050000N

(b) Quartz + plagioclase + biotite ± K-feldspar ± almandine gneisses

number	locality
4123, 4124, 4128, 4129	D.D.H. 2770; 49m, 65m, 148m, and 181m below collar respectively
4189	D.D.H. 1560A; 2478m below collar
4138, 4139	D.D.H. 2630; 142m and 180m below collar respectively
4384	D.D.H. 2660; 712m below collar
4386	D.D.H. 2620; 338m below collar

Quartz and Feldspar-Rich Minor Rock Types in the Eastern Quartzofeldspathic Gneiss

number	locality
4142	D.D.H. 2630; 346m below collar
4127	D.D.H. 2770; 136m below collar
4199	g.r. 1767000E 21178000N

Numbers refer to specimens housed in the Department of Geology, University of Wollongong reference collections. Grid references are given for surface samples; diamond drill hole collar locations are to be found in Figure 1B.

The Spawn and Development of twenty-nine New South Wales Opisthobranchs (Mollusca: Gastropoda)

R. A. ROSE

(Communicated by D. T. ANDERSON)

ROSE, R. A. The spawn and development of twenty-nine New South Wales opisthobranchs (Mollusca: Gastropoda). *Proc. Linn. Soc. N.S.W.* 108 (1), (1984) 1985: 23-36.

The egg masses and developmental modes of 29 opisthobranchs are compared with those of other opisthobranchs reported in the literature. None of the species varies its pattern of development seasonally or geographically and production of nurse eggs or extrazygotic food reserves does not occur in the populations studied. The four bullomorphs and three sacoglossans examined all have planktotrophic development. Fourteen of the 22 nudibranchs have planktotrophic, two lecithotrophic and six have direct (non-pelagic) development. The results of this survey in terms of the types of developmental modes found and the incidence of their occurrence are similar to those found from other parts of the world. The zoogeographical ranges of all but one of the species are consistent with their mode of larval development. For that species, the anomaly between its geographic range and larval development are discussed.

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INTRODUCTION

Most of the published information on the egg masses and development of gastropod opisthobranchs pertains to species occurring outside of Australia. Except for a few papers (e.g., Kenny, 1970; Thompson, 1970, 1972a and b, 1975), literature available on eastern Australian opisthobranchs is concerned largely with adult morphology (e.g., Angas, 1864; Basedow and Hedley, 1905; Allan, 1932, 1933, 1947, 1950; Burn, 1957, 1962, 1965, 1966a and b, 1969, 1972; Thompson and Bennett, 1970; Gascoigne, 1976; Rudman, 1983).

Although publications by Kenny (1970) and Thompson (1970, 1972a and b, 1975) deal primarily with the taxonomy of 92 adult opisthobranchs, they also consider type of spawn and larval development as an important facet in describing a number of species. Kenny (1970) describes and illustrates the egg masses of two dorids, *Chromodoris lineolata* (van Hasselt) and *Asteronotus cespitosus* (van Hasselt) and two pleurobranchs *Pleurobranchus hilli* Hedley and *P. mamillatus* Quoy and Gaimard from Queensland. Thompson (1970) describes not only the egg masses but also the ova of two pleurobranchs, *Umbraculum sinicum* Gmelin and *Tylodina corticalis* Tate, from New South Wales. In his paper on eastern Australian chromodorids, Thompson (1972a) illustrates the juvenile forms of two direct developing species, *Hypselodoris bennetti* (Angas) and *Chromodoris thompsoni* Rudman, 1983 (misidentified as *C. loringi* (Angas) by Thompson) and mentions that *Chromodoris amoena* Cheesman has planktotrophic development. In his paper on eastern Australian dendronotids, Thompson (1972b) briefly describes the spawn and planktotrophic development of *Hancockia burni* Thompson and *Doto yongei* Thompson. Similarly, on eastern Australian dorids, Thompson (1975) describes and illustrates the newly hatched juvenile of the direct developing species *Dendrodoris (= Doriopsilla) miniata* (Alder and Hancock).

Of the 18 species of sacoglossans recorded in Australia (Thompson, 1973) only two species other than those reported in this study have had their development described; they are *Elysia maoria* Powell and *Hermaea (Placida) dendritica* (Alder and Hancock). Both of these species have planktotrophic development as reported by Reid (1964) and Trinchese (1881, cited by Thompson, 1976), respectively.

Recognizing this paucity of information, a survey on the types of spawn and development of 29 species of opisthobranches from New South Wales was undertaken. Seven of the 29 species have had their spawn and/or development previously described. Descriptions for two of the species were based on Australian specimens (Thompson, 1972a and 1975) and for the other five on specimens from overseas (Ostergaard, 1950; Baba *et al.*, 1956; Gohar and Aboul-Ela, 1959; Kay and Young, 1969; Reid, 1964). In this paper the development of these 29 New South Wales opisthobranchs is reported and compared with those from other regions. An attempt is made to relate the developmental mode of each species to their known geographic range.

MATERIALS AND METHODS

The survey was conducted from 1976 to 1979. Species investigated were collected either subtidally with aqualung or intertidally and came from nine collection sites located within the Sydney metropolitan area or from four sites outside of Sydney (Table 1).

In the laboratory, under artificial illumination provided for 12 hrs of the day, animals were kept in aquaria filled with unfiltered, aerated seawater and supplied with known foods whenever practical. Egg masses deposited were removed and cultured in glass beakers at 33-35°/₀₀S and 18-27°C. Sea water used for culturing was changed daily. Planktotrophic larvae were fed a variety of unialgal phytoplankton *(Phaeodactylum tricornutum, Dunaliella tertiolecta, Pavlova lutheri)* but none of them grew to metamorphosis and settlement.

Observations and photographs were made using a phase contrast microscope with camera attachment. The developmental type of each larva was categorized as planktotrophic (Type 1), lecithotrophic (Type 2), or direct (Type 3) according to morphological and behavioural characteristics devised by Thompson (1967). Direct development was further categorized as either ametamorphic capsular embryogenesis (ameta., Type 3) if the embryo did not pass through a veliger stage before hatching, or metamorphic capsular veliger (cap., Type 3) if during embryogenesis the embryo passed through a veliger stage and possessed functional larval organs before metamorphosing into a benthic juvenile and hatching (Bonar, 1978). Egg masses were categorized according to criteria used by Hurst (1967) or Fernandez-Ovies (1981) and larval shells according to those of Thompson (1961).

RESULTS

Egg masses

Except for those of *Bullina lineata* Gray, all egg masses observed fall into three of the four categories devised by Hurst (1967): type A (spirally arranged upright ribbon); type B (spirally arranged cylindrical cord); and type C (globular sac with a mucus strand attaching it to the substratum). Egg masses of *B. lineata* are comparable to those described for *Cumanotus* sp. Odhner by Thompson (1976) and belong to Fernandez-Ovies' (1981) type b_5 category (cylindrical cord coiled like a spring with one end connected to a long mucus strand).

Larval shells

The kinds of veliger shells observed fall into only one of the two main types identified by Thompson (1961). This is type 1, which is characterized by an uninflated shell with a distinct curvature that is greater than three quarters of a whorl but less than one complete whorl (Hurst, 1967). It is by far the most common shell found among opisthobranch veligers. Shell type 2, which was not observed, is rarer and is a bulbous, egg-shaped shell found, for example, in *Eubranchus olivaceus* (O'Donoghue) and *Hancockia burni* as described by Hurst (1967) and Thompson (1972b), respectively.

TABLE 1

Spawning and developmental characteristics and collection data for opisthobranchs from New South Wales. Spawn types are categorized according to schemes used by Hurst (1967) or Fernandez-Ovies (1981). Asterisk after name of a species means that its spawn and development are being described for the first time

DEVELOPMENT *ORDER* SPECIES	SPAWN TYPE	EMBRYONIC PERIOD (DAYS)	TEMP. (°C) OF CULTURE	NO. OVA PER SPAWN	NO. OVA PER CAPSULE	DIAMETER OF OVUM (μm)	LARVAL LENGTH (μm) AT HATCHING	LOCATION ON SHORE INTERTIDAL	LOCATION ON SHORE SUBTIDAL	SEASON COLLECTED Sp	Su	Au	Wn	COLLECTION SITE
PLANKTOTROPHIC (TYPE 1)														
BULLOMORPHA														
Bullina lineata Gray	b_5	8	22-23	800- 4 500	1	67	96	X			X	X		LONG REEF
Hydatina physis (Linnaeus)	C	9	20-21	128 914	1 to 5 (3 to 4 most comm)	75	81	X			X	X		LONG REEF
Chelidonura hirundinina (Quoy & Gaimard)*	C	6-7	18-22	12 000- 14 000	1	82	106	X					X	LONG REEF
C. inornata Baba*	C	6-7	18-22	12 000- 14 000	1	81	106	X					X	LONG REEF
SACOGLOSSA														
Oxynoe viridis Pease*	B	6-7	22-23	30 600	1	56	105	X			X			LONG REEF
Elysia australis (Quoy & Gaimard)*	B	6-7	22-23	420- 3 000	1	64	110	X		X	X	X	X	LONG REEF, CAPE BANKS, BARRENJOEY, MANLY, MONA VALE, WEST HEAD.
E. maoria Powell	B	6	22-23	1 000- 6 000	1	70		X			X			LONG REEF
NUDIBRANCHIA														
Casella atromarginata (Cuvier)	A		22-23	18 000	1	132		X		X	X	X		LONG REEF
Chromodoris geometrica (Risbec)*	A		22-23	>10 000	1			X						LONG REEF
Dendrodoris nigra (Stimpson) form 1	A	8-9	22-23	120 000- 242 000	1 (occasionally 2 to 11)	75	114	X		X	X	X	X	LONG REEF, NEWPORT BEACH
" form 2*	A	8-9	22-23	67 584	1	121-129	153	X			X	X		BOTTLE & GLASS, CLOVELLY, PILOTS BEACH.

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[a] diameter of gastrula [b] diameter of blastula [c] diameter of blastula [d] two days after hatching [e] three days after hatching [f] two days after hatching.

Table 1 (continued)

DEVELOPMENT *ORDER* SPECIES	SPAWN TYPE	EMBRYONIC PERIOD (DAYS)	TEMP. (°C) OF CULTURE	NO. OVA PER SPAWN	NO. OVA PER CAPSULE	DIAMETER OF OVUM (μm)	LARVAL LENGTH (μm) AT HATCHING	LOCATION ON SHORE		SEASON COLLECTED				COLLECTION SITE
								INTERTIDAL	SUBTIDAL	Sp	Su	Au	Wn	
Dendrodoris gemmacea Alder & Hancock*	A	6-7	22-26	>10 000	1 (sometimes 2)	105	150		X		X			WATSONS BAY
Discodoris palma Allan*	A	8	20-21	114 000	1	75^a	103	X				X	X	LONG REEF
Hypselodgris obscura Stimpson*	A	10	23-25	59 400	1 or 2	131^b	150		X		X			WRECK BAY
Jorunna sp. Bergh*	A	5	22-23	27 900	1	74^c	95	X					X	LONG REEF
J. pantherina (Angas)*	A	5	20-21	43 120	1	77	112	X					X	LONG REEF
Nembrotha sp. Bergh*	A	8	20-21	100 000	1	62	80		X				X	BARE ISLAND
Plocamopherus imperialis Angas*	A	8	22-23	>10 000	1			X			X			LONG REEF
Rostanga muscula Abraham*	A	10	23-25	18 900	1	70	167		X		X			WATSONS BAY
Sclerodoris apiculata Alder & Hancock*	A	6	22-23	78 400	1	77		X			X			LONG REEF
Madrella sanguinea (Angas)*	B	5-6	20-21	1 000-3 000	1	78	150	X		X	X			LONG REEF
Austraeolis ornata (Angas)*	B	6	22-23	2 000-6 000	1	78	172	X		X	X	X		LONG REEF, NEWPORT BEACH
LECITHOTROPHIC (TYPE 2) *NUDIBRANCHIA*														
Bornella digitata Adams & Reeves*	B	13	20-21	200-300	1		160	X			X	X		LONG REEF, NEWPORT BEACH
Hoplodoris nodulosa (Angas)*	A	16, 18-20	22-23 20-21	925-1066	1 (occasionally 2)	139	167	X			X	X		LONG REEF
DIRECT (ameta., Type 3) *NUDIBRANCHIA*														
Dendrodoris denisoni (Angas)*	A	18-19	22-23	2 664	1	186	440	X				X		PILOTS BEACH
Doriopsilla miniata (Alder & Hancock)	A	16-17	22-23	412-550	1	225-231	362^d	X				X		PILOTS BEACH, SHELLY BEACH

[a] diameter of gastrula [b] diameter of blastula [c] diameter of blastula [d] two days after hatching [e] three days after hatching [f] two days after hatching.

TABLE 1 (concluded)

DEVELOPMENT *ORDER* SPECIES	SPAWN TYPE	EMBRYONIC PERIOD (DAYS)	TEMP. (°C) OF CULTURE	NO. OVA PER SPAWN	NO. OVA PER CAPSULE	DIAMETER OF OVUM (μm)	LARVAL LENGTH (μm) AT HATCHING	LOCATION ON SHORE		SEASON COLLECTED				COLLECTION SITE
								INTERTIDAL	SUBTIDAL	Sp	Su	Au	Wn	
DIRECT (ameta., Type 3) *NUDIBRANCHIA*														
Hoplodoris sp. Bergh*	A	18	22-23	618-1737	1	159	290[e]	X				X		PILOTS BEACH, SHELLY BEACH
Hypselodoris bennetti (Angas)	A	20, 15-16	22-23 25-27	200-250	1	212-250	403	X		X	X	X	X	LONG REEF, NEWPORT BEACH
Noumea haliclona Burn*	A	16	20-23	478	1	151	230[f]	X			X			PILOTS BEACH
Rostanga arbutus (Angas)*	A	15	20-21	150-700	1 (occasionally 2)	184	234	X		X	X	X	X	LONG REEF, NEWPORT BEACH, CALLALA POINT (JERVIS BAY)

a diameter of gastrula [b] diameter of blastula [c] diameter of blastula [d] two days after hatching [e] three days after hatching [f] two days after hatching.

Development

The general pattern of cleavage, gastrulation and early embryogenesis for all 29 species examined is typical of that described for other gastropod opisthobranchs (e.g., Casteel, 1904; Thompson, 1958, 1962, 1967; Smith, 1967). Their spawn and developmental characteristics are summarized in Table 1. Detailed descriptions and illustrations of the egg masses and embryonic develoment of each species can be found in Rose (1981).

A. *Planktotrophy (Type 1)*

Although the survey covers a wide range of opisthobranch taxa, those with planktotrophy have similar developmental characteristics. Species with planktotrophic larvae (Table 1) originate from the smallest eggs (ranging from 56 to 132 μm), produce the greatest number of eggs per spawn (420 to 242,000), take less time to hatch (5 to 11 days) and are more often encapsulated in groups of more than two (2 to 11 embryos per capsule). These observations do not differ from the findings of other researchers (e.g., Ostergaard, 1950; Hadfield, 1963; and Thompson, 1967).

The four bullomorphs and three sacoglossans studied all have Type 1 development. The acteonids, *Bullina lineata* and *Hydatina physis* Linnaeus, produce smaller veligers than those described for *Acteocina canaliculata* (Say) by Franz (1971), but like that species their velar lobes are not unusually large. Development in the two aglajids, *Chelidonura hurindinina* Quoy and Gaimard and *C. inornata* Baba, is practically identical and both have spawn and veligers comparable to those reported for *Philine japonica* Lischke and *Doridium gigliolii* (Tapparone-Canefri) by Hamatani (1961). Like *P. japonica* and *D. gigliolii,* the veligers of both species of *Chelidonura* also have dark larval kidneys which are a well known feature of philinids (Thorson, 1946, cited by Hamatani, 1961). The veligers of the two species of *Elysia* Risso from this survey are remarkably similar morphologically to those described for *Limapontia capitata* Müller and *L. depressa* Alder and Hancock by Chia (1971). The mean diameter of eggs of *Oxynoe viridis* Pease from this study is smaller than that recorded for the planktotroph *O. antillarum* Mörch by Clark and Goetzfried (1978), and the number of eggs per spawn produced by *O. viridis* is approximately three times that produced by *O. antillarum.*

Three of the four chromodorids (*Casella atromarginata* (Cuvier), *Chromodoris geometrica* (Risbec) and *Hypselodoris obscura* Stimpson) have Type 1 development. The embryonic development of *Chromodoris geometrica* was not observed but the veligers are shaped more like those described for *Chromodoris inornata* Pease by Gohar and Soliman (1967a) and those described for *Chromodoris annulata* Eliot and *Chromodoris pulchella* (Rüppell and Leuckart) by Gohar and Aboul-Ela (1957) than those described for *Chromodoris tinctoria* (Rüppell and Leuckart) by Gohar and Soliam (1967b), particularly with respect to the formation of the velar lobes.

One of the two species of *Rostanga* Bergh has Type 1 development. Morphogenesis of the planktotrophic veliger of *R. muscula* Abraham is similar to that described for *R. pulchra* McFarland by Chia and Koss (1978).

Both species of *Jorunna* Bergh have veligers like that recorded for *J. tomentosa* (Cuvier) by Hadfield (1963) and Thompson (1967). The planktotrophic development of *Discodoris palma* Allan is similar to that described for *D. concinna* (Alder and Hancock) by Gohar and Soliman (1967c), except that their velar lobes are thicker and not as broad as those of *D. concinna.*

Two of the four dendrodorids studied have planktotrophic development (*Dendrodoris gemmacea* Alder and Hancock and *D. nigra* (Stimpson)). The morphology of veligers of *Dendrodoris gemmacea* is like that described for *Dendrodoris fumata* (Rüppell and Leuckart) by Gohar and Soliman (1967d) except that their velar lobes are not as large as those of *Dendrodoris fumata.* Veligers of *Dendrodoris nigra* (form 1) are not at all like those described for *Dendrodoris* *fumata* by Gohar and Soliman (1967d) but more like those described for *Discodoris concinna* by Gohar and Soliman (1967c). The well developed velar lobes of *Dendrodoris nigra* (form 2) veligers are similar to those of *Dendrodoris fumata* only larger.

B. *Lecithotrophy (Type 2)*

The two species from this survey with lecithotrophic development are both nudibranchs (Table 1). In contrast with the planktotrophs, the adults produce fewer embryos per spawn (200 to 1,066), their larvae originate from larger eggs (130 μm or greater) which are rarely found with more than one egg per capsule, and take longer to develop up to hatching (13 to 20 days). The larvae have a brief dispersal phase of 48 hours or less. These observations are in agreement with Thompson's (1967) definition of Type 2 development.

The veligers of *Hoplodoris nodulosa* (Angas) begin to metamorphose during or immediately after hatching. They seem to require no special physical or chemical clues to trigger settlement and metamorphosis. Most of their swimming is done with the use of their ciliated foot and not their well-developed velum. Veligers of *Bornella digitata* Adams and Reeves were not observed metamorphosing but they are negatively phototactic and possess a well-developed propodium, a pair of eye spots and a pair of yolk-filled digestive diverticula, with the right digestive diverticulum larger than the left. Except for short intervals of swimming they spend most of their time crawling and like *H. nodulosa* their foot, not their well-developed velum, is the primary organ of locomotion. Failure to metamorphose and subsequent death within 48 hours of hatching suggests, as reported for *Phestilla sibogae* Bergh by Harris (1975) and *Adalaria proxima* (Alder and Hancock) by Thompson (1958), that settlement and metamorphosis of veligers of *B. digitata* will not occur without the physical presence or chemical extracts of adult food. This conclusion, however, is valid only if veligers of *B. digitata* observed were healthy. Unlike *H. nodulosa*, two-thirds of the embryos of *B. digitata* died before hatching and those that lived developed opaque pigment spots which initially appeared in the tissue of the foot, then spread through the whole cephalopedal region. Whether these spots were normal and not caused by a disease which would have affected the success of settlement and metamorphosis was not determined.

The veligers of *Hoplodoris nodulosa* are like those described for *Cuthona adyarensis* Rao by Rao (1961), *Cuthona nana* (Alder and Hancock) by Rivest (1978) and *Trippa spongiosa* (Kelaart) by Gohar and Soliman (1967e). All three species do not need any physical or chemical stimulus to induce metamorphosis. However, unlike *C. nana*, whose lecithotrophic veligers are unable to swim (Rivest, 1978), the veligers of *H. nodulosa* are capable of swimming for short periods like those reported for *C. adyarensis* by Rao (1961). Commencement of metamorphosis in *H. nodulosa* varies with each larva, but like *T. spongiosa* as reported by Gohar and Soliman (1967e), some begin resorbing their velum immediately after hatching.

C. *Direct development (ameta., Type 3)*

Species with direct development from this survey are all nudibranchs (Table 1). They all originate from the largest eggs (151 to 250 μm), are produced in small numbers per spawn (150 to 2,664) and take the longest time to develop up to hatching (15 to 20 days). These observations are in agreement with Thompson's (1967) definition of Type 3 development.

The developmental patterns of the six direct-developing species from this survey are similar. All of them have embryos which pass through a suppressed or reduced veliger stage before hatching as benthic juveniles. This form of direct development has been categorized by Bonar (1978) as ametamorphic direct development (ameta., Type 3). None of the direct-developing species studied undergo metamorphosis from a fully-developed lecithotrophic veliger into a benthic juvenile while still inside their egg capsules. For example, none of them have capsular metamorphic development (cap., Type 3, as defined by Bonar, 1978) like that described for *Phyllaplysia taylori* Dall by Bridges (1975), *Elysia cauze* Marcus by Clark *et al.* (1979) or *Tenellia pallida* Alder and Hancock by Eyster (1979).

During the veliger stage all of the direct-developing embryos differ from lecithotrophic veliger embryos in not being able to retract completely into their shells and in not possessing an operculum or velum with locomotory cilia. Of the six direct developing species, the veliger stage is most suppressed in *Hypselodoris bennetti*, with the development and fate of the veliger structures of its embryos being like those reported for *Cadlina laevis* Linnaeus by Thompson (1967). One slight difference is that unlike *C. laevis*, where the vestigial shell regresses before hatching (Thompson, 1967), the small cap-shaped shell of *H. bennetti* is cast before hatching.

The development patterns of the remaining five direct-developing species are basically the same as each other. The differences are in the degree of organogenesis and the duration of appearance of various larval structures. *Doriopsilla miniata, Rostanga arbutus* (Angas) and *Noumea haliclona* Burn all have slightly more condensed developmental patterns than those of *Dendrodoris denisoni* (Angas) and *Hoplodoris* sp. Bergh. Their development resembles that described for *Casella obsoleta* (Rüppell and Leuckart) by Gohar and Soliman (1967f) except that unlike *C. obsoleta*, they have type 1 shells and partially differentiated viscera. The veliger embryos of *Dendrodoris denisoni* and *Hoplodoris* sp. also have type 1 shells, alimentary differentiation and the largest and most developed vela. Their developmental pattern is comparable to that described for *Retusa obtusa* (Montagu) by Smith (1967), *Doridopsis limbata* (Cuvier) by Tchang-Si (1931, cited by Bonar, 1978) and *Aeolidiella (Eolidina) alderi* (Cocks) by Tardy (1970), except that unlike these species *Dendrodoris denisoni* and *Hoplodoris* sp. do not have an operculum. Bonar (1978) has recorded *Retusa obtusa, Doridopsis limbata* and *Aeolidiella alderi* as having cap., Type 3 development. However, he does concede that *Retusa obtusa* and *Doridopsis limbata* are intermediate species between capsular metamorphic and ametamorphic direct development that show all of the larval structures but in a partially reduced state.

The newly-hatched benthic juveniles of *Dendrodoris denisoni* do not have spicules embedded into their mantle skirt and resemble those described for *Chromodoris thompsoni* by Thompson (1972a), who at the time misidentified this species as *C. loringi* (Rudman, 1983). Juveniles of *Doriopsilla miniata* and *Rostanga arbutus* are similar to those described for *Rostanga pulchra* by Chia and Koss (1978) in that they have mantles with pustules which are embedded with spicules.

DISCUSSION

Development

Seventy-two percent of the 29 species possess larvae with Type 1 development, 7% have Type 2 and 21% have direct development (ameta., Type 3). The types of development found and the incidence of dispersal forms of development (Types 1 and 2) among the species surveyed are similar to those found for surveys conducted elsewhere. Hadfield (1963) found that 32 of the 36 species of nudibranchs from Denmark have dispersal forms of development. Clark (1975) found that 17 species of nudibranchs and sacoglossans from Connecticut, U.S.A., all have dispersal forms of develoment. Clark and Goetzfried (1978) found that 84% of the 32 species of nudibranchs and sacoglossans from Florida, U.S.A., have dispersal forms of development. Thompson (1967) lists the type of development for 68 opisthobranchs from various parts of the world; of these, approximately 85% have dispersal larval develoment. Similarly, Bonar (1978) did the same for about 58 opisthobranchs from various regions and found that 88% of them also have either Type 1 or 2 development.

None of the species examined varies its mode of development either seasonally or geographically like that reported for a number of prosobranchs (Thorson, 1950; Mileikovsky, 1971) and opisthobranchs (Eyster, 1979; Franz, 1971; Clark and Goetzfried, 1978; Clark *et al.*, 1979). Production of nurse eggs like that observed in prosobranchs (Spight, 1975) or of extrazygotic nutrients like that observed in egg masses of sacoglossans (Clark and Goetzfried, 1978) also does not occur among the species surveyed. *Elysia maoria*, however, does produce oval-shaped packets of white or yellow granular material which are embedded into the upper surfaces of the egg mass matrix (see Reid, 1964, for details). Whether this granular material is used by embryos of *E. maoria* as a source of extrazygotic nutrient was not determined, but the laboratory embryos were never observed feeding or utilizing this material.

Colour morphs of *Dendrodoris nigra* (forms 1 and 2, Table 1) have different shaped larvae, suggesting that a complex of similar looking species have been classified as *Dendrodoris nigra*. Adults that are black with white speckles covering their dorsum (form 1) produce smaller veligers with less pronounced vela, typical of most planktotrophic opisthobranchs. Adults that are completely black or black with the outside edge of their mantle outlined in red (form 2) produce veligers which have enlarged velar lobes and no operculum on their foot. The velum of these veligers is so expansive than when fully extended the distance between both lobes is at least twice as great as the longitudinal length of the shell. Veligers of *D. nigra* (form 2) also are unable to withdraw completely the cephalopedal region into their shell.

Zoogeography

Although the geographic range of a species cannot be explained unless its complete life history is understood, the occurrence of most of the species from this survey can be explained partially by their mode of development. The known geographic occurrences of the species studied are summarized in Table 2. It should be realized that the recorded geographic range listed for each species is based only on where each one has been collected in the past by different researchers and does not necessarily reflect their entire geographic range.

As shown in Table 2, the four planktotrophic bullomorphs have ranges extending throughout the Indo-Pacific region. *Oxynoe viridis* is the most widely distributed of the three planktotrophic sacoglossans, with *Elysia maoria* restricted to eastern Australia and New Zealand, and *E. australis* to the southeastern and southwestern coasts of Australia.

Eight of the nudibranchs from this survey have been recorded as occurring throughout the Indian and Pacific Oceans (Table 2). Six of the species have Type 1 development (*Casella atromarginata*, both species of *Jorunna*, *Sclerodoris apiculata* Alder and Hancock, *Dendrodoris nigra* (forms 1 and 2) and *Dendrodoris gemmacea*), one has Type 2 development *(Bornella digitata)* and one has direct development *(Doriopsilla miniata)*.

Four of the planktotrophic nudibranchs have either a south or west Pacific geographic range (Table 2). Two of the species (*Plocamorpherus imperialis* Angas and *Rostanga muscula*) have west Pacific ranges, extending from eastern Australia to Japan. The other two species (*Nembrotha* sp. Bergh and *Chromodoris geometrica*) have a south Pacific range.

Ten of the nudibranchs have known geographic ranges restricted to Australia (Table 2). Five of the species have planktotrophic development (*Hypselodoris obscura, Discodoris palma, Madrella sanguinea* (Angas), *Austraeolis ornata* (Angas) and *Noumea haliclona*), one has lecithotrophic *(Hoplodoris nodulosa)* and four of them have direct development (*Rostanga arbutus, Dendrodoris denisoni, Hypselodoris bennetti* and *Hoplodoris* sp.).

Kay and Young (1969) have implied that *Hoplodoris nodulosa* may be synonymous with *Carminodoris nodulosa* (Angas) from Hawaii. Thompson (1975), however, has indicated that the reproductive anatomy of *C. nodulosa* and *H. nodulosa* are different and that these two

TABLE 2

Known geographic occurrence of opisthobranchs from this survey

DEVELOPMENT/SPECIES	GEOGRAPHIC RANGE (SOURCE)
PLANKTOTROPHIC	
Bullina lineata	Hawaii (Ostergaard, 1950); eastern Australia (Dakin *et al.*, 1952); Japan (Habe, 1955; Kira, 1962: from Rudman 1971); New Zealand (Rudman, 1971); Western Australia (Wells, pers. comm.).
Hydatina physis	eastern Australia (Dakin *et al.*, 1952); Hawaii (Ostergaard, 1955); Japan (Baba *et al.*, 1956); Western Australia (Wells, pers. comm.).
Chelidonura hirundinina	Indo-West-Pacific (Rudman, pers. comm.). Western Australia (Wells, pers. comm.).
Chelidonura inornata	Indo-West-Pacific (Rudman, 1971).
Oxynoe viridis	south eastern Australia, Japan, E. Africa, W. America (Burn, 1966c).
Elysia australis	northern New South Wales to central Victoria (Burn, 1965; Thompson, 1973); southern Queensland to south eastern Australia (Burn, 1972); Western Australia (Roberts and Wells, 1980).
Elysia maoria	New Zealand (Reid, 1964); New South Wales, Victoria (Thompson, 1973).
Casella atromarginata	Zanzibar, India, Philippines, Singapore (Eliot, 1904, 1906, 1907: from Thompson, 1972a); Vietnam (Risbec, 1956: from Thompson, 1972a); Japan (Baba, 1949: from Thompson, 1972a); China (Guang-Yu and Tchang-Si, 1965: from Thompson, 1972a); British Solomon Islands (Miller, 1969: from Thompson 1972); Tahiti (Marcus and Marcus, 1970: from Thompson, 1972a). Red Sea (Gohar and Soliman, 1967b).
Chromodoris geometrica	northern New South Wales, New Caledonia (Allan, 1947).
Dendrodoris nigra	eastern Australia (Allan, 1947; Kenny, 1970; Thompson 1975); Australia (Burn, 1965); Red Sea, South Africa, India (Gohar and Soliman, 1967f); New Zealand (Morton and Miller, 1968); Hawaii (Kay and Young, 1969); Tanzania (Edmunds, 1971); Japan (Baba: from Thompson, 1975); Western Australia (pers. obs., Roberts and Wells, 1980).
Dendrodoris gemmacea	Japan (Baba *et al.*, 1956); New Zealand (Morton and Miller, 1968); China (Guang-Yu and Tchang-Si, 1965: from Thompson 1975); E. Africa, India, Tubuai Island (Marcus and Marcus, 1970: from Thompson, 1975).
Discodoris palma	New South Wales, Victoria (Burn: from Thompson, 1975).
Hypselodoris obscura	Queensland, New South Wales (Rudman, pers. comm.).
Jorunna sp.	Indo-Pacific, European Atlantic (Thompson, 1967).
Jorunna pantherina;	Australia, E. Africa (Rudman, pers. comm.)
Nembrotha sp.	south Pacific (Allan, 1947); Western Australia, Queensland (Burn: from Thompson, 1975).
Plocamopherus imperialis	New South Wales, Tasmania (Burn: from Thompson, 1975); Japan (Angas: from Thompson 1975).
Rostanga muscula	Japan (Baba: from Thompson, 1975); New South Wales (this survey).
Sclerodoris apiculata	New South Wales (Allan, 1947); Tanzania (Rudman, 1978); India (Alder and Hancock: from Rudman, 1978).
Madrella sanguinea	eastern Australia (Burn, 1965); Western Australia (Roberts and Wells, 1980).
Austraeolis ornata	southern Queensland to western Victoria (Burn, 1965; Kenny, 1970).
LECITHOTROPHIC	
Bornella digitata	Indo-Pacific (Burn, 1965).
Hoplodoris nodulosa:	New South Wales (Angas, 1864; Allan, 1950); Victoria (Burn, 1969); Australia (Burn, 1965);
DIRECT (ameta., Type 3)	
Dendrodoris denisoni	Queensland (Kenny, 1970); New South Wales (Dakin *et al.*, 1952); Western Australia (O'Donoghue, 1924: from Thompson, 1975).
Doriopsilla miniata	eastern Australia (Burn, 1969); Queensland, New South Wales, Western Australia (Burn: from Thompson 1975); India (Skyamasundari and Najbuddin, 1976); Western Australia (Roberts and Wells, 1980).

TABLE 2 (concluded)

DEVELOPMENT/SPECIES	GEOGRAPHIC RANGE (SOURCE)
DIRECT (ameta., Type 3)	
Hoplodoris sp.	New South Wales (Angas, 1864; Allan, 1950); Victoria (Burn, 1969); Australia (Burn: from Thompson, 1975);
Hypselodoris bennetti	Queensland, New South Wales (Kenny, 1970; Thompson, 1972a).
Noumea haliclona	New South Wales, Victoria (Burn: from Thompson, 1975).
Rostanga arbutus	Australia (Burn: from Thompson, 1975); Western Australia (Roberts and Wells, 1980).

species should not be considered synonymous. It would appear that *Hoplodoris nodulosa, Carminodoris nodulosa* and *Hoplodoris* sp. are part of a confused complex of species which Rudman (pers. comm.) feels will require extensive examination before clarification can be achieved.

The direct-developing species *Dendrodoris denisoni* has been considered to be synonymous with the planktotroph *D. gemmacea* by Thompson (1975), however, Rudman doubts this (pers. comm.) and the different developmental types suggest that they should be considered separate species. Consequently, the geographic range of *D. denisoni* is restricted to the coastline of Australia and probably does not have an Indo-West-Pacific distribution.

The wide geographic range of *Doriopsilla miniata* is not consistent with its non-pelagic (ameta., Type 3) mode of development. Two possible explanations could account for this. First, and probably foremost, specimens currently identified as *D. miniata* in New South Wales are probably another species which is similar but taxonomically different to *D. miniata* recorded in India (Rudman, pers. comm.). Second, the wide geographic range of *D. miniata* may have to do with some behavioural aspect of the adult. Edmunds (1977) has suggested that adults (and probably the egg masses) of *Doriopsilla areolata* Bergh may cross the Atlantic on floating debris or on the bottom of boats, thus maintaining a gene flow between Brazilian and Mediterranean populations. Such an event may occur between populations of *Doriopsilla miniata* from India and Australia.

SUMMARY

Studies of opisthobranch development in other regions of the world have shown that planktotrophy is the most common larval development and that lecithotrophy and direct are less common (e.g., Hadfield, 1963; Thompson, 1967; Clark, 1975; Clark and Goetzfried, 1978; Bonar, 1978). The survey has shown a similar trend among 29 species of gastropod opisthobranchs from New South Wales. Based on individuals from populations examined, none of the species varies its pattern of development seasonally or over their geographic range and none of them produce nurse eggs or extrazygotic food reserves for their embryos. Except for *D. miniata*, the known geographic range of 28 of the species can be largely explained by their mode of larval development. Until the taxonomy and ecology of nudibranchs currently identified as *D. miniata* in New South Wales are better understood, their Indo-West Pacific range cannot be accounted for on the basis of their non-pelagic development.

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A New Record of the Goblin Shark, *Mitsukurina owstoni* (Family Mitsukurinidae), from eastern Australia

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STEVENS, J. D., & PAXTON, J. R. A new record of the goblin shark, *Mitsukurina owstoni* (family Mitsukurinidae), from eastern Australia. *Proc. Linn. Soc. N.S.W.* 108 (1), (1984) 1985: 37-45.

Conclusive proof of the presence of *Mitsukurina owstoni* in Australian waters is provided by the capture of a 384cm total length male specimen, which also establishes a new size record for the species. Nomenclature problems at the familial and generic level are discussed, and reported capture information on all *Mitsukurina* from Australia and elsewhere is reviewed. The present specimen is described and its proportional measurements compared with all those provided in the literature for other individuals.

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INTRODUCTION

The goblin shark, *Mitsukurina owstoni,* is a deepwater species most frequently caught off Japan (Jordan, 1898; Kobayashi *et al.*, 1982), but also recorded from South Africa (Bass *et al.*, 1975), Europe (Quéro, 1972), Guiana (Quéro, 1972), the Indian Ocean (Piotrovskiy and Prut'ko, 1980) and, with some uncertainty, Australia (Glover, 1976). This shark reaches a large size (up to 373cm total length [TL]) (Kobayashi *et al.*, 1982), but because it is usually found only in deep water, it is captured infrequently and almost nothing is known of its biology (Bass *et al.*, 1975).

On August 26, 1983 the F.R.V. 'Kapala' trawled a 384-cm TL, 212-kg male *M. owstoni* from 960m off Sydney at 33°47'S, 151°58'E. As well as providing conclusive proof of the presence of this species in Australian waters, this is also the largest specimen for which we can find a record. Following measurement, dissection and casting, the head, tail, fins and claspers were preserved in the collection of the Australian Museum, Sydney (AMS I.24053-001).

NOMENCLATURE

The goblin shark has been the subject of nomenclatural controversy since Jordan (1898) described the extant species, *Mitsukurina owstoni,* as a new family, Mitsukurinidae, from Japan. The problem centres on whether the Cretaceous fossil species, given the generic name *Scapanorhynchus* by Woodward (1889) as a replacement for the preoccupied *Rhinognathus* of Davis (1887), is congeneric with the extant species. Some early authors (Regan, 1906: Hussakoff, 1909; Garman, 1913) followed Woodward (1899) in considering the two distinct only at the species level. Others (Jordan and Fowler, 1903; Bean, 1905; Snyder, 1912) followed Jordan (1898) and recognized *Mitsukurina* as a valid genus based on purported differences in snout length and other (undescribed) minor details (Jordan and Fowler, 1903). White (1936) erected the new family name Scapanorhynchidae for the extant goblin shark and most subsequent authors, including Fowler (1941), Bigelow and Schroeder (1948) and Bass *et al.* (1975) have used Scapanorhynchidae and *Scapanorhynchus.* However, Signeux (1949) and Capetta (1980) compared more complete fossils with the living species and found striking differences in dentition and fin structure. Since Mitsukurinidae (Jordan, 1898) has priority over Scapanorhynchidae (White, 1936), we agree with Compagno (1973 and personal communication) in using Mitsukurinidae and *Mitsukurina* as the correct name for the extant goblin shark.

Three living species of *Mitsukurina* have been described: *M. owstoni* (Jordan, 1898), *M. jordani* (Hussakoff, 1909) and *M. dofleini* (Engelhardt, 1912). A fourth species, *M. nastus* (Bragança, 1904), is quoted by Bass *et al.* (1975) and Capetta (1980) but no reference is given; we have also been unable to locate this description. All of these species probably refer to a single, widely-distributed, deepwater species (Bass *et al.*, 1975; Compagno, 1973).

Historical Review

Australian Records

M. owstoni was first recorded from Australia by Zietz (1908), on the basis of a specimen supposedly netted near the mouth of the Murray River, South Australia. This record was subsequently excluded from the list of South Australian fishes by Scott (1962) and Scott *et al.* (1974) after Whitley (1940) questioned its validity. Glover (1976) found the specimen, re-examined the issue and located contemporary documentation which, he submitted, substantiated the record. However, some doubt still exists, particularly on the exact capture locality. The apparently shallow capture depth for this shark is unusual, given that the majority of specimens have been taken in >350m (although two individuals were reported from 160-220m off France [Quéro, 1972]). A second *M. owstoni* from Australia was apparently seen by Stead in 1919, having been taken in about 140m off New South Wales (Stead, 1963). However, this record remains unsubstantiated as the specimen was not preserved.

Following the brief account of the capture of our specimen in 'Australian Fisheries' (Anon., 1983), Noden (1984) recorded the capture of two specimens in 250 fathoms in Bass Strait 25 miles east of Tuna Platform in October 1981. The male and female were both about 250 kg and about four metres long. Although both specimens were discarded, the published photograph confirms the identification of *Mitsukurina owstoni.*

All Records

Table 1 is a compilation from the literature on locality, date and depth of capture, size, sex, museum registration number and reference of all *Mitsukurina* specimens for which we can find record. Individuals without any accompanying details have not been included. Of 33 specimens in Table 1, 23 came from Japan.

Description

Proportional dimensions of the 384cm TL *M. owstoni* (Fig. 1) and of a stuffed 234cm TL female from Japan, (Australian Museum collection AMS I.7697), are given in Table 2. Measurements of all other *Mitsukurina* reported in the literature are also presented in Table 2, including two individuals of the nominal species *M. jordani.*

The tooth count of the 384cm TL male is $\frac{12,11\text{-}3\text{-}3\text{-}10,12}{15,9\text{-}3\text{-}3\text{-}10,15}$ (following Bass *et al.*, 1975, beginning at the posterior end of each jaw and counting both sides; a dash represents a gap and a comma indicates an abrupt change in tooth size without any gap). In both jaws the first nine or ten teeth are erect, slender and lanceolate without basal cusps, the next two to five are similar but with a small basal cusp, usually on each side, while the remaining 12 to 15 teeth on each side are much smaller and flattened. The tooth count of the mounted Japanese specimen is $\frac{11,10\text{-}3\text{-}3\text{-}11,9+}{8+,8\text{-}4\text{-}4\text{-}8,8+}$. In contrast to the 384cm individual, the largest

TABLE 1

Details of Mitsukurina *specimens reported in the literature*

Locality	Year	TL (cm)	Sex	Depth (m)	Museum Reg. No.	Reference
Japan	1898	107	M		Imp. Univ. Tokyo	Jordan, 1898
Japan	1903	366		>550		Dean, 1903
Japan		250			MNHN (Paris)	Vaillant, 1904
Portugal						Bragança, 1904; cited by Bass *et al.*, 1975
Japan		353			USNM (Washington)	Jordan & Snyder, 1904
Japan					Brussels Museum	Jordan & Snyder, 1904
Japan	1903	335	F	274-366	USNM 50972	Bean, 1905
Japan		130	F		AMNH (New York)	Hussakoff, 1909
Japan		116	F		Zool. Dept. Columbia Univ.	Hussakoff, 1909
Japan		Head only	M			Hussakoff, 1909
Japan			F			Hussakoff, 1909
Japan	1903	210	F		Munich Museum	Engelhardt, 1912
Japan		264	M		MCZ 1048 (Harvard Univ.)	Garman, 1913
Japan					Yamada Museum	Jordan & Hubbs, 1925
Australia	1919	107		137		Stead, 1963
Japan					MCZ 1279	Springer & Garrick, 1964
France				160-220		Quéro, 1972
France				160-220		Quéro, 1972
Guiana						Quéro, 1972
South Africa	1966	116	F	549	ORI 2348 (Durban)	Bass *et al.*, 1975
Australia	1906	117	F		SAM F2129 (Adelaide)	Glover, 1976
Japan	1904	205	F		SAM F4140	Glover, 1976
Japan	1967	132	M	400		Uyeno *et al.*, 1976
Japan	1968	141	F			Uyeno *et al.*, 1976
W. Indian Ocean	1977	250		0-1300		Piotrovskiy & Prut'ko, 1980
W. Indian Ocean	1977	322	M	0-1300		Piotrovskiy & Prut'ko, 1980
Japan	1980	269	M	270-280		Kobayashi *et al.*, 1982
Japan	1980	191	F	270-280		Kobayashi *et al.*, 1982
Japan	1980	232	F	270-280		Kobayashi *et al.*, 1982
Japan	1980	373	F	270-280		Kobayashi *et al.*, 1982
Japan	1906	234	F	366-549	AMS I.7697	Present study
Australia	1983	384	M	960	AMS I.24053-001	Present study

gap is between the fourth and fifth tooth in the lower jaw and only between one and four teeth near the centre of the jaw have no cusps. The remaining lanceolate laterals are variable, some having a cusp on each side while on others the cusps are unclear or absent. Counts of the smaller, flattened lateral teeth, particularly in the lower jaw, are not complete as some were covered by mounting medium when the specimen was prepared.

The 384cm TL male was mature (based on the criteria of Bass *et al.*, 1975) with fully calcified, rotatable claspers which were 3.9% of TL. A small amount of sperm was present

Fig. 1. Head of a 384cm TL *Mitsukurina owstoni* captured off Sydney.

in the seminal vesicles and the testes weighed 160g (0.08% of body weight). Siphon sacs, originating from the proximal end of the clasper, were present but it was not possible to define their anterior extension under the dermis with any certainty. Because of their relevance to questions on buoyancy and activity in large deep-water sharks, the liver and the heart were weighed and comprised respectively, 9.0 and 0.08% of body weight.

Stomach Contents

The stomach was partly everted into the throat but still contained an elongate, silvery structure with a central lumen, which appeared to be a fish swim bladder. No other fish remains were found, but other contents could have been lost during partial eversion of the stomach during capture or subsequent weighing before we were able to examine the specimen. The contents of the spiral valve were washed into formalin and examined under a binocular microscope. No food items were found.

DISCUSSION

The number of *Mitsukurina* specimens for which detailed measurements are available in the literature is sufficient to allow only some general observations on changes in body proportions with growth. Small specimens have a proportionately larger head (including the rostral appendage) and caudal fin than larger individuals (Table 2) as was noted by Bean (1905). Conversely, the increased trunk length in larger sharks is reflected in increases in some of the fin bases and spacing between the fins in this region (Table 2).

TABLE 2

Proportional dimensions of Mitsukurina *specimens shown as percentages of total length*

	Jordan, 1898	Bass *et al.*, 1975	Hussakoff, 1909 (*S.jordani*)	Hussakoff, 1909 (*S.jordani*)	Uyeno *et al.*, 1976	Uyeno *et al.*, 1976 (distorted)	Kobayashi *et al.*, 1982	Our Data	Piotrovskiy & Prut'ko, 1980 *	Garman, 1913	Kobayashi *et al.*, 1982	Piotrovskiy & Prut'ko, 1980 *	Bean, 1905	Our Data
	M	F	F	F	M	F	F	F	?	M	M	?	F	M
TL (cm)	107	115	116	130	132	141	232	234	250	264	269	322	335	384
Snout to mouth	8.3	7.0						5.3	9.9			9.9		2.5
outer end nostrils					12.7	11.5	11.2	11.5	11.8		10.6	11.8		9.4
inner end nostrils		12.5						11.5						10.0
eye	15.2	14.0	15.6	16.2				13.9					13.3	11.8
spiracle		17.3						15.8						12.9
1st gill-slit	21.4	21.8	25.1	25.0				20.9	21.7			21.7	20.8	16.4
5th gill-slit								27.4		26.9				23.4
pectoral origin		27.3	28.6	27.7				28.2	29.2			29.2		24.5
1st dorsal origin		35.5	37.2	36.2	32.9	34.8	34.9	37.2	38.2	34.6	32.7	38.2	35.2	35.7
pelvic origin		45.7						46.4	51.9			51.9		45.6
2nd dorsal origin			54.5	54.6				57.7	61.2			61.2		56.3
anal origin								60.7	67.7			67.7		60.2
upper caudal origin		66.0						68.4	77.0			77.0		72.5
Eye diam.	1.2	1.0	1.3	1.4	1.1	1.5		1.1	0.7			0.7	1.1	0.7
Spiracle length		0.2	0.3	0.2				0.2					1.1	0.2
Nostril length		1.1						1.0						0.9
Distance between inner end nostrils		3.6			5.8	4.4		4.7	7.2			7.2		3.7
Mouth width		5.8					7.5	5.0	5.6		7.2	5.6		6.0
Mouth length		5.1			6.4	5.7	6.0	4.9			6.0			5.5
Height 1st gill-slit		3.6						4.0	4.6			4.6		4.2

* Piotrovskiy and Prut'ko (1980) measured one shark but it is unclear whether they refer to a 250 or 322cm specimen.

TABLE 2 (continued)

	Jordan, 1898	Bass *et al.*, 1975	Hussakoff, 1909 *(S. jordani)*	Hussakoff, 1909 *(S. jordani)*	Uyeno *et al.*, 1976	Uyeno *et al.*, 1976 (distorted)	Kobayashi *et al.*, 1982	Our Data	Piotrovskiy & Prut'ko, 1980 *	Garman, 1913	Kobayashi *et al.*, 1982	Piotrovskiy & Prut'ko, 1980 *	Bean, 1905	Our Data
	M	F	F	F	M	F	F	F	?	M	M	?	F	M
TL (cm)	107	115	116	130	132	141	232	234	250	264	269	322	335	384
Height 3rd gill-slit		3.5						3.5						4.0
Height 5th gill-slit	3.6	3.4	3.3	3.2					3.3	5.3		5.3		3.7
Interorbital								6.4	6.8			6.8	6.1	5.2
Post. eye to spiracle			3.1	3.1				1.2					1.5	1.1
1st to 5th gill-slit		5.7							6.5	7.4		7.4		7.5
Pectoral base	4.5	4.9						4.5						5.5
length	8.1	9.0			9.1	10.2								10.5
1st dorsal height	7.9	3.4					4.1	2.1			4.4		7.6	3.7
base	4.5	5.7	4.8		6.8	6.3	6.5	5.0	8.4		7.8	8.4	5.7	8.1
2nd dorsal height														
base	4.0	5.3	5.2	4.6	6.0	5.5		4.7					3.8	6.3
Anal height	3.6	2.9						1.8						4.1
base	7.6		8.2	9.2	8.3	10.4		7.8					9.1	10.4
Pelvic anterior edge		6.1						7.7					6.8	7.6
origin to tip		9.2			9.5	10.9		10.3						12.2
Caudal upper lobe	35.7	35.1			34.3	34.5	32.0	31.8		32.7	32.3		29.5	27.6
lower lobe		9.5					7.6				7.3			7.9
Sub-terminal notch to caudal tip		4.8						4.5						3.6
Between dorsal bases	14.3	12.6						15.8						15.9

* Piotrovskiy and Prut'ko (1980) measured one shark but it is unclear whether they refer to a 250 or 322cm specimen.

TABLE 2 (concluded)

	Jordan, 1898	Bass *et al.*, 1975	Hussakoff, 1909 (*S. jordani*)	Hussakoff, 1909 (*S. jordani*)	Uyeno *et al.*, 1976	Uyeno *et al.*, 1976 (distorted)	Kobayashi *et al.*, 1982	Our Data	Piotrovskiy & Prut'ko, 1980 *	Garman, 1913	Kobayashi *et al.*, 1982	Piotrovskiy & Prut'ko, 1980 *	Bean, 1905	Our Data
	M	F	F	F	M	F	F	F	?	M	M	?	F	M
TL (cm)	107	115	116	130	132	141	232	234	250	264	269	322	335	384
Pectoral to pelvic origins		18.6						18.5						22.5
Space between 2nd dorsal & caudal								6.5						9.6
anal and caudal								1.5						2.3
Clasper length	1.9				2.0									3.9
Depth at 5th gill-slit								9.2	12.1			12.1		12.2
pectoral			9.5	10.4				9.2					9.1	12.5
1st dorsal			11.7	11.2				10.2					8.3	14.3
caudal peduncle								2.8	4.7			4.7		4.6
Max. caudal depth			9.5	9.2										10.4

* Piotrovskiy and Prut'ko (1980) measured one shark but it is unclear whether they refer to a 250 or 322cm specimen.

Tooth counts of our Australian and Japanese material are essentially the same as the count of $\frac{10?,10\text{-}3\text{-}3\text{-}10,13}{13,9\text{-}3\text{-}3\text{-}9,13}$ obtained for a South African specimen (Bass *et al.*, 1975) and the less detailed counts of two Japanese sharks reported as 48-50 rows (Fowler, 1941) and $\frac{48\text{-}52}{42\text{-}48}$ rows (Garman, 1913). However, Jordan's (1898) count of $\frac{13}{12}$ rows on either side for the type specimen is considerably lower, and together with his description of the teeth as 'all needle-shaped, very slender and pointed' suggests that he has omitted or overlooked the small, flattened lateral teeth.

While Bass *et al.* (1975) state, on the basis of its dentition, that the diet of *Mitsukurina* probably consists of small fish and squid, the limited stomach contents from the Australian shark are all that is presently available. The overhanging snout is soft and covered with ampullae of Lorenzini; its function would appear to be sensory rather than as an organ for digging prey organisms out of the substrate.

ACKNOWLEDGEMENTS

We thank Mr Terry Gorman, Mr Ken Graham and the crew of the F.R.V. 'Kapala' of the New South Wales State Fisheries for providing the specimen of *M. owstoni,* Dr L. J. V. Compagno for advice on the correct nomenclature of the goblin shark and Miss Stephanie Davenport and Mr David Rodgers for the photograph.

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The Cladocera (Crustacea) of New Caledonia

B. V. TIMMS

TIMMS, B. V. The Cladocera (Crustacea) of New Caledonia. *Proc. Linn. Soc. N.S.W.* 108 (1), (1984) 1985: 47-57.

Thirteen species are reported with only *Chydorus eurynotus* and *Simocephalus exspinosus australiensis* common. A new subspecies *Latonopsis brehmi dedeckkeri* is erected while *Disphanosoma sarsi* var *novae-caledoniae* is synonymized with *D. sarsi.* The species present are mainly common cosmopolitan or circumtropical forms or have Australian affinities.

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INTRODUCTION

The cladoceran fauna of New Caledonia was documented by Stingelin in 1915. He examined collections from two localities and recorded 7 species, namely, *Diaphanosoma sarsi* Richard var. *novae-caledoniae* (new variety), *Daphnia carinata* King forma *mirabilis* (new form), *Ceriodaphnia rigaudi* Richard, *Simocephalus acutirostratus* (King), *S. australiensis* (Dana), *Ilyocryptus halyi* Brady var. *longiremis* (Sars) and *Alonella* (syn. *Alona*) *karua* (King).

In July-August 1981 Patrick DeDeckker collected widely on the island in order to survey its lacustrine fauna. His collections were made available to the author for study, resulting in the identification of 12 species from 14 of the localities. Full details of the nomenclature and location of the collecting sites will be given in DeDeckker (in prep); for the present his locality numbers are used in the text, with brief nomenclature given in the Appendix.

Microslides of many of the species have been deposited in the Australian Museum under registration numbers P 33799 to P 33815. In the comments that follow only brief synonymies are given; more extensive ones are given in Smirnov and Timms (1983) and/or in the last reference of each synonymy.

SPECIES LIST AND COMMENTS

Latonopsis brehmi dedeckkeri new subspecies

(Fig. 1)

Localities: 2,5,19.
Slides: Holotype ♀ P 33799; Paratype ♀♀ P 33800; P 33801.
Specimens: ♀ ♀ P 33815 — 43 specimens in spirit.
Description: The New Caledonian material assigned to this new subspecies of *Latonopsis brehmi* Petkovski differs only slightly from the nominate form. The most obvious differences are: (i) the basal segment of the endopodite of the antenna is longer (3x width instead of 2x width), (ii) the proximal segment of the endopodite of the antenna has 6-8 setae instead of 8-10, (iii) there are 9-12 fairly evenly spaced anal teeth rather than 13-16 with a few apparently duplicated so that the teeth are unevenly arranged and (iv) on the lower margin of the valve there are 10-12 denticles in each cluster between the setae instead of 3-5.
Length: 2.1mm.
Type Locality: Lac Yaté, New Caledonia, 22°09'S, 167°00'E.
Comments: Originally *L. brehmi* was described from two localities in Australia, one (now drained) in eastern N.S.W. and the other in southwestern W.A. It has since been

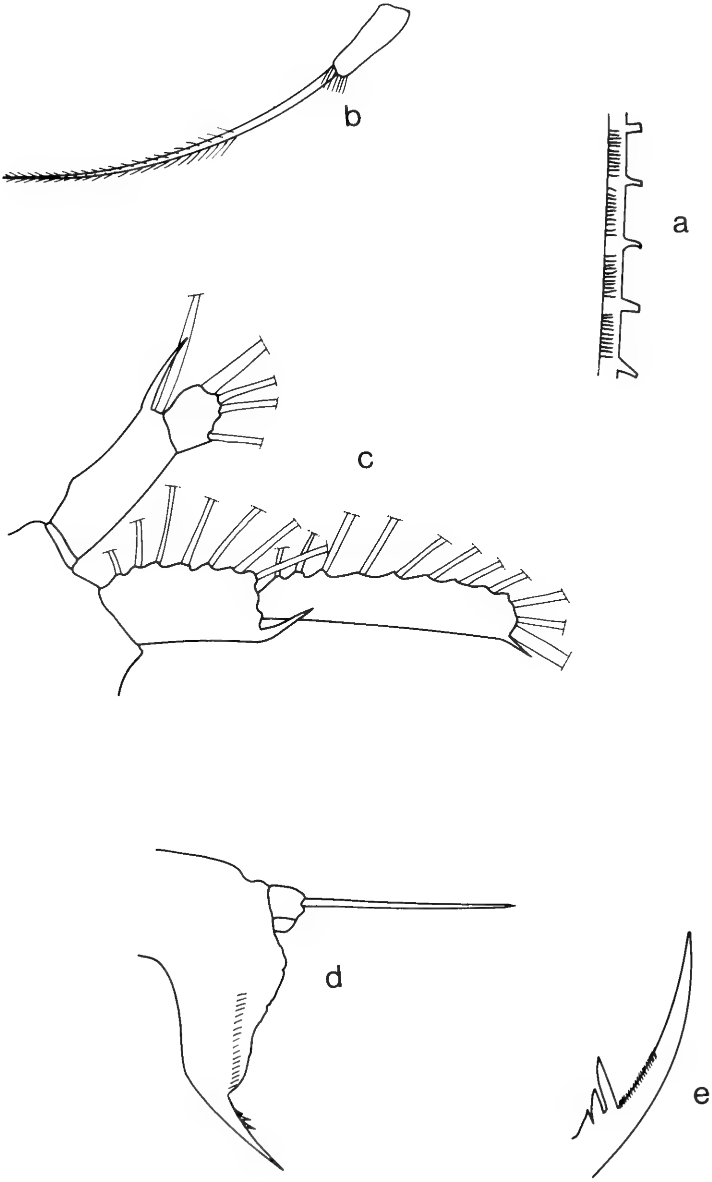

Fig. 1. Latonopsis brehmi ♀. **a** – carapace edge, **b** – antennae I, **c** – antennae II, **d** – postabdomen, **e** – claw.

found in a few localities elsewhere in Australia – southwestern W.A. (R. Shiel, personal communication), Kakadu National Park, N.T. and Cape York (author, unpublished data). The extent of variability of taxonomic characters in these isolated populations is unknown at present, so the author's approach of erecting a new subspecies for the New Caledonian form is tentative, but conservative.

Ecology: pH range 6.4-7.8, conductivity range 4.5-75 μScm^{-1}.

Diaphanosoma sarsi Richard 1894

Diaphanosoma sarsi Richard 1894: 568, figs 4-5.
Diaphanosoma sarsi var *novae-caledoniae* Stingelin 1915: 198, 199, figs 1-3.
Diaphanosoma sarsi, Korovchinsky 1981: 825-827, fig. 8.

Locality: 29.

Slide: P 33802.

Comments: Stingelin recorded *D. sarsi* from New Caledonia but maintained that his specimens were slightly different, so he named his form *D. sarsi novae-caledoniae.* The only characteristic feature he noted was that his specimens had 20-25 denticles on the lower part of the posterior margin of the valves, whereas in *D. sarsi* ***sensu stricto*** there are 18-22. Both the specimen on slide P 33802 and another in the author's collection have 17-21 spines and in all other features are *D. sarsi.* Significantly Stingelin's figure shows only 22 enlarged denticles though they are followed by a few small ones. In that distal denticles in this row lack clear size separation, it is possible Stingelin's count was excessive. Even in the absence of type material for checking, it seems reasonable that his specimens were indeed *D. sarsi* ***sensu stricto.***

Length: 1.1mm.

Ecology: pH 8.4, conductivity 550 μScm^{-1}.

Alonella clathratula Sars 1896

(Fig. 2)

Alonella clathratula Sars 1896: 43-45, pl. 6, figs 7-8.
Alonella excisa var *clathratula,* Smirnov 1971: 260-263, fig. 265.
Alonella clathratula, Smirnov and Timms 1983: 26, fig. 26.

Locality: 25.

Slide: P 33803.

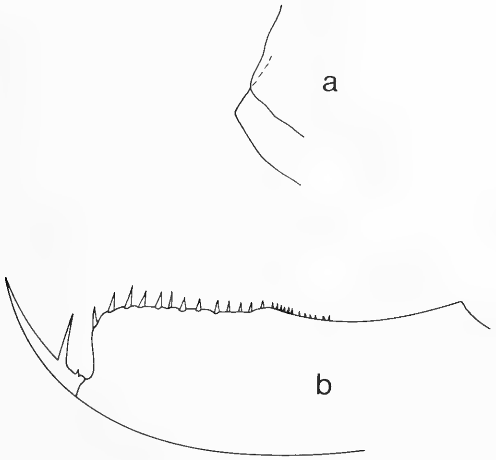

Fig. 2. Alonella clathratula ♀. **a** — ventroposterior corner of carapace, **b** — postabdomen.

Comment: Both the specimen on slide P 33803 and one in the author's collection have relatively elongated valves and postabdomen while the posterioventral corner of the valve is rounded with little indication of an indentation above it. Hence they have the identifying feature of *clathratula* (Smirnov and Timms, 1983). However it is possible that this form is but a subspecies of *excisa* as maintained by Delachaux (1919) and Smirnov (1971). A detailed study is therefore needed.

Length: 0.42mm.

Ecology: pH 7.6, conductivity 126 μScm^{-1}.

Chydorus eurynotus Sars 1901

Chydorus eurynotus Sars 1901: 70, pl. II, figs 3a-c.

Chydorus eurynotus, Smirnov 1971: 306-308, figs 337-342.

Localities: 2, 8, 19, 25, 27, 29.

Slide: P 33804.

Comments: *Chydorus eurynotus* is the most often encountered cladoceran in New Caledonia. Of the various subspecies listed by Smirnov (1971) the New Caledonian species belongs to the nominate one.

Length: 0.34mm.

Ecology: pH range 6.4-8.4, conductivity range 4.5-550 μScm^{-1}.

Ephemeroporus cf. ***barroisi*** (Richard, 1894)

(Fig. 3)

Pleuroxus barroisi Richard 1894: 375-377, figs 7-12.

Chydorus barroisi, Sars 1895: 75-78, p14, figs 9-13.

Chydorus barroisi, Smirnov 1971: 198-301, figs 328-332.

Ephemeroporus barroisi, Frey 1982: 234-237.

Localities: 2, 7, 19.

Slide: P 33805.

Comments: The specimen on slide P 33805 is not well presented, but there is little doubt it is a member of the *barroisi* complex (*sensu* Frey, 1982), for there are four teeth on the labrum, a spine at the ventroposterior corner of the valve and the three most proximal denticles on the postabdomen are the longest. Specific allocation within the complex must await further study of the *barroisi* group (see Frey, 1982).

Fig. 3. Ephemeroporus barroisi ♀. **a** — labrum, **b** — ventroposterior corner of carapace.

Length: 0.28mm.
Ecology: pH range 6.4-7.8, conductivity range 4.5-78 μScm^{-1}.

Dunhevedia crassa King 1853

Dunhevedia crassa King 1853b: 261, pl. VIIF.
Dunhevedia crassa, Smirnov 1971: 319-320, figs 358-360.

Locality: 30.
Slide: P 33806.
Comments: *Dunhevedia crassa* is a common cosmopolitan species although it is apparently rare in New Caledonia. Of the various subspecies listed by Smirnov (1971), the New Caledonian specimens belong to the nominate one.
Length: 0.51mm.
Ecology: pH 7.6, conductivity 590 μScm^{-1}.

Alona rectangula Sars 1862 *sensu lato*

(Fig. 4)

Alona rectangula Sars 1862: 160.
Alona rectangula, Smirnov 1971: 346-348, figs 391-405.

Locality: 32.
Slide: P 33807.
Comments: *Alona rectangula*, an ill-defined species which groups many described subspecies, is probably a species complex and is in need of revision (Smirnov, 1971 and personal communication). The specimen on slide P 33807 is tentatively designated as

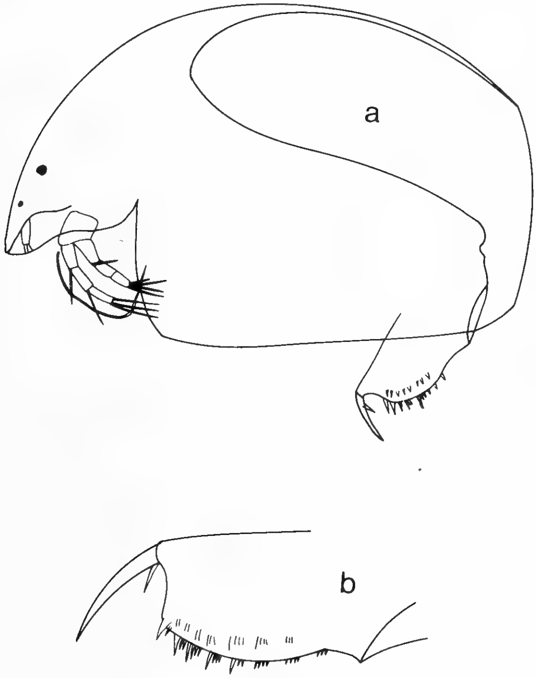

Fig. 4. Alona rectangula ♀. **a** — lateral view of whole animal, **b** — postabdomen.

A. rectangula rectangula, a form recorded in nearby Australia (Smirnov and Timms, 1983) but not New Zealand (Chapman and Lewis, 1976). Other forms of *A. rectangula* are common in both Australia and New Zealand (op. cit.).
Length: 0.26mm.
Ecology: pH 8.6, conductivity 175 μScm^{-1}.

Biapertura karua (King 1853)

(Fig. 5)

Alona karua King 1853b: 260, pl. VIII.
Biapertura karua, Smirnov 1971: 479-480, figs 600-603.
Localities: 28, 29.
Slide: P 33808.
Comments: *Biapertura karua* is a common cosmopolitan species between 40° N and 40° S (Smirnov, 1971) and is one of the few species previously recorded for New Caledonia by Stingelin (as *Alonella karua*). Some authors do not recognize Smirnov's erection of the genus *Biapertura* and so use the name *Alona karua.*

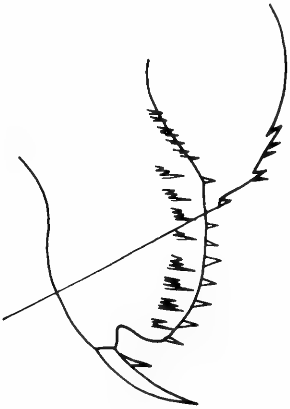

Fig. 5. Alona karua ♀. Ventroposterior corner of valve and postabdomen.

Length: 0.28mm.
Ecology: pH 8.0-8.4, conductivity 550 μScm^{-1}.

Biapertura macrocopa (Sars 1895)

(Fig. 6)

Alona macrocopa Sars 1895: 20-23, pl. III, figs 11-15.
Biapertura macrocopa, Smirnov and Timms, 1983: 62, 63, figs 73, 74.
Locality: 25.
Slide: P 33809.
Comments: Although this species is described inadequately, the specimen on slide P 33809 has the diagnostic features given by Sars (1895) and Smirnov and Timms (1983), namely, the antenna has spines 1-0-1 / 1-1-1 with those at the distal end of the first and second exopodite segments being noticeably elongated. The postabdomen also is characteristic (Timms, in prep.), in that it is short with a rounded distal part bearing 5-6 larger anal denticles followed anteriorly by numerous slender ones. There are also about

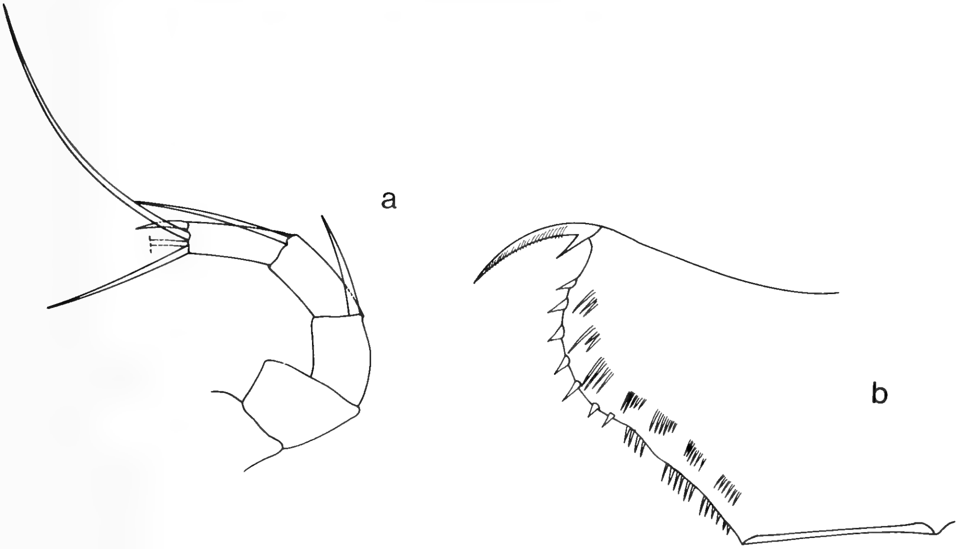

Fig. 6. Alona macrocopa ♀. **a** — antennae II exopodite, **b** — postabdomen.

7 lateral fascicules with the most distal ones having an enlarged seta reaching the edge of the postabdomen.

Biapertura macrocopa (syn = *Alona macrocopa*, see earlier comment) is basically an Australian species, being mainly found in northern areas (Smirnov and Timms 1983; Timms, in prep.), but it also occurs rarely in N.Z. (Sars, 1895) (Chapman and Lewis, 1976). Its presence in New Caledonia, located between Australia and New Zealand, is therefore not surprising.

Length: 0.34mm.

Ecology: pH 7.6, conductivity 126 μScm^{-1}.

Macrothrix spinosa King 1853

Macrothrix spinosa King 1853b: 256, pl. VIF.

Macrothrix spinosa, Smirnov 1976: 73-76, figs 41-44.

Locality: 30.

Slide: P 33810.

Comments: The characteristics of the specimen on slide P 33810 agree with those for this common cosmopolitan species.

Length: 0.48mm.

Ecology: pH 7.6, conductivity 590 μScm^{-1}.

Daphnia cephalata King 1853

(Fig. 7)

Daphnia carinata var. *cephalata* King 1853a: 254, pl. 6, fig. B.

Daphnia cephalata Hebert 1977: 385-388, figs 51-62.

Localities: 8, 30.

Slides: P 33811.
Comments: The taxonomy of *Daphnia* in Australia is in a confused state. Hebert's (1977) erection of many new species and the resurrection of others seems to be invalidated by the unpublished isozyme work of John Benzie (personal communication) which at present suggests that most of Hebert's species are morphs of *D. carinata.* However, the specimens from New Caledonia comfortably fit Hebert's (1977) description of *D. cephalata.* A further complication occurs by trying to determine the taxonomic status of Stingelin's *D. carinata* form *mirabilis* which he described from New Caledonia. Hebert (1977) suggests it is similar to *D. longicephala.* A study of the figured specimen indicates it is *D. carinata* while the present finding of only *D. cephalata* on New Caledonia points to both species being present or to a possible synonymy. The situation cannot be resolved until J. Benzie's work is published.

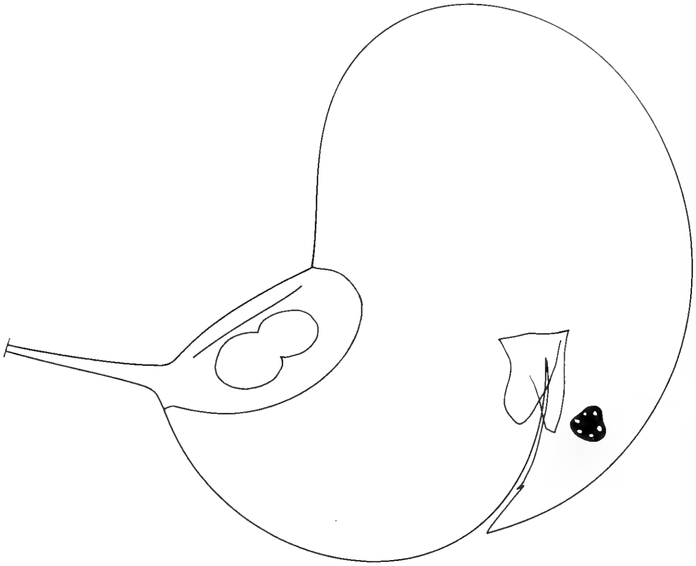

Fig. 7. Daphnia cephalata ♀. Lateral view of whole animal.

Length: 4.2mm (excluding tail spine).
Ecology: pH 7.6, conductivity range 215-590 μScm^{-1}.

Simocephalus exspinosus australiensis (Dana, 1852)
Daphnia australiensis Dana 1853: 1271-1272, pl. 89, fig. 4.
Simocephalus australiensis, Sars 1888: 15-25, pl. 2, figs 1-5.
Simocephalus exspinosus australiensis, Dumont *in* Smirnov and Timms 1983: 104, pl. 1.
Localities: 20, 31, 32, 33.
Slide: P 33813.
Comments: Stingelin (1915) recorded this species as *S. australiensis* (Dana), but Dumont *in* Smirnov and Timms (1983) considered it a subspecies of the cosmopolitan *S. exspinosus.* The *australiensis* form is distinguishable from other forms of *exspinosus* by having unequal triangular spines in the pecten on the postabdominal claw.

Length: 1.6mm.
Ecology: pH range 6.6-9.4, conductivity range 38-500 μScm^{-1}.

Simocephalus acutirostratus (King, 1853)

Simocephalus elisabethae var *acuti-rostrata* King 1853b: 254, pl. VIC.
Simocephalus acutirostratus, Sars 1888: 67.

Locality: 30.
Slide: P 33814.
Comments: Although the specimen on slide P 33814 is immature, it displays the typical characteristics of *S. acutirostris*, namely a pointed anterior part of the head, ocellus rhomboidal and a broad postabdomen with two deep embayments. Stingelin (1915) also recorded this species from New Caledonia.
Length: 1.9mm.
Ecology: pH 7.6, conductivity 590 μScm^{-1}.

DISCUSSION

Seven species were reported by Stingelin (1915) and 13 in this study, with 5 common to both, so that altogether 15 species of Cladocera are now known for New Caledonia. The Sididae are represented by 2 species (*Diaphanosoma sarsi, Latonopsis brehmi dedeckkeri*), the Chydoridae by 8 species (*Alonella clathratula, Chydorus eurynotus, Ephemeroporus* cf. *barroisi, Dunhevedia crassa, Alona rectangula, Biapertura karua* and *B. macrocopa*), the Macrothricidae by 2 species (*Ilyocryptus hayli* var *longiremis* = synonym *I. sordidus* and *Macrothrix spinosa*) and the Daphniidae by 4 species [*Daphnia cephalata, Simocephalus acutirostratus, S. exspinosus australiensis* and *Ceriodaphnia riguadi* (possibly synonymous with *C. cornuta*)]. The families Bosminidae and Moinidae, common in nearby Australia, remain unrecorded.

The most common species are *Chydorus eurynotus* and *Simocephalus expinosus australiensis.* Four more (*Latonopsis brehmi dedeckkeri, Ephemeroporus* cf. *barroisi, Biapertura karua, Daphnia cephalata*) could be regarded as reasonably common, but the remainder seem to be uncommon, as only one or a few specimens were found in just one of the present 14 collections or in one of Stingelin's collections.

Many of the species occurring in New Caledonia generally are regarded as being common cosmopolitan or circumtropical forms. Examples include *Diaphanosoma sarsi, Chydorus eurynotus, Ephemeroporus* cf. *barroisi, Dunhevedia crassa, Alona rectangula, Biapertura karua*, and *Macrothrix spinosa.* A few have more limited distribution [e.g. *Daphnia cephalata* ranges from India to Australia to Argentina (Hebert, 1977)] or are not so common worldwide e.g. *Alona clathratula, Ilyocryptus sordidus.* The remaining 4 species have Australian affinities. New Caledonia is the only record outside Australia for *S. acutirostratus* and is the first record outside Australia for *Latonopsis brehmi*, and *Simocephalus exspinosus australiensis.*

Probably most, if not all, of the species of Cladocera in New Caledonia dispersed from Australia 1200km to the west, or less likely from New Guinea further away to the northwest. It is significant then that there are mainly common cosmopolitan and circumtropical species plus a few species of Australian affinities present. This is because to reach New Caledonia, a cladoceran needs the good dispersal powers widespread species must have, or otherwise originate nearby. Other islands of the Pacific east of New Caledonia can be expected to have even fewer species because of their smaller size and greater distance from continental Australia (MacArthur and Wilson 1967). Unfortunately most have not been explored for Cladocera so that not much more information is available than when Stingelin (1915) examined the subject. Limited data

(Dana, 1852; C. H. Fernando, personal communication) for Fiji which is somewhat smaller (10400 km^2), than New Caledonia (16700 km^2) and 1100 km further east, indicate a cladoceran fauna of more than 5 species (including *Diaphanosoma sarsi, Alona davidi, Biapertura karua* and *Moina micrura*, all cosmopolitan or circumtropical species). The main island of Tahiti (area = 1040 km^2, 6000 km east of Australia) has just one species recorded, a form of *Chydorus sphaericus* ***sensu lato*** (Timms, unpublished data).

ACKNOWLEDGEMENTS

I wish to thank Patrick De Deckker for making available his collections for study and for his comments on the manuscript. Prof. C. H. Fernando is thanked for valued discussion and access to unpublished data. I collected cladocerans in Tahiti in June 1982 with the help and hospitality of Ranold Doon, to whom I am most grateful.

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APPENDIX

List of localities in New Caledonia sampled by P. De Deckker which contain Cladocera.
De Deckker's original numbers are retained.

NC 2	Lac Yaté, westernmost side. 31-vii-1981.
NC 5	Lac Yaté, near dam wall. 31-vii-1981.
NC 7	Floodplain of 'Rivière des Lacs'. 31-vii-1981.
NC 8	Pond on autoroute between Tontouta and Noumea. 1-viii-1981.
NC 19	Lac en Y. 2-viii-1981.
NC 20	Small dam on property near Nakele. 4-viii-1981.
NC 25	Water reservoir for Noumea, near dam wall. 5-viii-1981.
NC 27	Pool near La Dumbea River. 8-viii-1981.
NC 28	Swamp on southern entrance to Bouloupari. 8-viii-1981.
NC 29	Pond north of Bouloupari. 8-viii-1981.
NC 30	Dam on farm on road to La Foa. 8-viii-1981.
NC 31	Swamp at Naina. 8-viii-1981.
NC 32	Duck dam near La Foa. 8-viii-1981.
NC 33	Drain on autoroute between Tontouta and Noumea. 8-viii-1981.

A Review of the ophiocomin Genus *Clarkcoma* Devaney, 1970 (Ophiuroidea: Ophiocomidae)

F. W. E. ROWE

ROWE, F. W. E. A review of the ophiocomin genus *Clarkcoma* Devaney, 1970 (Ophiuroidea: Ophiocomidae). *Proc. Linn. Soc. N.S.W.* 108 (1), (1984) 1985: 59-69.

The ophiocomin genus *Clarkcoma* Devaney, 1970, and its three species are reviewed. *C. pulchra* (H. L. Clark) is recognized as a valid species. Colour patterns are specific for each of the species *C. canaliculata* (Lütken), *C. pulchra* (H. L. Clark) and *C. bollonsi* (Farquhar). *C. bollonsi*, previously known only from New Zealand, is recorded from southwestern and southeastern Australia.

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INTRODUCTION

Stimulated by both H. L. Clark's (1921) revision of the Ophiocominae and Murakami's (1963) work on ophiuroid dental and oral plates, Devaney (1970, 1978) began a series of reports dealing with the species and genera of the family Ophiocomidae. In his first report (1970) Devaney re-evaluated the tropical genus *Ophiocoma* and described a new genus, *Clarkcoma*, to accommodate the temperate-water species *Ophiocoma canaliculata* Lütken, with which he concluded *O.c.* var. *pulchra* H. L. Clark and *O. punctata* Koehler to be conspecific, and *O. bollonsi* Farquhar. *Clarkcoma* occurs in southern Australian and New Zealand waters. The purpose of this paper is to review the genus *Clarkcoma*, and its species.

During 1981 and 1982 extensive collections of echinoderms were made along the southern coast of New South Wales (1981) and northern New South Wales (1982) by the Australian Museum. Among the collections were some 500 specimens of the ophiuroid genus *Clarkcoma*. In the field it was apparent that four colour forms of *Clarkcoma* could be recognized. Examination in the laboratory, however, showed that using structural features in combination with colour, only three species could be recognized, the fourth colour form representing juvenile specimens of one of the other species. This material was then compared with established collections of *Clarkcoma* in the Australian and Western Australian Museums, with specimens of *C. bollonsi* borrowed from the National Museum of New Zealand, with the lectotype of *O. canaliculata* borrowed from the Zoologiske Museum, Copenhagen, and with the holotype of *O.c.* var. *pulchra* from the South Australian Museum.

Each of the species of *Clarkcoma* has been adequately described either by its author or by subsequent workers, so that only a diagnosis of the significant features is given for each species in this paper. Because of the bulk of material examined, locality data are kept to a minimum. Additional information can be retrieved from the relevant institution housing the material by quoting the appropriate register number. Numbers of specimens examined from each registered 'lot' are given in parenthesis. The history of each species is discussed in the light of new information now available. As a result, this study has confirmed the identity of *Clarkcoma* and clarified the status and limits of the species contained therein.

ABBREVIATIONS

AM	Australian Museum, Sydney, N.S.W., Australia.
CM	Zoologiske Museum, Copenhagen, Denmark.
NMNZ	National Museum of New Zealand, Wellington, New Zealand.
SAM	South Australian Museum, Adelaide, South Australia.
WAM	Western Australian Museum, Perth, Western Australia.
dd	disc diameter
R	arm length
l	length (of dental plate)
br	breadth (of dental plate)

SYSTEMATIC ACCOUNT

Family OPHIOCOMIDAE Ljungman, 1867

Subfamily OPHIOCOMINAE Matsumoto, 1915

Genus *Clarkcoma* Devaney, 1970

Clarkcoma Devaney, 1970: 1

Diagnosis: A genus of Ophiocominae characterized by thin, compressed arm spines; adoral shields extending proximal to the oral shield and sometimes contiguous; small, vertically-directed buccal tentacle scales, which are separated from the adoral shields, additional small papillae may be present between the outer oral papilla and buccal tentacle scale; oral plate with abradial muscle scar concave, a narrow medial ridge and several short processes; adradial muscle scar restricted to a small part of the adradial side of the plate; radiating grooves and ridges absent from abradial muscle scar; hyaline tipped teeth; well developed teeth foramina in the dental plate.

Type species: *Ophiocoma canaliculata*, Lütken, 1869; designated by Devaney, 1970.

Other species included: *C. bollonsi* (Farquhar, 1908); *C. pulchra* (H. L. Clark, 1928).

Distribution: Dongara, Western Australia, along the south and east coasts of Australia to Mooloolaba, Queensland; New Zealand and the Chatham Rise; 0-630m depth.

Remarks: Devaney (1970) considered *Clarkcoma* to be most closely related to *Ophiocomina* and *Ophiopteris*, with which it shares three features: buccal tentacle scales not in contact with the adoral shields; the position of the adoral shields on the proximal edge of the oral shields, where the adorals are often broadly in contact; similarity of the arm spines. Using these features, he separated the three genera from *Ophiocoma, Ophiomastix, Ophiarthrum* and *Ophiocomella*, in the subfamily Ophiocominae. I can add that in the species of *Ophiocoma* (except *O. pusilla*), *Ophiomastix* and *Ophiarthrum* the abradial muscle scar on the oral plates characteristically bears parallel or slightly radiating grooves and ridges (Murakami, 1963: pl. VII, figs 11-34; Devaney, 1970: figs 30, 44). These ridges and grooves are absent in species of *Clarkcoma, Ophiocomina* and *Ophiopteris*. Neither are they present in *Ophiocomella*, but in this case there is an aperture through the abradial muscle scar (Devaney, 1970: fig. 43). I have not found this aperture in any of the other ophiocomin genera. Devaney (1970) found a similar feature in the oral plates of *Ophiactis savignyi*, and concluded that it might be linked to the phenomenon of fissiparity exhibited by both species.

The hyaline-tipped teeth and the size and/or presence of the foramina in the dental plates were used by Devaney to distinguish *Clarkcoma* from *Ophiocomina* and *Ophiopteris*. Although I can confirm that the foramina are absent in the dental plates of the *Ophiocomina nigra* which I have examined, I have found that those in the dental plates of *Ophiopteris* species are not reduced compared with species of *Clarkcoma*. I have found a remarkable similarity in plate shape, size of tooth foramina and distribution of teeth and of tooth papillae in *C. bollonsi* and the two species of *Ophiopteris, O. papillosa* and *O.*

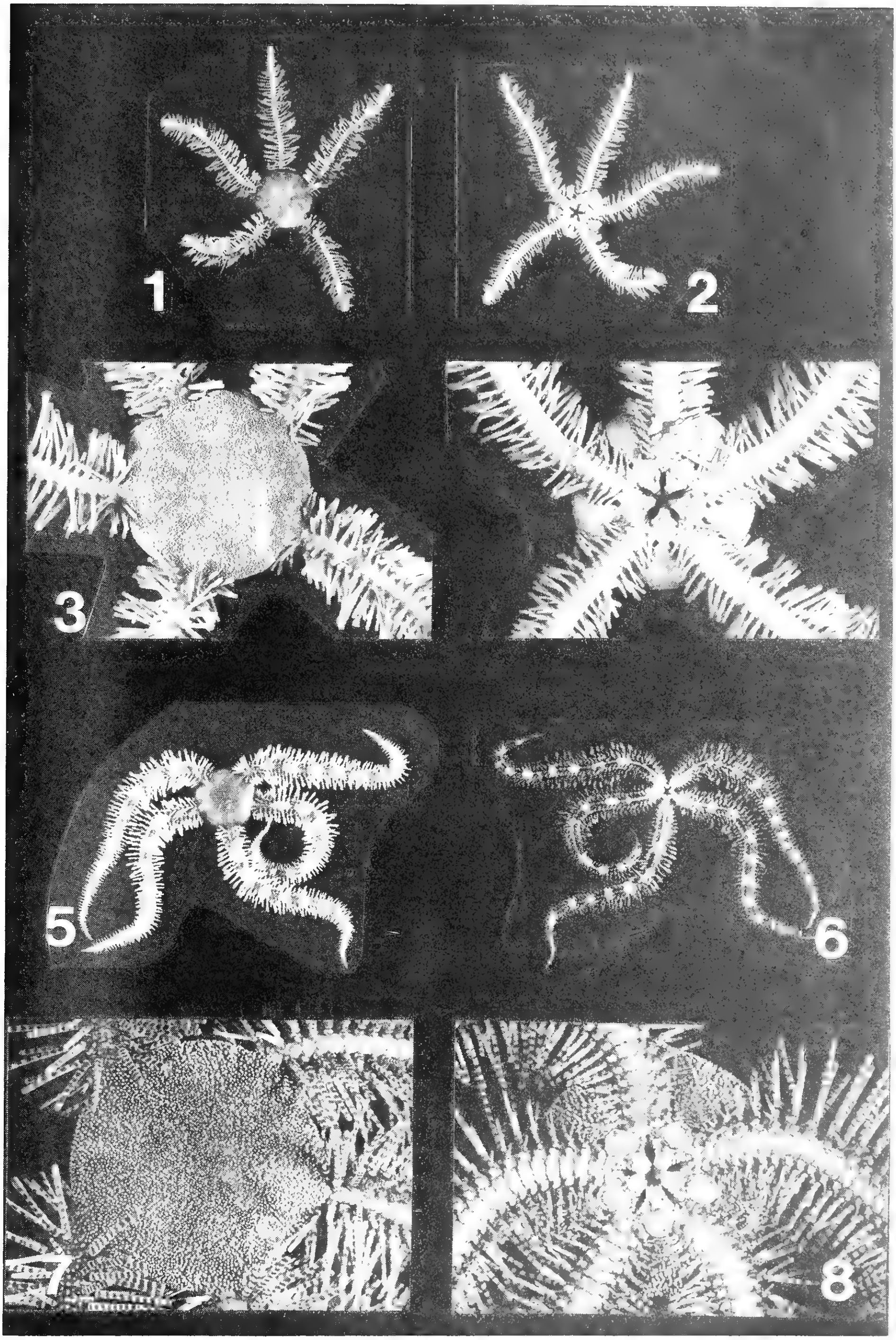

Fig. 1. **1-4,** *Clarkcoma canaliculata*, lectotype, (CM), dd = 20 mm. **5-6,** *C. canaliculata*, (AMJ14390), dd = 5 mm. **7-8,** *C. pulchra*, (AMJ14631), dd = 20 mm.

antipodum. The dental plates of *C. canaliculata* and *C. pulchra* are shorter than those of *bollonsi* and the species of *Ophiopteris*, the foramina are relatively larger, and the number and form of the tooth papillae differ. However, as Devaney points out, the teeth of species of *Clarkcoma* are hyaline-tipped, whereas those of *Ophiopteris* and *Ophiocomina* are not.

Differences in the form of the arm spines of *Clarkcoma* and *Ophiopteris* are more marked than is evident from the earlier descriptions. The spines of *Ophiopteris* are in fact more similar to some species of *Ophiocoma* (e.g. *O. scolopendrina*). However, distinctively the uppermost one (or two) spines are reduced and squamate in *Ophiopteris*.

Clarkcoma canaliculata (Lütken)

Fig. 1, **1-6**

Ophiocoma canaliculata Lütken, 1869: 46; Koehler, 1904: 75, figs 30-32
Clarkcoma canaliculata, Devaney, 1970: 5 (part) (for reference to *O. canaliculata* only) figs 8-9, 11; Baker, 1982: 431 (part) fig. 10, 18b; Rowe and Vail, 1982: 223
Clarkcoma pulchra, Rowe and Vail, 1982: 223 (non *C. pulchra* (H. L. Clark 1928))

Diagnosis: A species of *Clarkcoma* with dd up to 24mm, dd/R=c.3:1; granules relatively fine, close, up to 120/mm^2, ventral disc scaling mostly bare, only a shallow v-shaped wedge of granules extending below the ambitus of the disc; dental plates with lateral and central tooth papillae similar in size, central papillae few, up to c.14; some arm spines, to about 1/2R, with reddish-orange, thick-skinned saccule covering their tips in life; colour in life varies with size, juveniles with disc dark brown-black, arms with wide, transverse bands of cream-white (Fig. 1, **5-6**); adults are uniformly reddish-brown-black (Fig. 1, **1** and **3**), a longitudinal cream line extends along the mid ventral line of the arms, (Fig. 1, **2, 4, 6**), distributed from Rottnest Island, W.A., to Long Reef (Collaroy), N.S.W., also circumscribing Tasmania; depth, 0-40m.

Material examined:

CM: Lectotype, Bass Strait, 1866.

AM: New South Wales; Long Reef (Collaroy) J12417(1); Port Jackson, J4485(1), J6812(1); Port Hacking, J10063(2); Shellharbour, J4358(2), J4415(11), J4509(2), J4602(1), J4712(1), J4718(1); Jervis Bay, 4.5-33m, J9731(1), J11057(1), J14392(1), J14393(4), J14720(16), J14724(8), J15731(2); Ulladulla, 9.5-19m, J14389(4), J15730(2); Bateman's Bay, 6.5-36m, J13988(6), J13996(16), J13999(13), J14384(2), J14388(4), J14721(4), J14723(2), J14725(10); Montague Island, 9.5-38m, J13968(24), J13976(3), J14387(3), J14390(2), J14623(5), J15432(1); Bermagui, 26m, J14625(7); Merimbula, 9.5m, J14626(3); Eden, 23m, J14622(1).

Tasmania; Rocky Cape, 1.5-4.5m, J11385(1); Maria Island, 22m, J11318(1); Devonport, J10545(2); Hunter Island, J6844(1).

Victoria; Warrnambool, J10788(2); Port Fairy, G10968(2).

South Australia; Kangaroo Island, 5m, J12612(1); Gulf St Vincent, J6211(2).

Western Australia; King George Sound, J3971(1), J3974(1), J3976(1); Bunker's Bay, J6208(2); Point Peron, J6304(2); Garden Island, J17037(1); Rottnest Island, 13m, J17611(5).

WAM: Victoria; Barwon Heads, 385-79(2).

South Australia; Port Willunga, 265-39(part) (3).

Western Australia; Doubtful Islands Bay, 358-75(1), 516-75(1); Two-People's Bay, 625-76(1); King George Sound, 203-76(part) (4); Augusta, 600-78(1); Cowaramup Bay, 199-76(2), 598-78(1); Wyadup, 71-72(1), 72-72(1); Yallingup, 200-76(1); Cape Naturaliste, 35-74(1), 36-74(1), 38-74(1), 48-74(1), 1505-74(1), 196-76(1), 198-76(1), 19-1979(1); Dunsborough, 44-74(2); Point Peron, 265-39 (part) (1); Cockburn Sound, 230-70(part) (1), 37-71(1), 197-71(1), 20-74(1), 22-74(1), 23-74(1), 24-74(1), 183-76(1), 186-76(1); Fremantle, 1319-75(1); Rottnest Island, 180-76(2), 181-76(1).

Discussion: Lütken (1869) described *canaliculata* from an unspecified number of specimens collected from Bass Strait. He did not figure the species but gave measurements for the species of 'dd = 20 mm' and 'R = 65 mm or less'. Lyman (1882) commented that *O. canaliculata* possessed small scales at the base of the first dorsal arm spines. Neither Koehler (1922) nor I have found scales described by Lyman. In a key to the species of *Ophiocoma*, Lyman separated *canaliculata* from other species he included in the genus, by virtue of its spatulate arm spines. Koehler (1904) redescribed and figured what he believed to be Lütken's only specimen of *canaliculata* in the Copenhagen Museum. Koehler pointed out that the arms measure about 40mm in length rather than the 65mm given by Lütken. Presumably Lütken's other specimens are lost. Clark (1921) reported that he had examined only one specimen of *canaliculata* from Victoria, though the collector (of the specimen) had indicated that '. . . he feels sure that 10 or 12 years ago it was quite common at the spot which has been spoiled as a collecting ground by certain harbour improvements'! Clark reported the colour of the dried specimen as 'light brown, with a distinctly greenish tinge on the disc and with arms quite reddish'. He commented that *canaliculata* was a particularly rare and little-known form. Clark drew attention to the close relationship between *O. bollonsi* Farquhar and *canaliculata*, and in particular to the large adoral plates which both species possess. However, because of Farquhar's description of spiniform granules near the disc margin, he placed *bollonsi* in the *pumila* section of his key of *Ophiocoma* species, acknowledging in his text little relationship between those two species. Prophetically, Koehler (1922) suggested that *canaliculata* may need to be placed in a new genus primarily because of the form and position of the adoral plates, this differing from all other species of *Ophiocoma.* Interestingly Koehler (1922) considered *O. bollonsi* to be closest to *O. scolopendrina*, differing from it in having 6 arm spines at the base of the arm. Clearly he had not examined any specimens of *bollonsi*, and was not aware of the form of the adoral plates. Presumably, also, Koehler (1922) would not have been aware of Clark's (1921) comments about *canaliculata* and *bollonsi* at the time he was preparing his manuscript. Clark (1928) recorded 14 specimens of *canaliculata* from South Australia, and described the colour of two juveniles with a dark grey disc and widely scattered white marks occurring irregularly along the dorsal side of the arms, and a broad white band ventrally. He described adults as light blackish-brown with arm spines lighter and, on the underside of the arms, a longitudinal white band. In 1938, Clark reported some 93 specimens, extending in geographic range from Shellharbour, N.S.W. to Rottnest Island, Western Australia. He also recorded live colour for specimens from Port Willunga, South Australia: 'all uniformly black in life with a reddish cast on sides and orally', and Point Peron, Western Australia: 'pale alive, light brown to dark brown'. In 1946, Clark considered *canaliculata* to be an endemic Australian species and one of the most characteristic brittle-stars of temperate Australian waters. However, he noted that the species had not been recorded from Tasmania. A. M. Clark (1966) recorded *canaliculata* from Port Phillip. Devaney (1970) examined 19 specimens, including a paratype of *O. punctata* Koehler and two paratypes of *O. canaliculata* var *pulchra* H. L. Clark. He concluded that *punctata* and *pulchra* are conspecific with *canaliculata* and designated *canaliculata* as type-species for the new genus *Clarkcoma.* Rowe and Vail (1982) record *C. canaliculata* from Tasmania for the first time.

I have examined the remaining type specimen, herein designated the lectotype, of *canaliculata* (Fig. 1, **1-4**) and some 231 specimens from the coast of New South Wales (167), Tasmania (5), Victoria (6), South Australia (2) and Western Australia (51).

I can confirm Koehler's (1904) description and measurements of the lectotype. The only additional information necessary relates to the number of tooth papillae present in the lectotype. There are 3-4 lateral papillae on each side of the dental plate and 7-8 central papillae. Mortensen (1924) and Devaney (1970) describe and count the tooth papillae in *transverse rows* across the plate in *bollonsi*, though Devaney (1970) describes the papillae in *irregular columns* for *canaliculata*. A more standardized description of the arrangement of tooth papillae can be given since a longitudinal row of papillae can be recognized along each side of the dental plate, between which the remaining (central) papillae are regularly or irregularly arranged. Because these central papillae are slightly (*pulchra* and *canaliculata*) or markedly *(bollonsi)* smaller than the laterals, they are relatively easy to count. The central papillae count includes those papillae seen clustered at the apex of the oral angle, since they occur on the dental plate. The papillae occurring along the margin of the oral plates are not counted. Devaney (1970) used the difference between dental plate shape and number of tooth papillae as major characters separating *canaliculata* from *bollonsi*. However, the shape of the plate and papillae number offer no differences with which to separate *canaliculata* from *pulchra*.

I can confirm, also, the range of live and preserved colour described by H. L. Clark (1928, 1938, 1946). There is, however, no doubt that both H. L. Clark and Koehler (1930) were correct in recognizing a second species, the name for which is *pulchra*. The colour pattern alone is constant for each species. In addition the coarser granulation, more extensive ventral granulation and shape of the dorsal arm plates of *pulchra* afford reliable characters which separate these two species.

A character not hitherto reported for *canaliculata* is the presence, in life, of an orange-red, thick-skinned saccule covering the tip of a number of the larger arm spines (see Fig. 1, **5-6**). These occur to about 1/2R. The spines bearing this structure are usually slightly thicker than adjacent spines and flaring at the tip. In preserved state the skin is retracted, giving the spine a thickened, club-tipped appearance. Similar structures occur on spines of *C. bollonsi* and some other ophiocomins, but are absent from *C. pulchra*. This feature is discussed further for *C. bollonsi*.

Clarkcoma pulchra (H. L. Clark)
(Fig. 1, **7-8**, Fig. 2, **1-2**)

Ophiocoma canaliculata var. *pulchra* H. L. Clark, 1928: 439, figs 131a-b
Ophiocoma punctata Koehler, 1930: pl. 14, figs 2-5
Clarkcoma canaliculata, Devaney, 1970: 5 (part; reference to *O. pulchra*) fig. 15. Baker, 1982: 431 (part), fig. 10, 19b (non *C. canaliculata* (Lütken))

Diagnosis: A species of *Clarkcoma* with dd up to 21mm, dd/R c.3.5, granulation coarse, spaced, up to 40-50 granules/mm^2, extending on to ventral surface of disc almost to oral shields, only a narrow area of naked scales bordering the genital slits and oral shield; dental plates with lateral and central tooth papillae of similar size, central papillae few, up to c.14; spine sacculae absent; colour in life of both juveniles and adults variegated maroon and cream/white, arm spines banded (Fig. 1, **7-8**, Fig. 2, **1-2**); distributed from Byron Bay, N.S.W., to Dongara, W.A. but not recorded from Tasmania; 0-40m depth.

Material examined:

SAM: Holotype, K241, ?South Australia.

AM: New South Wales; Byron Bay, 9.5-26m, J14872(2), J14879(2), J14883(1); Solitary Islands, 9.5-28m, J11604(1), J1276(1), J14838(5), J14850(3), J14895(1), J14906(1), J14925(3), J15020(3), J15022(5), J15023(1), J15024(3), J15048(1); S.W. Rocks, 26m, J14890(12), J15021(1); Long Reef (Collaroy), J4184(1), J6307(1), J7297(1), J7372(2), J10386(2), J11351(1), J12413(1), J12414(1), J12415(1), Port Jackson, G7737(1), G11439(2), G11440(1), J461(1), J1653-5(3), J1980(2), J1985(1), J2389(1), J3316(13), J3321(1), J3360(4), J3361(1), J3364(2), J4623(1), J6786(1), J9858(1), J11568(2); Coogee, G1278(1), J2370-5(5); Botany Bay, 8m, J11386(1); Shellharbour, J4357(1), J4359(2), J4512-4(3), J4529(1), J4534(2), J4547(1), J4548(1), J4800(2), J14726(1), J14738(5), J14739(3); Jervis Bay, 4.5-28m, J14383(1), J14391(10), J14731(2); Ulladulla, 9.5-26m, J14735(5), J14737(3); Bateman's Bay, 9.5-36m, J13971(4), J14727(6), J14729(1), J14730(1), J14732(3), J14734(2), J14736(9); Montague Island, 6-38m, J13987(21), J14386(2), J14627(3), J14728(6), J14733(1); Bermagui, 19-26m, J14628(1), J14630(12), J15583(1); Merimbula, 9.5m, J14631(9); Eden, 0-28m, J6699(1), J1429(2), J14632(1).

Western Australia; Cockburn Sound, 0-1m, J16326(3); Perth, 6m, J17351(1); W.A., J2369(1).

WAM: New South Wales; Long Reef (Collaroy), 64-73(1). Western Australia; King George Sound, 203-76(part) (1); Cape Naturaliste, 37-74(1), 189-76(2), 603-78(1); Dunsborough, 77-72(1); Bunbury, 1074-81(1), 1085-81(1); Penguin Island, 36.5m, 28-78(3); Cockburn Sound, 0-33m, 39-71(1), 187-71(1), 188-71(1), 196-71(1), 198-71(1), 223-71(1), 225-71(1), 229-71(1), 1061-75(12), 182-76(1), 184-76(1), 185-76(4), 187-76(1), 26-78(2), 59-78(1), 24-80(1); Fremantle, 6-14m, 1957-75(1), 179-76(1), 87-80(3), 88-80(3); Perth, 0-21.9m, 50-74(3), 201-76(2), 797-76(2), 800-76(1); off Dongara, 18.3m, 631-77(1).

Discussion: *C. pulchra* was described by H. L. Clark (1928) as a variety of *Ophiocoma canaliculata*. He examined six specimens, two of which (including the holotype) were without definite locality in South Australia, whilst the remainder were documented from 'Dr Verco's collection in Spencer or St Vincent Gulf'. Clark considered that the specimens were similar to *canaliculata* in everything but colour, and that since they would probably be found to intergrade with the sympatric *canaliculata*, he concluded that it was '. . . not likely they represent a different species'. Koehler (1930) gave a very detailed account of two specimens he described as a new species, *Ophiocoma punctata*, collected from Port Jackson, New South Wales. He concluded that although closely related to *canaliculata, punctata* differed in the form of the dorsal arm plates, the non-canaliculate arm spines, the form of the oral shields and in coloration. H. L. Clark (1938) concluded not only that *punctata* and *pulchra* are conspecific but, since he had found no intermediate forms (of colour) between *pulchra* and *canaliculata*, that it would be better to retain these two as separate species. In 1946 Clark maintained the identity of *pulchra* and *canaliculata*, noting that the cross-banding of the arm-spines and variegated ventral arm plates were very obvious and constant characters distinguishing *pulchra*. He was, however, still somewhat doubtful about the relationship between the two species, which he found occurred together and over a similar geographical range. After examining a paratype of *punctata* and two paratypes of *pulchra*, together with 14 other specimens he identified as *canaliculata*, Devaney (1970) concluded that all three nominal species were conspecific, believing differences between them to reflect variation in a single species. Rowe and Vail's (1982) record of *pulchra* from Tasmania is based on the misidentification of juvenile *canaliculata*. However, considering the widespread distribution of *pulchra*, its occurrence, at least on the northern coast of Tasmania, might be expected.

I have examined the holotype of *Ophiocoma canaliculata* var. *pulchra*, together with nearly 300 specimens of *pulchra* from New South Wales (228) and Western Australia (67). The colour pattern of the species is remarkably constant, even in juvenile specimens (dd=5mm; Fig. 2, **1-2**), and conforms with both H. L. Clark's (1928, 1938, 1946) and Koehler's (1930) descriptions (Fig. 1, **7-8**; Fig. 2, **1-2**). I can confirm, also, the characters outlined by Koehler (1930) which distinguish *punctata* (i.e. *pulchra*) from *canaliculata*. In addition, the coarse disc granulation and greater extension of granules onto the ventral surface of the disc in *pulchra* serve to separate the two species. *C. pulchra*,

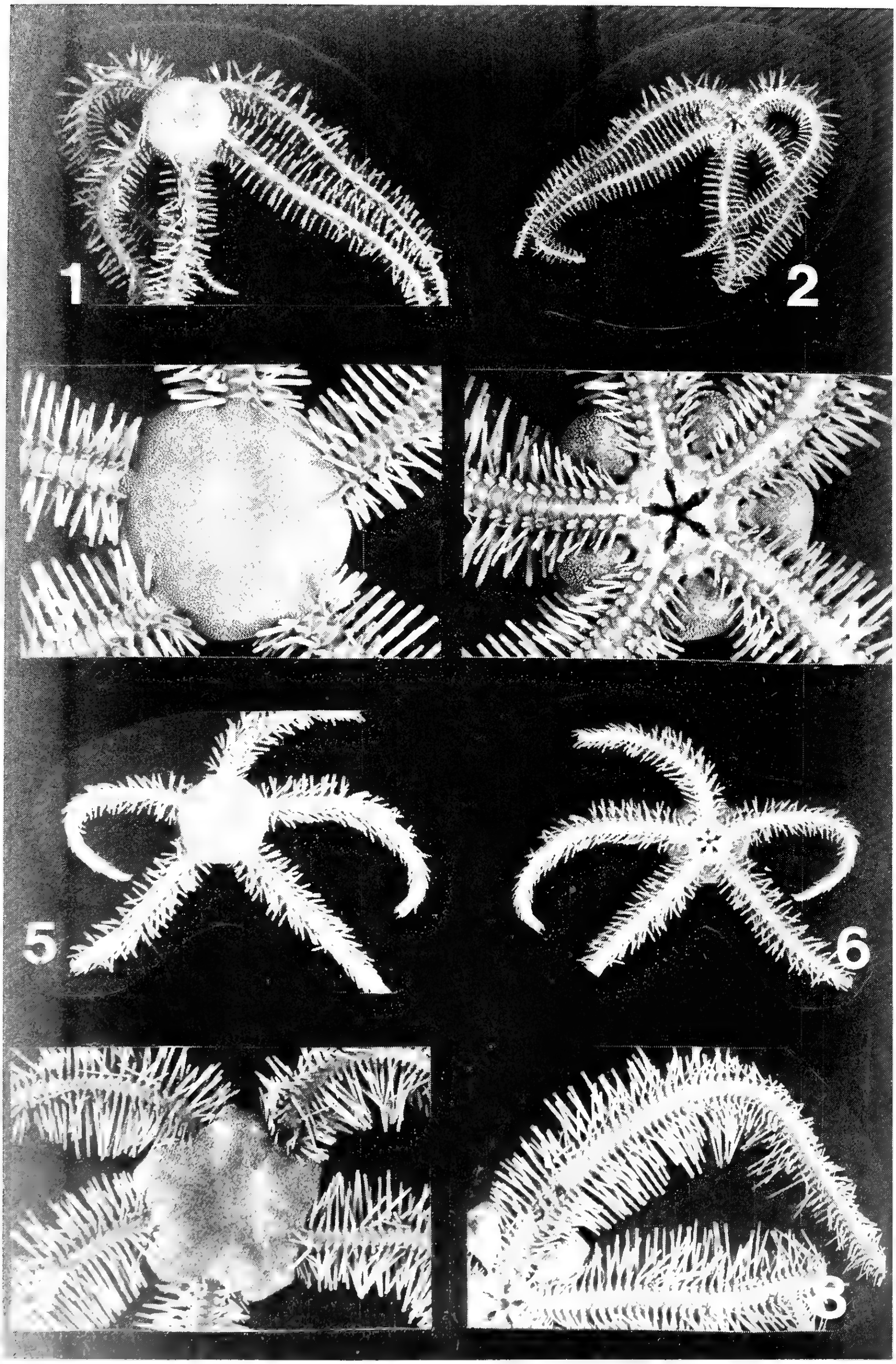

Fig. 2. **1-2,** *Clarkcoma pulchra*, (AMJ13987), dd = 5 mm. **3-4,** *C. bollonsi*, (AMJ15506), dd = 11 mm. **5-6,** *C. bollonsi*, (AMJ15509), dd = 5 mm. **7-8,** *C. bollonsi*, (NMNZ, E3778), dd = 27 mm.

like *canaliculata*, has dental plates with relatively few tooth papillae. This character, alone, easily separates these two species from *bollonsi*. Additionally, the colour pattern of *pulchra* distinguishes it from *bollonsi*.

Finally, unlike either *canaliculata* or *bollonsi*, none of the arm spines of *pulchra* has a sacculate skin covering.

Clarkcoma bollonsi (Farquhar)

Fig. 2, **3-8**

Ophiocoma bollonsi Farquhar, 1908: 108

Clarkcoma bollonsi, Devaney, 1970: 5 (for references), figs 10, 12, 14

Diagnosis: A species of *Clarkcoma* with dd up to 27mm, dd/R = c.3:1; granulation relatively fine, up to 120/mm^2, ventral disc scaling mostly bare, only a shallow, v-shaped wedge of granules extending below the ambitus of the disc; dental plates with lateral papillae larger than central papillae, central papillae numerous, up to c.20-25; some arm spines, to about 1/2R, with reddish-orange, thick-skinned saccule covering their tips in life; colour in life of both juvenile and adults uniformly reddish-brown, with a light transverse line across the distal edge of each of the dorsal arm plates, a cream line extends midventrally along the arms for a short distance from the mouth (Fig. 2, **3-8**), rarely mottling occurs on parts of the arms in juveniles; present known distribution disjunct, Dongara to Hamelin Bay, W.A., Cape Everard, Victoria to Mooloolaba, southern Queensland, coasts of New Zealand and on the Chatham Rise; 9-630m depth.

Material examined:

WAM: Western Australia; Dongara to Hamelin Bay, 47-183m, 188-76(15), 190-76(1), 191-76(1), 192-76(3), 193-76(2), 194-76(1), 195-76(1), 197-76(1), 227-77(1), 228-77(19), 233-77(1), 234-77(1), 603-77(6), 605-77(1), 637-77(2), 817-77(1), 818-(1), 819-77(1), 839-77(9), 840-77(1), 841-77(1), 842-77(25), 843-77(7), 845-77(1), 269(1), 272-78(1), 309-78(1).

AM: Victoria, 126-135m, J5404(1).

New South Wales; Bermagui, 26m, J15514(1); Montague Island, 28-144m, J4764(2), J15505(21), J15512(3), J15513(5); Bateman's Bay, 26-36m, J15506(5), J15507(4), J15508(2), J15509(6), J15515(2), J15521(1); Ulladulla, 9.5m, J14382(1), J14722(3); Jervis Bay, 9.5-35m, J9343(2), J14385(5), J15510(15), J15519(6); Shellharbour, J15520(2), J15516(1); Port Hacking, 15m, J15511(1); Port Jackson, G11443(1), J1935(2); Long Reef (Collaroy), 21-30m, J12416(1), J10561(1); Solitary Islands, 16-24m, J15116(6), J15117(1), J15118(1), J15119(6), J15123(3), J15124(2), J15126(1); Byron Bay, 9.5-16m, J15125(1).

Queensland; Mooloolaba, 9.5-19m, J15120-1(3), J15122(2).

New Zealand; Cook Strait, 256-276m, J14767(3).

NMNZ: New Zealand; Between southern Rangitoto Islands and D'Urville Island, 59-64m, E3165(3), E3173(4); off Three Kings Islands, 90m, E3777(1); Mayor Island, 46m, E3156(1); Cook Strait, 256-274m, E3184(4); off Otago, depth not recorded, E3778(1).

Discussion: *O. bollonsi* was described by Farquhar (1908) from a single specimen collected near Stephens Island in New Zealand's Cook Strait. Like Lütken (1869), Farquhar did not figure his species. Mortensen (1924) identified a number of specimens from localities around the North Island of New Zealand. He considered there was little to add to Farquhar's (1908) description but included illustrations of the species. However, Mortensen did include two important observations. He described the arrangement of tooth papillae, commenting that they were 'exceptionally numerous for an *Ophiocoma*'. Mortensen also described some of the arm spines as being club-shaped, due to thickening of skin towards their tips. He thought this was due to some infesting, parasitic organism but was unable to confirm this histologically. In 1936, Mortensen recorded a specimen collected from Cook Strait, and described the colour: 'Each dorsal arm plate has a narrow, white transverse band, the ground colour being brownish. This gives the arm a fine banded appearance'. Fell (1952) recorded the colour as 'dark brownish-purple' and agreed with Mortensen's conclusion that the club-shaped spines represent a pathological condition. Fell (1958) commented that the species was not as rare as previously thought, and recorded the colour of specimens he examined as 'rich reddish-brown'. Pawson (1965) described the colour of specimens preserved in alcohol as 'dark greyish-brown on the aboral surface, light reddish-brown adorally', recording the species as occurring along 'the entire New Zealand coast, in 9-630m'. McKnight (1967) has recorded *bollonsi* from the Chatham Rise. Devaney (1970) examined 7 specimens of *bollonsi* from New Zealand waters and referred the species to *Clarkcoma*. He gave a joint diagnosis for *canaliculata* (incorporating *pulchra*) and *bollonsi*, which showed little difference between the species in disc diameter, granulation, arm spine sequence, number and shape. However, he did find major differences in the shape of the dental plate, l/br = 2.9-3.1:1 in *bollonsi*, 2.0-2.7:1 in *canaliculata* (and *pulchra*) and in the number and distribution of tooth papillae — 'several transverse rows' in *bollonsi* 'irregularly placed in three or four columns, relatively larger and less extensive than for *bollonsi* of similar size' — in *canaliculata* (and *pulchra*).

Devaney commented that he had not seen evidence of the elongate granules towards the margin of the disc, as described by Farquhar (1908), concluding this to be a variable character and of no specific value.

I have now examined some 245 specimens from Western Australia (107), Victoria (1), New South Wales (117), Queensland (5) and New Zealand (17). It is evident that *C. bollonsi* is widespread in southern Australian and New Zealand waters. Occurrence of the species might be expected in the little-sampled Great Australian Bight and around the coast of Tasmania. *C. bollonsi* is a shelf species occurring at greater depth than either *C. canaliculata* or *C. pulchra*.

The specimens from Western Australia are relatively small, with dd up to 10mm. They are more or less bleached, but sufficient colour remains to indicate the typical colour pattern on the dorsal arm plates. The material from south-eastern Australia has disc diameter ranging up to 20mm, whilst the largest specimen examined was collected from north of Otago (New Zealand) (depth unknown) with a dd = 27mm. With the exception of a few specimens from New Zealand which are reddish-orange in colour, and the more or less bleached specimens from Western Australia, the colour of the remaining specimens is dark brown. In all specimens, the distal edge of each dorsal arm plate bears a cream transverse line. Ventrally, a light median line extends a short way along the arms. This concurs with Mortensen's (1936) description of a specimen from Cook Strait.

For about 1/2R, some of the long spines of living specimens collected in New South Wales were tipped with an orange-reddish, thick-skinned saccule. The saccule contracted after preservation, forming a thickened epithelial covering to the spine tip. This is obviously related to Mortensen's (1924) observation of club-shaped spines. Interestingly, these sacculae occur on the spines of *C. canaliculata* but not on *C. pulchra*. Among other ophiocomids, this structure has been reported on *Ophiocoma pusilla* and a number of species of *Ophiomastix* (Devaney 1970, 1978). The function of these sacculae is unclear, though accordingly histological investigation has revealed glandular tissue present and it has been suggested that these organs secrete a poisonous substance which may kill small animals, but apparently the toxicity has not been confirmed either in laboratory or clinical reports (Devaney, 1978).

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Four new Species of *Glycaspis* Taylor (Homoptera: Spondyliaspididae) from some endangered Species of *Eucalyptus*

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MOORE, K. M. Four new species of *Glycaspis* Taylor (Homoptera: Spondyliaspididae) from some endangered species of *Eucalyptus*. *Proc. Linn. Soc. N.S.W.* 108 (2), (1984) 1985: 71-78.

Some rare and endangered species of *Eucalyptus* L'Herit. have been examined for associated species of Psylloidea, and four new species of *Glycaspis* Taylor are described and figured.

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INTRODUCTION

Of more than 500 known species of *Eucalyptus* L'Herit., nearly one quarter are recorded as being at some risk of survival (Pryor, 1981). Known and possible causes contributing to these risks are discussed by Pryor, who lists 125 species considered to be at present or potentially threatened.

Because of their restricted occurrences, these rare eucalypt species generally are not readily located in the field, so that precise and detailed locality information is essential for an examination of the species as possible psyllid hosts.

Eucalyptus pumila Cambage, found only on an area of c. 20 ha near Cessnock, New South Wales (Baur, 1981: 59), is probably the extreme example of restricted eucalypt distribution.

RESULTS

Four eucalypt species in Queensland and three in New South Wales were sampled with a hand-net to determine possible Psylloidea associations. The species examined were *E. argophloia* Blakely, *E. bakeri* Maiden, *E. conglomerata* Maiden & Blakely, *E. largeana* Blakely & de Beuzeville, *E. rummeryi* Maiden, *E. scoparia* Maiden and *E. tetrapleura* L. Johnson.

From each of those eucalypt species, Psylloidea of genera other than *Glycaspis* Taylor were collected for studies by psyllid taxonomist K. L. Taylor, and the species of *Glycaspis* obtained are the subject of this paper.

A new gall-forming species and a new round lerp-forming species of *Glycaspis* was obtained from *E. conglomerata*. The first species to be recorded as constructing square (and rectangular) lerps was obtained from *E. bakeri*, and a new species constructing round to oval lerps was obtained from *E. argophloia*.

These four *Glycaspis* species are described and illustrated, and all specimens are in the Australian National Insect Collection, CSIRO, Canberra.

Of the relatively rare eucalypts listed by Pryor, the following have been previously examined for *Glycaspis* species (Moore, 1961, 1970a, 1970b, 1977, 1984), an asterisk denoting a *Glycaspis* host:— *E. alpina* Lindl., *E. brachyandra** F. Muell., *E. caesia* Benth., *E. cneorifolia* DC., *E. comitae-vallis** Maiden, *E. cosmophylla* F. Muell., *E. curtisii* Blakely & White, *E. diptera* Andrews, *E. dongarraensis** Maiden & Blakely, *E. dunnii** Maiden, *E. erythrocorys* F. Muell., *E. fasciculosa** F. Muell., *E. ficifolia* F. Muell., *E. gonianatha* Turcz., *E. grossa* F. Muell. ex Benth., *E. guilfoylei* Maiden, *E. howittiana** F. Muell., *E. jacksonii*

Maiden, *E. mckieana** Blakely, *E. nitens** Maiden, *E. pachyloma* Benth. and *E. raveretiana** F. Muell.

DESCRIPTIONS AND NOTES

Glycaspis (Synglycaspis) surculina sp.n.

Figs 1-3

Types. Holotype ♂ on slide labelled Beerwah, Qld, Forestry Scientific Area, 16 ix 1983, K. M. Moore, *E. conglomerata*, ex gall. Paratypes, 2 slides of single wholemount males; 1 ♂, 1 ♀ in 90% ethanol in tube. All with same label data.

General colour: males pale yellow, claspers darker yellow, fore wings suffused pale yellow on costal one third; females deeper yellow than males, fore wings suffused deep yellow.

Claspers and aedeagus as in Figs 1-3. Length of aedeagus 0.297-0.330mm (3 specimens). Galls: nymphs form relatively thin-walled galls variable in shape, pale to deep green with or without red coloration, only on young shoots.

Notes. The phyletic position of *G. surculina* is in the *brunosa* group (Moore, 1983). The species appears to be nearest to *G. encystis* Moore but differs in the following characters: the median dorsal edge of the aedeagus bears an undulation which is lacking in other gall-formers except *G. belua* Moore; distal end of aedeagus ovoid rather than rounded, and usually below the general dorsal aspect; claspers strongly sclerotized along anterior and posterior edges, antero-distal edge flattened, strong inner spine less curved and obliquely truncate apically, pegs posterior to spine stouter and more numerous.

Etymology. The Latin noun *surculus* = a young shoot, with the suffix *-ina* = belonging to.

Glycaspis (Synglycaspis) wallumaris sp.n.

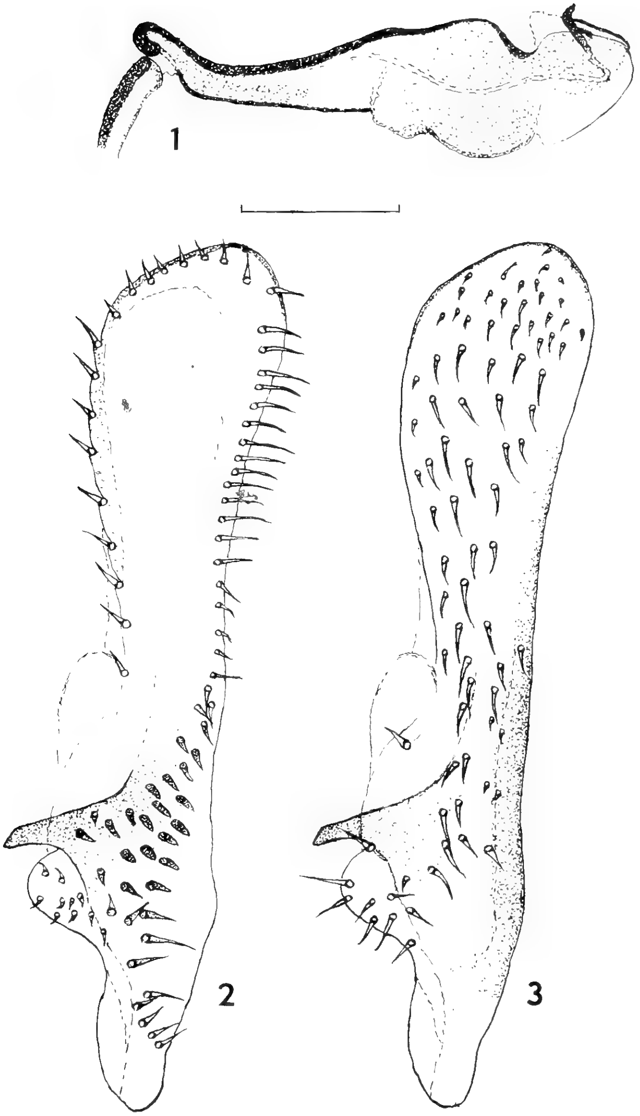
Figs 4-6

Types. Holotype ♂ on slide labelled Beerwah, Qld, Forestry Scientific Area, 16 ix 1983, K. M. Moore, *E. conglomerata*, round lerps. Paratypes, 1 ♀, 1 nymph in 90% ethanol in tube with same label data.

General colour: male pale yellow with few dark markings; females orange with dark markings more extensive, abdomen suffused red. Claspers and aedeagus as in Figs 4-6. Length of aedeagus 0.248mm. (1 specimen). Lerps round.

Notes. The phyletic position of *G. wallumaris* is in the *endasa* group. The species appears to be nearest to *G. particeps* Moore from which it differs in the following characters: the median dorsal edge of the aedeagus protrudes further and more sharply above the general dorsal line, both the dorsal and ventral edges are more extensively and heavily sclerotized, and the distal end is more rounded; claspers are narrower distally, posterior edge straighter, anterior edge more clearly defined and more gradually tapering to the well-defined basal 'foot', anterior and posterior edges and their bases more heavily sclerotized, external setae more sparse.

Etymology. The Latinized adjective indicates the type of environment known locally as 'wallum', with the suffix *-aris* = pertaining to.

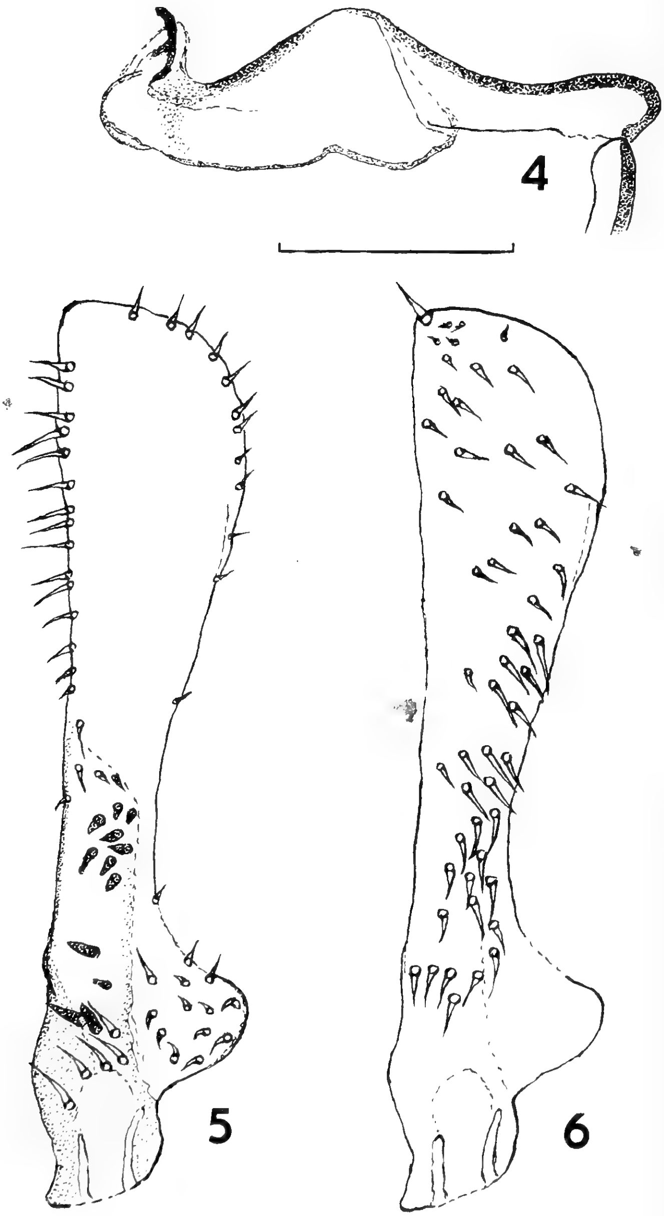


Figs 1-3. Glycaspis surculina sp.n. **1**, aedeagus; **2**, clasper, internal face; **3**, clasper, external face. Scale line 0.1mm.

Glycaspis (Glycaspis) inusitata sp.n.

Figs 7-9

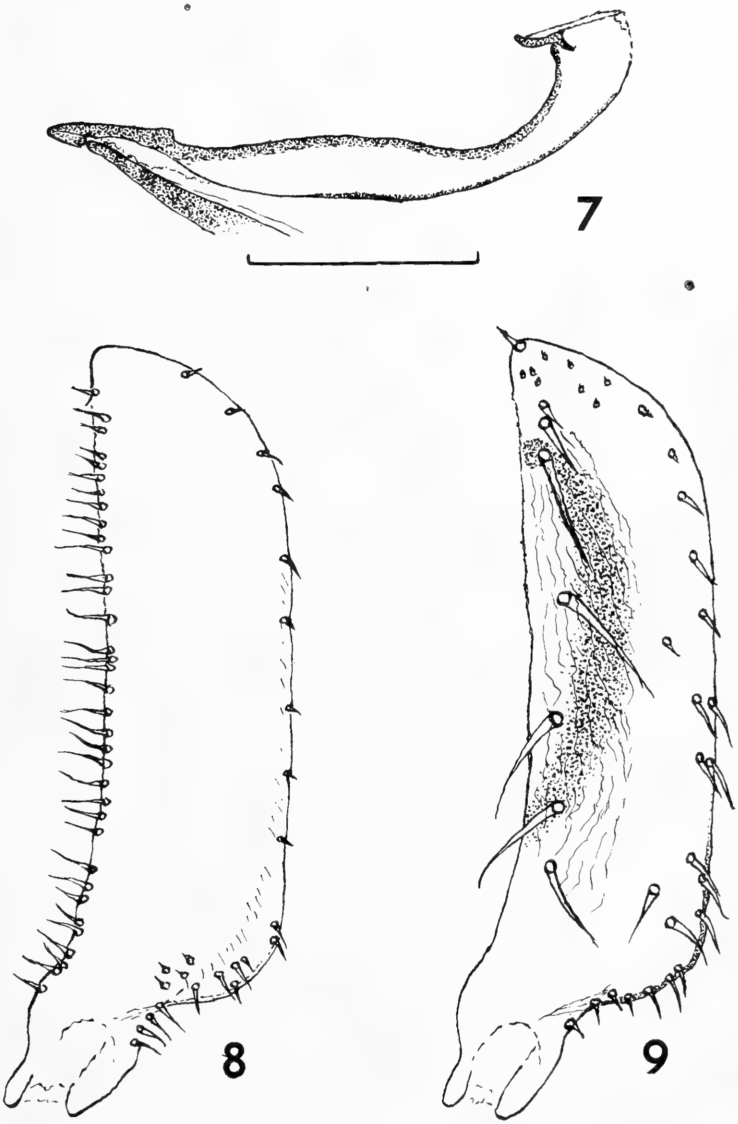
Types. Holotype ♂ on slide labelled Warwick, Qld, Palgrave State Forest 444, 19 ix 1983, K. M. Moore, *E. bakeri*. Paratypes, 3 slides of single wholemount males; 1♂, 5♀♀, 2 nymphs, several lerps, in 90% ethanol in tube. All with same label data.



Figs 4-6. Glycaspis wallumaris sp.n. **4**, aedeagus; **5**, clasper, internal face; **6**, clasper, external face. Scale line 0.1mm.

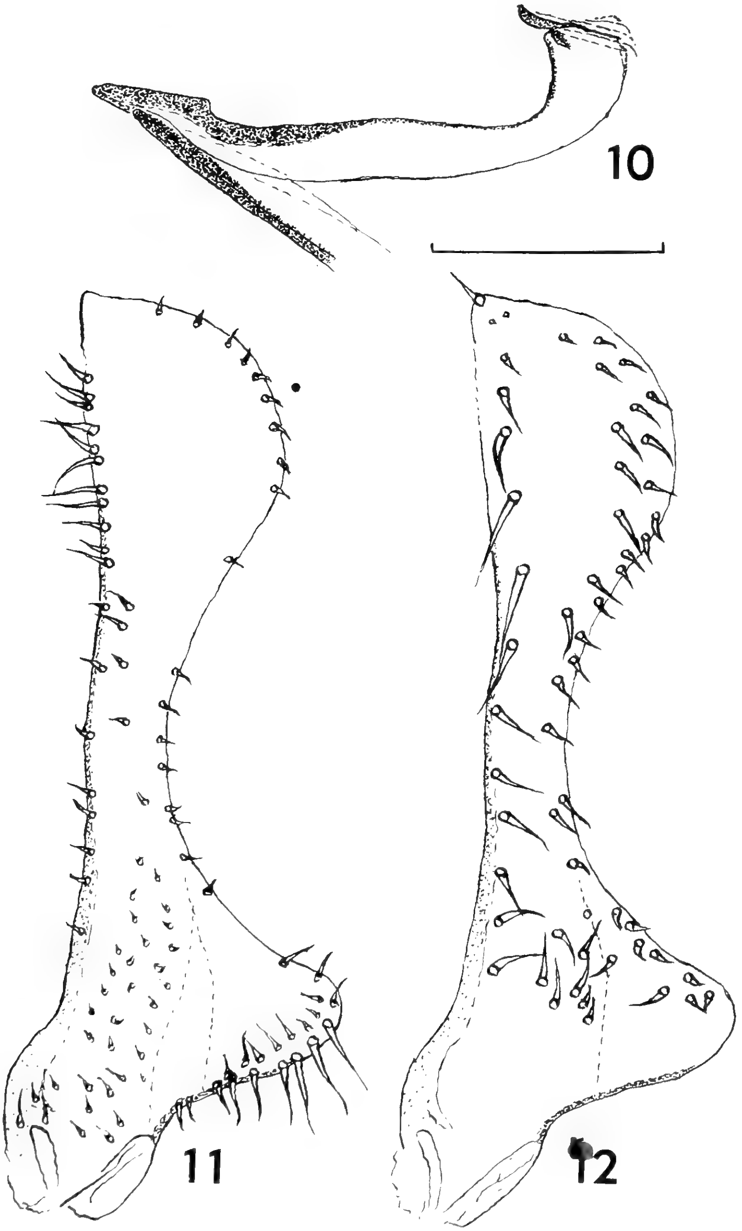
General colour: males cream with extensive dark markings and red suffusion; females with dark markings and red suffusion more extensive and intense. Claspers and aedeagus as in Figs 7-9. Length of aedeagus 0.248-0.264mm (4 specimens). Antennal rhinaria on segments 4, 5 (atrophied), 6, 8 and 9. Hindwing vein Cu_1 as Group (i) (Moore, 1970a, 1983). Lerps square to rectangular.

Notes. The phyletic position of *G. inusitata* is in the *deirada* group complex (Moore, 1970a: 306, 1970b: 351, 1983: 180, 182). The species appears to be nearest to *G. deirada* Moore but differs from it in the following characters: the dorsal edge of the aedeagus indented



Figs 7-9. Glycaspis inusitata sp.n. **7**, aedeagus; **8**, clasper, internal face; **9**, clasper, external face. Scale line 0.1mm.

contiguous to both the proximal ridge and the distal neck, neck incurved, proximal ridge more nearly horizontal, ventral edge more heavily sclerotized from neck to half the distance proximally; claspers with anterior and posterior edges more nearly parallel and vertical, dark median area less extensive and not extending to base or posterior edge,



Figs 10-12. Glycaspis riguensis sp.n. **10**, aedeagus; **11**, clasper, internal face; **12**, clasper, external face. Scale line 0.1mm.

antero-basal curve more acute with narrower sclerotized area not extending to base, internal basal setae absent and the position of those near the antero-basal curve quite distinct.

There were some round lerps on *E. bakeri*, as has previously been observed on some of the hosts recorded for species in the *deirada* complex (Moore, 1970a: 306-7, 1983: 182 (group 11).

Etymology. The specific name is formed from the Latin prefix *in-* = not, and *usitata* = usual (= extraordinary), referring to the first observed occurrence of square lerps in this genus.

Glycaspis (Glycaspis) riguensis sp.n.

Figs 10-12

Types. Holotype ♂ on slide labelled Burncluith, c. 20 km NE Chinchilla, Qld, 13 ix 1983, K. M. Moore, *E. argophloia*. Paratypes, 4 slides of single wholemount males; about 7 ♂♂, 25 ♀♀, lerps, in 90% ethanol in tube. All with same label data.

General colour: males pale yellow sometimes with light red suffusion and few dark markings; females darker yellow with more intense and extensive dark marks and red suffusion.

Claspers and aedeagus as in Figs 10-12. Length of aedeagus 0.228-0.248mm (5 specimens). Lerps round to oval.

Notes. The phyletic position of *G. riguensis* is in the *anomala* group. The species appears to be nearest to *G. mesicola* Moore from which it differs in the following characters: the aedeagus is more curved distally and with ventral edge straighter; posterior edge of claspers from base to two thirds its length more heavily sclerotized and with distal one third more upright, median anterior edge curved in a more or less even arc, antero-basal 'foot' thus more depressed with ventral edge more heavily sclerotized and with an additional line of internal setae extending downwards from apex.

Etymology. The Latin adjective *riguus* = well watered, with the suffix *-ensis* = pertaining to or belonging to; referring to the flat poorly-drained locality with lagoons and much surface water.

ACKNOWLEDGEMENTS

The Committee of the Science and Industry Endowment Fund, CSIRO, supported this work with a monetary grant for which I am most grateful.

The following are also thanked for much assistance with locality data and directions enabling location of the eucalypt species: Dr R. W. Johnson, Director, and W. J. F. McDonald, of the Queensland Herbarium, Brisbane; Senior Forest Technician D. N. Goschnick, Beerwah; D. J. West, Forest Research Officer, Dalby; Mrs J. Harslett, Amiens, Qld; P. V. Holzworth, District Forester, Warwick; G. N. Baur, Chief Sylviculturist, Forestry Commission of N.S.W., Sydney.

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A new gall-forming Species of *Glycaspis* (Homoptera: Spondyliaspididae) from *Eucalyptus obliqua*

K. M. MOORE

MOORE, K. M. A new gall-forming species of *Glycaspis* (Homoptera: Spondyliaspididae) from *Eucalyptus obliqua*. *Proc. Linn. Soc. N.S.W.* 108 (2), (1984) 1985: 79-81.

Glycaspis (Synglycaspis) cameloides sp.n., nymphs of which form galls on foliage of *Eucalyptus obliqua* L'Herit. in South Australia, is described.

K. M. Moore, Prospect Street, Statue Bay, Yeppoon, Australia 4703; *manuscript received 16 October 1984, accepted for publication 20 February 1985.*

INTRODUCTION

Galls formed by a species of *Glycaspis (Synglycaspis)* occurred in large numbers on *Eucalyptus obliqua* L'Herit. throughout the Adelaide Hills, South Australia, particularly on new growth produced following the bushfires of 1983 (personal communication, G. S. Taylor, May 1984).

Two adult male specimens of *Glycaspis* Taylor bred from galls collected at Uraidla, some 15km west of Adelaide, were forwarded for identification.

With this new species here described, the subgenus *Synglycaspis* now includes 19 gall-forming species.

DESCRIPTION AND DISCUSSION

Glycaspis (Synglycaspis) cameloides sp.n.

Figs 1-3

Types. Holotype ♂ on slide labelled Uraidla, S.A., 18 iv 1984, G. S. Taylor, ex gall, *E. obliqua*. Paratype, 1 slide of a single wholemount male with same label data as the holotype. Specimens are lodged with the Australian National Insect Collection, CSIRO, Canberra, A.C.T.

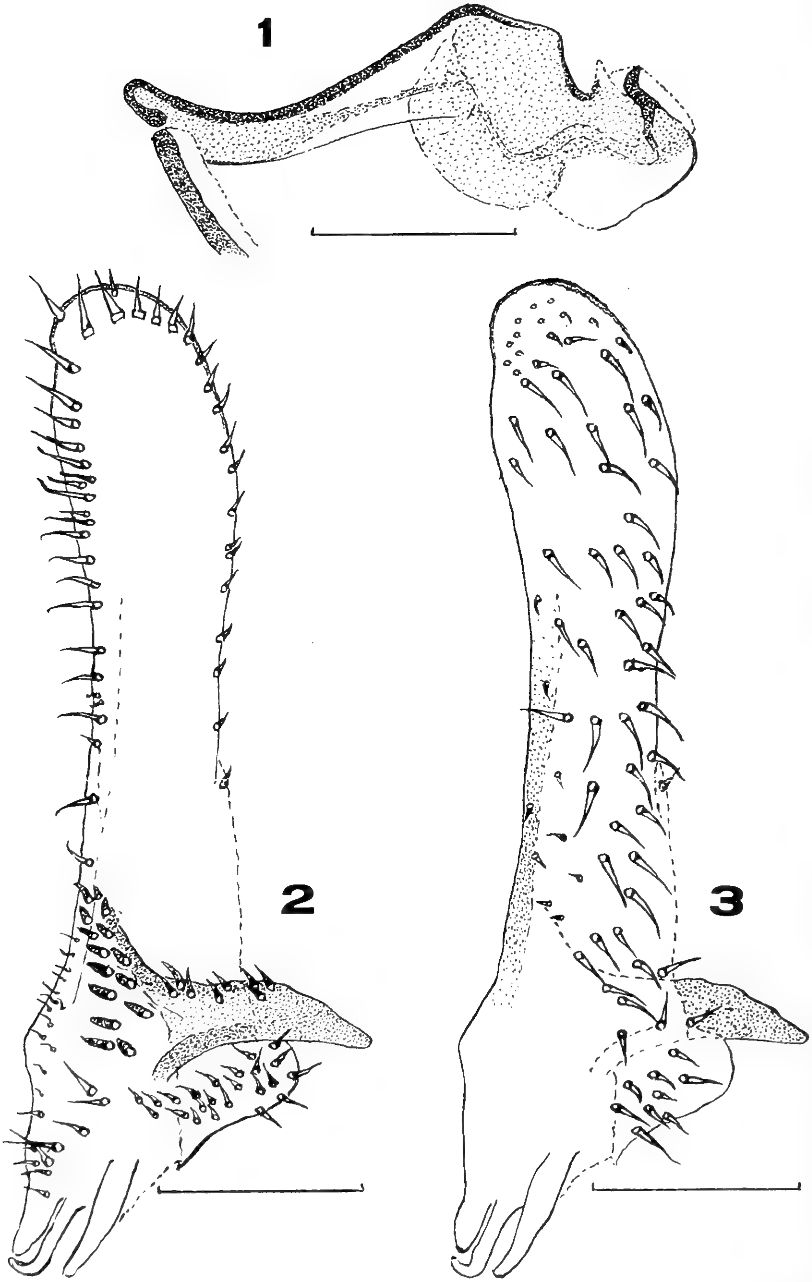
General colour: males pale yellow with genitalia darker yellow. Female specimens and galls not seen. Aedeagus and claspers as in Figs 1-3. Length of aedeagus 0.281mm (2 specimens).

Notes. The phyletic position of *G. cameloides* is in the *brunosa* group of gall-forming species (Moore, 1983).

The morphology of the aedeagus which bears a distinctive medio-dorsal hump (Fig. 1) readily separates this species from all other gall-formers in *Synglycaspis.*

G. cameloides appears to be nearest to *G. morgani* Moore in the general shape of the claspers, but approaches both *G. cellula* Moore and *G. morgani* in the shape and size of the large inner spine on the claspers (Fig. 2).

A single male specimen with genitalia dissected, on a slide labelled 'Nat. Bot. Gdns. A.C.T., 12 Nov. 1981, S. Donaldson, *Euc. macrorhyncha*' also bears a similar medio-dorsal prominence on the aedeagus, but this specimen is not included in the Type material of *G. cameloides* as further material from *E. macrorhyncha* needs to be studied. The length of the aedeagus of this specimen is 0.274mm, and the remainder of the specimen is held with two female specimens in ethanol in tube labelled as above plus 'genit. on slide A'.



Figs 1-3. Aedeagus and claspers of *Glycaspis cameloides* sp.n. (Scale lines 0.1mm). **1**. Aedeagus. **2**. Internal face of claspers. **3**. External face of claspers.

Etymology. camelus (L.) = a camel; the suffix *-oides* = likeness of form.

Reference

MOORE, K. M., 1983. — New species and records of *Glycaspis* Taylor (Homoptera: Spondyliaspidae) with phyletic groupings. *J. Aust. ent. Soc.* 22: 177-184.

Some Species of *Aganippe* (Araneae: Ctenizidae) from eastern Australia

RICHARD J. FAULDER

FAULDER, R. J. Some species of *Aganippe* (Araneae: Ctenizidae) from eastern Australia. *Proc. Linn. Soc. N.S.W.* 108 (2), (1984) 1985: 83-96.

Aganippe berlandi (Rainb.) is re-defined, and three new species of *Aganippe (A. montanus, A. winsori* and *A. planites)* from eastern Australia are described. A possible explanation for the observed distribution is given.

Richard J. Faulder, P.O. Box 136, Yanco, Australia 2703; *manuscript received 18 September 1984, accepted for publication 20 February 1985.*

INTRODUCTION

Main (1957: 437-8) discussed *Aganippe* species then known from east of the Flinders Ranges, South Australia, and considered them to belong to *Aganippe smeatoni* Hogg and *A. subtristis* Cambridge. In the first half of 1980 specimens from Kiamba, via Wagga Wagga, and Hillston in New South Wales, came into the author's possession, and could not be assigned to any existing species of the genus *Aganippe*. Subsequent investigations of the male specimens of members of this genus originating in the area east of the Flinders Ranges demonstrated the existence of two species-complexes in this area, made up of one named species (*Aganippe berlandi* Rainb.) and at least three undescribed species. While female specimens in museums are relatively common and collected from a wide area, male specimens are rare, and only the latter can at present be used for determining the ranges of the species.

NOTES ON DESCRIPTIONS

Measurements are given in millimetres and expressed as mean ± standard deviation. Dorsal abdominal spinule density was measured in the area bounded by the sigillae, and is expressed in spines per 2mm^2. Leg spine counts are given in terms of dorsal and ventral fields, and only leg segments bearing spines are listed.

Unless stated otherwise all specimens are in the Australian Museum, Sydney.

Aganippe berlandi Rainbow

Aganippe berlandi Rainbow, 1914, *Rec. Aust. Mus.* 10: 199;
Main, 1957, *Aust. J. Zool.* 5: 429.

Diagnosis:

Male palpal embolus twisted, twisting being marked by two flanges. Lower tibial apophysis unifid, having a covering of short spines on side proximal to base of limb, other side being bare of spines. Upper tibial apophysis small (length about 1½ times its diameter) and located about half way between lower apophysis and distal end of tibia.

Female inner margin of spermathecal canal parallel with long axis of body.

Male (Figs 1-3): Description as in Rainbow (1914) except as follows.

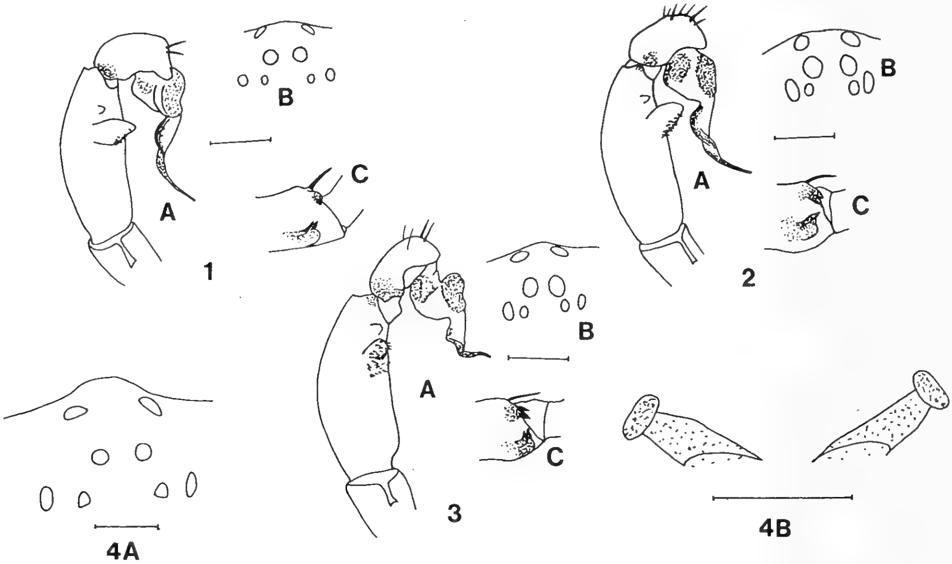
Biometrics (3 males): Carapace length; 6.3 ± 0.5; Carapace width, 5.4 ± 0.2; Carapace height, 2.3 ± 0.1; Maxillary length, 2.2 ± 0; Maxillary width, 1.1 ± 0.1; Sternum length, 3.5 ± 0.2; Sternum width 2.8 ± 0.3; Labium length, 0.3 ± 0.1; Labium width, 0.8 ± 0.1; Dorsal abdominal spinule density, 35 ± 0.

Variability of other characters:

Strong setae on lateral margins of carapace, in a line reaching from eyes almost to fovea, and in weak bands radiating from fovea. Carapace and legs yellow to yellowish-red. Abdomen with a dark dorsal patch.

Remarks:

More specimens might confirm trends in variations of the shape of the lower apophysis and the placement of spines on and around it which might necessitate the erection of a new species. However, for the moment the situation will be left as is.



Figs 1-4. Aganippe berlandi Rainb. Bars are 2mm. *1.* Moonie male. **A**: right palp, **B**: eyes, **C**: tibial apophyses of right leg. *2.* Male holotype. **A**: right palp, **B**: eyes, **C**: tibial apophyses of right leg. *3.* Coonamble male. **A**: right palp, **B**: eyes, **C**: tibial apophyses of right leg. *4.* Coonamble female. **A**: eyes, **B**: spermathecae.

Metallotype Female (KS9109) (Fig. 4)

Carapace length 10.2, width 8.0, height 5.0. Abdomen shrivelled, so dorsal abdominal spinule density not measured, length 13.0, width 9.8.

Colour in alcohol:

Carapace reddish-brown, chelicerae darker. Abdomen dark yellowish-brown. Legs concolorous with carapace. Glabrous strips on femorae, patellae and tibiae. Sternum lighter.

Carapace:

Broadly ovate, laterally of fovea narrowing posteriorly. Setae radiating in bands from fovea. Fovea procurved. Spines and setae between and in front of anteriolateral eyes.

Chelicerae:

Length 6.5, height 4.7, width 3.0. Horizontal. Dorsally a glabrous strip enclosed at front and sides by bands of setae. Rastellum of 16 large teeth. Margins of cheliceral furrow with 6 teeth on each side with smaller teeth in groove.

Labium:

Length 1.0, width 1.5. Semicircular anteriorly, indented anteriomedially. No cuspules. Separated from sternum by a furrow.

Maxillae:

Length 4.5, width 6.4. Slightly flattened, projecting toward midline of body from base. A few cuspules anteriobasally.

Sternum:

Length 6.8, width 5.0. Anterior pair of sigillae halfway along sternum, separated from margin by their diameter. Posterior pair of sigillae two-thirds along sternum, separated from margin by 2½ times their diameter.

Legs:

Dense scopulae on ventral surfaces of tarsi of palp and legs I and II only.

Spines on tibiae, where present setiform, with strong setae on ventral palpal tibiae.

	Palp	I	II	III	IV
Femur	5.5	6.5	6.0	5.0	7.2
Patella	2.5	3.1	3.7	3.2	4.7
Tibia	3.2	4.1	3.5	2.5	4.7
Metatarsus	—	2.9	3.0	3.0	4.5
Tarsus	4.2	2.2	2.5	2.2	3.0

Spines:

Palp: tarsus, 6v. Leg I: tibia, 5v; metatarsus, 7v; tarsus, 7v. Leg II: tibia, 4v; metatarsus, 9v; tarsus, 8v. Leg III: tibia, 4v 1d; metatarsus, 13v 13d; tarsus, 18v 2d. Leg IV: tibia, 6v; metatarsus, 14v 2d; tarsus, 21v.

Trichobothria:

Palp: tibia, 10; tarsus 12. Leg I: tibia, 15; metatarsus, 13; tarsus, 19. Leg II: tibia, 17; metatarsus, 15; tarsus, 15. Leg III: tibia, 10; metatarsus, 14; tarsus, 19, Leg IV: tibia, 12; metatarsus, 11; tarsus, 16.

Claws:

Superior tarsal claws with 1 small basal tooth.

Spinnerets:

4 (posterior median spinnerets broken off). Basal segment of posterior lateral spinnerets 1.3 long, apical segment 0.5 long.

Types

Holotype male collected Narrabri, N.S.W. In the Australian Museum, Sydney (KS1668).

Paratype Males:	Coonamble, N.S.W., 21.v.1979, J. Stork (KS8322); Moonie, Q., 1974, T. Adams (in Queensland Museum).
Paratype Females:	Coonamble, N.S.W., 10.vii.1968, J. T. Ewers (KS9109); Coonamble, N.S.W., 2.vi.1978, G. Fenton (KS1528).

Aganippe montanus sp. nov.

Diagnosis:

Male palpal embolus similar to *A. berlandi*. Lower tibial apophysis bifid, distal process with short spines. The other process is roundly pointed and bare of spines above its base. Upper tibial apophysis small and located at extreme distal end of tibia.

Female inner margin of spermathecal canal parallel with long axis of body.

Biometrics (4 males): Carapace length, 7.0 ± 1.0; Carapace width, 5.7 ± 0.7; Carapace height, 2.6 ± 0.6; Maxillary length, 2.3 ± 0.3; Maxillary width, 1.3 ± 0.1; Sternum length, 4.2 ± 0.4; Sternum width, 3.1 ± 0.1; Labium length, 0.3 ± 0.1; Labium width, 0.8 ± 0.2; Dorsal abdominal spinule density 39 ± 9.

Variability of other characters:

Strong setae in median line reaching at least two-thirds of the way from the eyes to the fovea. Carapace and legs reddish-brown through reddish-yellow to yellowish-red, with legs concolorous. Abdominal coloration usually black dorsally and ventrally, but sometimes reduced to a dark dorsal pattern.

Holotype male (KS5055) (Fig. 6)

Carapace length 6.8, width 5.4. Abdomen length 5.5, width 4.5.

Colour in alcohol:

Carapace reddish-yellow; chelicerae darker. Abdomen black dorsally and laterally, lighter ventrally. Legs concolorous with carapace. Glabrous strips on femorae, patellae and tibiae. Sternum lighter.

Carapace:

Broadly ovate, laterally of fovea narrowing posteriorly. Spines on lateral margins of carapace, in a line reaching two-thirds of the way from eyes to fovea and in well-developed bands radiating from the fovea. Fovea very slightly procurved. Four large spines between anteriolateral eyes, smaller setae in front of these.

Chelicerae:

Length, 4.8; height, 2.0; width, 1.3. Curved downward. Dorsally a glabrous triangle enclosed on each side by bands of setae. Rastellum of 4 large teeth plus smaller teeth. Margins of cheliceral groove with 4 teeth on each side, evenly spaced.

Labium:

Length 0.3, width 0.9. Semicircular anteriorly, indented anteriomedially. No cuspules. Separated from sternum by a furrow.

Maxillae:

Length 2.0, width 1.2. Slightly flattened cylinder. A number of cuspules present anteriobasally.

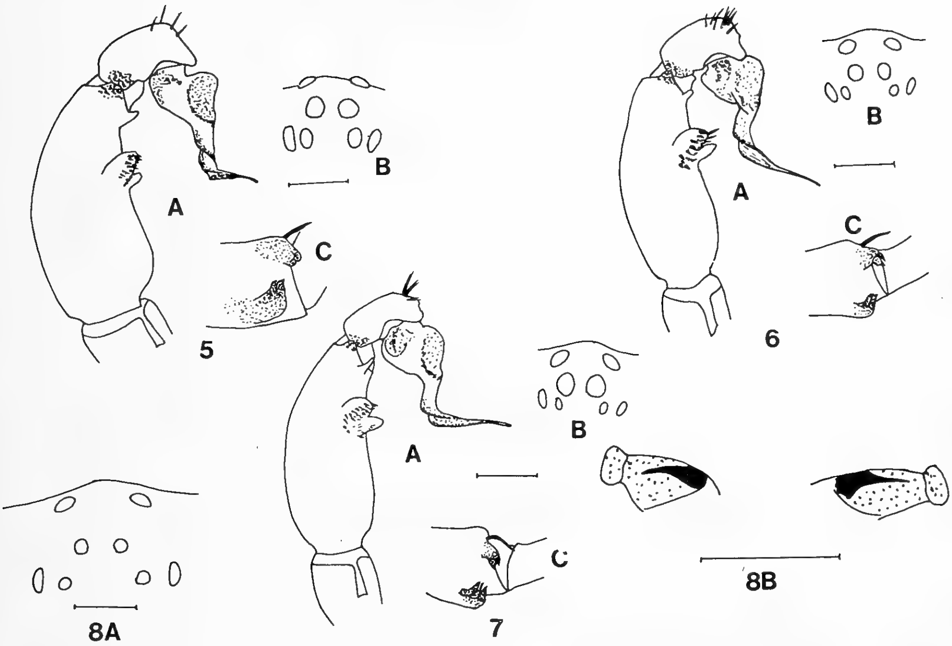
Sternum:

Length 3.8, width 3.2. Covered with setae and bristles. Anterior pair of sigillae halfway along sternum, separated from margin by 1½ times their length. Posterior pair of sigillae two-thirds along sternum, separated from margin by 2½ times their length.

Legs:

Dense scopulae on ventral surfaces of tarsi I and II only.

	Palp	I	II	III	IV
Femur	4.2	7.0	6.3	4.6	6.3
Patella	2.1	3.1	2.7	1.8	2.0
Tibia	3.6	5.0	5.0	3.7	5.3
Metatarsus	—	4.5	4.3	4.5	5.6
Tarsus	1.5	3.0	3.2	3.5	3.6



Figs 5-8. Aganippe montanus sp. nov. Bars are 2mm. *5.* Forbes male. **A**: right palp, **B**: eyes, **C**: tibial apophyses of right leg. *6.* Male holotype. **A**: right palp, **B**: eyes, **C**: tibial apophyses of right leg. *7.* Wagga Wagga male. **A**: right palp, **B**: eyes, **C**: tibial apophyses of right leg. *8.* Young female. **A**: eyes, **B**: spermathecae. Note sclerotized region of canal, not observed in other specimens.

Spines:

Palp: tibia, 11d. Leg I: tibia, 2v; metatarsus, 8v. Leg II: tibia, 11v 4d; metatarsus, 11v. Leg III: tibia, 8v 10d; metatarsus, 19v 14d; tarsus, 19v 9d. Leg IV: tibia, 8v 13d; metatarsus, 10v 15d; tarsus, 19v 8d. All spines except those on palpal tibiae setiform and surrounded by strong setae, which makes differentiation uncertain.

Trichobothria:

Palp: tibia, 7; tarsus, 9. Leg I: tibia, 11; metatarsus, 11; tarsus, 13. Leg II: tibia, 7; metatarsus, 12; tarsus, 15. Leg II: tibia, 10; metatarsus, 9; tarsus, 14. Leg IV: tibia, 6; metatarsus, 8; tarsus, 11.

Claws:

Superior tarsal claws with 6 long teeth in one row.

Spinnerets:

4, not visible dorsally, posterior median spinnerets 0.4 long, 0.2 wide. Basal segment of posterior lateral spinnerets 0.5 long, apical segment 0.5 long.

Paratype female (KS4417) (Fig. 8)

Carapace length 9.6, width 7.7, height 4.1. Abdomen shrivelled, so dorsal abdominal spinule density not counted, length 15.3, width 11.0.

Colour in alcohol:

Carapace reddish-brown, chelicerae concolorous, abdomen greyish-yellow dorsally, less grey ventrally, with lungbook covers darker. Legs concolorous with carapace. Glabrous strips on femorae, patellae and tibia. Sternum lighter.

Carapace:

Broadly ovate, laterally of fovea narrowing posteriorly. Fine setae on margins of carapace and in bands radiating from fovea. Fovea procurved. Strong setae between and in front of anteriolateral eyes.

Chelicerae:

Length, 6.0; height, 4.8; width, 2.6. Horizontal. Dorsally glabrous, except along the margin adjacent to the other chelicera, and a thin band of setae reaching halfway from anterior end. Rastellum of 24 large teeth. Margins of cheliceral furrow with 6 teeth, plus nodules in furrow.

Labium:

Length 0.6, width 1.1. Semicircular anteriorly, indented anteriomedially. No cuspules. Separated from sternum by a glabrous band.

Maxillae:

Length 4.0, width 2.2. Slightly flattened, projecting toward midline of body from base. A few cuspules anteriobasally.

Sternum:

Length 5.8, width 4.8. Covered with setae and bristles. Anterior pair of sigillae in an indentation halfway along sternum, separated from margin by their length. Posterior pair of sigillae two-thirds along sternum, separated from margin by 1½ times their diameter.

Legs:

Dense scopulae on ventral surface of tarsi of palp and legs I and II only. Spines on tibia where present setiform, with strong setae on venters of all tibiae.

	Palp	I	II	III	IV
Femur	6.3	6.0	5.8	4.6	6.4
Patella	3.2	3.5	3.5	3.1	4.2
Tibia	3.3	4.0	3.5	2.4	4.2
Metatarsus	—	2.8	2.9	3.0	4.0
Tarsus	3.8	2.3	2.2	2.3	2.5

Spines:

Palp: tarsus, 2v. Leg I: tibia, 2v; metatarsus, 6v; tarsus, 3v. Leg II: tibia, 1v; metatarsus, 5v; tarsus, 11v. Leg III: metatarsus, 7v 14d; tarsus, 12v 2d. Leg IV: tibia, 1v; metatarsus, 11v, tarsus, 16v.

Trichobothria:

Palp: tibia, 10; tarsus 15. Leg I: tibia, 10; metatarsus, 14; tarsus, 14. Leg II: tibia, 12; metatarsus, 12; tarsus, 14. Leg III: tibia, 12; metatarsus, 9; tarsus, 19. Leg IV: tibia, 16; metatarsus, 7; tarsus, 17.

Claws:

Superior tarsal claws with one small basal tooth.

Spinnerets:

4 visible dorsally. Posterior median spinnerets 0.6 long, 0.4 wide. Basal segment of posterior lateral spinnerets 0.8 long, apical segment 0.6 long.

Types

Holotype male collected Young, N.S.W., 9.iv.1980 by P. A. Parker. In the Australian Museum, Sydney (KS5055).

Paratype Males:	Young, N.S.W., 20.v.1971, A. Gibbons (KS5897); Forbes, N.S.W., 23.iv.1979 (KS2722); Yass, N.S.W., 4.iv.1979 (KS3071); Kiamba, near Wagga Wagga, N.S.W., 15.v.1980, L. Hemsley (KS8323).
Paratype Female:	Young, N.S.W., 16.i.1980 (KS4417).

Aganippe winsori sp. nov.

(Fig. 9)

Diagnosis:

Male palpal stigma twisted, as for *A. berlandi*. Lower tibial apophysis as for *A. montanus*, except that proximal process is also spinose. Upper tibial apophysis absent.

Holotype male (KS5894)

Carapace length 7.3, width 6.3, height 2.0. Abdomen length, 5.6; width 4.1. Dorsal abdominal spinule density, 51.

Colour in alcohol:

Carapace dark reddish brown, chelicerae concolorous, abdomen black dorsally and laterally, lighter ventrally. Legs concolorous with carapace. Glabrous strips on femorae, patellae and tibiae. Sternum lighter.

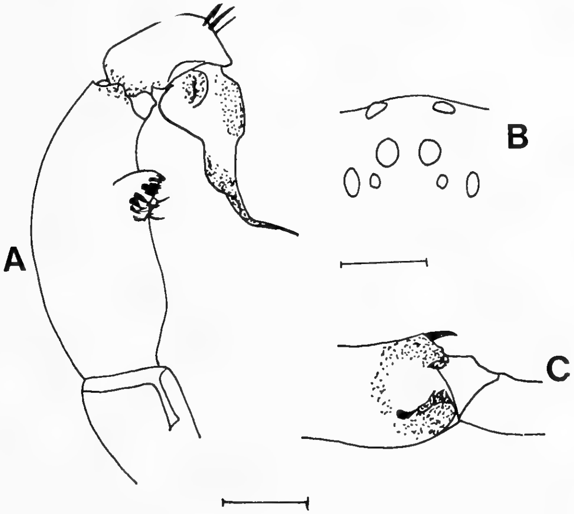


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Fig. 9. Aganippe winsori sp. nov. Bar is 2mm. Male holotype. **A**: right palp, **B**, eyes, **C**: tibial apophyses of right leg.

Carapace:

Broadly ovate, laterally of fovea narrowing posteriorly. Strong setae on lateral margins of carapace, in a line reaching two-thirds of the way from eyes to fovea, and in well-developed bands radiating from near fovea. Fovea straight. Four large setae between anteriolateral eyes, smaller setae in front of these.

Chelicerae:

Length, 3.1; height, 1.9; width, 1.1; curved downward. Dorsally a long glabrous triangle enclosed on each side by bands of setae. Rastellum of 5 large teeth plus smaller teeth. Inner margin of cheliceral furrow with 5 teeth, outer margin with 2.

Labium:

Length 0.3, width 0.7. Semicircular anteriorly, indented anteriomedially. No cuspules. Separated from sternum by a furrow.

Maxillae:

Length 2.0, width 1.4. Slightly flattened cylinder. A few cuspules present anteriobasally.

Sternum:

Length 3.9, width 2.9. Covered with setae and bristles. Anterior pair of sigillae halfway along sternum, separated from margin by half their length. Posterior pair of sigillae two-thirds along sternum, separated from margin by 2½ times their length.

Legs:

Dense scopulae on ventral surfaces of tarsi I and II only.

	Palp	I	II	III	IV
Femur	4.2	7.0	7.2	6.1	7.2
Patella	1.9	3.2	3.0	2.5	3.0
Tibia	3.5	5.8	5.7	4.5	6.2
Metatarsus	—	4.7	4.2	5.0	6.2
Tarsus	1.4	3.2	3.1	3.5	4.5

Spines:

Palp: tarsus, 5d; Leg I: tibia, 8v; metatarsus, 10v. Leg II: tibia, 12v; metatarsus, 9v. Leg III: tibia, 13v 12d; metatarsus, 11v 14d; tarsus 20v. Leg IV: tibia, 11v 27d; metatarsus, 12v 12d; tarsus 26v. All spines setiform and, except on metatarsi I and II and tarsi of palp and leg III, surrounded by strong setae, which makes differentiation uncertain.

Trichobothria:

Palp: tibia, 8; tarsus, 12. Leg I: tibia, 9; metatarsus, 15; tarsus, 14. Leg II: tibia, 11; metatarsus, 7; tarsus, 13. Leg III: tibia, 9; metatarsus, 10; tarsus, 15. Leg IV: tibia, 12; metatarsus, 8; tarsus, 14.

Claws:

Superior tarsal claws with 7 long teeth in one row.

Spinnerets:

4, not visible dorsally, posterior median spinnerets 0.4 long, 0.2 wide. Basal segment of posterior lateral spinnerets 0.6 long, apical segment 0.4 long.

Type

Holotype male collected Grampians Range, near Reid's Lookout track, Victoria, 24.iv.1973 by L. Winsor. In the Australian Museum, Sydney (KS5894).

Aganippe planites sp. nov.

Diagnosis:

Male palpal stigma bent, but not twisted, and without ridges. Lower tibial apophysis unifid and flattened at its apex, with a covering of short spines over flattened portion. Upper tibial apophysis long and narrow (about 5 times diameter — 7 times in the type) and located close to lower apophysis (about a quarter of distance between lower apophysis and distal end of tibia) (Figs 10-12).

Biometrics (7 males): Carapace length, 7.6 ± 0.5; Carapace width, 6.5 ± 0.7; Carapace height, 2.4 ± 0.5; Maxillary length, 2.5 ± 0.3; Maxillary width, 1.4 ± 0.2; Sternum length, 4.6 ± 0.4; Sternum width, 3.5 ± 0.3; Labium length, 0.2 ± 0.1; Labium width, 1.0 ± 0.1; Dorsal abdominal spinule density 35 ± 9.

Variability of other characters:

Strong setae in a line reaching at most two-thirds of the way from eyes to fovea.

Holotype male (KS8324)

Carapace length 7.3, width 7.0, height 1.9. Abdomen length, 7.7; width 6.1. Dorsal abdominal spinule density, 27.

Colour in alcohol:

Carapace reddish-yellow, chelicerae darker. Abdomen with a darker dorsal pattern. Legs concolorous with carapace, except that setiferous areas of patellae are dark and coxae and trochanters darker than carapace dorsally. Glabrous strips on femorae, patellae and tibiae. Sternum lighter.

Carapace:

Broadly ovate, laterally of fovea narrowing posteriorly. Strong setae on lateral margins of carapace, in a line reaching halfway from the eyes to the fovea and in weak bands radiating from the fovea. Fovea very slightly procurved. Two very large setae between anteriolateral eyes, smaller setae in front of these.

Chelicerae:

Length, 3.2; height, 2.0; width, 1.5. Curved downward. Dorsally a glabrous triangle enclosed on each side by bands of setae. Rastellum of 4 large teeth plus smaller teeth. Inner margin of cheliceral furrow with 3 teeth, outer margin with 4.

Labium:

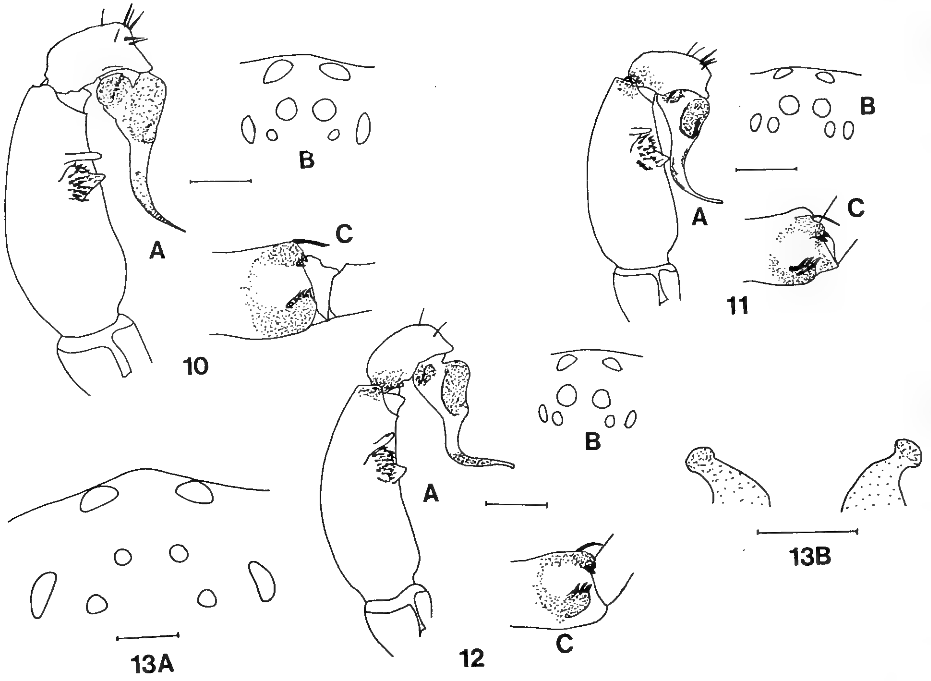
Length 0.2, width 0.9. Semicircular anteriorly, indented anteriomedially. No cuspules. Separated from sternum by a furrow.

Maxillae:

Length 2.9, width 1.4. Slightly flattened cylinder. A number of cuspules present anteriobasally.

Sternum:

Length 4.9, width 3.7. Covered with setae and bristles. Anterior pair of sigillae halfway along sternum, separated from margin by their length. Posterior pair of sigillae two-thirds along sternum, separated from margin by 2½ times their length.



Figs 10-13. Aganippe planites sp. nov. Bars are 2mm. ***10.*** Male holotype. **A**: right palp, **B**: eyes, **C**: tibial apophyses of right leg. ***11.*** Benalla male. **A**: right palp, **B**: eyes, **C**: tibial apophyses of right leg. ***12.*** Tamworth male: **A**: right palp, **B**: eyes, **C**: tibial apophyses of right leg. ***13.*** Hay female. **A**: eyes, **B**: spermathecae.

Legs:

Dense scopulae on ventral surfaces of tarsi I and II only.

	Palp	I	II	III	IV
Femur	3.2	7.8	7.1	5.7	6.6
Patella	2.2	3.9	3.9	3.1	3.9
Tibia	3.8	6.0	5.6	4.0	6.3
Metatarsus	—	5.1	5.3	3.9	6.6
Tarsus	1.5	3.0	3.5	3.5	3.8

Spines:

Palp: tarsus, 5d. Leg I: tarsus, 9v; metatarsus, 7v. Leg II: tibia, 7v 1d; metatarsus, 9v. Leg III: tibia, 9v 4d; metatarsus, 12v 9d; tarsus, 13v 8d. Leg IV: tibia, 8v 5d; metatarsus, 10v 6d; tarsus, 14v 8d. All spines setiform and, except on metatarsi I and II, surrounded by strong setae, which makes differentiation difficult.

Trichobothria:

Palp: tibia, 9; tarsus, 15. Leg I: tibia, 10; metatarsus, 15; tarsus, 21. Leg II: tibia, 12; metatarsus, 13; tarsus, 14. Leg III: tibia, 11; metatarsus, 8; tarsus, 19. Leg IV: tibia, 12; metatarsus, 6; tarsus, 12.

Claws:

Superior tarsal claws with 6 long teeth in one row.

Spinnerets:

4, visible dorsally. Posterior median spinnerets 0.5 long, 0.3 wide. Basal segment of posterior lateral spinnerets 1.0 long, apical segment 0.6 long.

Paratype female (KS9108) (Fig. 13)

Carapace length 10.0, width 9.3, height 4.0. Abdomen length 16.0, width 11.5. Dorsal abdominal spinule density, 38.

Colour in alcohol:

Carapace grey-brown, chelicerae darker and redder. Abdomen yellow-grey, with a darker dorsal pattern. Legs concolorous with carapace except that setiferous areas of leg segments are darker. Glabrous strips on femorae, patellae and tibiae. Sternum lighter.

Carapace:

Broadly ovate, narrowing posteriorly from about a third from front. Fine setae on lateral margins of carapace and in bands radiating from the fovea. Strong setae between and in front of anteriolateral eyes and in a band reaching two-thirds of way from eyes to fovea. Fovea procurved.

Chelicerae:

Length, 6.0; height, 3.9; width, 3.0. Horizontal. Dorsally glabrous except for a setiferous triangle pointing backward from the front. Rastellum of 19 teeth. Outer margin of cheliceral groove with 8 teeth plus nodules adjacent in the furrow. Inner margin of groove with 6 large teeth.

Labium:

Length 1.0, width 2.1. Semicircular anteriorly, indented anteriomedially. No cuspules. Separated from sternum by a furrow.

Maxillae:

Length 3.7, width 3.0. Flattened, with a basal projection toward midline of body. Cuspules present anteriobasally.

Sternum:

Length 7.8, width 5.5. Covered with setae and bristles. Anterior pair of sigillae halfway along sternum, separated from margin by their length. Posterior pair of sigillae just behind these, separated from margin by twice their length.

Legs:

Dense scopulae on ventral surfaces of tarsi of palps and legs I and II only. Tibial spines setiform.

	Palp	I	II	III	IV
Femur	5.2	6.9	6.0	5.2	7.0
Patella	5.3	4.3	4.2	3.8	4.9
Tibia	3.3	4.1	3.3	2.6	4.8
Metatarsus	—	2.5	2.4	3.0	5.2
Tarsus	4.1	2.3	2.2	2.6	3.1

Spines:

Palp: tibia, strong setae + 4a; tarsus, 3v. Leg I: tibia, 2v; metatarsus, 6v; tarsus, 9v. Leg II: tibia, 2v + strong ventral setae; metatarsus, 7v; tarsus, 8v. Leg III: metatarsus, 9v 22d; tarsus, 14v 8d. Leg IV: metatarsus, 10v; tarsus, 14v.

Trichobothria:

Palp: tibia, 5; tarsus, 9. Leg I: tibia, 15; metatarsus, 5; tarsus, 12. Leg II: tibia, 15; metatarsus, 7; tarsus, 19. Leg III: tibia, 15; metatarsus, 8; tarsus, 23. Leg IV: tibia, 14; metatarsus, 8; tarsus, 17.

Claws:

Superior tarsal claws with one small basal tooth.

Spinnerets:

4, not visible from above. Posterior median spinnerets 1.0 long, 0.9 wide. Basal segment of posterior lateral spinnerets 1.2 long, apical segment 0.8 long.

Types

Holotype male collected Hillston, N.S.W., 23.v.1980 by S. McCarthy. Australian Museum, Sydney (KS8324).

Paratype males:	Warren, N.S.W., 29.v.1978 (KS1527); Girilambone, N.S.W. (KS1669); Hay, N.S.W., 11.v.1981, F. Cole (KS8325); Tamworth, N.S.W., 11.x.1982, C. Easton; Benalla, V., 20.v.1981 (in Museum of Victoria).
Paratype female:	Hay, N.S.W., 19.iv.1982, D. Melia (KS9108).

DISCUSSION

Specimens assigned to '*Aganippe subtristis*' in both the Australian Museum, Sydney, and the South Australian Museum, Adelaide, were examined with a view to determining their relationship to the eastern species. None of these was *A. subtristis,* **sensu** Main 1957, apparently belonging to an as yet undescribed species (Main, pers. comm.) which, like *A. planites*, has an untwisted palpal style. On the other hand, specimens from the South Australian Museum clearly of *A. smeatoni* have been examined and the twisting of the palpal style, accurately represented by the diagram in Hogg (1902), is of a completely different nature from that observed in *A. berlandi, A. montanus* and *A. winsori.*

At this time behavioural data on members of the genus in this area do not exist in useful quantities (although it is hoped to rectify this situation in the future) so that these cannot be used to distinguish the species.

The eyes are moderately enlarged, so that the spiders possibly exhibit both twig-lining and non-twig-lining behaviour (Main, 1957: 467). Specimens displaying both twig-lining and non-twig-lining behaviour occur throughout the Lake Cargelligo — Mount Hope — Nyngan region (Gray, pers. comm.).

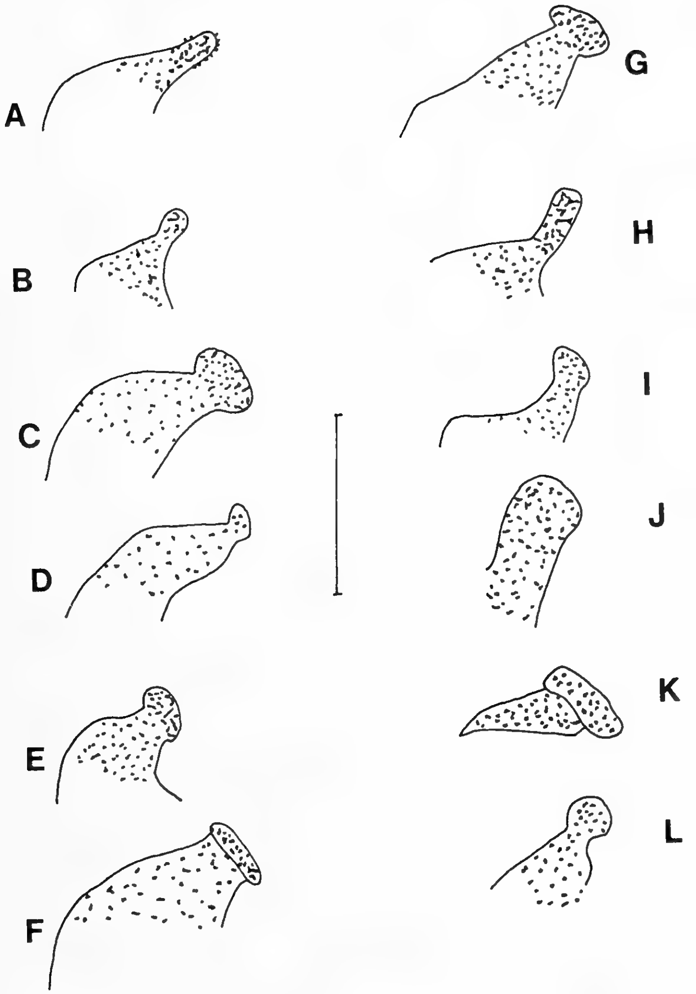


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Fig. 14. Variation in right spermathecae of eastern Australian *Aganippe* spp. Females figured are unidentified specimens collected from within the range of named males. Bar is 2mm. **A-F:** With inner margin of canal parallel with body axis. **A-C:** From areas associated with straight-stigma males. **D-F:** From areas associated with twisted-stigma males. **G-L:** With inner margin of canal pointing outward. **G-K:** From areas associated with twisted-stigma males. **L:** From area associated with straight-stigma males.

In conclusion attention is drawn to the geographic distribution of these species. *Aganippe planites* is found on the plains, and is characterized by an untwisted male palpal embolus. On the other hand, the other species considered are characterized by an embolus which is twisted in a common manner, even though there is variation in the tibial apophyses. Main (1981, pers. comm.) believes that *Aganippe* has radiated virtually **in situ**, i.e. through adaptive specialization of local populations. However, the situation in the eastern part of the continent nevertheless suggests that, following the retreat of the sea at the end of the Middle Tertiary, there was a movement eastwards by the genus in two distinct directions from the Flinders Ranges area if the postulate in Main (1957: 464) is held to be correct. One group moved onto the plains, and, because of the relatively uniform nature of the environment, remained as a single species, *A. planites*. However, a second group moved into the western end of the Great Dividing Range. From there, this group moved eastwards and northwards along the inland slopes of the Great Divide. The reproductive isolation favoured by the more dissected terrain resulted in more intensive speciation, producing at least three (and possibly more) species — *winsori, montanus* and *berlandi*. The last has so far been found on plains adjacent to mountains.

Spermathecae from a number of females were examined (Fig. 14) and a clear, although not totally consistent, trend emerged. Females from areas associated with straight-stigma males tended to have the inner margin of the spermathecal canal lying parallel with the long axis of the body, before bending sharply outwards. In contrast, females from areas associated with twisted-stigma males tended to have the inner margins pointing outward from their origins. Unfortunately the high degree of variability means that this is not a totally reliable criterion for species-separation.

ACKNOWLEDGEMENTS

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Composition and Geographic Distribution of Mangrove Macroalgal Communities in New South Wales

ROBERT J. KING and MARK D. WHEELER

KING, R. J., & WHEELER, M. D. Composition and geographic distribution of mangrove macroalgal communities in New South Wales. *Proc. Linn. Soc. N.S.W.* 108 (2), (1984) 1985: 97-117.

This study of the algae associated with the pneumatophores of mangrove communities on the New South Wales coast records the presence of 32 taxa of macroalgae, including 15 Rhodophyta, 6 Phaeophyta, and 11 Chlorophyta. Relevant morphosystematic and distributional data are included for each species. There are twenty-two new records for the mangrove communities of NSW, but only a few of these are new records for the State: *Bostrychia kelanensis*, *Caloglossa adnata*, and *Striaria attenuata*. The most frequently occurring algae were those of the *Bostrychia* — *Caloglossa* association, with *Caloglossa leprieurii* the most frequent, and *Catenella nipae* the most widespread. Comparison of the New South Wales mangrove algal flora with the floras of mangrove communities elsewhere in eastern and southern Australia indicates that it shows greatest similarity in both total number of species, and shared species, with that of southern Queensland. There are several species of tropical or subtropical affinity: *Bostrychia flagellifera*, *B. kelanensis* and *Caloglossa adnata*.

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INTRODUCTION

With few exceptions data on algae associated with Australian mangrove communities have been collected only as an adjunct to works dealing with the phanerogamic vegetation. The major exceptions are the studies on the composition and geographic distribution of mangrove algae in Victoria (Davey and Woelkerling, 1980) and in the Spencer Gulf, South Australia (Beanland and Woelkerling, 1982, 1983). For localities on the eastern seaboard there is a species list and a brief site description for Moreton Bay, SE Queensland (Cribb, 1979), and a limited account for the lower Hunter River in New South Wales (Cheng, 1983). King (1981b, c) has described in detail some aspects of the algal communities of Botany Bay, Sydney.

King (1981a) and Saenger *et al.* (1977) provided general species lists which summarized earlier Australian data and included newer records. In the former it was not clear which were additions to previously published records, nor which were in mangrove communities, salt marshes or both. Post (1936 *et seq.*) included numerous records of Australian mangrove zone algae in her series of papers on the distribution of the 'Bostrychietum', and specifically in her description of the Bostrychietum from Wilsons Promontory, Victoria and the Minnamurra River, New South Wales (Post, 1964).

The New South Wales coast, running as it does essentially along a line of longitude, provides an ideal opportunity to study the transition from temperate to tropical environments. Within the mangroves themselves the differences are marked, with six mangrove species in northern NSW and only two, *Avicennia marina* and *Aegiceras corniculatum*, extending to the south coast. This paper presents the results of a broad scale survey of the floristic composition of mangrove algal communities at 20 sites distributed along the entire New South Wales coast from Tweed Heads in the north to Pambula in the south. The frequency of species occurring on mangrove pneumatophores is also given. The New South Wales mangrove algal flora is compared with those of the algal communities associated with mangroves in temperate Australia, and the relationship with the lesser known tropical Australian flora is discussed.

MATERIALS AND METHOD

Community composition and frequency data were collected from 20 sites on the NSW coast. At all but three localities (Mill Creek, Cattai Creek on the lower Manning River, and Sussex Inlet), two transects were run normal to the shore, and the five pneumatophores closest to the midpoint of each quarter of the transect length were collected (see Table 1 for details of transect length). A listing of all algae on the forty pneumatophores formed the basis for the analysis of frequency. At Mill Creek two transects were made, one at the head and the other at the mouth of the creek; at the lower Manning River site the transect extended across the shallow arm of the river (a full collection was made at Harrington only 10km distant); and at Sussex Inlet there was such a dearth of algal material that 100 pneumatophores from 5 transects were examined. In addition to the transect data a general collection of algae was made. Pneumatophores which appeared to support algae not found during the transect sampling were collected as well as algae growing directly on the mud or any solid substratum (wood, rock, rubbish).

The material was examined in fresh condition. All algae were carefully scraped from the pneumatophores with a sharp razor blade and washed on a cheese-cloth gauze to remove mud, and to separate the debris. Microscopic algae (Bacillariophyta and cyanobacteria) were not included in the data compilation. Voucher specimens have been deposited in the John T. Waterhouse Herbarium in the School of Botany, University of New South Wales (UNSW).

Frequency data for each species at each locality were calculated using the same formula as in Beanland and Woelkerling (1982).

$F = \Sigma N/N \times 100$ where

F = the percentage frequency; ΣN = the number of pneumatophores on which a particular alga occurred; and N = the total number of pneumatophores surveyed.

For ease of comparison with published data from southern Australia the 'relative profusion of taxa' was determined from the percentage frequency data, on the same basis as used by Woelkerling and his co-workers. Species have been assigned to one of 5 categories: Rare ($F < 5\%$); Sporadic ($F = 5\text{-}24\%$); Occasional ($F = 25\text{-}49\%$); Common ($F = 50\text{-}75\%$); Abundant ($F > 75\%$).

RESULTS

Community composition

A total of 32 taxa of macroalgae (15 Rhodophyta, 6 Phaeophyta, and 11 Chlorophyta) were recorded in this study of the mangrove communities of New South Wales. This includes species on pneumatophores for which frequency data were calculated, as well as algae growing directly on the mud or other substrata. The localities at which these species occurred are given in Table 1. The genera are listed alphabetically within each Division and the following information is given: (i) selected references which are of taxonomic significance, in which the species is figured, or which refer specifically to Australian material; (ii) type locality; (iii) reported world wide distribution; (iv) specimens examined; (v) general remarks including distribution in Australia; as well as relevant morphological or taxonomic data.

Microalgae and cyanobacteria were common at all localities, but only occasionally were cyanobacteria in sufficient quantities to be conspicuous. *Scytonema* (*S. crispum* (C. Agardh) Born. — see Geitler, 1932: 748, fig. 477) occurred as dense tufts completely covering mangrove pneumatophores in a water-logged area of the mangal at Stuarts

TABLE 1

Location of collecting sites on the New South Wales coast

Location	Latitude	Date	Salinity	Transect length and orientation	Mangrove species present
Tweed Heads Ukerebagh Island	28°10'S	Aug. '83	14%	150m: 300°	Ac[1](UNSW 15157); Am; Bg (15156); Ht (15155); Rs (15159)
Hastings Point	28°22'	Aug. '83	14	40m: 40°	Ac (15162); Am (15161); Rs (15160)
Ballina					
North Arm	28°52'	Aug. '83	24	40m: 90°	Ac; Am; Bg (15169); Ea (15170); Ht
Stuarts Point	30°49'	Aug. '83	23	160m: 105°	Ac; Am
Port Macquarie					
Settlement Point	31°27'	Aug. '83	36	80m: 90°	Ac; Am; Ea (15174)
Harrington	31°52'	Aug. '83	24	40m: 90°	Ac; Am
Cattai Ck (lower Manning River)	31°52'	Aug. '83	18	70m: 0°	Ac; Am
Tuncurry					
North Arm, Wallis Lake	32°11'	Sept. '83	33	28m: 125°	Ac; Am
Port Stephens (near Nelson Bay)	32°44'	Sept. '83	34	80m: 18°	Am
Fullerton Cove (2km north of Stockton Bridge)	32°52'	Sept. '83	29	50m: 115°	Ac; Am
Careel Bay	33°37'	Sept. '83	22	160m: 135°	Ac; Am
Middle Cove (Roseville Bridge)	33°49'	Sept. '83	39	200m: 125°	Am
Weeney Bay (Botany Bay)	34°02'	Sept. '83	36	360m: 90°	Ac; Am
Mill Ck (off Georges R.)	34°00'				
mouth		June '83	2	80m: normal to	Ac; Am
head		June '83	0	6m: Creek	Ac; Am

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[1] Ac = *Aegiceras corniculatum* (L.) Blanco; Am = *Avicennia marina* (Forsk.) Vierh.; Bg = *Bruguiera gymnorhiza* (L.) Lamk; Ht = *Hibiscus tiliaceus* L.; Rs = *Rhizophora stylosa* Griff.; Ea = *Excoecaria agallocha* L.

TABLE 1 (concluded)

Location	Latitude	Date	Salinity	Transect length and orientation	Mangrove species present
Georges Hall Georges R.	33°58′	Sept. '83	2	4m:	Am
Minnamurra River	34°38′	Sept. '83	34	100m: 270°	Ac; Am
Sussex Inlet	35°09′	July '83	34	230m: 108°	Ac; Am
Batemans Bay Cullendulla Ck	35°44′	Sept. '83	36	48m: 320°	Ac; Am
Bermagui	36°25′	Sept. '83	36	40m: 200°	Am
Pambula	36°56′	Sept. '83	34	28m: 90°	Am

1. Ac = *Aegiceras corniculatum* (L.) Blanco; Am = *Avicennia marina* (Forsk.) Vierh.; Bg = *Bruguiera gymnorhiza* (L.) Lamk; Ht = *Hibiscus tiliaceus* L.; Rs = *Rhizophora stylosa* Griff.; Ea = *Excoecaria agallocha* L.

Point (UNSW 15033) and although it was otherwise widely distributed it was not common. *Lyngbya*, or a related genus in the Oscillatoriaceae, and a member of the Stigonematales (?*Brachytrichia balani* (Lloyd) Born. *et* Fl. — see Geitler, 1932: 553, fig. 347) were also widely distributed.

Division RHODOPHYTA

Genus *Bostrychia* Montagne 1842

Bostrychia flagellifera Post 1936: 34
References: May, 1965: 377; Post, 1961: 101, fig. 1,2(I,II)
Type locality: Parramatta R., Sydney
Reported distribution: east coast of Australia, New Zealand and Japan
Specimens examined: UNSW 13890 (lower Manning R.), 14177 (Sussex Inlet), 14188 (Mill Ck mouth), 15001 (Stuarts Point), 15011 (Tweed Heads), 15022 (Ballina), 15037 (Port Macquarie), 15050 (Careel Bay), 15066 (Fullerton Cove), 15095 (Middle Cove), 15228 (Nelson Lagoon), 15253 (Bonna Point), 15323 (Weeney Bay), 17085 (Minnamurra R.)
Remarks: B. flagellifera was locally abundant on pneumatophores in both sun-exposed and shaded positions. It also occurred on sand or mud around the bases of salt marsh plants (*Sarcocornia quinqueflora, Juncus kraussii* and *Suaeda australis*). This species has been recorded in Queensland by Saenger *et al.* (1977) and Cribb (1979). On the NSW coast it was abundant in mangroves north of Sydney. Its distribution is now extended to Nelson Lagoon (just north of Tathra) in southern NSW. It has never been recorded in Victoria or South Australia.

Bostrychia intricata (Bory) Montagne 1852: 317
References: May, 1965: 377; Tseng, 1943: 174, pl. 1, figs 4-5; Harvey, 1860: pl. 176A (incorrectly as 276A in index) as *B. mixta* Hooker and Harvey; Kumano, 1979: 15 figs 3, 12-15 as *B. mixta*; Post, 1963: 94, fig. 6 as *B. mixta*
Synonym: B. mixta Hooker and Harvey
Type locality: Falkland Islands (Islas Malvinas)
Reported distribution: Widespread in subantarctic regions and in warmer waters
Specimens examined: UNSW 15024 (Ballina), 15034 (Stuarts Point), 15241 (Pambula)
Remarks: This species is apparently common in the eulittoral of sheltered rocky shores of NSW. It has been recorded for Queensland by Saenger *et al.* (1977) and Cribb (1979), on littoral zone mud surfaces in Victoria (Davey and Woelkerling, 1980) and at Kangaroo Island, South Australia (Womersley, 1950; Post, 1963), and in Tasmania (Harvey, 1860; Cribb, 1954). It was not recorded in Spencer Gulf, South Australia (Beanland and Woelkerling, 1982).

Bostrychia kelanensis Grunow ex Post 1936: 20
References: Kumano, 1979: 18, figs 33-37; May, 1965: 377; Post, 1936: 20-22: 1968a: 81-150; Tseng, 1943: 169-171
Type locality: Kelana, New Guinea
Reported distribution: Tropical waters of the Indo-Pacific region
Specimens examined: UNSW 15012 (Tweed Heads)
Remarks: This is the only record of this species for NSW though it has been recorded for the Brisbane River (Post, 1968a). It is a predominantly tropical species and has been reported from a number of other Queensland localities (Saenger *et al.*, 1977; Cribb, 1979; Ngan and Price, 1980).

Bostrychia moritziana (Sonder) J. Agardh 1863: 862
References: Kumano, 1979: 20, figs 51-59; May, 1965: 376; Post, 1936: 10; 1963: 57
Type locality: French Guiana
Reported distribution: Widespread in tropical and temperate seas
Specimens examined: UNSW 13879, 14192 (Mill Ck head), 13888 (Harrington), 14170, 15211 (Georges Hall), 14182 (Sussex Inlet), 15025 (Ballina), 15041, 15042 (Port Macquarie), 15051 (Careel Bay), 15061, 15068 (Port Stephens), 15079 (Fullerton Cove), 15254 (Bonna Point), 15322 (Weeney Bay), 17086 (Stuarts Point)
Remarks: B. moritziana was recorded for all localities except Hastings Point and Batemans Bay. It was widespread on mangrove pneumatophores generally intermixed with other species of *Bostrychia* and *Caloglossa*. This species was abundant in Victoria (Davey and Woelkerling, 1980) and South Australia (Beanland and Woelkerling, 1982), and was also recorded for Queensland (Saenger *et al.*, 1977; Cribb 1979).

Bostrychia simpliciuscula Harvey ex J. Agardh 1863: 854
References: May, 1965: 376; Tseng, 1943: 173, pl. II, figs 6-7; Harvey, 1860: pl. 176B (incorrectly as pl. 276B in index); Post, 1936: 22 as *B. tenuis* (Harvey) Post; 1963:66 as *B. tenuis*
Synonym: B. tenuis Post
Type locality: Friendly Islands
Reported distribution: Widespread in the southern hemisphere in temperate waters
Specimens examined: UNSW 14179, 14181 (Sussex Inlet), 14187 (Weeney Bay), 14190 (Mill Ck mouth), 15006 (Stuarts Point), 15013 (Tweed Heads), 15023 (Ballina), 15030 (Hastings Point), 15078 (Fullerton Cove), 15087 (Middle Cove), 15213 (Bermagui), 15223, 15224, 15249 (Minnamurra R.), 15227 (Nelson Lagoon), 15225 (Bonna Point)
Remarks: This species has been recorded for southern Australia (Womersley, 1950; Post, 1936, 1963 and 1964) including Tasmania (Cribb, 1954) but was not recorded for Victoria by Davey and Woelkerling (1980) nor Spencer Gulf, South Australia (Beanland and Woelkerling, 1982). However in these latter studies the tropical species *B. radicans* was recorded as the most abundant and widespread alga. The relationship between *B. radicans* and *B. simpliciuscula* requires further investigation.

Genus *Caloglossa* J. Agardh 1876

Caloglossa adnata (Zanardini) De Toni
References: May, 1965: 385; Post, 1936: 47, fig. 1; 1955: pl. 4; 1963: 99
Type locality: Kuching, Borneo, East Malaysia
Reported distribution: Widespread in tropical waters
Specimen examined: UNSW 15020 (Ballina)
Remarks: This species has been recorded for Queensland, the southern-most records being for Brisbane River (Post, 1963) and Moreton Bay (Cribb, 1979). The record for Ballina (28° 52′S) extends the known range of the species south into NSW. Within the mangal it was found only in densely shaded regions and grew on pneumatophores, mangrove tree bases and rock surfaces.

Caloglossa leprieurii (Montagne) J. Agardh 1876: 499
References: May, 1965: 395; King, 1981a: fig. 12.7C,D; Papenfuss, 1961: figs 1-30; Post, 1936: 40; 1963: 99
Type locality: Cayenne, French Guiana
Reported distribution: Widespread in tropical and temperate seas
Specimens examined: UNSW 13881 (Mill Ck mouth), 13883 (Mill Ck head), 13886 (Harrington), 13891 (lower Manning R.), 13895 (Stuarts Point), 14168 (Liverpool), 14169

(Deepwater Park), 14180 (Sussex Inlet), 14184, 15256 (Weeney Bay), 15008 (Tweed Heads), 15021 (Ballina), 15031 (Hastings Point), 15036 (Port Macquarie), 15047 (Careel Bay), 15063 (Port Stephens), 15065 (Fullerton Cove), 15086 (Tuncurry), 15209 (Georges Hall), 15215, 15216 (Bermagui), 15221 (Minnamurra R.), 15244 (Pambula), 15263 (Quibray Bay), 15264 (Bonna Point)

Remarks: C. leprieurii occurred at all sites on the NSW coast except Batemans Bay. It occurred widely throughout the mangal in both shaded and sun-exposed areas. It may occur as the sole alga on pneumatophores but was more often mixed with other species of the '*Bostrychia-Caloglossa* Association'. It is otherwise widely distributed in mangrove communities in southern Australia (Davey and Woelkerling, 1980; Beanland and Woelkerling, 1982) and also in north-eastern Australia (Saenger *et al.*, 1977; Cribb, 1979).

Caloglossa ogasawaraensis Okamura

References: Post, 1936: 60; 1963: 104; 1966: 317, fig. 3; 1967: 263, figs 5,6; 1968: 279, fig. 10

Synonym: C. bombayensis Boergesen

Type locality: Bonin Islands (Ogasawara-jima), Japan

Reported distribution: Widely distributed in tropical waters

Specimens examined: UNSW 13885 (Harrington), 14171 (Deepwater Park), 14185 (Weeney Bay), 15016 (Tweed Heads), 15026 (Ballina), 15027 (Hastings Point), 15043 (Port Macquarie), 15052 (Careel Bay), 15077 (Port Stephens), 15089 (Middle Cove), 15205 (Georges Hall)

Remarks: C. ogasawaraensis was recorded for Queensland (Saenger *et al.*, 1977; Cribb, 1979). It was recorded in NSW from earlier records of the Parramatta River (Post, 1936), and as *C. bonayensis* (Post 1961). At Careel Bay (salinity 22°/∞) it was locally abundant on pneumatophores at the seaward edge of the mangal. At Georges Hall, Georges R., (salinity 2°/∞) it was abundant and often the only conspicuous alga on the pneumatophores and rocks.

Genus *Catenella* Greville 1830

Catenella nipae Zanardini 1872: 143

References: King, 1981a: fig. 12.7B; May, 1965: 360; Min-Thein and Womersley, 1976: figs 17, 56; Post, 1936: 68; 1963: 116, fig. 8; 1964: 251; Tseng, 1942: 143, fig. 2

Type locality: Sarawak, Borneo

Reported distribution: India, south-east Asia, Australia and New Zealand

Specimens examined: UNSW 13878 (Mill Ck, midway between head and mouth), 13880, 13882 (Mill Ck head), 13887 (Harrington), 13893 (lower Manning R.), 13894 (Stuarts Point), 14178 (Sussex Inlet), 14190 (Mill Ck mouth), 15010 (Tweed Heads), 15019 (Ballina), 15028 (Hastings Point), 15035 (Port Macquarie), 15053 (Careel Bay), 15062 (Port Stephens), 15064 (Fullerton Cove), 15094 (Middle Cove), 15214 (Bermagui), 15225 (Minnamurra R.), 15229 (Nelson Lagoon), 15242 (Pambula), 15258 (Spit Bridge), 15259 (Weeney Bay), 15260, 15262 (Bonna Point), 15261 (Quibray Bay)

Remarks: C. nipae was widely distributed in Victoria (Davey and Woelkerling 1980) but was not recorded for Spencer Gulf, South Australia (Beanland and Woelkerling, 1982). In NSW it was recorded at all sites except the hyposaline locality at Georges Hall. It occurs predominantly on pneumatophores and the bases of the mangrove trees especially in shaded areas where it may be the only conspicuous alga. It is also recorded for Queensland (Saenger *et al.*, 1977; Cribb, 1979).

Genus *Centroceras* Kuetzing 1841

Centroceras clavulatum (C. Agardh) Montagne 1846: 140
References: Abbott and Hollenberg, 1976: 604, fig. 547; May, 1965: 371
Type locality: Caloa, Peru
Reported distribution: Widely distributed in temperate and tropical waters
Specimen examined: UNSW 15073 (Port Stephens)
Remarks: C. clavulatum was recorded in the mangals of Spencer Gulf, South Australia (Beanland and Woelkerling, 1982) and Victoria (Davey and Woelkerling, 1980). Cribb (1979) recorded it for Moreton Bay, Queensland. In this survey it was recorded at only one locality, Port Stephens, where small plants occurred mixed with species of *Bostrychia* and *Caloglossa* on pneumatophores.

Genus *Chondria* C. Agardh 1817

Chondria sp.
Specimen examined: UNSW 15067 (Port Stephens)
Remarks: This species was recorded at only one locality, Port Stephens. It was common in the mid to lower portion of the mangrove zone. The large (*c.* 10cm long) plants were attached to the bases of the pneumatophores and spread over the mud surface. The infertile plants appear to belong to an as yet undescribed species which also occurs in southern Australia (E. Gordon-Mills, pers. comm.).

Genus *Erythrotrichia* J. Agardh

Erythrotrichia carnea (Dillwyn) J. Agardh 1883: 15
References: Abbott and Hollenberg, 1976: 286, fig. 228; Chapman, 1969: 11, fig. 4; Kornmann and Sahling, 1978: 258, pl. 148A-C; Levring, 1953: 462; May, 1965: 354
Type locality: Wales
Remarks: E. carnea was recorded at Ballina only, but the species is cosmopolitan. It was recorded for mangrove areas in South Australia (Beanland and Woelkerling, 1982) though at only one locality. The small size of the plant may cause it to be overlooked in a broad vegetation survey.

Genus *Gracilaria* Greville

Gracilaria verrucosa (Hudson) Papenfuss 1950: 195
References: May, 1948: 18, figs 1-2, pls 1(1,2), 2(1) as *G. confervoides* (Linnaeus) Greville
Synonym: G. confervoides (Linnaeus) Greville
Type locality: England
Reported distribution: Widely distributed in temperate and tropical waters
Specimens examined: UNSW 15014 (Tweed Heads), 15017 (Ballina), 15038 (Port Macquarie), 15056 (Careel Bay), 15091 (Middle Cove).
Remarks: G. verrucosa was recorded in mangrove swamps in NSW and Queensland, as *G. confervoides*, in Saenger *et al.* (1977). In this survey *G. verrucosa* was common in most sites north of Sydney but on the south coast was recorded only at Pambula. The plants spread out on the mud surface and are, at least initially, attached to pneumatophores or small shell fragments in the mud. Since only algae growing attached to pneumatophores were scored for frequency *Gracilaria verrucosa* is under-represented in the data. The older plants are often apparently unattached and therefore comparable to the free-living *Gracilaria secundata* f. *pseudoflagellifera* communities reported for New Zealand (Chapman, 1975).

Genus *Polysiphonia* Greville

Polysiphonia ?scopularum Harvey
Reference: Womersley, 1979: 467-469, fig. 2A-E
Type locality: Rottnest Island, Western Australia
Reported distribution: Southern Australia and Queensland, otherwise widespread
Specimens examined: UNSW 15054 (Careel Bay), 15075 (Port Stephens), 15081 (Tuncurry), 15090 (Middle Cove)
Remarks: Sterile plants of *Polysiphonia ?scopularum* were recorded for a few localities. The species has been recorded from mangroves in Spencer Gulf, South Australia (Beanland and Womersley, 1982) and for Queensland (Cribb, 1979).

Genus *Spyridia* Harvey 1833

Spyridia filamentosa (Wulfen) Harvey 1833: 336
References: Abbott and Hollenberg, 1976: 608; Womersley and Cartledge, 1975: fig. 1; May, 1965: 369 as *S. breviarticulata* J. Agardh
Type locality: Adriatic Sea
Reported distribution: Widely distributed in tropical and subtropical waters. All around the Australian coast
Specimens examined: 15076 (Port Stephens), 15080 (Tuncurry), 15257 (Quibray Bay)
Remarks: S. filamentosa was recorded at only four localities. In Careel Bay and Botany Bay it was common in the lower regions of the mangal in the late summer and autumn, but not in spring. It may not have been recorded from other localities as a result of its seasonal nature. It was recorded in the mangals of Spencer Gulf, South Australia (Beanland and Woelkerling, 1982) and was also reported for Queensland (Saenger *et al.*, 1977, Cribb, 1979).

Division PHAEOPHYTA

Genus *Acinetospora* Bornet 1891

Acinetospora crinita (Carmichael ex Harvey) Kornmann 1953: 205, figs 1-14
Reference: Kornmann and Sahling, 1978: fig. 60(A-H)
Type locality: Appin, Scotland
Reported distribution: Common in temperate seas
Specimen examined: UNSW 15055 (Careel Bay)
Remarks: In Australia *A. crinita* has been recorded on rocky coasts (Clayton, 1974). In this survey it was recorded only at Careel Bay where it formed tangled tufts amongst pneumatophores at the seaward edge of the mangrove vegetation.

Genus *Asperococcus* Lamouroux

Asperococcus bullosus (Lamouroux) De Toni 1895: 493
Reference: Borowitzka *et al.*, 1982: 22, fig. 9
Type locality: 'Medit. Gall'
Reported distribution: Widespread
Specimens examined: UNSW 13844 (Botany Bay), 15057 (Port Stephens), 15218 (Bermagui)
Remarks: A. bullosus was recorded in estuaries in southern Australia and north to Pittwater (Borowitzka *et al.*, 1982). This survey extends the recorded range of this species north to Port Macquarie. Initially the species grows as an epiphyte on *Posidonia* and cast plants continue to grow in the mangrove swamps.

Genus *Ectocarpus* Lyngbye 1819

Ectocarpus siliculosus (Dillwyn) Lyngbye 1819: 131
Reference: Kornmann and Sahling, 1978: 94, fig. 45(B,C)
Type locality: Europe
Reported distribution: Cosmopolitan
Specimens examined: UNSW 15004 (Stuarts Point), 15206 (Georges Hall), 15217 (Bermagui), 15233 (Batemans Bay), 15245 (Pambula)
Remarks: This species has been recorded for mangroves in South Australia (Beanland and Woelkerling, 1982), Victoria (Davey and Woelkerling, 1980) and Queensland (Cribb, 1979). In this survey fertile *E. siliculosus*, with very long spine-like plurilocular sporangia (some subtending hair-like filaments), was recorded at five localities. It occurred draped over pneumatophores at the seaward edge of the mangal and also extended into the sublittoral as an epiphyte on *Zostera.*

Genus *Hormosira* (Endlicher) Meneghini 1838

Hormosira banksii (Turner) Decaisne 1842: 331
References: Borowitzka *et al.*, 1982: 43, fig. 25B; Clarke and Womersley, 1981: 497, fig. 1A; King, 1981a: 325, fig. 12.9(A,B); 1981b: 569, figs 3 & 9; 1981c: 107
Type locality: 'Novae Hollandae'
Reported distribution: Widespread in temperate Australasia
Specimens examined: UNSW 13708 (Weeney Bay), 15212 (Bermagui), 15240 (Pambula)
Remarks: King (1981a,b,c) provided details on the extensive unattached *H. banksii* communities in southern Botany Bay. Such well developed free-floating communities have not been found at other localities, although a community covering over 200m of shore is present in Carama Ck, which runs into Hare Bay in northern Jervis Bay. Populations of *H. banksii* on the southern NSW coast (Narooma, Bermagui and Pambula) are not of the same form as that in Botany Bay and are initially attached to pneumatophores at the lower levels of the mangroves. The plants attain a large size (up to approximately 50cm in length) but in contrast to the attached populations of *H. banksii* growing in hypersaline waters with *Avicennia* at Booti Is., Wallis Lake (King, 1981b: fig. 9), they are much branched.

Genus *Sphacelaria* Lyngbye 1819

Sphacelaria sp.
Specimens examined: UNSW 14183 (Weeney Bay), 15049 (Careel Bay), 15071 (Port Stephens), 15088 (Middle Cove), 15246 (Pambula)
Remarks: Sphacelaria was recorded at six localities but in each case plants were small and infertile. No plants bore vegetative propagules.

Genus *Striaria* Greville 1828

Striaria attenuata Greville 1828: 44
References: Kornmann and Sahling, 1978: 280, fig. 161; Skinner and Womersley, 1983: 60, fig. 1(A), 2(A-F)
Type locality: Isle of Bute, Scotland
Reported distribution: North Atlantic and Mediterranean, New Zealand, southern Australia
Specimen examined: UNSW 15243 (Pambula)
Remarks: This species has hitherto been recorded from only two localities in Australia: Westlakes (Port Adelaide), South Australia, and Southport, Tasmania (Skinner and

Womersley, 1983). In this survey *S. attenuata* was found at only one locality on the NSW coast, Mangrove Island, just south of Pambula. Large plants (up to 40cm in length) occurred commonly in tangled masses amongst the pneumatophores and embedded in sand on the outer edge of the mangroves. The material collected fitted the description of the species given by Skinner and Womersley, 1983, except for the generally larger size of the plants at Pambula (Skinner, pers. comm.).

Division CHLOROPHYTA

Genus *Chaetomorpha* Kuetzing 1845

Chaetomorpha capillaris (Kuetzing) Boergesen 1925: 45, fig. 13
References: Womersley, 1956: 256; 1984: 178, figs 56C, 57E,F
Type locality: Nice, France
Reported distribution: Mediterranean Sea and Atlantic Ocean, southern Australia
Specimens examined: UNSW 15045 (Careel Bay), 15092 (Middle Cove)
Remarks: This species has previously been recorded in salt marsh and mangrove vegetation from Westernport, Victoria (Davey and Woelkerling, 1980), Spencer Gulf, South Australia (Beanland and Woelkerling, 1982) and Queensland (Saenger *et al.*, 1977). In this survey *C. capillaris* was recorded at four localities in the Sydney region. It occurred entangled on pneumatophores and as mats on mud surfaces amongst pneumatophores.

Genus *Cladophora* Kuetzing 1843

Cladophora coelothrix Kuetzing 1843: 272
Reference: Womersley, 1984: 190, figs 60C, 61C,D
Type locality: Livorno, Italy
Reported distribution: Fremantle, Western Australia to Moreton Bay, Queensland. Otherwise widespread
Specimen examined: UNSW 15015 (Tweed Heads)
Remarks: C. coelothrix was recorded at Tweed Heads where it occurred on *Avicennia* pneumatophores in sun-exposed areas.

Cladophora sp.
Specimens examined: UNSW 15048 (Careel Bay), 15074 (Port Stephens), 15234 (Batemans Bay)
Remarks: Plants of *Cladophora* were found attached to pneumatophores at a large number of localities. Specimens were small (mostly less than 1cm) and too young to identify with certainty.

Genus *Enteromorpha* Link 1820

Enteromorpha intestinalis (Linnaeus) Link 1820
References: Bliding, 1963: 139; Kornmann and Sahling, 1978: 78, fig. 37; Christianson *et al.*, 1981: pl. 148; Womersley, 1956: 353; 1984: 161, figs 50D, 51G,H
Type locality: Uncertain
Reported distribution: Cosmopolitan?
Specimens examined: UNSW 15046, 15203 (Careel Bay), 15204 (Middle Cove), 15220 (Minnamurra R.)
Remarks: Small plants, referable to *E. intestinalis*, were recorded for Middle Cove, Careel Bay and the Minnamurra R. Many of the small plants of *Enteromorpha* not identified to species level may belong to this taxon.

Enteromorpha prolifera (Mueller) J. Agardh 1883: 129
References: Bliding, 1963: 45, figs 19-29; Kornmann and Sahling, 1978: 71, pl. 32; Womersley, 1956: 353; 1984: 156, figs 48D, 49H
Type locality: Lolland, Denmark
Reported distribution: Widespread in temperate seas
Specimen examined: UNSW 15060 (Port Stephens)
Remarks: Material referable to *E. prolifera* was recorded only for Port Stephens.

Enteromorpha sp.
Remarks: Enteromorpha plants occurred on pneumatophores and other solid substrata at a number of localities. Most plants were small (less than 1cm) and none could be identified to species with certainty.

Genus *Percursaria* Bory 1828

Percursaria percursa (C. Agardh) Rosenvinge 1893: 963
References: Abbott and Hollenberg, 1976: 70, fig. 22; Bliding, 1963: 20, figs 5-6; Kornmann and Sahling, 1978: 62, fig. 27; Womersley, 1984: 135, figs 42A, 43A,B
Type locality: Hofmansgave, Denmark
Reported distribution: Widespread, on both tropical and temperate sheltered coasts
Specimens examined: UNSW 14172 (Sussex Inlet), 15059 (Port Stephens), 15084 (Tuncurry), 15247 (Pambula), 16264 (Towra Pt, Botany Bay)
Remarks: P. percursa has been recorded for a number of salt marsh and mangrove localities in south-eastern Australia (Womersley, 1984). In this survey it was found at a number of sites as far north as Tuncurry. Since it generally occurs only at the landward margin of the mangal on the sandy or muddy substrate, it is either not recorded or under-represented in the frequency data. At some localities (e.g. Sussex Inlet) it was abundant with skein-like masses draped over pneumatophores and completely covering the substratum. In Botany Bay it occurred as floating masses in shallow salt marsh pools.

Genus *Rhizoclonium* Kuetzing 1843

Rhizoclonium implexum (Dillwyn) Kuetzing 1845: 206
References: Abbott and Hollenberg, 1976: 92, fig. 45; Womersley, 1984: 167, fig. 53A
Type locality: Bantry, Eire
Reported distribution: Cosmopolitan
Specimens examined: UNSW 15009 (Tweed Heads), 15096 (Middle Cove), 15201 (Careel Bay), 15226 (Minnamurra R.), 15230, 15235 (Batemans Bay)
Remarks: R. implexum often occurred mixed with other algae especially *Percursaria percursa* on mud surfaces in the landward portion of the mangal. The plants agree well with the concept of *R. implexum* in Abbott and Hollenberg (1976). The species has been recorded in the mangroves of Spencer Gulf, South Australia (Beanland and Woelkerling, 1982) and also for Queensland (Saenger *et al.*, 1977; Cribb, 1979).

Rhizoclonium riparium (Roth) Harvey 1849: pl. 239
References: Abbott and Hollenberg, 1976: 92, fig. 46, pl. 1, fig. 9; Kornmann and Sahling, 1978: 47, pl. 18A-F; Womersley, 1956: 361; 1984: 170, fig. 53D
Type locality: Norderney, Germany
Reported distribution: Cosmopolitan
Specimens examined: UNSW 13892 (lower Manning R.), 15002 (Stuarts Point)
Remarks: R. riparium was recorded at only two localities (lower Manning R. and Stuarts Point). Both these localities were hyposaline (18‰ and 23‰ respectively). *R. riparium*

occurred on the landward edge of the mangal either directly on the sandy substrate (Stuarts Point) or on logs and stones (lower Manning R.). The plants agree with the description of Californian plants (Abbott and Hollenberg, 1976) though only plants from lower Manning R. possessed the short rhizoidal branches generally regarded as characteristic of the species (Kornmann and Sahling, 1978). *R. riparium* was common in Victorian mangrove communities (Davey and Woelkerling, 1980) and in Spencer Gulf, South Australia (Beanland and Woelkerling, 1982). In the latter case the authors noted that rhizoidal branches were rare. Womersley (1984) regarded the range of filament diameters in the material of Beanland and Woelkerling to be too great.

Family Udoteaceae
(Genus *?Pseudochlorodesmis*)

?*Pseudochlorodesmis* sp.
Specimens examined: UNSW 15007 (Tweed Heads), 15029 (Hastings Point)
Remarks: This species formed a thick growth around pneumatophores of *Avicennia*, accreting mud to form a spongy cone-shaped collar around the pneumatophores. It occurred most commonly at the seaward edge of the mangrove vegetation.

Genus *Ulvaria* Ruprecht 1851

Ulvaria oxysperma (Kuetzing) Bliding 1968: 585, figs 31-34
References: Womersley, 1971: 113, fig. 1; 1984: 136, figs 42B, 43C,D; Abbott and Hollenberg, 1976: 68, fig. 19 as *Monostroma oxyspermum* (Kuetzing) Doty
Synonym: Monostroma oxyspermum (Kuetzing) Doty
Type locality: Baltic Sea, Germany
Reported distribution: Widespread in temperate regions
Specimens examined: UNSW 13884 (Mill Ck head), 13889 (Harrington), 15005 (Stuarts Point), 15018 (Ballina), 15032 (Hastings Point), 15039 (Port Macquarie), 15044 (Careel Bay), 15058 (Port Stephens), 15083 (Tuncurry), 15093 (Middle Cove), 15201 (Georges Hall), 15222 (Minnamurra R.), 15248 (Pambula)
Remarks: This species was not recorded for the mangrove communities of either Victoria (Davey and Woelkerling, 1980) or Spencer Gulf, South Australia (Beanland and Woelkerling, 1982). Womersley (1984) recorded it as widespread, in winter, in calm waters, bays and inlets in southern Australia and north to Botany Bay, NSW. It was present at almost all sites on pneumatophores and especially on other solid substrata (wood, stones and decaying leaves and twigs of terrestrial vegetation). It appeared to be more abundant in the more sun-exposed positions of the seaward and landward edges of the mangrove vegetation. Cribb (1979) recorded *Monostroma ?oxyspermum* for Moreton Bay, Queensland.

FREQUENCY DATA

Frequency data for the taxa collected at all sites, are summarized in Table 2. Table 2 also records presence of species not epiphytic on pneumatophores. Nine taxa occurred commonly (percentage frequency, F = 50-75%) or abundantly (F > 75%) at one or more localities: *Bostrychia flagellifera, B. moritziana, B. simpliciuscula, Caloglossa leprieurii, C. ogasawaraensis, Catenella nipae, Chaetomorpha capillaris, ?Pseudochlorodesmis,* and *Ulvaria oxysperma*. Based on the mean frequency values (i.e. $\bar{F} = F/N$ where F is the sum of all recorded frequencies greater than zero and N the total number of localities at which the alga occurred) *Caloglossa leprieurii* is the most frequently occurring alga (F = 57), followed by *Bostrychia flagellifera* (F = 55). *Catenella nipae* was the most widespread species, occurring at all localities except the hyposaline site at Georges Hall. Five other species,

TABLE 2

Percentage frequency data for algae associated with New South Wales mangroves
(Taxa found outside sampling transects or not growing epiphytically on pneumatophores are recorded as present — P).

SITES	Tweed Heads	Hastings Point	Ballina	Stuarts Point	Port Macquarie	Harrington	lower Manning R.	Tuncurry	Port Stephens	Fullerton Cove	Careel Bay	Middle Cove	Weeney Bay	Mill Ck head	Mill Ck mouth	Georges Hall	Minnamurra R.	Sussex Inlet	Batemans Bay	Bermagui	Pambula	Mean % Frequency
No. of pneumatophores sampled	40	40	40	40	40	40	20	40	40	40	40	40	40	20	20	40	40	100	40	40	40	
TAXON																						
RHODOPHYTA																						
Bostrychia flagellifera	48	60	P	75	15	P	85		53	58	3	P	P		100		P	P				55
B. intricata			P	P														P			P	
B. kelanensis	P																					
B. moritziana	63		43	25	68	3	35	25	65	23	60	25	45	95		68	10	2		28	20	39
B. simpliciuscula	90	53	18	45	8			8	13	15		20	48		20		20	P		8	50	31
Caloglossa adnata			33																			33
C. leprieurii	55	60	58	40	75	23	70	45	53	75	58	38	75	95	95	P	30	3		55	78	57
C. ogasawaraensis	13	P	25		23	P	5		90		58	23	3			25						29
Catenella nipae	3	8	45	13	90	P	5	5	40	55	58	23	45	P	50		30	2	P	15	53	32
Centroceras clavulatum									15													15
Chondria sp.									43													43
Erythrotrichia carnea			3																			3
Gracilaria verrucosa	5	18	10		5		5				3	P	5								3	7
Polysiphonia ?scopulorum								P	P		P	P										
Spyridia filamentosa								3	8		P		P									6
PHAEOPHYTA																						
Acinetospora crinita											10											10
Asperococcus bullosus									P				P							P		
Ectocarpus siliculosus				P												P			P	P	P	
Hormosira banksii													P							P	13	13
Sphacelaria sp(p).									33		13	38	P			3				3	33	21
Striaria attenuata																					P	
CHLOROPHYTA																						
Chaetomorpha capillaris											5	18	P	60								28
Cladophora coelothrix	8																					8
Cladophora sp.		3	20			13			18		3		P	10			23		P	3	23	13
Enteromorpha intestinalis											P	5					10					8
E. prolifera								P														
Enteromorpha sp.	3					8		5	5		13			30		8			28	13	28	14
Percursaria percursa								P	P			3	P					P			3	3
Rhizoclonium implexum	5	3		P	3	13		13	3	3	P	15	13	5			P	2	P	38	30	11
R. riparium				P			20															20
?Pseudochlorodesmis	50	38																				44
Ulvaria oxysperma		P	10	P	P	15		3	P		10	3		50		P	18	7	5	63	70	23

Bostrychia flagellifera, B. moritziana, B. simpliciuscula, Caloglossa leprieurii and *Ulvaria oxysperma* occurred at more than 75% of localities.

DISCUSSION

The marine flora of southern Australia is rich and diverse with over 1100 species of macroalgae recorded (Womersley, 1981). The marine botany of the NSW coast is less well known, and although there are many distinctive and endemic floral elements (Allender and Kraft, 1983) it has been accepted generally that the flora is not as rich as its southern counterpart. This is due to the fact that many of the cool-temperate elements, and in particular many of the endemic southern species in the Fucales, Caulerpales, and the Rhodophyta generally, do not extend to NSW, and the relatively few more tropical species do not compensate for this loss.

In comparison with the flora of adjacent rocky coasts, the algal flora of mangrove habitats is generally depauperate. In Victoria only 23 species of algae (13 Rhodophyta, 3 Phaeophyta, 6 Chlorophyta, 1 Chrysophyta) have been recorded (Davey and Woelkerling, 1980) and for Spencer Gulf, South Australia 49 species (28 Rhodophyta, 9 Phaeophyta, 10 Chlorophyta, 2 cyanobacteria), (Beanland and Woelkerling, 1982). King (1981a) listed 18 species of macroalgae (13 Rhodophyta, 2 Phaeophyta, 2 Chlorophyta, 1 Xanthophyta) for salt marsh and mangrove habitats in NSW, while the present more detailed study reports 32 taxa (15 Rhodophyta, 6 Phaeophyta, 11 Chlorophyta) for mangrove habitats only.

When making direct comparisons between such species numbers provided by different authors, some caution is necessary.

The criteria used to assign a particular alga to the mangrove habitat are rarely the same in each study. Many algae washed in from adjacent rocky coasts or seagrass beds can survive, unattached, in the mangrove habitat for variable lengths of time. Since many of the mangrove algae also occur in adjacent communities (rocky coast and seagrass beds), it is sometimes unclear whether some plants recorded should be properly regarded as part of the mangrove system. In his study in Moreton Bay, Cribb (1979) included essentially subaerial species such as *Pseudendoclonium submarinum* and two species of *Trentepohlia* from the trunks of the mangrove trees. *Trentepohlia* was common on mangrove trunks at most sites along the NSW coast, but was not included in the present study.

Seasonal factors affect the number of species recorded and this is particularly relevant when surveys are carried out over a limited part of the year, e.g. Davey and Woelkerling, 1980, March-September; Beanland and Woelkerling, 1982, March-July. The present study was undertaken during July-October, 1983.

The degree to which the species collected at any site represents the total algal flora must also be considered. The use of transects and general collections in the vicinity of the transects does not guarantee that all the species present at a site will be collected. For example, it would have been easy to have failed to record *Caloglossa adnata* at Ballina, since it appeared to have a localized distribution in areas of dense shade within the widespread and well developed mangrove vegetation in the area. Species such as the mangrove form of *Hormosira banksii*, have very limited distributions, but where they are found they occur in abundance. Unattached *H. banksii* populations are reported only for southern Botany Bay (King, 1981a,b,c) and Carama Inlet (Jervis Bay) on the NSW coast but at both localities the distribution is very limited in extent.

Direct comparisons of species lists are made particularly difficult when taxa are not fully identified.

For these reasons the species lists available for various parts of the Australian coast cannot be readily compared.

Of the 18 taxa that King (1981a) listed for NSW, eight were not recorded in the present study, while an additional 22 species were recorded. The eight taxa previously recorded for NSW but not found in this survey are:

Bostrychia binderi. Post (1963) recorded *B. binderi* south to Sydney on the basis of a specimen collected by Grunow (December 1884) at the mouth of the Parramatta River. There are no more recent records.

Bostrychia radicans. Until the relationship between *B. radicans* and *B. simpliciuscula* is clarified we have referred all our material to the latter species.

Bostrychia tenella was recorded for NSW, but until authenticated specimens are available this record should be regarded with suspicion. The species is recorded by Cribb (1979) for Moreton Bay and Saenger *et al.* (1977) for Gladstone, Queensland.

Ceramium was not recorded in this survey, although the genus is generally common on NSW coasts.

Gracilaria edulis was recorded for NSW by Saenger *et al.* (1977), as *G. lichenoides*. This species is widely distributed in estuarine localities in NSW (May 1948) but until its presence and true status within mangrove systems is elucidated, it should be excluded from the NSW list.

Dictyota dichotoma is probably best considered not part of the characteristic mangrove algal community. If it is included then it would be proper to include species of *Colpomenia, Microdictyon, Codium* and *Sargassum*, all of which continue growth in the mangal as cast plants.

Ulva lactuca was not recorded at any locality in this survey, although *Ulva* does occasionally occur on pneumatophores at least in Botany Bay.

Vaucheria sp. was recorded by King (1981a) but it appears to be confined to the salt marsh.

None of the species recorded in this survey is endemic to NSW, which reflects both the cosmopolitan nature of mangrove-associated algae and the fact that NSW represents a transition between temperate and tropical climatic regimes. Some of the species are widely distributed in NSW mangroves, as well as in the mangroves of Spencer Gulf (South Australia), Victoria, Queensland and extra-Australia. These include *Bostrychia moritziana, B. simpliciuscula, Caloglossa leprieurii, Ectocarpus siliculosus* and *Rhizoclonium implexum. Catenella nipae* and *Ulvaria oxysperma* have similarly broad distributions, although *C. nipae* was not found in South Australia, and *U. oxysperma* has not been recorded in mangals in either Spencer Gulf or Victoria. *Ulvaria* does however occur in southern Australia in estuarine localities (Womersley, 1984). The absence of *Ectocarpus siliculosus, Rhizoclonium implexum* and *Ulvaria oxysperma* from previous NSW taxonomic lists reflects the limited work carried out on mangrove habitats in this state. *Spyridia filamentosa* is similarly widespread (though not reported for Victoria), and its absence from many sites in NSW may be attributed to seasonal occurrence. In Botany Bay it has been abundant in September but at other times apparently absent.

A few of the algal species recorded are of tropical affinity and extend varying distances south into NSW. New records for *Bostrychia kelanensis* and *Caloglossa adnata* extend their known distributions to Tweed Heads and Ballina respectively. The sub-tropical *Bostrychia flagellifera* extends south to Nelson Lagoon but is only abundant in northern localities. Some species of cool-temperate affinities extend northwards into NSW. New records for *Percursaria percursa* extend its known distribution north to Tuncurry. The range of *Asperococcus bullosus* has been extended from Pittwater north to Port Stephens.

This species is initially epiphytic on *Posidonia* leaves in the sublittoral and it is therefore not strictly a mangrove alga.

Apart from those species with tropical and cool-temperate affinities and those that are widespread on the NSW coast, there are other species of limited distribution. In some cases such discrete distributions seem to be related to characteristics of the particular collection site. Thus *Centroceras clavulatum* and *Chondria* sp., which normally occur on rocky coasts in NSW, were recorded as epiphytes on pneumatophores only at Port Stephens. This may be explained by the open marine nature of this particular site, which also had a sandy substrate. The distribution of *Erythrotrichia carnea* is probably wider than the single record at Ballina indicates, as the small size of the plants makes them easily overlooked in broad scale survey. *Bostrychia intricata* was previously recorded for Sydney (Kirribilli, Port Jackson) by Post (1936). In this survey it was never abundant in mangroves but occurred sporadically throughout the state. It is recorded, however, for Victoria, South Australia and Queensland. The sole NSW record of *Striaria attenuata* at Pambula represents a significant extension of its reported distribution. *Acinetospora crinita* was recorded only from Careel Bay where it formed tangled masses amongst pneumatophores at the seaward edge of the mangrove zone.

TABLE 3

Comparison of the distribution of macroalgae

Based on species of algae recorded from mangrove ecosystems in Queensland, NSW, Victoria and South Australia. The number of species for each algal Division is given along with the percentage of species common to NSW. Taxa not identified to species level are excluded from this comparison as are all cyanobacteria, Xanthophyta and Chrysophyta, a number of microscopic green algae reported by Cribb (1979) for Moreton Bay *(Apatococcus lobatus, Pseudendoclonium submarinum, Trentepohlia odorata, T. rigidula)* and cast plants found in mangrove communities but which were originally growing on nearby rocky shores and/or adjacent sublittoral seagrass beds (e.g. *Gracilaria edulis, Asperococcus bullosus, Colpomenia sinuosa, Dictyota dichotoma*). (Reference sources are numerically coded.)

	NSW (1,2)	QLD (3,4)	VIC (5)	SA (Spencer Gulf)(6)
RHODOPHYTA	15	25 (87%)	12 (47%)	28 (40%)
PHAEOPHYTA	4	2 (25%)	2 (25%)	7 (50%)
CHLOROPHYTA	10	8 (30%)	4 (30%)	8 (50%)
TOTAL	29	35 (59%)	18 (38%)	43 (45%)

Reference code: 1, Present study; 2, King (1981a); 3, Cribb (1979); 4, Saenger *et al.* (1977); 5, Davey and Woelkerling (1980); 6, Beanland and Woelkerling (1982).

A comparison with the number of species in other states is given in Table 3. It is surprising that only 18 species of mangrove-associated algae are recorded for Victoria given the large diversity of open coast species in that state. In Victoria however, mangroves reach their southernmost limit and communities are not well developed. Also they occur over a limited latitudinal range. The total number of species recorded in Spencer Gulf, South Australia, is enhanced by five coralline algae (O. Cryptonemiales, F. Corallinaceae) and three species of *Audouinella* (O. Nemalionales, F. Acrochaetiaceae) (Beanland and Woelkerling, 1982).

Overall, the NSW mangrove algal flora has greatest similarity with that of Queensland: 59% of the NSW species are also found in Queensland, compared with only 38%

in Victoria and 45% in South Australia. The percentage of species shared with Queensland is highest in the Rhodophyta (87%). This is due to those algae regarded as characteristic of the mangrove habitat, the so-called '*Bostrychia-Caloglossa* Association' being essentially the same in both states. The low species numbers in both the Phaeophyta and Chlorophyta reported in Australian mangrove ecosystems means that comparisons for these Divisions have little value, especially so since almost all of the species are more generally found on nearby rocky shores.

The frequency data are based only on algae collected on pneumatophores of *Avicennia marina*. Given the limited sampling strategy adopted in this broad scale survey the data have limited statistical significance. Pneumatophores provide one of the few stable substrata for the attachment of epiphytic algae in the mangrove habitat. In mangrove communities dominated by *Avicennia* the pneumatophores allow for rapid collection of data. While pneumatophores provide the substratum for the characteristic '*Bostrychia-Caloglossa* Association', other algae, especially in the Divisions Chlorophyta and Phaeophyta, have members which grow directly on the mud or sand surfaces, either amongst the pneumatophores or behind the mangroves and extending into the saltmarsh vegetation. Such species include *Ectocarpus siliculosus, Hormosira banksii, Striaria attenuata* (Phaeophyta) and *Rhizoclonium implexum, R. riparium, Chaetomorpha capillaris, Percursaria percursa* and *Ulvaria oxysperma* (Chlorophyta). This limits the value of collections and statistical data resulting only from collections on pneumatophores. Furthermore where the substratum is sandy or gravelly, and presumably more aerated, *Avicennia* produces fewer pneumatophores (as for example at Batemans Bay and Pambula), and in these situations the characteristic mangrove algae are much less common, and free floating forms or forms that grow directly on the mud or sand substratum are comparatively well represented.

Avicennia is the dominant mangrove tree species on the NSW coast, and the only one that produces pneumatophores. *Aegiceras corniculatum*, which occurs in association with *Avicennia* at most of the sites studied, sometimes forms almost pure stands. In such localities it is impossible to collect frequency data as outlined in this report. In northern NSW other mangrove species occur which produce either different root modifications on which algae can grow (the silt roots of *Rhizophora stylosa* and the knee roots of *Bruguiera gymnorhiza*) or no root modifications at all *(Excoecaria agallocha* and *Hibiscus tiliaceus).* The latter two species occur only at the most landward margin of the mangal. These other mangrove species reduce the density of *Avicennia marina* especially at upper levels, as well as providing alternative substrata on which algae can grow. Since the frequency data are based on the algae on the five pneumatophores nearest the transect point, this does not necessarily bias the collection. In no case were there no *Avicennia* pneumatophores within 50cm of the transect point.

The most frequently occurring and widely distributed algae were those of the *Bostrychia, Caloglossa, Catenella* group, along with *Ulvaria oxysperma. Caloglossa leprieurii* occurred with the highest frequency (percentage mean frequency, 57% as it also did in Victoria, at 69% (Davey and Woelkerling, 1980) and Spencer Gulf, 50% (Beanland and Woelkerling, 1982). Comparison of the number of species present at any particular locality (Table 2) reveals wide variation. Long term salinity data are not available but there does appear to be a considerable reduction in the number of species present in the hyposaline localities at lower Manning River, Mill Creek and Georges Hall. At other localities, e.g. Batemans Bay, some other factor(s) must play a role. There, and at Sussex Inlet, the pneumatophores are relatively free of epiphytic algae, the frequency of all algae being 5 and 16 respectively. Corresponding figures for Tweed Heads and Port Macquarie are 301 and 334.

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The Geological Development of the Thora District, northern Margin of the Nambucca Slate Belt, eastern New England Fold Belt

E. C. LEITCH and D. ASTHANA

LEITCH, E. C., & ASTHANA, D. The geological development of the Thora district, northern margin of the Nambucca Slate Belt, eastern New England Fold Belt. *Proc. Linn. Soc. N.S.W.* 108 (2), (1984) 1985: 119-140.

Early Permian strata of the Nambucca Slate Belt abut Late Carboniferous sedimentary rocks of the Coffs Harbour Block across the Euroka Fault north of Thora in northeastern New South Wales. Massive black siltstone and redeposited coarser clastic rocks of volcanic provenance, grouped in the *Moombil Siltstone*, characterize the Coffs Harbour Block. They dip steeply and young to the north. An imperfect slaty cleavage fabric formed during low-grade regional metamorphism is overprinted by a biotite-bearing static thermal metamorphic assemblage. The *Glenifer Adamellite* and members of the *Dundurrabin Granodiorite* were emplaced in the Coffs Harbour Block synchronous with the static metamorphism. The Nambucca Slate Belt sequence comprises two siltstone-dominated sedimentary units, the *Bellingen Slate* (>1000 m) and the *Buffers Creek Formation* (>1500 m) which are separated by pillowed and massive flows and shallow intrusives of the *McGraths Hump Metabasalt* (2000 m). Despite complexities at the top of the last unit the sequence is considered conformable. Sandstone and conglomerate within the Nambucca Slate Belt units are all redeposited; they are mainly of intermediate-silicic volcanic provenance and are associated with thin ash-fall tuffs. Deposition occurred within a narrow rift similar to those formed at the onset of ocean-basin evolution. However only local emplacement of ocean-ridge basalt took place. Microdiorite and later microadamellite, that collectively comprise the *Dorrigo Mountain Complex*, were emplaced in the Nambucca Slate Belt during or before deformation. Deformation and accompanying prehnite-pumpellyite metagreywacke facies regional metamorphism, at about 255 Ma, resulted from regional compression and a reversal of movement on faults that developed during rifting. The Coffs Harbour Block and the Nambucca Slate Belt were in close proximity at the time of emplacement of the Dundurrabin Granodiorite, for members of this unit are found south as well as north of the Euroka Fault but their earlier spatial relationship is not known. Late movement on the fault is indicated by contrasts in metamorphic character, and deformation features in adjacent granites.

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INTRODUCTION

The eastern part of the New England Fold Belt is made up of a mosaic of fault-bounded blocks each characterized by a distinctive geological history. Recent investigations (Flood and Fergusson, 1982; Cawood, 1982; Cawood and Leitch, 1985) indicate that the blocks developed during the Permian disruption of a formerly simple arrangement of tectonic elements by strike-slip faulting and major folding. Disruption was accompanied by rapid sedimentation, mafic and silicic magmatism, metamorphism and penetrative deformation.

In this paper we describe the geological development of the Thora district in the Mid-North Coast region of northeastern New South Wales (Fig. 1). It is geologically significant for several reasons: (i) it straddles the boundary between two of the major blocks, the Coffs Harbour Block and the Nambucca Slate Belt, (ii) rocks of the Nambucca Slate Belt here are less highly metamorphosed and less deformed than further south, they form a recognizable stratigraphic sequence, and primary structures are preserved, (iii) the sequence includes a thick unit of basaltic rocks, rocks only sparsely developed elsewhere in the Slate Belt, and (iv) structural and metamorphic relationships between stratified rocks and several small granitic bodies can be established.

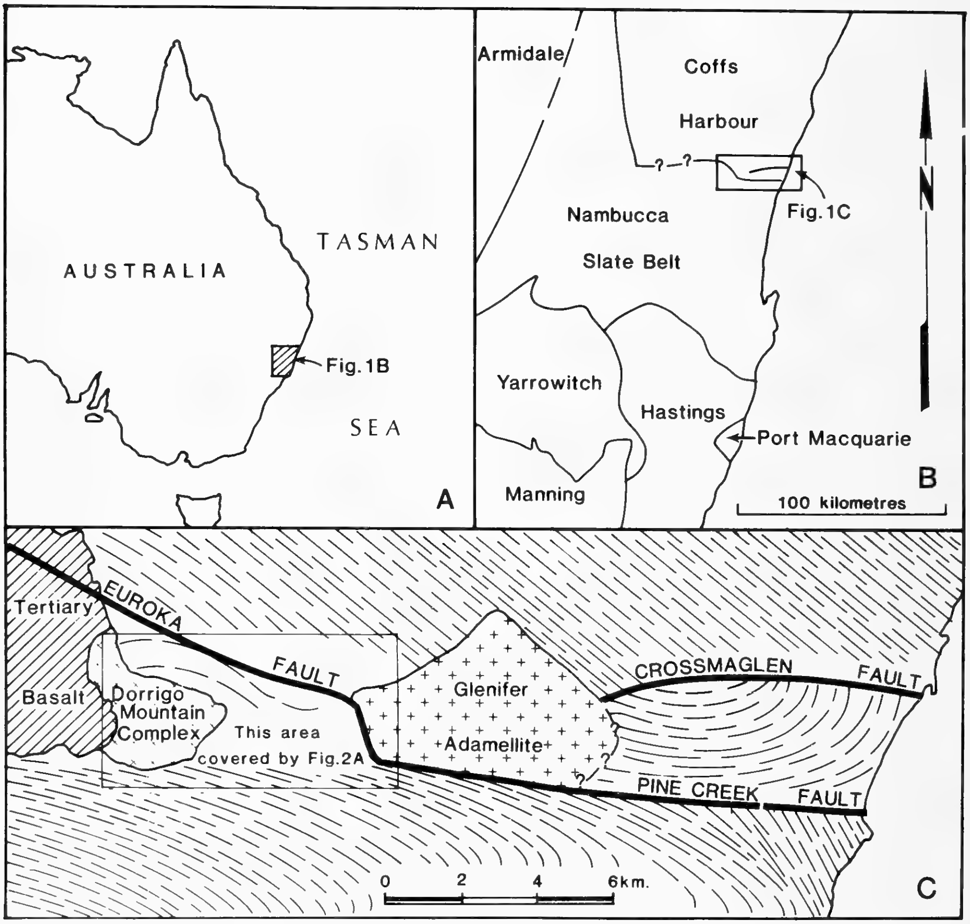


Fig. 1. Location and geological setting of Thora District. **A**. General location. **B**. Major structural blocks of the southeastern New England Fold Belt. **C**. Eastern part of Bellingen Fault System. Dashed lines indicate strike of slaty cleavage.

The Thora district is rugged, mostly heavily timbered and traversed by few roads or tracks. Impenetrable masses of lantana encroach on once-cleared areas and choke many of the smaller creeks. Most field work was carried out along the major drainage systems and the more openly forested ridges. Although outcrops on the latter are quite common most are loose and rubbly. Good outcrop occurs in the large creeks, notably the Little North Arm and Buffers Creek and their tributaries.

Grid references (g.r.) specified in this paper refer to the four 1:31 680 topographic sheets Bellingen (94537-II-S), Brooklana (9437-II-N), Darkwood (9437-III-S), and Dorrigo (9437-III-N), published by the New South Wales Department of Lands. A representative collection of rocks has been placed in the collection of the Department of Geology and Geophysics, University of Sydney (Catalogue numbers 57673-57676, 59637-59772).

PREVIOUS INVESTIGATIONS

Voisey (1934) distinguished between rocks south of the Bellingen River which he described as phyllite and slate and grouped in his Nambucca Series, and those further north, 'chert, quartzite and indurated slate . . . interstratified with phyllite' (p.335), which he termed the Coffs Harbour Series. He noted a major strike difference between the two units, and favoured an unconformable relationship, with the supposedly Silurian Coffs Harbour rocks overlying the Nambucca rocks of assumed Ordovician age. The same two divisions were recognized by Kenny (1936), who referred to the rocks in the north as the Fitzroy Series and placed the boundary between the units at Bonville Creek about 8 km north of the Bellingen River. Further work led Voisey (1959) to revise his earlier assumption in favour of a fault contact between the units, supposedly a left-lateral transcurrent structure he variously referred to as the Bellinger or Bellenger Fault.

The two-fold division was retained by Leitch *et al.* (1971) who showed that each could be subdivided, and termed their areas of outcrop the Coffs Harbour Block and the Nambucca Slate Belt. They considered all the rocks to be of Late Palaeozoic age. A faulted boundary was maintained in the position indicated by Kenny where a fracture termed the Crossmaglen Fault was mapped. A parallel fault further south along the line of Voisey's Bellinger Fault was also recognized but this was shown as lying entirely within the Nambucca rocks.

Korsch (1978a, 1978b, 1978c) described the stratigraphic subdivision, metamorphism and sedimentary petrography of the southern part of the Coffs Harbour Block, whereas Leitch (1976, 1978) has given brief accounts of the regional metamorphism and structural development of the Nambucca Slate Belt.

ROCK UNITS

MOOMBIL SILTSTONE

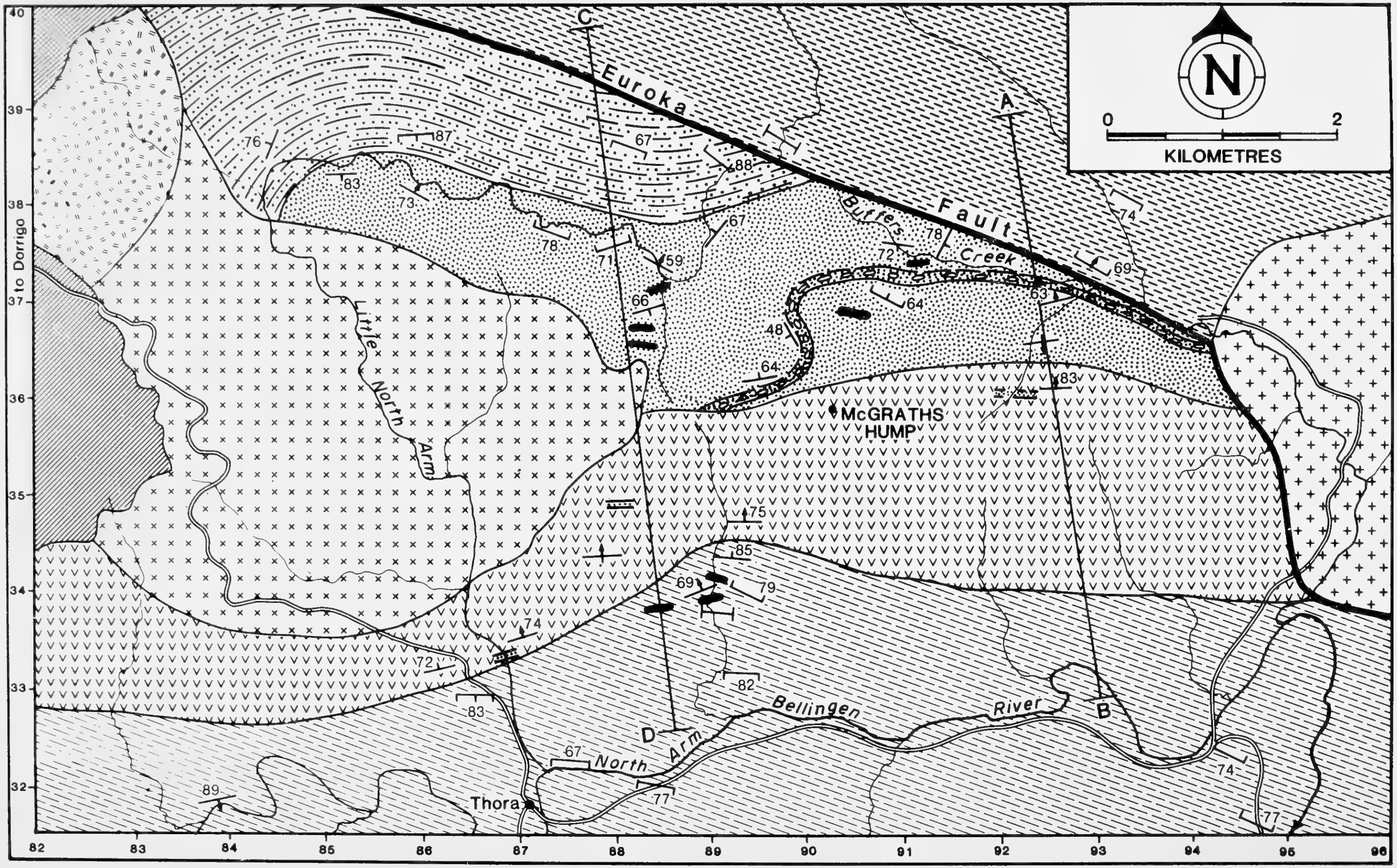
Nomenclature

Rocks north of the Euroka Fault (Fig. 2) comprise massive black siltstone and rare sandstone and granule conglomerate, imperfectly cleaved and largely lacking in sedimentary structures. They are typical of a widespread fine-grained unit that occupies the southwestern corner of the Coffs Harbour Block and have previously been grouped in the Moombil Beds (Leitch *et al.*, 1971; Korsch, 1978a). We suggest the name Moombil Siltstone is more appropriate for the unit, which derives its distinctive character both from its sedimentary parentage and the effects of biotite-grade static thermal metamorphism (Leitch, 1974; Korsch, 1978b). The name derives from Mt Moombil, 9 km northeast of McGraths Hump, where typical exposures of rocks occur.

Content

In the Thora district siltstone, by far the most abundant rock type, is characteristically fine-grained, dark, splintery and siliceous. Bedding is uncommon and other sedimentary structures have not been observed. A crude cleavage is widely developed. Thin section examination shows these rocks comprise a fine aggregate of anastomosing mica films, chlorite flakes and quartz, through which are scattered subangular quartz and plagioclase grains.

Sandstone forms massive grey beds 0.1 to 1.5 m thick some of which are graded. Angular intraformational siltstone clasts are locally prominent. Korsch (1978c) described the sedimentary petrography of these rocks and our observations confirm his main conclusions. The sandstones are lithofeldspathic rocks in which felsic volcanic fragments, some porphyritic in plagioclase, are most abundant (40%). Plagioclase and quartz are the most common detrital minerals each contributing about 15%. Quartz is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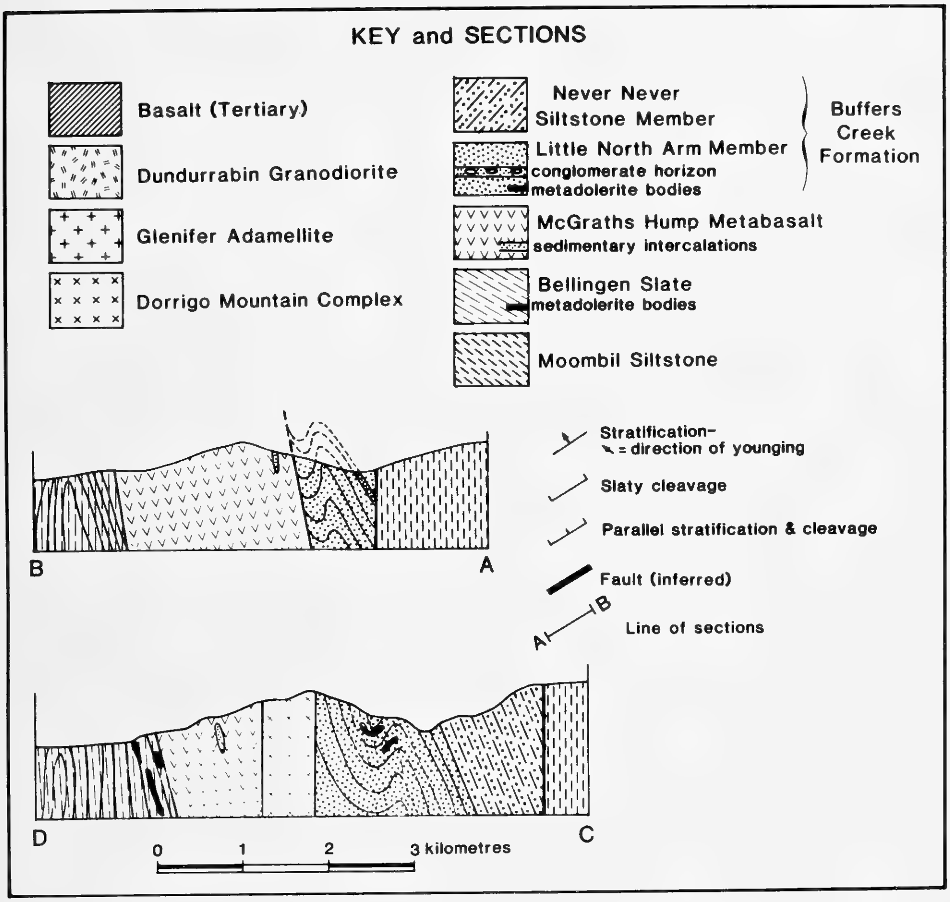

Fig. 2. Geological map and cross-sections, Thora district.

mostly of clear, monocrystalline, volcanic type. Both orthoclase and microcline are present, but together form no more than 1% of the rocks, and granitic fragments (quartz-perthite aggregates) and microlithic rock fragments are rare. The matrix, and possibly some detrital lithic grains, have been recrystallized to a fine quartz-mica-chlorite-albite aggregate.

Thickness and Age

Insufficient is known about the structure of the Moombil Siltstone to allow an accurate estimate of its thickness. Thus, although the unit outcrops over a wide area and consistently faces north, suggesting a considerable thickness (Korsch, 1978a), structural repetition cannot be ruled out (Fergusson, 1982). No fossils have been found in the Moombil Siltstone or in the adjacent Brooklana Formation (Korsch, 1978a). Detrital components are similar to those in Late Carboniferous rocks from elsewhere in the New England Fold Belt and this age appears most likely.

BELLINGEN SLATE

Definition

The name Bellingen Slate is applied to a sequence of cleaved siltstone containing interstratified micaceous sandstone and granule and pebble conglomerate that outcrops in the northern part of the Nambucca Slate Belt. The name is derived from the North Arm of the Bellingen River. Outcrops along the river between g.r. 713287 and 724297, some 14 km west of Thora, constitute the type section (Leitch, *in preparation*). Strata exposed in the south of the Thora district are lithologically indistinguishable from those in the type section and are included in this unit.

Distribution

Bellingen Slate outcrops over the southern quarter of the Thora district. In the north it is in contact with the McGraths Hump Metabasalt except in the extreme east where it abuts the Glenifer Adamellite.

Content

Soft, dark grey- to black-coloured slate, derived from the very low grade metamorphism of micaceous carbonaceous siltstone, is the most common and characteristic rock type in the Bellingen Slate. Beds range in thickness from 0.1 to 5 m with those thicker than about a metre showing internal stratification marked by changes in colour and grainsize. Reconstitution of these rocks is incomplete. Sand-sized grains of quartz and plagioclase are scattered through a groundmass of aligned turbid mica shreds, dark carbonaceous films, chlorite aggregates and quartz-albite lenses, the last probably remnants of silicic volcanic grains. Detrital mica flakes are widespread; many are squashed and kinked and they are distinguished from metamorphic mica on these characters and their relatively coarse grain size.

Pale grey and pale green siltstones interbedded with the slate are minor lithologies. They are harder than the latter, contain a greater proportion of groundmass quartz and are less well cleaved. Beds, some of which are laminated, rarely exceed 0.3 m in thickness.

Pale grey-coloured sandstone beds, many of which are graded, some from a basal division of granule conglomerate, occur throughout the Bellingen Slate. Beds range in thickness from 0.1 to about 2 m. In their upper parts some pass simply into siltstone whereas in others the graded layer is succeeded by rocks showing parallel and convolute layering and cross lamination (Bouma B and C divisions). The bases of sandstone beds are planar or are modified by loading.

Compositionally the sandstones are lithofeldspathic types in which grains of silicic volcanic rocks, siltstone of intraformational origin, clear volcanic quartz and plagioclase (now mostly altered to albite) are ubiquitous. Much of the lithic detritus has been affected by the low grade metamorphism of the rocks; grain boundaries are difficult to pick with the quartzo-feldspathic material of clastic fragments merging with similar material produced by recrystallization of the matrix. Irregular chlorite aggregates, probably highly altered mafic-intermediate volcanic clasts, are scattered through the rocks. Accessory detrital minerals are zircon, muscovite and biotite whereas the most common metamorphic phases are albite, quartz, white mica and chlorite. Calcite and prehnite are locally important secondary minerals.

Many of the sedimentary rocks of the Bellingen Slate are bioturbated and locally infaunal activity has destroyed sedimentary structures and modified rock textures.

The only igneous rocks in the Bellingen Slate are altered dolerite sills concentrated northeast of Thora, close to the southern contact of the McGraths Hump Metabasalt.

They range up to several tens of metres in thickness and contain screens of slaty rock. Some are incipiently cleaved.

Thickness and Age

Reversals in younging direction indicate that the Bellingen Slate is affected by macroscopic folds. Although exposure of the unit in the Thora district is too poor to allow axial traces to be accurately located, unrepeated sequences up to 1000 m thick are indicated from scattered younging determinations and persistent steep dips. Minimum thicknesses of 1300 m are indicated in the region around the type section where the structures can be better established.

No body fossils have been discovered in the Bellingen Slate. The unit is similar to thick micaceous siltstone sequences that were deposited widely over the southern part of the New England Fold Belt in the Early Permian. This age is consistent with metamorphism in the early Late Permian (c. 255 Ma; Leitch and McDougall, 1979) and with the inferred relationship of the formation to fossiliferous Early Permian rocks in the southern part of the Nambucca Slate Belt (Leitch, 1972).

MCGRATHS HUMP METABASALT

Definition

The McGraths Hump Metabasalt comprises altered basaltic pillow lavas and massive flows, dolerite intrusions and rare intercalations of epiclastic sedimentary rocks, that outcrop to the north of the North Arm of the Bellingen River (Fig. 2). McGraths Hump, the prominent ridge between Buffers Creek and the North Arm, is the source of the name.

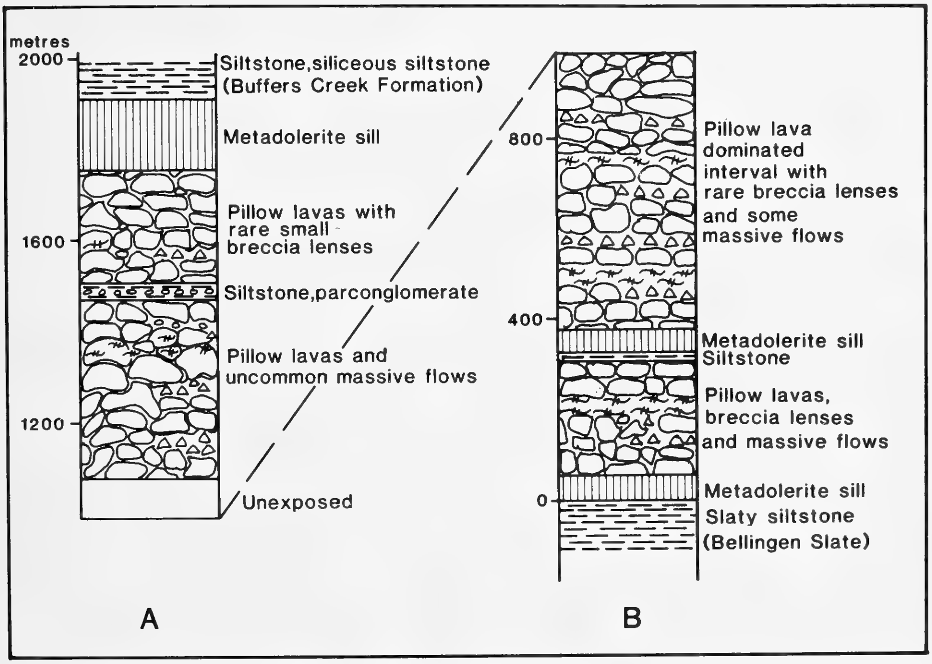

Fig. 3. Composite type section, McGraths Hump Metabasalt. Column **A** lies along a tributary of Buffers Creek (g.r. 922365-919357) whereas **B** is from the Little North Arm of the Bellingen River (g.r. 868332-865343).

A composite type section is designated (Fig. 3). That for the upper part of the formation lies along a tributary of Buffers Creek south from g.r. 922365 to the McGraths Hump ridge at g.r. 919357 whereas that for the lower part of the formation follows the Little North Arm north from g.r. 868332 to g.r. 865343. It is not possible to link these two sections by mapping but general structural trends suggest the top of the Little North Arm section lies less than 100 m stratigraphically below the lowest stratigraphic level reached in the Buffers Creek tributary section.

Distribution and Contacts

The McGraths Hump Metabasalt is faulted against the Glenifer Adamellite in the east and pinches out 3 km west of the area shown in Fig. 2, in steep, heavily-forested country north of Upper Thora. To the south the Metabasalt is considered to rest conformably on the Bellingen Slate. No exposure of the contact between the units has been located but the attitude of stratification in both is similar, both young north, the mapped position of the contact accords with a conformable relationship, and slaty sandstone intercalated in the lower part of the Metabasalt on the Little North Arm (g.r. 867335) is identical with sandstone in the Bellingen Slate. Altered dolerite bodies in the Bellingen Slate around g.r. 889342 are petrographically indistinguishable from those in the McGraths Hump Metabasalt and are possible representatives of the feeder system for this unit.

The nature of the boundary between the McGraths Hump Metabasalt and the Buffers Creek Formation to its north is incompletely established. The contact is exposed at the top of the type section (g.r. 922365) where a dolerite body is chilled against siltstone of the Buffers Creek Formation. Younging directions in the sedimentary rocks of the Buffers Creek Formation could not be determined here, but 250 m to the north graded bedding indicates south younging, whereas pillow structures in the McGraths Hump Metabasalt south of the dolerite show the latter unit youngs north. Either a small syncline occurs just north of the dolerite body or the contact is discordant. The latter interpretation is supported by the distribution of a conglomerate horizon within the Buffers Creek Formation which runs into the contact in the west (Fig. 2). On the other hand, the dolerite is geochemically allied with the other mafic rocks of McGraths Hump and the discordance must have formed before the end of mafic magmatic activity. One possibility is that deposition of the Buffers Creek Formation succeeded extrusion of McGraths Hump lavas with little or no break. Emplacement of a dolerite sill at the contact of the two units took place under a relatively thin cover of little-consolidated Buffers Creek strata and caused some disruption of these rocks, producing local overturning adjacent to the upper surface of the sill. Similar dolerite bodies occurring higher in the Buffers Creek Formation attest to the continuation of intrusive activity well after the commencement of deposition of this unit.

The contact between the McGraths Hump Metabasalt and the Dorrigo Mountain Complex is intrusive. A large mass of metabasalt that outcrops around g.r. 848338, surrounded by Dorrigo Mountain Complex rocks, is interpreted to be a large xenolith derived from the McGraths Hump Metabasalt that forms the wall-rocks nearby.

Lack of contact metamorphism and the presence of crushed granodiorite close to the contact indicate that the McGraths Hump Metabasalt is faulted against the Glenifer Granodiorite.

Content

Epiclastic metasedimentary rocks comprise less than 2% of the McGraths Hump Metabasalt, breccias less than 10%, dolerite intrusions no more than 15%, and massive and pillow basalt flows, with the latter of much greater abundance, the remainder.

Massive and pillowed flows. Basaltic rocks, characteristically fine-grained and of dark-green colour, form both pillow lavas and massive flows. Vesicles, always less than 4 mm diameter, are uncommon and larger irregular primary cavities, now filled by secondary minerals, are rare. The rocks are tectonically fractured but there is little sign of earlier cooling joints. Pillow structures are most readily identified in creek and cliff sections, but even where outcrops are too jointed and lichen-covered to allow recognition of individual sacs the presence of dark chilled selvedges suggests their presence. Pillows mostly have bean- or ellipse-shaped cross-sections, some with tear-drop shaped basal protruberances. The maximum dimension of pillows ranges from about 0.5 to 2.0 m; selvedges, now completely devitrified, are between 2 and 5 cm thick. Small pillows of near circular section occupy spaces between the larger sacs yielding a closely packed stack. Small inter-pillow interstices are filled by basaltic fragments and abundant secondary minerals.

Massive basaltic flows 1 to 5 m thick occur intercalated with the pillow lavas. Some show an incipiently brecciated base and a number have pillowed upper parts.

Breccias. Fragmental basaltic rocks are uncommon. They consist of angular clasts of devitrified selvedge and microcrystalline basalt cemented by a fine-grained aggregate of secondary minerals, mostly epidote, prehnite and albite. Blocks range up to about 10 cm in longest dimension and show no signs of rounding or sorting. Breccia mainly occurs in lenses less than 1 m in maximum thickness and in small inter-pillow spaces.

Metadolerite bodies. Most metadolerite bodies outcrop as scattered rounded boulders that are difficult to trace along strike and which do not show contacts with surrounding rocks. An intrusive habit and sill form are indicated in a few creek exposures where chilled margins up to 10 cm wide are present and contacts are approximately parallel to stratification as indicated by pillow shape. At least in the type section metadolerite bodies occur at the top and bottom of the McGraths Hump Metabasalt, with that at the base about 50 m thick and that at the top some 150 m thick and the thickest body recognized. Geochemical data (Asthana, 1984) indicate the metadolerite bodies are comagmatic with the flows and support the suggestion of Scheibner and Pearce (1978) that the rocks have ocean floor affinities.

Epiclastic sedimentary rocks. Sequences of epiclastic sedimentary rocks up to 30 m thick occur intercalated with the extrusive rocks. The most extensive consists of interbedded siltstone, siliceous siltstone and paraconglomerate found about 400 m below the top of the type section. These rocks are identical with those of the Buffers Creek Formation to the north. The siltstone comprises angular sand-sized grains of quartz and plagioclase scattered through a very fine-grained aggregate of turbid, low crystallinity mica, quartz, albite and chlorite. Siliceous siltstone is petrographically similar but with more quartz and less mica in the groundmass. Conglomerate contains abundant silicic volcanic pebbles, some porphyritic in plagioclase, some with a prominent vitroclastic texture, and others showing spherulitic recrystallization structures. Also present are clasts of sandstone, siltstone and basalt, the latter of intergranular texture in which fine plagioclase laths form a framework between which augite granules and small chlorite pools are preserved. The conglomerate matrix is a silty sand; grains of plagioclase, quartz and silicic lithic volcanics are the major components but it also contains rare detrital epidote, brown hornblende, and chlorite aggregates, all set in a turbid micaceous groundmass.

Siltstone in a unit 10 m thick found 300 m from the base of the formation (Fig. 3) is identical with that of the Bellingen Slate. Scattered angular grains of plagioclase and quartz, flattened silicic volcanic grains, and flakes of detrital biotite and muscovite, are set in a matrix composed mostly of aligned mica shreds which impart a cleavage to the rock.

Sandstone in irregular vein-like structures up to 3 cm wide occurs in massive lavas on the Dorrigo Mountain road at g.r. 864331. The sandstone consists of angular grains of plagioclase and silicic volcanic rock set a dark irresolvable matrix. The form of the bodies suggests they are small dykes emplaced in early joints in the metabasalt, their injection probably caused by the loading of a mobile sandstone bed by the basalt flow.

Thickness and Age

The composite type section, a near-complete section through the thickest part of the McGraths Hump Metabasalt, totals approximately 1900 m. To the west the top of the unit has been removed by emplacement of the Dorrigo Mountain Complex, and further west it progressively pinches out at the top of the Bellingen Slate. As both the Bellingen Slate and the Buffers Creek Formation are of Early Permian age the McGraths Hump Metabasalt which is intercalated between these two units is also accorded an Early Permian age.

BUFFERS CREEK FORMATION

Definition and Intraformational Stratigraphy

The Buffers Creek Formation is introduced here for the sequence of interbedded siltstone, sandstone, paraconglomerate and silicic tuff, together with associated dolerite bodies and possibly a lens of pillow basalt, that outcrops along the northern margin of the Nambucca Slate Belt in the Thora district. Buffers Creek, which cuts through the eastern part of the unit, is the source of the name.

The formation has been divided into two members. The stratigraphically lower is termed the Little North Arm Member, from the tributary of the Bellingen River of the same name. This member comprises interbedded grey, green and black siltstone and sandstone, conglomerate and silicic tuff. A prominent paraconglomerate horizon has been mapped in the lower part of the member and several outcrops of mafic igneous rocks occur in the unit. The lower part of the Little North Arm Member is typically exposed along Buffers Creek from g.r. 930370 northwest to g.r. 928372 and then southeast up a tributary stream to g.r. 922364, whereas the upper part of the member is typically exposed along the Little North Arm from g.r. 860383 to g.r. 872381. A thickness of about 800 m is indicated.

The Little North Arm Member passes gradationally up into a lithologically monotonous unit to which is applied the name Never Never Siltstone Member after the Never Never State Forest. This consists mostly of massive grey and green siltstone with widespread thin silicic tuff beds and only rare coarse epiclastic rocks. It is typically exposed along the Little North Arm of the Bellingen River and a prominent tributary between g.r. 850384 and g.r. 845387. The top of the member is cut off by the Euroka Fault and calculations based on numerous bedding orientations indicate a minimum thickness of about 1400 m.

Distribution and Contacts

The formation outcrops in an irregular, eastward tapering wedge from the Dorrigo Plateau 4 km southeast of Dorrigo to near the confluence of Buffers and Never Never Creeks. To the north it is faulted against the Moombil Formation along the Euroka

Fault, in the west and southwest it is cut off by the intrusive rocks of the Dorrigo Mountain Complex and to the east it is faulted against the Glenifer Granodiorite. In the south the Buffers Creek Formation adjoins the McGraths Hump Metabasalt.

Content

Siltstone, the major constituent of the Buffers Creek Formation, ranges from hard, conchoidally fracturing, pale grey and green siliceous varieties to softer, well-cleaved, dark grey to black types. The lighter-coloured rocks contain scattered small detrital relics of quartz and plagioclase (now albite) set in a groundmass composed of strongly aligned anastomosing shreds of white mica and smaller amounts of chlorite, albite and quartz. Albite and quartz form numerous narrow veins in these rocks and occupy small segregations elongate parallel to the mica fabric. Small grains and grain aggregates of pyrite and calcite occur in some samples.

The dark siltstones are less clearly recrystallized with much of the rocks consisting of murky, low-crystallinity mica interwoven with dark carbonaceous shreds and irregular chlorite patches. Some of these siltstones are uniformly fine-grained with tiny angular quartz and albite grains scattered through the phyllosilicate groundmass, whereas others contain scattered sand-sized grains of quartz, albitized plagioclase, and vitric silicic volcanic rock.

Siltstone beds range up to several metres in thickness although most thicker than a metre are internally thin-bedded or laminated. There are extensive siltstone-dominated sections in the formation wherein uncommon sandstone and tuff beds provide the only variation. Bioturbation of the siltstones is widespread. Some beds are crudely graded and irregular soft-sediment disruption has affected a few units.

Sandstone, grey in colour and mostly of fine to medium grainsize, is widespread in the Little North Arm Member. Individual beds range from a few centimetres up to at least 5 m in thickness. Graded beds are common as are beds with a prominent parallel lamination. Medium-sized cross-sets are discontinuously developed in the upper parts of some parallel laminated beds and small-scale cross-lamination (Bouma C division) is widespread in many thinner sandstones. Irregular syn-sedimentary deformation structures are widespread in the upper part of the Little North Arm Member. The bases of sandstone beds are sharp and usually planar or slightly loaded; scours and erosional sole markings have not been observed.

Petrographically the sandstones are feldspathic and lithofeldspathic varieties. Detrital quartz abundance ranges between about 10 and 20%. Most of the feldspar is albitized plagioclase but grains of orthoclase are also present. Lithic grains are mostly volcanic; vitric silicic types are most abundant and are accompanied by small amounts of microlitic and highly altered mafic volcanic detritus. A few granitic fragments, mainly coarse quartz-orthoclase intergrowths, occur in the sandstones, and flattened dark siltstone grains of intraformational origin are widespread. Detrital quartz is present in the form of clear, monocrystalline grains of volcanic provenance. Biotite flakes are a common minor detrital constituent; epidote, muscovite and zircon are present in small amounts.

Low grade metamorphism of these rocks is reflected in their finely granular quartz-albite-chlorite matrix that is flecked by small white mica flakes, and in the presence of replacement patches and veins of prehnite in several of the sandstones.

Hard, pale grey beds 0.02-0.3 m thick, interbedded with siltstone resemble chert but have a somewhat more granular appearance. Microscope and X-ray diffraction studies show they consist almost entirely of approximately equal amounts of quartz and albite that form an interlocking aggregate of fine anhedral grains. These rocks, described in detail by Leitch (1981), are considered to be recrystallized silicic ash-fall tuffs. Only rarely are traces of shard structure preserved but angular plagioclase crystals are widespread. Some of the beds are structureless, some graded and a few show cross-lamination.

Rudaceous rocks, with one exception, are restricted to the Little North Arm Member. Siltstone breccias, consisting of angular intraformational siltstone fragments up to 0.2 m long, set in a sandstone matrix, occur throughout this unit. Some form discrete beds ranging up to 2 m in thickness whereas others are the basal parts of beds that grade rapidly up into sandstone. Cobbles and pebbles of extrabasinal origin, together with abundant intraformational clasts, occur in a mappable conglomerate horizon several tens of metres thick in and south of Buffers Creek (Fig. 2). Intraformational debris comprises angular slabs, of massive and laminated siltstone and interbedded sandstone and siltstone up to 0.4 m in largest dimension. Extrabasinal material consists of clasts of silicic and intermediate volcanic rock, granodiorite, chert and vein quartz. The matrix is a sandstone of similar composition to the sandstone within the Buffers Creek Formation but much less well sorted and with a high silt content. Most of the conglomerate is of open framework character, with an average clast to matrix ratio of about 1:4. Conglomerate is lacking in internal structures; its lower contact is irregular and probably erosional but no upper contacts have been observed.

The only conglomeratic rock discovered in the Never Never Member is a thin ($<$0.1m) unit of paraconglomerate interbedded with siltstones near Cedar Falls at g.r. 890385. This rock consists of subangular pebbles of metabasalt set in a pale green, cleaved, siltstone matrix. The metabasalt pebbles show quench textures similar to those in some McGraths Hump Metabasalt rocks; subvariolitic plagioclase aggregates and elongate quenched augite prisms are set in a devitrified (chloritic) matrix.

No extrusive igneous rocks have been discovered in the Buffers Creek Formation but their presence is suspected. Between g.r. 884374 and 886376 blocks of basaltic pillow lava occur on the steep heavily timbered slope above Little North Arm Creek. The blocks, which are up to 10 m across, appear to be too large to have come from the small outcrops of McGraths Hump Metabasalt that just encroach onto the upper part of the slope, and a lens of metabasalt within the Buffers Creek Formation seems a more likely source. Although a search of the slope failed to reveal such a lens, several metadolerite masses were located, notably at g.r. 884373 where a 4 m wide dyke is emplaced in the formation, and at g.r. 882362 where several intrusions cut the unit. Metadolerite bodies were also noted in the Buffers Creek Formation further east (g.r. 903368 and g.r. 910373).

Age

Prismatic shell material in paraconglomerate of the Little North Arm Member at g.r. 893361 is believed to be fragments of the bivalve *Atomodesma* and hence to indicate a Permian age for the formation. Metamorphism of the rocks of the Nambucca Slate Belt in the early Late Permian (c. 255 Ma; Leitch and McDougall, 1979) provides an upper age limit for the unit.

DORRIGO MOUNTAIN COMPLEX

Nomenclature

The name Dorrigo Mountain Complex, first used by Leitch *et al.* (1971), is applied to a composite pluton of silicic and intermediate rocks that outcrops over an area of about 16 km^2 in and adjacent to the Dorrigo National Park. Typical exposures occur in extensive cuttings where the Dorrigo-Bellingen road ascends Dorrigo Mountain, the source of the name.

Content and Petrography

All outcrops of this pluton are sheared and many show brecciation, but in spite of much secondary alteration two distinct rock types are readily identified: an earlier microdiorite and a later microadamellite. The dioritic component has been extensively disrupted by intrusion of the microadamellite and in some exposures occurs as angular blocks ranging from 50 mm to several metres in longest dimension floating in the more silicic material. Elsewhere approximately planar dykes of microadamellite up to a metre wide transgress massive outcrops of microdiorite and in other outcrops the adamellite forms irregular anastomosing veins less than 0.3 m thick penetrating the dioritic rocks. Approximately equal amounts of the two rock types are present in the body.

The rocks show no obvious foliation and aplitic and pegmatitic veins are absent. No xenolithic material was found in the microdiorite, and blocks of the latter constitute the only xenoliths encountered in the microadamellite.

The microdiorite is an even-grained rock of hypidiomorphic-granular texture with an average grain size that rarely exceeds 1 mm. Plagioclase is the dominant phase; it is frequently extensively altered and partially replaced by albite. Magmatic relics are of andesine composition and show slight normal zoning. Potash feldspar is a minor constituent which occurs in small anhedral grains some of which are perthitic; cross-hatched twinning is absent. Small amounts of quartz are present, typically in strained, anhedral patches moulded around earlier phases. The major mafic mineral is colourless calcic clinopyroxene. No orthopyroxene was identified but chlorite aggregates which occur in all rocks have possibly replaced this phase. Green hornblende forms euhedral to subhedral crystals, some with a clinopyroxene core. Accessory minerals are apatite, an opaque oxide phase and zircon.

The microadamellite is of comparable grain-size to the microdiorite. It consists of approximately equal amounts of plagioclase, potash feldspar and quartz. Plagioclase is frequently altered; relics are very slightly zoned and have compositions close to the andesine-oligoclase boundary. Quartz, which is usually strained, forms anhedral masses which reach 2 mm in diameter. Subhedral potash feldspar shows microcline twinning in some grains but elsewhere in the same section only simple twins were observed. Chlorite has pseudomorphically replaced biotite. Accessory phases are hornblende, similar to that in the microdiorite, apatite, an opaque mineral, zircon and rarely allanite. Secondary minerals found in the complex are quartz, albite, chlorite, epidote, prehnite, sphene, calcite and pyrite.

Age

The pluton intruded the Buffers Creek Formation and the McGraths Hump Metabasalt prior to the end of deformation and regional metamorphism in the Nambucca Slate Belt. A late Early or early Late Permian age is thus indicated.

GLENIFER ADAMELLITE

Nomenclature

The name Glenifer Adamellite is applied to a granitic pluton that outcrops over an area of about 50 km^2 a few kilometres north of Bellingen. The body is typically exposed along the Never Never River between g.r. 002400 and g.r. 997385. Only its western part occurs in the Thora district (Fig. 2). Leitch *et al.* (1971) considered the pluton to be a composite body and termed its northern two-thirds the Glenifer Adamellite and the remainder the Valery Granodiorite. However modal analyses (Leitch, 1972) although showing that the rocks in the south have a higher plagioclase/microcline ratio than those further north, suggest a progressive rather than abrupt change in this ratio. No distinct contact between two discrete bodies can be recognized and we treat the pluton as a single mass.

Content and Petrography

The pluton is composed of slightly porphyritic medium to coarse-grained adamellite. Small xenoliths composed of a granoblastic aggregate of quartz, plagioclase and biotite are widespread. Aplite veins are rare and no pegmatitic material was noted. The rocks lack foliation but are cut by diversely oriented shears up to 20 mm wide along which severe cataclasis has taken place.

Typical adamellite consists of microcline phenocrysts set in a hypidiomorphic-granular aggregate of stout plagioclase laths, randomly oriented biotite flakes and rounded anhedra of quartz. Most microcline occurs in irregularly-bounded crystals up to 14 mm × 10 mm that poikilitically enclose grains of all other phases. Cross-hatched twinning is common in this mineral, although developed in widely differing degrees of perfection, and it is typically perthitic with exsolved albite occupying anastomosing microveins. Plagioclase laths average between 2 and 3 mm in length and are generally subhedral. They show only minor normal zoning and most are of oligoclase composition. Plagioclase enclosed within microcline is frequently embayed and shows irregular margins. Myrmekite occurs at boundaries between plagioclase and microcline in some rocks, commonly forming lobate projections into the alkali feldspar. Quartz is always anhedral and occurs in irregular masses up to 5 mm diameter. Subhedral plates of red-brown biotite up to 2.5 mm across tend to occur in clusters but show no preferred orientation. Opaque minerals, muscovite, apatite and zircon are accessory phases. Secondary alteration of the rocks is widespread. The most common products are quartz, albite and chlorite but epidote, prehnite, sphene and rutile have also been identified.

Although on an outcrop scale deformation appears to have been concentrated along discrete shears evidence of strain occurs on a microscopic scale in all rocks. Biotite flakes are bent and kinked, twin lamellae in plagioclase are distorted and, in the more markedly strained rocks, feldspar crystals have been fractured and displaced. Quartz has undulatory extinction and deformation bands are common, although in some rocks polygonization has produced strain-free aggregates of small crystals.

Age

The petrography of the Glenifer Adamellite indicates that it is a member of the Hillgrove Suite of the New England Batholith, a group of plutons typified by the presence of microcline rather than orthoclase, a quartz-rich character, the absence of hornblende and at least incipient cataclasis.

Flood and Shaw (1977) have shown that Rb-Sr whole rock isotopic data are consistent with an age of 289 ± 25 Ma for this suite (Shaw and Flood, 1981). An age within this range does not conflict with the geological relationships of the Glenifer Adamellite the only major constraints on which are that its emplacement post-dated deposition of the Moombil Siltstone and pre-dated the end of the faulting along the northern margin of the Nambucca Slate Belt. Hensel *et al.* (1982) reported a substantially older age for the Hillgrove Suite (312 ± 10 Ma) but the data on which this is based remain unpublished. This age, which seems to conflict with the emplacement of members of this Suite into strata of Early Permian age (Binns, 1966), may be that of an event other than the final intrusion of the bodies (Leitch, 1978).

DUNDURRABIN GRANODIORITE

Coarse, slightly strained biotite granodiorite has intruded the Dorrigo Mountain Complex and the Buffers Creek Formation in the northwest corner of the Thora district.

This mass, and similar rocks a little north of Dorrigo (Leitch *et al.*, 1971), are petrographically similar to the Dundurrabin Granodiorite and may be exposures of the eastern continuation of this body most of which is hidden by basalt. The Dundurrabin Granodiorite, a Hillgrove Suite body (Binns *et al.*, 1967) is probably of similar age to the Glenifer Adamellite although the possibility that members of the Suite collectively span a significant time range needs to be considered.

TERTIARY BASALT

Basalt flows and intervening fossil soil horizons and tuffs in the western part of the Thora district are part of the extensive basalt field that mantles much of the dissected plateau area west of Dorrigo. Basalt from Ebor, 30 km west of the occurrences mapped here, has yielded an Early Miocene K/Ar age (21 Ma; McDougall and Wilkinson, 1967).

METAMORPHISM

Mineral assemblages and textures in the Moombil Siltstone provide evidence for an early regional metamorphic episode (M1 of Korsch, 1978b) succeeded by a static thermal event (M2 of Korsch, 1978b). Thus in western outcrops an early slaty cleavage fabric is preserved in the alignment of relic detrital grains and the parallelism of micaceous films. However, the films now consist of tiny randomly oriented biotite flakes which have also grown in inter-film domains. The flakes become coarser in rocks further east but still retain a decussate form; scattered lithic fragments, detrital quartz and feldspar, and silt-sized material here is extensively recrystallized. Adjacent to the northwestern margin of the Glenifer Adamellite these rocks merge with completely recrystallized hornfels in which the typical assemblage is quartz-biotite-muscovite-plagioclase-(cordierite)-(garnet).

Subsequent to the growth of biotite and allied phases many of the Moombil rocks have been strained. Quartz shows strong undulatory extinction, biotite has been partially replaced by chlorite, and veins containing quartz, albite, chlorite, prehnite and calcite transect the rocks. The Glenifer Adamellite has been similarly affected.

All the Palaeozoic rocks south of the Euroka Fault have been affected by regional metamorphism under prehnite-pumpellyite metagreywacke facies conditions (Leitch, 1976). Phyllosilicate crystallization during metamorphism contributed to the development of slaty cleavage in the stratified rocks, but these conditions were also realized when small gashes and veins cross-cutting and disrupting cleavage were filled. The most diverse and characteristic prehnite-pumpellyite metagreywacke facies assemblages occur in the McGraths Hump mafic rocks. Non-specific quartz-albite-chlorite-white mica-(epidote)-(calcite) assemblages are widespread in the Buffers Creek Formation and the Bellingen Slate but both also contain quartz-prehnite bearing assemblages, as do rocks of the Dorrigo Mountain Complex. The more important assemblages in the stratified units are listed in Table 1.

Actinolite is patchily developed in McGraths Hump mafic rocks only within about 100 m of the southern contact of the Dorrigo Mountain Complex. It is believed to be of contact metamorphic origin, and is earlier than abundant quartz-prehnite-epidote-pumpellyite veins that cut these rocks. On the northeastern side of the Dorrigo Mountain Complex, dolerite within the Buffers Creek Formation contains actinolite of similar origin. Associated siltstone has recrystallized to hornfels containing a granoblastic assemblage of quartz, plagioclase, biotite and muscovite, throughout which are scattered small cordierite porphyroblasts. Replacement of cordierite by chlorite and white mica is widespread and the rock is cut by late chlorite-epidote veins.

TABLE 1

Regional metamorphic assemblages in stratified rocks of the Nambucca Slate Belt in the Thora district

Sandstone and siltstone (including slate)
Quartz — albite — prehnite — (calcite)
Quartz — albite — chlorite — prehnite — (calcite)
Quartz — albite — white mica — chlorite — prehnite — (calcite)
Quartz — albite — chlorite — epidote — prehnite — (calcite)
Quartz — albite — calcite
Quartz — albite — chlorite — (calcite)
Quartz — albite — white mica — chlorite — (calcite)
Quartz — albite — white mica — (calcite)

Silicic tuff
Quartz — albite — white mica
Quartz — albite — white mica — chlorite — (calcite)
Quartz — albite — white mica — epidote — (sphene)
Quartz — albite — epidote — prehnite — (calcite)

Metabasic rocks
Quartz — albite — chlorite — pumpellyite — prehnite — calcite
Quartz — albite — chlorite — pumpellyite — prehnite — (white mica)
Quartz — albite — chlorite — epidote — pumpellyite — prehnite — calcite
Quartz — albite — epidote — pumpellyite — prehnite
Quartz — albite — chlorite — epidote — pumpellyite — (white mica)
Albite — chlorite — epidote — calcite — white mica
Quartz — albite — chlorite — prehnite — calcite
Albite — chlorite — epidote — hydrogrossular
Quartz — albite — pumpellyite — prehnite — hydrogrossular — calcite — white mica

North of the Dorrigo Mountain Complex on the Little North Arm around g.r. 845387 siltstone of the Buffers Creek Formation has been converted to quartz-plagioclase-biotite-muscovite hornfels. In contrast to the cordierite-bearing rocks the stumpy mica flakes here show a strong preferred orientation, the result of mimetic crystallization parallel to earlier slaty cleavage. This thermal metamorphism is considered to result from the Dundurrabin Granodiorite, which is hence interpreted as having been emplaced after slaty cleavage formation. The character of the hornfels to the east tentatively suggests that the Dorrigo Mountain Complex was intruded prior to this event. The Dundurrabin hornfels is cut by quartz-prehnite veins and biotite is partially replaced by chlorite.

STRUCTURAL GEOLOGY

The Bellingen Fault System

Our detailed work in the Thora district, together with reconnaissance work to the east, indicates that the development of the boundary between the Coffs Harbour Block and the Nambucca Slate Belt resulted from movement along at least three sections of an east-west trending fault complex (Fig. 1**B**), which we refer to as the Bellingen Fault System (cf. Voisey, 1959). The fault section in the Thora district comprises the *Euroka Fault.* East of McGraths Hump it bends to the southsoutheast and joins the *Pine Creek Fault*, which transects Nambucca Slate Belt rocks near the coast but forms the southern boundary of the Glenifer Adamellite north of Bellingen (cf. Leitch *et al.*, 1971). The *Crossmaglen Fault* marks the southern boundary of the Coffs Harbour Block from the Bonville district (Kenny, 1936) west to the Glenifer Adamellite.

The Euroka and Crossmaglen Faults are marked by changes in rock type, metamorphic grade and, especially in the east, structural trend. The Pine Creek Fault marks a major change in the orientation of cleavage in Nambucca Slate Belt rocks, its presence indicated by large irregular conjugate kink folds, by sheared granite along the edge of the Glenifer Granodiorite, and by the absence of a contact aureole in the adjacent Bellingen Slate.

Complete specification of the movement history of the Euroka Fault must await mapping in the poorly exposed rocks east of the Glenifer Adamellite, as well as the results of investigations now underway west of Dorrigo. Early movements, mainly transcurrent, probably took place along the Euroka Fault — Crossmaglen Fault line. Emplacement of the Glenifer Adamellite disrupted this early structure and later faulting, with a large dip-slip component, was concentrated along the Euroka-Pine Creek line.

Structure North of the Euroka Fault

The only structural markers within the Moombil Siltstone, slaty cleavage and bedding, strike NW-SE and dip about the vertical (Fig. 4**A**). The few facing directions available indicate north-younging. Insufficient information is available to test the suggestion that these rocks have been disrupted by imbricate thrust faulting (Fergusson, 1982); the younging direction is consistent with this model but neither thrust surfaces nor repeated stratigraphic sequences have been recognized.

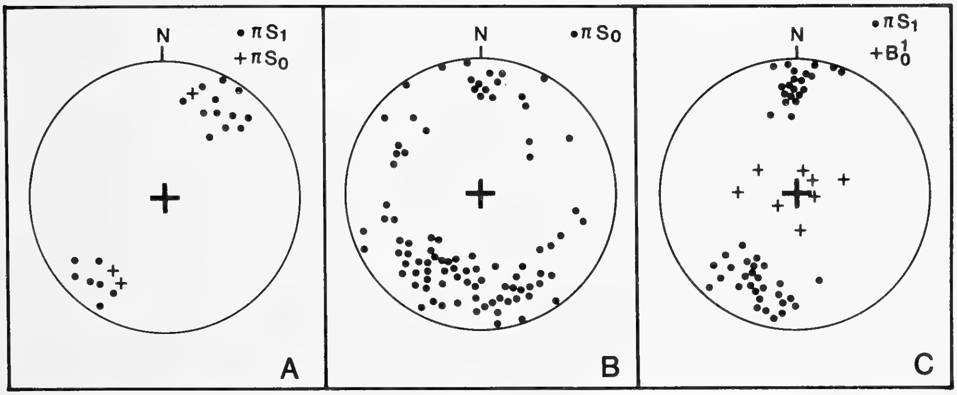

Fig. 4. Equal-angle stereographic projection of structural data. **A**. Poles to bedding (S_0) and slaty cleavage (S_1) from north of the Euroka Fault. **B**. Poles to stratification (S_0) from south of the Euroka Fault. **C**. Poles to slaty cleavage (S_1) and axes of mesoscopic folds with bedding as form surface and S_1 as axial surface structure (B_0^1).

Structure South of the Euroka Fault

Leitch (1978) showed that marginal parts of the Nambucca Slate Belt are characterized by the presence of an early slaty cleavage (S_1) that formed parallel to the axial surface of tight to isoclinal folds in bedding (S_0). Although later crenulation cleavages overprinted S_1 in central parts of the Belt the margins were only subsequently affected by a broad macroscopic warping unattended by the formation of penetrative mesoscopic structures. This general pattern holds in the Thora district. Here S_1, penetratively developed in metasedimentary rocks, is axial plane to tight-isoclinal mesoscopic folds in the Bellingen Slate (e.g. at g.r. 873323) and tight folds in the Buffers Creek Formation (e.g. at g.r. 868382). The folds have rounded profiles with narrow hinge zones and long limbs. The distribution of poles to S_0 (Fig. 4**B**), and the shape of mapped horizons within the Buffers Creek Formation, indicate that a comparable style prevails on a macroscopic scale. Overall S_1 strikes about NNW-SSE and dips steeply; poles to S_0 and the attitude of mesoscopic folds and lineations produced by the intersection of S_0 and S_1 indicate that major folds plunge steeply (Fig. 4**B**,**C**).

GEOLOGICAL HISTORY

Both the Coffs Harbout Block and the Nambucca Slate Belt provide important information on the Late Palaeozoic history of the eastern part of the New England Fold Belt, but their present juxtaposition is a result of movements on the Bellingen Fault System and evidence of their mutual relationships prior to emplacement of the Dundurrabin Granodiorite is lacking. Until detailed palinspastic reconstructions of the Late Palaeozoic arrangement of these structural blocks have been drawn up the depositional and early orogenic history of the rocks on either side of the Euroka Fault must be viewed independently.

Coffs Harbour Block: During Late Carboniferous times the Moombil Siltstone was deposited in an environment which received a steady influx of fine terrigenous sediment but into which sand-sized detritus was only infrequently carried by turbidity currents. An abundance of intermediate-silicic volcanic detritus in the coarser rocks indicates accumulation adjacent to a magmatic arc (Korsch, 1981), and tectonic reconstructions involving the rocks favour deposition in front of the arc (Flood and Fergusson, 1982). The dominance of fine-grained material is consistent with deposition in an outer fore-arc (including slope basin) or trench environment.

Deformation and accompanying regional metamorphism in the Late Carboniferous or Early Permian resulted in the near-vertical dip of the strata, the growth of white mica and other low-grade minerals and the imposition of a penetrative slaty cleavage.

Nambucca Slate Belt: The Nambucca Slate Belt sequence of the Thora district accumulated in a marine basin during the Early Permian. All coarse-grained sediment was carried in by mass flow and the resulting deposits are intercalated with more voluminous siltstones, some of which are probably turbidity current products and others the result of more continuous hemipelagic accumulation. There is no evidence of sediment reworking by bottom currents; thin tuff layers are preserved, and the emplacement of a mass of basalt up to 2000 m thick produced little change in the nature of sedimentation. These characters collectively indicate a deep-water environment.

One major episode of basaltic volcanism is indicated and perhaps a later, minor extrusion. The quiet effusion of mainly pillowed flows was the dominant eruptive process. Breccias probably formed at flow margins. There is no evidence for the contemporaneous sedimentary reworking of the basalts nor of interflow oxidation. Minor breaks in extrusion are indicated by thin intercalations of clastic sediments which also suggest that volcanism did not built up a significant topographic feature. Shallow intrusive activity accompanied volcanism.

Sedimentary detritus for the Slate Belt sequence was derived from a source dominated by silicic volcanic rocks, and the presence of ash-fall tuffs within the sequence indicates contemporaneous explosive activity. Some contribution from plutonic and low-grade metamorphic rocks is suggested by widespread detrital muscovite, orthoclase, microcline and zircon.

The tectonic character and position of the basin in which these rocks accumulated is difficult to discern. Sediment deposition on oceanic crust is implicit in the schemes of Leitch (1974, 1975, 1978), Scheibner (1973, 1976) and Cawood (1982). All favoured accumulation on the oceanic (eastern) side of a major mass of earlier subduction-accreted rocks. Leitch considered they were deposited in essentially the same basin as the earlier rocks whereas Scheibner and Cawood favoured deposition in a distinct marginal basin that opened in the Early Permian. The presence of basalts of mid-ocean ridge character intercalated with sedimentary material argues for accumulation in a basin undergoing active rifting, and the presence of interlayered sills, sedimentary rocks and silicic ash-fall tuffs, the volcanic provenance and the thickness of the sedimentary sequence, and the occurrence of alkalic rocks intercalated with the basin fill elsewhere (Asthana, 1984) are all consistent with a marginal basin origin (Dick *et al.*, 1980; Leitch, 1984). However, a recent reconstruction of the distribution of major crustal blocks in New England at the time of inception of the basin (Cawood and Leitch, 1985), indicates that rifting probably occurred within and to the west of the earlier accreted rocks. This basin was subsequently disrupted by major strike-slip faulting and large scale folding (Cawood, 1982; Flood and Fergusson, 1982; Asthana, 1984).

In spite of the occurrence of mid ocean-ridge type basalts in the Thora district there is no evidence to suggest that any organized pattern of spreading occurred within the basin. Basaltic rocks are rare overall, no truly pelagic rocks have accumulated, and all preserved parts of the basin received coarse epiclastic debris (Leitch, 1972). Although Cawood (1982) drew an analogy between the Nambucca basin and the Andaman Sea we consider that greater parallels lie with the earliest stages of opening of regions like the Gulf of Aden and the Gulf of California. In both these regions organized sea-floor spreading was preceded by normal faulting and diffuse spreading (Cochran, 1981; Moore and Curray, 1982). Moore and Curray recognized several types of extension in their study of the opening of the Gulf of California. The earliest stages involved (i) crustal thinning by normal listric faulting accompanied by variable amounts of dyke injection, and (ii) mixing of thinned fragments of continental crust with newly generated ocean crust. We doubt that rifting in the Nambucca Basin proceeded further than this (see also Scheibner and Pearce, 1978). Perhaps the Salton Trough at the head of the Gulf provides a useful tectonic analogue, with its history of rapid subsidence, thick sedimentation and inferred limited spreading (Crowell, 1981). The presence of both basaltic rocks of sea-floor type and rhyolites in this region (Robinson *et al.*, 1976) finds a parallel in the Nambucca Slate Belt where, in addition to the McGraths Hump Metabasalt silicic volcanic rocks occur locally (Leitch, 1982; McKelvey and Gutsche, 1969). It remains unclear as to whether basin opening was associated with large transcurrent movements as favoured by Cawood (1982) and is the case with the Salton Trough. In both rifting closely followed magmatic arc activity temporally, although in the case of southeastern California rifting occurred within the magmatic arc (Dickinson, 1981), whereas in New England it was concentrated in the fore-arc region.

In the Thora district emplacement of the Dorrigo Mountain Complex pre-dated deformation of the Nambucca Slate Belt rocks and intrusion of the Dundurrabin Granodiorite. Scheibner and Glen (1972) suggested the rocks were closely related to the McGraths Hump Metabasalt but preliminary geochemical studies (Leitch and Willis, *unpublished data*) indicate this to be unlikely. Rather, these rocks are regarded as early representatives of the New England Batholith *(sensu lato)*.

Strong deformation of the Nambucca Slate Belt rocks followed emplacement of the Dorrigo Mountain Complex. Stresss was sufficiently high to produce slaty cleavage in sedimentary rocks but the more competent igneous material mostly remained massive and failed along discrete fractures. Slickensided, chlorite-covered surfaces produced during deformation are widespread in Dorrigo Mountain rocks, but less common in the McGraths Hump Metabasalt. Low grade regional metamorphism accompanied deformation; mineral assemblages indicate an intermediate pressure facies series with temperatures of about 300°C and pressures of approximately 4 Kbar (Leitch, 1976).

Several writers have suggested that deformation of the Nambucca Slate Belt occurred during subduction (Scheibner, 1973, 1976; Olgers *et al.*, 1974; Crook, 1980) but this view gains little support from our observations in the Thora district; we interpret the thick sequence here as a normal stratigraphic one not as a series of imbricate fault slices, the ocean-floor basalts probably do not have a faulted base, and melange zones are absent. The Nambucca basin probably closed by the reversal of movement on the normal faults active during basin development during regional compression. Basin fill was squeezed between the opposed margins. Steep fold plunges suggest lateral as well as vertical flow in reaction to compression and/or the presence of a significant shear component parallel to the basin margins during closure.

K-Ar dating of Nambucca Slate Belt rocks suggests deformation occurred at about 255 Ma (Leitch and McDougall, 1979), but data from the Coffs Harbour Block only constrain early deformation to an interval between the ages of the Moombil Siltstone (Late Carboniferous) and the Dundurrabin Granodiorite.

The Dundurrabin Granodiorite and the Glenifer Adamellite are probably of similar age, emplaced at the younger age limit of the Hillgrove Suite immediately after deformation of the Nambucca Slate Belt. Crustal thickening brought about by this deformation was probably important in triggering the melting of sedimentary material to yield the plutons (cf. Shaw and Flood, 1981). Recognition of Dundurrabin material on either side of the Euroka Fault suggests that the Coffs Harbour Block and the Nambucca Slate Belt were in close proximity by this time, although the faulted southern contact of the Glenifer body indicates later movements on the Bellingen Fault System. The gradational relationship between hornfels adjacent to the Glenifer Adamellite and the regional static metamorphic assemblage in the Coffs Harbour Block suggests that the static metamorphism accompanied emplacement of the Hillgrove Suite plutons. The presence of only a contact aureole around the Dundurrabin pluton in the Nambucca Slate Belt is considered to show that these rocks occupied a higher crustal position at the time of emplacement. Late movement on the Euroka Fault thus involved a large dip-slip component with downthrow to the south. Retrogression of the thermal metamorphic rocks, the formation of mesoscopic shear zones and deformation features including kink bands, undulose extinction and strain twins in the granitic rocks, and replacement of igneous phases by low-grade metamorphic minerals, are all related to late movements on the Bellingen Fault System.

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The Blue Mountains Water Skink, *Sphenomorphus leuraensis* (Lacertilia: Scincidae): A Redescription, with Notes on its Natural History

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(Communicated by H. G. COGGER)

SHEA, G. M., & PETERSON, M. The Blue Mountains Water Skink, *Sphenomorphus leuraensis* (Lacertilia: Scincidae): A redescription, with notes on its natural history. *Proc. Linn. Soc. N.S.W.* 108 (2), (1984) 1985: 141-148.

Sphenomorphus leuraensis (Wells and Wellington, 1984) is redescribed from the eight specimens known. A diagnosis and an analysis of variation, lacking in the type description, are presented. *S. leuraensis* differs from most other water skinks (*S. quoyii* complex) in having no parietal contact posterior to the interparietal scale. Spring collected specimens are reproductively active. *S. leuraensis* is apparently restricted to 'hanging' swamps on the Blue Mountains and Newnes plateaux. Investigation of the conservation status and range of *S. leuraensis* is of importance if the species is not to be threatened with extinction.

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INTRODUCTION

Wells and Wellington (1984), without comment, resurrected the genus *Eulamprus* Fitzinger for the group of Australian 'water skinks' formerly placed in *Sphenomorphus*, and described two new species: *E. heatwolei* and *E. leuraensis*. The former is the widespread 'Warm Temperate Form' of *S. tympanum* recognized by Rawlinson (1969) and later authors (Rawlinson, 1971, 1974; Cogger, 1975; Emison *et al.*, 1978; Jenkins and Bartell, 1980; Norris *et al.*, 1983; Spellerberg, 1972a,b,c,d; Thomas and Gilmore, 1976).

Eulamprus leuraensis was described from a single specimen, and was known from only five specimens from a restricted area of the Blue Mountains and Newnes plateaux (Wells and Wellington, 1984). The species description is a description of the holotype, with no account of variation in the known specimens or diagnosis. Since the description, two further specimens have been collected, and an eighth specimen identified in the collections of the Museum of Victoria.

The purpose of this paper is to give a redescription and diagnosis of this species, and to present such habitat notes and reproductive data as are available.

In the absence of any justification for recognition of the genus *Eulamprus*, the name is referred back to the synonymy of *Sphenomorphus*, pending a systematic analysis of the genus.

Head scale definitions are those of Taylor (1935), and measurements are those defined by Cogger (1975), with the addition of head length (tip of snout to anterior margin of ear), head width (widest point of head) and head depth (from highest point of parietal table, and including lower jaw).

Midbody scales are counted at mid axilla-groin interval, paravertebral scales from first scale behind parietals to last scale anterior to level of anterior margin of hindlimbs, and subcaudal scales (on original tails only) from anteriormost scale subequal to adjacent lateral caudals to and including the terminal sheathing scale.

Sphenomorphus leuraensis (Wells and Wellington, 1984)
Eulamprus leuraensis Wells and Wellington, 1984: 93
Holotype: Australian Museum R111988 (originally AM Field Series 28559)

Diagnosis: *S. leuraensis* differs from most other water skinks (*S. quoyii* complex, defined below) in having no parietal contact posterior to the interparietal and 30-32 midbody scales. Some specimens of *S. kosciuskoi* (Snowy Mtns and Barrington Tops) and *S. heatwolei* have no parietal contact. *S. leuraensis* may be distinguished from Barrington Tops *S. kosciuskoi* and *S. heatwolei* by midbody count (30-32 *vs* 35-40 and 38-45). *S. lauraensis* differs from Snowy Mtns *S. kosciuskoi*, which sometimes have 31-32 midbody scales and parietals not in contact, in having a pair of very narrow (less than ½ a scale wide) gold paravertebral stripes on a very dark brown to black dorsal ground (*vs* a pair of broad (1 scale wide) light brown paravertebral stripes on a mid to dark brown ground). In melanistic individuals of *S. leuraensis* (Fig. 1) these stripes are less obvious.

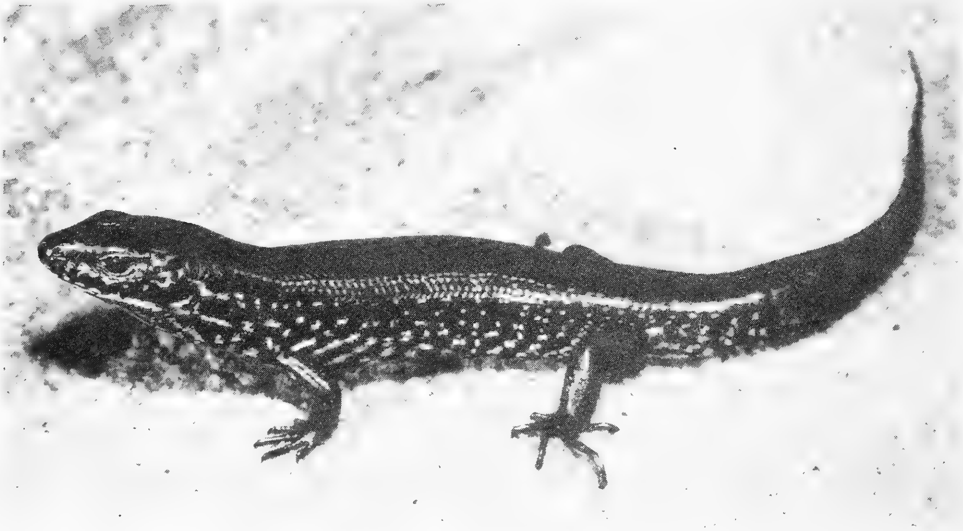

Fig. 1. Sphenomorphus leuraensis in life. In this heavily melanized individual from Wentworth Falls Lake the paravertebral stripes are less obvious than those in lighter coloured specimens. (Photo: M. Peterson)

Description: Nasals entire, moderately separated by contact of rostral and frontonasal; post- and supranasals absent; prefrontals in broad contact, separating frontonasal and frontal; frontal elongate, broadest rostrally; frontoparietals paired; parietals unfragmented, completely separated posteriorly by distinct, narrow interparietal; transversely enlarged nuchals 0-3 on each side ($\bar{x} = 1.1$, $n = 7$); loreals two; supraoculars four, anterior three contacting frontal, second largest; supraciliaries 10-11 ($\bar{x} = 10.1$, $n = 8$), first largest, second and last two large, subequal, third large, slightly elongate, remainder small, subequal; presuboculars three, between posterior loreal and subocular supralabial; subocular series of 1-3 scales completely separating supralabials from granules of lower eyelid; lower eyelid scaly; postsuboculars 4-6 ($\bar{x} = 5.1$, $n = 8$), third from top enlarged and projecting posteriorly from postsubocular line; primary temporal single; secondary temporals two, upper single, elongate, bordering parietal, lower single; 1-3 scales ($\bar{x} = 2.3$, mode $= 2$, $n = 8$) bordering posterior ('free') edge of lower secondary temporal; 3-4 scales (x̄ = 3.9, n = 8) in a row between lower secondary temporal and anterior margin of ear; usually a single intercalated scale, occasionally two, between upper secondary temporal and nuchal; ear large, vertical, subrectangular, without projecting lobules around margin; supralabials 7, fifth below centre of eye; infralabials 7-9 (x̄ = 7.6, n = 8), anterior two contacting single postmental; first pair of chin shields in broad contact; second pair of chin shields separated; third pair of chin shields longitudinally divided, seven scales in the row between infralabials.

Dorsal scales smooth, in 30-32 longitudinal rows (x̄ = 30.6, n = 8) at midbody; scales in a paravertebral row 56-61 (x̄ = 57.6, n = 8), scarcely wider than adjacent lateral dorsals; subcaudal scales 83-89 (n = 2); medial pair of preanals greatly enlarged; lamellae below fourth toe 21-26 (x̄ = 22.6, n = 8), paired basally, single but deeply grooved distally.

Presacral vertebrae 26 (n = 5), postsacral vertebrae 45-49 (n = 2); phalangeal formula of manus and pes 2.3.4.5.3 and 2.3.4.5.4 respectively; premaxillary teeth 8 (n = 2).

Snout — vent length 48.0 - 72.0mm (x̄ = 62.0, n = 8); axilla-groin length 45.9 - 51.4% of SVL (x̄ = 49.3, SD = 1.81, n = 8); tail length 146.3 - 161.4% of SVL (n = 2); forelimb length 24.4 - 27.1% of SVL (x̄ = 26.4, SD = 0.95, n = 8); hindlimb length 37.6 - 44.3% of SVL (x̄ = 40.3, SD = 2.11, n = 8); head length 20.8 - 22.3% of SVL (x̄ =21.6, SD = 0.60, n = 8); head width 63.0 - 72.7% of head length (x̄ = 67.9, SD = 3.41, n = 8); head depth 48.8 - 55.8% of head length (x̄ = 51.4, SD = 2.12, n = 8).

Colour (*in preservative*): Dorsal ground very dark brown to black, with 4 very narrow, sometimes broken, golden to white stripes from nape to base of tail, continuing along tail as a series of spots. Stripes comprise the light centres of scales of the 1st (paravertebral) and 3rd dorsal scale rows. Head above with some lighter golden-brown variegations, also present along upper margin of supralabials. Limbs above black with fine golden-brown flecks.

Lateral ground as for dorsum, but with numerous blue-white macules, fine and scattered dorsolaterally, becoming coarser, more numerous and interconnected ventrolaterally to replace dorsal ground with blue-white ventral ground. Light and dark markings on tail largely vertically aligned as bars.

Venter, including lower surfaces of limbs and soles of feet, with coarse black variegations (extensions of dorsal ground). Infralabials with an immaculate blue-white stripe to ear, thence joining a short blue-white streak below ear. A similar short blue-white stripe above ear, not connected to infralabial stripe. Subdigital lamellae black.

Colour (*in life*): Wells and Wellington (1984) note that the coloration of live individuals is similar to preserved material, but more intense, and with the venter bright golden yellow. We have also noted a bright yellow ventral flush in live material from Wentworth Falls Lake.

The light paravertebral stripes of several very melanistic individuals observed by the junior author at Wentworth Falls Lake had been largely lost by invasion of the dark dorsal ground colour.

Sexual dimorphism: The three large male specimens (SVL = 54.5 - 72.0mm) have a higher head length / SVL ratio (21.4 - 22.2% *vs* 20.8 - 21.2%) and higher head width / head length ratio (70.5 - 72.7% *vs* 63.0 - 66.9%) than the three female specimens (SVL = 60.0 - 65.0mm). The scale counts for the two sexes overlap greatly.

Material: Australian Museum, Sydney: R67040, Wentworth Falls, I. Jordan, 1968 (formerly R. Wells collection R7-1408); R76629, R76630, Colo River Survey, approx. 14km N of Lithgow, P. Webber, Oct 1978; R80698, Newnes Plateau, Site X11 of Newnes Plateau Survey, I. Pulsford, 9 Jan 1979; R111988 (holotype), Leura, T. DeGovrik, 20 Nov 1969; R112952, R113300, Wentworth Falls Lake, G. Husband, G. Shea, S. Wilson, D. Knowles, 25 Aug 1984.

Museum of Victoria, Melbourne: D2001, Blue Mountains, don. T. Steel, ?1893 (registered 1943).

Reproduction: R113300, euthanased September 1984, is a male with enlarged, turgid testes 6mm in length, while R76629, collected October 1978, has enlarged, turgid testes 5mm in length. R76630, collected in the same month, is a female with 2 greatly enlarged (8mm diameter) yolking follicles in the right ovary and none in the left. R80698, collected 9 January 1979, is a female with small ovarian follicles.

Habitat: R76629-30 and R80698 were collected during the course of the Newnes Plateau faunal survey, carried out by the Australian Museum (Kingston *et al.*, 1979). R80698 is given in the Australian Museum registers as taken in 'open forest/low open scrub/shrub swamp'. Site X11, from which the specimen was taken, is described as 'swampy heath', with rocks as a major feature (Kingston *et al.*, 1979). According to this report, two speciments were found at this site, but one appears to have been released.

The two specimens R76629-30 are presumably the two specimens of '*S. kosciuskoi*' recorded from site T11 by the survey team. These two specimens are recorded in the Australian Museum registers as taken 'in mammal trap set near sedge swamp/stream flowing over sandstone'. Site T11 is described as tall open-forest with creek.

A fifth specimen of '*S. kosciuskoi*' was recorded from site P6, described as tall open-forest with creek, but this specimen appears to have been released.

On the basis of these five records, *S. leuraensis* (as *S. kosciuskoi*) was described as preferring tall open-forest and swampy heath by Kingston *et al.* (1979).

On 18 March 1984, the junior author, accompanied by R. Wells, R. Wellington and B. Coulson, observed several *S. leuraensis* (Fig. 1) at the western end of Wentworth Falls Lake (Fig. 2). *S. leuraensis* was only observed in the wet swampy zone immediately bordering the main stream flowing into the lake, and in similar marshy habitat about a pipeline traversing the area. *S. heatwolei* was also common at this locality, but was observed only in the drier low heath bordering the swamp habitats.

When disturbed, *S. leuraensis* rapidly took shelter either in dense grass tussocks or down holes (possibly yabby burrows) in the peat substrates.

Two specimens (AM R112952, R113300) were later collected by the senior author, accompanied by G. Husband, S. Wilson and D. Knowles, at the same locality. Following winter rains, the sites inhabited by *S. leuraensis* in March were waterlogged, and both specimens were found torpid under tin at the edge of the swampy area.

Wells and Wellington (1984) state that *S. leuraensis* is confined to a relictual, endangered habitat of 'hanging' swamps, and they consider the species to be endangered. While the habitat of *S. leuraensis* at the two eastern localities (Wentworth Falls and Leura) is very restricted, the species appears to be common at at least the Wentworth Falls locality, and the known populations on the Newnes Plateau are largely within the boundaries of the Newnes State Forest (Fig. 3). We agree with Wells and Wellington's recommendation that investigation of the conservation status of the known populations and of the range of the species be urgently undertaken. However, we consider that a 'rare'

Fig. 2. Habitat at western end of Wentworth Falls Lake. *S. leuraensis* and *S. heatwolei* inhabit the swamps and heaths in the foreground. (Photo: M. Peterson)

classification (Holloway, 1979; Covacevich *et al.*, 1982) is more appropriate for the species on current knowledge.

Comparison with similar species: *S. leuraensis* is a member of the 'water skink' complex within *Sphenomorphus*, characterized by the following combination of characters: adpressed limbs overlap; peritoneum black; nuchals present; two infralabials in contact with the postmental; supranasals and postnasals absent; four supraoculars, the anterior three contacting the frontal; third postsubocular from top enlarged, projecting posteriorly from postsubocular line; third pair of chin shields divided, 7 scales in the row; subdigital lamellae divided or deeply grooved; live-bearing. The latter six characters are probably derived within the *Sphenomorphus* lineage, and may diagnose the group as monophyletic.

Within the water skink complex, *S. leuraensis* is most similar to *S. kosciuskoi* in possessing a striped dorsal pattern, 8 premaxillary teeth, and in being largely restricted to swampy habitats (Greer, 1979; Spellerberg, 1972b).

S. leuraensis is allopatric with the three known populations of *S. kosciuskoi* inhabiting the eastern margin of the New England Plateau, the Barrington Tops Plateau, and the Snowy Mtns of N.S.W. and Victoria (Spellerberg, 1972b; Coventry and Robertson, 1980; Mansergh, 1982). It differs from all but the topotypic population in the Snowy Mtns in possessing 30-32 midbody scale rows and parietals separated by interparietal (Table 1). The type population of *S. kosciuskoi* is similar to *S. leuraensis* in having the parietals usually separated by the interparietal, only 31-37 midbody scale rows and dorsal stripes well defined, but differs in its broader paravertebral stripes, lighter dorsal ground, pale head with little dark variegation, reduced or absent subauricular white streak and reduced ventral extension of dorsal ground (to midlateral level rather than to venter, as in *S. leuraensis*).

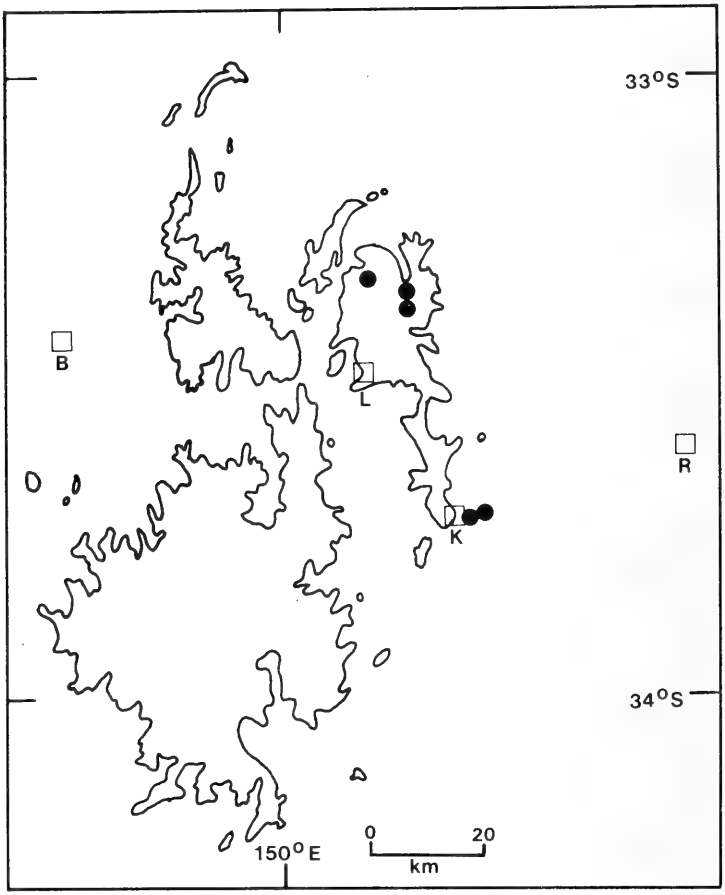

Fig. 3. Distribution of *S. leuraensis* (●). B,L.K and R are Bathurst, Lithgow, Katoomba and Richmond respectively. The solid line is the 1 000m contour.

S. leuraensis differs from all known populations of *S. tympanum, S. heatwolei* and *S. quoyii* in its striped dorsal pattern. More detailed comparisons are restricted to populations on or in the near vicinity of the Blue Mountains Plateau (Table 1). These three species are larger, have more numerous paravertebral and midbody scales, and have the parietals usually in contact behind the interparietal. *S. quoyii* and *S. heatwolei* additionally have more numerous subdigital lamellae. Only *S. heatwolei* is sympatric with *S. leuraensis*, at both the Newnes and Wentworth Falls localities.

S. leuraensis has a superficially similar colour pattern to several *Ctenotus* species, but differs from these in lacking ear lobules, having divided subdigital lamellae and parietals completely separated by interparietal. Further, *Ctenotus* species inhabit more xeric environments than *S. leuraensis*.

TABLE 1

Comparison of several morphological features of the Water Skinks

	Midbody scales				Paravertebral scales				Subdigital lamellae				Parietals (% in contact)	SVL (≥54.5mm)		
	Ra	$\bar{x}$	SD	n	Ra	$\bar{x}$	SD	n	Ra	$\bar{x}$	SD	n		Ra	$\bar{x}$	n
S. leuraensis	30-32	30.6	0.92	8	56-61	57.6	2.07	8	21-26	22.6	1.36	16	0	54.5-72.0	64.0	7
S. kosciuskoi																
1. Snowy Mtns	31-37	33.1	1.53	24	51-63	58.2	2.68	24	18-26	21.7	1.67	48	16.7	54.5-81.0	67.3	17
a. Type series	32-35	33.2	1.30	5	57-59	58.2	0.84	5	18-24	21.8	1.87	10	40.0	69.5-78.0	74.5	3
2. New England	32-38	35.2	1.24	44	58-70	63.6	2.46	44	20-26	22.8	1.54	80	100.0	55.5-80.5	67.1	40
3. Barrington Tops	35-40	37.1	1.36	17	61-72	66.1	2.95	17	18-27	22.8	1.83	32	47.1	59.0-73.0	66.1	17
S. tympanum	36-41	38.1	1.27	28	59-73	66.0	2.79	26	20-26	22.6	1.39	50	100.0	62.0-85.0	71.5	22
S. heatwolei	38-45	40.5	1.84	40	65-80	71.5	4.07	40	20-29	25.5	1.83	73	87.1	64.0-92.0	79.3	31
S. quoyii	38-45	40.8	1.93	15	67-79	73.2	3.66	14	26-36	29.9	2.29	28	100.0	55.5-115.0	92.0	13

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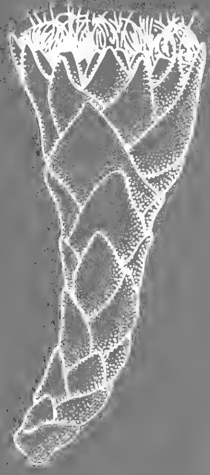

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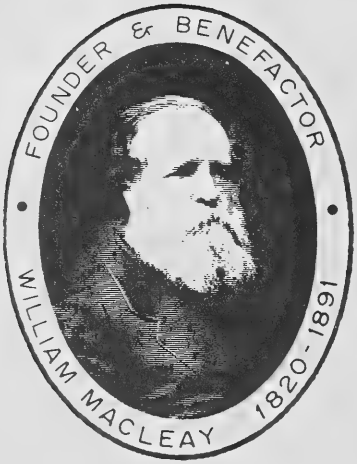

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Sydney Earth and after: Mineralogy of colonial Australia 1788-1900

T. G. VALLANCE

VALLANCE, T. G. Sydney Earth and after: mineralogy of colonial Australia 1788-1900. *Proc. Linn. Soc. N.S.W.* 108 (3) (1985) 1986: 149-181.

Like Sydney Earth — the clay once supposed to contain a new chemical element, its custodian in London, Sir Joseph Banks, did little for Australian mineralogy. Banks, in fact, was no complete Linnaean naturalist and his regard for minerals barely passed the useful and exploitative. And in influential British circles of his time Banks was not thought eccentric. Concern for Australian minerals had to arise slowly as exploration and settlement of the country progressed, and as interest was fostered in no small measure by non-British newcomers. When, after 1851, the wealth generated by gold allowed establishment of centres for higher learning and research, the first significant local work in mineralogy was that in Melbourne of the German-trained G. H. F. Ulrich. With his departure to New Zealand, the focus of mineral studies shifted to Sydney and domination by the British-trained chemist A. Liversidge. While the change brought no diminution in the pace of contributions to what once was called mineral geography it certainly involved an eclipse of those aspects of non-chemical mineralogy of which Ulrich was master.

Nothing from colonial Australia seriously influenced the course of mineral science. Effort here had first to be devoted to local exploration and discovery, to diagnosis and census. Australian circumstances dictated the style. Yet by 1901 when the several Australian colonies became one nation the country had already yielded to science no fewer than thirteen new mineral species that are still deemed valid. And eleven of that tally were first recognized as novel by workers in Australia. For a country all but unknown to Europeans in 1788 it is a not unimpressive record, and one that shows the British colonies had wider cultural debts.

T. G. Vallance, Department of Geology & Geophysics, University of Sydney, Australia 2006; the full, revised text of a paper presented in shortened form to the XI INHIGEO symposium History of Mineralogy *at the XXVII International Geological Congress, Moscow, August 1984; accepted for publication 18 December 1984.*

INTRODUCTION

At the time advances in chemistry and crystallography in Europe were beginning to set the study of minerals on a course away from natural history towards physical science, even the coastal limits of Australia remained imperfectly known. The very whereabouts of the continent's eastern shores emerged just two years before J. B. L. Romé de l'Isle [1736-1790], in his *Essai de Cristallographie* (1772), started to define geometrically various arrangements of crystal face forms, and by so doing showed how Linnaeus's qualitative observations of crystals could be developed. Romé saw the geometry of face patterns as a main characteristic of crystals and, thinking of natural crystals, prefaced his book with a passage from *De Re Metallica* of Christoph Entzelt (Encelius) [1517-1583] about the marvels that nature, by geometry, wrought within the earth. But while Romé, his younger rival R. J. Haüy [1743-1822] and their followers in Europe were exploring the geometry of nature, nature's challenge in Australia (or New Holland as it was then called) continued to be one chiefly of geography.

It might have been otherwise. Since Entzelt's time a notion persisted that all southern lands held mineral treasures. A Dutch document of 1622 (Jack, 1921: 30) reveals that samples of gold, silver, copper and lead were taken to New Holland in the hope they would be recognized by the inhabitants and local sources revealed. William Dampier [1651-1715] recalled the thought in 1699 (Dampier, 1703: 138) but saw only sand and nondescript rocks, which presumably he left unsampled. Had Dampier taken specimens they, like his plants, would have gone to the physician and naturalist John Woodward [1655-1728] who in 1710 gave his herbarium to William Sherard [1658/9-1728]. Dampier's plants remain in the Sherardian collection at Oxford (Clokie, 1964: 63). By contrast, the mineral cabinet Woodward bequeathed to Cambridge appears to owe nothing to Dampier and New Holland. In fact, apart from the suspicion of a Dutch crew in 1756 (Jack, 1921: 81) that natives of the Gulf of Carpentaria were familiar with gold, a suspicion left unpursued, there is no evidence any early European visitor to the country had his hope of finding minerals increased. Most travellers no doubt came upon barren places, but not all did.

Having discovered and reconnoitred the east coast of Australia, James Cook [1728-1779] on 22 August 1770 landed with his naturalists on a small island off Cape York. He called it Possession Island, for there he claimed British sovereignty over that tract he had named New South Wales. Cook then sailed on, unaware the flag he saluted had stood next to an auriferous quartz vein. Between 1897 and 1901 that vein would yield 2480 ounces of gold (Jack, 1921: 660). The *Hints* (Beaglehole, 1955: 514-519) of the president of the Royal Society concerning points of natural history to be watched for during the *Endeavour* voyage had been overlooked at Possession Island: 'It has been alledged by some Naturalists that Gold is not found in Veins, as other Metals. If that, or any other Metal should be met with, it would be curious and Instructive, to examine minutely how they lye in the Earth in their Brute State, and how the Veines *Hade*, as well with respect to the angle of their declivity, as their bearing on the Mariners Compass'. It was, however, no isolated lapse at Possession Island. Cook's naturalists, Joseph Banks [1744-1820] and Daniel Solander [1736-1782], had consistently passed over the president's hints about minerals. There are no observations, let alone collections, of rocks and minerals to stand with the wealth of material relating to the animal and vegetable kingdoms as souvenirs of the *Endeavour* voyage.

Rocks indeed did travel on *Endeavour*, as ballast. Specimens of basalt from Raiatea and schist from Ship Cove, Queen Charlotte's Sound, New Zealand, have been retrieved in recent years from the sea floor off Queensland where Cook lightened ship after striking a coral reef. Such material had a use, but not to the naturalists. As a gloss one notes that vesicular basalt taken from Iceland during Banks's visit of 1772 ended up supporting a moss garden at Kew (Faujas de Saint Fond, 1797: 97). There was, however, a mineralogical dimension to that Icelandic venture. The Swedish priest and later archbishop of Uppsala, Uno von Troil [1746-1803], who accompanied Banks and Solander there took an interest in such nature. His account of Iceland (Troil, 1780), supplemented as it is with remarks by Torbern Bergman [1735-1784], makes one regret a person like-minded had not sailed on *Endeavour*.

Banks's involvement with Cook's first voyage to the Pacific may have been prompted by Linnaeus and his writings (Smith, 1821: 231) but if so the influence at best was incomplete. From the first edition (1735) of *Systema Naturae* Linnaeus had sought to systematize the productions of all three kingdoms of nature. Natural order among mineral substances however troubled him, as the disclaimer of 1768 prefacing remarks on *Regnum Lapideum* clearly shows: '*Lithologia mihi cristas non eriget*' (Linnaeus, 1770: 3). Nevertheless, his approach was careful and perceptive (cf. Sjögren, 1909). Carl Linnaeus [1707-1778] could admit his natural history method alone, that based on observation of visible characters and applied with some success to the ordering of plants and animals, yielded no comparably-adequate system for stones and their constituents. Linnaeus recognized that the student of minerals needed aptitudes beyond those of the natural historian, in chemistry, in physics and in mathematics. It was a view destined to be confirmed as mineral science took shape (cf. Greene and Burke, 1978: 1-16). Further, the distinction between simple and compound minerals admitted by Linnaeus and others would be set with the rise of geology. Compound minerals (rocks) became stuff for geologists; mineralogists were free to concentrate on the study of mineral species. Despite his unaccustomed modesty, Linnaeus on the mineral kingdom was a shrewd and prophetic guide. That guidance, it seems, was lost on Banks.

The student of plants and animals had a more straightforward approach. As a rule his material could be gathered with no great difficulty and identified by reference to known samples or to descriptions, many of them illustrated. Illustration remains an invaluable source for the biological taxonomist. There is no such continuing tradition for minerals. The appearance of one specimen offers no certain guide to recognition of others of the same mineral species. Again, to the diverse mastery required of the serious student of minerals must be added the particular effort involved in acquiring specimens, not only the effort of digging and clearing, but in some places also that of competing against those who would turn the material to the service of art or industry. Banks's interest in nature lay with the obvious and the accessible. As president of the Royal Society of London from the year of Linnaeus's death until his own, Banks numbered mineralogists among his associates, and acquired works on the subject for his library, but where is the evidence his concern for minerals went much beyond the practical? He was, after all, a mine owner. The once-famous Gregory lead mine, long a source of income to him, became almost entirely Banks's property in 1792 by inheritance from an uncle of estates near Ashover, Derbyshire. Banks was no complete disciple of Linnaeus but as he paid for the natural history effort on H.M.S. *Endeavour* he also called the tune. Solander, though trained by Linnaeus and no stranger to minerals, accordingly reserved his attention on the voyage for plants and animals, with impressive results.

Indeed, the less-than-Linnaean comprehensiveness of *Endeavour* natural history is easily overlooked in the face of its rich store of biological observation. What matters here is that the partiality then expressed by Banks continued to influence attitudes to Australian nature. When eventually the British government looked to colonizing New South Wales Banks, by virtue of his experience with Cook as well as his office and social standing, became its unquestioned adviser. The record of the early years of settlement shows how zealously Banks performed that unofficial duty. It also shows how concern about minerals in the new territory, unlike that for plants and animals, had to arise within the context of practical value rather than science.

A Penal Settlement and Ill-favoured Nature

Those in England who claimed, in the hearing of Watkin Tench [1758?-1833], that 'the discovery of mines was one of the secondary objects' (Tench, 1789: 121) for settling New South Wales must have been dreaming. Certainly, the prospect of finding 'metals of all kinds' (Barton, 1889: 430) had been urged as a reason for occupying the country but there is no evidence officialdom in London was impressed. In any case the British then regarded commercial exploitation of minerals as the prerogative of private capital whereas the colony resolved to be fixed in New South Wales was to be a government establishment for transported convicts under military guard. Royal instructions (Barton, 1889: 481-487) to the founding governor, Arthur Phillip [1738-1814], dwelt on the need to maintain order and security and to promote agriculture; there is nothing in them about mines or minerals. The governor's main task would be to survive. How he and his people managed was up to them. That they did owed little to any information about the country Phillip brought with him from England.

Banks's choice of Botany Bay, the abode of plants that excited him in 1770 when there with Cook, as the place to settle proved quite unsuitable. Forced to look elsewhere, Phillip happened upon Port Jackson, named but not examined by Cook, and within that harbour selected the place he called Sydney Cove. An advance party was already clearing space for tents there on 26 January 1788 when the governor proclaimed foundation of the colony and publicly wished it success. Routine survey of the port and its vicinity began as the convict transports moved from Botany Bay but the governor had no one on his staff who could make expert investigation of the land. Cultivation of the seeds and plants brought with the fleet was left to convicts working patches of soil among rocky outcrops. More than one of the officers, however, soon discovered an instinct for the more obvious branches of natural history. Their letters and journals are generously provided with observations of native plants and animals, not least of the human variety. Many made sure Banks remembered them, by keeping him supplied with notes, drawings and even specimens. Interestingly, few seemed to take any notice of minerals or rocks. Like agriculture, mineral substances tended to be left to the attention of convicts.

Writing to his secretary of state on 28 September 1788 (*Hist. Rec. N.S.W.* I(2): 190) Phillip observed: 'This country is supposed to have mines of iron and tin or silver by those who have been used to work in mines. . . . A convict, used to work in the Staffordshire lead mines, says the ground we are now clearing contains a large quantity of that metal; and copper is supposed to be under some rocks which have been blown in sinking a cellar for spirits'. But, as Phillip added: 'I give no encouragement to search after what, if found in our present situation would be the greatest evil that could befal the settlement'. The view was understandable; only a month before one of the convicts had fraudulently claimed to have found a gold mine (i.e. deposit). Clearly there was talk of minerals about the settlement, most of it no doubt uninformed but intriguing enough to make Tench (1789: 122) regret 'that some one capable of throwing a better light on it, is not in the colony'. In fairness also to Phillip it must be remarked that his attitude to mineral materials was not uniformly bleak.

The exploring expedition led by J. F. G. de La Pérouse [1741-1788] anchored at Botany Bay on the day Phillip was at Sydney Cove launching his colony; it remained in the bay six weeks before sailing off to a disastrous end. During the stay Phillip came to know various members of La Pérouse's scientific staff, among them the young priest J. A. Mongez [1751-1788]. Mongez had some reputation as an authority on physical and agricultural subjects and, until his departure from France in 1785, assisted his uncle François Rozier [1734-1793] editing the *Journal de Physique* or its antecedent. Mongez had also translated and edited the French version (1784) of Torbern Bergman's *Sciagraphia Regni Mineralis* (1782). His were talents beyond any at Phillip's disposal. Yet this Frenchman, the first person with recognized mineralogical expertise to visit Australia, left a memento of his stay. In the letter of 28 September 1788 mentioned earlier, Phillip reported that 'the Abbé that came out with Monsieur Perouse as a naturalist'*, had told him the white clay used by the natives for body paint and found in abundance about Sydney 'would make good china'. The governor went on (*Hist. Rec. N.S.W.* I(2): 190): 'Specimens [of the clay] were sent to Sir Joseph Banks, and a stone taken out of a slate quarry that I thought contained some metal'.†

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* One notes, and rejects, the identification by Lawson (1971: 17) of Phillip's 'Abbé' as Louis [Laurent?] Receveur whose duty on *Astrolabe* as chaplain and naturalist with responsibility for 'analizing and examining minerals' (Milet Mureau, 1798: I, 6) matched that of Mongez on *Boussole*. Receveur was wounded in a skirmish with natives at Tutuila and died of his injuries at Botany Bay on 17 February 1788. Only the scientifically more distinguished Mongez was fit for work in New South Wales. His name could have slipped Phillip's memory. Receveur's, on the other hand, would more likely have been remembered, for the governor in April 1788 ordered erection of an inscribed name plate over the naturalist's grave.

† It is surely remarkable that not one of the letters written from Sydney by Phillip to Banks is recorded in the census of Banks correspondence in British collections (Dawson, 1958, and suppl.). No letters of Banks in reply to Phillip in Sydney seem to be known anywhere. Phillip to Banks letters in the Mitchell and Dixson

The stone was heard of no more. Presumably a shale (there is no slate for quarrying near Sydney), the 'metal' was most likely an iron sulphide mineral. Banks must have thought it not worth attention. With the clay, however, went a request that it be submitted to a ceramist and there Banks obliged, giving a portion to the potter-chemist Josiah Wedgwood [1730-1795]. Examples remain of the medallion Wedgwood successfully made from the clay but greater interest here lies in his chemical study. Wedgwood (1790) reported, for instance, that aqueous dilution of hydrochloric acid in which the clay had been digested yielded an insoluble white precipitate. The response was quite unlike that observed with common china clay and led Wedgwood to claim discovery of a new 'earth', a new chemical element he named Sydney Earth or Sydneia (Sidneia) after its source. J. F. Blumenbach [1752-1840] of Göttingen repeated the experiment on another part from Banks's stock, and while not achieving such a striking result as Wedgwood felt able to confirm his claim (Blumenbach, 1791).

With no great interest in the clay himself, Banks continued to dispense portions to interested inquirers. Thus the Viennese mineralogist Karl Haidinger [1756-1797] got some when he called on Banks in 1795, and gave it to the chemist Martin Klaproth [1743-1817] in Berlin. When Klaproth (1797: 66-69) announced his failure to repeat Wedgwood's result he was attacked by the dead potter's friend William Nicholson [1753-1815] who suggested Klaproth's sample was somehow not genuine (Nicholson, 1797). However not even Nicholson could object after Charles Hatchett [1765-1847], using material directly from Banks, demonstrated the Sydney clay behaved as Klaproth had reported (Hatchett, 1798). It was clear, Hatchett argued, that Wedgwood had been led into error by using 'the common acids of the shops, without having previously examined and purified them'. Vallance (1975: 19) has suggested the offending contaminant was bismuth. The business of Sydneia was an aberration, begun with no more than practical intention and developed through the unfortunate, but not entirely inappropriate, use of a commercial reagent. Science became involved by accident. In a way it also profited. As Hatchett showed, the Sydney clay was the 'common [hydrous] silicate of alumina' with some admixed iron oxide and graphite. On his evidence Hatchett might have called the silicate kaolin, the term from China already used in English and, as kaolinite, still applied to a valid mineral species. But Hatchett left his contribution to Australian mineralogy undefined. He had succeeded in setting straight the chemical record; the nature and source of the clay were of no great moment to him.

During its brief floruit Sydneia gained wide notice in scientific literature. It even raised thought of mineral nature in Australia having a novelty to match those of the plants and animals. Yet strangely the thought seems not to have prompted activity. Other mineralogical specimens sent to London by governor Phillip disappeared without trace. Did their ordinariness curtail the thought of novelty even before Sydneia was demolished? The mineral kingdom in Australia remained ill-favoured, of some use to the colony for building material but little else. Clay was being made into bricks long before the result of Wedgwood's ceramic tests became known. The need for mortar led to search for limestone, without success (Tench, 1793: 164); convicts had to continue gathering shells by the shore. Tench might deplore the lack of expertise in the colony but, in fairness, no expert would have done better in that search. The area about the settlement held no particular mineral riches. Interesting discoveries had to wait until

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collections, Sydney, indicate that in fact a wide variety of geological specimens were sent at different times to Banks and that some, at least, of the clay samples came not from Sydney but from an island (presumably Lion Island) at the mouth of the Hawkesbury River. This latter point was reported in print in an article 'Sydney Pottery. By M.L.' in *The Sydney Morning Herald*, 24 Sept. 1927. 'M.L.' also had no doubt Phillip's adviser was the 'Abbé Monges'.

more of the country was examined, and examined by people able to make informed observations. Not surprisingly, the lead such as it was came from exploring expeditions that happened to call.

In the account of his visit to King George's Sound, Western Australia, in 1791 George Vancouver [1757-1798] introduced some remarkable discussion about a chalky substance found there and which from tests with acids and blowpipe as well as optical examination was deemed to 'resemble an earth described in Cronstadt's Mineralogy at the bottom of his note (y), page 21' (Vancouver, 1798: I, 50). One wonders how many of Vancouver's readers, then or since, have penetrated the passage. He refers to Cronstedt (1788: I, 21) and discussion of a 'white earth' from 'the province of Smoland in Sweden' that would now be termed earthy gypsum. For an explorer in Australia this was a piece of quite unexpected sophistication and, although Vancouver gives no acknowledgement, there can be little doubt he was reporting the work of his naturalist Archibald Menzies [1754-1842]. Menzies evidentally had a copy of Cronstedt with him, and knew how to use it. Furthermore, this was no isolated instance of Menzies' attention to minerals during the voyage. His Australian material may be lost but the Chilean collection remains, donated by Menzies to the British Museum in 1800. Remembered chiefly as a botanist, and one described recently (Vancouver, 1984: I, 31) as 'very much Banks' man', Menzies enjoyed what I like to think of as a Scottish breadth towards nature. He had learned his botany in Edinburgh from John Hope [1725-1786], whose successor in the botanical chair was the discoverer of nitrogen Daniel Rutherford [1749-1819], and whose son the chemist T. C. Hope [1766-1844] did much in the 1790s to clarify the nature of barium and strontium minerals. Scots at the time ordered their scientific education with greater rigour and comprehensiveness than the English, more in line with the style of continental Europeans.

The Spanish expedition led by the Italian-born Alessandro (Alejandro) Malaspina di Mulazzo [1754-1809] that visited Port Jackson for a month in 1793 (*Hist. Rec. N.S.W.* II: 24-25) in fact represented a nation with an established system of training in mineralogy and mining under royal patronage (Lopez de Azcona and Sampelayo, 1974). Elsewhere during the voyage (1789-94) such matters had been attended to but in Sydney, the only Australian port of call, the expedition naturalists seemed more intent on botany and social observation. That at least is the impression gained from an incomplete record. The expedition clearly ended in some confusion. Malaspina, in disgrace, spent years imprisoned. His journal of the voyage lay unpublished until 1885 (Aurousseau, 1971) and, at least in Australia, is still little known. A. J. Cavanilles [1745-1804], though not of the expedition, rescued some of the scientific results but even his general paper (Cavanilles, 1799) on the terrain, soils, plants and aborigines about Port Jackson and Botany Bay is rarely noticed. Louis (Luis) Née [fl. 1780-1803], the one naturalist to return to Spain with the expedition, published nothing after a description of the Majon volcano (1803) in the Philippines. Interest seems to have lapsed with Cavanilles' final illness. Kelly (1965), however, points to a wealth of unpublished material, much of it botanical, still in Spanish archives. Of Malaspina's naturalists, Antonio de Pineda died in the Philippines in 1792 and Née's companion at Port Jackson, Thaddäus Haenke (Tadeo Heenke in the Spanish record) [1761-1817], left the expedition to settle in South America. Haenke there acquired property, including a silver mine, and devoted time to writing on botany and mineral resources. Many of his works dealing with South America have been published in the present century. One wonders if anything on New South Wales by this most geological of Malaspina's scientists is preserved in his adopted home Bolivia.

Problems also beset the French expedition under A. R. J. de Bruni d'Entrecasteaux [1739-1793] that visited Australian waters between 1792 and 1794, problems arising from political turmoil in France and from war with Great Britain. The expedition had been sent out in an attempt to discover the fate of La Pérouse and, like his venture, to enlarge scientific and geographical knowledge. Of the five naturalists assigned to the ships under d'Entrecasteaux's command, four might best be described as botanists though C. A. G. Riche [1762-1797], former secretary of the *Société Philomatique* in Paris, had broad interests in natural history as did the best-known of them, J. J. H. de La Billardière [1755-1834]. The fifth, Jean Blavier [1764-1828], went as mineralogist. His appointment, like those of Mongez and Receveur with La Pérouse, underlined the breadth of French perceptions of natural history. Australia, however, was denied Blavier's inspection. Taken ill at Cape Town, he had to withdraw on the outward voyage. Consideration of rocks and minerals became an added duty for the botanists and to it La Billardière, at least, responded positively. Take for instance that day in February 1793 when coal seams were found inland from South Cape, Tasmania (then Van Diemens Land). From the vicinity of the coal La Billardière (1799: II, 22) noted pieces of 'bronze-red' hematite as well as red ochry earth and 'tripoli'. The last was probably a clay, not diatomaceous earth, but otherwise the statement is persuasive. However, neither these nor any other minerals observed on the voyage received detailed study. There may indeed have been little chance for later work on them for, as Hulot (1894: 134) remarked with fine understatement, many of the expedition's mineral samples 'went astray'. Conflict between naval officers and the citizen scientists brought the expedition to a shambles. De Beer (1960: 45-68) outlines the sorry story. Eventually, with the help of Banks, La Billardière managed to regain possession of his plants and with them alone make important contribution to Australian science. The mineralogist is left to regard the visits of the d'Entrecasteaux and Malaspina expeditions as having the interest of unfulfilled promise. In fact, the cause of mineral discovery in Australia during the 1790s, at least in terms of information made known, seems to have been better served by the colony's relatively unsophisticated residents.

Some mineral materials are so generally familiar their identification presents no difficulty. Coal is one such; it had been found north of Sydney by runaway convicts in 1791 (Vallance, 1975: 30). 'Ironstone' is another. One does not need La Billardière's knowledge of hematite to recognize it. By 1801 samples of the material from New South Wales had been reduced to metal in England (*Hist. Rec. N.S.W.* IV: 595). Salt, too, could be easily identified. An exploring party in 1798 returned to Sydney with news of 'an immense cliff of salt, a specimen of which they brought in' (Collins, 1802: 88). A revisit, like the first encouraged by governor John Hunter [1737-1821], yielded more samples, some of which were sent to Banks with uncertain result. It is possible Banks informed Robert Jameson [1774-1854] who added the detail to published science (Jameson, 1805: 17) though by then that author as easily could have relied on Collins. Cambage (1920) gives an explanation of what became reputed in mineralogical literature a mountain of rock salt in the interior of New South Wales. At the place Cambage took to be that visited in 1798, a locality near the confluence of the Bargo and Nepean rivers, protected faces of Hawkesbury Sandstone bear incrustrations of sodium chloride.

Collins (1802) reported other points of mineralogical interest, many of them arising from discoveries made after he left the colony in 1796 and for news of which he depended mainly on Hunter. David Collins [1756-1810], officer of marines and sometime deputy judge-advocate in New South Wales, had been secretary to both Phillip and his successor, Hunter, Phillip's second-in-command at the foundation of Sydney. Hunter knew how during Phillip's incumbency the difficult circumstances of settling a community had prevented much effort being devoted to other than local reconnaissance. When he returned to Sydney, as governor, in 1795 he determined to encourage exploration, insofar as his resources would allow. The first of only two governors of New South

Wales in the first fifty years of the colony who had attended a university, Hunter had a genuine interest in promoting knowledge of his territory. It was his good fortune to meet on the voyage back to Sydney two young naval men, Matthew Flinders [1774-1814], then a midshipman, and surgeon George Bass [1771-1803], ready to serve that interest.

In June 1797 Hunter sent Bass to examine and report on coal seams found south of Sydney by survivors of a shipwreck. Bass's remarks on the visit are preserved in a letter of 20 August 1797 (*Hist. Rec. N.S.W.* III: 289-290) to William Paterson [1755-1810]. Hunter must have thought the effort useful. On 1 August 1797 he wrote to Banks (BM(NH) Dawson Turner copies 10(2): 108) urging the need for a systematic investigation to be made of the minerals of New South Wales. No doubt Hunter envisaged such effort in terms of practical results but the contrast with Phillip's attitude just nine years earlier was remarkable. The colony had survived and now, as Hunter saw it, it could be served by knowledge of natural resources, among which minerals offered greater promise of usefulness than the native plants and animals. Banks, however, took no notice of Hunter's request. The governor would have to rely on those in the colony like his young naval friends who, though relatively inexpert, were prepared to take notice of minerals. A nice example of such interest comes from Preservation Island in the Furneaux Group, visited by Bass and Flinders during their exploration (1798-9) of Bass Strait.

Bass's description of the island (Collins, 1802: 147-152) includes notes on rocks and shell-beds, on wood in various stages of fossilization and on accumulations in beach sand of 'black metallic particles which [also] appear in the granite as black shining specks, and are in all probability grains of tin'. Bass also knew, from the mariners whose coal discovery he inspected in 1797 and who had been wrecked on the island, that water there was injurious to health. Accordingly, Bass tested the black particles by heating them in a crucible and noted generation of a 'large fume of what bore marks of arsenic'. Surgeon Bass would have made no mistake in that diagnosis yet he seems not to have wondered why his 'tin' behaved so strangely. 'Tin' (tinstone, or cassiterite) yields no such fume on heating. The seeming confusion, however, did not deter Liversidge (1888: 77) from claiming that Bass indeed found cassiterite, and would have known it 'since he appears to have possessed considerable geological knowledge'. Liversidge's argument falls well short of proof but one notes with interest its endorsement by an author who knew the region (Petterd, 1910: 39). If Bass was the first discoverer of cassiterite in Australia there is even more evidence he came across a common associate of that mineral, the arsenical phase mispickel (arsenopyrite).

To credit Bass thus clearly involves going beyond the record he left. It is possible to do so however because the insufficient mineral diagnostics are in some measure compensated for by facts about locality and occurrence. Apart from the common rock-forming varieties, minerals tend to be more confined in space than plants and animals. No part of the study of nature finds detail of 'where' and 'how' more revealing than that concerning minerals. It is instructive in this regard to contrast Bass at Preservation Island with a near-contemporary work on black beach-sand by a better-known scientist.

Early in 1801 the Irish chemist and mineralogist Richard Chenevix [1774-1830] received from Sir Joseph Banks 'a quantity of sand, which had been found on the sea coast in Providence Island, and thence brought over to England in the course of the winter' (Chenevix, 1801: 132). In addition to quartz and some red grains that Chenevix took to be garnet, the sample contained an abundance of black, slightly magnetic grains of an iron-titanium oxide similar in composition to the mineral reported six years earlier and named menachanite (manachanite, menaccanite and other variant spellings now all subsumed in the later term ilmenite) after its Cornish locality. What was the source of this second sample? 'From Botany Bay' appears in the title to Chenevix's paper which ends with a passage reminiscent of the launching of Sydneia: 'If the mineralogical riches of the country, from which this sand was brought, are at all to be prejudged, from the valuable productions with which we have become acquainted in the vegetable and animal kingdoms, we may look forward to many interesting discoveries'. Yet the locality Providence Island is not Australian. Leonhard (1808: II, 224-225) resolved things to his satisfaction by assigning the mineral to both Providence Island, North America, and to New South Wales (Botany Bay). K. C. von Leonhard [1779-1862], however, gave no authorities, and Chenevix appears to have studied only one batch of sand. Had Banks been slipshod in fixing its provenance? Whatever the cause, Chenevix's hope of encouraging interest in Australia's minerals was nullified. If in fact the sand had come from Australia the confusion is the more extraordinary for at the time Chenevix got it Banks was in closest contact with a man just returned from Sydney, a man who could have brought the material with him.

Soon after he reached London in the latter part of 1800, Flinders made himself known to Banks with a letter outlining what he and Bass had achieved and a plan for a more comprehensive hydrographic and natural history survey of the Australian coasts. He sought Banks's patronage and, perhaps thinking he knew the baronet's inclinations, emphasized the potential for enlarging knowledge of natural history, of which he added 'the mineralogical branch would probably not be the least interesting' (Vallance and Moore, 1982: 3). Flinders must have been quickly disabused; his enthusiasm for minerals was not shared. Otherwise, Banks responded warmly to the plan. Before the end of 1800 a vessel, renamed H.M.S. *Investigator*, had been chosen for an expedition under Flinders' command. In public Flinders chose to be diplomatic. His account of travels with Bass (Flinders, 1801), a work dedicated to Banks, gave scarcely a hint of the explorers' interest in mineral nature. Privately, he kept trying to have a mineralogist appointed (cf. his letter of 24 January 1801 to Banks, *Hist. Rec. N.S.W.* IV: 291), but to no avail. Banks determined the style of the expedition's scientific effort. Although aware the French had recently despatched N. T. Baudin [1754-1803] to Australia with two vessels and a large scientific staff that included two trained mineralogists, Banks resolved that Flinders would be suitably served by one naturalist, and he a botanist. In what may have been a grudging nod to Flinders, the naturalist was allowed the assistance not only of a gardener and a botanical artist but also of a 'practical miner' (Vallance and Moore, 1982: 3-4).

Much has been written about the expeditions to Australia led by Baudin and by Flinders, and in the context of Baudin's venture at least too much of it is confused and contradictory. This is no place to set about major revision but as a step towards clarifying the French provision for science I have gathered in an Appendix a tally, based on scattered sources, of Baudin's naturalists. Baudin, already an experienced commander of scientific expeditions, sailed for Australia with a staff of ten scientists, some veterans of travel with him, who were assigned to the principal divisions of nature. Having arranged the issue of passage documents in case of war, Banks knew what the French had done. His response was to choose as Flinders' sole naturalist an assistant surgeon in the army, Robert Brown [1773-1858], known to have interest in botany but without any experience of long sea voyages. In science the French appeared to hold every advantage. That the appearance became illusion is history not of Banks's making. Defection, rancour, illness, death, each took an awful toll of the Baudin expedition. Careful French planning of the scientific effort provided little defence against human frailty. By contrast Banks, in choosing Brown, chose shrewdly. He wanted a botanist, and got one of distinction. But Brown, like Archibald Menzies before him, had Scottish breadth in his approach to nature. Brown's contribution to Australian mineralogy, for instance, can stand comparison with what is known of the results of Baudin's two mineralogists, Louis Depuch and J. C. Bailly (see Appendix).

Admittedly, the record of work by Depuch and Bailly is incomplete. Among the scientists they seem to have stayed reasonably loyal to their commander whose journal provides glimpses of their activity (Baudin, 1974). Extracts from their notes are given there and in the official record of the expedition (Péron, 1807; Péron and Freycinet, 1816) but the main documentary source is an unpublished detailed catalogue of the rock and mineral collection (transcript in Mitchell Library, Sydney, Baudin Expedition Papers B1265). It describes what seems to be a reasonably representative gathering of what would have been seen at the stopping places along the western and southern coasts of Australia, in Tasmania and in Timor. Not much more than that can be said with confidence; the samples are now lost (Vallance, 1983a: 135-136). One notes, however, impressive agreement between the catalogue diagnoses and the descriptions of selected specimens seen by Leopold von Buch [1774-1853] in Paris during 1810 (Buch, 1814). There is no reason to doubt Depuch and Bailly did their work soundly but apart from Buch and J. A. H. Lucas [1780-1825], who noted such Australian minerals as Depuch's 'arragonite' from Tasmania and the same collector's menachanite sent from Botany Bay (Lucas, 1813: 37, 487), there are few signs the collection drew much interest. Certainly it can have contained no new, rare or valuable materials but that was no good reason for condemning the work of the mineralogists as of little interest (Jussieu, 1804: 7). Decision-makers in Paris might despatch mineralogists on expeditions yet be as uninterested in promoting the science as Banks. At least Banks's partiality was honest.

Until recently what was known of mineralogy and the *Investigator* voyage came from the commander himself. Flinders (1814) provides many instances of such observation, and as study of Brown's notes has advanced it is clear that what Flinders published was largely his own. It is clear also that Flinders took his own mineral samples, and deeply regretted their loss by shipwreck. The same disaster deprived us of much of Brown's rock and mineral collection. Fortunately, one part was not packed and ready when Flinders sailed. It returned to England with Brown in 1805, to be set aside and after some years handed over to the British Museum where its neglect long continued. Vallance and Moore (1982) have restored to order what remains and described the material. With specimens available, assessment of the quality of Brown's mineralogy becomes a far simpler task than that faced with Depuch and Bailly. Brown, too, may have found no new, rare or particularly valuable minerals but clearly he was observant and possessed a good working knowledge of the subject. This writer, having worked through Brown's collection and notes, is especially impressed by the field-identification at Melville Bay, Arnhem Land, of colloform pyrolusite as 'oxyd of manganese?' (Vallance and Moore, 1982: 24). The manganese deposits now exploited in northern Australia had to be rediscovered while Brown's material lay unregarded. But then Brown himself can hardly have been expansive about his thought on manganese; Flinders (1814: II, 224) at the same locality mentions what was surely the same material as ironstone. Brown is justly praised for his Australian botany; had he been more communicative he would have deserved greater credit as a mineralogist.

By coincidence, on the day (16 February 1803) Brown was inspecting his pyrolusite, a man in London was considering the offer of a novel appointment in Australia. Two days later A. W. H. Humphrey [1782?-1829] indicated acceptance of the post of H.M. Mineralogist in New South Wales. Ill-favoured nature had found British royal patronage. Never before, not even in the United Kingdom, had there been a British Crown appointment in mineralogy, and in the colonial establishment of New South Wales only the mineral kingdom would have its official cultivator under royal commission. A remarkable first step had been taken to fix resident concern for minerals in Australia.

MINERALS ACKNOWLEDGED: THE GROWTH OF RESIDENT INTEREST

Humphrey's appointment marked a distinct, and unexpected, shift in British decision-making about Australia, one it need hardly be said that owed nothing to Banks. Indeed why the decision was made to appoint a mineralogist at that particular time remains unclear. Equally unclear is why C. F. Greville [1749-1809] chose then to press the government on the matter. There had been no mineral discovery in Australia to excite public attention and what mineralogical results might stem from the French and British expeditions were still unknown. Perhaps Greville, a man of influence in politics and science like Banks but who was also a noted mineral collector, simply felt the mineral kingdom in Australia had been too long neglected. Whatever the prompt, and no case can be made for Greville's private advantage, his advocacy drew a favourable response from government. Greville seems to have envisaged a prospecting survey, a practical collecting venture rather than one of detailed science. It is not surprising therefore that when authorized to seek a suitable person Greville should turn to the dealers in natural history. Humphrey's links with that trade are outlined elsewhere (Vallance, 1981); to those remarks need be added only the information gleaned by John Currey (in Humphrey, 1984: 26) that Humphrey attended courses in chemistry given by Alexander Crichton [1763-1856] who, in turn, was to supply Greville with a useful testimonial on Humphrey's behalf. Currey's discovery shows Humphrey had experience requisite to use the apparatus with which he was supplied in Australia, and about which he grumbled with good reason (Vallance, 1981: 141).

What is known of Humphrey's career in Australia has been discussed at some length in recent works (Vallance, 1981; Humphrey, 1984). Despite his fine title, Humphrey was little more than a prospector and apart from the period he was in the field with Robert Brown (1803-4) seems to have been not remarkably diligent. His interest to us arises from the office he occupied rather than any particular discoveries. Yet Humphrey's presence in the colony may have been spur to others not previously much given to minerals. Bass's friend Paterson for instance soon after receiving charge of the settlement at Port Dalrymple, Tasmania, ordered his men to collect samples for despatch to Sydney: 'A variety of rare and apparently valuable minerals have been received; among which is the pure asbestos, combined with a ponderous ore, which is found in great abundance' (*Sydney Gazette*, 24 Nov. 1805: 2). Humphrey is known to have worked on some such consignments, and even selected material for despatch to England (Vallance, 1981: 117).

Humphrey had come to Australia in 1803 with the contingent led by David Collins intended to fix a settlement at Port Phillip, but that place being found unsuitable Collins turned to the Derwent estuary in Tasmania and there founded Hobart Town (1804). The extension of settlement brought increased opportunity that in turn drew more free settlers to the country with prospects of land grants and free convict labour. Some of those settlers were men of education able, if willing, to enlarge colonial sophistication. A nice example is Robert Townson [1762-1827], another protégé of Greville but unlike Humphrey already a man of consequence and learning, LL.D. (1796) of Edinburgh and author of several works on travel and science, among them *The Philosophy of Mineralogy* (1798). Vallance and Torrens (1984) give an outline of Townson's European career and the background to his decision to settle in Australia. Townson plainly hoped to continue his scientific activities for which purpose, through Greville's good offices, he obtained £100 for books and apparatus. Unfortunately, Townson found no easy welcome in

Sydney. The governor, William Bligh [1754-1817], seemed in no hurry to oblige and Townson had become a grumbler long before the equally-unacceptable officers who overthrew the governor granted him land. Writing to a friend in England Townson attributed his misfortunes to there being too many in the colony enjoying appointments procured by Banks: 'things will be no better while he has any influence' (H.S. Torrens, pers. comm.). By letter 2 April 1808 (British Library Add. MSS 42071 f.356) he warned Greville: 'you must expect nothing about science from me until I am more at ease — at present I have enough to do to keep myself from destruction'. He had then been in the colony less than a year but one suspects that in his view saving himself from destruction became a continuing diversion. Nevertheless he managed an existence of reasonable comfort in Australia and his candidature (1822) for election to the short-lived Philosophical Society of Australasia (*J. Proc. Roy. Soc. N.S.W.* 55, 1921: cii) shows old interests persisted. Perhaps that late conjunction was appropriate; both Townson and the society are more easily recognized as indicators of an emerging colonial refinement than as contributors to scientific knowledge.

As colonial society became more diversified so also did local industry, some of it dependent on minerals. Brick-making has been noticed. By 1801 coal was being mined by convicts at the Hunter River and shipped to Sydney. In 1812 the then governor, Lachlan Macquarie [1762-1824], accepted Humphrey's resignation as mineralogist. According to Macquarie, Humphrey had found nothing 'Worthy of Notice' but whatever the scale of Humphrey's failure (and it was not unrelieved failure, as Vallance (1981) shows) it did not prevent the governor from seeking a 'scientific mineralogist' by way of replacement. London, however, seemed in no hurry to respond. Macquarie was no longer governor when John Busby [1765-1857] reached Sydney in 1824 to begin duty as civil engineer and mineral surveyor, not as H.M. Mineralogist. Humphrey's post had become extinct and a distinctly more useful orientation fixed. Busby, in fact, would be kept far busier securing Sydney's water supply than prospecting for minerals.

Meanwhile, other industrial ventures emerged. In 1812 newspaper advertisements in Sydney announced locally-made domestic glassware. The effort seems not to have prospered but is of interest through the involvement of a convict, John Hutchison [d. 4 December 1820], recently transported for forgery. Hutchison plainly had influential friends. The Society of Arts, for instance, petitioned Whitehall that 'his general Abilities and chemical Knowledge' be employed in New South Wales in the study of natural products, especially those useful to the dyeing trade (*Hist. Rec. Austr.* I, VII: 541-542). Somewhat reluctantly one suspects governor Macquarie provided Hutchison with apparatus and reagents, and in return received reports of supposed progress (*Hist. Rec. Austr.* I, VIII: 212-235). Their interest to the mineralogist may not be great but included are remarks on tests of mineral pigments, on local clays for earthenware and copperas made 'from Pyrites I had from the Coal [Hunter] River'. The latter must surely rank as the first experiments on sulphide minerals in Australia. However, by March 1814 the governor must have decided the convict's efforts were unrewarding. Hutchison was granted leave to engage in business; his death notice (which confirms the name as here and in Macquarie's correspondence, not Hutchinson as some claim) has him then superintendent of the Lachlan Water Mills (at Botany, near Sydney). Hutchison left no particular mark either on the colony or science, but interestingly not many years later one of his initiatives would be resumed. In 1831 James King [1800-1857], who had come to Sydney of his own accord to set up as a merchant, drew attention to the suitability for glass-making of certain local sands (cf. King, 1833). King, in fact, was to give many leads to colonial industry, notably in ceramics and viticulture. A man of unusual talent, his letter of 1 August 1827 to the physicist David Brewster [1781-1868] supplying details on the climate and geology of New South Wales gained a place in scientific literature

(King, 1828). Brewster (1827), with his optical study of Australian topaz, a mineral of which Humphrey is credited the discoverer (Jameson, 1811), has another claim to notice here (cf. Vallance, 1975: 19).

Completion in 1815 of a road across the rugged Blue Mountains that hitherto had kept settlement at Sydney confined to the coast opened the way for inland exploration of the mainland colony. That desired material limestone had been found west of the mountains by the surveyor G. W. Evans [1780-1852] even before the road was finished. In view of Evans's later work on Tasmania, with its intelligent collection of detail about minerals (Evans, 1822: 58-59), the argument seems strange that he lost leadership of future mainland exploration on account of inadequacy in geology and botany (Weatherburn, 1966: 53). The fact was, for minerals at least and despite growing interest in them, the colony possessed little available sophistication (and Townson plainly was not 'available'). In those terms it seems unjust to have rated Evans deficient. Yet on the 1817 expedition led by J. J. W. M. Oxley [1785?-1828], in which Evans was second-in-command (Oxley, 1820), a convict William Parr held the title 'mineralogist', or 'Acting Mineralogist' as Macquarie styled him in a requisition for reagents 'for making experiments of Ores & metals' (Mitchell Library, Sydney, A763 (Wentworth Papers) 197). Oxley (1820: 375) indeed reported that a small 'mineralogical collection' had been made and that Parr had done 'as much as could be done in that branch' but Parr's expertise was surely limited to that of collector. Parr remains a shadowy figure (records even differ as to whether he was William, S. or T. Parr); Morgan (1958: 189-192) gives a few details. For some reason Parr did not accompany Oxley and Evans on their 1818 exploring journey when rocks and minerals were also collected, presumably by the field botanist and 'Colonial Collector' Charles Fraser [1788?-1831]. Manuscript lists, now in the British Museum (Natural History), of specimens donated to the Geological Society of London bear witness to geological activity by Fraser and by his colleague on Oxley's 1817 venture Allan Cunningham [1791-1839], the eminent collector for the Royal Gardens at Kew. The specimens themselves must be presumed lost.

Other explorers who followed Oxley and his parties into the interior also returned with rock and mineral samples, and no doubt some of them too were sent to London, there to be neglected. But rocks and minerals became incidental; the enthusiasm that set Parr the 'mineralogist' with Oxley would not be repeated in the early days. Even in the colony there could be extraordinary failures in communication, none more than assistant surveyor James McBrien's discovery of particles of gold in sand near the Fish River (Pittman, 1901: 1). Had the news spread in a society still substantially convict there might have been highly disruptive consequences, but the surveyor's notebook with its critical entry for 15 February 1823 lay unregarded until near the end of the century. There is no evidence that McBrien's find was suppressed.

It might be thought that establishment at Sydney in 1827 of a colonial natural history museum, since 1834 the Australian Museum, would have enlarged local interest in minerals by affording colonists access to a reference collection and, in turn, attracting donated specimens. In fact, the first printed catalogue, issued in 1837, lists few minerals of any sort and only one Australian sample. Although early opportunity for mineralogy was lost, it seems appropriate here to anticipate later developments. The Australian Museum employed no one to work on its minerals until 1859 when, briefly, it had the service of J. R. Gygax [1809?-1859].* Not until 1881 did the museum admit that its mineral collection, which by then had a large local component, deserved a curator and

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* John Rudolph Gygax, the man off-handedly described by Etheridge (1919: 387) as 'apparently a German of sorts' and mineralogist at the museum during August-October 1859, had an interesting career that deserves notice. Of Herzogenbuchsee, a place between Bern and Zurich in Switzerland, Gygax had medical training but early evinced interest in minerals. During a visit to the Azores in 1838 he found and collected on Fayal the

apppointed the French-born Felix Ratte [1845-1890] to the post (Chalmers, 1979). In earlier days no doubt it was thought simpler, and cheaper, to rely on acquisition of identified material, much of it therefore foreign. Most other museums in Australia, as they came into being, seem to have found that sort of practice attractive. None can be said to have fostered mineralogical study before the emergence of the Industrial and Technological Museum in Melbourne in 1870. It was an appropriate place for innovation; Melbourne itself did not exist when the Sydney museum began.

With negligible help from the Australian Museum, colonial interest in minerals began to prosper during the 1830s. Collections would still be sent overseas and occasionally come to scientific notice, some by unexpected ways. One of the first to receive careful examination, by Francis Alger [1807-1863] in Massachusetts, had been acquired in Calcutta. When Alger (1840) saw the material locality details were already lost; his identifications suggest sources in Tasmania. The merit of Alger's work lies in its descriptive detail; few, if any, Australian minerals had been given that sort of attention before. And, it must be admitted, the time when such work would be done in Australia was still remote. Nevertheless impressive changes had begun. The Australian College, a Presbyterian school then being founded in Sydney, advertised mineralogy as part of its curriculum (*Sydney Herald*, 19 Dec. 1831). A month earlier the school had announced the purchase for its use of the scientific apparatus of Andrew Ure [1778-1857]. Ure had recently relinquished a chair in the Andersonian University, Glasgow, to work in London and presumably no longer needed the equipment. One wonders if Ure also provided the mineral cabinet the school claimed to be importing at this time. Not surprisingly, the school and its plans for instruction in science received useful publicity in the *Herald*; the teacher, John McGarvie [1795-1853], Presbyterian clergyman and Glasgow graduate, was a proprietor of the newspaper. The Scots schoolmaster may have left no record of mineral observation but his role as a communicator is not to be underrated. Nor was McGarvie's an isolated advocacy of science during the 1830s. That decade saw the arrival in Australia of two highly individual characters, Jan (Johann, John) Lhotsky [1795-1866] and Johann Menge [1788-1852]. They too in their different ways were communicators but, unlike McGarvie, they were active searchers after, and students of, minerals. Their experience of minerals likewise had differed, Lhotsky academic and Menge practical, yet both brought to Australia aspects of the continental European tradition. This latter fact, of itself, is significant. As will be shown later, mineral science in the British colonies of Australia really emerged from that tradition.

Born at what was then Lemberg in Austrian Galicia (now the Polish city of Lwow), Lhotsky's ancestry was Bohemian and his education chiefly German in the cultural sense. After studying medicine for a while in Prague he moved to Vienna and then

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unusual mineral (Gygax, 1839) analysed for him by L. R. von Fellenberg [1809-1878]. The substance was named *fayalite* in 1840 by C. G. Gmelin [1792-1860]. By 1846 Gygax was in Ceylon (Sri Lanka) making a mineral survey for the local branch of the Royal Asiatic Society, a work extended under government commission during 1847-8. Apart from official reports, Gygax (1847) gave an outline of the subject he pioneered in Ceylon. He also curated the society's mineral collection and prepared at least one district mineral catalogue later (1855) issued by the society (see also Tennent, 1859: 31-32). It is not known when Gygax left Ceylon. He appears to have been there in August 1850 but lists of the Schweizerische Gesellschaft für gesammten Naturwissenschaften, of which he was a member, suggest residence in Java about 1853. By 1854, he was on the Australian goldfields, at Sofala, from which locality he supplied a collection of rocks and minerals for the Paris Exhibition Commissioners (1854). Though not listed in the N.S.W. medical register, Dr Gygax is known to have practised at Rylstone before removing to Sydney to undergo medical treatment perhaps early in 1859. Although Etheridge attributed Gygax's employment in the Australian Museum to the agency of R. J. Want, a letter of July 1859 in the Macleay Papers, Linnean Society of London, from W. B. Clarke to W. S. Macleay recommends Gygax for service. Gygax died suddenly at his lodgings 3 October 1859. A coroner reported his age as 50 and death by natural causes. As the coroner also heard that Gygax had intended soon to go to New Caledonia for geological work, 50 is taken as a more likely age than the 70 on Gygax's death certificate.

Berlin, becoming increasingly engaged by philosophy and politics. At Jena in 1819 he gained the doctor of philosophy degree. The first clear sign of interest in minerals appears in 1822 when he attended the lectures of A. J. M. Brochant de Villiers [1772-1840] in the Paris *École des Mines*. To those classes and to the tuition of C. F. C. Mohs [1773-1839] in Vienna, where Mohs became professor of mineralogy in 1826, Lhotsky would later ascribe his training in mineralogy (Vallance, 1977: 42). Both Brochant and Mohs had studied under A. G. Werner [1749-1817] at the *Bergakademie*, Freiberg; through them their pupil would become linked to the Wernerian school of thought. But Lhotsky had also developed other links, political links actively disfavoured by the Austrian government. His acquisition of mineralogy in fact was interrupted by imprisonment as a supposedly dangerous radical. He reached Sydney in 1832, a political exile hoping to prosper as a travelling collector of natural history material. By then he had to his credit a paper on the hydrous iron phosphate mineral cacoxenite (Vallance, 1977: 44) in a respected European journal. It may have been essentially a natural history study, without much evidence of crystallographic or chemical mastery, but the quality suffices to show that as a mineralogist in the New South Wales of his time Lhotsky was unrivalled.

In Australia Lhotsky tends to be remembered, if at all, as namer of the Snowy River and for a prophecy that one day a great city would stand at Limestone Plains. Limestone Plains is now occupied by the nation's capital, Canberra. But Lhotsky not only travelled about, he left an unfinished account (Lhotsky, 1835) of his journey to the Australian Alps that contains much on all branches of natural history, he collected and dealt in specimens, he gave public lectures on mineralogy, botany and zoology, and, withal, antagonized the establishment. Rebuffs seemed in no way to damage his self-esteem, as can be seen from his prospectus of a company (The Australian Mine Exploring Company) he hoped to float (*Sydney Monitor*, 8 August 1833): 'Dr. Lhotsky will ever remain of the opinion that he was the first person in this Colony who, by his lectures on Mineralogy and Geology, and by his travels and collections, raised and excited the interests of our community upon these highly interesting and important sciences . . . His lectures, his voyages and his collections (which last by the kind communications of many friends of science, are the general Repository of all minerals ever collected in the Country,) have thoroughly refuted the inveterate prejudice, that Australia is poor in Mineralogical productions, that it is altogether deficient in precious metals: as even with Dr. L.'s small means, he has found the vestiges of some of these.' In 1860 Lhotsky was to claim reward as a gold-finder (Vallance, 1977: 53); it had no more success than the prospecting venture, and perhaps failed for much the same reason. Lhotsky lacked powerful friends.

For a time in Sydney Lhotsky conducted the natural history section of a local magazine. The essay 'Mineralogy of Australia' (*New South Wales Magazine*, I(1), August 1833: 43-45), prepared in that office, is an interesting work. Much of it, certainly, is borrowed from earlier German sources but the geographical list of Australian minerals depends on closer knowledge. This list, the first of its kind to appear in Australia, is in my view a statement of Lhotsky's experience (Vallance, 1977: 46). It makes one regret the man had so little support in the colony. He moved to Hobart in 1836. Two years later he was in London, still hoping to improve human knowledge and society; he died there still an exile.

One of the lesser-known founders of the colony of South Australia, Johann Menge, like Lhotsky, was both idealist and enthusiast. Interest in minerals was shared but where Lhotsky had politics Menge kept religion, apparently a more socially-acceptable eccentricity. Few in South Australia seem to have thought Menge a nuisance. Also unlike Lhotsky, he came to minerals the practical way. At the age of 17 Menge began assisting

K. C. von Leonhard in the latter's mineral dealing business at Hanau. That he made some impact is clear from a record left by J. W. von Goethe [1749-1832] of a visit in July 1814 when Goethe was shown the stock by Leonhard's '*Faktor Joh. Menge*' (Goethe, 1949: 59). After Leonhard became professor of mineralogy at Heidelberg in 1817, Menge ran the business for a time. He then adopted the life of a travelling collector, first in Iceland (1819) and, later, in the Ural Mountains. His grasp of mineralogy can be judged from the published accounts of his travels (see Vallance, 1975: 41) and an uncommon monograph issued at Hanau (Menge, 1819). In eponymous honour Menge ranks among the unfortunates, indeed the doubly unfortunate. Through confusion among J. F. A. Breithaupt [1791-1873], H. J. Brooke [1771-1857], A. T. von Kupffer [1799-1865] and Gustav Rose [1798-1873], all of them students of Menge specimens from the Urals, 'mengite' twice emerged as a mineral name and twice dropped into synonymy, in one case supplanted by ilmenite (also of Menge's collecting) which has displaced our earlier menachanite.

This pioneer of Uralian mineralogy moved to London in 1830, as dealer in minerals and teacher of languages. In 1836 he became mine and quarry agent to the South Australian Company, then planning its colonizing experiment. Menge reached Australia in January 1837 but after little more than a year with the company his employment was terminated. He remained in South Australia to follow the style he plainly preferred, that of a solitary prospector. By 1840 his list of minerals found in the colony had appeared in an Adelaide newspaper. There and in later lists, published and unpublished (South Australian Archives), one finds idiosyncratic names like 'gawlerite' ('a red mineral') and 'sturtite' alongside others familiar and recognizable. Whatever Menge's 'sturtite' may have been, one can be confident it was not the same as the material from Broken Hill given that name in 1930. In South Australia Menge seems not to have maintained links with those who once welcomed his specimens. For minerals not identified by the simple field tests to which he now had access Menge simply devised his own names. It was no exemplary principle but, fortunately for mineral taxonomists, even those Menge names that got to print were not in recognized media. One suspects Menge did not care; his message was to fellow colonists, not to scientists abroad. He wanted local people to know about minerals and the mineral riches (including precious opal which he had found) beneath them. Menge, at least, was not surprised in 1841 when lead ore was found near Adelaide. With that and other finds soon after the then youngest of the Australian colonies became the first to develop a metalliferous mining industry, lead and copper mainly, but also gold. No one denied the inspirer of colonial metal mining his Australian soubriquet 'Menge the Mineralogist' (Cawthorne, 1859).

By the mid-1840s South Australia was attracting people with practical knowledge of minerals, miners, assayers and the like. The first monograph on geology and mineralogy to appear in Australia (Burr, 1846), a work by the then deputy surveyor-general of South Australia Thomas Burr [1813?-1866], even had a local market; other copies went overseas to publicize the colony's mineral riches. A contemporary work (Dutton, 1846) by F. S. Dutton [1818-1877] had a like purpose. It has the added interest of reference to the chemical and mineralogical skills of a fellow-colonist C. D. E. Fortnum [1820-1899] and chemical data on South Australian atacamite supplied by the Dr Ure who had sold his apparatus to Sydney College. Information, including data from colonial analysts, among whom Edward Davy [1806-1885] was already prominent in Adelaide, began to attract attention in Europe (e.g. Tremenheere, 1846). So also did collections of South Australian ore minerals. These were no longer accidental pickings along the path of an explorer but suites that could invite study of associations. James Apjohn [1796-1886] in Dublin (Apjohn, 1851) and A. L. Sack [fl. 1849-1852+] at Halle (Sack, 1851) were among the first to respond.

Overseas awareness of Australian minerals was being re-kindled, and far more productively than in the days of Sydneia. A sign of how that new interest grew can be traced through the American *A System of Mineralogy* by J. D. Dana [1813-1895]. The second edition (1844) mentions only coal and wood opal from Australia. To these in the third edition (1850) are added alunogen, galena, chalcopyrite, cuprite and apophyllite; by the fourth (1853) gold, diamond, corundum and atacamite from Australia also have their places. Even these, of course, were not exhaustive. Dana, writing at Yale, introduced only what he considered of general interest, whether in terms of occurrence or more often by dint of some supplementary information. He was, however, better placed than most of his foreign colleagues; he had visited Sydney in 1839-40 and travelled a bit in New South Wales. His concerns then were more broadly geological though his account of observations in the colony published in 1849 includes illustrated notes on the calcite pseudomorphs at Glendon (see Dana, 1884: 29, 34) now known as glendonites. The identity of the pseudomorphed phase for these and similar bodies in other parts of the world has long been a puzzle. Shearman and Smith (1985) suggest they derive from the calcium carbonate hexahydrate ikaite. Curiously, Dana seems to have found no place even in the fourth edition of *A System* . . . for these pseudomorphs from New South Wales, though comparable examples were mentioned under gaylussite and 'natrocalcite'. But then he also overlooked the remarkable malachite and azurite being yielded by South Australia. To discover that these were already known overseas, one has only to inspect the frontispiece to Varley (1849) and the catalogues and reports of the great exhibition of 1851 in London.

The success of that London exhibition set a style emulated through the rest of the century. Exhibitions became show-places for Australia's minerals; their catalogues afford means for tracing progress in mining activity and, less directly, in mineralogy. Change came swiftly. Even before the 1851 exhibition had closed its doors for the last time, word was abroad of gold discoveries in New South Wales and of people flocking there in pursuit. Copper mines had been operating in the original colony for a few years, like lead-mining in Western Australia as offshoots of South Australian enterprise. Such activities, however, had no defence against the lure of gold and when, later in 1851, the Port Phillip district, newly detached from New South Wales as the colony of Victoria, was also found to be auriferous, southeastern Australia began to repeat the Californian experience of 1849. This was indeed a turning point. The resident interest in Australian minerals that had grown slowly over half a century, and more particularly in the decade since metal mining began, became surpassing. From the change arose circumstances that would allow development of more or less independent studies of scientific mineralogy in Australia.

THE GOLDEN LEGACY: AUSTRALIAN MINERAL SCIENCE

From 1851, gold transformed Australian society and nowhere more plainly than in Melbourne, a quiet provincial town that soon had to serve as capital of the country's richest colony, Victoria. At Sydney a university was in due process of creation before the gold rushes erupted; teaching began in 1852. No provision had been made for a teacher of mineralogy but, as a manifestation of local concern, one notes the gift of Edward Deas-Thomson [1800-1879] in 1854 of funds to establish within the university three scholarships to encourage natural science. The third of those scholarships was for mineralogy. By 1855 Melbourne also had a university, a new natural history museum and, significantly ahead of Sydney, the beginnings of a well-organized geological survey and two scientific societies about to publish journals. If all these depended on minerals, not one of them at the time employed a mineralogist. The founding scientific professors in the universities, in Sydney a chemist John Smith [1821-1885], in Melbourne a palaeontologist Frederick McCoy [1817-1899], only nodded to minerals in their classes, though Smith had sufficient curiosity to tour the goldfields in 1860. McCoy, by establishing control over the Melbourne museum and close links with the government mining department and geological survey, gained the means to acquire minerals and advance their study; he seems to have been content with acquisition. Neither universities nor natural history museums would provide the first institutional milieu in Australia for mineralogical research. How strikingly that matched the example of the colonies' motherland.

In 1850 both Oxford and Cambridge claimed to have professors of mineralogy. Cambridge indeed had in its chair the celebrated crystallographer W. H. Miller [1801-1880] but where were the mineralogists he trained? Oxford did not even have a mineralogist as professor of mineralogy until M. H. N. Story-Maskelyne [1823-1911] succeeded the geologist William Buckland [1784-1856] in 1856. Furthermore, the influence of men like Buckland had helped fix British earth science interests on palaeontology and stratigraphy. The British Museum's extensive collection of minerals enjoyed no specialist keeper until 1857 when Story-Maskelyne added that duty to his office at Oxford. Notwithstanding some notable individual achievements, British mineralogy was backward by continental standards at the middle of the nineteenth century. Great Britain had done practically nothing to match the system of scientific and technical training begun in Europe over the past hundred years. British shortcomings in this regard seem only to have been admitted and repaired with the 1851 exhibition. One consequence was the establishment in London of a Royal College of Science, embracing among others a school of mines, for which European precedent went back at least to 1765 and the Freiberg *Bergakademie*. Graduates of the London college in time would contribute to Australian science and industry but the early lead, almost of necessity, came from Europe. There was no contemporary British work on Australian minerals to approach in quality researches published in the period 1855-75 by, for instance, A. L. O. L. Des Cloizeaux [1817-1897] on quartz, J. F. C. Klein [1842-1907] on atacamite, Albrecht Schrauf [1837-1897] on azurite and brochantite, and V. L. von Zepharovich [1830-1890] also on atacamite. Even Australian samples in the British Museum, of malachite, chabazite and others, came to notice through the attention of Viktor von Lang [1838-1921].

Scientific interest in the copper minerals of South Australia plainly continued. Indeed alluvial gold-diggings could hardly compete with rock mining as the source of fine crystal specimens. Few gold nuggets were left for study or display though analyses such as those of G. H. B. Kerl [1824-1905] in Germany and A. B. Northcote [1831-1869] in London early revealed the contrasted compositions of Australian and Californian gold (Kerl, 1853; Northcote, 1853). Gem stones from auriferous drifts received attention from G. M. Stephen [1812-1894] and, later, J. I. Bleasdale [1822-1884] (Stephen, 1854; Bleasdale, 1866); according to Bleasdale, Stephen coined the name *barklyite* for a nearly-opaque, magenta-coloured variety of corundum found in the Victorian drifts. The label was meant to honour Sir Henry Barkly [1815-1894], governor of Victoria 1856-63, but where Stephen first announced it has not been traced. It receives comment here because, unlike Menge's terms honouring local notables, this one did get into mineralogical literature. Of other minerals turned up in alluvial workings, one notes cassiterite from the Ovens River, samples of which were seen in Sydney by F. H. Storer [1832-1915], chemist and geologist to the U.S. North Pacific Exploring Expedition. In a letter dated U.S.S. *Vincennes*, Port Jackson, 4 January 1854 and printed in the *Sydney Morning Herald*, Storer gave some account of his examination. There were also early reports of natural gold crystals from drifts, for instance by Stephens (1854), but similar material was regarded by Lang (1863) as artificial. Natural gold crystals became well-known and prized after the advent of reef-mining. The status of zinc reported to occur in basalt near Melbourne by the German-born artist and naturalist L. P. H. Becker [1808-1861], and regarded by him (Becker, 1857) as native, raises kindred problems.* Here was the first claim that elementary zinc occurred in nature. A few others, some from Australia, have followed. Opinion as to whether these are instances of genuine native element has varied over the years; one suspects a more favourable view is beginning to return. Unfortunately, Becker's material has long since disappeared but no one can deny the interest of this, his mineralogical legacy.

Becker (1857) made a significant acknowledgement, to 'Mr George Ulrich (a gentleman employed by the Mining Commission, and whose ability, as also care and exactness in analysing inorganic bodies is well known)'. Perhaps Ulrich had a hand also with the mineralogical remarks in the zoologist Blandowski's accounts of excursions in Victoria that were published in the same volume as Becker's paper. J. W. T. L. Blandowski [1822-1878?], naturalist at the Melbourne museum, clearly held some concern for minerals and might have done more useful work in that regard. His falling-out with McCoy in 1856, however, over arrangements for the museum put an end to such hope. But from what might have been we return to what was. In 1857 G. H. F. Ulrich [1830-1900], the man thanked by Becker, joined the geological survey in Victoria. The new recruit had qualified at the *Bergakademie* in Clausthal as a mining geologist. To the mastery of mineral science gained there Ulrich, since his arrival at Melbourne in 1853, had added experience as a digger on the goldfields and then as an assistant to the mining commission. Although assigned to the survey's field-mapping programme Ulrich quickly demonstrated his particular interest in a paper describing the uncommon minerals pharmacosiderite and scorodite from auriferous quartz reefs at Tarrengower, Victoria (Ulrich, 1857). When, in 1862, the survey added a chemist to its staff, Ulrich took the opportunity to promote the study of samples collected by field parties. C. S. Wood [1837-1864], the first chemist, however had little chance to make an impact; he was already ailing when appointed. Ulrich had to await the arrival of his successor, J. C. Newbery [1843-1895], a graduate of Harvard University but, like Wood, also trained in the new London college. With the chemists as collaborators, Ulrich could look back and forgive the pushy R. B. Smyth [1830-1889] for publishing on a supposed new mineral (Smyth, 1858) and using Ulrich's inconclusive remarks without permission. Ulrich, in fact, soon after showed the new mineral was only bournonite.

In a work (Selwyn and Ulrich, 1866), prepared with his survey chief as an exhibition essay, Ulrich offered a descriptive list of Victorian minerals, mostly of his determining. Three years later came an announcement that, for mineral science in Australia, retains great significance. It was the first record from Australia of a mineral species new to science and still recognized as valid. The novelty of the material Ulrich called *maldonite* after its source locality had been established in Melbourne and its formula Au_2Bi fixed from Newbery's analyses. However, what ought to have been a year for rejoicing turned out otherwise. Economic uncertainty had succeeded golden prosperity in Victoria. To save money the government disbanded its geological survey. Fortunately for mineralogy, and Ulrich and Newbery, new opportunity appeared in Melbourne. At the end of 1869 the government agreed to reorganize its public museums (Pescott, 1954). The mineral, mining and agricultural collections of what had become McCoy's museum were transferred to a new Industrial and Technological Museum. There, at last, minerals would be in sure hands; in 1870 Newbery became scientific superintendent and Ulrich in effect his curator of minerals in the new institution. The fruitful

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* So does the tin found in stream-washings near Oban, New South Wales, and reported as native element by F. A. Genth [1820-1893] of Philadelphia (Genth, 1886: 30-31).

collaboration of these two continued at the museum until 1878 when Ulrich left to become professor of mining at Dunedin, New Zealand.

Ulrich's curatorship practically began with a notable work (Ulrich, 1870) that supplied further detail on maldonite as well as many new data on ore minerals, on zeolites, on struvite found in Skipton Cave near Ballarat, and two materials Ulrich named 'selwynite' and 'talcosite', thinking them new species. The latter need not detain us, they were long ago shown to be fine-grained mixtures, but the study of struvite deserves remark. Besides analyses made by Newbery's assistant E. F. Pittman [1849-1932], Ulrich presented a list of angle measurements on crystals and other descriptive detail. If those measurements were made by Ulrich, and he acknowledges no source, they stand as the earliest results of crystal goniometry obtained and published in Australia.

At the museum Ulrich and Newbery continued their study of the Skipton guano, a sort of material many mineralogists might consider uninviting. Yet thanks to the skill and enterprise of this pair Skipton Cave was to become the most prolific single source of new mineral species in colonial Australia. Reference works attribute authorship of *hannayite* and *newberyite* (Table 1), both from Skipton, to Ulrich's friend J. J. G. vom Rath [1830-1888] of Bonn. While there is no question Rath published the names, and contributed crystal data, it must be pointed out the material went to him from Melbourne with chemical and other detail that indicated the novelty was already recognized. Ulrich and Newbery deserve to be known as co-authors; so does a young chemist R. W. E. MacIvor [1856?-1917]* who made many of the analyses and suggested the name *hannayite*. Hannay (1878), incidentally, offers another Australian link but the mineral from Victoria (and not supplied by MacIvor!) there described as 'youngite', a sulphide of zinc and lead, is now taken to be a variety of sphalerite and not a distinct mineral species. Returning to *hannayite*, it should be noted that even Rath (1879) admitted MacIvor's essential part in the discovery. Ulrich and Newbery had befriended MacIvor on his arrival in Melbourne and, with the newcomer's interest in fertilizers, it was natural he should be drawn into the study of the Skipton guano. MacIvor, in fact, would take over the work after Ulrich's departure for New Zealand.

Two more new phosphate species from Skipton were announced by MacIvor (1887) on his return to London. However, only one of the names he then proposed, *dittmarite*, is still considered valid. The problem with the other arose from no failure in MacIvor's science but incompleteness in the published statement. In 1887 he had suggested

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* It is cause for regret we know so little about this active contributor to Australian mineralogy. No obituary has been found, but the death certificate for Ralph Waldo Emerson MacIvor (General Register Office, London) shows he died, aged 61, at his residence in Harrow, Middlesex, on 1 April 1917. Fruitless search of birth records for 1855-7 in London and Edinburgh suggests he was born outside England, Wales or Scotland. Robertson (1982: 258), however, points to early residence in Scotland and association with John Ballantyne Hannay [1855-1931] in chemical experiments at the latter's parental home at Helensburgh. That youthful association is recalled in the mineral name *hannayite*. MacIvor attended the Andersonian University, Glasgow, and was for a time assistant professor of chemistry there. Wilhelm Dittmar [1833-1892] and Arnulf Schertel [1841-1902], both remembered in Australian minerals named by MacIvor, were his teachers and/or colleagues in Glasgow.

MacIvor moved to Victoria, probably late in 1875, at the invitation of a wealthy landowner, Sir William Clarke [1831-1897], to set up a laboratory and provide farmers with lectures and advice on agricultural chemistry. While in Melbourne he edited *MacIvor's Farmers' Year Book* and wrote *The Chemistry of Agriculture* (Melbourne, 1879) and *Agricultural Chemistry* (Brisbane, 1879). His portrait will be found in J. Periam's *The Pictorial Home and Farm Manual* (Sydney, 1885), which MacIvor adapted for Australasian readers. He was an unsuccessful applicant for the chair of chemistry at the University of Melbourne in 1882 (Radford, 1978: 29), and a member of the Royal Society of Victoria 1880-3. About 1887 MacIvor came to Sydney as head of the agricultural department in the technical college but seems to have stayed barely a year. He returned to London where he was active for some two decades as a consulting chemist. In his early years at least MacIvor was member or fellow of various chemical societies (Radford, 1978: 23). He was F.R.G.S. 1887-*c*.97 but at no stage seems to have been a notably active supporter of scientific societies.

TABLE 1

Valid new mineral species yielded by Australia in colonial time (1788-1900)

Name	Formula	Colony	Author(s)	Year
MALDONITE	Au_2Bi	Victoria	Ulrich	1869
HANNAYITE	$(NH_4)_2Mg_3H_4(PO_4)_4.8H_2O$	Victoria	Rath (Ulrich/MacIvor)	1878/9
NEWBERYITE	$MgHPO_4.3H_2O$	Victoria	Rath (Ulrich/MacIvor)	1879
DITTMARITE	$(NH_4)MgPO_4.H_2O$	Victoria	MacIvor	1887
SCHERTELITE	$(NH_4)_2MgH_2(PO_4)_2.4H_2O$	Victoria	(MacIvor)	1906
syn: schertalite (MacIvor, 1902), muellerite (MacIvor, 1887)				
MARSHITE	CuI	New South Wales	Liversidge	1892
DUNDASITE	$PbAl_2(CO_3)_2(OH)_4.H_2O$	Tasmania	Petterd	1892
STIBIOTANTALITE	$SbTaO_4$	Western Australia	Goyder	1893
WILLYAMITE	(Co,Ni)SbS	New South Wales	Pittman	1893
HEAZLEWOODITE	Ni_3S_2	Tasmania	Petterd	1896
RASPITE	$PbWO_4$	New South Wales	Hlawatsch	1897
MIERSITE	(Ag,Cu)I	New South Wales	Spencer	1898
SULVANITE	Cu_3VS_4	South Australia	Goyder	1900

'muellerite' (to honour the botanist F. J. H. von Mueller [1825-1896]) as name for a phase identified only by chemical formula. Some years later, an Italian mineralogist applied a similar name to another mineral described in some detail. Ironically, Zambonini's 'müllerite' (1899) is now discredited but at the time, though junior to MacIvor's term, it was preferred. So MacIvor (1902) amended his 'muellerite' to 'schertalite', which in 1906 had to be corrected to *schertelite*. MacIvor had misspelled the name of his Glasgow friend, who had since followed a distinguished career as professor in the *Bergakademie* at Freiberg. *Dittmarite* and *schertelite* are names credited to MacIvor and although the second belongs to this century both represent discoveries from colonial Australia. No one in the Australian colonies had more success recognizing valid new mineral species than MacIvor, and no one is more undeservedly overlooked.

The year 1888 marked the centenary of British settlement of Australia; the separate colonies that became states of a commonwealth at federation in 1901 were already firmly established. In that century Australia had yielded five mineral species new to science and still deemed valid. Every one of them was from Victoria and had been recognized as novel in Melbourne. And in some way Ulrich was connected with each. That, I believe, is the measure of G. H. F. Ulrich's achievement as Australian mineralogist and inspirer of mineralogists. With the mastery he brought from Germany, he was surely the founder of scientific mineralogy in Australia; and he made Melbourne the founding centre. Of course, he could at times be misled, as 'selwynite' and 'talcosite' showed, but such fine-grained materials not evidently-crystallized would continue to raise problems until the advent of X-ray diffraction methods. Edward Goldsmith [1833?-1925] of Philadelphia had been similarly misled into thinking an alteration product on stibnite, part of a collection of Victorian minerals exhibited in Philadelphia in 1876, was a new mineral. The 'stibianite' of Goldsmith (1878) was long ago discredited.

As Ulrich's inspiration in Melbourne faded, so the pace and quality of mineralogical research there subsided. His successor at the museum until 1892, the Australian-born O. R. Rule [1835-1926], though an energetic collector, made no particular impact on science (Coulsell, 1980). A young man fresh from Ulrich's classes at Dunedin followed Rule but he, R. H. Walcott [1870-1936], soon found himself enmeshed in museum politics that led to his mineral collection returning to the older natural history museum. Walcott had few opportunities to show scientific mettle in his early Melbourne years. Yet Ulrich's going had not quite extinguished Victoria's mineralogical light. A candle burned, a miner's candle. During the 1870s mining schools had sprung up on the goldfields, in Ballarat (1870) and Bendigo (1873) at the start. These became the places where much of the basic mineralogy taught in the colony was offered. From men like the chemist A. M. Smith [1844-1926] and the geologist F. M. Krause [1841-1918] Victorian students learned there was more to minerals than was extractable in a treatment works. Krause (1896) aimed to serve the needs of such students.

Meanwhile, leadership in Australian mineralogical research had passed to Sydney. There had been signs, even while Ulrich lived in Melbourne, of activity in the older city that could make it a rival. With Ulrich's departure any rivalry became one-sided in favour of Sydney. The shift involved a distinct contrast of styles. Ulrich had made the Technological Museum in Melbourne a centre for excellence in mineralogy; in Sydney the science became fixed in the university. Ulrich's collaboration with Newbery and other chemists brought an enviable breadth to mineralogical research in Melbourne. The results that began coming from Sydney about 1870 were from the start more focused, more particularly chemical. Sydney's mineral science reflected the educational origins of its leading exponents, Britons trained as chemists in the United Kingdom. They, it seemed, possessed little of the enthusiasm for crystallography and physical mineralogy enjoyed by mineralogists like Ulrich of German training. The distinction of mineralogy in colonial Sydney arose from the quality of its chemists.

In 1866 A. M. Thomson [1841-1871] joined the University of Sydney to assist in the teaching of practical chemistry and, as reader, to offer instruction in geology and mineralogy. Of these latter he was soon promoted professor, the first in Australia. At the end of a sadly-short career his legacy included several papers, a book on minerals (Thomson, 1869) of an elementary and practical character, the beginnings of a rock and mineral collection at the university, and many unpublished analyses that passed to his successor Archibald Liversidge [1847-1927], like Thomson a product of the London college (Branagan, 1973: 3-6). Two years after coming to Sydney, Liversidge in 1874 became professor of geology and mineralogy; from 1882 until his retirement in 1907 he was professor of chemistry, and of mineralogy also for much of that time. If by 1888 Victoria had five new mineral species to its credit, New South Wales had a work of information about minerals unmatched in colonial Australia. Liversidge (1888) was the third edition of a collection begun before 1874 and first published in 1876. In the history by P. H. Groth [1843-1927], *'das wertvolle Werk'* of Liversidge is rated the outstanding source for Australian mineralogy (Groth, 1926: 159). Certainly, by 1888 it had become an impressive tome, a remarkable token of what, in the main, Liversidge himself had done. But already Liversidge's achievement went beyond that of an assiduous individual investigator. His position and influence enabled him to promote his favoured science elsewhere in Sydney.

By 1888 Liversidge could recall the establishment of the geological survey of New South Wales and of a government mining museum that lost its collection by fire in 1882 and had started anew. Later, with appointment of the London-trained G. W. Card [1865-1943] in 1892 the museum, in collaboration with geological survey chemists, would gain respect as a place for mineralogical research. For Liversidge, however, his closest ties outside the university remained with the Australian Museum which, like Thomson before him, he served as a trustee. Both men gave unstinting honorary attention to the museum's minerals. Thomson indeed is acknowledged as identifier of the Australian material listed in the museum's first mineral catalogue (Krefft, 1873), compiled by the zoologist J. L. G. Krefft [1830-1881], secretary and curator of the whole museum. Liversidge continued what Thomson began and his hand was surely behind the eventual decision to employ a curator of minerals in 1881 (see p. 161). That Ratte (1885) could list a collection apparently more than doubled in size in twelve years reflected well on an active curator and a no less active trustee. Ratte however seems to have found little time for original research on minerals. He may, in fact, have possessed neither the means nor experience to go much further than straightforward determinative mineralogy, but any doubts on that score became unhappily irrelevant when Ratte suicided after nine years in office. His successor, Thomas Cooksey [1864-1945], a chemist trained in England and Germany, held the post until 1899 when he turned to other fields. Cooksey had published a few mineralogical notes, none of particular importance, and it was not until after Charles Anderson [1876-1944] from Edinburgh joined the museum in 1901 that research there in mineral science became impressive. Anderson's expertise in crystallography and physical as well as chemical mineralogy was something hitherto rare among British graduates settling in Australia. Anderson brought to Australia shining evidence of how, at last, mineralogical training in Great Britain had learned to profit from continental European experience. Although his Australian career was entirely post-colonial, students of that earlier period find his bibliography (Anderson, 1916) a valued key.

If Liversidge (1888) could point to no new mineral species from New South Wales, there were already some remarkable finds from Broken Hill to report. Discovery of silver-lead-zinc deposits there in 1883 had opened a new phase in colonial mining activity and a major source of fine mineral specimens (Worner and Mitchell, 1983). From Broken Hill were to come all the new species contributed to mineralogy by colonial New South Wales. Miners, managers and townspeople (among them, notably, the publican E. H. Aldridge [d. 1909]) at Broken Hill succumbed to the brilliance of crystallized ore and gangue minerals. As Australia's best-known mineralogist and the only one a fellow of the Royal Society of London, Liversidge became the referee for those local mineral collectors and amateur mineralogists. The natural copper iodide Liversidge termed *marshite* in 1892 appeared in analysed samples sent to him by C. W. Marsh [fl. 1890-1909+] of the British Mine. In view of Marsh's eponymous fame it is to be hoped more can be discovered about his career; I lose track of him on the mineral fields of Western Australia. The variety and quality of Broken Hill specimens quickly attracted the notice of overseas mineralogists. Among such material at the British Museum L. J. Spencer [1870-1959] in 1898 recognized the silver analogue of marshite which he named *miersite* after the British mineralogist H. A. Miers [1858-1942]. A year earlier Carl Hlawatsch [1870-1947] in Vienna found the new mineral *raspite*, named for the discoverer of the Broken Hill deposits Charles Rasp [1846-1907], in collections made by Heinrich von Foullon [1850-1896] during his ill-fated tour. But even locally not everything went to Liversidge. The cobalt nickel antimony sulphide called *willyamite* (a name still current, though redefined (Cabri *et al.*, 1970), it derives from the intended title for the town of Broken Hill) in 1893 by E. F. Pittman, once Newbery's assistant in Melbourne and at the time government geologist of New South Wales, had been sent to the geological survey by the mine manager and amateur of minerals George Smith [1861-1944].

The literature of Australian mineralogy in late colonial times has many contributions from informed amateurs like George Smith. D. A. Porter [1851-1928], an inspector of school buildings in the New England region of New South Wales, for instance emerged as a leading authority on the minerals of that region. Porter's papers, and those of others mentioned here, are listed in Anderson (1916). However, preeminent among amateurs was the Tasmanian dealer in boots and shoes W. F. Petterd [1849-1910]. 'Petterdite', erected by his geological friend W. H. Twelvetrees [1848-1919], has alas been discredited but Petterd himself is remembered as author of *dundasite* (1892) and *heazlewoodite* (1896), both for type localities in his native Tasmania, and of the first extensive census of Tasmanian minerals (Petterd, 1893).

Petterd's census was but one of a number that expressed the remarkable growth of knowledge about Australian minerals during the last few decades of the nineteenth century. Again, Liversidge inspired the effort. At its inaugural meeting in Sydney in 1888 the Australasian Association for the Advancement of Science, a body effectively founded by Liversidge, set up a continuing committee for mineral census with Liversidge its secretary. Two years later progress was reported in Melbourne, the committee papers being printed with the record of that second congress. For the occasion Liversidge supplied additions relating to New South Wales since his book of 1888. E. B. Lindon [1860-1891], briefly mineralogist to the Queensland Museum and since 1887 in practice as a mining engineer, likewise revised an earlier list (Lindon, 1887). The colony of Queensland, not previously mentioned here, already had a flourishing mining industry but few facilities for higher education and scientific research. Such mineral investigations as were conducted in Queensland took place mainly in the natural history museum (Queensland Museum) in Brisbane or in the geological survey and government chemical laboratory. Serviceable links existed between them; indeed the government chemist K. T. Staiger [1833-1888] in the 1870s was also honorary custodian of the museum and curator of its minerals. Between him and Lindon the minerals were in the care of one H. F. Wallmann (Vallance, 1983b: 272), a shadowy figure remembered, if at all, for a paper on mineral pseudomorphs. Colonial Queensland in one regard, however, gave a lead to Australia. It alone, as far as I am aware, employed what became known as travelling mineralogical lecturers. One such lecturer, A. W. Clarke [1857?-1893], was a member of Liversidge's committee; later, briefly, he served as government chemist in Queensland.

Ulrich's successor, Rule, was one of two Victorians on the mineral census committee but the colony once preeminent in Australian mineralogy furnished nothing in 1890. The deficiency was not repaired until the appearance of Atkinson (1897), to which Walcott (1901) added more detail. Who this worthy compiler John A. Atkinson was remains for me a mystery. His claim 'that Victoria seems to rank highest of the colonies in the number of its mineral species' (Atkinson, 1897: 69) suggests local pride. Yet the work deserves respect for what seems critical treatment. One notes, for instance, no mention by Atkinson (or Walcott for that matter) of the mineral from Yarraville analysed and described by Thomas Steel [1858-1925] as near dawsonite in composition (Steel, 1890), a record even taken up by Anderson (1916). Steel's data make little sense; I am impressed that Atkinson ignored them.

Strangely, Liversidge's committee had no representative from South Australia, where metal-mining in this country began. There had long been a museum (Hale, 1956) in Adelaide, and a university there since 1875. Neither had a mineralogist though the professor of chemistry, E. H. Rennie [1852-1927], born in Sydney and a student of A. M. Thomson, once took an interest in the so-called rubies (garnets) of South Australia. In 1899 his sometime lecturer, A. J. Higgin [1860?-1922], brought to science an account of the rare nickel telluride mineral melonite from Worturpa. In general, however, the Adelaide university chemists did not follow Liversidge into mineralogy. H. Y. L. Brown [1844-1928], government geologist in the colony from 1882, through his many reports helped spread information about the distribution of minerals but mineralogy itself depended more on amateurs like the metallurgist T. C. Cloud [1847-1918] of the Wallaroo mines. Cloud, who gave spare-time honorary service to the museum, had prepared a local mineral census (Cloud, 1883). He revised it for Liversidge to present in the name of South Australia in 1890. By then Cloud was not alone. Schools of mines in Adelaide and regional centres had begun to spread interest in minerals. J. J. East [fl. 1884-1911+], another of our little-known pioneers, deserves mention. It was East, while attached to the Adelaide school of mines, who arranged the examination of material from Greenbushes, Western Australia, in which G. W. Goyder [1855-1940] found the new mineral *stibiotantalite* (1893). For a time government chemist in his native South Australia, Goyder was also responsible for recognizing the only new mineral species yielded by that colony, *sulvanite* (1900) from the Burra district.

There was no one from Western Australia on the census committee and in 1890 no report. After the mining episode of the 1840s that colony, vast in area, had all but abandoned such activity until the discovery of gold there in the 1880s. Yet the colonists' interest in minerals had not quite vanished over the intervening years. Mainly through the efforts of men like the clergyman C. G. Nicolay [1815-1897] minerals gained places in Western Australian displays at the international and intercolonial exhibitions that became such a feature in the wake of London and 1851. Nicolay himself kept a geological museum at Fremantle and this in 1889 became part of a public natural history museum in the capital, Perth. Two years later B. H. Woodward [1846-1916], of a family well-known in British geological circles, was appointed custodian and assayer at the new museum. He seems to have left few signs of activity as a mineralogist. In that regard his cousin H. P. Woodward [1858-1917], sometime government geologist of Western Australia, did better. H. P. Woodward's geological and mining reports contain many notes on mineral occurrences. One might add that they are reasonably typical of the sort of mineral work done by colonial geological surveys in Australia at this time — estimable, but mineralogically unexciting. In 1896, however, A. G. Holroyd [1865?-1931] announced the discovery of telluride ore in the gold mines at Kalgoorlie. If Broken Hill hitherto had been an Australian focus for mineralogists across the world, it now was forced to share interest with Kalgoorlie and Coolgardie. In the ensuing excitement two supposed new telluride species emerged, the 'kalgoorlite' (1898) of Pittman and 'coolgardite' (1901) of M. A. Carnot [1839-1920] in Paris. Both were discredited as mixtures by L. J. Spencer in 1903. But that is already beyond our period.

The significant achievements in Western Australian mineralogy really belong to the present century. Yet even before the Australian colonies came together as states of a commonwealth in 1901 one of the principal makers of that western achievement had started his life's work. In 1897, E. S. Simpson [1875-1939], a Sydney graduate trained under Liversidge, joined the mines department in Perth as its mineralogist and chief chemist. Three volumes of the posthumously-published *Minerals of Western Australia* bear witness to Simpson's devoted service. One wonders if his teacher's book of 1888 inspired emulation. At any rate it is a notable fact that, so far, only New South Wales and Western Australia have been thus served. In that regard the mineralogical legacy from Australia's colonial period has yet to be fully developed. But the seemingly-diminished tendency to compile grand regional mineralogies during the present century has been offset by successful re-establishment of broadly-based mineral research.

At the outset of Australian colonization, interest in minerals had been delayed by British partiality, the sort of partiality that allowed mineral nature chiefly a utilitarian value. Such value, not considered relevant by the original planners, however gained recognition as Australian exploration and settlement advanced through the nineteenth century. And with exploitative interest came also that of science. Nevertheless, at the end of the colonial period Australian mineral studies were still dominated by British partiality, this time that of chemists trained in the United Kingdom before about 1880. The breadth of contemporary German mineralogy Ulrich had brought to Melbourne effectively left with him. His chemist friends Newbery and MacIvor shared background with Liversidge, whose claim to leadership of the science in Australia was already clear. Under the chemists, distinguished as they were, physical aspects of mineralogy received scant attention. Crystallography, in particular, was left largely to outsiders, in Europe, in the United States of America and in Great Britain where, increasingly towards the end of the century, mineralogists began making study-pilgrimages to Europe.

The contrast of styles here and abroad is evident in the treatment of new species from Broken Hill during the 1890s. The definition of *marshite*, for instance, emerged from the data of analytical chemistry provided by Marsh and Liversidge. On the other hand, Hlawatsch's treatment of *raspite* embraced not only chemical data but a wealth of morphological information. Even Spencer's record of *miersite*, though brief, noted the crystal character of that mineral, and of *marshite.* The Englishman Spencer, by the way, after leaving Cambridge had studied with Paul Groth in Munich as preparation for duty at the British Museum (Smith, 1959: 182).

Nor was the contrast confined to new species. The crystallographic investigation of Tasmanian crocoite by Charles Palache [1869-1954] of Harvard University (Palache, 1896) added a new dimension to knowledge of that colony's minerals. Other overseas studies took up what had been pioneered long before. Thus the morphological observations of Australian topaz (Eakle, 1898) by the Stanford mineralogist A. S. Eakle [1862-1931] stand in succession to what Haüy's student Armand Levy [1791-1841] in a way began with his records of Australian samples in a British collection (Levy, 1838: I, 267-268, 274-275, 286).

It is not my intention, however, to parade such deficiencies which, in any case, began to be put in process of repair with the arrival in 1901 of Charles Anderson at the Australian Museum. From its uncertain beginnings in a country scarcely known, the scientific study of minerals here had become firmly established before the separate Crown colonies became one nation. Mineralogy in colonial Australia may not have changed the course of the science but the country had already contributed an impressive tally of substances never before recognized in nature, substances that are still admitted as valid mineral species.

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APPENDIX

Botanists, Mineralogists, and Zoologists appointed to the French Expedition to Australia 1800-04

BOTANISTS

1. André MICHAUX [1746-1802] — *Dict. Amer. Biogr.* 12: 591-592

A man with far wider experience than any of his colleagues on the expedition, Michaux had already travelled as a botanist in France, in Iran and Iraq, and in North America, and held the rank of associate in the *Institut National* (Cornell, 1965: 57). The document quoted by Cornell indicates Michaux's place as 'first botanist', a statement hard to reconcile with Bory de St Vincent's (1805: 6) claim that Michaux travelled on the *Naturaliste* as a passenger free to make his own plans. At any rate, on arrival at Mauritius (March 1801) Michaux informed the commander, Baudin, he would accompany him no further. He left the expedition to botanize privately on Mauritius and in Madagascar, where he died.

2. André Pierre LEDRU [1761-1825] — Michaud *Biogr. Univers.* 23: 565-566

Formerly a clergyman, Ledru obtained a teaching post in the *École Centrale*, Le Mans, after returning from the voyage (1796-8) to the West Indies led by Baudin, and of which he became chronicler (Ledru, 1810). Appointed second botanist to the Australian expedition, Ledru had to withdraw for private reasons a few months before it departed 19 October 1800. The vacancy created was not filled by a botanist but by an extra junior zoologist, an arrangement that matched Georges Cuvier's interest but extraordinary if Michaux were known to be only a passenger.

élève 1. Jean Baptiste Louis Claude Théodore LESCHENAULT DE LA TOUR [1773-1826] — Michaud *Biogr. Univers.* 24: 294 (but errors)

An *élève* at the *Muséum* in Paris when appointed, Leschenault de la Tour was to serve as the expedition's only botanist after his colleagues found reasons to stay at Mauritius on the outward voyage. He had to be left sick at Timor in June 1803 during the *Géographe*'s return run but went on to botanize in Java before making his own way back to France in 1807. His remarks on the Australian flora were printed in Péron and Freycinet (1816: 358-372). During the Australian voyage Leschenault de la Tour, of necessity, was committed to botany but later, in the years 1816-21 of travel in India and Ceylon, he envinced notable talent as an observer and collector of minerals (Holland, 1900). And unlike the Baudin expedition's mineral collections from Australia, his from India and Ceylon were studied in some detail, by Bournon (1823) and others later, and remain, I believe, in the Paris *Muséum d'Histoire Naturelle.*

élève 2. Jacques DELISSE — no biography found

Another *élève* at the *Muséum*, and a student of botany for two years (Cornell, 1965: 57), Delisse was attached to the *Naturaliste* on the voyage from France. Claiming ill-health, he withdrew at Mauritius in 1801. His chemical study of water at Mauritius is mentioned by Péron (1807: 54). Péron there refers to him as 'Deslisse', the form also used by Bory de St Vincent (1805). Delisse was still at Mauritius when Bory left for France in March 1803 but expected soon to follow.

MINERALOGISTS

1. Louis DEPUCH [d. February (?) 1803] — no biography found

From Jonzac in the Charente-Maritime, Depuch (according to Buch, 1814) was educated at the *École des Mines*, Paris, and had been a student of Haüy. Presumably Haüy, already a member of the *Institut National*, recommended him to the *Institut*'s expedition advisory commission. Depuch took a prominent part in the scientific effort (passages from his notes are quoted in Baudin (1974), and in Péron (1807)) during the voyage of the *Géographe* until he became weakened by dysentery at Timor (Sept. 1801). He continued to perform what duty he could but at the end of the stay at Port Jackson (Nov. 1802) Baudin transferred him to the *Naturaliste* for earlier return home. The commander's many kindly, if at times exasperated, remarks about Depuch and the arrangements made to provide the invalid with fresh food (Baudin, 1974: 441) show the claim about by Péron (1807: 445) that Baudin acted spitefully towards Depuch is a lie. On reaching Mauritius (Feb. 1803) Depuch was too debilitated to go further. He was taken ashore and died there, according to one source (Péron and Freycinet, 1816: xxvii) after a few days, or some months (Jussieu, 1804: 4). Strangely, Bory de St Vincent (1805) makes no mention of the *Naturaliste*'s call though he was on the island at the time. Attempts to trace a record of Depuch's death have been unsuccessful.

2. (*aide-minéralogiste*) Joseph Charles BAILLY [1777-1844] — *Dict. Biogr. Franç.* 4: col. 1355

Born at Nancy, Bailly had just completed studies at the Paris *École Polytechnique* when in June 1800 he was appointed to the expedition. Attached to the *Naturaliste*, Bailly transferred at Sydney to Depuch's place on the *Géographe* and returned to France (March 1804) with that vessel. Buch (1814), mistakenly, claimed he went off to Java with Leschenault de la Tour; the error suggests remarkable ignorance or lack of concern among Buch's informants. Yet on the voyage Bailly had been an active participant. His notes, as Depuch's, were extensively quarried for the official record (Péron, 1807; Péron and Freycinet, 1816). Most of the surviving unpublished catalogue of Australian rocks and minerals seems to be the work of Bailly, and to have been prepared in Sydney. Although only he and Péron, of all Baudin's scientists, returned with the expedition, Bailly was given no opportunity to work up the mineralogical results. Jussieu's (1804: 7) dismissive view of the mineralogists' achievement and the myopic *Rapport* of Cuvier (Péron, 1807: I-XV) that found merit only in zoology (and hence employment for Péron), betokened the lack of any powerful interest in the rock and mineral collections. Fortunately, Bailly had done some hydrographic work during the voyage. In 1806 he joined the French hydrographic service and there followed a distinguished career under C. F. Beautemps-Beaupré [1766-1854], himself a veteran of Australian survey under Bruni d'Entrecasteaux.

ZOOLOGISTS

1. René MAUGÉ [d. 20 February 1802] — no biography found

Maugé was an *aide-naturaliste* at the Paris *Muséum* when appointed first zoologist to the Australian expedition. He had already sailed with Baudin to the West Indies (1796-8) and remained his friend on the *Géographe*. Like Depuch, Maugé fell victim to dysentery at Timor. His death, at Maria Island (Tasmania) was a bitter blow to the commander who remarked in his *Journal*: 'This naturalist did not have the title of scientist, but, alone, he did more than all the scientists put together' (Baudin, 1974: 340). Maugé, as first zoologist, surely had scientific rank. Perhaps Baudin meant to distinguish him from the sometimes, and in Péron's case probably always, difficult younger men from the higher *Écoles*. Baudin's estimate of his first zoologist's scientific work is not matched by Péron's acknowledgement of his senior colleague. Yet Baudin's praise was not eccentric. Maugé, '*cet homme estimable*', is even lauded as a mineral collector in Lucas (1813: 102).

2. Jean Baptiste Georges Marie BORY DE SAINT VINCENT [1778-1846] — *Dict. Sci. Biogr.* 2: 321

Bory de St Vincent early became interested in the fauna and flora of his native Guyenne and while still a youth began corresponding with established naturalists. Conscripted into the army in 1799, the next year he was seconded to the Baudin expedition, as second zoologist, on the recommendation of Bernard de Lacépède who thought him versed in zoological book-learning (Cornell, 1965: 58). Although Bory travelled on the *Naturaliste* he took a vehement dislike to Baudin and withdrew at Mauritius (1801), claiming fragile health. There and on Réunion Bory busied himself as a private naturalist until he returned to France (July 1803) and resumed military service. His account of the voyage under Baudin and the sojourn in the Mascarene islands (Bory de St Vincent, 1805) is marred by a sustained attempt to depreciate and ridicule the commander. The scientific work for which Bory is remembered belonged, for the most part, to his later years.

élève 1. Désiré DUMONT — no biography found

According to Cornell (1965: 58) Dumont had been recommended by Maugé and other *aides* at the *Muséum* as preparator of animal specimens on the expedition. Dumont was said to be a good hunter, of robust health and able to bear fatigue. Nevertheless he withdrew from the *Naturaliste* at Mauritius, pleading ill-health. In his records of physical performance Péron (1807: 482) notes Dumont as 'surgeon' and Bory de St Vincent (1805: 66) claims he sought a surgeon's place for Dumont at Mauritius, by way of refuting the charge that his friend had left to join a wealthy brother on the island. Bory adds that Dumont was then 'turned of twenty-eight' and no conscript to military service. Dumont was still on Mauritius when Bory departed in March 1803.

élève 2. Stanislas LEVILLAIN [d. 22/23 December 1801] — no biography found

Levillain, from Le Havre, had sailed with Baudin to the West Indies and distinguished himself as a collector and student of animals, in particular of insects. At first attached to the *Géographe*, Levillain was moved at Mauritius to the *Naturaliste* which had lost by defection or other reason all except Bailly of its naturalists. Levillain became another victim of dysentery during the 1801 visit to Timor. At sea early 23 December 1801 Baudin received a signal from the *Naturaliste* advising Levillain had died (Baudin, 1974: 288). The date (29 Dec.) given by Péron and Freycinet (1816: xxvii) is wrong; that offered by Wallace (1984: appendix) is an invention.

élève 3. François PÉRON [1775-1810] — *Dict. Sci. Biogr.* 10: 517-8; *Dict. Austr. Biogr.* 2: 323-4 (but neither entirely reliable)

'As there is now a vacancy through the resignation of one of the naturalists, the commission proposes to substitute, on the request of Cuvier, a student of the *École de Santé* called Péron' (Wallace, 1984: 30). So Jussieu, on behalf of the advisory commission, informed the Navy minister by letter 7 August 1800. The proposal, quickly approved, was that Péron should join as third *élève* zoologist with a responsibility for Cuvier's special field, comparative anatomy. Travelling throughout on the *Géographe*, Péron alone of the zoologists completed the voyage. On his return to Paris, with Cuvier's powerful support and with Bailly cast aside, Péron became official recorder of the expedition. He only of the scientific travellers was granted the means to develop the expedition's results. Péron (1807) and its sequel are, of course, major sources but their partisan character, especially in regard to Péron's shameless self-glorification and his unrelieved denigration of the commander, cannot be ignored. Dunmore (1969: 11), indeed, warns that 'Péron's reliability is limited to scientific subjects'. Yet even on that score opinions differ. Those who accept Péron on his terms consider him a hero (e.g. Wallace, 1984); others, more critical, even find aspects of his science defective (e.g. Moore in Degérando, 1969). Péron's ambition and zeal for science are undoubted; he had talent but, sadly, he was also an intriguer, a liar and a spy. His legacy is a still-unravelled web of science and politics. How differently Ledru (1810) dealt with Baudin's scientific voyage to the West Indies.

A new Species of *Mugilicola* Tripathi (Copepoda: Poecilostomatoida) and a Review of the Family Therodamasidae

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(Communicated by C. N. SMITHERS)

BOXSHALL, G. A. A new species of *Mugilicola* Tripathi (Copepoda: Poecilostomatoida) and a review of the family Therodamasidae. *Proc. Linn. Soc. N.S.W.* 108 (3), (1985) 1986: 183-186.

A new species of *Mugilicola* is described from the gills of *Sillago ciliata* caught off the coast of New South Wales. *Mugilicola* and *Paeonodes* are closely related but neither exhibits the same tagmosis as *Therodamas*, the type genus of the family Therodamasidae to which all three genera have been referred. There is no apparent justification for retaining the Therodamasidae as a separate family since these genera can be regarded as highly transformed representatives of the Ergasilidae.

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KEY WORDS: parasitic copepod — Therodamasidae — Australia — fish host.

INTRODUCTION

The genus *Mugilicola* was established by Tripathi (1960) to accommodate a copepod parasite of two species of *Mugil* from India. Tripathi placed *Mugilicola* in a new family, the Therodamasidae, based on the genus *Therodamas* Krøyer, 1863. This family is closely related to the Ergasilidae, as recognized by Thomsen (1949) and Tripathi (1960). Cressey (1972), in his discussion of the genus *Therodamas*, suggested that it might be accorded subfamilial separation within the family Ergasilidae. Hewitt (1969) enlarged the Therodamasidae by the transfer of the genus *Paeonodes* Wilson, 1944. *Paeonodes* and *Mugilicola* share the same tagmosis and are closely related but their relationship with the type genus, *Therodamas*, is slight. The discovery of a third species of *Mugilicola* from Australia stimulated this review of the family.

MATERIALS AND METHODS

A single female was collected from the gills of a whiting, *Sillago ciliata* Cuvier & Valenciennes, 1829, caught off Arrawarra Beach, New South Wales, Australia. The specimen was part of an extensive collection made by Klaus Rohde (University of New England, Armidale) from fishes of southeastern Australia. The holotype ♀ is deposited in the collections of the British Museum (Natural History), Reg. No. 1984.189. The specimen was dissected and examined in lactophenol. Drawings were made using an Olympus BH-2 microscope and drawing tube.

Mugilicola australiensis new species

Description: Body of adult female (Fig. 1**A**) highly transformed and lacking any obvious external segmentation. Head small, widest posteriorly but without cephalic lobes. Neck long and slender comprising over 60 per cent of the total body length and merging imperceptibly with the broader trunk. Trunk bearing first legs just posterior to its mid-level, legs 2 and 3 on its posterior surface (Fig. 1**B**). Small urosome (Fig. 1**C**) consisting

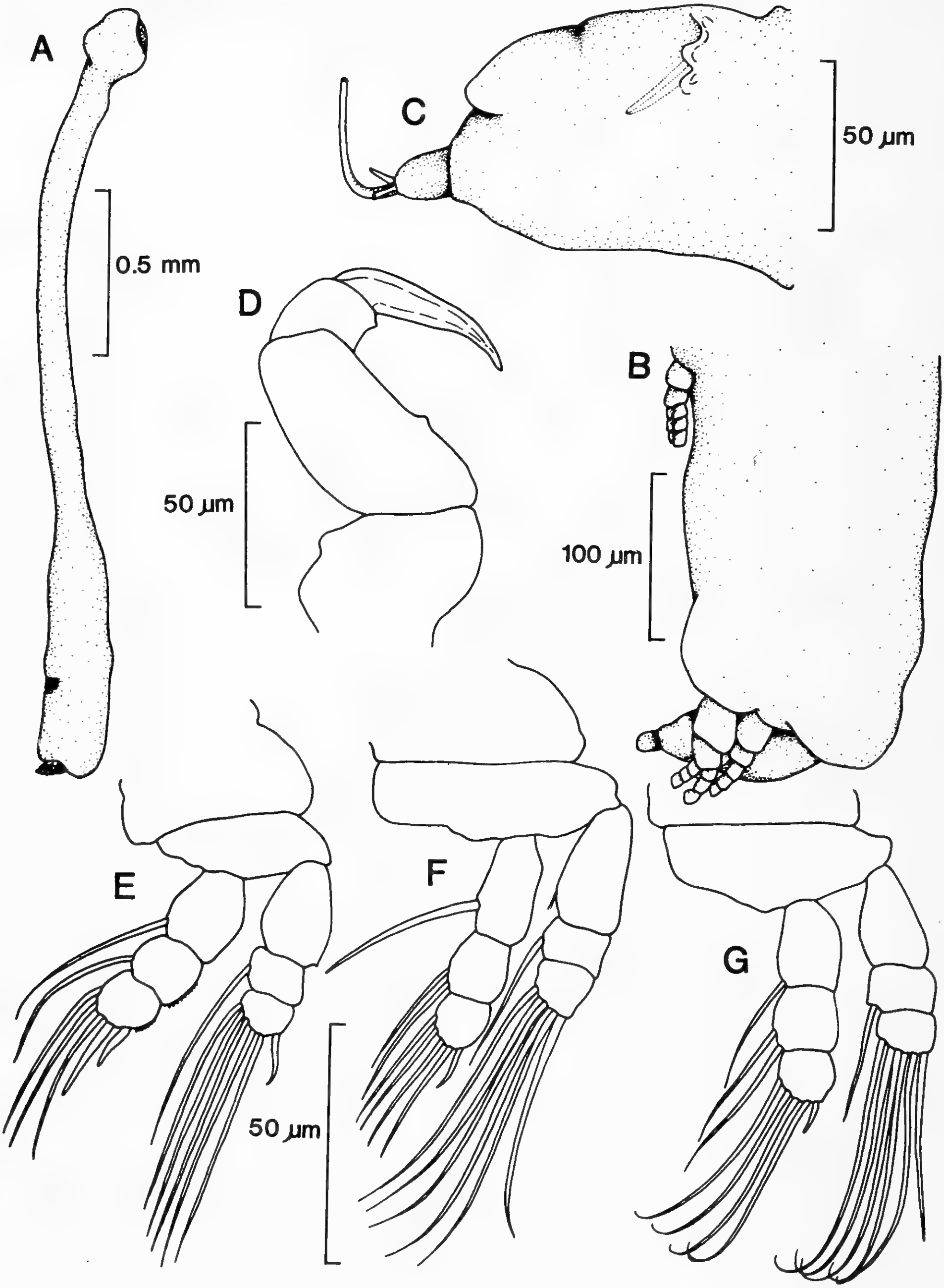

Fig. 1. Mugilicola australiensis, holotype female. **A**, Dorsal. **B**, Posterior end of trunk, lateral. **C**, Urosome, lateral. **D**, Antenna. **E**, Leg 1. **F**, Leg 2. **G**, Leg 3.

of the fused genital complex and a single abdominal segment which bears the caudal rami posteriorly. Urosome directed posteroventrally (Fig. 1**B**) and largely concealed by posterior leg pairs, although this may be a fixation artifact. Armature of caudal rami damaged but comprising at least 3 setae. Total length of holotype ♀ 2.38 mm.

The head of the holotype is damaged and, of the cephalic appendages, only the antenna is intact. Antenna (Fig. 1**D**) subchelate, first segment unarmed, second segment bearing a small process on inner margin, third segment carrying terminal claw. Legs 1-3 biramous, with 3-segmented rami (Figs 1**E-G**); armature formula as follows:

	coxa	basis	endopod	exopod
leg 1	0-0	0-0	0-1;0-1;0,II,3	0-0;0-1;0,I,5
leg 2	0-0	0-0	0-1;0-2;0,I,4	0-0;0-1;0,1,5
leg 3	0-0	0-0	0-1;0-2;0,I,4	0-0;0-1;0,1,5

Terminal armature element on third exopod segment of legs 2 and 3 setiform. Legs 4 and 5 absent. Leg 6 forming an unarmed plate serving to close each genital aperture.

Etymology: The specific name, *australiensis,* is derived from the type-locality.

Remarks: The new species can be distinguished from its congeners by its general facies. It differs from *M. smithae* Jones and Hine, 1978 in the shape of its head, *M. smithae* being provided with trilobate posterolateral processes on its head. It differs from *M. bulbosus* Tripathi, 1960 in having a relatively longer and narrower neck and in the relatively small size of its urosome. These three species also show differences in the armature of their swimming legs. *M. bulbosus* and the new species have 2 setae on the second endopod segment of leg 2 whereas *M. smithae* apparently has only one. There may, however, be an error in the labelling of the legs in Jones and Hine (1978) as it is very unusual in copepods in general for leg 2 to have only 1 seta on this segment when legs 1 and 3 have 2 setae. *M. bulbosus* has one armature element less on the apex of the endopod of all three legs than the new species. *Mugilicola* species can be distinguished from *Paeonodes* species by the number of swimming legs, 3 in the former and 4 in the latter.

DISCUSSION

The genera *Mugilicola, Paeonodes* and *Therodamas* all possess mouthparts of the basic ergasilid type (see Tripathi, 1960; Hewitt, 1969; Cressey, 1972). The mandible is falcate with a reduced palp, the maxillule is a lobe bearing 2 setae, and the maxilla is two-segmented with the second segment armed with many small spinules. The maxilliped is absent in the adult female. The antennule is 5-segmented in all three genera. The antenna has 3 segments plus a terminal claw in *Mugilicola* and *Paeonodes* but in *Therodamas* the 3 segments are fused into a single robust basal segment bearing the terminal claw. The swimming legs are biramous in all three genera but *Mugilicola* has only 3 pairs rather than 4. Apart from the derived condition of the antenna in *Therodamas* all of these characters occur within the Ergasilidae.

Therodamas, Mugilicola and *Paeonodes* differ in tagmosis from all the genera included in the Ergasilidae by Kabata (1979) in their possession of a long neck. It was this character more than any other upon which Tripathi (1960) based the family Therodamasidae. However, the neck of *Therodamas* is not homologous with that of *Mugilicola* and *Paeonodes.* The neck of the latter two genera is postcephalic in origin whereas that of *Therodamas* is cephalic, separating the antennae from the oral region (Cressey, 1972). The common possession of a postcephalic neck is a synapomorphy between *Mugilicola* and *Paeonodes.*

The possession of typical ergasilid cephalic appendages and the lack of a maxilliped in the adult female are the diagnostic apomorphies of the family Ergasilidae. These characters are sufficient to place *Therodamas, Mugilicola* and *Paeonodes* in that family. They are highly derived mesoparasitic representatives of a family which typically contains ectoparasitic forms but there is no apparent justification for their separation at the familial level.

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Seed Protein Content of Australian Species of *Acacia*

D. R. MURRAY and C. M. MCGEE

MURRAY, D. R., & MCGEE, C. M. Seed protein content of Australian species of *Acacia*. *Proc. Linn. Soc. N.S.W.* 108 (3), (1985) 1986: 187-190.

Seed samples of 26 species of *Acacia* have been milled and extracted with 5% (w/v) potassium sulphate in 0.1M sodium phosphate buffer, pH 7.0, in the presence of Polyclar AT (0.3g per g of meal). The protein concentration of the extracts was determined with a reliable assay involving the biuret reaction. The values obtained for extractable protein content ranged from 4.89% of seed weight *(Acacia victoriae)* to 14.27% *(A. alata)*.

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INTRODUCTION

Acacia seeds may represent an under-utilized human food resource, especially the seeds of Australian species, as these are free of the serious neurotoxins found among the non-protein amino acids of African and Asian species (Evans *et al.*, 1977). Recently, members of the University of Sydney Human Nutrition Unit claimed that the seeds of nine species of *Acacia* eaten by Aborigines were 'strikingly nutrient rich with higher energy, protein and fat content than crops such as wheat and rice and even higher than some meats' (Anonymous, 1984).

In contrast, Murray *et al.* (1978) reported that the amount of protein extracted from seeds of *Acacia sophorae* (Labill.) R.Br. and *A. longifolia* (Andrews) Willd. accounted for only 12 to 13% of seed dry matter content. Analyses have now been performed for a total of 26 species of *Acacia*, including nine considered to be edible (e.g. see Cribb and Cribb, 1976: 78).

MATERIALS AND METHODS

Seed samples of eight edible species of *Acacia* were supplied by Mr M. L. Farrar of Nowra, N.S.W.: *A. adsurgens, A. aneura, A. cowleana, A. coriacea, A. holosericea, A. bivenosa, A. murrayana* and *A. victoriae*. Seeds of *A. tetragonophylla* were provided by Mr J. R. Maconochie of the Northern Territory Herbarium, Alice Springs. Seeds of *A. alata* were collected (by D.R.M.) in the Kooringal Forest south of Perth, W.A.

Seeds of *A. binervata, A. riceana, A. obtusifolia* and *A. triptera* were purchased from Flamingo Enterprises, Nowra, N.S.W. Seeds of *A. floribunda, A. implexa, A. lasiocarpa, A. leioderma, A. mitchellii* and *A. oxycedrus* were from Nindethana Seed Service, Narrikup, W.A. Seeds of the remaining species were from the same batches as recorded in Weder and Murray (1981) and Murray *et al.* (1978). Seed specimens from all the species studied have been retained and will be lodged with the new Wollongong Herbarium.

Extraction Procedure

Seeds (3g to 5g) were finely milled in an electric coffee grinder. Samples of meal (1.0g) were weighed and combined with 0.3g of insoluble polyvinyl pyrrolidone (Polyclar AT) as a precaution against interference by phenolic compounds from seed coats, then suspended in 10ml of 5% (w/v) K_2SO_4 in 0.1M Na phosphate, pH 7.0 (Murray, 1979). Each suspension was stirred continuously for 1h at room temperature, then squeezed through two layers of cheesecloth and centrifuged at 12,000*g* for 20 min. The volume of recovered supernatant was measured and three aliquots (50μl or 100μl) were removed for protein estimation.

Almost all of the extractable protein is removed with a single extraction step (Murray *et al.*, 1978: 763), but for the samples of edible species supplied by Mr M. L. Farrar, a second extraction was performed by grinding the squeezed material in a mortar with a further 10ml of extraction medium. This homogenate was squeezed through cheesecloth and centrifuged as before. The two supernatants were pooled, mixed thoroughly, and sampled for protein determination as above.

Protein Determination

The aliquots removed for protein determination were treated with ethanol (final concentration 80%, v/v). The resulting precipitates were collected by centrifugation and washed once by resuspension to remove soluble amino nitrogen. The precipitates were collected again by centrifugation, redissolved in 0.25M NaOH, and treated with biuret reagent (Gornall *et al.*, 1949). The absorbance of each tube was read at 540nm. Bovine serum albumin, treated to remove lipids, was used as a reference standard (Collier and Murray, 1977; Murray *et al.*, 1978; Murray, 1979).

RESULTS AND DISCUSSION

The extractable protein contents of the seeds of 26 species of *Acacia* are presented in Table 1. As a proportion of seed weight, the protein content ranged from as little as 4.89% *(A. victoriae)* to as much as 14.27% *(A. alata).* Values for protein content around 10% are common, but it is not possible to conclude that high, medium or low seed protein contents are related to the systematic treatment of an individual species. Of the species considered to be edible, *A. sophorae* (Cribb and Cribb, 1976) had the highest seed protein content (Table 1, and compare Table 5 of Murray *et al.*, 1978).

The biuret method of estimating protein content has been chosen deliberately. The biuret reaction depends upon a property shared by all polypeptide chains — the possession of adjacent pairs of peptide bonds. The procedure is admirably suited to mixtures of different proteins, as a single standard protein is sufficient, and the outcome is independent of differences in amino acid composition between individual proteins.

In contrast, the Kjeldahl method for determining total nitrogen content is far too often applied uncritically to studies of plant proteins, a situation that has not altered since the beginning of this century (Petrie, 1908). In the case of bean seeds *(Phaseolus vulgaris)* a Kjeldahl nitrogen value in mg multiplied by 6.25 yields an apparent protein content that is an overestimate by a factor of two (Adriaanse *et al.*, 1969). An even greater disparity has been observed for seeds of *Cuscuta reflexa*, where a protein estimation based on Kjeldahl nitrogen determination exceeds the seeds' content of extractable protein by 5.7-fold (Rahman and Krishnan, 1971).

Petrie (1908) was probably the first person to study the nitrogenous constituents of *Acacia* seeds, and he determined that as much as 45% of the total nitrogen of mature *A. pycnantha* seeds occurs as non-protein nitrogen. Total reliance on the Kjeldahl procedure has thus led to overestimation of *Acacia* seed protein content by the group referred to previously (Anonymous, 1984). Their estimate of 24% protein for immature *A. cowleana* seeds must be compared with a value of 10.42% for mature seeds of this species (Table 1). The range of 17% to 27% protein content for seeds of all the species in this group's sample is clearly extravagant. We question their view that 'many bushfoods appear to be richer sources of nutrients than similar cultivated plants' (Anonymous, 1984). The quantity, the quality and the availability of proteins from seeds are all factors that need to be assessed. At this stage little is known about any of these properties for the seed

TABLE 1

Extractable Protein Content of Acacia *Seeds*

Species	Mean seed mass (mg)	Protein content: mg per seed	% of seed weight
Botryocephalae			
A. decurrens Willd.	13.1	1.35	10.34
A. elata A. Cunn. ex Benth.	43.2	3.69	8.55
Uninerves: Racemosae			
A. bivenosa DC[1,2]	34.9	2.53	7.24
A. murrayana F. Muell. ex Benth.[1]	29.4	2.01	6.84
A. victoriae Benth.[1]	26.6	1.30	4.89
Phyllodinous Species of Indistinct Alliance			
A. binervata DC[3]	20.6	1.72	8.35
A. tetragonophylla F. Muell.	30.7	4.06	13.23
Plurinerves			
A. coriacea DC[1]	70.1	4.82	6.88
A. implexa Benth.	20.8	1.80	8.67
A. melanoxylon R.Br. ex Ait.	15.2	1.21	7.94
Juliflorae (with Spicatae)			
A. adsurgens Maiden & Blakely[1]	7.9	0.68	8.61
A. floribunda (Vent.) Willd.	7.1	0.69	9.72
A. longifolia (Andr.) Willd.[4]	24.6	3.20	13.02
A. sophorae (Labill.) R.Br.[1,5]	37.7	4.70	12.47
A. obtusifolia A. Cunn.	14.2	1.63	11.50
A. oxycedrus Sieb. ex DC	19.6	1.77	9.01
A. riceana Henslow	9.9	0.99	10.03
A. triptera Benth.	11.1	1.21	10.90
A. aneura F. Muell. ex Benth.[1]	18.2	1.97	10.82
A. cowleana Tate[1]	11.5	1.20	10.42
A. holosericea A. Cunn. ex G. Don.[1]	11.4	1.06	9.32
Pulchellae and *A. alata*			
A. alata R.Br.[6]	10.0	1.43	14.27
A. drummondii Lindl.	2.66	0.31	11.66
A. lasiocarpa Benth.	4.52	0.44	9.81
A. leioderma Maslin	5.26	0.61	11.61
Other Bipinnatae			
A. mitchellii Benth.[6]	14.3	1.49	10.41

1 considered edible.
2 = *A. ligulata*, see Pedley (1979).
3 see Tindale and Roux (1969, 1974).
4 freshly milled sample from batch L1(2), Murray *et al.* (1978).
5 freshly milled sample from batch S3, Murray *et al.* (1978).
6 for discussion, see Guinet *et al.* (1980), Murray and Weder (1983).

proteins of native legumes. It may be assumed that the contents of essential sulphur-containing amino acids in *Acacia* seed globulins are very low, as values for these amino acids were not included in the analyses reported by Pettigrew and Watson (1975). The best-balanced protein sources from seeds are to be found among the albumin fractions of some of the cultivated legumes (for review, see Murray, 1984a,b).

Detailed electrophoretic studies on the seed proteins of the *Acacia* species listed in this paper will be the subject of a future communication.

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The Chemistry and Distribution of *Cladonia capitellata* (J. D. Hook. & Taylor) Church. Bab. (Lichenes) in Australia

A. W. ARCHER

ARCHER, A. W. The chemistry and distribution of *Cladonia capitellata* (J. D. Hook. & Taylor) Church. Bab. (Lichenes) in Australia. *Proc. Linn. Soc. N.S.W.* 108 (3), (1985) 1986: 191-194.

The taxonomy of the lichen species *Cladonia capitellata* (J. D. Hook. & Taylor) Church. Bab. in Australia is reviewed. Three varieties are recognized, *C. capitellata* var. *capitellata* (usnic and thamnolic acids), *C. capitellata* var. *interhiascens* (Nyl.) Sandst. (usnic acid only) and the new variety *C. capitellata* var. *squamatica* A. W. Archer (usnic and squamatic acids) is described.

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KEY WORDS: *Cladonia capitellata* var. *capitellata, Cladonia capitellata* var. *interhiascens, Cladonia capitellata* var. *squamatica*, lichens, chemotaxonomy, distribution, Australian lichens.

INTRODUCTION

Cladonia capitellata, a fruticose lichen species, was first described by J. D. Hooker and T. Taylor (1844); the type material was collected by Hooker in New Zealand during the antarctic voyage of H.M.S. *Erebus* and *Terror.* The same taxon was later reported as *Cladina interhiascens* from Campbell Island (Nylander, 1876) and as *Cladonia xanthoclada* from Western Australia (J. Müller, 1882). These two taxa were later reduced in taxonomic status to *C. capitellata* var. *interhiascens* (Nyl.) Sandst. (Sandstede, 1938) and *C. capitellata* subsp. *xanthoclada* (Müll. Arg.) Vainio (Vainio, 1887) respectively. Vainio (1887) reported *C. capitellata* from Brazil but the cited specimen represents an unidentified species containing fumarprotocetraric and usnic acids (T. Ahti, **in litt.** 1984). *C. capitellata* has been reported from South Australia (Filson and Rogers, 1979), Victoria (Leighton, 1867), New South Wales (Vainio, 1887), the Australian Capital Territory (Elix and Streimann, 1982) and Tasmania (Wilson, 1892). A recent description of *C. capitellata* has been given by Filson and Rogers (1979) and Galloway (1985) and photographs of the species may be found in Filson and Rogers (1979: pl.3A) and Martin and Child (1972: pl.4).

CHEMISTRY

The chemistry of *C. capitellata* has been described briefly (Archer, 1985). The species always contains usnic acid, which may be the sole lichen compound present, as in the type materials of *Cladina interhiascens* and *Cladonia xanthoclada*, or the usnic acid may be accompanied by thamnolic acid as in the type material from New Zealand (T. Ahti, **in litt.**), or squamatic acid. Fertile specimens of the last two chemical varieties also contain barbatic acid in the apothecia. This localization of barbatic acid in the apothecia of fertile specimens in many species of the genus *Cladonia* has been reported from the northern hemisphere (Tønsberg, 1980; Ahti, 1983) and has also been found, by the author, in other Australian taxa in the genus *Cladonia*, viz. *C. squamosula* Müll. Arg. and *C. pertricosa* Krempelh. Specimens of *C. capitellata*, and *C. cenotea* (Ach.) Schaer., *C. crispata* (Ach.) Flotow, *C. subfurcata* (Nyl.) Arnold, *C. squamosa* Hoffm. and *C. uncialis* (L.)

Weber in Wigg. from the northern hemisphere, containing squamatic acid also contain a phenolic lichen acid of unknown structure, here tentatively named 'consquamatic acid'. This compound is fluorescent under ultra-violet light like squamatic acid and gives the same colour reactions as squamatic acid with sulphuric acid (Culberson and Kristinsson, 1970) and MBTH (Archer, 1978). It is distinguished from squamatic acid by thin-layer chromatography (Culberson, 1972); in each mobile phase consquamatic acid has an R_f value of 0. The chemistry and morphology of *C. capitellata* place the species in the infra-generic group Unciales, in the recently-proposed classification of the genus *Cladonia* (Huovinen and Ahti, 1982).

The infra-specific chemical variations described above are correlated with distributional differences (described below) but not with any apparent morphological differentiation. Hawksworth (1976) proposed that the replacement of one lichen compound by a biogenetically closely related compound, correlated with geographical differences within a taxon, be given taxonomic recognition as a variety. Squamatic and thamnolic acids are considered to be closely related biogenetically (Huovinen and Ahti, 1982) and therefore the chemically differentiated specimens are here formally listed and described as varieties.

VARIETIES OF ***Cladonia capitellata.***

Cladonia capitellata (J. D. Hook. & Taylor) Church. Bab. *Fl. Novae-Zel.* 2:296 (1855).
Cenomyce capitellata J. D. Hook. & Taylor, *London J. Bot.* 3:652 (1844).
Type collection: New Zealand, **sine loc.** Lectotype: BM.

var. *capitellata.*
Thallus K− yellow, KC+ yellow, Pd− yellow; contains usnic and thamnolic acids and barbatic acid in the apothecia.
Also examined (selected specimens only):
Australia, Western Australia, Mt Chudalup, N. Sammy 15.v.1972 (PERTH NS840926); Frenchmans Bay, Albany, D. Richardson, 18.iv.1980 (PERTH 000841); Porongorups, A. W. Archer 953, 10.x.1980 (NSW).
Tasmania, near Cradle Mountain, R. Filson, 7.i.1965 (MEL 40177); Pine Lake Pass, 22km SSW of Deloraine, G. Bratt, 27.i.1968 (HO 52941); River Crossing, 11km S of Paratah, G. Bratt, 8.v.1971 (HO 40757).

var. *interhiascens* (Nyl.) Sandst.
Fedde's *Repert.* Beih. 103:36 (1938).
Cladina interhiascens Nyl.
C.R. Séanc. Acad. Sci. Paris 83:87 (1876).
Type collection: New Zealand, Campbell Island, Filhol. Lectotype: H-NYL 37608.
Cladonia capitellata f. *interhiascens* (Nyl.) Vainio
Acta Soc. Fauna Fl. Fenn. 10:466 (1894).
Cladonia xanthoclada Müll. Arg.
Flora, Jena 65:297 (1887).
Type collection: Australia, Western Australia, King George's Sound, Harris L53; Holotype: G.
Cladonia capitellata subsp. *xanthoclada* (Müll. Arg.) Vainio
Acta Soc. Fauna Fl. Fenn. 4:277 (1887).
Thallus K−, KC+ yellow, Pd−; contains usnic acid.
Also examined:

Australia, New South Wales, Pigeon House Range, W. A. Weber, 13.iv.1968 (MEL 33067, NSW); 8km NE of Nerriga, J. A. Elix 3050, 30.iii.1977 (ANUC). Australian Capital Territory, Black Mountain, R. D. Hoogland, 19.x.1961 (NSW L1915).

Tasmania, Mt Field West, R. Filson, 20.ii.1968 (MEL 1023708); Lake St Clair, J. A. Elix 5642, 18.i.1979 (ANUC).

Cladonia capitellata var. *squamatica* A. W. Archer, var. nov.

Sicut var. *capitellata* sed acidum squamaticum continens. Thallus K–, KC+ flavescens, Pd–.

The new variety is similar to var. *capitellata* but differs in containing squamatic acid in place of thamnolic acid; fertile podetia also contain barbatic acid in the apothecia. Thallus K–, KC+ yellow, Pd–.

Type collection: Australia, New South Wales, Tinderry Range, 60km N of Cooma, alt. **ca** 1100m, A. W. Archer 1222A, 15.xi.1981. Holotype: NSW; isotype: MEL 1047760.

Also examined (selected specimens only):

Australia, Western Australia, Mt Chudalup, N. Sammy, 15.v.1972 (PERTH NS 840927); 2km W of Shannon River, 21.vii.1953, (PERTH 000529); Porongorups, D. Richardson, 20.iv.1980 (PERTH 000913).

South Australia, 14km SE of Mt Burr Township, J. B. Wilson 549, 7.ix.1966 (AD 97413229).

Victoria, Grampians, Black Range, L. D. Williams 1449, 2.ix.1962 (AD 9204); Byaduk Caves, Byaduk, A. C. Beaglehole 3943, 2.i.1956 (MEL 33181); Nicholson Creek near Maffra, F. R. M. Wilson, —.iii.1889 (NSW L3880); Mt Feathertop, A. F. Wilson, —.iii.1888 (NSW L3883); Beechworth, Ovens River, F. von Mueller, 1881, (G).

Australian Capital Territory, Black Mountain, J. Taylor 18, 22.vii.1975 (CBG 8004120); Blue Range, 25km SW of Canberra, A. W. Archer 1121, 1.ix.1981 (NSW).

New South Wales, Goulburn, E. Cheel, 18.iv.1908 (NSW L3730); Mt Dowe, A. W. Archer 1270, 12.x.1981 (NSW); Five Dock, E. Cheel, 16.ix.1911 (NSW).

Tasmania, Seal Island, Bass Strait, J. S. Whinsay, 16.xii.1973 (MEL 1012788); Mt Barrow, A. W. Archer 893, 24.ii.1980 (NSW); Cracroft Range, G. Bratt 2682, 17.ix.1965 (HO 53035).

TABLE 1

Number of collections of Cladonia capitellata *varieties in Australian States*

	WA	NT	SA	Q	NSW[a]	Vic.	Tas.	Total
var. *capitellata*	4	–	–	–	–	–	19	23
var. *squamatica*	7	–	1	–	35	16	7	66
var. *interhiascens*	1	–	–	–	3	–	2	6
Total								95

[a] including ACT.

DISTRIBUTION

The distributions of the three varieties of *C. capitellata* are summarized in Table 1. Within each State or Territory the taxa appear to be restricted to the cooler, wetter areas; *C. capitellata* **sens. lat.** occurs only in the south-west of Western Australia, the south-east of South Australia and in the southern and eastern areas of Victoria and New South Wales and throughout Tasmania. Based on an examination of 95 specimens, the most common variety is *squamatica* which occurs throughout the entire range of *C. capitellata*

sens. lat. var. *capitellata* occurs only in Western Australia and Tasmania and var. *interhiascens*, the least common variety, is restricted to a few localities above 700m in New South Wales and Tasmania, and to one location in Western Australia. A preliminary examination of a limited number of specimens from New Zealand however, showed var. *interhiascens* to be the most common variety, in contrast to the restricted distribution of var. *interhiascens* in Australia.

ACKNOWLEDGEMENTS

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Nephtyid Polychaetes from the west Coast of Phuket Island, Andaman Sea, Thailand, with Description of five new Species*

A. NATEEWATHANA and J. HYLLEBERG

(Communicated by P. A. HUTCHINGS)

NATEEWATHANA, A., & HYLLEBERG, J. Nephtyid polychaetes from the west coast of Phuket Island, Andaman Sea, Thailand, with description of five new species. *Proc. Linn. Soc. N.S.W.* 108 (3), (1985) 1986: 195-215.

Eight species of nephtyids have been collected in the Andaman Sea off the west coast of Phuket Island, Thailand, as part of a three-year programme on studies of marine macrobenthos. The polychaetes were collected during April 1980 – June 1982 from quantitative samples obtained at 15 stations ranging in depth from 10 to 30m. The eight species, comprising five new species and three new records from Thailand, are *Aglaophamus phuketensis* n. sp., *Aglaophamus urupani* n. sp., *Aglaophamus* cf. *verrilli* (McIntosh, 1885), *Inermonephtys* cf. *gallardi* Fauchald 1968, *Inermonephtys patongi* n. sp., *Micronephthys sphaerocirrata* (Wesenberg-Lund, 1949), *Nephtys danida* n. sp. and *Nephtys phasuki* n. sp.

Anuwat Nateewathana and Jorgen Hylleberg, Phuket Marine Biological Center, P.O. Box 60, Phuket 83000, Thailand; *a paper presented at the First International Polychaete Conference, Sydney, July 1983; manuscript received 24 October 1984, accepted for publication 19 June 1985.*

* Miscellaneous Contribution No. 21 from the Phuket Marine Biological Center, Thailand.

INTRODUCTION

Hartman (1950) provided a review of the morphological and taxonomic features of the family Nephtyidae and recognized three genera, *Aglaophamus, Micronephthys* and *Nephtys*. Fauchald (1968) added a fourth genus, *Inermonephtys*. Thirteen species of nephtyids have been found in the northern Indian Ocean (Hartman, 1974). Until now the polychaete fauna in the Andaman Sea has been little studied. Only one species, *Nephtys malmgreni* Théel, was recorded from the Andaman Sea (Fauvel, 1953). The present work enlarges our knowledge of nephtyids from the Andaman Sea on the basis of an ecological survey off Phuket Island, Thailand.

MATERIALS AND METHODS

The present collections have been obtained along an approximately 40km-long stretch of the west coast of Phuket Island (8°N, 98° 20E), Andaman Sea, Thailand, as part of a three-year ecological survey (Hylleberg *et al.*, 1985b) from 1980-1982. The material was collected from fifteen stations, ranging in depth from 10-30m, off four bays: the open bays of the Airport, Bang Tao, and Kamala, and the sheltered bay of Patong (fig. 1 in Hylleberg and Nateewathana, 1984a). The distribution of the nephtyids is described in Hylleberg and Nateewathana (1984b) where *Aglaophamus* sp.1 and sp.2 refer to *A. phuketensis* n.sp. and *A. urupani* n.sp., respectively. *Inermonephtys* sp.1 = *I. patongi* n.sp., and *Nephtys* sp.1 and sp.2 = *N. danida* n.sp. and *N. phasuki* n.sp., respectively. Details of the sediment of the various stations are described in Hylleberg *et al.* (1985a).

A total of 780 nephtyids were collected and identified. Holotypes and paratypes are deposited in the Reference Collection of Phuket Marine Biological Center (PMBC), Phuket 83000, Thailand (Boonprakob and Hylleberg, 1983). Duplicate specimens (paratypes) will be deposited at the Australian Museum, Sydney (AM), the British Museum (Natural History), London (BMNH), the Smithsonian Institution, Washington (USNM), and the Zoological Museum, Copenhagen (ZMC).

All animals were fixed in 10% formalin and later transferred to 70% alcohol before identification. In order to see morphological details of undissected specimens under the microscope the polychaetes were stained with methylene blue. After examination in water (Wild M5 and M7) the stain was removed in alcohol, which was used for permanent storage of the specimens. Details of parapodia were observed at a maximum magnification of 1250 times (Wild M11 and Zeiss Ergaval).

DESCRIPTION OF THE SPECIES

Aglaophamus Kinberg, 1866

Eversible pharynx with 14-22 longitudinal rows of papillae. Interramal cirri involute. Acicula distally hooked in most species.

Aglaophamus phuketensis n.sp.

Figs 1**A-F**, 2

Holotype: A complete specimen with 74 setigers; length 25mm. — Airport Bay (station 2), Phuket Island, Thailand; very coarse sand, 20m depth, 7.4.1981 (PMBC no. 3159).
Paratypes will be deposited as follows: –1, PMBC (no. 3160): Anterior fragment with 51 setigers, pharynx everted. Patong Bay (station 12), very fine sand, 30m depth, 29.6.1981. –2, USNM: Complete specimen with 85 setigers, length 18.2mm, Bang Tao Bay (station 6), very fine sand, 10m depth, 29.6.1981. –3, BMNH: Complete specimen with 75 setigers, length 18.0mm, Kamala Bay (station 8), fine sand, 10m depth, 23.12.1981. –4, AM: Complete specimen with 84 setigers, length 22.1mm, Kamala Bay (station 8), fine sand, 10m depth, 10.4.1980. –5, ZMC: Complete specimen with 55 setigers, length 9.6mm, Airport Bay (station 2), coarse sand, 20m depth, 26.4.1982.
Material Examined: A total of 238 specimens was collected from the four bays, Airport Bay, Bang Tao Bay, Kamala Bay, and Patong Bay, from very coarse sand to silty clay at depths of 10-30m.
Description: The longest complete specimen had 85 setigers, a length of 25mm and a width of 1.5mm. Body white in alcohol. The pygidium terminates in a long cirriform process.

Prostomium subpentagonal and somewhat longer than wide, in holotype 0.45mm long and 0.4mm wide (Fig. 1**A,B**); one pair of antennae, which are slender and about half as long as the prostomium; one pair of ventro-lateral palps of about the same size and shape as the antennae; eyespots absent; one pair of small nuchal organs present at the corners of the prostomium.

Pharynx distally with 20 bifid papillae surrounding the buccal aperture, proximal region with 14 longitudinal rows of subterminal papillae, each row with 3-6 slender papillae decreasing in size proximally. A long and slender middorsal papilla present (Fig. 2), proximal surface of the pharynx smooth.

All parapodia biramous, projecting up to 0.8mm, including setae, from the body. First setiger with parapodia reduced and directed forward, lying adjacent to prostomium; notopodium with prominent conical acicular lobe surrounded by small pre- and postacicular lamellae, notopodial cirrus small; neuropodium with prominent acicular lobe, inconspicuous pre- and postacicular lamellae, neuropodial cirrus elongate, about the same size as the antennae. At the third setiger, notopodium with conical acicular lobe, low rounded preacicular lamellae, postacicular lamella best developed above level

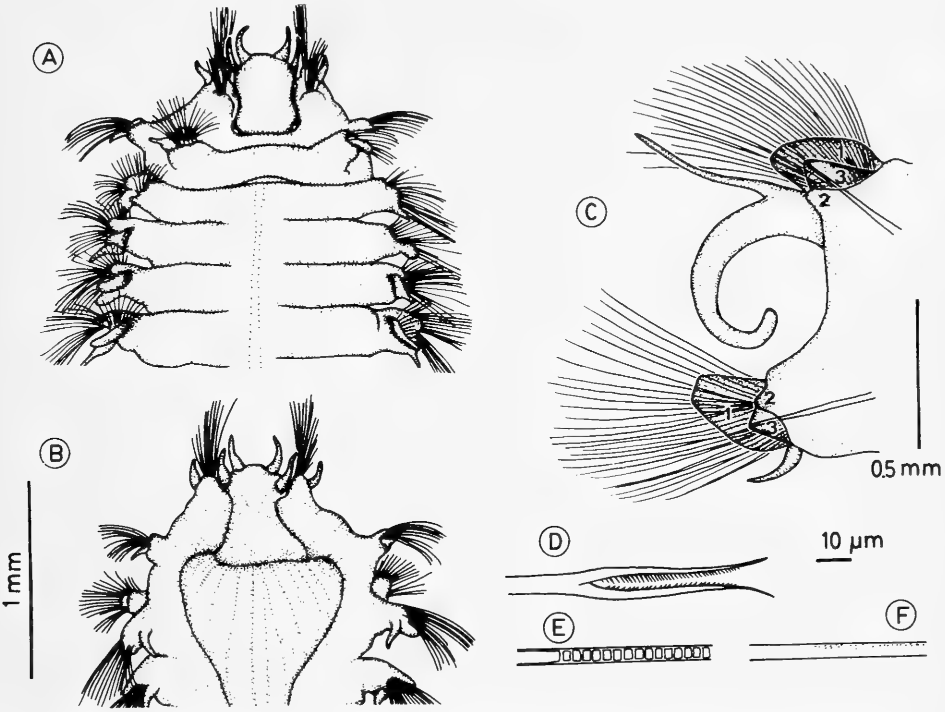

Fig. 1. Aglaophamus phuketensis n.sp.: **A**, anterior end, dorsal view. **B**, anterior end, ventral view. **C**, twenty-fifth setiger, anterior view. The numbers 1-3 refer to postacicular, preacicular, and acicular lobes, respectively. **D**, lyrate seta. **E**, part of barred seta. **F**, part of subulate seta.

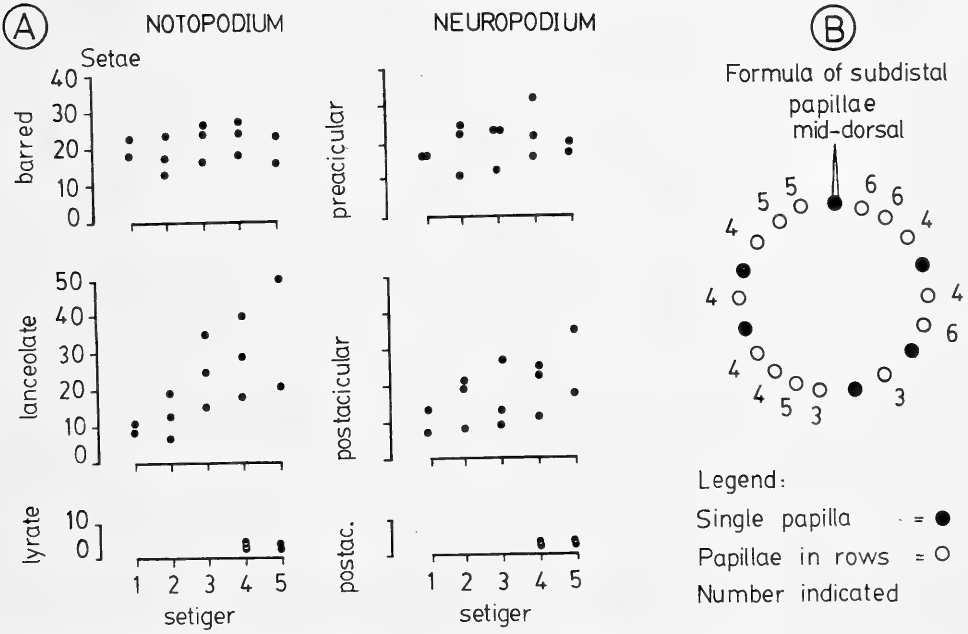

Fig. 2. Aglaophamus phuketensis: **A**, counts of setae at the first five setigers. **B**, count of subdistal papillae on pharynx.

of the acicular lobe, notopodial cirrus long; neuropodium with conical acicular lobe, pre- and postacicular lamellae similar to those of the notopodium. Interramal cirri involute, first present at setiger 3, continuing until the last setiger, full sized between setiger 10 and setiger 30, and then gradually decreasing in size. At the twenty-fifth setiger (Fig. 1**C**), notopodium with rounded conical preacicular lamella, conical and pointed acicular lobe, postacicular lamella rounded and much bigger than the acicular lobe, notopodial cirrus long and slender; neuropodium thick at the base, preacicular lamella of notopodium, conical and rounded, postacicular lamella much longer than the acicular lobe, neuropodial cirrus slender and tapering.

Acicular stout, single in all parapodial rami, extending to apex of the acicular lobes, tips fine, strongly curved.

Setae of three types: barred, lanceolate (smooth to spinose), and lyrate (Fig. 1**E**-**F**). Barred setae present in preacicular position, lanceolate setae in postacicular position. First setiger with barred and lanceolate setae in notopodium, barred setae in neuropodium. Lyrate setae first present from setiger 4 (Fig. 2).

Variation encountered within this species was examined by scanning the collected material and random samples were taken for detailed counting and dissection. Setal counts at the first five setigers are shown in Fig. 2. It was not possible to distinguish accurately between spinose, spinulose and capillary setae (Rainer and Hutchings, 1977) so these setae are referred to as lanceolate setae. Noto- and neuropodia were similar with respect to type and number of setae in the anterior segments. As a whole, the taxonomic characters were constant; barred and lanceolate setae present in all parapodia, lyrate setae started at setiger 4, interramal cirri started at setiger 3 and continued to the last setiger although the size decreased posteriorly. The number of setigers in 12 complete specimens averaged 73 ± 12 (s.d.).

Etymology: The species is named after Phuket Island, Andaman Sea, Thailand.

Discussion: *Aglaophamus phuketensis* is characterized by 14 rows of subdistal papillae on pharynx, 3-6 papillae in each row, presence of middorsal papilla, absence of eyespots, interramal cirri start at setiger 3, and lyrate setae at setiger 4. This combination of characters has so far only been reported in *A. tepens* Fauchald, 1968. The two species may be distinguished by the following characters:

A. phuketensis

i) interramal cirri present until the last setiger
ii) the neuropodial postacicular lamella is about twice as long as the acicular lobe and has a cut-off, triangular shape at setiger 25
iii) the ventral cirrus is slender and tapering at setiger 25

A. tepens

i) interramal cirri present from setiger 3 to 25
ii) the neuropodial postacicular lamella is about the same length as the acicular lobe and is a rounded square shape at setiger 25
iii) the ventral cirrus is short and stout at setiger 25.

Aglaophamus urupani n.sp.

Figs 3**A**-**F**, 4 and 5

Holotype: A complete specimen with 64 setigers; length 15.5mm. — Patong Bay (station 12), Phuket Island, Thailand; very fine sand, 30m depth, 18.6.1982 (PMBC no. 3102).

Paratypes will be deposited as follows: –1, PMBC (no. 3103): Complete specimen with 57 setigers, length 11mm, Kamala Bay (station 10), fine sand, 10m depth, 18.6.1982. –2, USNM: Complete specimen with 62 setigers, length 18.5mm, Kamala Bay (station 9),

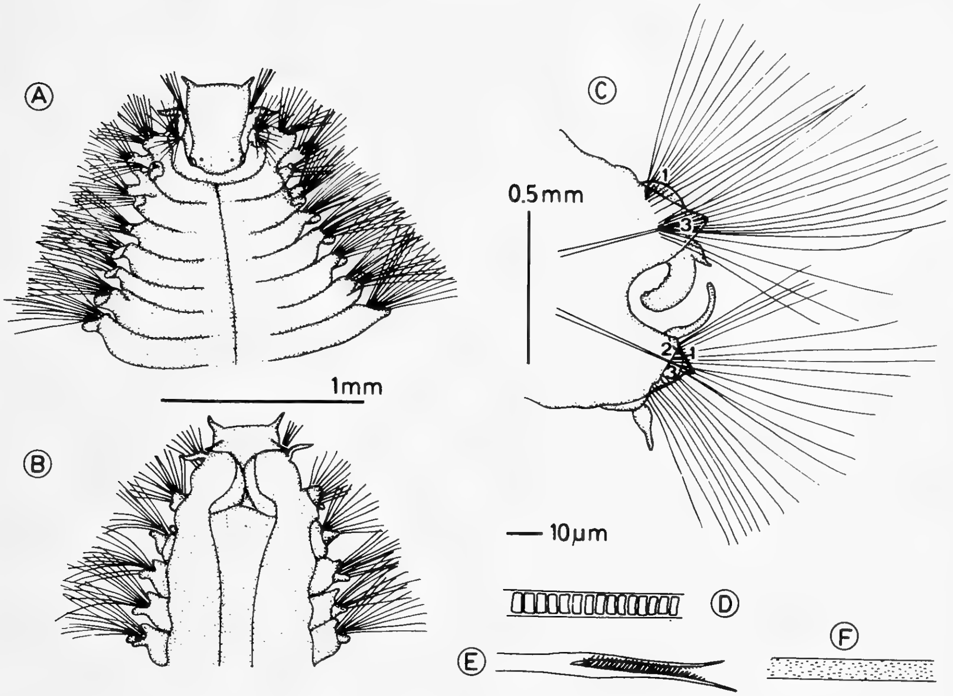

Fig. 3. Aglaophamus urupani n.sp.: **A**, anterior end, dorsal view. **B**, anterior end, ventral view. **C**, twenty-fifth setiger, anterior view. The numbers 1-3 refer to postacicular, preacicular, and acicular lobes, respectively. **D**, part of barred seta. **E**, lyrate seta. **F**, spinose part of subulate seta.

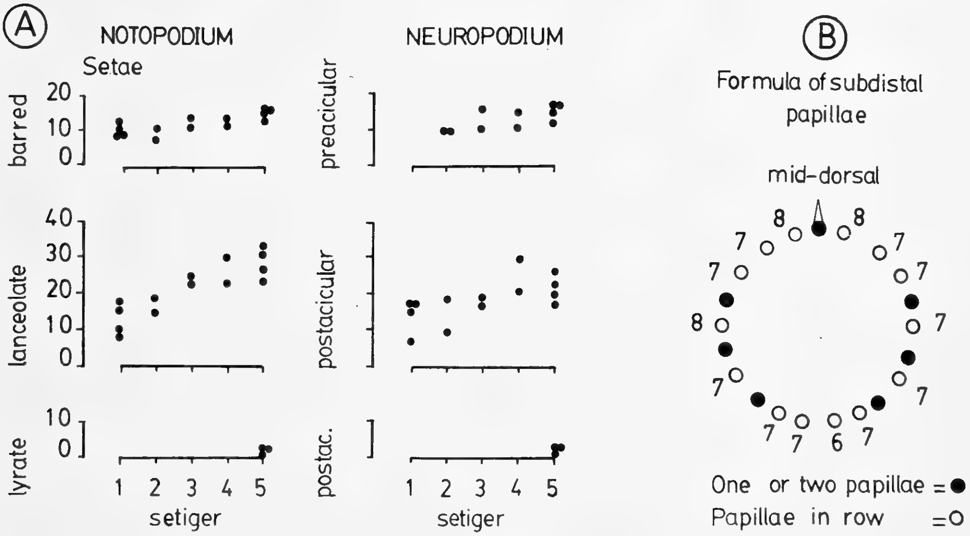

Fig. 4. Aglaophamus urupani n.sp.: **A**, counts of setae at the first five setigers. **B**, count of subdistal papillae on pharynx.

fine sand, 10m depth, 11.6.1980. –3, BMNH: Complete specimen with 52 setigers, length 9.0mm, Bang Tao Bay (station 4), very fine sand, 30m depth, 15.10.1980. –4, AM: Complete with 68 setigers, length 22.2mm, Patong Bay (station 13), very fine sand, 20m depth, 11.6.1980. –5, ZMC: Complete specimen with 59 setigers, length 13.3mm, Patong Bay (station 12), very fine sand, 30m depth, 27.2.1982.

Material Examined: A total of 156 specimens was collected from the four bays, Airport Bay, Bang Tao Bay, Kamala Bay, and Patong Bay, from fine sand to silty clay at depths of 10-30m.

Description: The longest complete specimen had 68 setigers, a length of 22.2mm and a width of 1.8mm. Body white in alcohol. The pygidium terminates in a long cirriform process.

Prostomium approximately rectangular (Fig. 3**A**), in holotype 0.5mm long, 0.3mm wide, anteriorly truncate, one pair of short, conical antennae on the frontal margin of prostomium; one pair of ventrolateral palps about the same size and shape as the antennae (Fig. 3**B**). Two eyespots present near the posterior margin of prostomium, a pair of nuchal organs at the corners of the posterior margin of prostomium (Fig. 3**A**).

Pharynx distally with 20 bifid papillae, dorsal and ventral median papillae absent. Subdistal region with a short middorsal papilla about two times as long as the neighbouring papillae, shorter subdistal papillae decreasing in length towards base of pharynx, arranged in 14 rows proximally, 6-8 papillae per row; no warts (verrucae) present. In some of the distal rows the papillae are doubled resulting in 20 papillae when counted around the pharynx (Fig. 4).

All parapodia biramous, projecting up to 1.2mm, including setae. First parapodium reduced; notopodium directed forward, prominent conical acicular lobe, obscure pre- and postacicular lamellae; neuropodium directed forward, conical acicular lobe, obscure pre- and postacicular lamellae; both notopodial and neuropodial cirrus elongated, approximately of the same size as antennae and palps but longer than those of the succeeding setigers. Second parapodium directed forward, noto- and neuropodium with low, rounded acicular lobes, obscure pre- and postacicular lamellae, notopodial and neuropodial cirri with broad base. Interramal cirri first present as small knobs from setiger 2 to 11. They start from setiger 12, increase gradually in length until they become fully involuted at setiger 16; absent from the last 13 setigers. From the 3rd setiger, notopodium with small, rounded postacicular lamellae, gradually changing to become conical at setiger 8 and half-circular at the following setigers. At the 8th setiger, notopodium with prominent acicular lobe, broadly-rounded preacicular lamellae, conical postacicular lamellae, dorsal and interramal cirri small; neuropodium with prominent conical acicular lobe, preacicular lamella broad and about the same size as the more conical postacicular lamella, neuropodial cirrus somewhat larger than notopodial cirrus. By 25th setiger (Fig. 3**C**) notopodium with half-circular postacicular lamella, conical acicular lobe, preacicular lamella broad and inconspicuous, notopodial cirrus short and conical; neuropodium with rounded, short postacicular lamella, conical acicular lobe, small preacicular lamella, neuropodial cirrus well-developed. Notopodial cirri present to the last setiger. Long slender superior neuropodial cirrus first present at setiger 15, absent from the last 14 setigers.

Acicula single, with curved tips, extending to the apex of acicular lobes in all parapodial rami. Acicula at anterior and middle part of body with a few granules of red pigment, posteriorly clear and colourless.

Setae of three types: barred, lyrate and lanceolate (smooth to spinose) (Fig. 3**D**,**E**,**F**). Barred setae restricted to preacicular position, lyrate setae to postacicular position, lanceolate setae predominantly postacicular (Fig. 4). First setiger with barred and lanceolate setae in notopodium; lanceolate only in neuropodium. Preacicular

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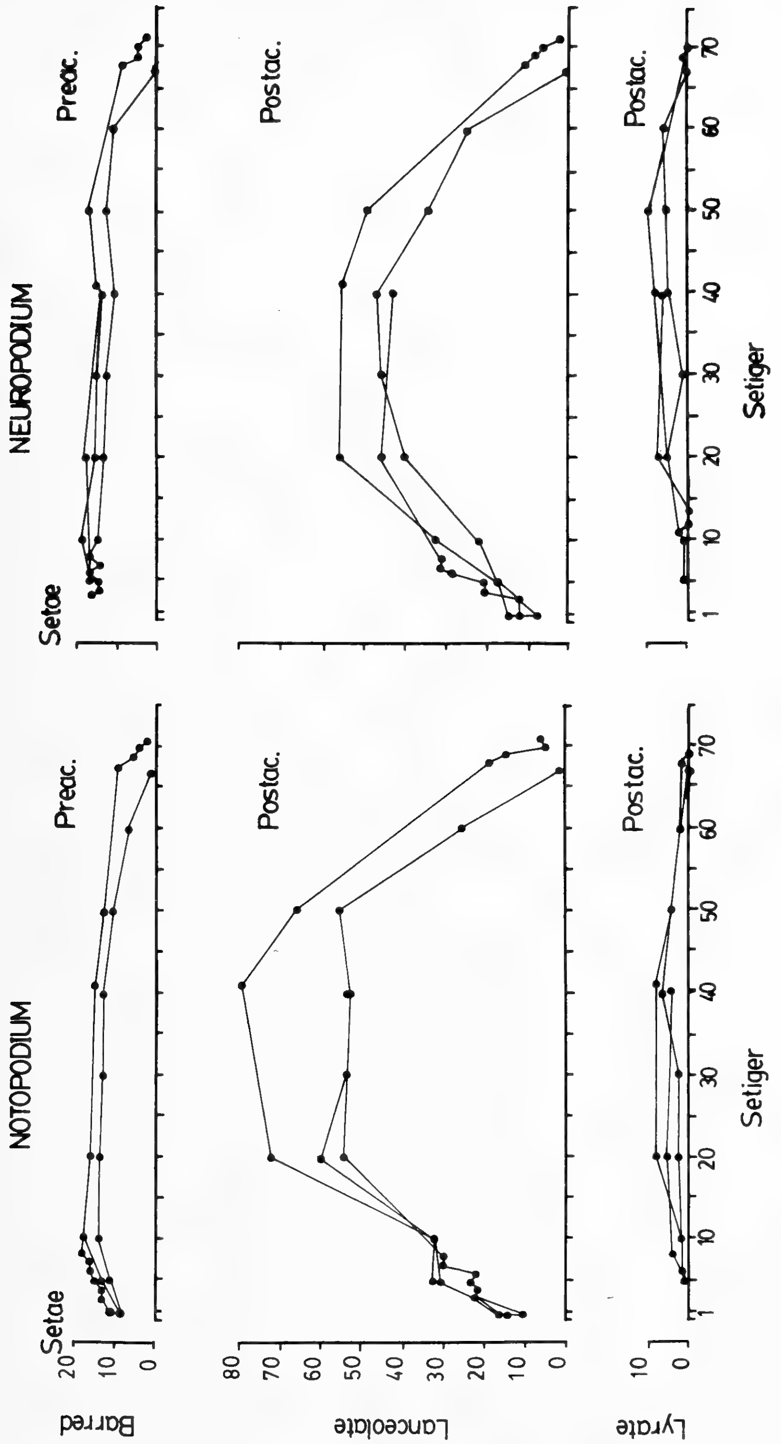

Fig. 5. Aglaophamus urupani n.sp.: Count of setae along the body of two complete specimens (65 & 71 setigers) and one anterior fragment (40 setigers).

barred setae in neuropodium first present from setiger 2. Both barred and lanceolate setae present throughout the body; greatest number present between 20th to 40th setiger and then gradually decreasing to about 2-3 at the last setiger (Fig. 5). Lyrate setae small (measuring about 50 μm), subequal branches and armed with numerous long spines, first present from setiger 5 and absent from the last 2-3 setigers.

Setal counts are shown in Fig. 5. The number of lanceolate setae peaked between setiger 20 and 50 in both noto- and neuropodia. Barred and lyrate setae varied little along the body apart from a fast increase and decrease in the anterior and posterior segments, respectively. As a whole, this species displayed moderate individual variation.

The following variation was found among 14 specimens: first interramal cirrus (defined as the first cirrus with a recognizable notopodial cirrus) at setiger 7 to 10 (11 records at setiger 8); interramal cirri disappeared gradually at the posterior 7 to 16 segments; superior neuropodial cirri were found from setiger 14 to 16 (10 records at setiger 15), such cirri disappeared gradually at the posterior 7 to 17 segments; the number of setigers in these 14 complete specimens averaged 60 ± 8 (s.d.).

Etymology: The species is named after the former Director of PMBC Mr Urupan Boonprakob in recognition of his support of our studies.

Discussion: *Aglaophamus urupani* is characterized by a pharynx with 14 rows of subdistal papillae, 6-8 papillae in each row, presence of middorsal papilla, presence of eyespots, interramal cirri start at setiger 8 (7 to 12) and lyrate setae at setiger 5. This combination of characters is not found in other species within the genus.

Aglaophamus urupani resembles *A. dibranchis* Hartman, 1950, *A. malmgreni* Théel, 1879, *A. orientalis* Fauchald, 1968, and *A. vietnamensis* Fauchald, 1968, but may be distinguished by the following characters: Interramal cirri start at setiger 4-5 in *A. dibranchis*. Eyespots, middorsal papilla, and lyrate setae are absent in *A. malmgreni*. Interramal cirri start at setiger 3 in *A. orientalis*. Eyespots are absent in *A. vietnamensis*. In addition, *A. vietnamensis* has rudimentary postacicular lamellae compared with well-developed postacicular lamellae especially at the notopodium in *Aglaophamus urupani*.

Aglaophamus cf. *verrilli* (McIntosh, 1885)

Figs 6**A**-**F**, 7

Material Examined: A total of 27 specimens has been sampled at depths between 10 and 20m.

Description: Based on a complete specimen from Kamala Bay (station 10), fine sand, 10m depth, 18.6.1982 (PMBC no. 3169), 95 setigers, pharynx fully everted. Length 29.6mm, width 2.2mm, excluding setae, pharynx 2.7mm wide and 3.2mm long. Colour in alcohol white. The pygidium terminates in a filiform process.

Prostomium (Fig. 6**A**) rectangular, 0.3mm wide and 0.5mm long; antennae and palps short, conical and almost the same size; small nuchal organs at the posterior corners of prostomium; one pair of small black eyes on posterior fifth of prostomium.

Everted pharynx divided into short muscular distal region and longer inflated proximal region; distal region with 20 bifid papillae and a pair of short, simple middorsal and midventral papillae surrounding a dorsoventral slit; proximal region with 22 longitudinal rows of 4-7 subdistal papillae decreasing in size towards base of pharynx, proximal surface smooth (no warts). No middorsal subdistal papilla (Fig. 7).

All parapodia biramous, projecting about one third of the body width in the anterior part. First parapodium reduced, directed anteriorly; notopodium with a conical acicular lobe, inconspicuous pre- and postacicular lamellae and notopodial cirrus; neuropodium with low, rounded acicular lobe and neuropodial cirrus; notopodial cirrus cirriform and somewhat longer than the neuropodial cirrus which is more slender and

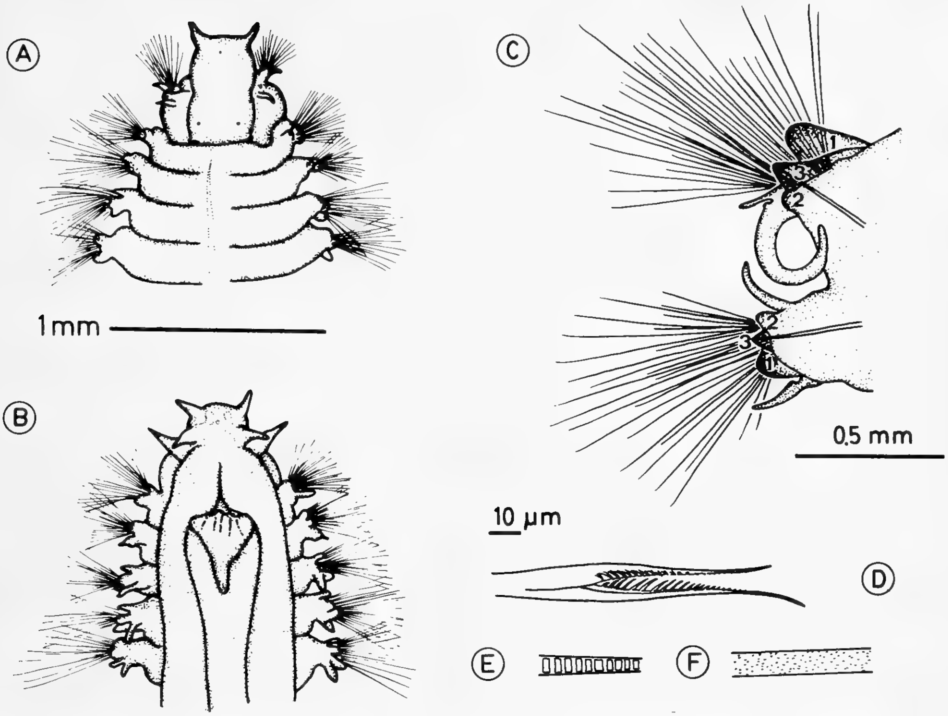

Fig. 6. Aglaophamus cf. *verrilli* (McIntosh, 1885): **A**, anterior end, dorsal view. **B**, anterior end, ventral view. **C**, twenty-fifth setiger, anterior view. The numbers 1-3 refer to postacicular, preacicular, and acicular lobes, respectively. **D**, lyrate setae. **E**, barred seta. **F**, spinose part of lanceolate seta.

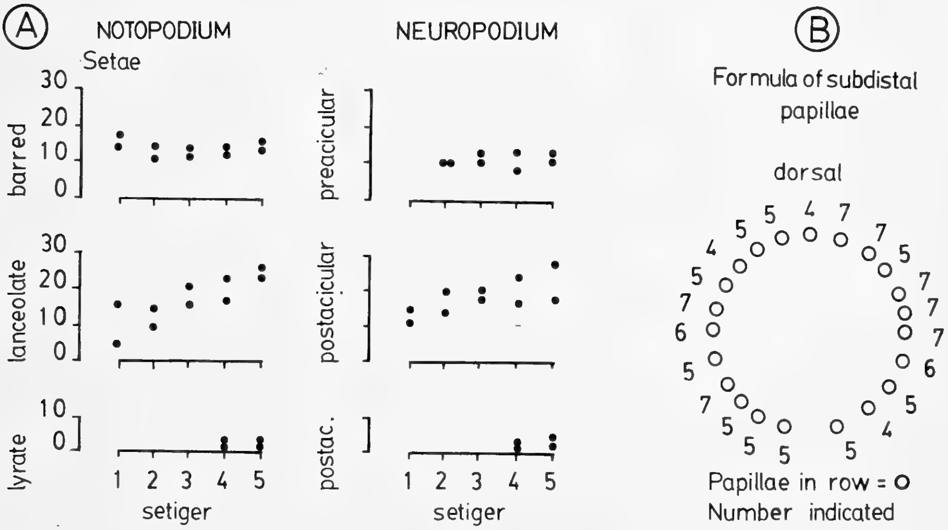

Fig. 7. Aglaophamus cf. *verrilli*: **A**, counts of setae at the first five setigers. **B**, count of subdistal papillae on pharynx.

enlarged basally, both cirri longer than antennae and palps. Second parapodium basically similar to remaining parapodia; notopodial cirrus as long as the neuropodial cirrus, enlarged basally, shorter than the cirrus of first setiger. Notopodial cirrus and notopodial postacicular lamella expanded to full size at setiger 4; neuropodial cirrus and neuropodial postacicular lamella reach full size at setiger 3. Interramal cirrus recognizable as small knobs from setiger 2, start fully developed from setiger 6, absent from the last 6 setigers. Superior neuropodial cirrus present from setiger 7, digitate, inwardly curved. Parapodium of setiger 25 (Fig. 6**C**) with conical acicular lobes; notopodial postacicular lamella auricular, about half of the lobe attached superior to the fascicle, notopodial cirrus slender, tapering and half as long as the superior neuropodial cirrus, preacicular notopodial lamella reduced but in most specimens almost as well developed as the preacicular neuropodial lamella, postacicular neuropodial lamella smaller than the corresponding notopodial lamella.

Acicula extending to apex of acicular lobes, tip curved. A single aciculum in all parapodial rami.

Setae of three types: preacicular barred setae, postacicular lanceolate setae, and lyrate setae both in pre- and postacicular position. First setiger: notopodium with barred and lanceolate setae, neuropodium only with lanceolate setae. From setiger 2, neuropodia with barred and lanceolate setae (Fig. 7). The number of setae increases gradually until maximum at setiger 30-50, carrying more than 30 lanceolate setae in both rami. The number of setae decreases gradually towards the pygidium.

Variation in *Aglaophamus* cf. *verrilli* was studied by examining 10 complete specimens. The interramal cirrus was fully developed from setiger 6 and disappeared at the posterior 6 to 10 segments; the superior neuropodial cirrus started gradually at setiger 7 to 9 and disappeared gradually from the posterior 2 to 10 setigers; the number of setigers averaged 85 ± 11 (s.d.).

Discussion: *Aglaophamus* cf. *verrilli* is characterized by 22 rows of subdistal papillae, 4 to 7 papillae in each row, absence of middorsal papilla, presence of eyespots, interramal cirri start at setiger 6 and lyrate setae at setiger 4.

This combination of characters is found in *A. dicirris* (Hartman, 1950) considered synonymous with *A. verrilli* (McIntosh, 1885) by Rainer and Hutchings (1977). There is also a strong resemblance to *A. dicirroides* Fauchald, 1968, but this species can be distinguished by the lyrate setae (with one long and one very short spurlike limb), and interramal cirri commencing at setiger 3.

The differences between our material and *A. verrilli* are lack of a papillated proximal surface of the pharynx (Hartman, 1950) referred to as pharyngal verrucae by Rainer and Hutchings (1977). Furthermore, the outer edges of the noto- and neuropodial postacicular lamellae are about level with the tips of the acicular lobes. In *A. verrilli* the postacicular lamellae project significantly beyond the tips of the acicula. In *A. verrilli* the notopodial postacicular lamellae are located directly behind the acicular lobes. In our material these lamellae are somewhat superior to the acicular lobes. These differences seem not so important that the erection of a new species is justified, and we have chosen to place our material in the vicinity of *A. verrilli*.

Inermonephtys Fauchald, 1968

Eversible pharynx without papillae. Interramal cirri involute, acicula distally hooked.

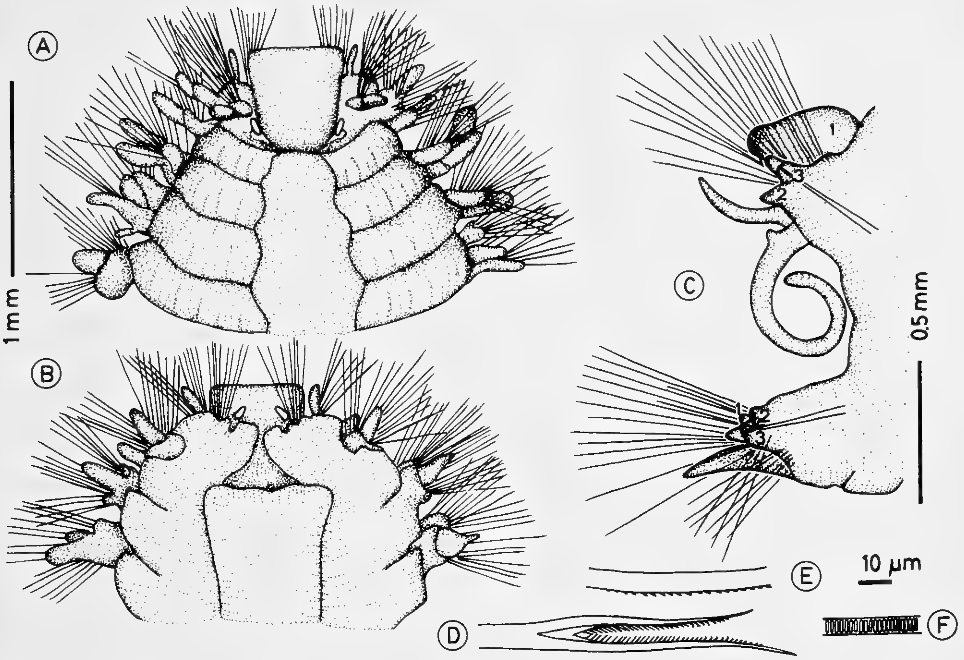

Fig. 8. Inermonephtys cf. *gallardi*: **A**, anterior end, dorsal view. **B**, anterior end, ventral view. **C**, twenty-fifth setiger, anterior view. The numbers 1-3 refer to postacicular, preacicular, and acicular lobes, respectively. **D**, lyrate seta. **E**, part of serrated, subulate seta. **F**, part of barred seta.

Inermonephtys cf. *gallardi* Fauchald, 1968
Figs 8**A-F**, 10

Material Examined: A total of 13 specimens were obtained from very fine sand, 10-30m depths of Airport, Bang Tao, Kamala and Patong Bays.

Description: Complete specimen (PMBC no. 3161). Body white in alcohol. Pygidium terminates in cirriform process.

Prostomium (Fig. 8**A**) small, nearly quadrangular, 0.65mm long, 0.6mm wide, with rounded frontal corners. One pair of minute palps on the ventral surface (Fig. 8**B**). A pair of oblong, rounded and stout nuchal organs present near the posterior corners of the prostomium. No eyespots. Eversible pharynx without papillae (seen in dissection).

All parapodia biramous. First setiger: notopodium and neuropodium placed close together; notopodium with reduced preacicular lamellae and acicular lobe, postacicular lamellae rounded, inflated and bigger than the preacicular lamellae and acicular lobe, notopodial cirri long and stout; neuropodium with rudimentary pre- and postacicular lamellae, small acicular lobe, neuropodial cirri similar to the notopodial cirri. Notopodium well developed from the 2nd setiger (Fig. 8**C**). Notopodium with rounded conical acicular lobe which distally terminates in a digitiform lobe, preacicular lamella conical and somewhat longer than the acicular lobe, postacicular lamella foliaceous, broad with rounded tip and bigger than the preacicular lamella and acicular lobe, notopodial cirri slender and digitiform. Neuropodium small at 2nd and 3rd setiger, fully developed from setiger 4. Neuropodia with acicular lobe, similar to the notopodial one, digitiform lobe on top of the aciculum at the inferior side, preacicular lamella conical and somewhat longer than the acicular lobe, postacicular lamella short and rounded, neuropodial cirrus long, slender, with broad base and pointed tip. Interramal cirri present as small knobs from setiger 15, but start as involute cirri by setiger 20. Fully developed interramal cirri slender and fill the interramal space, length of cirri decreases slightly toward the end of body. In the hindmost setigers the notopodial cirrus becomes longer than the interramal cirri. Each interramal cirrus with a small accessory cirrus.

Two stout, parallel acicula in each acicular lobe, tips exposed.

Setae of three kinds: barred setae, lanceolate and lyrate. Barred setae restricted to preacicular position from 1st to 20th setiger in notopodium and to 17th setiger in neuropodium. Lanceolate setae restricted to postacicular position in noto- and neuropodia. Lyrate setae first present at setiger 4, one to three setae in noto- and neuropodia (Fig. 10).

Variation in setigers carrying the first curved interramal cirri was examined in 10 individuals. The range was 12 to 17 with dominance at setiger 15 (3 records), setiger 14(2), setiger 16(2), and one record at setiger 12, 13 and 17. Only three specimens were complete. The number of setigers ranged from 90 to 181. Two pairs of weak eyespots observed in smaller specimens.

Discussion: *Inermonephtys* cf. *gallardi* is characterized by interramal cirri present from setiger 12 to 20, usually from setiger 15, entire preacicular fascicles, postacicular lamellae about as long as the acicular lobes, often somewhat longer, acicular lobes carry erect digitiform lobes centrally from the projecting acicula.

The main difference between our material and *I. gallardi* Fauchald, 1968 is the division of noto- and neuropodial presetal lobes into two parts in *I. gallardi*, and, in consequence, presetal setae in two fascicles. None of our specimens shows this character. The setae form a continuous fascicle, in the shape of a horseshoe, surrounding the acicular lobe. This continuous fascicle can be subdivided into two portions each supported by undivided pre- and postacicular lamellae. Apart from this difference the Thai specimens fit the description of *I. gallardi* from Vietnam and our material is very close to this species.

Inermonephtys patongi n.sp.

Figs 9**A**-**J**, 10

Holotype: An anterior fragment with 101 setigers; length 45mm. — Kamala Bay (station 8). Phuket Island, Thailand; medium sand, 10m depth, 18.6.1982 (PMBC no. 3170).

Paratypes will be deposited as follows: –1, PMBC (no. 3171): Complete specimen with 131 setigers, length 25mm, Patong Bay (station 14), very fine sand, 10m depth, 7.4.1981. –2, USNM: Anterior fragment with 82 setigers, length 19.8mm, Patong Bay (station 14), very fine sand, 10m depth, 7.4.1981. –3, BMNH: Anterior fragment with 86 setigers, length 22.4mm, Patong Bay (station 14), very fine sand, 10m depth, 7.4.1981. –4, AM: Anterior fragment with 93 setigers, length 23.7mm, Patong Bay (station 11), very fine sand, 10m depth, 7.4.1981. –5, ZMC: Anterior fragment with 89 setigers, length 15mm, Patong Bay (station 14), very fine sand, 10m depth, 26.4.1982.

Material Examined: A total of 62 specimens were collected from Patong Bay and Kamala Bay, from medium sand to very fine sand at depths of 10-20m.

Description: Anterior fragment PMBC no. 3170. Body white in alcohol.

Prostomium subrectangular, 0.29mm long, 0.25mm wide, narrower posteriorly, straight margin anteriorly, rounded at the frontal corners (Fig. 9**A**). One pair of tiny palps on the ventral surface, nuchal organs digitiform, everted, attached approximately 1mm above the posterior margin of the prostomium, two pairs of faded eyespots close to the nuchal organs.

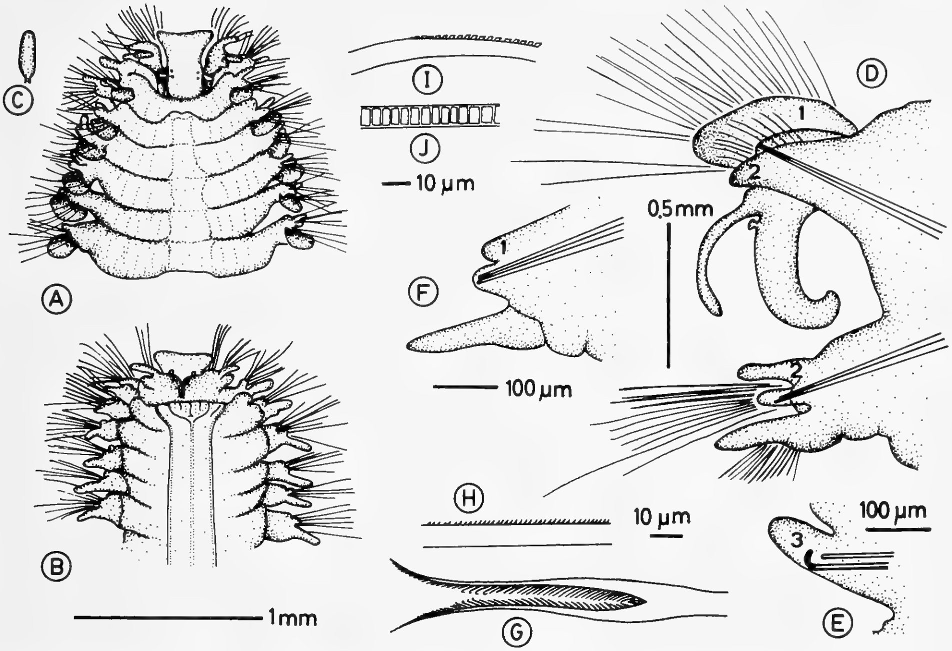

Fig. 9. Inermonephtys patongi n. sp.: **A**, anterior end, dorsal view. **B**, anterior end, ventral view. **C**, shape of everted nuchal organ. **D**, twenty-fifth setiger, anterior view. **E**, neuropodial acicular lobe showing curved, accumulated red pigment at tip of the lower aciculum. **F**, twenty-fifth setiger of juvenile, showing reduced acicular lobe and presetal lamella at neuropodium. **G**, lyrate seta. **H**, spinose part of postacicular lanceolate seta. **I**, serrated part of presetal seta. **J**, part of barred seta. The numbers 1-3 refer to postacicular, preacicular, and acicular lobes, respectively.

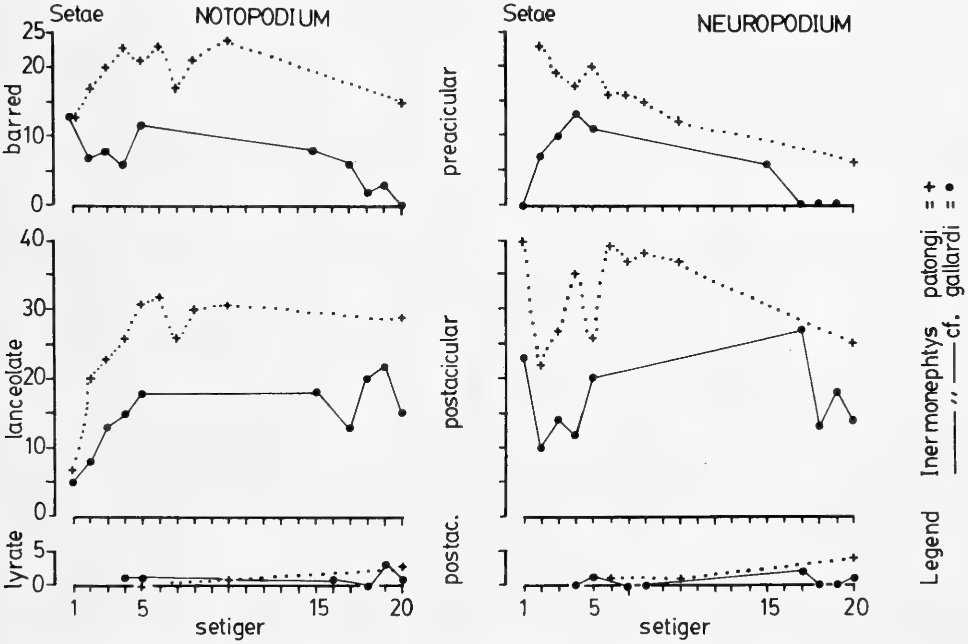

Fig. 10. Inermonephtys cf. *gallardi* and *Inermonephtys patongi* n.sp. Comparison of setal counts along the first 20 setigers.

Pharynx lacking papillae (seen in dissection).

All parapodia biramous. First parapodium directed anteriorly, both rami close together; notopodium with conical rounded acicular lobe, inconspicuous preacicular lamellae, postacicular lamellae rounded, inflated and well developed, notopodial cirri long and oval; neuropodium with conical acicular lobe, small and obscure pre- and postacicular lamellae, neuropodial cirri of the same shape and size as in the notopodium. From setiger 2 the noto- and neuropodium gradually increase in length until fully grown at setiger 7. At setiger 7, notopodium with rounded, digitiform acicular lobe, preacicular lamellae rounded and somewhat lower than the acicular lobe, postacicular lamellae inflated, triangular and much longer than the acicular lobe; neuropodium with two conical acicular lobes, separated by the acicular setae, inferior lobe rounded, inflated at the basis, superior lobe digitiform (Fig. 9**E**). Notopodial and neuropodial cirrus long and well-developed. Interramal cirrus first present as a small knob at setiger 5, start as involute cirri from setiger 6, filling the interramal space at setiger 9, posteriorly reduced in size but present to the last setiger. At the posterior 11 setigers, notopodial cirrus longer than the interramal cirrus (PMBC paratype). Interramal cirri carry an accessory cirrus. Setiger 25: notopodium with long, digitiform acicular lobe, preacicular lamellae conical and longer than the acicular lobe, postacicular lamellae inflated, triangular, much bigger than other lobes, notopodial cirrus long and slender; neuropodium with long digitiform acicular lobe, appear as one lobe because the inferior lobe is reduced, preacicular lamellae conical similar to notopodial preacicular lamellae, longer than the acicular lobe in the holotype but shorter in juvenile specimens (Fig. 9**F**). In the latter, preacicular lamellae gradually become longer than acicular lobes after mid-body. Postacicular lamellae rudimentary, neuropodial cirrus large and digitiform.

Acicula clear, in anterior body two in each parapodial ramus, extending to about the middle of the digitiform acicular lobe, tips exposed (Fig. 9**E**).

Setae of three types: barred setae, lanceolate and lyrate. Barred setae restricted to preacicular position, lanceolate predominantly postacicular but occasionally in preacicular position, lyrate setae present both in noto- and neuropodia. First setiger with barred and lanceolate setae in notopodium, barred setae in neuropodium. Preacicular barred setae with clear crossbars present from 1st setiger to about setiger 25 in neuropodium and until setiger 35 in notopodium. Lyrate setae first present from setiger 6, one to seven setae in neuro- and notopodia (Fig. 10).

Variation in setigers carrying the first interramal cirrus was examined in 37 individuals. The first interramal cirrus was most frequent at setiger 6 (24 records) and setiger 7 (12 records). In one large anterior fragment, short digitiform cirri were present from setiger 3 but not fully developed until at setiger 7.

Etymology: The species is named after Patong Bay on the west coast of Phuket Island.

Discussion: *Inermonephtys patongi* is closely related to *I. inermis* (Ehlers, 1887) as described by Hartman (1940) and Fauchald (1968). It may be distinguished by the following characters:

Inermonephtys patongi

i) interramal cirri present from setiger 6 or 7
ii) digitiform lobes on noto- and neuropodial acicular lobes
iii) noto- and neuropodial preacicular lamellae longer than the acicular lobes at setiger 25
iv) with accessory cirri
v) with 13-25 barred setae in the anterior preacicular fascicles
vi) with eyespots

Inermonephtys inermis
- i) interramal cirri present from setiger 4
- ii) noto- and neuropodial acicular lobes conical, pointed or with obtuse tip
- iii) noto- and neuropodial preacicular lamellae much shorter than the acicular lobes at setiger 25
- iv) without accessory cirri
- v) few barred setae in preacicular fascicles
- vi) no eyespots.

Micronephthys Friedrich, 1939

Pharynx with 22 rows of subdistal papillae. Interramal cirri reduced or absent; acicula blunt-tipped, but not capped.

Micronephthys sphaerocirrata (Wesenberg-Lund, 1949)

Nephthys sphaerocirrata. Wesenberg-Lund, 1949: 294-295, figs 24-25.
Nephthys (Micronephthys) sphaerocirrata. Day, 1967: 347-348, figs 15.3a-d.
Micronephthys sphaerocirrata. Fauchald, 1968: 17-18, figs 36-40.
Micronephthys sphaerocirrata. Rainer and Hutchings, 1977: 320, figs 12,41.

Material Examined: A total of 172 individuals were collected from Airport Bay, Kamala Bay and Patong Bay at depths between 10-20m.

Discussion: Wesenberg-Lund (1949) described material of *M. sphaerocirrata* from the Iranian Gulf with many pharyngeal papillae in each row, and Rainer and Hutchings (1977) suggested 8-11 papillae from the figure. According to Rainer and Hutchings (1977) and Day (1967), material of *M. sphaerocirrata* from South Africa lacked preacicular lobes and had 9 papillae in each subdistal row. Fauchald (1968) identified *M. sphaerocirrata* in material from Vietnam; his specimens had prominent preacicular lamellae and 14-16 papillae in each subdistal row. Australian specimens reported by Rainer and Hutchings (1977) had 8-11 papillae in each row and obsolete preacicular lamellae, and it was suggested that *M. sphaerocirrata* of Fauchald (1968) should be considered a separate species closely related to the Australian-South African species. Our specimens of *M. sphaerocirrata* have 8-11 papillae in each subdistal row in accordance with the latter materials. However, the Thai specimens differ in having the presetal notopodial lobe rudimentary but the presetal neuropodial lobe more developed and of the same size as the acicular lobe. It should be noted that the postsetal notopodial lobe is larger than the presetal noto- and acicular lobe. If we compare the lyrate seta of our specimens with the lyrate seta in Wesenberg-Lund's figure, they are very different. The lyrate seta of *M. sphaerocirrata* from South Africa (Day, 1967), Vietnam (Fauchald, 1968) and our material are the same. On this background we conclude that our material is identical with *M. sphaerocirrata* from South Africa and Australia.

Nephtys Cuvier, 1817

Eversible pharynx, generally with 20-22 rows of papillae. Interramal cirri recurved. Acicula in most forms with a distal cap.

Nephtys danida n.sp.
Figs 11**A-H**, 13

Holotype: A complete specimen with 47 setigers; length 9.5mm. — Bang Tao Bay (station 3), Phuket Island, Thailand; very fine sand, 10m depth, 27.2.1982 (PMBC no. 3163).

Paratypes will be deposited as follows: –1, PMBC (no. 3164): Anterior fragment with 35 setigers, length 5.1mm, Kamala Bay (station 9), very fine sand, 10m depth, 7.4.1981. –2, USNM: Complete specimen with 42 setigers, length 6.4mm, Patong Bay (station 11), very fine sand, 10m depth, 26.4.1982. –3, BMNH: Complete specimen with 38 setigers, length 4.1mm, Patong Bay (station 14), very fine sand, 10m depth, 18.6.1982. –4, AM: Complete specimen with 40 setigers, length 7.5mm, Patong Bay (station 14), very fine sand, 10m depth, 26.4.1982. –5, ZMC: Complete specimen with 42 setigers, length 5.7mm, Bang Tao Bay (station 3), very fine sand, 10m depth, 18.6.1982.

Material Examined: A total of 107 individuals were collected from very fine sand, 10m depth of Bang Tao, Kamala and Patong Bays.

Description: Body slightly swollen in anterior part, tapers gradually from 14th setiger to the last setiger. Pygidium with filiform process. Colour white in alcohol.

Prostomium rounded, quadrangular (in holotype 0.2 × 0.2mm) (Fig. 11**A**); antennae conical, anteroectal; two pairs of palps present at ventral side, the distal pair conical and somewhat shorter than antennae, the proximal pair conical and about ½ size of the first pair, placed close together (Fig. 11**B**). A pair of eyespots present on the posterior brain (not always visible through the integument, but seen in dissection. Nuchal organs obscure (Fig. 11**C**).

Pharynx of paratype (PMBC no. 3164) distally with 20 bifid papillae surrounding a dorsoventral slit, subdistal papillae in 18 (16?) longitudinal rows, each with 6-8 conical papillae directed proximally, decreasing in size towards the base of pharynx. No verrucae, no median papillae.

All parapodia biramous. First pair of parapodia reduced, noto- and neuropodium placed close together and directed forward; notopodium with conical, prominent acicular lobe, pre- and postacicular lamellae, including notopodial cirri, reduced; neuropodium with conical, pointed acicular lobe, pre- and postacicular lamellae small, inconspicuous and surrounding the base of acicular lobe, neuropodium cirri rounded, conical, about half size of neuropodial acicular lobe. Parapodia from 2nd to 14th setiger almost identical structure; notopodium and neuropodium widely separated, notopodium with conical prominent acicular lobe, low rounded inconspicuous preacicular lamellae, postacicular lamellae low, rounded and gradually increasing in size until somewhat higher than the acicular lobe at 14th setiger (Fig. 11**D**), notopodial cirri short, rounded, constricted at the base; neuropodium with conical acicular lobe, preacicular lamellae gradually developed from low, rounded lamellae in 2nd setiger to digitiform rounded shape at the 14th setiger but smaller than the acicular lobe; postacicular lamellae well developed, inflated, quadrangular in shape and much bigger than the acicular lobe and preacicular lamellae, neuropodial cirri short and oval. Interramal cirri recurved, thick, first present from 5th setiger, fully grown, then decreasing in size posteriorly to the last setiger. At 19th setiger: notopodium and neuropodium similar in structure, acicular lobe pointed, conical and prominent, preacicular lamellae small and rounded, but postacicular lamellae in notopodia rounded conical, shorter than acicular lobe and smaller than postacicular lamellae in neuropodia. At 30th setiger, noto- and neuropodia of similar shape; acicular lobe pointed and conical, preacicular lamellae small and rounded, postacicular lamellae broadly rounded, noto- and neuropodial cirri short and digitiform.

Acicula stout, distally striated, bluntly acute tips which are tapering and curved. A single aciculum present in both parapodial rami.

Setae of two types: barred (Fig. 11**F**) and lanceolate. Postacicular noto- and neurosetae of 1st setiger lanceolate, preacicular notosetae barred. Lanceolate postacicular

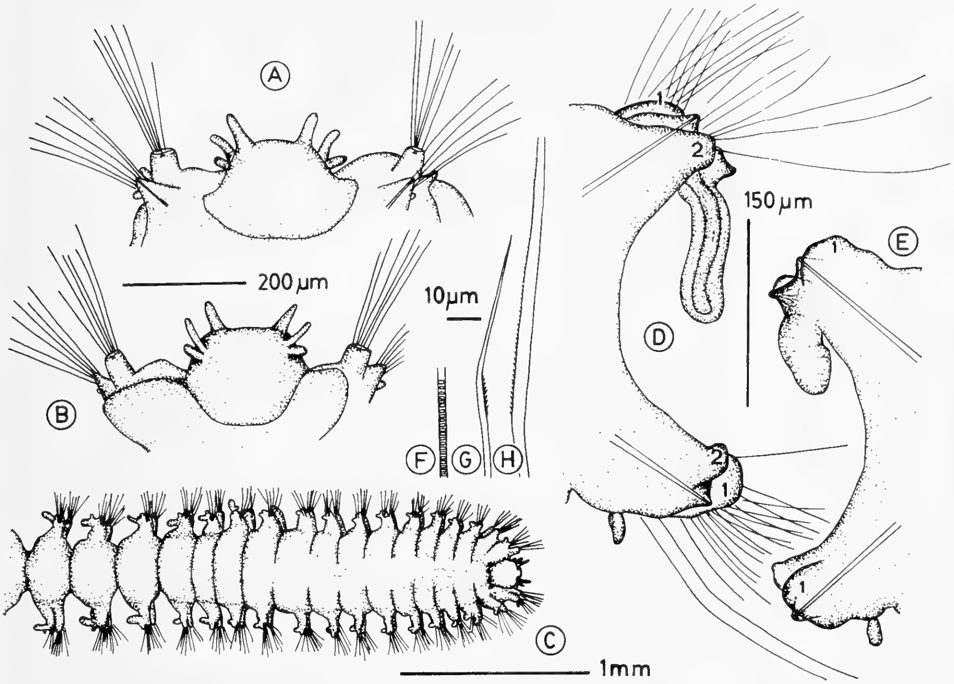

Fig. 11. Nephtys danida n.sp. **A**, anterior end, dorsal view. **B**, anterior end, ventral view. **C**, anterior body, dorsal view. **D**, fourteenth setiger, anterior view. **E**, twenty-fifth setiger, posterior view. **F**, part of barred seta. **G**, geniculate preacicular seta. **H**, part of postacicular spinose seta. The numbers 1 and 2 refer to post- and preacicular lamellae, respectively.

notosetae present from 2nd setiger. Barred setae continue to 13th setiger, with approximately 5 notosetae and 6 neurosetae in 5th setiger, 2 notosetae and 2 neurosetae in 13th setiger (Fig. 13). From 14th setiger to the last setiger, preacicular and postacicular noto- and neurosetae somewhat geniculate, lanceolate (Fig. 11**G-H**).

Etymology: The species is named after the Danish International Development Agency (DANIDA). This agency provided funds for construction of the Reference Collection Building of Phuket Marine Biological Center.

Discussion: The important character of *Nephtys danida* is the presence of two pairs of palps. This character is rare among nephtyids. A similar structure was recorded as deeply bifurcated or bifid palps in *Nephtys cornuta* Berkeley and Berkeley, 1945 and its subspecies *N. cornuta franciscana* Clark and Jones, 1955. According to Hartman (1968) the subspecies may not be separable from the stem species, except in smaller size; *N. cornuta cornuta* has up to 35 setigers with a total length of 10-12mm (Hartman, 1968), while *N. cornuta franciscana* has up to 31 setigers and a total length of 7.5mm (Banse, 1972). These small species are closely related but may be distinguished by the following characters:

Nephtys danida

i) two pairs of palps present on the ventral side of the prostomium
ii) absence of middorsal papilla
iii) barred preacicular setae restricted to the first 13-14 setigers
iv) pre- and postacicular lamellae well developed in both rami
v) notopodial cirri without distal filament

- vi) a pair of eyespots present on the posterior brain (not always visible through the integument, but seen in dissection)

Nephtys cornuta cornuta Berkeley and Berkeley, 1945

- i) a pair of bifid palps present on the ventral side of the prostomium
- ii) middorsal papilla? (pharynx not described)
- iii) barred preacicular setae present in anterior segment and absent in the posterior half of the body
- iv) pre- and postacicular lamellae inconspicuous
- v) notopodial cirri with distal filament
- vi) no eyespots

Nephtys cornuta franciscana Clark and Jones, 1955

- i) a pair of bifid palps present on the ventral side of the prostomium
- ii) long slender middorsal papilla
- iii) barred preacicular setae in all segments
- iv) pre- and postacicular lamellae inconspicuous
- v) notopodial cirri with distal filament
- vi) a pair of eyespots present in the third setiger.

Nephtys phasuki n.sp.

Figs 12**A-H**, 13

Holotype: An anterior fragment with 30 setigers, length 8.5mm — Patong Bay (station 13), Phuket Island, Thailand; medium sand, 20m depth, 18.6.1982 (PMBC no. 3172).
Paratype: Anterior fragment with 31 setigers, length 10.6mm — Patong Bay (station 15), Phuket Island, Thailand; coarse sand, 10m depth, 10.4.1980 (PMBC no. 3173).
Material Examined: Only 6 specimens were collected from medium and coarse sand, 10-20m depth at Patong Bay.
Description: Prostomium slightly longer than wide (in holotype 0.3 × 0.25mm), slightly notched at the frontal margin. One pair of long, slender anteroectal antennae, about ½ length of prostomium, one pair of somewhat thinner and shorter palps at the ventral side of prostomium, antennae and palps close together. A pair of small, everted nuchal organs at the proximal corners of the prostomium. No eyespots visible.

Pharynx: None of the specimens had an extended pharynx. Dissection failed to reveal the number of subdistal papillae with any degree of certainty. The proximal pharynx is smooth.

All parapodia biramous. First pair of parapodia directed forward, lying adjacent to prostomium, noto- and neuropodia close together; notopodium with long, conical acicular lobe (Fig. 12**D**), inconspicuous pre- and postacicular lamellae, notopodial cirri small, rounded; neuropodium with small conical acicular lobe, much shorter than notopodial acicular lobe, pre- and postacicular lamellae forming a cylinder (Fig. 12**D**) much higher than — and surrounding — the acicular lobe, neuropodial cirri well developed, oblong and slightly shorter than antennae. Second setiger similar to the remaining setigers; notopodium with conical acicular lobe, preacicular lamellae low, rounded, somewhat lower than acicular lobe, postacicular lamellae rounded, nearly as high as acicular lobe. Postacicular lamellae increase gradually in size, until fully grown, rounded, inflated, longer than acicular lobe and preacicular lamellae at 5th setiger. The size is strongly reduced after 20th setiger. Recurved interramal cirri first present at 5th setiger. Notopodial cirri conical, broad base and digitiform tip. Neuropodium with slender conical acicular lobe, preacicular lamellae inflated, almost square in shape at 2nd setiger, then gradually changing to rounded oblong form, tips pointed towards inferior side at 3rd setiger and following setigers, lamellae never grow higher than acicular lobe; postacicular lamellae conical, as high as acicular lobe at 2nd setiger, increasing in size until fully developed at 5th setiger, then the size decreases; neuropodial cirri small, short and oblong (Fig. 12**C**).

Acicula usually stout, striated, projecting curved tip (Fig. 12**F**). One aciculum in each ramus.

Setae of 2 types: barred and lanceolate; barred setae restricted to preacicular lamellae, first present in notopodia at 1st setiger and in neuropodia at 2nd setiger, then absent from about 17th setiger, lanceolate setae present in both noto- and neuropodia of 1st setiger until last setiger of fragment, short, more geniculate in preacicular lamellae, longer in postacicular lamellae (Figs 12**G-H**, 13).

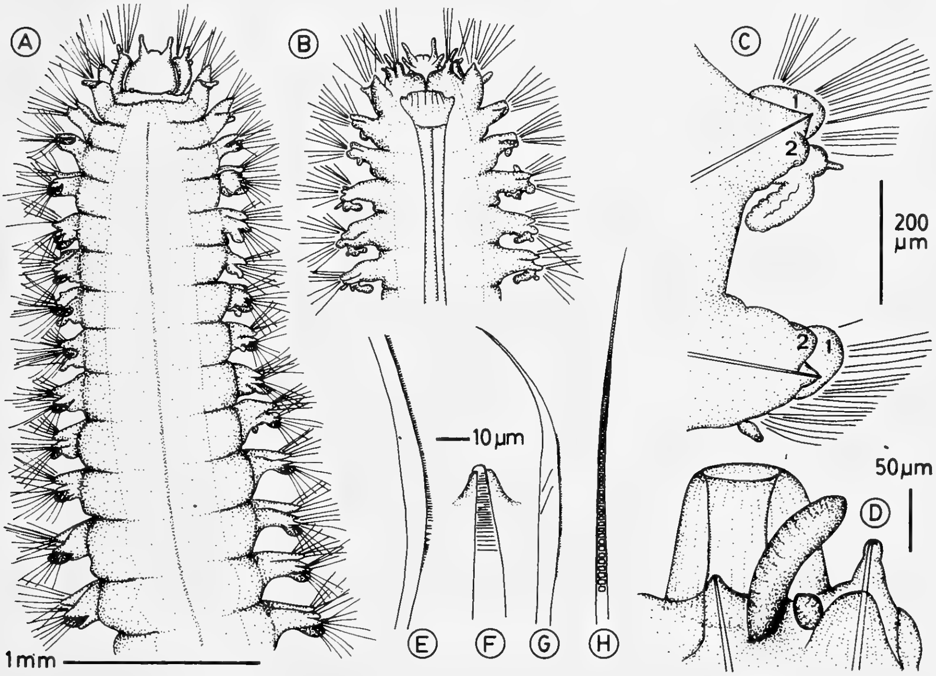

Fig. 12. Nephtys phasuki n. sp. **A**, anterior end, dorsal view. **B**, anterior end, ventral view. **C**, fourteenth setiger, anterior view. The numbers 1 and 2 refer to post- and preacicular lamellae, respectively. **D**, first setiger. **E**, part of spinose lanceolate seta. **F**, aciculum. **G**, geniculate preacicular seta. **H**, barred seta.

Etymology: The species is named after the present Director of PMBC, Mr Boonlert Phasuk. We are grateful for his support of polychaete studies.

Discussion: Only a few species of *Nephtys* resemble *Nephtys phasuki*. However, none of them has interramal cirri commencing at setiger 5 apart from *Nephtys inornata* Rainer and Hutchings, 1977 (see discussion by these authors). *Nephtys inornata* is a small species with a number of features similar to *Nephtys phasuki*, notably interramal cirri commence at 5th setiger, barred setae disappear by setiger 16 and proximal pharynx smooth. The two species may be distinguished by the following characters:

Nephtys phasuki

i) neuropodial cirrus much longer than dorsal cirrus at 1st setiger
ii) notopodial cirrus with digitiform lobe

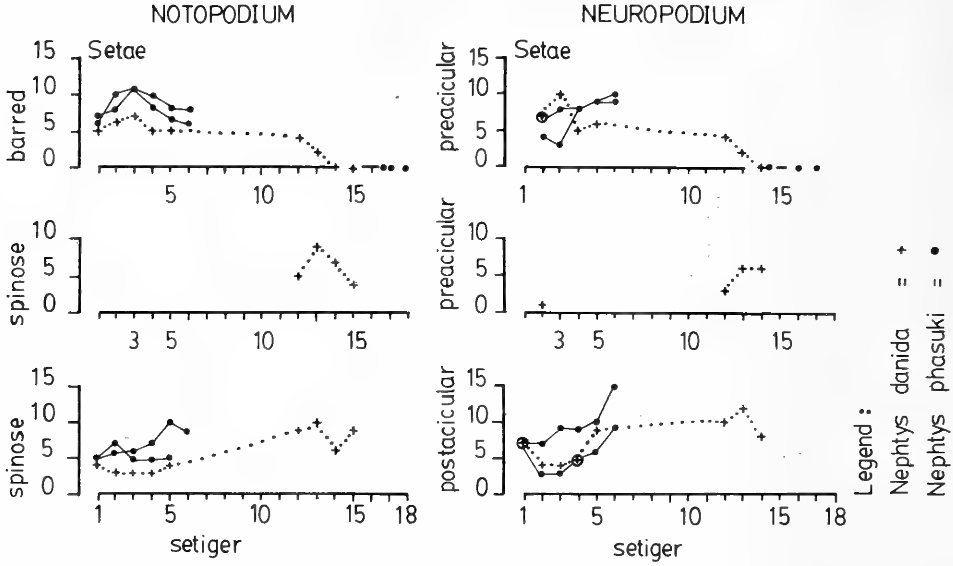

Fig. 13. Nephtys danida n.sp. and *Nephtys phasuki* n.sp. Counts of setae at the first 18 setigers.

iii) neuropodial cirrus posterior to ventral junction of post- and preacicular lamellae

Nephtys inornata

i) neuropodial cirrus slightly longer than dorsal cirrus at 1st setiger
ii) notopodial cirrus pear-shaped
iii) neuropodial cirrus at ventral junction of post- and preacicular lamellae.

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Observations on the Behaviour and Taxonomy of the Australian Tailless Whipscorpion *Charinus pescotti* Dunn (Amblypygi: Charontidae)

M. R. GRAY and M. L. ROBINSON

GRAY, M. R., & ROBINSON, M. L. Observations on the behaviour and taxonomy of the Australian Tailless Whipscorpion *Charinus pescotti* Dunn (Amblypygi: Charontidae). *Proc. Linn. Soc. N.S.W.* 108 (4), (1985) 1986: 217-224.

The male of *Charinus pescotti* Dunn, 1949 is described and the female figured. An unusual prey capture technique involving the whip-like first legs is described and a relationship between small brood size and longevity is suggested.

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INTRODUCTION

The Amblypygi are widely distributed in the warmer tropical regions of the world. In Australia they are poorly represented and their presence has generally been overlooked in revisions of the group. The following notes aim to better characterize the Australian species *Charinus pescotti* Dunn from both taxonomic and behavioural viewpoints. The behavioural observations were made by M. L. Robinson.

TAXONOMY

Weygoldt (1972) established the circumtropical nature of the distribution of the genus *Charinus* Simon. However, in his list and key to species of *Charinus* he does not mention *C. pescotti* or the presence of the genus in Australia.

Two species of Amblypygi have been described from Australia. They are *Charon annulipes* Lauterer, 1895 and *Charinus pescotti* Dunn, 1949. The status and affinities of *Ch. annulipes* (type locality Brisbane, Queensland) are uncertain. The description is inadequate, the deposition of the type specimen is unknown and no additional material has ever been collected. The latter suggests that either the specimen was accidentally introduced or a locality data error has occurred. *C. pescotti* occurs in rainforest habitats in north Queensland. The female holotype comes from Barron Falls near Cairns. More recent collections have been made in rainforest localities between Cairns and Cooktown (Monteith, 1965; Baehr, 1974). In addition, Monteith (1964) attributed to *C. pescotti* specimens from a separate, more northerly rainforest region east of Coen on Cape York Peninsula. This material has not been seen but warrants reexamination to confirm the conspecificity of these two disjunct groups.

Here, the male of *C. pescotti* is described for the first time and the description of the female given by Dunn (1949) is augmented with several diagrams (Figs 5-11). The female illustrated comes from the Cape Tribulation area, north Queensland. Some size and colour variation is apparent in specimens from different localities but in other respects resemblance is very close. Dunn (1949) nominated several specimens from the Solomon Islands as paratypes of *C. pescotti* (in Dominion Museum, New Zealand). However, his comments on differences in pedipalpal armature between these and the Australian holotype suggest that the Solomon Island sample could represent a different species.

All measurements given below are in millimetres.

Charinus pescotti Dunn, 1949

Charinus pescotti Dunn, 1949:8. Monteith, 1965:87. Baehr, 1974: 101

Types: Holotype female: Barron Falls near Cairns, Queensland, G. F. Hill, about 1923 (in National Museum of Victoria, not seen). **Metallotype** male. **(New designation):** 2km WNW of Cape Tribulation, Queensland, 23.9.-7.10.1982, Monteith, Yeates and Thompson (in Queensland Museum).

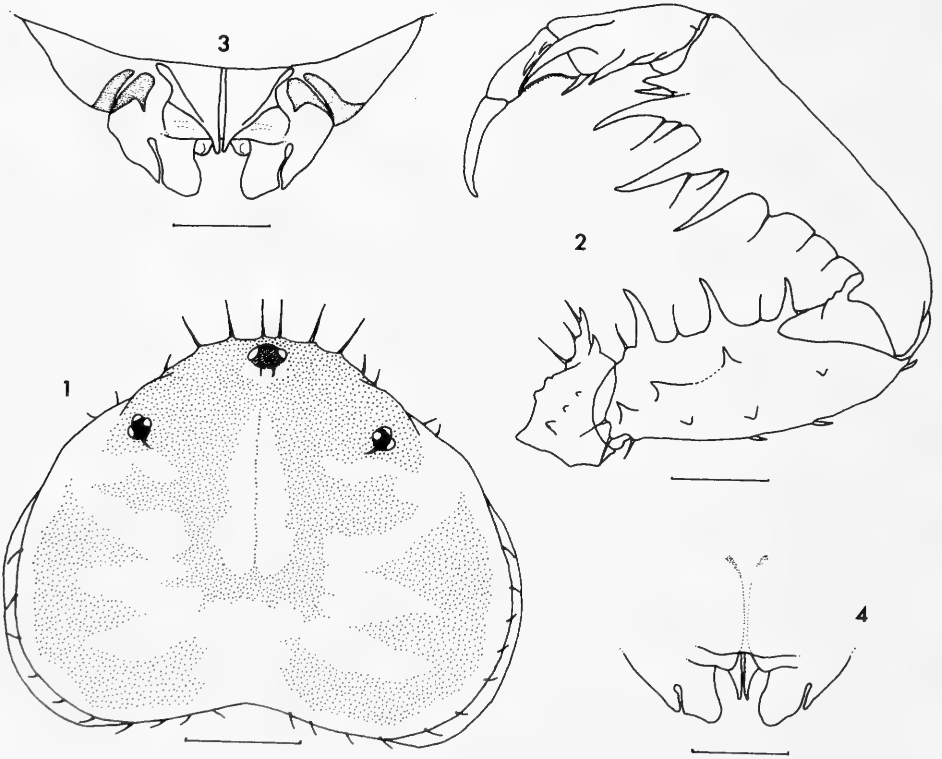
Diagnosis: Spiniform bristles and spines on carapace and pedipalps. Pedipalpal tarsus with 2 teeth prolaterally, distal tooth largest. Basitarsus longer than tarsus. Proximal tarsal segment only slightly longer than remaining segments together. Basitarsus 4 with 16 trichobothria, laterodistal rows 5, 5. Female genitalia with an anterior sclerite. Male genitalia with lateral lobes divided distally into two parts.

Dimorphism: Males and females are similar in general morphology. However, the pedipalpi are longer in relation to carapace width in males than in females. Ratio carapace width to length of palpal femur plus tibia: ♀ ca 0.80:1; ♂ ca 0.65:1.

Description of MALE metallotype (Figs 1-4)

Carapace length 3.53, width 4.41. Abdomen length 4.80, width 3.68.

Carapace punctate, spiniform bristles placed along anterior margin, central 6 largest; colour reddish brown with greyish patches on cephalic, foveal and lateral thoracic areas. Abdomen light orange-brown with a median and two lateral greyish patches on each segment. Legs indistinctly banded, brownish-grey. Pedipalps orange-grey.



Figs 1-4. Charinus pescotti, male. Scale lines = 1mm. 1. Carapace. 2. Pedipalp, prolateral. 3. Genitalia, ventral. 4. Genitalia, dorsal.

Eye group width 2.42. Anterior pair of eyes on low tubercle with 2 small bristles posteriorly; anterior eyes separated by 1.5 times their diameter. A single bristle behind each lateral eye triad.

Chelicerae with 5 prolateral teeth, basal tooth largest, two distal teeth fused at base. Pedipalpi relatively short but longer than in female; male femur about as long as carapace. Femur length 3.48; tibia length 4.00. Distribution of spur-like teeth on pedipalps (p = prolateral, r = retrolateral): coxa 2r; femur 3p, 3r; tibia 4p, 2r; basitarsus 2p, 1r; tarsus 2p (distal tooth largest). Pedipalpal spines and bristles spiniform. Prosternum prong-like, anteriorly with a pair of long apical bristles and several basal bristles (ca 10-12). Meso- and metasternum both with 4 bristles, a larger lateral pair and a smaller medial pair. Abdominal pedicel with a pair of bristles.

Leg lengths (both second legs damaged — lack post-patellar segments):

	Femur	Patella	Tibia	Basitarsus	Tarsus
1	6.68	0.57	12.14	1.07	9.74
2	4.35	0.90	—	—	—
3	5.00	0.94	4.10	2.21	1.70
4	4.26	0.84	4.21	2.01	1.64

Tibia 4, length of subsegments: proximal 2.07, middle 0.62, distal 1.52. Proximal tarsal segment of legs 3, 4 (tarsi 2 missing) slightly longer than combined length of distal segments. Tibia 1 with 23 subsegments. Tarsus 1 with 40 subsegments. Trichobothria, leg 4: basitarsus 3 proximal, 13 distal (apicodistal 3, laterodistal 5, 5); tibia, distal segment 1.

Genitalia: lateral lobes large, partially divided into a larger inner and a smaller outer part. Medial lobes slightly smaller, tapering distally, triangular. Ventro-medial lobes (adjacent to sclerotized lateral lobe bases) short and rounded. Dorsal lobes short and blunt.

Material Examined: Males: the metallotype only. Females: 4, 2km WNW of Cape Tribulation, Queensland, 23.9-7.10.1982, Monteith, Yeates and Thompson; 3, Barron Falls, near Cairns, Queensland, 3.9.1901, C. Hedley.; 2, 50km north of Cairns, Queensland, 28.12.1969, N. C. Coleman.

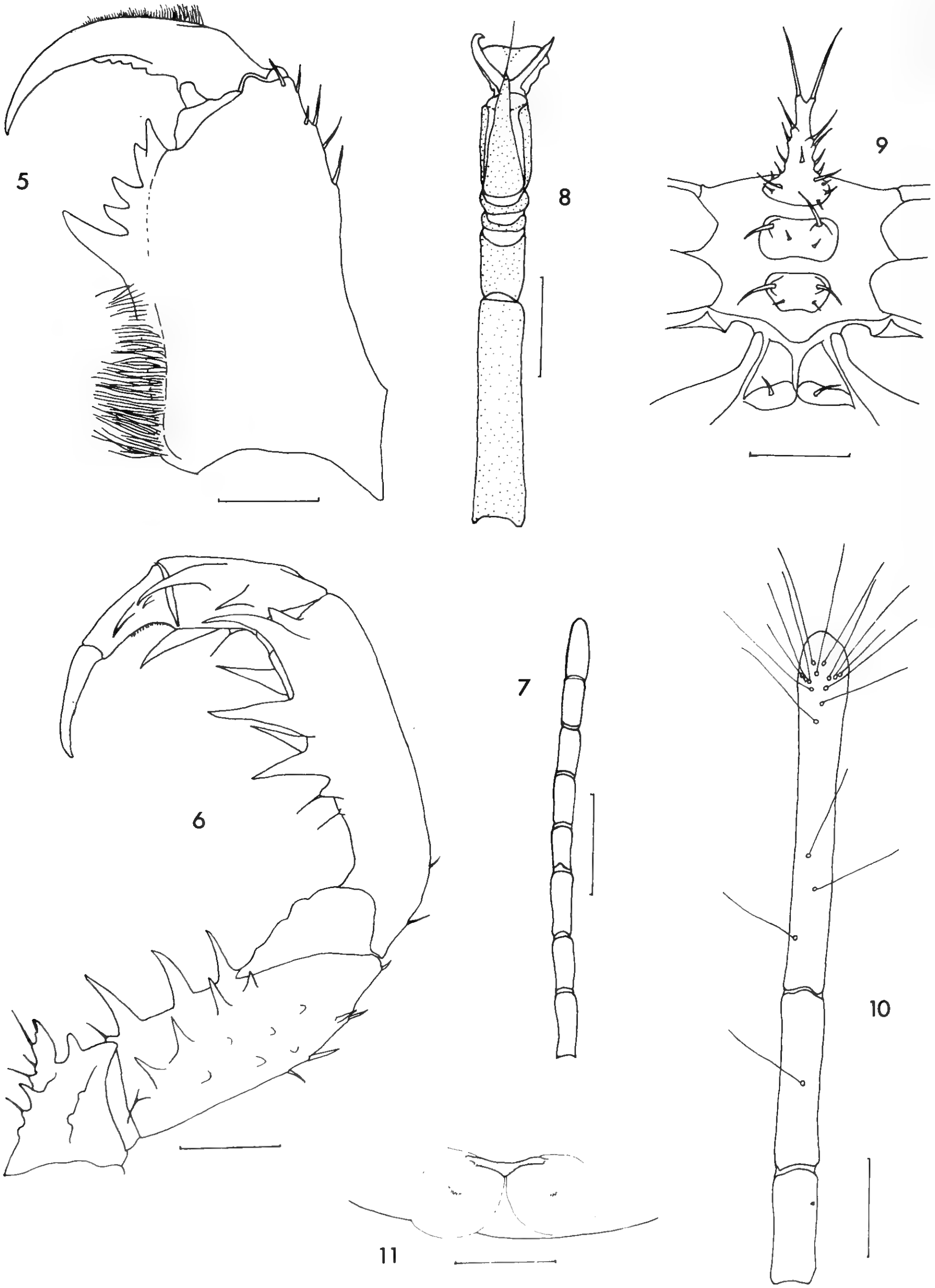
BEHAVIOUR

Specimens of the Tailless Whipscorpion *Charinus pescotti* Dunn, 1949 were collected in lowland rainforest at 'Gap Creek farm', Bloomfield River district, north Queensland. All were found on the under surface of stones or logs, never on the substrate below. Gravely (1915) records similar behaviour in Ceylonese tarantulids. They occurred singly except where associated with a rock or log greater than ca 130cm diameter.

The specimens collected for behavioural study were as follows: 2 ♂♂, 4 ovigerous ♀♀, 1 ♀ with young on the back, and 2 immature specimens.

Initially a male, a female and a juvenile male were maintained in a perspex container measuring 12cm × 12cm × 15cm high for detailed observation of feeding and breeding behaviour. Later five adults (1 ♂, 4 ♀♀) were moved into an aquarium measuring 62cm × 31cm × 37cm high. Captive conditions were arranged similarly to wild conditions with stones, sections of old termite eaten wood (*Ficus* sp.) and dampened 50/50 leaf mulch, soil mixture. Pieces of *Helxine* sp. were added to simulate the forbs of the forest floor.

Live food consisted of flies (family Phoridae), Collembola (family Poduridae), and young isopods *(Porcelio scaber)* all of which bred in the containers. This was supplemented with Vinegar Flies, *Drosophila melanogaster.* No dead food was observed taken.



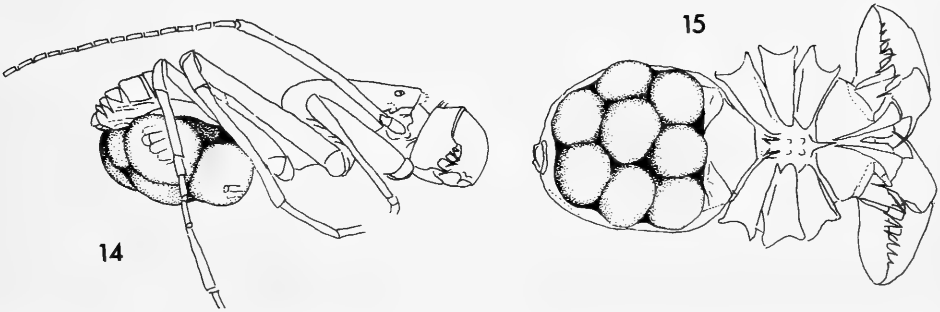
Figs 5-11. Charinus pescotti, female. Scale lines = 1mm. 5. Chelicera, retrolateral. 6. Pedipalp, prolateral. 7. Leg 1, distal tarsus. 8. Leg 4, tarsus. 9. Sternum and ventral pedicel. 10. Leg 4, tibia. 11. Genitalia, ventral.

High humidity was maintained and the containers were kept under natural lighting except when nocturnal observations were made. Nocturnal observation used normal room lighting with occasional use of a penlight torch.

(a) Feeding behaviour

Under captive conditions it became clear that not only does each individual have its own nocturnal feeding site and daytime retreat unshared by others, but aggressive encounters are minimal with almost no physical contact between individuals. If an aggressive adult male advances into the feeding site of a female or juvenile the length of the whips ensures the subordinate individual of early warning and it retires accordingly. It is only in confined areas (e.g. collecting tubes) that damage in the form of lost whip tips and (in extreme cases) legs below the patella has been observed. When newly-independent young are present cannibalism occurs readily, but this has never been observed amongst individuals of similar size.

At night individuals moved out onto the side or upper surface of their retreats and took up feeding stances. The substrate was used only to cross from one daytime retreat to another. At no time was feeding observed during transit. If an individual was chased off its feeding site it would adopt a feeding stance on the glass or perspex sides of the container.



Figs 12-13. Charinus pescotti, feeding behaviour. 12. Hunting position. 13. Prey capture by 'herding' with first leg 'whips'.

Figs 14-15. Charinus pescotti, female with embryos in abdominal brood pouch. 14. lateral. 15. ventral.

The legs, particularly the long first pair, are the primary sensory structures of the amblypygids (Weygoldt, 1972b; Foelix *et al.*, 1975). In *C. pescotti* the eyes seem to be of little use in detecting prey or predators, although Gravely (1915) has suggested such use in an Indian amblypygid. The first legs or 'whips' are often swept toward a moving object before it can be reached, suggesting vibrational or air current sensitivity.

In the feeding stance (Fig. 12) *C. pescotti* usually raises its body some 2mm above the substrate (in contrast to its more depressed resting stance), with a slight downward slant anteriorly. The pedipalps, although folded, appear to be turned slightly forward at the coxa-trochanter joint and are slightly opened at the armed ends. The whips are swept backwards and forwards at an angle approaching, or greater than 90° to each other so that one is usually pointing laterally while the other points anteriorly, thus covering the front and both sides without the need to move the body. Gravely (1915) records similar behaviour for *Phrynichus ceylonicus*. The ends of the whips are remarkably flexible and can easily trace a circular path at their tips or point back along their length (Figs 12, 13). Consequently the tips never appear still even though movement is slow. This stance, immobile except for the whips, is usually kept up for an hour or more before either prey is caught, reorientation in another direction occurs, or some other stimulus disrupts the procedure.

Once the nearby movement of potential prey is detected, one or other of the whips is moved towards it. As soon as the whip touches it the prey usually moves away at a tangent to the whip axis. Assuming it to be within the area enclosed by the whips it then encounters the other whip being moved rapidly towards it. This then causes the prey to move back towards the first whip and the process is repeated. As the whips are being flexed at the patella towards each other the result is that the prey pursues a zig-zag path towards the strongly-armed pedipalps. When within range both pedipalps flick out very rapidly and hook the prey into the chelicerae (Fig. 13). The use of the whips for detecting prey presence and of the pedipalps for grasping prey is well known (Cloudsley-Thompson, 1985; Alexander, 1962; Weygoldt, 1972a). However, the use of the whips for 'prey herding' prior to capture appears to be unrecorded.

If the prey is first contacted at the end of the whip up to three further contacts can be required before the prey is herded into range of the pedipalps. In the case of phorid flies the above action can be quite rapid and is somewhat reminiscent of a pinball machine. The ends of the whips often curl inwards if the prey moves off at an angle which might take it outside their range. Prey which comes in contact with the outer edge of the whip (i.e. outside the angle formed by the two whips) is often lost but an attempt is usually made to get it between the whips.

The rapid movement of the pedipalps during prey capture and occasional sideways darts to avoid unpleasant stimuli were the only fast movements observed. All other movements are slow and deliberate with constant local reconnaissance by the sweeping whips. The whips are thrust into any crevices prior to the animal entering (characteristically sideways). Possibly prey is also located and caught in this manner although this was not observed.

Large prey is avoided by *C. pescotti* and most prey taken was small in size — the largest capture was a newly moulted (and therefore soft) slater *P. scaber*, 6mm body length, by a male specimen approximately 9mm body length. Appetites do not appear to be voracious and often several days elapse between meals, especially in colder weather. The young feed on the same (but smaller) prey as adults. Prey was never seen to be chased — it was always a matter of prey coming to predator.

(b) **Breeding observations**

No complete courtship or mating was ever witnessed. In late December 1982 a captive male specimen was observed slowly investigating a female with his whips. Normally she would have vacated the area of his close proximity. However, in this case she remained inactive for almost a minute before moving off. The male did not follow and this behaviour was not observed again.

Fig. 16. Charinus pescotti, female.

Most of the reproductive activity at the Bloomfield collecting site seems to occur in late December-January. On 6th January 1983 all adult females observed in the field were either ovigerous or carrying young. No newly independent young were noticed at this time. The young seem mostly to have dispersed by February just before the start of the wet season. Ovigerous females from other areas have been collected from late September to late December.

In the ovigerous females the developing eggs are visible as somewhat depressed hemispheres on the underside of the abdomen (Figs 14, 15). They are completely covered by a transparent membrane, the brood sac. These hemispheres become very obvious in the later stages of development. The females at this time carry their abdomens at a definite upward tilt.

Three ovigerous specimens from Cape Tribulation, north Queensland and one from the Mossman area proved to have 7, 8, 11 and 16 eggs respectively. Egg diameters ranged from 1.45-1.80mm. Developing embryos were visible through the walls of the largest eggs. Cloudsley-Thompson (1958) records egg size of 2-3mm and noted that the number of eggs may vary from 7 to 80 or more, depending on the size of the mother. *C. pescotti* therefore is within the range of the smaller brood sizes recorded. A maximum of only 5 young (average 4) were recorded as being carried by 7 Bloomfield specimens. This could indicate either that different populations may have different brood size ranges or that not all young survive. Gravely (1915) noted that not all embryos develop successfully. The strategy here seems to be a reversal of the usual invertebrate trend of producing a large number of small young. The young, white on emergence from the brood sac, are quite large, the Bloomfield specimens averaging 0.7mm carapace width as compared to 3.6mm for adult females.

After emergence the young congregate mainly on the mother's abdomen. Due to their large size they must wrap around the abdomen and each other. Usually within a week they undergo their first moult, gain pigment on the cephalothorax and abdominal segments, and disperse.

On two occasions the original female produced two broods in one season. Both times the broods were observed in early January and late January—early February. Whether this occurs in the wild could not be determined. The females can also survive at least into a third breeding year. These two factors may provide a counterbalance to the small brood size. Growth to maturity appears to be slow, certainly exceeding 12 months. Gravely (1915) records *Charinides bengalensis* as taking at least 3 years to reach maturity at a carapace width of 3.5mm. *C. pescotti* has an adult carapace width of 3.54-4.67mm.

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The cidarid Echinoids (Echinodermata) of New South Wales

F. W. E. ROWE and A. K. HOGGETT

ROWE, F. W. E., & HOGGETT, A. K. The cidarid echinoids (Echinodermata) of New South Wales. *Proc. Linn. Soc. N.S.W.* 108 (4), (1985) 1986: 225-261.

Fifteen species of cidarid echinoids are now recorded from New South Wales waters (including Lord Howe Island), from the shore to 1,500m depth. A newly-described species of *Prionocidaris* is common in N.S.W. waters, and also occurs in Queensland, Lord Howe Island, ?Norfolk Island, the Kermadec Islands and New Caledonia. Four other species were not previously known to occur in Australian waters, and new records for N.S.W. are represented for another three species.

F. W. E. Rowe and A. K. Hoggett, Australian Museum, Sydney, Australia, 2000 (A. K. Hoggett, new address, *Northern Territory Museum of Arts and Sciences, Darwin, Australia, 5794); *manuscript received 3 June 1985, accepted for publication 23 October 1985.*

INTRODUCTION

The cidarid echinoids are a conspicuous feature of the invertebrate fauna of southern Australia, in both shallow and moderately deep water. The Cidaridae were the subject of a monograph by Mortensen (1928b), and the Australian cidarids have been reported by H. L. Clark (1946).

The echinoderm fauna of the New South Wales coast is currently being surveyed with the intention of describing its origins and zoogeographical relationships. Comprehensive collections of echinoderms have been made along the New South Wales coast and from Lord Howe Island, from the shoreline to 35m depth. In addition, large collections of echinoderms have been made by the New South Wales State Fisheries research vessel 'Kapala' from off the N.S.W. coast to depths of 1,200m. All this material is deposited in the Australian Museum.

Examination of these collections has revealed the existence of fifteen species of cidarids in New South Wales waters (including Lord Howe Island), compared with seven reported by H. L. Clark in 1946. A new species of *Prionocidaris* is described, four species of cidarid are newly recorded from Australian waters, and three other species have their ranges extended into N.S.W. waters.

The following abbreviations are used: AM = Australian Museum, Sydney; WAM = Western Australian Museum, Perth; NMNZ = National Museum of New Zealand, Wellington; NZOI = New Zealand Oceanographic Institute, Wellington; Qld. = Queensland; N.S.W. = New South Wales; Vic. = Victoria; Tas. = Tasmania; S.A. = South Australia; W.A. = Western Australia; N.T. = Northern Territory; N.Z. = New Zealand. Registration numbers are given only for those specimens examined which are type material, or which belong to an institution other than the Australian Museum.

SYSTEMATIC ACCOUNT

Family CIDARIDAE Gray

Subfamily HISTOCIDARINAE Mortensen

Genus ***Histocidaris*** Mortensen

Histocidaris is a well-defined genus, having well-developed tridentate pedicellariae but no globiferous pedicellariae. Crenulate tubercles and rather sparse tuberculation of the apical system are also conspicuous features of the genus (Mortensen, 1928b).

Three species of *Histocidaris* (*elegans* Agassiz, 1879, *australiae* Mortensen, 1928a and *crassispina* Mortensen, 1928a) have been recorded from N.S.W. waters. The species are separated mainly on the nature of the primary spines (Mortensen, 1928a,b). The collection of *Histocidaris* from N.S.W. waters in the Australian Museum includes only two recognizable forms; *crassispina*, which is known from a single specimen, is not represented.

Mortensen (1928b) includes 14 nominal species in the genus, of which 8 are each known from a single specimen. Examination of his descriptions shows each species to have one of two basic forms of tridentate pedicellariae: either with broad, spoon-shaped valves, or with narrow, elongate valves. Within these two groups, the species have been separated mainly by the form of the primary spines. It seems likely that insufficient variation in the character of the primary spines at least has been allowed by Mortensen, and a thorough revision of the genus would probably result in considerably fewer species being recognized.

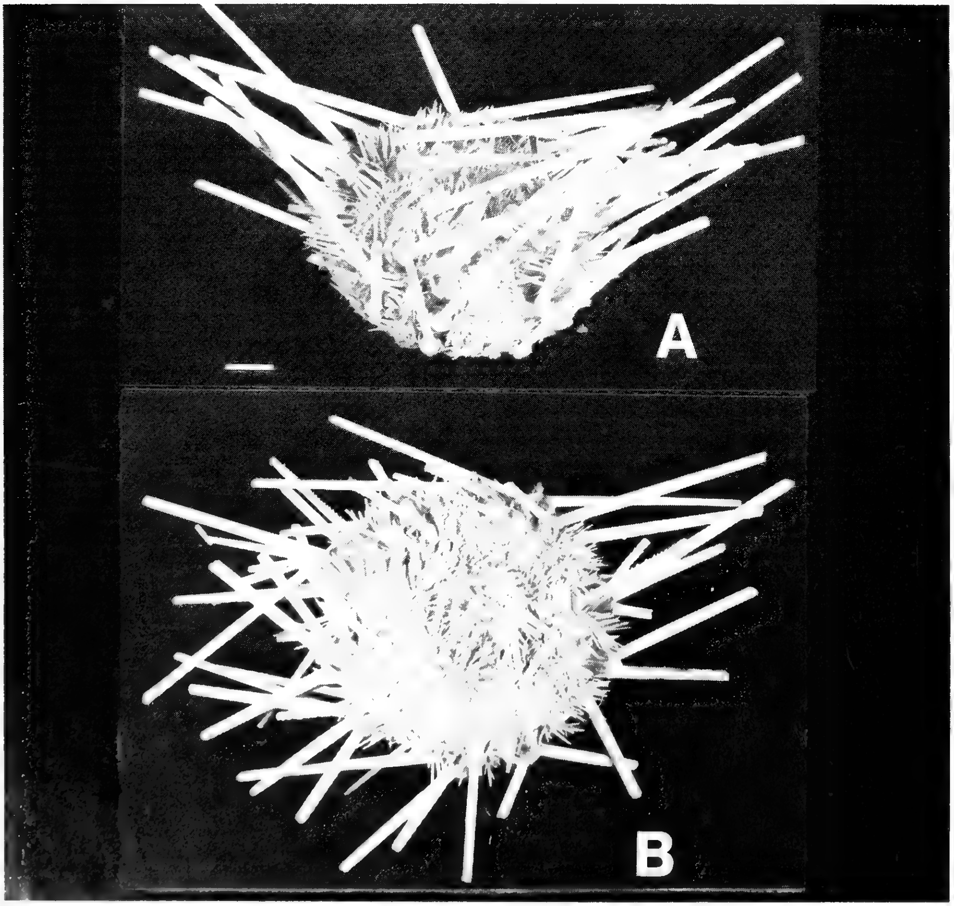


Fig. 1. **A,B.** *Histocidaris elegans*, J15802, off Broken Bay, N.S.W., 720m. Scale = 10mm.

Histocidaris elegans (Agassiz)

Fig. 1**A-B**

Porocidaris elegans Agassiz, 1879:198.
Histocidaris elegans: Mortensen, 1928b: 72 (synonymy), pl. 1, figs 1-5, pl. 2, figs 1-3, pl. 68, fig. 6, pl. 75, fig. 16, pl. 76, figs 9-13; H. L. Clark, 1946:294; Dartnall, 1980:43; McNamara, 1984:88.

Diagnosis: Primary spines have longitudinal rows of very fine serrations covering the shaft; spines are slender, cylindrical for most of their length, but some spines taper and others become flattened near the tip, with serrations becoming more marked; diameter at distal end of the collar of primary spines above the ambitus is 1.4-2.9mm (specimens 21-65mm horizontal diameter); oral primary spines are flattened, not appreciably widened beyond the collar except for the strongly serrate margins.

Material: 202 specimens housed in the Australian Museum from off Sugarloaf Pt., N.S.W. to off Flinders Is., Bass St., and from off Broome, W.A. 150-1,475m (188 specimens from N.S.W. waters, 8 from eastern Victorian waters (Gabo Is.), 2 from Bass Strait, and 4 from W.A. waters); 2 specimens, NMNZ Ech 92, 248, 300 miles E. of Cape Farewell, N.Z., 1,980m, 'Challenger'.

Distribution: Japan; Philippines; Indonesia; northwest Australia; eastern coast of Australia as far south as Bass Strait; New Zealand. 150-1,980m.

Remarks: The species appears to be quite common in moderately deep water off the southeast Australian coast. *H. elegans* will almost certainly be represented in collections made from suitable areas off the Queensland coast. The species is recorded from northwestern Australia for the second time (McNamara, 1984).

Histocidaris australiae Mortensen

Fig. 2**A-E**

Histocidaris australiae Mortensen, 1928a:66; 1928b:91, pl. 10, figs 1-2, pl. 11, figs 1-5, pl. 68, figs 1-3; H. L. Clark, 1946:295.

Diagnosis: Ornamentation of the primary spines changes with growth of the individual; initially, the shafts bear conspicuous scattered thorns, becoming serrated longitudinal ridges distally; larger specimens lose all trace of the thorns and have a smooth shaft, which may have very slight longitudinal ridges; spines gradually taper; diameter at distal end of collar of primary spines above the ambitus 2.5-5.0mm (specimens 38-95mm horizontal diameter; oral primary spines flattened and widened, with a marked broadening of the spine beyond the collar; large specimens have rudimentary primary tubercles on the uppermost coronal plate in each series.

Material: 8 specimens in the Australian Museum collection from the range indicated below.

Distribution: Off Crowdy Head, N.S.W. to off Flinders Is., Bass St. 180-540m.

Remarks: Some characteristics of the specimens are listed in Table 1. Two specimens (E5910) are not included as they are in very poor condition.

The eight specimens examined are considered to be conspecific despite the differences apparent in the ornamentation of their primary spines. The few remaining spines (all broken) on the three largest specimens are very smooth and shining, with the exception of one spine on specimen number J15812, which has a few rounded bumps occurring in longitudinal series. It seems likely that coarse thorns on the primary spines become less pronounced with growth of an individual, resulting in smooth spines on large specimens.

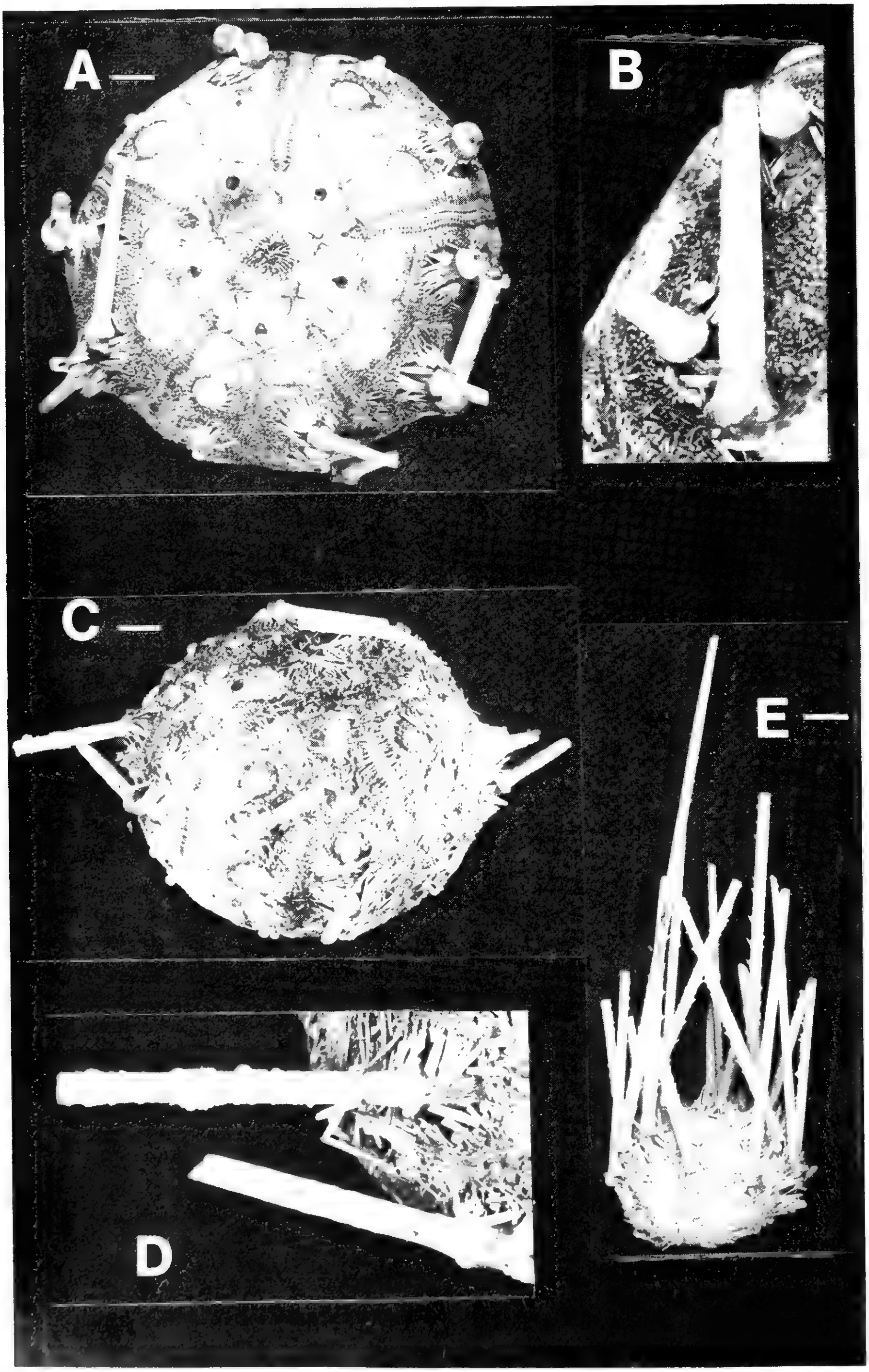


Fig. 2. Histocidaris australiae. **A**. J15812, off Shoalhaven Head, N.S.W., 306-360m. Scale = 10mm. **B**. Primary spine of J15182. **C**. J15798, off Gabo Is., Vic., 540m. Scale = 10mm. **D**. Primary spine of J15798. **E**. E4736, off Flinders Is., Bass Strait, 180-540m, 'Endeavour'. Scale = 10mm.

TABLE 1

Measurements of individuals of Histocidaris australiae

1 = horizontal diameter (mm), 2 = vertical diameter (mm), 3 = apical system diameter (mm), 4 = peristome diameter (mm), 5 = interambulacrum width (mm), 6 = ambulacrum width (mm), 7 = no. interambulacrals, 8 = no. ambulacrals/interambulacral, 9 = longest spine (mm), 10 = spine diameter at distal end of collar (mm)

	1	2	3	4	5	6	7	8	9	10
E4376	38	29	18	17	18	4	7	10	120	3.0
J18954	70	54	31	22	33	7	9-10	13-14	—	3.1
J15798	74	55	37	26	35	7.5	9	11-12	—	3.2
J15811-1	81	75	33	26	41	7.1	10-11	12-14	—	4.7
J15811-2	92	83	36	28	46	7.4	10-11	13-15	—	4.9
J15812	94	85	40	29	47	7.2	10-11	12-14	—	5.0

The only known specimen of a *Histocidaris* species with perfectly smooth spines was described by Mortensen (1927) as *H. magnifica.* The smooth-spined specimens from N.S.W. waters differ from the holotype of *magnifica* in that the peristome is relatively smaller (about 20% of h.d. compared with 26%), and the ambulacra are relatively much narrower (about 16% of interambulacral width compared with 28.6%). Also, the spine diameter of *magnifica* appears smaller from Mortensen's photograph (1927: pls 48,49) than that of the N.S.W. specimens.

The spines of *australiae* are described as being not much longer than the horizontal diameter of the test (Mortensen, 1928b). The longest spines of specimen number E4376 are at least 3 times its horizontal diameter. Mortensen (1928b: pl. 10, figs 1,2) figures the only specimen of *australiae* for which he provides spine-length data. All the spines of this specimen appear to be broken. As the specimens at hand agree in most other respects with Mortensen's (1928a,b) descriptions, the diagnosis of *australiae* is broadened to include specimens with longer spines.

One of the specimens, E4376, is considerably smaller than any previously recorded. The oral primary spines of this specimen are more slender than those of larger specimens, but are more robust than those of similarly-sized specimens of *elegans.* The existence of this small specimen indicates that *australiae* is not an 'old and probably senescent *elegans*' as H. L. Clark (1946) conjectured. *H. australiae* is certainly rarer than *elegans*, and appears to be more restricted in its distribution. Only thirteen specimens of *australiae* are now recorded, compared with hundreds of specimens of *elegans.*

Histocidaris crassispina Mortensen

Histocidaris crassispina Mortensen, 1928a:66; 1928b:77, pl. 10, figs 4-5, pl. 68, fig. 5, pl. 75, figs 1-2, pl. 77, fig. 23; H. L. Clark, 1946:294.

Diagnosis: Primary spines are thick and fusiform, with uniform, fine serrations (after Mortensen, 1928b).

Remarks: We have not examined any material of this species, which is known only from the holotype. This specimen was collected from south of Sydney, N.S.W., in 720m, by the 'Challenger' (stn 164b). This is the same station from which the type specimens of *H. elegans* were collected. Despite the large amount of *Histocidaris* material recently obtained from off the N.S.W. coast, no specimens conform to the description of *crassispina.* The species is either very rare or is based on an aberrant specimen of *H. elegans.* H. L. Clark (1946) doubted the validity of this species.

Subfamily GONIOCIDARINAE Mortensen

Genus ***Goniocidaris*** Agassiz and Desor

Goniocidaris forms the basis of the subfamily Goniocidarinae, which is distinguished from other cidarids primarily by the presence of grooves or pits in the horizontal sutures between coronal plates, and by the nature of the pedicellariae. Tridentate pedicellariae are either lacking or are of an unusual, coarse, form developed from small globiferous pedicellariae. Large globiferous pedicellariae are without an end tooth, and small globiferous pedicellariae usually have a conspicuous end tooth (Mortensen, 1928b).

Mortensen's terminology for the two different forms of globiferous pedicellariae as 'large' and 'small' is unfortunate, as pedicellariae of the form described as 'small' can range widely in size. A considerable number of *Goniocidaris* species do not possess 'large', toothless pedicellariae, but possess a range of sizes of 'small', toothed pedicellariae. Mortensen's (1928b) key to the genus groups of the Stereocidarinae is thus quite unsatisfactory. Each of the 'groups' included in the subfamily Stereocidarinae by Mortensen (1928b) have subsequently been elevated to subfamily status by Fell (1966).

Within the Goniocidarinae, *Goniocidaris* is distinguished from the other three genera by the nature of the primary spines, which are said to have either a terminal or a basal disc, or both, on the apical spines (Mortensen, 1928b). However, this feature is absent from a number of *Goniocidaris* species, so this character is not particularly useful in diagnosing the genus. *Goniocidaris* includes a large number of morphologically-diverse species which have been grouped into five poorly-delineated subgenera (Mortensen, 1928b). It appears that the Goniocidarinae is in need of thorough revision.

In practice, *Goniocidaris* is distinguished from other genera by the presence of pits in the sutures of the ambulacra and interambulacra, and by the presence of globiferous pedicellariae with an end tooth, although globiferous pedicellariae without an end tooth may also occur (Mortensen, 1928b).

Goniocidaris tubaria (Lamarck)

Figs 3**A-D,** 5 **A-B**

Cidarites tubaria Lamarck, 1816:382.
Goniocidaris tubaria: Mortensen, 1928b:156 (synonymy), pl. 12, figs 1-7, pl. 13, figs 10-11, pl. 69, fig. 4, pl. 78, figs 1-6; H. L. Clark, 1946:291 (part).
Goniocidaris geranoides tubaria: Stach, 1938:333 (part), pl. 18, fig. 10e [?non figs 10a-d].
Adelecidaris tubaria: Cotton and Godfrey, 1942:217.

Diagnosis: Basal discs are absent from primary spines; globiferous pedicellariae are of two forms, the larger of which does not have an end tooth and is conspicuous due to its globular shape (Mortensen, 1928b); genital plates (other than madreporite) have tubercles in two patches, one surrounding the genital pore and another on the inner edge, thus leaving bare lateral areas; miliary spines are more or less pointed; interpore areas of ambulacra have a wide, continuous bare area.

Material: 478 specimens housed in the Australian Museum from the areas indicated below (428 specimens from N.S.W. waters, 19 from Victorian waters, 8 from Tasmania and Bass Strait, 18 from S.A. waters, and 5 from W.A. waters).

Distribution: Ballina, N.S.W., south to Oyster Bay, Tasmania, across Victoria and South Australia to Perth, W.A., shore — 630m.

Remarks: *Goniocidaris impressa* Koehler, 1926, was regarded by Mortensen (1928b) and H. L. Clark (1946) to be merely a variety of *G. tubaria.* However, examination of the large collection of *Goniocidaris* material in the Australian Museum (including the type material of *impressa*) indicates that they can be readily distinguished, and *G. impressa* should be recognized as a distinct species. Cotton and Godfrey (1942) arrived at the

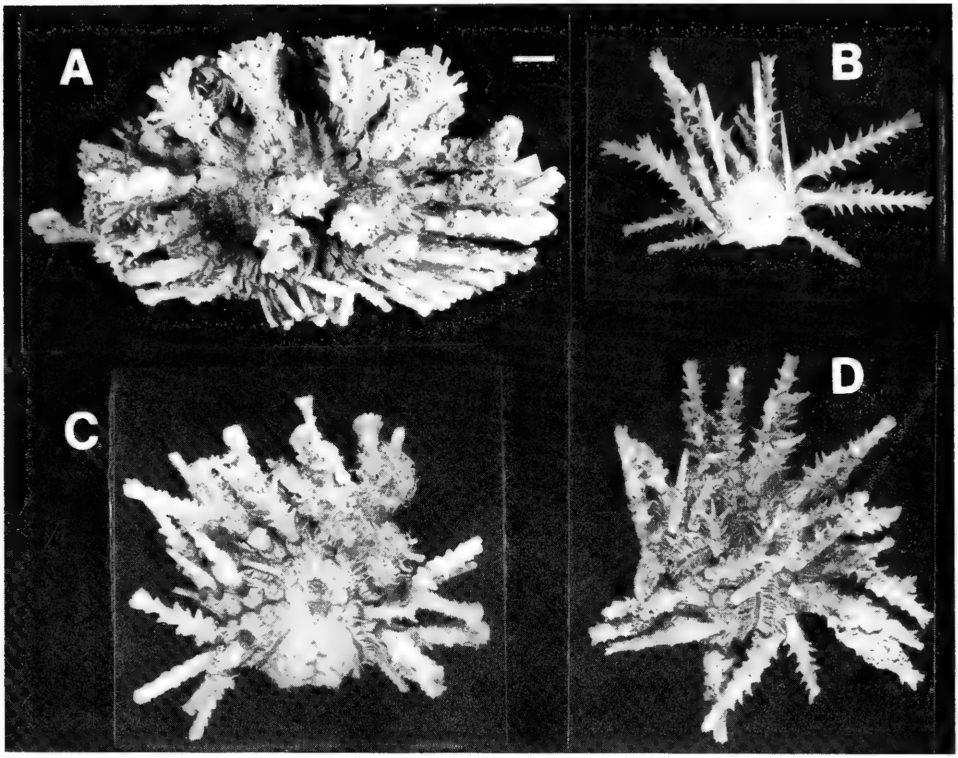


Fig. 3. Goniocidaris tubaria. **A**. J234, Port Phillip, Vic. **B**. J6046, off Broughton Is., N.S.W., 81-90m. **C**. J12106, Sorrento Reef, Perth, W.A. **D**. J3480, Norah Head, N.S.W., 47-68m. Scale = 10mm.

same conclusion after examining South Australian and Tasmanian specimens. *G. impressa* is illustrated in Figs 4 **A-C**, 5 **C-D**, for comparison with *G. tubaria*.

G. impressa differs from *tubaria* in the following features: genital plates are evenly covered with tubercles; miliary spines are more or less club-shaped; the interpore zones of the ambulacra have small tubercles extending into the bare median areas, often to the extent that the bare area becomes a discontinuous series of patches.

The primary feature used by Mortensen (1928b) and H. L. Clark (1946) to distinguish the 'varieties' was the last-mentioned one above. This character is slightly variable in *impressa*, leading to the impression that forms intermediate between *tubaria* and *impressa* exist. However, tuberculation of the genital plates provides a very consistent difference between the species. This feature was noted by Mortensen (1928b:163, fig. 51), but he apparently placed little emphasis on it. Mortensen's (1928b) fig. 51.2 shows the apical system of a male specimen of *G. tubaria* with only slightly bare patches on the genital plates. This figure represents the most extreme case of tuberculation in this position on any specimen of *tubaria* we have examined. Mortensen (1928b) describes *tubaria* as having club-shaped miliary spines. This must be due to his having confused the species, as the miliary spines of *tubaria* are pointed, or at the most, flattened and slightly spatulate. The miliary spines of *impressa*, however, are distinctly club-shaped.

When the species are separated on the basis of tuberculation on the apical system and miliary spine shape, much of the apparent gradation of characters between the

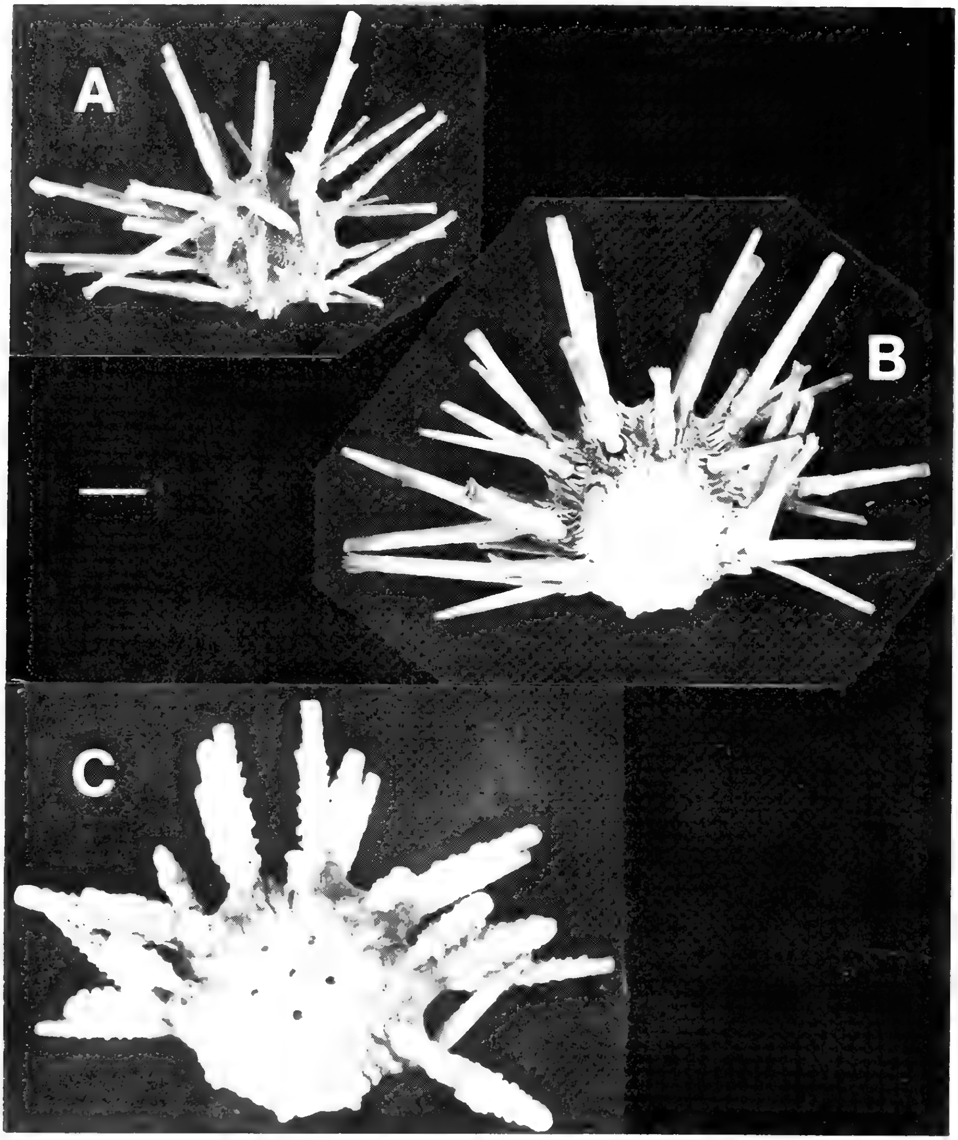


Fig. 4. Goniocidaris impressa. **A**. J4908 (part), paratype, Maria Is., Tas., 117m. **B**. J5438, D'Entrecasteaux Channel, Tas., 9m. **C**. J11396, Flinders Is., Bass Strait. Scale = 10mm.

species is lost. A continuous bare area in the interpore zone of the ambulacrum is a constant feature of *G. tubaria*; large bare areas are also usually present in the interambulacra, but the extent of these is slightly variable. All specimens of *G. tubaria* have thorny primary spines, though there is some variation in their relative length and thickness. In comparison, *G. impressa* has a softer appearance, due to the less thorny primary spines, the club-shaped miliary spines and the greater tuberculation of the apical system, ambulacra and interambulacra. The denuded tests also differ in colour. The ambulacra and median interambulacral regions of *impressa* are, at most, slightly darker

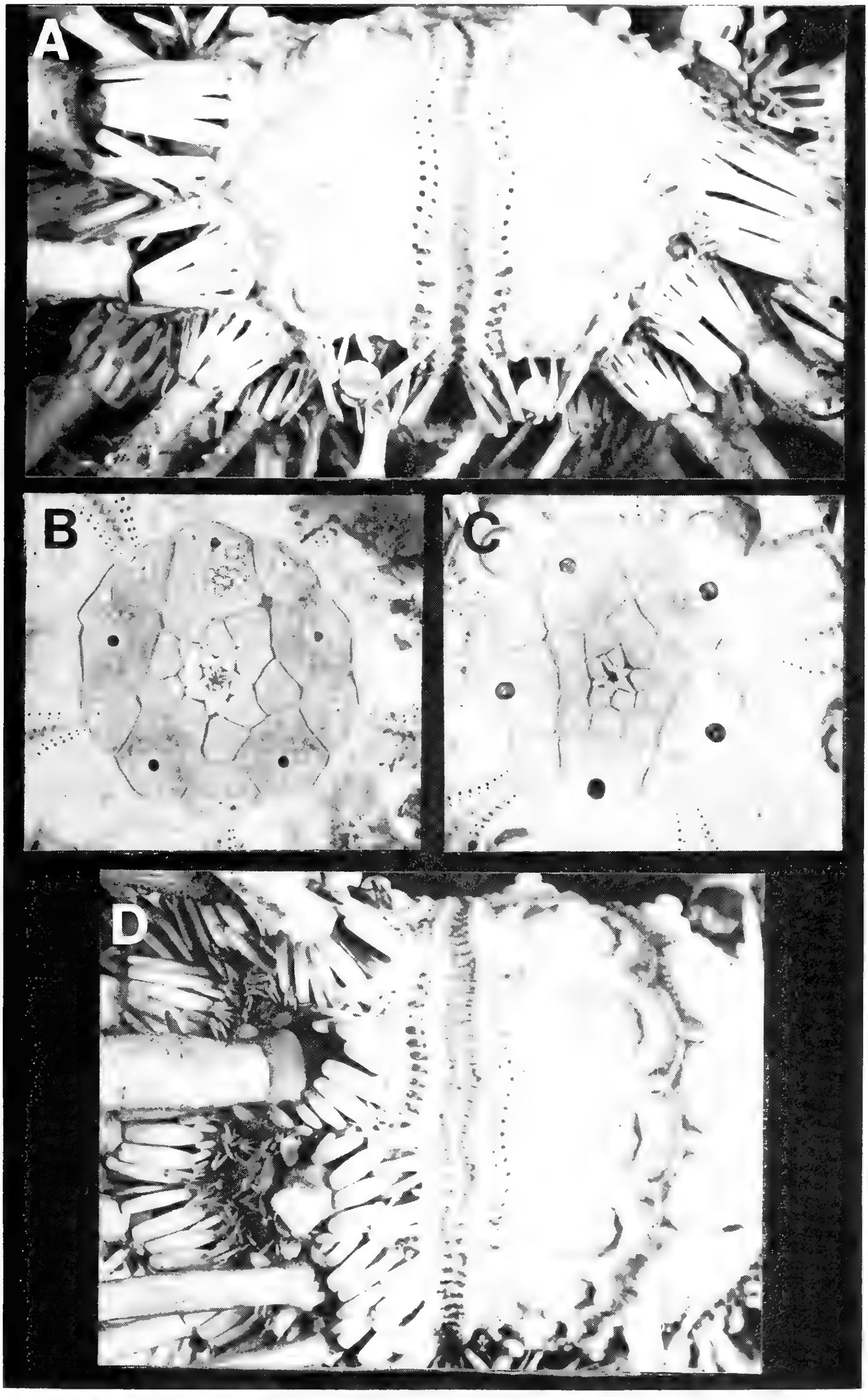


Fig. 5. **A**. Lateral view of test of *Goniocidaris tubaria*, J6046. **B**. Apical system of *G. tubaria*, J6046. **C**. Apical system of *G. impressa*, J5348. **D**, Lateral view of test of *G. impressa*, J5348.

than the rest of the cream-coloured test, and there is often a distinct greenish cast over the apical system. There is no green colour present on the apical system of *tubaria*, and the bare areas of the ambulacra are usually conspicuously purple.

G. tubaria and *G. impressa* are closely related to the New Zealand species *G. magi* Pawson, 1964, and *G. corona* Baker, 1968. These are the only four *Goniocidaris* species which do not possess either terminal or basal discs on the primary spines, and constitute the nominate subgenus of *Goniocidaris* (Mortensen, 1928b). *G. magi* and *G. corona* lack the large, globular globiferous pedicellariae (Baker, 1968) which are conspicuous on the two Australian species. Both New Zealand species are small in size, the largest specimen (a paratype of *magi*) having a reported horizontal diameter of 19mm (Pawson, 1964).

We have examined this paratype of *magi* (NZOI P11), and find its horizontal diameter to measure only 18mm. The tuberculation of the apical system is similar to that of *G. tubaria*. We concur with Pawson (1964) that the two species are distinct; the primary spines of *magi* lack conspicuous thorns, and the ambulacra and interambulacra of *magi* have fewer secondary tubercles than those of *tubaria*. In addition, the marginal ambulacral spines are virtually indistinguishable from the scrobicular spines in *magi*, whereas in both *tubaria* and *impressa*, the marginal spines are distinctly shorter and narrower than the scrobicular spines.

Comparison of a specimen of *corona* (AM J9291) from Bay of Islands, New Zealand, with Australian *Goniocidaris* specimens shows that this species is also distinctive. Like *magi*, its marginal ambulacral spines are of approximately the same size as its scrobicular spines. Baker (1968) describes the miliary spines of *corona* as club-shaped, but the specimen we have examined has club-shaped spines only on the peristome. Those of the apical system are quite cylindrical, and those on the ambulacra and interambulacra are flattened. Baker's (1968: fig. 1J) figure of the apical system of *corona* shows the even distribution of tubercules to be similar to that of *impressa*, though the density is less. The position of the genital pores differs, however, with those of *corona* being right at the outer edge of the plate, while those of *impressa* being situated away from the edge, about half way to the centre of the plate.

Specimens of *G. tubaria* from localities west of Bass Strait differ slightly in appearance from those occurring on the east coast of Australia. Preserved east coast specimens (including those from Victoria and Bass Strait) have pink/red scrobicular spines, usually with greenish tips. Most specimens from South Australia and Western Australia which we have examined have much paler scrobicular spines, either white or cream, with no change in colour near the tip. Cotton and Godfrey (1942) describe the colour of the secondary spines of live South Australian specimens as being cream to yellow. One specimen from Western Australia (AM J12246), however, has exactly the same colour pattern as its east Australian counterparts. The primary spines of the western specimens are generally shorter and thicker than those of most of the eastern specimens. Also, the thorns on the primary spines of the western specimens are either poorly developed or are not as sharp as those on the eastern specimens. It is possible, with more material from west of Bass Strait, that the western form may be found to comprise a valid species distinct from *tubaria*.

G. tubaria is apparently quite rare in Tasmania, as only two specimens are known from there. The distribution of *G. impressa*, determined from the 132 specimens (including the type series) in the Australian Museum, is from Cape Jarvis, S.A., to Wilson's Promontory, Vic., through Bass Strait and circumscribing Tasmania, 9-160m. A single specimen of *impressa* is labelled as being from 'Off Sydney, "Challenger" '; this record is regarded as dubious. Similarly, Cotton and Godfrey's (1942) record of a specimen of *impressa* from Port Curtis, Qld, is probably erroneous. *G. impressa* and *G. tubaria* thus co-occur along the Victorian and South Australian coast, in Bass Strait and rarely in Tasmania.

Goniocidaris sibogae Mortensen

Fig. 6 **A-D**

Goniocidaris clypeata: H. L. Clark, 1916:102 [non *Goniocidaris clypeata* Döderlein, 1885].
Goniocidaris alba Mortensen, 1928a:67.
Goniocidaris sibogae Mortensen, 1928a:68.
Goniocidaris australiae Mortensen, 1928a:68; H. L. Clark, 1946:293; Dartnall, 1980:45.
Goniocidaris (Aspidocidaris) alba: Mortensen, 1928b:193, pl. 15, fig. 14, pl. 69, fig. 7, pl. 79, fig. 6.
Goniocidaris (Aspidocidaris) sibogae: Mortensen, 1928b:198, pl. 16, figs 6-9, pl. 69, fig. 11, pl. 78, figs 14-16.
Goniocidaris (Aspidocidaris) australiae: Mortensen, 1928b:201, pl. 16, figs 1-5, pl. 69, fig. 12, pl. 78, figs 21-25.

Diagnosis: Basal discs are present on the primary spines and the adapical ones have a conspicuous terminal disc; globiferous pedicellariae are of a single, slender form, in which an end tooth is present; primary spines are finely thorned; secondary spines are flattened with a straight-cut tip; a distinct greenish colour is often present on the apical area of the denuded test.

Material: 44 specimens in the Australian Museum collection from Norah Head, N.S.W. to the eastern and southern coasts of Tasmania. (30 specimens from N.S.W. waters, 8 from Victorian waters, 2 from Bass Strait and 4 from Tasmanian waters. The specimens from Victoria, Bass Strait and all but one from Tasmania were collected by the 'Endeavour' in 1914.)

Distribution: Japan; Indonesia; east Australian coast as far south as Tasmania, 120-490m.

Remarks: The southeast Australian specimens at hand clearly fall into the group of *Goniocidaris* species united in the subgenus *Aspidocidaris* Mortensen, which is characterized by the presence of basal and terminal discs, a coat of anastomosing hairs on the primary spines, and by the secondary spines which are flattened with a straight-cut tip. Seven species have been referred to this subgenus: *clypeata* Döderlein, 1885, *fimbriata* De Meijere, 1904b, *alba* Mortensen, 1928a, *crassa* Mortensen, 1928a, *sibogae* Mortensen, 1928a, *australiae* Mortensen, 1928a and *parasol* Fell, 1958. In light of the variation observed in the 40 Australian specimens, it seems likely that some of these species have been based on characters which are subject to individual variation.

The species occurring in southeastern Australia was first identified as the Japanese species, *G. clypeata*, by H. L. Clark (1916). However, Mortensen (1928a,b) did not consider the Australian specimens to be conspecific with *clypeata* due to differences in the disc and hair coat of the primary spines, the relative size of the peristome, and colour of the naked test. Mortensen (1928a) described a new species, *australiae*, for the Australian specimens.

Two forms of globiferous pedicellariae are said to occur in *clypeata*: a larger form without an end tooth, and a smaller form with a conspicuous end tooth (Mortensen, 1928b). Only various sizes of the toothed form have been found to occur in the other six nominal species of *Aspidocidaris*. (The pedicellariae of *parasol* have not been described, but examination of 2 specimens (AM J7109 and J7796) revealed only the toothed form.) Mortensen (1928b) notes the lack of these 'large' globiferous pedicellariae in the descriptions of *fimbriata, alba, crassa* and *sibogae*, but indicates they are present in *australiae* and provides figures of one. Mortensen's material of *australiae* comprised specimens obtained by the 'Endeavour' in 1914 off the eastern Victorian coast. We have not seen the type

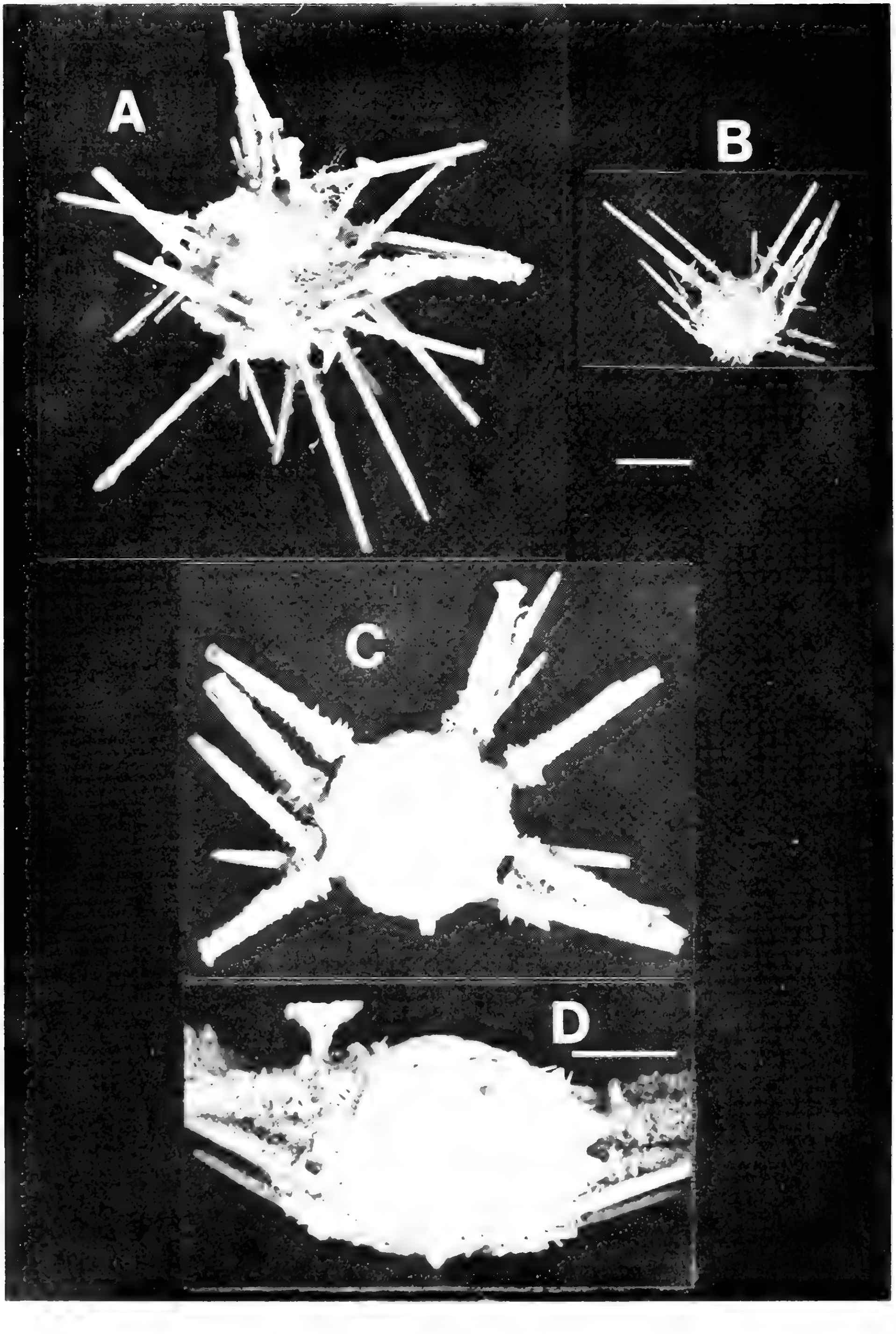


Fig. 6. Goniocidaris sibogae. **A**. E5919 (part), S. of Cape Everard, Vic., 360-486m, 'Endeavour'. **B**. E5114, E. of Maria Is., Tas., 230m. **C,D**. J15844, off Kiama, N.S.W., 405m. Scale = 10mm.

material, but 13 of the specimens examined by us were collected by the 'Endeavour' from near the type locality. None of the specimens we have examined has globiferous pedicellariae of the form indicated by Mortensen (1928b: pl. 78, figs 21-23). This form of pedicellaria is thus either extremely rare, or it is in fact absent from the Australian specimens, Mortensen's assertion to the contrary being a mistake. Assuming that *clypeata* does have pedicellariae of two distinct forms, the absence of this feature in all other species of the subgenus indicates the distinctness of *clypeata.*

De Meijere (1904b) described *fimbriata* from two specimens of 10 and 11mm horizontal diameter respectively. Neither of the type specimens has terminal discs. Later, Mortensen (1928b) referred two other specimens of 13 and 15mm diameter to the species. These specimens have very well-developed, shield-shaped terminal discs. Mortensen (1928b) considered De Meijere's specimens to be juveniles which had not yet developed terminal discs. The extreme development of the discs shown in Mortensen's specimens (1928b: pl. 15, figs 8, 11) appears unlikely to have occurred with just 2-5mm of growth in horizontal diameter. On the evidence provided by Mortensen (1928b), we consider it unlikely that the larger specimens are conspecific with the types of *fimbriata.*

In common with the types of *fimbriata*, there are no terminal discs on the apical spines of the four known specimens of *G. crassa.* These specimens are considerably larger (19-24mm in horizontal diameter) than the types of *fimbriata*, but Mortensen (1928b) considers them to be juveniles of a species which will eventually develop terminal discs. If Mortensen's identification of the two larger specimens referred to *fimbriata* is incorrect, there is no reason to recognize *crassa* as a species distinct from *fimbriata.* Accordingly, we regard *crassa* as a junior synonym of *fimbriata.* If *fimbriata* does not develop terminal discs, its position in *Aspidocidaris* is questionable.

Of the remaining species in the subgenus, *parasol* is quite distinct from *alba, sibogae* and *australiae.* The ambulacra of *parasol* have a broad, bare, sunken median area which is almost straight. This feature is conspicuous and apparently constant. In contrast, the median areas of the ambulacra of the other three nominal species are more heavily tuberculated, the narrow bare areas being clearly zig-zag in arrangement.

The 40 Australian specimens which we have examined are regarded as being conspecific, but different individuals fit variously into the descriptions of *alba, sibogae* and *australiae.* The specimens range in horizontal diameter from 7mm to 26mm. The smallest specimens (7 and 8mm) do not have terminal discs on their primary spines. Although many of the spines are broken, it appears that terminal discs occur on all specimens larger than these. As the horizontal diameter increases, the relative length of the apical spines bearing the discs decreases, and the size of the discs increases. A similar change occurs with growth in *G. parasol* (we have compared juvenile specimens, identified by Fell, with Fell's description of adult specimens of *parasol*). Other changes which occur with growth are loss of green coloration on the apical area of the naked test, and increased tuberculation of the median areas of the ambulacra and interambulacra. Specimens thus range from small, with a green apical area, wide bare areas in the interambulacra, and with long, slender apical primary spines bearing small discs, to large, with a white apical area, narrow bare areas in the interambulacra, and with short, squat apical primary spines bearing large discs. There is also considerable individual variation in the thickness of the primary spines, and some variation in the thorniness of the shaft.

The three nominal species, *alba, sibogae* and *australiae*, whose descriptions were published simultaneously by Mortensen (1928a), were separated on the basis of the extent of the naked vertical midline of the interambulacra, the shape and thickness of the primary spines, and the presence or absence of green coloration on the naked test. Given the variation indicated above, the three nominal species are regarded as synonymous.

G. sibogae is selected as the name of the taxon under the first revisor principle of the International Code of Zoological Nomenclature (Article 24A), as this name does not describe a colour or locality which is no longer applicable to the species.

The species is thus known from little material in distant localities: *sibogae* was originally known only from 3 specimens from Indonesia, *alba* was described on a single specimen from Japan, and *australiae* was thought to be an endemic southeast Australian species. The two specimens (from Indonesia) with terminal discs, referred by Mortensen (1928b) to *fimbriata*, are also likely to represent *sibogae*.

G. sibogae is readily distinguished from *G. tubaria* and *G. impressa*, with which it occurs in southeast Australian waters, by its lack of globular globiferous pedicellariae without an end tooth, and by the presence of terminal and basal discs on the apical primary spines.

Subfamily STEREOCIDARINAE Lambert

Genus ***Stereocidaris*** Pomel

The genus is characterized by the presence of grooves in the upper interambulacral sutures, rudimentary upper primary tubercles, globiferous pedicellariae without an end tooth, and pores which are not very close together and are not confluent (Mortensen, 1928b). Mortensen (1928b) recognizes 16 species and 7 varieties of *Stereocidaris*, 14 of which taxa were originally described by him. Many of these taxa are based on very few specimens, and little variation within a species or variety appears to have been allowed. It seems likely that re-examination of Mortensen's material would reveal considerably fewer species and varieties of *Stereocidaris*.

Although *Stereocidaris* was first recorded from northwestern Australian waters by McNamara (1984), he did not identify the species. The species identified here, therefore, are newly recorded from Australian waters.

Stereocidaris sceptriferoides (Döderlein)

Fig. 7**A**

Cidaris (Stereocidaris) sceptriferoides Döderlein, 1887:5, pl. II, figs 12-17, pl. III, figs 3a-e.
Stereocidaris sceptriferoides: Mortensen, 1928b:274 (synonymy), pl. 29, figs 5-7, pl. 67, figs 1-3, pl. 70, fig. 12, pl. 81, figs 1-4; Pawson, 1965:199, pl. 1.

Diagnosis: Small globiferous pedicellariae have slender, elongate valves, resembling tridentate pedicellariae; primary spines occur above the ambitus, are more or less circular in cross-section, and either gently taper or flare at the tip; primary spines bear numerous low, serrated, longitudinal ridges, and the neck is conspicuous and shining; marginal ambulacral spines are flattened; miliary spines are slender, more or less cylindrical and abruptly differentiated from the longer, flat, scrobicular spines; genital plates are convex, longer than wide, and pointed on the outer edge forming a pentagonal plate.

Material: 1 specimen, off Clarence R., N.S.W., 450m, 'Kapala'.

Distribution: Japan; eastern Australia (Ballina, N.S.W.); north of New Zealand. The variety *lanceolata* Mortensen, 1928a, is recorded from the Sagami Sea, and the variety *lamellata* Mortensen, 1927, is recorded from the Kei Islands, 360-841m.

Remarks: Some characteristics of the specimen are listed below.

Horizontal diameter (mm)	43
Vertical diameter (mm)	26
Apical system diameter (mm)	20
Peristome diameter (mm)	15
No. interambulacrals	6
Width interambulacrum (mm)	20

Width ambulacrum (mm)	5
Longest spine (mm)	50

The ambulacra differ from Mortensen's (1928b) description only in that the midline is not sunken, the whole interporiferous zone being slightly convex. Similarly, Pawson (1965) described three specimens of *sceptriferoides* from northeast of New Zealand as being without a sunken midline. The interambulacra are as described by Mortensen (1928b).

The apical system is slightly raised, the genital plates in particular being convex. All the apical plates are densely tuberculate, as depicted by Pawson (1965: fig. 2), and the genital plates do not exhibit the bare areas described by Mortensen (1928b). Some periproctal plates, one genital plate and one ocular have apparently suffered damage. Oculars I, II and III are broadly exsert, and ocular IV is broadly insert. The genital pores are approximately 1mm in diameter, and are situated near the outer edge of the plates. The specimen is thus probably a male (Pawson, 1965).

The primary spines differ from Mortensen's (1928b) description only in that they do not flare conspicuously near the tip. Some of the spines appear to be intact, and these taper gently throughout their length. They are more or less cylindrical, with slight evidence of carination on some spines. The conspicuous, shining neck is pale pink in colour.

The scrobicular and miliary spines are of the shape and size described by Mortensen (1928b) for the 'typical' variety of *sceptriferoides*, but there is a moderately abrupt transition between the two. The miliary spines appear to be appressed, but this is probably a result of preservation.

No tridentate pedicellariae were found. Two forms of globiferous pedicellariae are present, one having very long, slender valves (Mortensen, 1928b). Both forms have a small subterminal opening. Spicules of the tube feet are fenestrated plates.

Two varieties of *sceptriferoides* have been described: *lanceolata* Mortensen, 1928a, differs from the nominal variety in the character and distribution of secondary spines, and *lamellata* Mortensen, 1927, is characterized by the presence of conspicuous lamellae on the primary spines. The specimen at hand represents the 'typical' variety described by Mortensen (1928b).

A group of *Stereocidaris* species have small globiferous pedicellariae with very elongate valves, resembling tridentate pedicellariae. Tridentate pedicellariae are rare or absent from these species, which include *sceptriferoides, alcocki, capensis*, and apparently *indica*. Mortensen's (1928b) figures of the pedicellariae of *indica* show them to be elongate, but the position of *indica* in Mortensen's key indicates the opposite to be the case.

S. sceptriferoides appears to be closely related, if not identical, to *S. alcocki* var. *teretispina* (Döderlein, 1906), which is known from a single specimen. The diameter of the peristome relative to the horizontal diameter ($<25\%$ or $>30\%$) is the key character used by Mortensen (1928b) to distinguish between these nominal taxa. This ratio is about 35% in the specimen at hand, clearly indicating *sceptriferoides*. However, the measurements given by Pawson (1965) for three specimens referred by him to *sceptriferoides* indicate this ratio ranges from 24% to 31%, which straddles the supposed gap between the taxa.

McKnight (1975) recorded a specimen of *S. sceptriferoides* from the northern Tasman Sea. We have examined this specimen, and although no pedicellariae remain, it appears to represent a small specimen of *Stylocidaris reini* (see p.245).

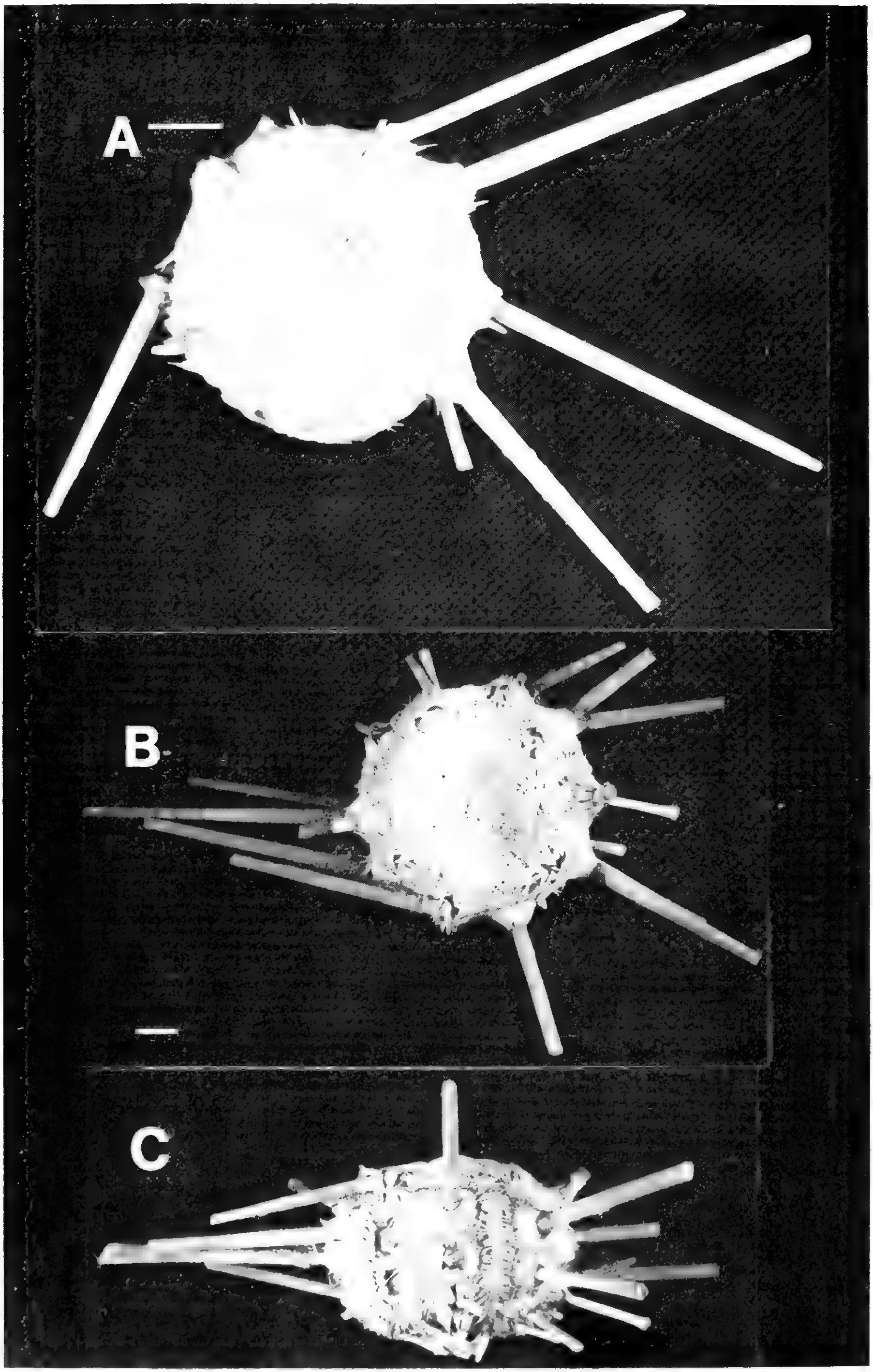


Fig. 7. **A.** *Stereocidaris sceptriferoides*, J15790, off Clarence R., N.S.W., 450m. **B,C.** *S. microtuberculatum*, J15791, off Shoalhaven Bight, N.S.W., 702-792m. Scale = 10mm.

S. sceptriferoides differs from the only other known species of *Stereocidaris* in Australian waters, *S. microtuberculata*, most markedly by the nature of the pedicellariae and of the miliary spines.

Stereocidaris microtuberculata (Yoshiwara)

Fig. 7**B**-**C**

Cidaris (Stereocidaris) microtuberculatus Yoshiwara, 1898:57.
Stereocidaris microtuberculata: Mortensen, 1928b:257 (synonymy).
?*Stereocidaris* sp.: McKnight, 1975:71.

Diagnosis: Globiferous pedicellariae are not elongated, not resembling tridentate pedicellariae; primary spines bear numerous longitudinal rows of low, rounded projections; miliary spines are flattened, pointed, scale-like and appressed to the test, more or less abruptly differentiated from the longer, flat, scrobicular spines; genital plates are more or less rectangular, broader than long.

Material: 8 specimens in the Australian Museum collection from off Brisbane, Qld to off Batemans Bay, N.S.W. (7 specimens from N.S.W. waters and 1 specimen from Qld waters).

Distribution: Japan; east Australian coast, 140-700m; ?New Zealand.

Remarks: Some characteristics of the specimens are listed in Table 2.

The specimens differ from the description of *microtuberculata* given by Mortensen (1928b) in that the ambulacra are slightly wider relative to the interambulacra (18-23% rather than 18-20%), and the few large primary spines remaining intact are not conspicuously widened or flaring. However, in the original description of the species, Yoshiwara (1898) indicates the ambulacra are 18.5-25% the width of the interambulacra, and he does not mention this feature of the primary spines. Mortensen (1928b) indicates that the oral primaries in particular are 'trumpet-shaped'. The oral primaries of the Australian specimens widen only slightly, if at all, and the adoral sides of the spines are flattened. This is apparently contrary to Yoshiwara's (1898) comment: 'Spines near peristome not flattened . . .'.

TABLE 2

Measurements of individuals of Stereocidaris microtuberculata

1 = horizontal diameter (mm), 2 = vertical diameter (mm), 3 = apical system diameter (mm), 4 = peristome diameter (mm), 5 = interambulacrum width (mm), 6 = ambulacrum width (mm), 7 = no. interambulacrals, 8 = longest spine (mm)

	1	2	3	4	5	6	7	8
J15792	50	36	23	18	23	5	6	55
J15848	55	40	28	17	28	6	6-7	—
J15791	57	42	26	19	28	6	7	70
J15789	59	42	26	24	28	6	7	60
J15788	61	38	31	23	30	6	6	50
J15851	78	58	34	24	37	8	7	—
J15849	82	54	36	25	40	9	7	—
J15850	85	68	35	25	39	8	7-8	—

The genital plates of all the specimens examined are considerably broader than long, in agreement with Yoshiwara's (1898) description. The plates have relatively straight sides, and are approximately rectangular in shape, rather than hexagonal or heptagonal as described by Mortensen (1928b). Other *Stereocidaris* species with broad genital plates are *grandis* Döderlein, *tubaria* var. *impressa* Mortensen, *hawaiiensis*

Mortensen, *granularis* Mortensen, *indica* Döderlein and *excavata* Mortensen. The specimens at hand do not have the concave genital plates characteristic of *excavata*. Of the remaining species, *microtuberculata* has the broadest and most rectangular genital plates.

McKnight (1975) recorded '4 fragments' from the northern Tasman Sea (32°01'S 168°03'E, 500m) as *Stereocidaris* sp. It is possible that these fragments represent *S. microtuberculata*, but judging from McKnight's description, the material is inadequate for positive identification.

The present material extends the range of *S. microtuberculata* from Japan to N.S.W.

Subfamily CIDARINAE Gray

Genus ***Stylocidaris*** Mortensen

Stylocidaris is characterized by the nature of the pedicellariae and the primary spines, the presence of non-conjugate pores, and that the pores occur in a single series on the peristome (Mortensen, 1928b).

S. conferta was the only species of the genus previously known to occur in N.S.W. waters. Two other species are here recorded from N.S.W. waters for the first time.

Stylocidaris conferta (H. L. Clark)

Figs 8**A**, 9**A**

Cidaris conferta H. L. Clark, 1916:100, pl. 38, figs 1-4.

Stylocidaris conferta: Mortensen, 1928b:351, pl. 37, figs 3-7, pl. 72, fig. 14, pl. 85, figs 30-32; H. L. Clark, 1946:289; Dartnall, 1980:43.

Diagnosis: Primary spines are cylindrical for most of their length, then abruptly taper close to the tip; spines are ornamented with evenly-sized, closely-spaced, low, rounded knobs, arranged without regular pattern; spines are pale in colour, white to yellow, and may have 1 or 2 pink transverse bands; a conspicuous dark brown spot is usually present on each genital plate, and dark spots are usually present at the corners of each interambulacral plate, particularly on the median side; secondary spines are faintly marked with a dull-coloured, median longitudinal stripe.

Material: Holotype, AM E4685, eastern slope, Bass Strait, 144-360m; 2 paratypes, E4740-1, south of Gabo Is., Victoria, about 360m; 96 other specimens in the Australian Museum collection, from the geographical and bathymetrical range indicated below (1 specimen from Qld waters, 81 specimens from N.S.W. waters, 7 from Victorian waters, 7 specimens from Tasmanian waters).

Distribution: Off Gold Coast, Qld (28°06'S 153°58'E) to off Wineglass Bay, Tasmania, 140-550m.

Remarks: The species was adequately described by H. L. Clark (1916) and by Mortensen (1928b). *S. conferta* has not previously been recorded from north of Port Jackson or south of Bass Strait. The present records thus extend the known geographical range of the species.

Stylocidaris reini (Döderlein)

Figs 8**B**, 9**B**

Cidaris (Dorocidaris) reini Döderlein, 1887:7, pl. 4, figs 1-7, pl. 8, figs 4a-d.

Stylocidaris reini: Mortensen, 1928b:342, pl. 35, figs 1-9, pl. 72, figs 17-19, pl. 84, figs 1-11.

Stereocidaris sceptriferoides: McKnight, 1975:71 [non *S. sceptriferoides* (Döderlein, 1887)].

Diagnosis: Primary spines are round in cross-section, tapering evenly throughout their length; small, sharp serrations are arranged in longitudinal ridges along the spines; small hairs cover the spines between the ridges; spines are pale in colour with numerous

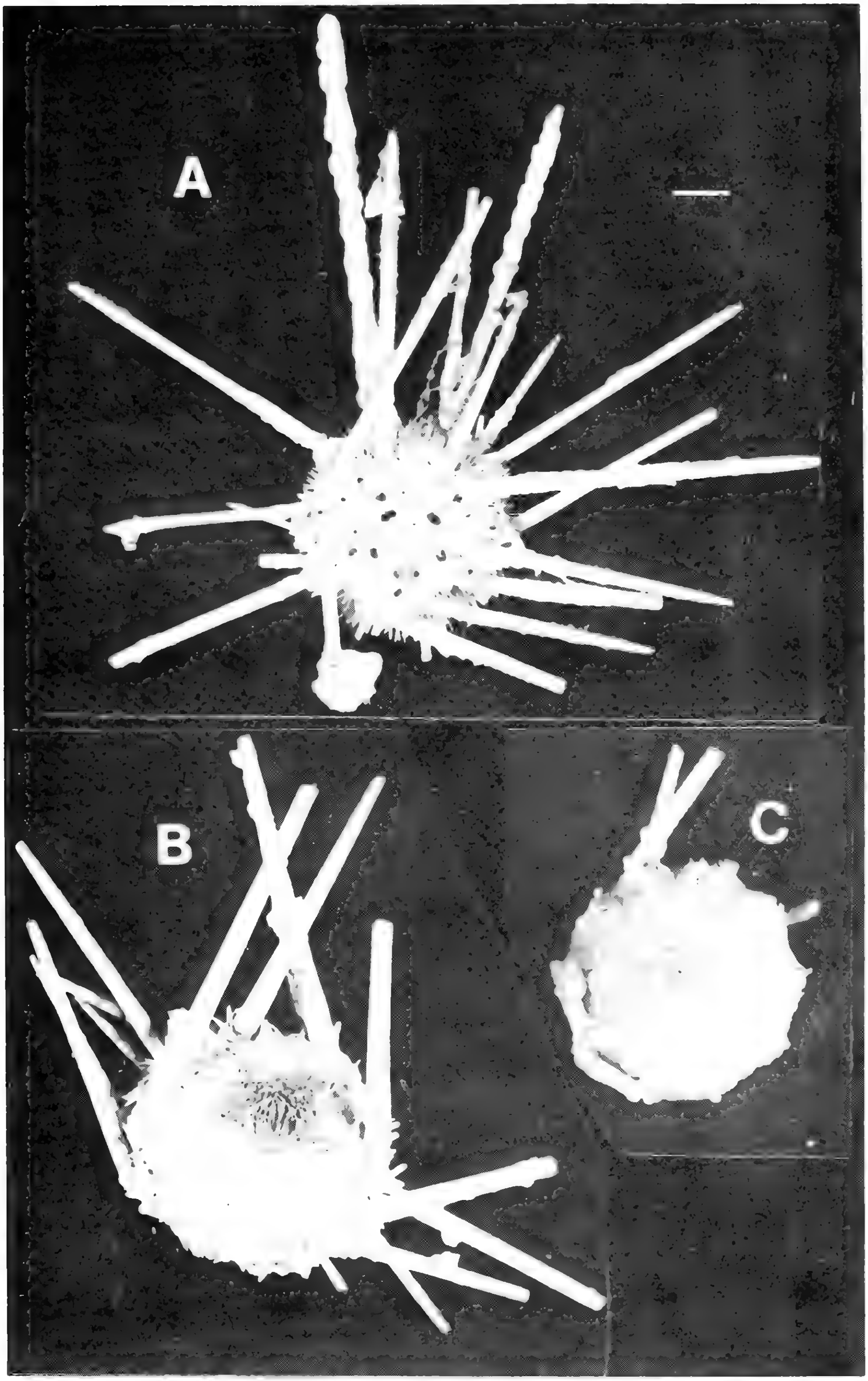


Fig. 8. **A.** *Stylocidaris conferta*, J15822, off Sydney, N.S.W., 266m. **B.** *S. reini*, J15816, off Newcastle, N.S.W., 270m. **C.** *S. brevicollis*, J15750, off Ball's Pyramid, Lord Howe Is., 90-180m. Scale = 10mm.

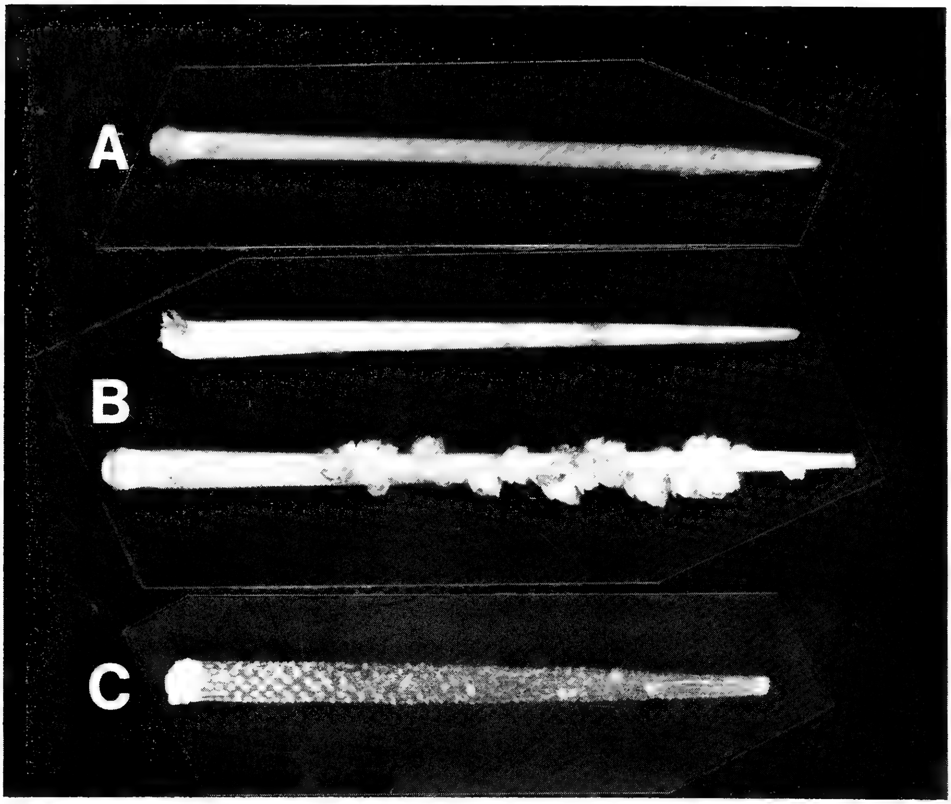


Fig 9. **A.** Primary spine of *Stylocidaris conferta*, J15822. **B.** Primary spine of *S. reini*, J15816. **C.** Primary spine of *S. brevicollis*, J15750.

pink transverse bands; whole of the apical area is usually conspicuously darker in colour than the rest of the animal; secondary spines have a conspicuous, dull-coloured, median longitudinal stripe.

Material: 32 specimens in the Australian Museum collection: (1 specimen from the Philippines, 1 from Indonesian waters, 14 from Qld waters, and 16 specimens from N.S.W. waters); 1 specimen, NZOI stn Z2098, east of Norfolk Island (28°39.5'S 173°01'E), 841m.

Distribution: Japan; Philippines; Indonesia; New Guinea; east coast of Australia, as far south as Montague Is., N.S.W.; northern Tasman Sea, east of Norfolk Island, 100-841m.

Remarks: Mortensen (1928a) described two varieties of *reini*. The variety *cladothrix* is distinguished from 'typical' *reini* by the hairs of the primary spines being 'bush-shaped' rather than simple. One of the specimens examined (AM J5158, Philippines) was identified as *cladothrix* by Mortensen. There are no hairs remaining on the spines of this specimen, but the serrations on the primary spines are very large compared with those on the N.S.W. specimens. The specimen from Kei Ids, (AM J5157) and the specimen from Bowen, Qld (AM J205) also have more prominent serrations, especially basally, than the N.S.W. specimens. The variety *rubra* differs from 'typical' *reini* mainly in the coloration of the primary spines, although other slight differences also occur. However, Mortensen (1928a,b) noted that these characters are not reliable as distinguishing features.

The N.S.W. specimens range in horizontal diameter from 8-56mm. They do not have 'bush-shaped' spine hairs which are characteristic of *cladothrix*, but the primary spines of most of the specimens are conspicuously banded with red as in *rubra*. Similarly, the interporiferous zone is rather bare in many of the N.S.W. specimens, but this feature is shared with the specimen from Kei Ids, (J5157), which was identified as *reini* by Mortensen.

McKnight (1975) recorded a specimen from the northern Tasman Sea (NZOI stn Z2098) as *Stereocidaris sceptriferoides*. We have examined this specimen, which is in poor condition. The test, 18mm in horizontal diameter, has lost many secondary spines, no pedicellariae were found, and only the bases of a few primary spines remain. Colour of the test and remaining spines, as well as test morphology, indicate that this specimen represents *Stylocidaris reini* rather than *Stereocidaris sceptriferoides*. The only difference observed between the NZOI specimen and those of similar size from N.S.W., is that the thorns of the primary spines of the former are more or less coalesced into longitudinal ridges.

S. reini was previously known to occur from Japan to New Guinea, and a single specimen was known from Bowen, Qld (Mortensen, 1928b). The occurrence of *S. reini* in the Tasman Sea thus represents a southern and eastern extension of range for the species.

Stylocidaris brevicollis (De Meijere)

Figs 8**C**, 9**C**

Cidaris (Cidaris) baculosa var. *brevicollis* De Meijere, 1904b:11, pl. 2, figs 8, 13 [non 7], pl. 11, fig. 110.

Stylocidaris brevicollis: Mortensen, 1928b: 379 (synonymy), pl. 38, figs 4-6, pl. 72, figs 1-2, pl. 85, figs 3, 16-20.

Diagnosis: Primary spines are round in cross-section, tapering evenly throughout their length; small, sharp, white thorns are arranged in longitudinal series along the red shaft; very short hairs occur on the surface of the shaft between the rows of thorns; the collar is very short (<1mm); scrobicular spines have a broad, red, longitudinal midline; miliary spines are scale-like, and red in colour; the naked test is red on the ambulacra, apical system, peristome and median area of the interambulacra.

Material: 3 specimens (1 in fragments) from off Ball's Pyramid, near Lord Howe Island, 90-180m.

Distribution: Indonesia; Lord Howe Island area, 69-180m.

Remarks: The two intact specimens measure 13mm and 39mm in horizontal diameter respectively, which corresponds almost exactly to that of the two type specimens (13mm and 40mm; Mortensen, 1928b). Other measurements of the Lord Howe specimens differ little from those of the type specimens. The only differences are that the larger specimen has only 7 interambulacral plates in a series (compared with 8 in the larger type specimen) and the vertical diameter is slightly less (23mm compared with 26mm in the largest type specimen). The specimens at hand agree with Mortensen's description in all respects, except that no large globiferous pedicellariae were found. The small globiferous pedicellariae have quite a small end tooth on each valve.

S. brevicollis has only rarely been collected, the three specimens reported here increasing the known number to eight. The species was previously known only from Indonesian seas, and its occurrence near Lord Howe Island represents a considerable extension of range.

Genus **Eucidaris** Pomel

Eucidaris is characterized by the nature of the pedicellariae and of the primary spines, which terminate in a small crown with a central prominence, and by having non-conjugate pores.

Eucidaris metularia (Lamarck)

Cidarites metularia Lamarck, 1816:56.
Eucidaris metularia: Mortensen, 1928b:386 (synonymy), pl. 41, figs 1-8, pl. 73, fig. 6, pl. 86, figs 11-14; H. L. Clark, 1946:288; Clark and Rowe, 1971:140, 150.

Diagnosis: Primary spines are thick and robust, usually shorter than the horizontal test diameter; shafts are set with low, rounded projections arranged in longitudinal series; apical system is very sparsely tuberculated, except for a single series of large tubercles around the outer edge.

Material: 1 specimen from Sugarloaf Island, Lord Howe Island, 15m; 28 other specimens in the Australian Museum collection (11 from Queensland waters, 1 from northwestern Australia, 16 from other Indo-west Pacific localities).

Distribution: Widespread throughout the Indo-Pacific, including Lord Howe Island. Littoral — 570m.

Remarks: The published record of *E. metularia* in Australian waters has rested on specimens from northwestern Australia in the British Museum reported by H. L. Clark (1925), and other specimens from the same area by Marsh and Marshall (1983). The collection of this species in the Australian Museum extends its known distribution in Australia to the entire length of the Great Barrier Reef to Lady Elliot Island, and to Lord Howe Island. Lord Howe Island represents the southern limit of distribution of *E. metularia.*

Subfamily RHABDOCIDARINAE Lambert

Genus **Acanthocidaris** Mortensen

Acanthocidaris is characterized by its long, flattened primary spines which have a long collar, and by having crenulate tubercles. The genus is here recorded from Australian waters for the first time.

Fell (1966) omitted this genus from his classification of the cidaroids. Following Mortensen's (1928b) conviction that *Acanthocidaris* is especially closely related to *Prionocidaris*, the genus is included here in the Rhabdocidarinae.

Acanthocidaris curvatispinis (Bell)

Fig. 10**A-D**

Cidaris curvatispinis Bell, 1892:303, pl. 38.
Porocidaris maculicollis De Meijere, 1904a:1.
Cidaris (Cidaris) maculicollis: De Meijere, 1904b:15, pl. 3, figs 18-19, pl. 11, figs 111-116.
Acanthocidaris hastigera Agassiz and Clark, 1907:39, pl. 11, figs 1-5, pl. 12, figs 1-17, pl. 12b, figs 18, 19, pls 37-42; Mortensen, 1928b:325 (synonymy), pl. 83, fig. 11.
Acanthocidaris maculicollis: Koehler, 1927:23, pl. 5, figs 2-3, pl. 23, fig. 4; Mortensen, 1928b:329 (synonymy), pl. 43, figs 1-2, pl. 44, fig. 1, pl. 54, figs 5-6, pl. 83, figs 12-15; 1932:157, pl. 5, fig. 6, pl. 11, fig. 5.
Acanthocidaris curvatispinis: Mortensen, 1928b:323 (synonymy), pl. 83, figs 16-18; Mortensen, 1932:156, pl. 5, figs 1-5, pl. 11, fig. 4, pl. 12, fig. 8; Mortensen, 1939:17, pl. 5, fig. 3.

Diagnosis: Primary spines are dorso-ventrally compressed and the collars are relatively long and conspicuous; colour pattern of primary spines is variable, but small dark spots are usually present in longitudinal series on the collars; spines below the upper 1 or 2 have numerous, low and narrow dark-coloured longitudinal ridges on upper and lower surface of shaft.

Material: 10 specimens in the Australian Museum collection: (9 specimens from between Ballina and the Solitary Islands, N.S.W. 108-126m; 1 specimen from Jurien Bay, W.A. 108m).

Distribution: Mauritius; Indonesia; northern N.S.W.; Hawaii; ?southern Africa; ?southwestern Australia; ?Japan. 40-355m.

Remarks: The three nominal species which have been referred to *Acanthocidaris* apparently differ from each other only in colour pattern. The colour of the spines given in the original description of each of the species is indicated in Table 3. The descriptions of *curvatispinis* and *hastigera* do not indicate the presence of spots on the collars of these species, but the plates provided with each of the original descriptions shows that the collars are indeed spotted. Despite the apparent colour differences, and because no significant morphological differences are known to exist between the nominal species, we consider them to be synonymous, and the name *curvatispinis* has priority. Mortensen (1928b) indicated that the distinction between *curvatispinis* and *hastigera* could probably not be maintained.

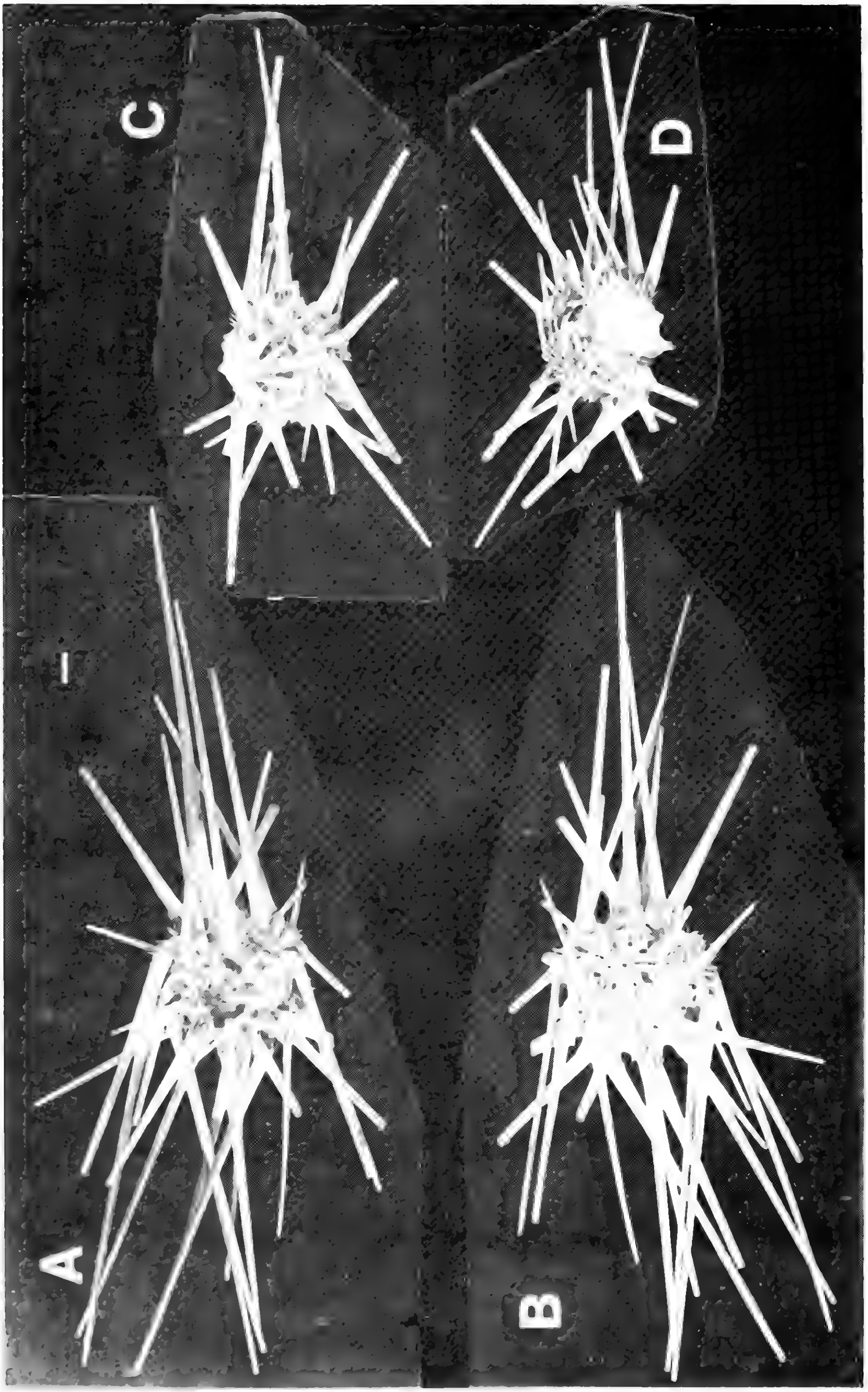
The *Acanthocidaris* specimens from N.S.W. waters present yet another apparently constant colour form. The shafts of the primary spines of all the N.S.W. specimens examined are red/brown on the upper surface and markedly paler on the lower surface. There are numerous low, narrow, dark brown longitudinal ridges on both sides. Some of the spines also have indistinct, darker spots occurring at intervals along the shaft. The uppermost 1-2 spines are not distinctively marked; they are without collars, and longitudinal ridges are absent.

TABLE 3

Original descriptions of the colour patterns of the nominal species of Acanthocidaris

	Primary spines		Secondary spines
	collar	shaft	
curvatispinis Bell, 1882	creamy yellow	reddish brown, occ. banded brown and pale yellow at tip	creamy or yellowish
hastigera Agassiz & Clark, 1907	yellowish or porcelain	brown with a pinkish tinge	uniformly chocolate brown
maculicollis De Meijere, 1904	pale greenish white with many red spots	ground colour not stated; 3-4 indistinct red bands	with a longitudinal median dark line

Collar ornamentation varies slightly between individuals and according to position of the spine on the test. Small specimens, and spines situated low on the test of larger specimens, have collars with pale yellow ground colour and numerous red/brown spots arranged in 5-7 longitudinal rows on the upper surface, corresponding to the longitudinal ridges of the shaft. Towards the base of the collar, the red/brown colour becomes



Acanthocidaris curvatispinis **A,B.** J16176(3), off North Solitary Is., N.S.W., 120-126m. **C,D.** J17938, Bar. W.A., 108m. Scale = 10mm.

more diffuse, and the colour pattern appears to be reversed: pale spots on a red/brown background. It is only on spines very low on the test that the pale areas between the red spots in each longitudinal series are situated on small tubercles. Larger specimens, and spines situated high on the test have collars with less marked ornamentation. Their upper surfaces are more or less uniform pink/brown with slightly paler longitudinal lines corresponding to the dark longitudinal lines on the shaft. The lower collar surface is generally paler, and is usually yellow laterally and pink/brown centrally, or longitudinal lines of red/brown spots may occur as on the upper surface.

The scrobicular spines are red/brown on the upper and lower sides of the areoles, and olive green with a darker green centre line on the lateral sides of the areoles. The marginal spines of the ambulacra are red/brown. 'Large' globiferous pedicellariae are as described for *curvatispinis* and *hastigera* (Mortensen, 1928b), having a long, poorly-defined terminal opening without an end tooth. An inconspicuous limb of projecting rods is present on the stalk. The 'small' globiferous pedicellariae have a distinct end tooth, and tridentate pedicellariae are present. Some measurements of the N.S.W. specimens are given in Table 4.

TABLE 4

Measurements of individuals of Acanthocidaris curvatispinis

1 = horizontal diameter (mm), 2 = vertical diameter (mm), 3 = apical system diameter (mm), 4 = peristome diameter (mm), 5 = interambulacrum width (mm), 6 = ambulacrum width (mm), 7 = no. interambulacrals, 8 = no. ambulacrals/interambulacral, 9 = pore zone width (mm), 10 = interpore zone width (mm), 11 = no. of exsert oculars, 12 = longest spine (mm)

	1	2	3	4	5	6	7	8	9	10	11	12
J17938	38	27	15	13	17	4.7	8	—	1.3	2.0	0	87
J16175-1	38	26	18	14	18	4.1	8	—	1.2	1.9	⩽2	121
J15770	40	28	16	15	19	4.3	8	11	1.4	1.9	⩽2	97
J16175-2	41	29	18	16	21	5.0	9	—	1.2	2.2	1	127
J16176-3	42	29	16	14	21	4.4	8	11	1.5	2.2	0	124
J16176-4	42	29	18	14	21	5.2	9	—	1.6	2.2	0	119
J16176-2	44	29	18	18	21	5.0	8	12	1.6	2.5	0	130
J16176-1	46	34	19	—	23	5.0	9	—	1.7	2.0	—	135
J15571-1	61	47	24	18	28	7.0	10	13	2.0	2.7	0	—
J15571-2	61	49	25	18	31	7.0	10	—	1.8	2.7	0	121

The N.S.W. specimens run down to *maculicollis* in Mortensen's (1928b) key, due to the presence of red spots on the collar of the primary spines. However, we have found that this character is not diagnostic of *maculicollis* as it is shared by the other two nominal species. The N.S.W. specimens resemble photographs of: the types *maculicollis* (De Meijere, 1904b: pl. 3, figs 18-19); specimens of *maculicollis* from the Indian Ocean (Koehler, 1927: pl. 5, figs 2-3); the types of *hastigera* (Agassiz and Clark, 1907: pls 37-42); and specimens of *curvatispinis* from Mauritius, the type locality of the species (Mortensen, 1932: pl. 5, figs 1-5).

The specimens identified as *maculicollis* by Mortensen (1928b: pl. 43, pl. 44, fig. 1; 1932: pl. 5, fig. 6) do appear to have a different colour pattern from the specimens indicated above. The dark spots on the collar are of a greater intensity, and appear to be more widely distributed over the collar. The bands of darker colour on the shafts of the primary spines are also much more conspicuous, especially in the specimen depicted in Mortensen's pl. 43.

A specimen from Jurien Bay, W.A. (AM J17938, donated by the Western Australian Museum) greatly resembles Mortensen's '*maculicollis*'. The primary spines of this specimen are white/yellow with red/brown spots occurring at intervals on both sides of the shaft, and darker, narrow longitudinal ridges are present. The collars are olive green on both sides, the upper surface with longitudinal series of small red/brown spots occurring on ridges corresponding to those on the shaft. Near the distal edge of the collar on the upper side, the small red/brown spots are arranged to form a larger spot similar to those occurring on the shaft. The under surface of the collar has one or two diffuse, red/brown spots situated centrally. The scrobicular spines are of similar colour pattern to the N.S.W. specimens, and the marginal spines of the ambulacra are olive green. The pedicellariae do not differ from those of the N.S.W. specimens, except that the 'large' globiferous form was not found.

The only morphological differences found between this specimen and the N.S.W. specimens is the slightly shorter length of primary spines and the relatively wider ambulacra in the former. The primary spines of Mortensen's '*maculicollis*' specimens also appear to be slightly shorter than those of other *Acanthocidaris* specimens. If the specimen from W.A. and the '*maculicollis*' specimens reported by Mortensen (1928b: Bay of Ambon, Bonin Islands, Sagami Bay; 1932: southern Africa) are not conspecific with *maculicollis* De Meijere (a synonym of *curvatispinis* Bell), they must represent an unnamed species.

The synonymy of *hastigera* and *maculicollis* with *curvatispinis* results in a species with a very wide geographical distribution. The occurrence of specimens of *A. curvatispinis* in N.S.W. waters represents a considerable extension of range for the species.

Genus ***Prionocidaris*** Agassiz

Prionocidaris is distinguished by the nature of the primary spines and by its distinctly conjugate pores.

The large collection of *Prionocidaris* material from N.S.W. waters in the Australian Museum collection contains two distinct colour forms. Both Mortensen (1928b) and H. L. Clark (1946) indicated the colour of *P. australis* to be variable, and both colour forms had been identified as this species. However, there are consistent morphological differences between them, and one is described as a new species.

Prionocidaris australis (Ramsay)

Figs 11, 13**A**

Phyllacanthus australis Ramsay, 1885:3, 46, pl. 1, 1a, 1b.
Cidaris (Cidaris) glandulosa De Meijere, 1904b:13, pl. 1, figs 5-6.
Prionocidaris australis: Mortensen, 1928b (part):456 (synonymy), pl. 52, pl. 53, fig. 12, ?pl. 73, fig. 17, ?pl. 86, figs 17-19, ?pl. 87, figs 6-8; H. L. Clark, 1946 (part):285.
Prionocidaris glandulosa: Mortensen, 1928b:461 (synonymy), pl. 54, figs 7-8, pl. 73, fig. 11, pl. 87, fig. 9.

Diagnosis: Collars of the primary spines have white spots on a green to purple background; scrobicular spines have a broad green midline, often becoming brown/purple near the tip; on the denuded test, the ambulacra (particularly the interpore zone) and the median interambulacral sutures are coloured brown/purple, and the apical system is brown/purple with some green; areoles of coronal plates above ambitus more or less circular (height 84-96% of width); coronal plates above ambitus bear a complete ring of scrobicular tubercles.

Material: Holotype of *P. australis*, AM J193, South Reef, Port Jackson, N.S.W., 10m; 54 other specimens in the Australian Museum collection (45 from N.S.W. waters and 9 from Qld waters).

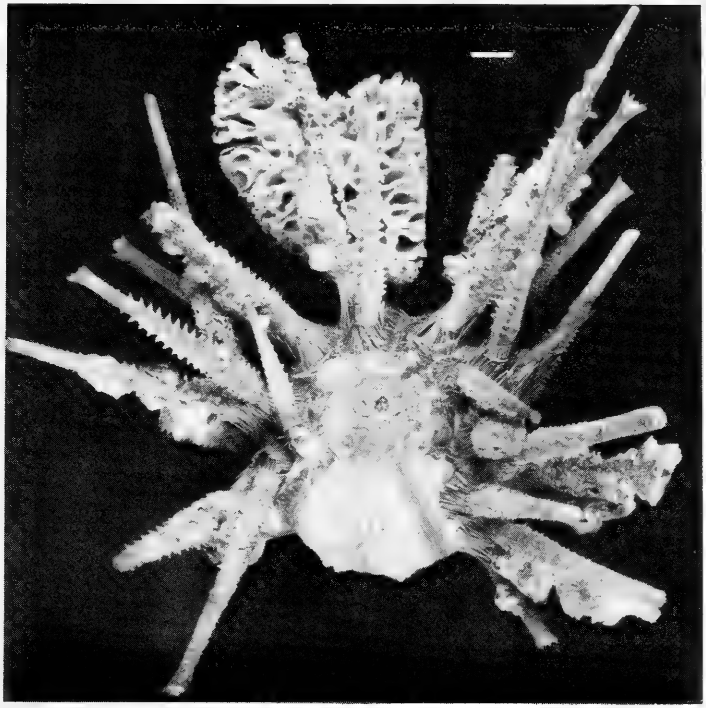


Fig. 11. Prionocidaris australis, holotype, J193, Port Jackson, N.S.W., 10m. Scale = 10mm.

Distribution: Philippines; Indonesia; Macclesfield Bank; east Australian coast (Fraser Is., Qld to Sydney, N.S.W.). 10-145m.

Remarks: Ramsay's original description (1885) of the species referred to two specimens, one of which is figured and referred to in the caption as 'the type'. This is accepted as designation of the holotype, and the specimen is present in the AM collection (J193). The holotype has never been adequately described, so some measurements are included in Table 5. The colour pattern of the holotype is as follows: collars of the primary spines change from purple basally to green distally, with white spots sometimes coalescing into lines; some primary spine tips exhibit pale/dark banding; scrobicular spines are cream-coloured on the edges, with a wide green midline becoming brown/purple near the spine tip; miliary spines are green, inconspicuous; ambulacral spines are brown; denuded test is generally cream-coloured, with the ambulacra conspicuously coloured brown/purple, and patches of this colour also occur on and near the median interambulacral sutures; the denuded apical system is dark, with greenish patches on the genital and ocular plates.

The colour pattern described for the holotype is typical of the species as is here limited. The overall impression of the colour of the animal is pale green. Measurements of a size range of specimens of *P. australis* are shown in Table 5.

Records of *P. australis* from Lord Howe Island (H. L. Clark, 1946) are incorrect, as all the *Prionocidaris* material from that locality present in the AM represents *P. callista* n. sp. Similarly, the record of *P. australis* from Norfolk Island (Pawson, 1965) also represents the new species. The differences between *P. australis* and *P. callista* are outlined on p.256.

TABLE 5

Measurements of a size range of specimens of Prionocidaris australis
1 = horizontal diameter (mm), 2 = vertical diameter (mm), 3 = apical system diameter (mm), 4 = peristome diameter (mm), 5 = interambulacrum width (mm), 6 = ambulacrum width (mm), 7 = no. interambulacrals, 8 = areole width (mm), 9 = areole height (mm), 10 = height/width areole (%), 11 = maximum spine length (mm)

	1	2	3	4	5	6	7	8	9	10	11
J193 (holotype)	63	41	27	22	30.0	6.7	8-9	10.8	9.2	85	81
J16171-1	45	28	19	18	21.3	5.0	7	8.3	7.1	86	68
J16171-2	43	25	20	18	20.5	4.6	7	8.3	7.2	87	65
J15846-1	36	20	17	16	17.0	4.1	6-7	7.0	5.9	84	>51
J16171-3	28	16	13	13	13.5	3.4	6	5.8	5.5	95	60
J18968	14	6	7	6	6.9	1.7	5-6	2.8	2.6	93	31

P. glandulosa (De Meijere, 1904b) is known from the Philippines, Indonesia and Macclesfield Bank. Its similarity to *P. australis* (as *P. bispinosa*: Agassiz, 1873, non Lamarck, 1816) has been indicated by De Meijere (1904) and H. L. Clark (1907). In 1925, H. L. Clark implied synonymy of the two nominal species by recording the 10 specimens from Macclesfield Bank as *P. australis*. However, Mortensen (1928b) considered the species to be distinct, owing to the smaller size of *glandulosa*, differences in their colour patterns, and their discontinuous geographical distributions.

The smallest specimen of *australis* in the AM collection (J18968, Table 5) was collected from off Moreton Bay, Qld in 75m. This specimen clearly fits into the growth series of *australis*, but it also has many of the features of *glandulosa*. Indeed, this specimen greatly resembles the photograph of a specimen of *glandulosa* published by Mortensen (1928b: pl. 54, figs 7-8). The specimen shares the following features with *glandulosa*: small size (the largest known specimen of *glandulosa* is 27mm in horizontal diameter), markings are more distinct on the adapical side of the collar, the apical system has a star-like pattern formed from dark-coloured genital and periproctal plates, and white ocular plates, and globiferous pedicellariae, without an end tooth on each valve and with a limb on the stalk, are common. De Meijere named the species *'glandulosa'* due to the abundance of these pedicellariae on the type specimens. Mortensen (1928b) notes, however, that the abundance of these pedicellariae is variable in *glandulosa*. On the basis of the obvious overlap of characters of this small specimen of *australis* with the descriptions of *glandulosa*, we consider *glandulosa* to be a junior synonym of *australis*. Collecting in suitable areas of Queensland should find the species. It is interesting that the species does not appear to reach a large size in tropical waters.

Prionocidaris callista n. sp.

Figs 12**A-B**, 13**B**

Prionocidaris australis: Mortensen, 1928b (part):456; H. L. Clark, 1946 (part):285; Pawson, 1965:202, pl. 2, figs 1-3; [non *P. australis* (Ramsay, 1885)].

Diagnosis: Collars of the primary spines have white spots on a brown/maroon background; scrobicular spines are red to maroon in colour; the ambulacra and apical system are slightly darker in colour than the rest of the cream-coloured denuded test, and the interambulacra are not pigmented; areoles of coronal plates above the ambitus are considerably wider than high (height 71-79% of width in specimens with horizontal diameter greater than 16mm); scrobicular tubercles of coronal plates above ambitus are reduced in size on the upper and lower sides of the areole.

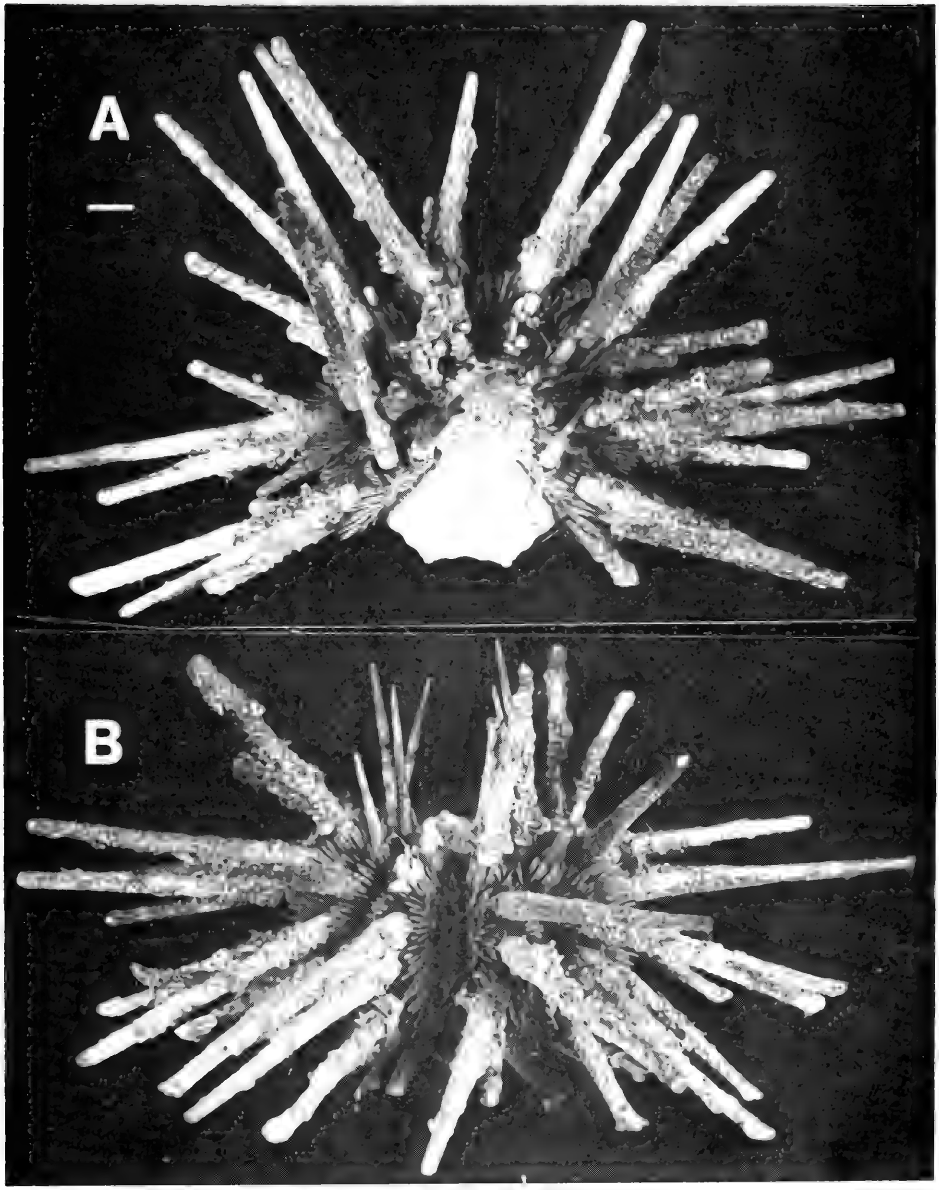


Fig. 12. **A,B.** *Prionocidaris callista*, holotype, J15715, Port Jackson, N.S.W., 2-4m. Scale = 10mm.

Material: Holotype, AM J15715, Bottle and Glass Rocks, Port Jackson, N.S.W., 2-4m; 5 paratypes, AM J18919-18923, South Solitary Is., N.S.W., 28m; 118 other specimens in the Australian Museum collection (57 specimens from N.S.W. coastal waters, 57 from Lord Howe Island area, 3 from Qld waters, and 2 from New Caledonia); 5 specimens, NMNZ Ech 1988, 4165, Raoul Island, Kermadec Islands, 20-44m.

Distribution: Bushy Is., Qld (20°57'S 150°05'E) to Montague Is., N.S.W.; Lord Howe Island; Norfolk Island; Kermadec Islands; New Caledonia. 2-275m.

Etymology: The species is named from the Greek *callista*, for its pleasing appearance.

Description of holotype: Dimensions of the holotype are listed in Table 6.

The ambulacra are only very slightly sinuate, the pore zones being sunken relative to the interpore zone and to the interambulacra. The pores are widely separated, conjugate. The interpore zone is about equal to the width of a pore zone at the ambitus. The marginal ambulacral tubercles are smaller than the scrobicular tubercles, in regular series. One to several smaller tubercles occur inside the marginals, usually also in regular longitudinal series. The denuded interpore zone is slightly green in colour.

The interambulacra have 10 coronal plates in each series. The coronal plates and areoles are markedly wider than high, the areoles separated only by a few reduced scrobicular tubercles. Laterally, there are 2-3 uneven rows of larger scrobicular tubercles. Outside these, the plate is covered with numerous, very small tubercles. The median area is about as broad as an areole, and when denuded, has a slightly greenish cast.

TABLE 6

Measurements of the holotype (J15715) and paratypes (J18919-23) of Prionocidaris callista
1 = horizontal diameter (mm), 2 = vertical diameter (mm), 3 = apical system diameter (mm), 4 = peristome diameter (mm), 5 = interambulacrum width (mm), 6 = ambulacrum width (mm), 7 = no. interambulacrals, 8 = areole width (mm), 9 = areole height (mm), 10 = height/width areole (%), 11 = maximum spine length (mm)

	1	2	3	4	5	6	7	8	9	10	11
J15715	60	38	26	21	29.7	7.4	10	9.7	7.2	74	74
J18919	43	24	18	17	21.6	4.9	7-8	7.9	5.6	71	72
J18920	39	23	16	17	19.4	4.8	7-8	7.7	5.6	73	63
J18921	31	16	14	12	14.2	3.2	7	6.2	4.8	77	61
J18922	28	15	13	12	13.0	3.4	6-7	5.6	4.2	75	55
J18923	17	8	8	8	7.6	2.0	6	3.4	2.7	79	29

The apical system has all the oculars insert, those abutting the slightly enlarged madreporite are less widely insert than the others. The outer edges of the denuded apical system plates are greenish, and the madreporite is brown.

Primary spines at the ambitus are slightly longer than the horizontal test diameter. They are of the form described for *P. australis* by Mortensen (1928b:458). Apart from the newly-formed adapical spines and the oral spines, the primary radioles are more or less completely covered with encrusting organisms. The collars are conspicuous, up to 4mm long, red with white spots which sometimes coalesce into lines.

The scrobicular spines are flattened. The marginal ambulacral spines are flattened basally, becoming round in cross-section near the tip, and tapering. The miliary spines are very short and pointed, not appressed to the test. Spines on the apical system of the holotype have been removed, but the paratype series shows the apical system to be covered with spines of varying lengths, so it does not appear conspicuously bare. All the secondary spines are dark red, with some of the miliary spines being brown/green at the base.

Tridentate and large globiferous pedicellariae were not found on the holotype. The small globiferous pedicellariae have a distinct end tooth, and exhibit no major differences from those described for *P. australis* (Mortensen, 1928b: pl. 87, fig. 6).

Remarks: The paratypes represent a wide size range of specimens, and their measurements are listed in Table 6. The width of the median interambulacral area appears to

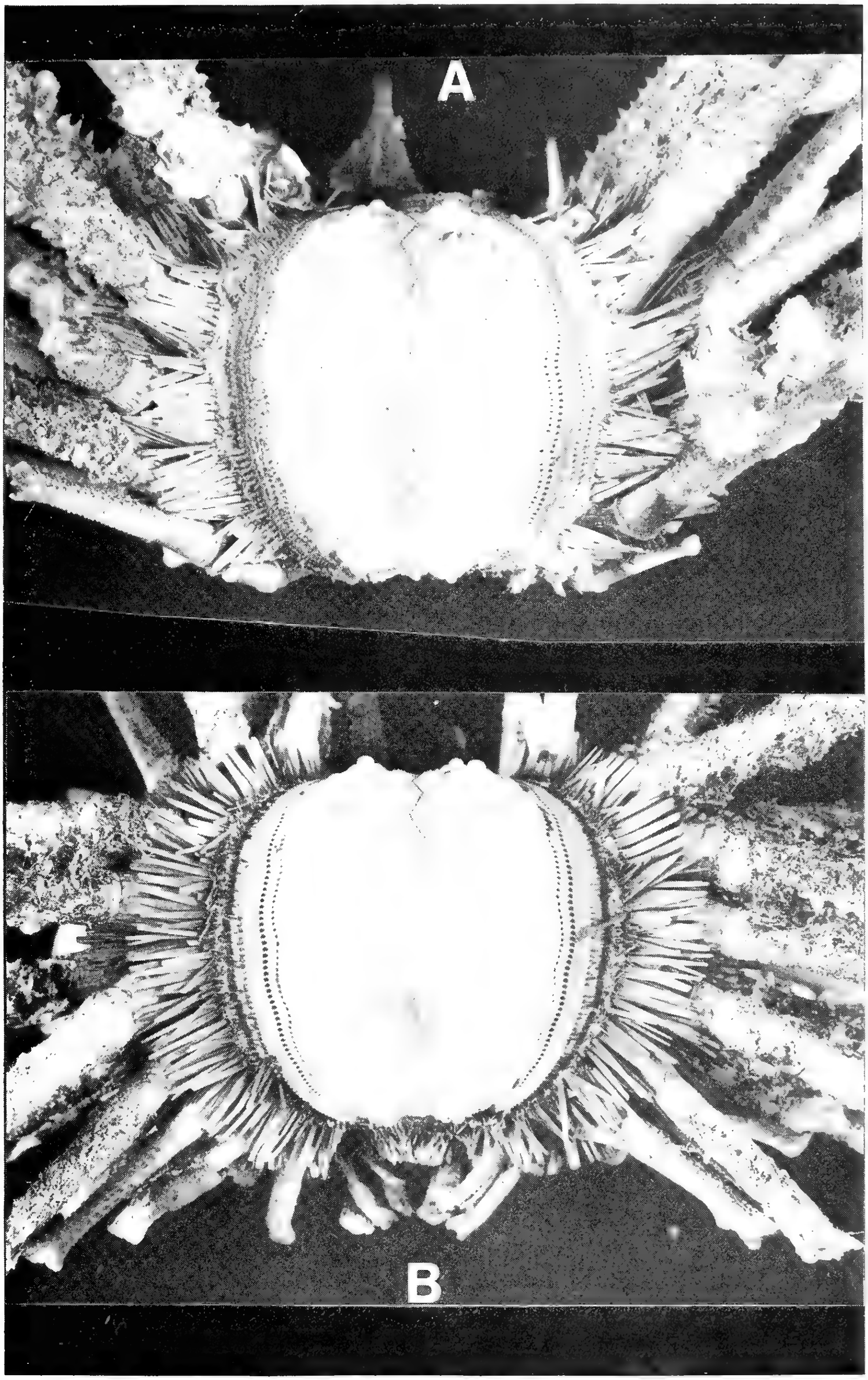


Fig. 13. Lateral view of test of **A.** *Prionocidaris australis*, and, **B.** *P. callista.*

increase with growth; this area may be only half the width of an areole in specimens smaller than the holotype. The paratypes do not otherwise differ significantly from the holotype.

The ambulacra of *callista* differ from those of *australis* in having a more densely tuberculated interpore zone. The colours of the denuded ambulacra are also different, that of *australis* being dark purple/brown, while that of *callista* is pale green or fawn.

The interambulacra show the most striking difference between the species. At a particular size, *callista* has one or two more coronal plates than *australis*. The areoles of *callista* are more transversely oval than those of *australis*, and the upper and lower scrobicular tubercles are much reduced in the former species, whereas on *australis*, the scrobicular ring is made up of more or less equally-sized tubercles. The median area of the denuded interambulacra may either have a greenish cast or be unpigmented in *callista*, but there are more or less distinct purplish patches in this position in *australis*. In large specimens, the median area of the interambulacra is about the width of an areole in *callista*, but is only about half this width in *australis*.

Very small specimens of *callista* (less than 17mm in horizontal diameter) may only be distinguishable from *P. australis* by their colour, as the oval shape of the areoles is a feature which becomes more conspicuous with growth.

P. callista appears to be closely related to *P. hawaiiensis* (Agassiz and Clark, 1907), which is known only from Hawaii. We have examined a specimen of *hawaiiensis* (AM G6098) of horizontal test diameter 27mm. The areoles of this specimen (height 80-83% of width) are slightly more round in shape than those of *callista*. There are major differences in colour: the naked ambulacra are bright orange in *hawaiiensis* and greenish or brownish in *callista*, and the primary spines are more or less orange in *hawaiiensis* and dark purple in *callista*. The primary spines of *callista* are shorter and broader than those of *hawaiiensis*. The proximal third of the primary spines of *callista* is noticeably bulging, whereas the primary spines of *hawaiiensis* taper continuously in the specimen at hand and Agassiz and Clark's photographs (1907: pl. 24-25).

We have not examined the small specimen from Norfolk Island reported by Pawson (1965) as *P. australis*, but consider this specimen represents *P. callista*.

Genus *Phyllacanthus* Brandt

The genus *Phyllacanthus* is very well-defined. Characters which separate it from other cidarid genera include: the nature of the pedicellariae, pore pairs are conjugate and occur in a double series on the peristome, madreporite is much enlarged, and the scrobicular tubercles are modified (Mortensen, 1928b).

Seven recent species of *Phyllacanthus* are known, of which five occur in Australian waters with little overlap in their distribution. *P. imperialis* (Lamarck, 1816) is widespread in the tropical Indo-Pacific (Clark and Rowe, 1971), and specimens in the Australian Museum have been collected from along the Queensland coast as far south as the Whitsunday Islands. *P. parvispinus* Tenison-Woods, 1880, is endemic to southeastern Australia, and is represented in the Australian Museum collections by specimens from Mooloolaba, Qld, to Gabo Island, Vic., and has been reported from Tasmania (Dartnall, 1980). *P. irregularis* Mortensen, 1928a, is endemic to southwestern Australia, occurring from Perth, W.A. to South Australia. *P. magnificus* H. L. Clark, 1914, was known only from the two type specimens, from between Fremantle and Geraldton, W.A. A juvenile specimen (Western Australian Museum 985-74) and four detached spines (WAM 572-71) appear to belong to this species, and extend the range of *magnifica* north to Shark Bay. *P. longispinus* Mortensen, 1918, is endemic to the west and north coasts of Australia (H. L. Clark, 1946; Clark and Rowe, 1971). Its distribution apparently

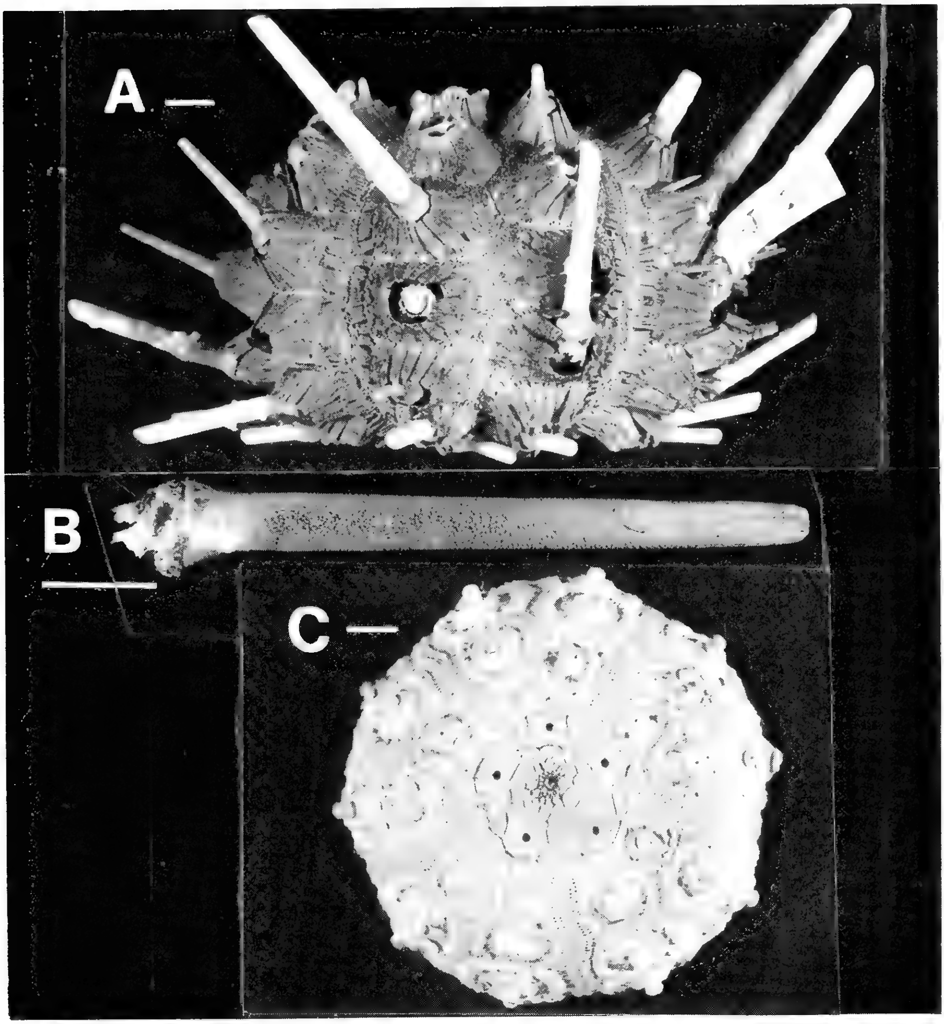


Fig. 14. Phyllacanthus parvispinus. **A.** Lectotype, J186, Port Jackson, N.S.W. **B.** Primary spine of J186. **C.** Paralectotype, J187, Port Jackson, N.S.W. Scale = 10mm.

overlaps that of *irregularis* and *magnificus* as a specimen from Rottnest Island, W.A. (WAM 12021), appears to represent *longispinus*, although it has primary spines which are shorter than usual. The five bear considerable superficial resemblance to each other.

P. dubius Brandt, 1835, from the Bonin Islands, appears to be closely related to *longispinus*, from which it differs mainly in having shorter primary spines. The existence of a short-spined specimen of *longispinus* in southwestern Australia may indicate that these nominal species are synonymous. *P. forcipulatus* Mortensen, 1936, from the Indian Ocean, has well-developed, coarse longitudinal ridges on the primary spines, which are unlike those of the other *Phyllacanthus* species.

Phyllacanthus parvispinus Tenison-Woods
Figs 14**A-C**, 15

Phyllacanthus parvispina Tenison-Woods, 1880:286, pl. 14.
Phyllacanthus parvispinus: Mortensen, 1928b:513, pl. 63, figs 1-3, pl. 64, fig. 3, pl. 74, fig. 8, pl. 88, figs 18-24; H. L. Clark, 1946:283; Dartnall, 1980:43.

Diagnosis: Primary spines are long, robust, and taper only slightly, terminating abruptly at a blunt tip; shaft of primary spine appears coarsely reticulate, due to the presence of numerous, low rounded projections without serial arrangement other than near the tip; marginal ambulacral spines very regular in length and arrangement, flattened with rounded tips; miliary spines on apical system are short, flattened and scale-like.

Material: Lectotype of *P. parvispinus*, AM J186, Port Jackson, N.S.W.; 1 paralectotype, AM J187, Port Jackson, N.S.W.; 160 other specimens in the Australian Museum collection (6 specimens from Queensland waters, 153 from N.S.W. waters, and 1 from Victorian waters); 3 specimens, NMNZ Ech 607, 274, Meyer Island and Macauley Island, Kermadec Islands.

Distribution: Pt. Cartwright, Mooloolaba, Qld, to Gabo Island, Vic., and Tasmania; Kermadec Islands. Shore — 80m.

Remarks: Tenison-Woods (1880) indicated that *P. parvispinus* was based on a number of specimens. However, he did not specify a type specimen, beyond providing figures of two specimens (pl. 14 A-B) labelled 'type specimen'. Both these specimens are present in the Australian Museum, and the larger, more intact specimen (J186) is here designated as the lectotype. The other specimen (J187) is thus a paralectotype. A specimen in the National Museum of Victoria, Australia, (H137), which was listed as a syntype of *parvispinus* by Smith (1970), is thus also a paralectotype. Tenison-Woods (1880) gave measurements of a specimen of horizontal diameter 100mm. Neither of the Australian Museum specimens, nor the Victorian Museum specimen (C. Lu, pers. comm.) fit these measurements. The present location of the specimen from which these measurements were taken is not known, but if it still exists, it is also a paralectotype.

The recent species of *Phyllacanthus* were distinguished by Mortensen (1928b) initially on the basis of the number of coronal plates in large specimens (50-70mm horizontal test diameter). This character is clearly of little value when dealing with small specimens. A character noted, but not stressed, by Mortensen (1928b) is the nature of the surface of the primary spines. Each of the species has small rounded knobs, usually described as granules, projecting from the surface of the spine.

P. imperialis is distinctly different from *parvispinus, irregularis* and *longispinus* in that these granules are not visible to the naked eye, and are closely arranged in numerous longitudinal rows, giving the shaft a finely striated appearance. In the other three species, the granules are considerably larger (visible to the naked eye), but vary in their arrangement.

The granules of *longispinus* are arranged in longitudinal series over almost the whole length of the shaft, giving the shaft a coarsely-striated appearance.

Tenison-Woods (1880) described the arrangement of granules on the spines of *parvispinus* as being 'very regular lines'. In fact, regular longitudinal series of granules in *parvispinus* occur only near the tip. Both *parvispinus* and *irregularis* have a random arrangement of granules over most of the shaft, with longitudinal series of granules evident only near the tip. The spine shafts of these species have a reticulate appearance. The neck of the spine is also longer in *parvispinus* and *irregularis* than in *imperialis* and *longispinus.*

P. irregularis is readily distinguished from *parvispinus* by the characters indicated by Mortensen (1928b), particularly the more pointed spines of the ambulacra and apical system in *irregularis.* However, the occurrence of larger tubercles on the inner edge of the genital plates is not a constant feature of *irregularis.*

Examination of the holotype of *P. magnifica* (WAM 4935) shows the arrangement of the granules on the primary spines to be similar to that of *irregularis* and *parvispinus*, but

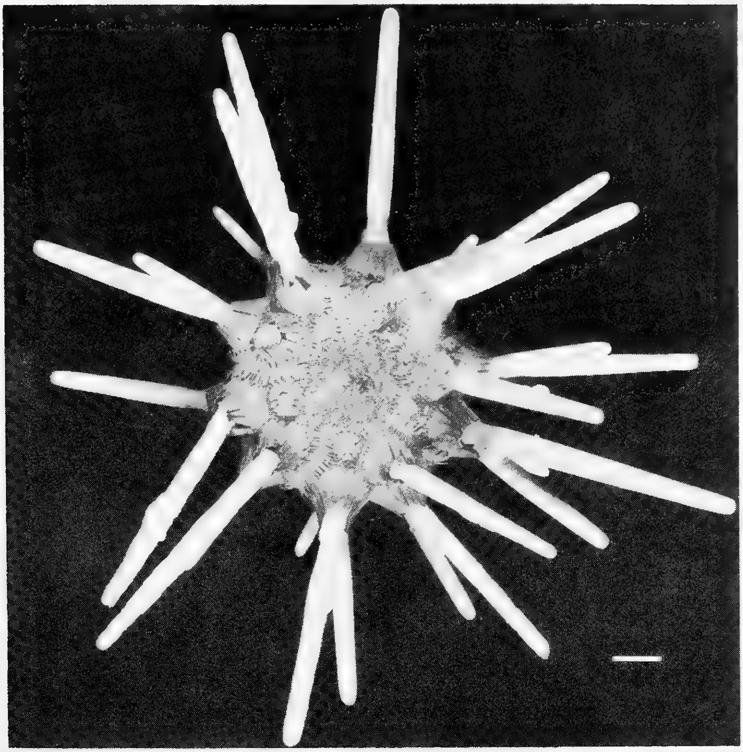


Fig. 15. Phyllacanthus parvispinus, J14260, Bateman's Bay, N.S.W. Scale = 10mm.

they are much coarser. In addition, the primary spines are often swollen just distal to the collar in *magnifica*.

P. parvispinus is here recorded from the Kermadec Islands for the first time. The three specimens in the NMNZ do not differ significantly from southeast Australian specimens. Two other specimens of *Phyllacanthus* from the Kermadec Islands (NMNZ Ech 273) must be referred to *P. imperialis* because of the ornamentation of the primary spines. This represents a new distribution record for *P. imperialis*.

SUMMARY OF TAXONOMIC CHANGES

New species
Prionocidaris callista

New synonymies

Goniocidaris alba Mortensen, 1928a, a junior synonym of *G. sibogae* Mortensen, 1928a

Goniocidaris australiae Mortensen, 1928a, a junior synonym of *G. sibogae* Mortensen, 1928a

Goniocidaris crassa Mortensen, 1928a, a junior synonym of *G. fimbriata* (De Meijere, 1904b)

Acanthocidaris maculicollis (De Meijere, 1904a), a junior synonym of *A. curvatispinis* (Bell, 1892)

Acanthocidaris hastigera Agassiz and Clark, 1907, a junior synonym of *A. curvatispinis* (Bell, 1892)

Prionocidaris glandulosa (De Meijere, 1904b), a junior synonym of *P. australis* (Ramsay, 1885)

Taxa with elevated status

Goniocidaris impressa Koehler, 1926, a valid species distinct from *G. tubaria* (Lamarck, 1816)

Species newly recorded from N.S.W. waters

(* indicates also newly recorded from Australia)

Goniocidaris sibogae
* *Stereocidaris sceptriferoides*
* *Stereocidaris microtuberculata*
Stylocidaris reini
* *Stylocidaris brevicollis*
Eucidaris metularia
* *Acanthocidaris curvatispinis*
* *Prionocidaris callista* n. sp.

ACKNOWLEDGEMENTS

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Type-specimens of Hemiptera (Insecta) transferred from the Macleay Museum, University of Sydney, to the Australian National Insect Collection, Canberra

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(Communicated by P. B. CARNE)

STEVENS, M. M., & CARVER, MARY. Type-specimens of Hemiptera (Insecta) transferred from the Macleay Museum, University of Sydney, to the Australian National Insect Collection, Canberra. *Proc. Linn. Soc. N.S.W.* 108 (4), (1985) 1986: 263-266.

The type-specimens of Hemiptera (Insecta) transferred on permanent loan from the Macleay Museum, University of Sydney, to the Australian National Insect Collection, Canberra, in 1969 are listed and their type status discussed.

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INTRODUCTION

In 1969 an agreement was reached which enabled recognized type-specimens of insects lodged in the Macleay Museum, University of Sydney, to be transferred to the Australian National Insect Collection (A.N.I.C.), Canberra, on a 'permanent loan' basis (Britton and Stanbury, 1981). All relevant specimens now deposited in the A.N.I.C. under this agreement bear the label 'On permanent loan from the Macleay Museum, University of Sydney'.

Hahn (1962) listed in duplicated form the type-specimens of insects known to be lodged in the Macleay Museum at that time. Britton and Stanbury (1981) listed the type material of Coleoptera (Insecta) transferred from the Macleay Museum to the A.N.I.C. in 1969. The present paper documents the type specimens of Hemiptera (Insecta) transferred.

THE ORIGIN AND STATUS OF THE RECOGNIZED TYPES TRANSFERRED FROM THE MACLEAY MUSEUM TO THE AUSTRALIAN NATIONAL INSECT COLLECTION

In total, 64 type-specimens of Hemiptera have been transferred to the A.N.I.C. They include types of species described by Goding and Froggatt (1904), Distant (1907), Musgrave (1930) and Evans (1939). The status of several of the types of Cicadoidea designated by Goding and Froggatt is doubtful. In some cases label and textual data do not correspond, or the number of type-specimens in a series or their place of lodgement is not specified in the original publication. Clarification of status must await taxonomic revision of the taxa concerned. The principal aim of this paper is to place on record the location of the type material under consideration.

The two type specimens of *Psaltoda plebeia* Goding and Froggatt reported as probably lost (Moulds, 1984) have been located in the A.N.I.C. and are listed.

Hahn's (1962) list of types contains the entry '*Tettigia tristigma* G. and F., Type male and Type female. N.T. South Australia. 1875. Tepper'. This species has been incorrectly attributed by Hahn to Goding and Froggatt, who redescribed *T. tristigma* (Germar, 1834) in their paper (Goding and Froggatt, 1904: 594). Two transferred specimens (1 ♂, 1 ♀) in the A.N.I.C. bearing the identification '*Tettigia tristigma* Germ' are labelled with the above distribution data, but are not labelled as types.

Three transferred specimens bear unpublished manuscript names (M. S. Moulds, T. E. Woodward, *personal communications*). The name *Abricta kadulua* Burns is attached to the female syntype of *Tibicen ruber* Goding and Froggatt; *Melampsalta alanubilis* Goding and Froggatt to another cicada specimen; and *Eucerocoropsis rufescens* Woodward to a specimen of Miridae.

Hahn (1962) incorrectly interpreted the locality labels of two paratypes of *Saldula azteca* Drake and Hottes as Colo, N.S.W.; the correct locality is Colorado, U.S.A. These, being non-Australian, will remain in the Macleay Museum.

Other type-specimens of Australian Hemiptera are known still to be in the Macleay Museum collection in Sydney and, undoubtedly, more await recognition.

CATALOGUE OF THE TYPES OF AUSTRALIAN HEMIPTERA TRANSFERRED FROM THE MACLEAY MUSEUM TO THE AUSTRALIAN NATIONAL INSECT COLLECTION

Abbreviations used:

H = Holotype or presumed holotype; S = Syntype or presumed syntype; P = Paratype;
A = Allotype; L = Lectotype; G & F = Goding and Froggatt;
* = additional labelling; $ = labelled as ♀; ⊕ = labelled as ♂

Specific Name	Original Genus	Superfamily	Type Locality *ex* labels(s)	Sex	Type(s)
annulata G & F, 1904	*Pauropsalta*	Cicadoidea	Southport, Q Townsville, Q	♂ $ ♂	2S
arenaria Distant, 1907	*Melampsalta*	Cicadoidea	Bulli, NSW	♂	2S
atrata G & F, 1904	*Melampsalta*	Cicadoidea	Australia	♂	S
basalis G & F, 1904	*Pauropsalta*	Cicadoidea	Townsville, Q	♂	H
binotata G & F, 1904	*Melampsalta*	Cicadoidea	SA Ardrossan, SA	♂ ♀	2S
borealis G & F, 1904	*Pauropsalta*	Cicadoidea	NT	♀	H
borealis G & F, 1904	*Tibicen*	Cicadoidea	K. G. Sound (WA)	♂	S
castanea G & F, 1904	*Pauropsalta*	Cicadoidea	Karth or Nearth, SA	♀ ⊕	H
compressa Evans, 1939	*Ledraprora*	Cicadelloidea	K. G. Sound (WA)	♀	H
congrua G & F, 1904	*Kanakia*	Cicadoidea	Brisbane, Q Kuranda, Q	♂ ♀ ♂	3S
doddi G & F, 1904	*Tibicen*	Cicadoidea	Kuranda, Q Cairns, Q *Kuranda, Q	♂ ♀	2S
dubia G & F, 1904	*Pauropsalta*	Cicadoidea	Fernshaw, V *Ferndale, V Lucindale, SA	 ♂ ♀	2S
emma G & F, 1904	*Pauropsalta*	Cicadoidea	Rockhampton, Q	♂	S
flavus Evans, 1939	*Austroagalloides*	Cicadelloidea	King George's Sound, WA	♀	H
fletcheri G & F, 1904	*Melampsalta*	Cicadoidea	Cook's R., NSW *Sydney	♀	H
hirsutus G & F, 1904	*Tibicen*	Cicadoidea	SA	♂	H

Specific Name	Original Genus	Superfamily	Type Locality *ex* labels(s)	Sex	Type(s)
infuscata G & F, 1904	*Melampsalta*	Cicadoidea	SA	♂	S
kurandae G & F, 1904	*Tibicen*	Cicadoidea	Kuranda, Q	♂ ♀	2S
latus Evans, 1939	*Anacephaleus*	Cicadelloidea	K. G. Sound (WA)	♂	H
leurensis G & F, 1904	*Pauropsalta*	Cicadoidea	Blue Mountains, (NSW)	♂ ♀	2S
monstrosa Evans, 1939	*Platyledra*	Cicadelloidea	K. G. Sound (WA)	♂	H
nigristriga G & F, 1904	*Pauropsalta*	Cicadoidea	Endeavour R. (Q)	♂	H
nodicosta G & F, 1904	*Pauropsalta*	Cicadoidea	Kalgoorlie, WA	♀	H
occidentalis G & F, 1904	*Tibicen*	Cicadoidea	WA	♂	H
plebeia G & F, 1904	*Psaltoda*	Cicadoidea	Australia NSW	♂ ♀	2S
prolongata G & F, 1904	*Pauropsalta*	Cicadoidea	SA	♀	H
punctatus Evans, 1939	*Cephalelus*	Cicadelloidea	K. G. Sound (WA)	♀	H
rubea G & F, 1904	*Melampsalta*	Cicadoidea	Brisbane, Q	♂ ♀	2S
ruber G & F, 1904	*Tibicen*	Cicadoidea	King's Sound, WA Rockhampton, Q	♂ ♀	2S
rubricinctus G & F, 1904	*Tibicen*	Cicadoidea	SA	♂	L
rubristrigata G & F, 1904	*Melampsalta*	Cicadoidea	Mt Lofty, SA	♂ ♀	2S
spinosa G & F, 1904	*Melampsalta*	Cicadoidea	New Holland	♂ ♀	2S
superba G & F, 1904	*Venustria*	Cicadoidea	Kuranda, Q	♂ ♀	2S
trispinosus Musgrave, 1930	*Deroploopsis*	Pentatomoidea	SA SA? without data	A ♀,2 ♂,1 ♀ 1 ♂,2 ♀ 5 ♀	A,11P
tristrigata G & F, 1904	*Melampsalta*	Cicadoidea	Kuranda, Q Sydney, NSW	♂ ♀	2S
variegata G & F, 1904	*Tettigia*	Cicadoidea	Townsville, Q	♂	L
viridis G & F, 1904	*Glaucopsaltria*	Cicadoidea	Tambourine Mtn, Q	♀	S

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The Geology of the Bungonia-Windellama Area, New South Wales

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JONES, B. G., HALL, C. G., WRIGHT, A. J., & CARR, P. F. The geology of the Bungonia-Windellama area, New South Wales. *Proc. Linn. Soc. N.S.W.* 108 (4) (1985) 1986: 267-286.

In the Windellama district of New South Wales the basement consists of Late Ordovician flysch, the Tallong Beds. These strata are overlain unconformably by the diachronous Tangerang Formation in which Early Devonian fossils occur just above the base. Low in the formation quartz-rich detritus and carbonate units are developed; higher levels are volcanogenic. The Brooklyn Conglomerate Member is proposed for a thin (60m) conglomeratic unit which immediately overlies the Tallong Beds in the southern part of the region. Palaeocurrents in the basal Brooklyn Conglomerate Member were from the south and west (052°) compared with an overall northerly trend (005°) for the whole Tangerang Formation.

Six plutons of the Marulan Batholith occur in the district, including two plutons named herein as the Torwood Granodiorite and the Bogungra Microtonalite. Deformation of the Tangerang Formation was presumably associated with the Bowning Orogeny, just prior to the intrusion of the Marulan Batholith. Late Devonian strata unconformably overlie the Tangerang Formation and the Marulan Batholith.

Invertebrate fossils from the Tangerang Formation are illustrated for the first time; these are the trilobites *Ananaspis ekphyma* sp. nov., cf. *Lioharpes* sp., *?Crotalocephalus* spp., an indeterminate proetid, and *?Acanthopyge (Lobopyge)* sp.; and the tabulate coral *Pleurodictyum* sp. These are Early Devonian (Lochkovian) faunas similar to those developed in the upper part of the Bungonia Limestone which underlies the Tangerang Formation south of Windellama.

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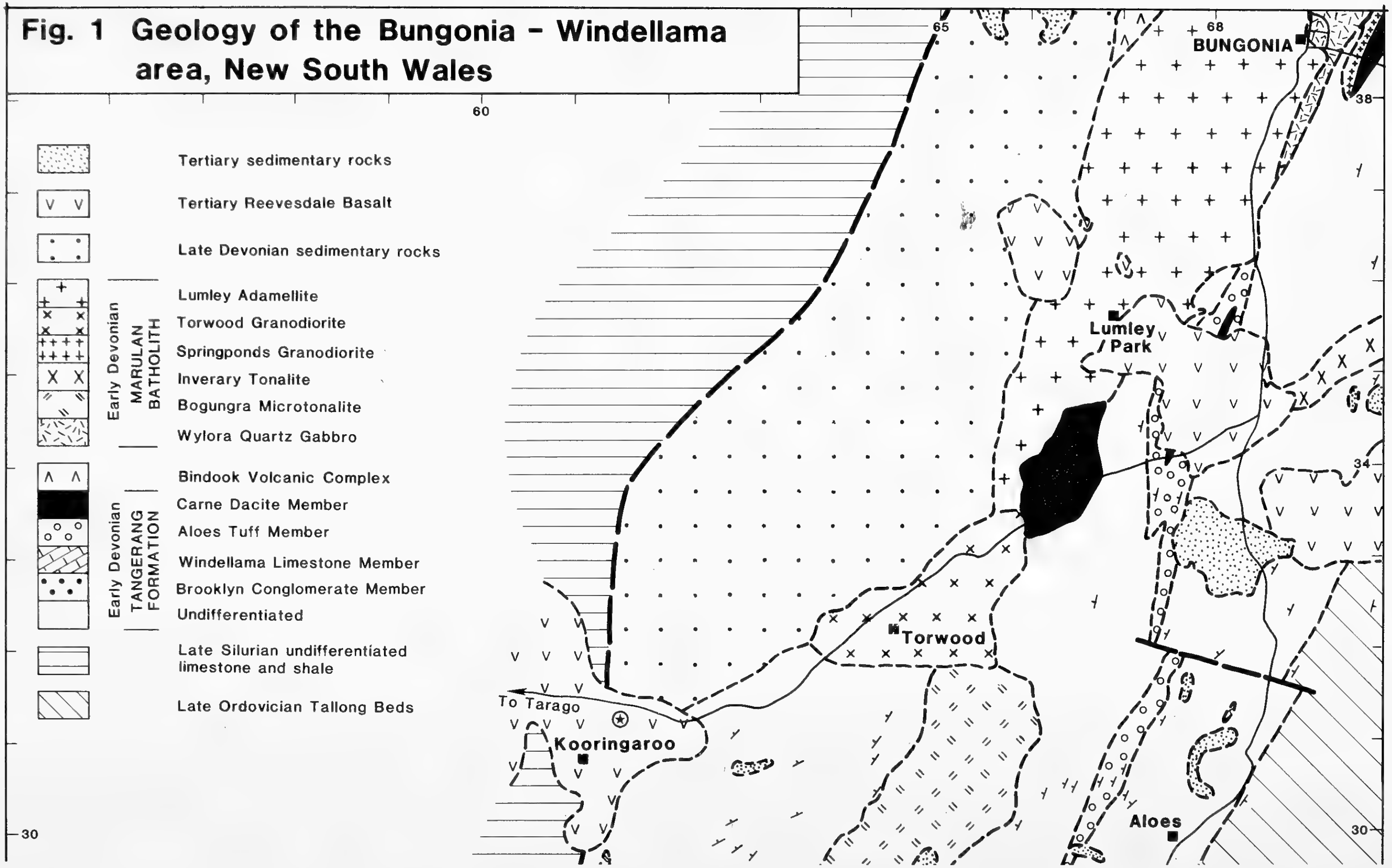
INTRODUCTION

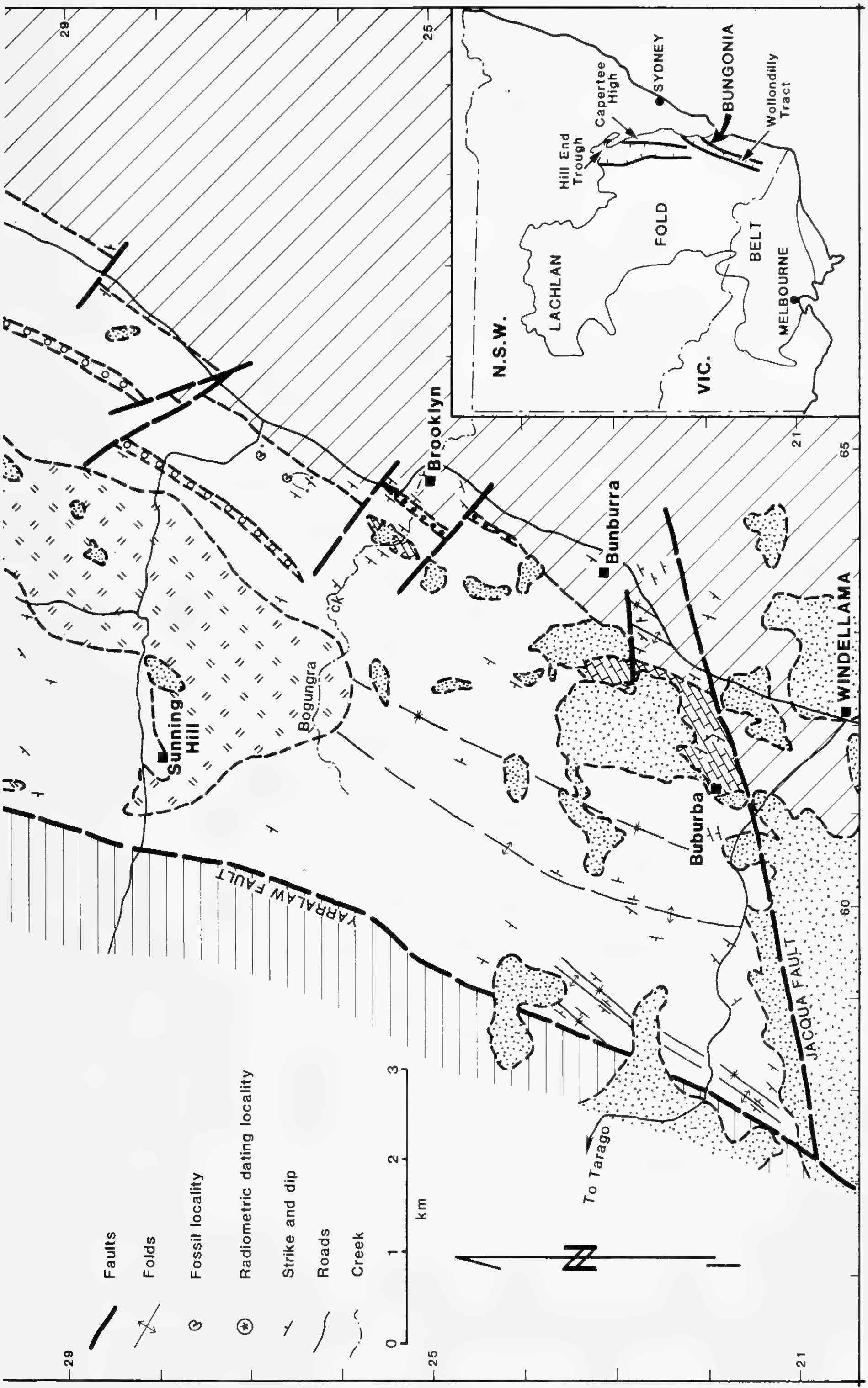
The Bungonia-Windellama area is situated on the exposed eastern margin of the Lachlan Fold Belt of New South Wales (Fig. 1). The geology of the region is typical of much of the Fold Belt and consists of Ordovician flysch overlain by Silurian and Early Devonian dacitic and rhyolitic volcanic units, tuffaceous sedimentary rocks and limestone. These Palaeozoic sequences were intruded by Devonian granitoids of the Marulan Batholith and in places are unconformably overlain by Late Devonian shallow marine and terrestrial deposits.

The regional stratigraphy of the Bungonia-Windellama region has been investigated by many authors. Woolnough (1909) carried out the first detailed geological study and further references to the regional geology were made by Naylor (1935, 1936, 1950) and Garretty (1937). Limestones of the region have been studied by numerous authors including Carne and Jones (1919), Pratt (1964), Pickett (1970, 1972), Ellis *et al.* (1972), Mawson (1975), Carr *et al.* (1980), Carr *et al.* (1981) and Jones *et al.* (1981). Parts of the Marulan Batholith have been described by Osborne (1931, 1949), Naylor (1939), Osborne and Lovering (1953) and Carr *et al.* (1981), and the batholith has been dated by Carr *et al.* (1980).

Brunker and Offenberg (1968) mapped the region on a 1:250,000 scale. They suggested that the sequence in the Bungonia-Windellama area consists of Ordovician sedimentary rocks conformably overlain by undifferentiated Ordovician-Silurian sedimentary rocks, which were intruded in the Middle Devonian by granite and tonalite porphyry, and capped by Tertiary basalt and laterite. Mawson (1975) conducted

Fig. 1 Geology of the Bungonia - Windellama area, New South Wales

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Hill End Trough
Wollondilly Tract

geological investigations in the Windellama area and concluded that the sequence consists of approximately 1700m of Early Devonian carbonate and terrigenous sedimentary rocks downfaulted into rocks '. . . at least in part of Late Silurian age' (Mawson, 1975: 29). This sequence is overlain by numerous Cainozoic units.

Carr *et al.* (1981) mapped the area north and east of Bungonia which consists of Late Ordovician sandstone and shale unconformably overlain by the Late Silurian to Early Devonian Bungonia Limestone. This latter formation is conformably overlain at Bungonia by the Tangerang Formation — a sequence of shallow marine to terrestrial limestone and volcaniclastic sandstone interbedded with tuff and lensoidal dacite flows (Jones *et al.*, 1984). The Marulan Batholith was emplaced during the Early Devonian (Carr *et al.*, 1980), eroded subsequently and covered by the shallow marine Late Devonian succession. The Ordovician to Devonian rocks are unconformably overlain by erosional remnants of Permian and post-Permian sedimentary and volcanic rocks.

The detailed geology of the area between Windellama and Bungonia has not been published previously. The aim of the present paper is to document the geology of this area, to describe a new species of the trilobite *Ananaspis*, to determine the relationship between the units at Windellama and Bungonia, and to ascertain how these sequences fit into the broader regional pattern.

Rock specimens are housed in the Department of Geology, University of Wollongong, and the fossils are housed in the Australian Museum, Sydney. Grid references refer to the Kooringaroo 1:25,000 topographic sheet (8828-II-S, First Edition, 1971).

TALLONG BEDS

The Late Ordovician Tallong Beds (Wass and Gould, 1969) form an extensive outcrop belt from Windellama northwards at least as far as Marulan. The Tallong Beds are composed of interbedded quartz-rich arenite, shale, slate and phyllite, with less common chert interbeds (Table 1). Poor outcrop exposure and tight to isoclinal folding of the Tallong Beds renders the determination of the stratigraphy of this sequence difficult.

TABLE 1

Petrography of the Tallong Beds

Lithology	Composition	Other Features
Quartz-rich arenite	Fine-grained, dark to mid grey, poorly to moderately sorted, immature sublitharenite. Framework grains (0.03–0.7 mm) are subangular to rounded, most are subrounded. Quartz (70–80%), feldspar (0–2%), siltstone and chert rock fragments (1–4%), muscovite (1–2%), minor amphibole, epidote, tourmaline, zircon, rutile and Fe-Ti oxides. Minor quartz cement. Muscovite flakes are parallel to bedding. Matrix (15–25%) of quartz, sericite, clay and Fe oxides.	Most abundant in southeast. Beds mainly massive and 10–30 cm thick (range 1–120 cm). Bouma sequences recognised in many beds — include erosional base, flute marks, load casts, graded beds, flat- and cross-laminated beds, contorted beds. Arenite is interbedded with thin shale beds.
Chert	Aphanitic pale grey to greenish grey chert (80–90%) with scattered detrital quartz (5–10%), as subangular to sub-rounded grains up to 0.25 mm, and muscovite (2–5%). Rare tourmaline, Fe-Ti oxides, rutile, amphibole and clay. Muscovite flakes are aligned parallel to bedding. One sample (R9495) contains about 3% slightly recrystallised Radiolaria.	Common near margin with Tangerang Formation. Beds 1–25 cm thick, mainly massive, strongly jointed and interbedded with thin shale laminae. Cut by numerous small quartz veins.
Shale, slate and phyllite	Blue-grey very fine-grained chloritic and sericitic clays. Detrital grains (5%) consist of quartz, muscovite (flakes up to 0.1 mm) and Fe-Ti oxides.	Occurs as interbeds in the arenite and chert and as distinct lenses. Cleavage subparallel to bedding on fold limbs.

In the northeastern part of the area the Tallong Beds crop out as a thinly-bedded slate-chert unit which exhibits large-scale isoclinal folds and probably represents deposition in quiet water with reducing conditions at the sediment-water interface. The Tallong Beds cropping out south of 'Bunburra' (Fig. 1) are represented by a well-bedded arenite-slate sequence. The thickness of individual beds is between 1cm and 1.2m. Large- and small-scale tight to isoclinal folds are common in this sequence, particularly in the shale interbeds which display prominent axial hinge thickening and weak to moderate bedding plane cleavage. Some localities (e.g. GR 631226) show complex small-scale deformation of the shale interbeds. Sedimentary structures are common in the arenite interbeds and include flute marks, graded bedding, slumped and contorted bedding, ripple cross-bedding, and ball and pillow structures. Bouma sequences at GR 628277 and the orientation of flute marks in the arenite at GR 631227 indicate that the beds are the right way up and that palaeocurrents were from the south. It is inferred that this interbedded arenite-slate sequence represents a distal flysch sedimentary accumulation.

The only fauna identified in the Tallong Beds in this area are Radiolaria in a greenish-grey chert at GR 658277 (sample R9495). However, the Tallong Beds in the Bungonia area are known to be of Late Ordovician age (Sherrard, 1949, 1954, 1962; Sherwin, 1972; Carr *et al.*, 1981) and equivalent rocks on the Braidwood 1:100,000 Geological Sheet consist of undifferentiated greywacke-slate sequences containing some Late Ordovician graptolitic black slate (Felton and Huleatt, 1977).

LATE SILURIAN BEDS

Unnamed Late Silurian limestone and shale crop out in the southern part of the area west of the Yarralaw Fault (Fig. 1). The limestone outcrops were mapped by Mawson (1975) and consist of grey, massive to weakly bedded, westerly dipping, partly dolomitized limestone containing a Late Silurian fauna of brachiopods, corals, nautiloids, gastropods and stromatoporoids. Farther north, unfossiliferous limestone occurs only as scree (e.g. GR 611301) and the most common lithology is pale buff to brown ferruginized shale. This limestone-shale unit was probably deposited in a shallow marine environment as a lateral equivalent of the Late Silurian portion of the Bungonia Limestone.

TANGERANG FORMATION

The Tangerang Formation between Bungonia and Windellama consists predominantly of an undifferentiated sequence of sublitharenite, volcaniclastic arenite and fine and coarse tuff. Lithological variations within this sequence primarily represent lateral facies changes and the distribution and petrography of these major lithologies are summarized below.

Clastic arenite. The basal sequence (approximately 550m) of the Tangerang Formation is characterized by sublitharenite but significant variations in composition occur (Table 2, Fig. 2). In general the sandstone from the lower levels of the formation has a finer grain size and is composed dominantly of detrital quartz and sedimentary lithic fragments with less common feldspar, and is classified as sedarenite or subsedarenite. As the stratigraphic sequence is ascended the sandstone becomes coarser grained, has a much greater feldspar content, contains small amounts of volcanic quartz and is classified as lithic arkose or feldspathic litharenite. This transition is not uniform throughout the area and scattered interbeds of volcaniclastic arenite are present at most levels.

TABLE 2

Petrography of the undifferentiated Tangerang Formation

Lithology	Composition	Other Features
Clastic arenite	Very fine- to coarse-grained (0.08–0.6 mm), moderately to poorly sorted, immature. Angular to rounded quartz, sedimentary rock fragments (siltstone, quartzite, chert), metamorphic rock fragments, minor plagioclase (An$_{30-36}$) and rare devitrified volcanic rock fragments. Accessory minerals include zircon, Fe-Ti oxides and tourmaline. Chert, microcrystalline quartz and clay matrix with secondary calcite and sericite.	Massive to well-bedded with beds ranging from 3–40 cm thick. Rare argillaceous interbeds present. Ripple cross-beds, symmetrical and asymmetrical current ripple marks. Fossils rare in the north (crinoid ossicles, bryozoans) but trilobites and corals are abundant in the south. A few interbeds of volcaniclastic arenite are present and become more abundant with increasing stratigraphic height.
Volcaniclastic arenite	Medium- to very coarse-grained (0.1–1.4 mm), poorly sorted, immature. Subangular to rounded detrital and volcanic quartz, K-feldspar (orthoclase), plagioclase (An$_{22-46}$), devitrified volcanic rock fragments, relict glass shards, sedimentary rock fragments (chert, siltstone, fine micaceous sandstone) and rare metaquartzite. Accessory minerals include muscovite, Fe-Ti oxides, zircon, tourmaline, amphibole, calcite and rare pyrite and biogenic detritus.	Generally moderately to well-bedded with beds ranging from 5–60 cm thick. Sedimentary structures include ripple and large-scale tabular cross-beds. Fossils are rare and fragmentary.
Coarse tuff and lapilli	Medium- to very coarse-grained (0.2–2.5 mm), poorly sorted, immature. Detrital and volcanic quartz, orthoclase, plagioclase (An$_{35-50}$), volcanic rock fragments (glass shards and aphanitic ejectamenta), sedimentary and metamorphic lithic fragments. Accessory uralite, biotite, pyrite, tourmaline and Fe-Ti oxides. Chert, uralite and chlorite matrix.	Most abundant in the upper part of the formation in the 'Torwood'-'Kooringaroo' area. Moderately to well-bedded. Beds ranging from 5–50 cm thick — occasionally massive. Ripple cross-bedding and large-scale tabular cross-bedding common. Rare fragmentary marine fossils (crinoids).
Fine tuff	Poorly to moderately sorted, fine- to medium-grained (0.05–0.3 mm), immature. Detrital and volcanic quartz, Fe oxides, relict glass shards and rare feldspar in a chert matrix.	Well-bedded, beds ranging from 2–50 mm in thickness. Alternating reworked and massive microbeds. Current ripple cross-bedding. No fossils. Similar distribution to coarse tuff.

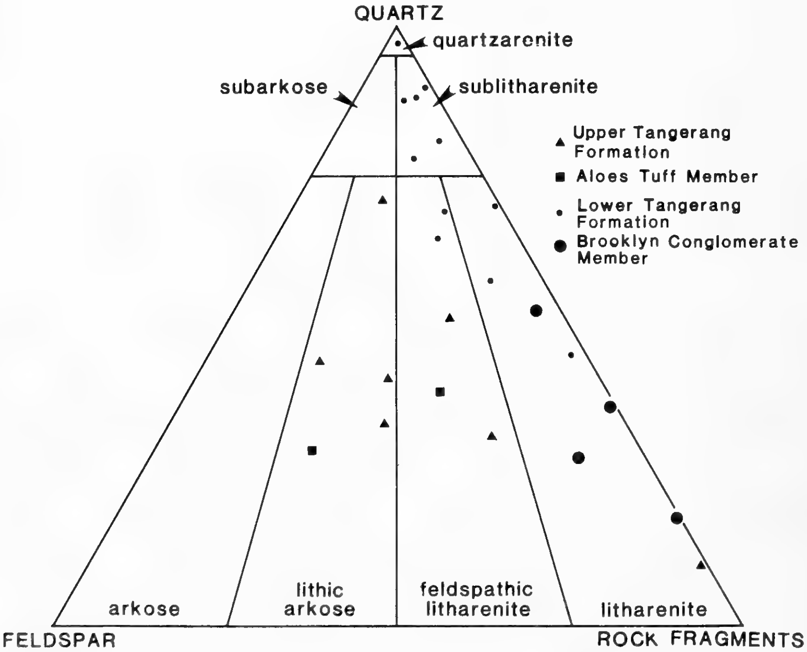


Fig. 2. Classification of sandstone (after Folk, 1974) from the Tangerang Formation in the Bungonia-Windellama area.

Volcaniclastic arenite. This lithology does not crop out as a distinct mappable unit, but rather as lenses within other sedimentary rocks of the Tangerang Formation. Beds range from 2cm to 50cm in thickness and may be internally laminated or massive. The volcaniclastic arenite is composed of detrital and volcanic quartz, plagioclase, K-feldspar and lithic fragments, with accessory Fe-Ti oxides, mica, tourmaline and rare zircon (Table 2) and ranges from lithic arkose to litharenite. Rocks from higher parts of the sequence are relatively enriched in volcanic quartz and volcanic lithic fragments. Some samples (e.g. R9480) contain abundant devitrified volcanic detritus and relict glass shards. The detrital volcanic component of the sandstone decreases in abundance south of 'Sunning Hill'. In this area the sandstone is commonly enriched in sedimentary lithic components, thus indicating that the source for the volcanic detritus was to the north.

Coarse and fine tuff. A distinctive lens of interbedded coarse and fine tuff with minor volcaniclastic arenite occurs in the 'Torwood'–'Kooringaroo' area and is up to 130m thick. Its northeasterly trend is attributed to displacement associated with the intrusion of the Marulan Batholith. The tuff shows no evidence of welding or fiamme but rather it is moderately- to well-bedded, containing some large-scale tabular cross-beds and crinoid ossicles. Relict glass shards and aphanitic volcanic fragments are common (Table 2) and the rocks probably represent primary and reworked ashfall tuffs. These tuffs are mineralogically and texturally very similar to the Aloes Tuff Member. A unit of coarse-grained volcaniclastic arenite and minor tuff occurs along the anticlinal axis in the southern part of the area. This may represent a unit equivalent to, but more extensively reworked than, the tuff near 'Torwood'.

Three lensoidal members were described from the Tangerang Formation by Jones *et al.* (1984) — the Windellama Limestone, Carne Dacite and Aloes Tuff Members. A distinctive basal conglomerate can be recognized in part of the Bungonia-Windellama area and is defined here as a fourth member — the Brooklyn Conglomerate Member.

BROOKLYN CONGLOMERATE MEMBER (new name)

The Brooklyn Conglomerate Member is proposed for a sequence of interbedded conglomerate and medium- to coarse-grained sandstone that crops out immediately above the Tallong Beds at the type locality (GR 645253) in Bogungra Creek. The member is named after the property 'Brooklyn' (GR 644252) and the unit can be seen unconformably overlying folded Ordovician flysch in a cutting on the Bungonia-Windellama road near 'Brooklyn' (GR 646254, Fig. 3). A thin band of conglomerate

Fig. 3. Sketch of the cutting on the Bungonia-Windellama road near Bogungra Creek showing the unconformable contact between the Late Ordovician Tallong Beds and the overlying Early Devonian Brooklyn Conglomerate Member of the Tangerang Formation (drawn from photographs). The cutting is very weathered and part of the conglomerate matrix may represent clay derived from the overlying soil. The conglomeratic sandstone at the northern end of the outcrop shows faint cross-bedding.

also crops out about 1km farther south at GR 641242. The Brooklyn Conglomerate Member lenses out rapidly north and south of 'Brooklyn' and has a maximum thickness of 60m.

The unit is moderately- to well-bedded and displays a uniform westerly dip of 30° to 40°. Medium- to coarse-grained sandstone interdigitates with beds containing angular and rounded clasts of quartzite, micaceous sandstone, chert and siltstone ranging from 2cm to 60cm in diameter. The clasts are set in a fine-grained quartz and clay matrix which also contains a few fossil fragments. The petrography of this unit is summarized in Table 3 and Figure 2. Analysis of cross-bed orientations in the arenite units indicates that the Brooklyn Conglomerate Member has a northeastward (052°) palaeocurrent trend.

TABLE 3

Petrography of Members of the Tangerang Formation

Member	Lithology	Composition	Other Features
Brooklyn Conglomerate Member	Polymictic conglomerate, sandstone	Medium- to very coarse-grained (0.1 mm to 60 cm clasts), very poorly sorted, immature. Angular and rounded clasts of quartzite, chert, siltstone and fine micaceous sandstone in a matrix of chert, fine-grained quartz and Fe oxides. Interbedded arenite with 0.1–1.3 mm grain size.	Moderately to poorly bedded; beds range from 10–80+ cm in thickness. Rare fragmentary marine fossils present (crinoid ossicles and corals). Grades to medium-grained cross-bedded sandstone.
Windellama Limestone Member	Limestone (biopelmicrite, biomicrite, biosparite), rare shale	Fine- to very fine-grained (<0.01–0.1 mm), moderately to well-sorted, wackestone texture. Pellets common in south, fossil fragments scattered throughout, micrite most abundant in south and is partly replaced northwards by spar calcite cement. Accessory minerals include quartz, pyrite and clay.	Well-bedded; beds range from 5–30 cm in thickness. Richly fossiliferous (rugose and tabulate corals, brachiopods, nautiloids, conodonts). Geopetal structures are common in the northern lenses.
Aloes Tuff Member	Coarse tuff and lapilli	Bimodal; fine- to coarse-grained (0.02–2.5 mm), poorly sorted, immature. Detrital and volcanic quartz, K-feldspar, plagioclase (An_{31-45}), volcanic rock fragments (aphanitic ejectamenta and pumice), relict glass shards, sedimentary rock fragments (chert, siltstone, fine sandstone) and metaquartzite. Accessory Fe-Ti oxides, zircon, tourmaline and rutile. Matrix of chert and clay.	Moderately to well-bedded in the south with beds ranging from 1–25 cm in thickness. Ripple cross-bedding and rare large-scale tabular cross-bedding. No fossils. In the north beds are up to 2 m thick and massive to weakly laminated. Accretionary lapilli are present in some beds with flattened lapilli occurring towards the base of each bed.
	Fine tuff	Very fine-grained (0.01–0.25 mm), moderately sorted, immature. Detrital and volcanic quartz, K-feldspar, plagioclase (An_{31-40}) and relict glass shards. Accessory zircon, hornblende, pyrite and rutile. Matrix of chert.	Well-bedded; beds ranging from 2–80 mm in thickness. Small-scale ripple cross-bedding. Rare crinoid ossicles.
Carne Dacite Member	Porphyritic hornblende dacite	Phenocrysts of embayed quartz, greenish plagioclase (An_{48-52}), hornblende and hypersthene. Very fine-grained groundmass of quartz, plagioclase, K-feldspar and minor hornblende, hypersthene, biotite and Fe-Ti oxides.	Extensively altered with common chlorite, sericite and kaolinite as devitrification products of the glassy groundmass.

The boulder conglomerate was probably deposited in a very shallow marine environment at the mouth of a large stream eroding the Late Ordovician basement in the area. Supporting evidence for this proposal includes:

i) the relatively restricted lateral occurrence of the unit;
ii) the restriction of large angular blocks to the base of the conglomerate;
iii) the polymictic nature of the conglomerate;
iv) the abundance of rounded, abraded clasts; and
v) the presence of fragmentary crinoids and corals.

WINDELLAMA LIMESTONE MEMBER

The main outcrops of the Windellama Limestone Member (Pickett and Huleatt, 1971; redefined by Jones *et al.*, 1984) southwest of 'Bunburra' have been described in detail by Mawson (1975) who subdivided the limestone into three units. The lowest unit is poorly-bedded and dolomitic, the middle unit is a black well-bedded, partly silicified pelletal micritic limestone and the highest unit is a massive dark grey micritic limestone. Fossils occur throughout the member but are most abundant in the middle unit. Lochkovian (earliest Devonian) conodonts were reported from this member by Mawson (1975); further faunal studies have not been attempted in the present study.

Lenses of limestone which are lithologically and faunally similar to the middle unit at Windellama occur near 'Brooklyn' (GR 641254) and 'Aloes' (GR 673303 and GR 683314). These lenses are interbedded within the arenitic strata of the Tangerang Formation and their petrography and sedimentary features are summarized in Table 3.

The thickness of the Windellama Limestone Member ranges from 285+m in the type section at GR 626230 to 25+m at the northernmost outcrop. The limestone was deposited in a shallow marine environment with the greatest water depths (about 50m) being attained during the deposition of the middle unit (Mawson, 1975).

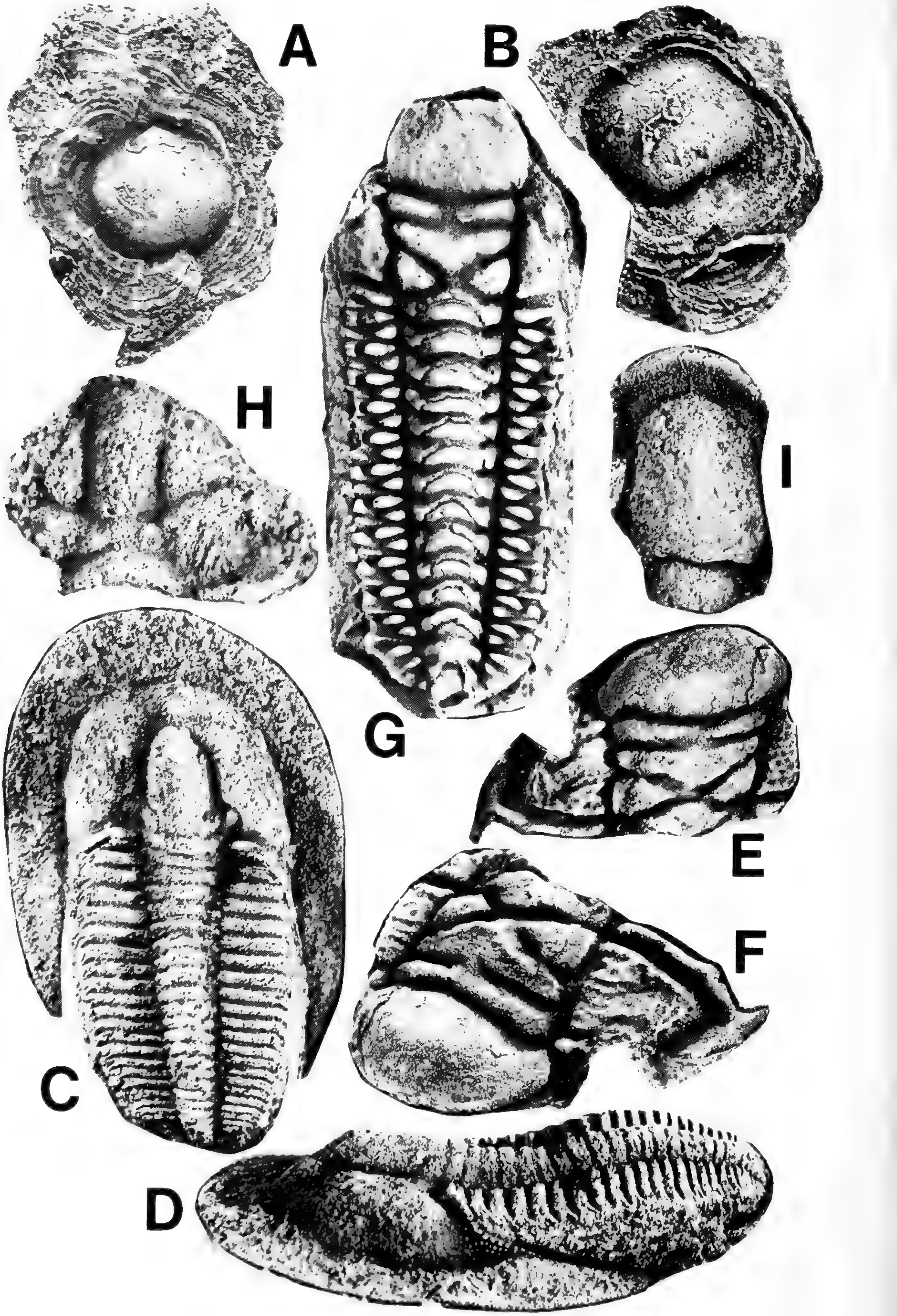
ALOES TUFF MEMBER

The Aloes Tuff Member, defined by Jones *et al.* (1984) is confined to the 'Lumley Park'–'Brooklyn' area where it occurs as an elongate lens approximately 550m above the base of the Tangerang Formation. The unit is thickest near 'Lumley Park' (230m) and it decreases in thickness southwards until it lenses out into reworked volcaniclastic sandstone in the 'Brooklyn' area.

In the 'Lumley Park' area the Aloes Tuff Member consists of thick (up to 2m), massive- to weakly-bedded, fine and coarse tuff with several beds of accretionary lapilli (e.g. GR 676337) and one outcrop of volcanogenic breccia. Occasional interbeds of coarse tuff containing scattered small (<2cm) fiamme represent the welded parts of ashflows and led Jones *et al.* (1984) to postulate that this part of the Aloes Tuff Member accumulated on the flanks of a subaerial volcano. Farther south the Aloes Tuff Member is well-bedded on a millimetre scale, the proportion of fine tuff increases and the unit shows increasing evidence of reworking in a marine environment as indicated by the presence of rare crinoid ossicles. The petrography and sedimentary features of the Aloes Tuff Member are summarized in Table 3 and Figure 2.

CARNE DACITE MEMBER

Three outcrops of dacite occur within the study area and all form part of the Carne Dacite Member as defined by Jones *et al.* (1984). The outcrop just east of Bungonia was previously described as the western hornblende dacite (Carr *et al.*, 1981). The second dacite occurring 2km northeast of 'Torwood' is pale grey, porphyritic and contains at least one interbed of coarse tuff and volcanogenic breccia (GR 663337); the dacite shows an abrupt southward termination into units of coarse tuff and volcaniclastic arenite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while its northward extent has been truncated by plutons of the Marulan Batholith. The limited extent of the dacite suggests that it has a domal form with a thickness of at least 410m. The third dacite occurs as a thin lens (maximum thickness of 40m) within the Aloes Tuff Member east and southeast of 'Lumley Park'. The petrography of these dacite units is given in Table 3.

FAUNA AND AGE

Invertebrate fossils from clastic strata occur at a number of localities mainly in the lower part of the Tangerang Formation. In most cases, the fossils are poorly preserved, tectonically deformed and silicified.

Useful faunas were obtained from three locations in the east-central part of the area (Fig. 1, GR 652268, 648262 and 647263). These faunas include: *Pleurodictyum* (Fig. 4**A-B**) and other indeterminate tabulate corals and solitary tetracorals; indeterminate fenestellid bryozoans and rare gastropods; the brachiopods cf. *Salopina* and cf. *Nucleospira*; and the trilobites cf. *Lioharpes* (Fig. 4**C-D**), *?Crotalocephalus* (Fig. 4**E-G**), *Ananaspis ekphyma* sp. nov. (see Appendix, Fig. 6**A-K**), *?Acanthopyge (Lobopyge)* (Fig. 4**H**), and proetid (Fig. 4**I**), scutelluid and odontopleurid fragments. Almost all shells are disarticulated, but show little evidence of abrasion due to transportation. Several *Pleurodictyum* specimens encrust cf. *Nucleospira* shells. These shells also bear a pre-existing epifauna which attests to a low-energy environment with intermittent sedimentation (Fig. 4**A-B**).

The three main faunal localities occur at a stratigraphic level approximating to that of the limestone lenses near 'Brooklyn' and 'Aloes' (Fig. 1). Hence, they would correlate with the middle part of the Windellama Limestone Member, for which a Lochkovian (Early Devonian) age was established by Mawson (1975) on the basis of conodonts. Similarity of the fauna north of 'Brooklyn' with Lochkovian faunas from the Bungonia Limestone (largely unpublished data) and Heathcote, Victoria (Talent, 1965; Holloway and Neil, 1982) — especially those from the Mt Ida Formation — supports this age determination.

Mawson (1975) inferred a Pragian age for the upper part of the Tangerang Formation on the basis of an occurrence of the cheirurid trilobite *Crotalocephalides* at GR 626240.

ENVIRONMENT OF DEPOSITION

The undifferentiated part of the Tangerang Formation was probably deposited in a shallow water marine environment which was characterized by generally calm conditions with weak to moderate currents. The sporadic occurrence of coarse-grained sedarenites may indicate short periods of storm activity or slight fluctuations in the relative sea level.

The overall palaeocurrent trend for the Tangerang Formation in the Bungonia-Windellama area is northerly (005°, Fig. 5). The lower undifferentiated part of the

Fig. 4. Early Devonian (probably Lochkovian) fossils from the Tangerang Formation, Windellama district, New South Wales. **A,B**, *Pleurodictyum* sp. encrusting the brachiopod cf. *Nucleospira* with epifauna. Both external moulds of basal surface of colony, x3. **A**, AMf68594; **B**, AMf68595. Locality GR 652268. **C,D**, cf. *Lioharpes* sp., internal mould in dorsal view (**C**) and lateral view (**D**). AMf68596, both x2. Locality GR 647263. **E,F**, *?Crotalocephalus* sp. A, dorsal (**E**) and antero-lateral (**F**) view of internal mould of cranidium. AMf68597, both x1.5. Locality GR 648262. **G**, *?Crotalocephalus* sp. B, internal mould in dorsal view. AMf30029, x1.5. This specimen is from the C.F. Laseron collection and is labelled 'Windellama, N.S.W.' **H**, *?Acanthopyge (Lobopyge)* sp., dorsal view of latex cast of internal mould of cranidium. AMf68598, x8. Locality GR 648262. **I**, indeterminate proetid cranidium, dorsal view of internal mould. AMf68599, x5. Locality GR 648262.

formation exhibits a consistent north-north-easterly palaeocurrent trend (016°) whereas the upper part of the formation shows more variable trends with northerly (359°), westerly (270°) and south-southeasterly (153°) modes. The latter palaeocurrents are probably responsible for the lensoidal bedding and the interdigitation of the clastic lithotypes in this part of the formation. The abundance of pyroclastic flows and lava in the 'Lumley Park' area may represent the build-up of a non-marine volcanic pile which would have affected the palaeocurrent patterns.

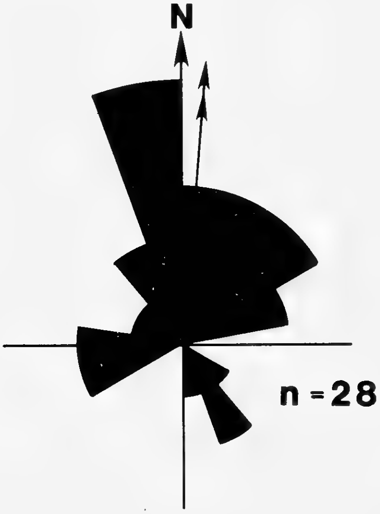

Fig. 5. Total palaeocurrent data from the Tangerang Formation in the Bungonia-Windellama area.

MARULAN BATHOLITH

The Marulan Batholith comprises a series of plutons which crop out discontinuously in a meridional belt extending over at least 60km from Windellama in the south to Bullio in the north. Various rock types have been described, including hybrid rocks (Osborne and Lovering, 1953) which O'Reilly (1972) has re-intepreted as contact metamorphic rocks produced by the intrusion of granitic rocks into silicic volcanics. Carr *et al.* (1981) mapped four plutons of the Marulan Batholith in the Bungonia area — the Springponds Granodiorite, Wylora Quartz Gabbro, Lumley Adamellite and Inverary Tonalite. K-Ar data for biotite separates from the granodiorite, quartz gabbro and adamellite indicate a mean age of emplacement of 398 Ma (Early Devonian) for the southern part of the Marulan Batholith (Carr *et al.*, 1980). Six plutons of the Marulan Batholith are recognized in the Bungonia-Windellama area. These include the four plutons described previously from Bungonia by Carr *et al.* (1981), together with the Torwood Granodiorite and Bogungra Microtonalite.

TORWOOD GRANODIORITE (new name)

The Torwood Granodiorite, which intrudes the Tangerang Formation and Bogungra Microtonalite in the central portion of the study area, is named after the property 'Torwood' (GR 645322) and has its type locality at GR 643321.

The granodiorite is a pale grey, leucocratic, medium- to coarse-grained hypidiomorphic granular rock composed of quartz, plagioclase, K-feldspar, hornblende and biotite. Fe-Ti oxides, rutile and zircon comprise the accessory phases whereas sericite, chlorite, uralite and prehnite are developed as secondary minerals. Plagioclase is the dominant mineral and it occurs as incipiently altered laths which have normal zoning from cores of An_{47} to rims of An_{26}. K-feldspar also shows extensive incipient alteration but hornblende and biotite have only minor replacement by secondary minerals.

BOGUNGRA MICROTONALITE (new name)

The Bogungra Microtonalite crops out as an elongate pluton in the central part of the study area and as a small apophysis at GR 614297. The intrusion exhibits obvious cross-cutting relationships with the surrounding sedimentary sequence (Fig. 1). The type locality is at GR 641295 and the intrusion is named after Bogungra Creek which traverses the southern margin of the pluton.

Hand specimens of the Bogungra Microtonalite are grey-green, leucocratic, holocrystalline and porphyritic with medium- to coarse-grained phenocrysts set in a very fine-grained quartzo-feldspathic groundmass. Plagioclase, hypersthene, augite, quartz and minor Fe-Ti oxides, biotite, zircon and apatite constitute the phenocrystic phases. The most abundant mineral is plagioclase and although a few phenocrysts show normal zoning from cores of An_{45} to rims of An_{17} most grains are andesine (An_{35-48}) in composition. Many of the plagioclase crystals show extensive sericitization and the pyroxenes are rimmed by hornblende and uralite. Quartz phenocrysts contain deep embayments and have recrystallized margins. Secondary minerals include prehnite, sericite, uralite and epidote.

Late Devonian Sedimentary Rocks

Naylor (1939) recorded a Late Devonian fauna from near the base of a quartz-rich sandstone and shale sequence which unconformably overlies the Tangerang Formation and Marulan Batholith. This unit displays a consistent shallow dip to the west (12°– 20°) where it is truncated by the Yarralaw Fault. The sequence includes poorly bedded or massive sandstone and thinly interbedded sandstone and shale with common sedimentary structures such as ripple marks, cross-beds and scours. The sandstone, ranging from fine-grained and moderately sorted to coarse-grained and poorly sorted, is composed of quartz, fine-grained micaceous siltstone and chert rock fragments and rare feldspar and volcanic rock fragments set in a matrix of clay, microcrystalline quartz and iron oxide. It is classified as an immature sedarenite.

Post-Devonian Sedimentary Rocks

Numerous small poorly exposed outcrops of immature quartzarenite and poorly to moderately consolidated conglomerate, manganiferous grit, ferruginous shale, silcrete, laterite and ferricrete unconformably overlie the Early and Middle Palaeozoic rocks of the Bungonia-Windellama area. The outcrops of quartzarenite are lithologically similar to outcrops north of Bungonia (Carr *et al.*, 1981) and at Marulan South (Wass and Gould, 1969) and probably represent outliers of Permian strata of the Sydney Basin sequence. Early Tertiary fine- to very coarse-grained sandstone has been preserved beneath the Reevesdale Basalt near 'Lumley Park' (GR 678342) where it fills irregularities on the pre-basaltic landsurface. The sandstone is overlain by brown and black organic-rich clay which contains a rich and diverse microflora of the late Early to Middle Eocene *Proteacidites asperopolus* Zone (E. M. Truswell, pers. comm., 1985).

Reevesdale Basalt

The Late Eocene Reevesdale Basalt (Carr *et al.,* 1981) occurs as a series of discontinuous outcrops in the northern portion of the study area where it unconformably overlies older rocks and sediments. Drilling by North Broken Hill Pty Ltd has indicated that the basalt is up to 58.5m thick at GR 678342. The rock is an alkali-olivine basalt consisting of plagioclase (An_{62-48}), olivine, titaniferous augite, Fe-Ti oxides and accessory apatite. K-Ar dating by Wellman and McDougall (1974) indicates an age of 47.2 Ma (recalculated using the decay constants of Steiger and Jager, 1977). The basalt cropping out near 'Kooringaroo' is petrographically indistinguishable from the Reevesdale Basalt and as it has a K-Ar age of 45.4 Ma (recalculated from Wellman and McDougall, 1974) it may represent part of a related flow.

The numerous pisolitic red-brown bauxite deposits occurring between 'Aloes' and 'Bunburra' were probably derived from the Tertiary basalts by intense weathering. The pisolites (5-20mm) are grey when fresh and consist predominantly of goethite.

Dolerite. A small subcircular dolerite intrusion at GR 623229 may represent a volcanic pipe. The rock is medium-grained, holocrystalline and mesocratic with an intergranular texture and no evidence of flow structures. It is composed of zoned plagioclase (An_{65-29}), titaniferous augite, olivine and accessory Fe-Ti oxides and analcime, and is classified as an alkali olivine dolerite. The mineralogy of this dolerite is similar to the numerous dolerite dykes reported by Carr *et al.* (1981) from the Bungonia area and it is probably also related to the extrusion of the Eocene basalt.

REGIONAL STRUCTURE

FOLDS

Tight to isoclinal folds are displayed in the Tallong Beds along the eastern margin of the study area. At locality GR 689317 medium- to large-scale isoclinal folds are present in a sequence of interbedded shale and chert. The limbs of these folds dip steeply to the west (approximately 85°), the axial planes trend north-northeast (average 030°) with a slight plunge (5°–10°) in the same direction. At locality GR 632228 moderate to tight north-northeast trending (028°) folds occurring in a quartzarenite-shale sequence have dips on the limbs ranging from 25° to 83°. Small-scale tight to isoclinal folds, showing weak bedding plane cleavage and pronounced thickening of fold hinges, are exhibited in the shale interbeds in this sequence. The axial planes of these small folds are subparallel to the larger folds, thus suggesting that they were all produced concurrently. Mawson (1975) described a series of folds with north-northeast trending axes in sedimentary units that she considered to be Silurian in age, but which are considered here to be part of the Ordovician Tallong Beds.

The fold style developed in the Tallong Beds in the study area is similar to that displayed in the unit at Bungonia (Carr *et al.*, 1981). At least one phase of folding of the Late Ordovician Tallong Beds occurred prior to the deposition of the Bungonia Limestone and Tangerang Formation and it was probably produced by the Late Ordovician-Early Silurian Benambran Orogeny.

Mawson (1975) noted broad gentle folds in the Early Devonian sequence cropping out near Windellama and these north-northeast trending folds can be traced northwards to the Bogungra Microtonalite (Fig. 1). These folds become tighter towards the Yarralaw Fault.

The consistent westerly dip of 25° to 40° displayed by the Tangerang Formation in the 'Brooklyn' -Bungonia area indicates that this sequence probably represents one limb of a broad regional fold (cf. Naylor, 1950). The uniformity in dip of the Tangerang Formation on both sides of the batholith suggest that the folding occurred during the Early Devonian Bowning Orogeny prior to the intrusion of the Marulan Batholith.

The Late Devonian sequence has a consistent shallow westerly dip of 12° to 20°.

FAULTS

The area studied is bounded on the west and south by the Yarralaw and Jacqua Faults respectively (Mawson, 1975). The north-northeast trending Yarralaw Fault separates an upthrown block of Late Silurian limestone and ferruginous shale in the west, from the downthrown block of Early Devonian Tangerang Formation in the east (Naylor, 1950; Mawson, 1975). The fault has a minimum vertical displacement of 2km — the thickness of the Tangerang Formation east of the fault. The northward extension of the Yarralaw Fault was mapped by Brunker and Offenberg (1968) from 'Kooringaroo' to the Hume Highway where it separates Late Devonian sedimentary strata (on the east) from undifferentiated Ordovician-Silurian sedimentary strata (on the west). Movement on the Yarralaw Fault is therefore post-Late Devonian and pre-Eocene.

The Late Ordovician-Early Devonian boundary in the study area is dissected by a number of small east-west faults (Fig. 1) which display elements of lateral, vertical and slight rotational movement. As these faults fail to offset the margins of the Bogungra Microtonalite they must be earliest Devonian in age, possibly associated with the Bowning Orogeny as suggested by Carr *et al.* (1980).

DISCUSSION

The Late Ordovician Tallong Beds at Windellama show a primary petrographic association of interbedded fine-grained quartz-rich sandstone, slate and chert, and a tight to isoclinal fold style. The presence of classical Bouma sequences in the Tallong Beds indicates deposition by turbidity currents whereas the occurrence of radiolarian chert interbeds represents slower deposition. Similar petrographic and structural associations in the Tallong Beds have been reported from the Bungonia area by Carr *et al.* (1981). Thus the whole Tallong Bed sequence in the Bungonia-Windellama area represents quartz-rich distal flysch similar to that which accumulated throughout the southern Lachlan Fold Belt, i.e., an extension of Unit B of Crook *et al.* (1973). The character and palaeocurrent data exhibited by the Tallong Beds are consistent with deposition in a forearc basin as suggested by Cas *et al.* (1980). The tight folds in the Tallong Beds were produced in the latest Ordovician or earliest Silurian as a result of tectonic movements associated with the Benambran Orogeny.

The Bungonia-Windellama region remained deeply submerged after the Benambran folding as indicated by the graptolitic distal flysch of the Early Silurian 'Jerrara Series' (Naylor, 1936) 5km west of Bungonia. A major period of uplift in the Canberra-Quidong region (e.g. Wenlockian Quidongan Orogeny of Crook *et al.*, 1973) accounts for the uplift of the Late Ordovician and Early Silurian sequences to form the eastern edge of the Benambran Landmass proposed by Powell (in Veevers, 1984). The dextral transform motion suggested in Veevers (1984) for the eastern Australian continental margin during the Middle Silurian would have led to the development of a series of meridional horsts and grabens. The Late Silurian to Early Devonian shallow marine facies in the Bungonia-Windellama area accumulated on the eastern margin of the Wollondilly Tract where it abuts the South Coast High.

Late Silurian limestone and shale occur extensively in the Bungonia region (Carr *et al.*, 1981) where they overlie eroded Tallong Beds on the shallowly submerged edge of the South Coast High. The Bungonia Limestone contains a higher terrigenous component towards the south, suggesting that the Tallong Beds were emergent nearby, shedding abundant material into the area between 'Lumley Park' and Windellama. The Late Silurian shallow marine limestone and shale cropping out west of the Yarralaw Fault near Windellama (Mawson, 1975) is presumably a lateral equivalent of the lower part of the Bungonia Limestone. The Late Silurian shoreline is not exposed in the Windellama area but probably lies beneath the Tangerang Formation. The occurrence of *Spathognathodus* sp. cf. *S. remscheidensis* in both the Windellama Limestone Member and the upper limestone of the Bungonia Limestone (Jones *et al.*, 1981) suggests that these two earliest Devonian units are correlatives. Further evidence for such correlation is the occurrence of broadly similar trilobite faunas in both the litharenite near the base of the Tangerang Formation between 'Bunburra' and 'Aloes' and the upper shale of the Bungonia Limestone. Thus deposition of the Tangerang Formation commenced earlier south of Bungonia than north of Bungonia where limestone deposition remained dominant for some short time into the Early Devonian (see Jones *et al.*, 1984: fig. 7). Termination of limestone deposition in the Bungonia-Windellama region was due to the eruption of acid volcanics and swamping of the region with primary and reworked volcanic debris.

The Early Devonian Tangerang Formation overlies the Late Ordovician Tallong Beds in the 'Aloes' -Windellama area with a marked angular unconformity (Fig. 3) and the Brooklyn Conglomerate Member represents deposition during an erosive phase at the start of a Devonian marine transgression. The Tangerang Formation is composed of a shallow marine sequence of conglomerate, limestone, sublitharenite, volcaniclastic arenite and tuff. The increasing volcanic content in the 'Lumley Park' area is demonstrated by the occurrence of lapilli and fine airfall tuff, accretionary lapilli, dacitic agglomerate and lava as well as associated volcaniclastic sedimentary rocks. The lack of marine fauna in this area together with the occurrence of accretionary lapilli, fiamme and thick beds of coarse pyroclastic debris indicates that the 'Lumley Park' area may have represented a subaerial vent during the Early Devonian. Palaeocurrent analysis has revealed progressive changes during the deposition of the Tangerang Formation from dominant easterly and northerly trends in the lower part of the formation to more variable northerly, westerly and south-southeasterly current directions in the upper part of the formation. This probably reflects interruption of the northerly palaeocurrent system along the axis of the Wollondilly Tract by the emergence of the subaerial volcanic centre near 'Lumley Park'. The lack of deformation in the Tangerang Formation associated with the intrusion of the Marulan Batholith suggests that the formation was folded into a broad regional open fold prior to the intrusion of the Early Devonian batholith, i.e., the folding was probably associated with an early phase of the Bowning Orogeny which produced the Snowy Mountains Uplift (Veevers, 1984).

Six phases of the Marulan Batholith have been mapped in the Bungonia-Windellama area and two of these bodies are confined to the Windellama region. The Bogungra Microtonalite is porphyritic, and has a very thin and low-grade metamorphic aureole, which accords with rapid cooling at a shallow depth. The microtonalite is intruded by the Torwood Granodiorite which grades northwards into the Lumley Adamellite of Carr *et al.* (1981). Intrusion of the southern portion of the Marulan Batholith (398 Ma, Carr *et al.*, 1981) probably occurred during the Bowning Orogeny.

The Bungonia-Windellama area presumably became emergent after the Bowning Orogeny as there is no record of Middle Devonian deposition. Late Devonian sandstone and shale unconformably overlie the Tangerang Formation and Marulan Batholith, and were deposited in a shallow marine to terrestrial environment (Naylor, 1939; Carr *et al.*, 1981). Post-Late Devonian movement occurred on the Yarralaw and Jacqua Faults preserving the Tangerang Formation and Late Devonian sequence as a downthrown westerly-dipping block.

Coarse-grained quartz-rich sandstone occurring unconformably above the Devonian rocks probably represents outliers of the Permian Sydney Basin sequence as noted by Wass and Gould (1969) in the Marulan area. The Reevesdale Basalt forms part of the Late Eocene Nerriga Province (Wellman and McDougall, 1974). The basalt flowed onto an irregular Early Eocene land surface and preserved an excellent flora in valley-fill sediments beneath the flow. A small alkali olivine dolerite body near 'Bunburra' is presumably an intrusive equivalent to the Tertiary basalts and may represent a feeder pipe. Small localized outcrops of Tertiary sedimentary units present in the Bungonia-Windellama area include manganiferous grit, ferruginous shale, pyrolusite-cemented quartzarenite, bauxite, ferricrete and silcrete.

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We thank J. F. Benison, S. H. Williams and all the property owners in the Bungonia-Windellama area for their assistance and cooperation. Studies of Devonian fossils by A. J. Wright have been supported by grants from the ARGS and the University of Wollongong. We also gratefully acknowledge the continued help and support of the technical and clerical staff in the Department of Geology at the University of Wollongong.

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APPENDIX

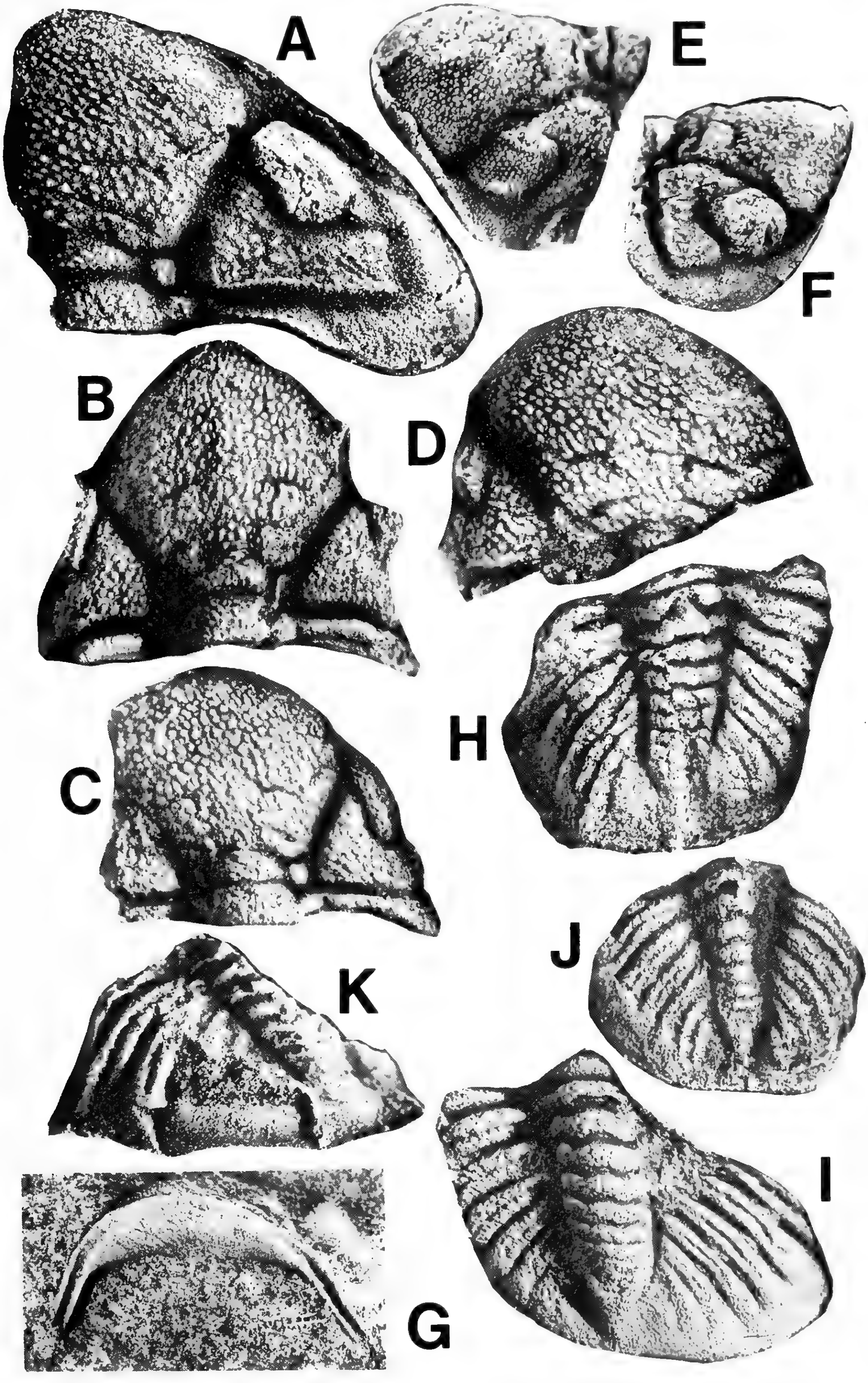
TAXONOMIC PALAEONTOLOGY

Phylum ARTHROPODA
Order PHACOPIDA Struve, 1959
Family PHACOPIDAE Hawle & Corda, 1847
Genus ANANASPIS Campbell, 1967

Type Species. *Phacops fecundus* Barrande, 1846

Remarks. This genus has been discussed by Campbell (1967), Chlupac (1977) and Holloway (1980). The first two authors are followed herein in assigning generic-level taxonomic importance to the vincular furrow, which in this genus is anteriorly shallow to absent. Other important characters include: pronounced 2s and 3s glabellar furrows; tubercles and granules on the glabella; and distinct interpleural furrows on the pygidium. Holloway (1980) suggested that, as the depth of the anterior part of the vincular furrow is variable in other phacopids, it is impossible to differentiate between *Ananaspis* and *Paciphacops (Paciphacops)* Maximova (1972) on that criterion; if so, perforated glabellar tubercles in *P. (Paciphacops)* may be the only important generic distinction between *Ananaspis* and *P. (Paciphacops).* Two other subgenera of *Paciphacops* — *P. (Viaphacops)*

Fig. 6. Anaspis ekphyma sp. nov. All from the Early Devonian (probably Lochkovian) Tangerang Formation, Windellama district, New South Wales. Locality GR 648262. **A**, AMf68600, holotype cephalon, dorsal view, x4. **B**, AMf68601, latex cast of paratype cephalon, dorsal view, x4. **C**, AMf68602, latex cast of paratype cephalon, dorsal view, x4. **D**, AMf68603, latex cast of paratype cephalon, dorsal view, x4. **E**, AMf68604, latex cast of paratype cephalon, lateral view, x4. **F**, AMf68605, paratype cephalon, lateral view, x3. **G**, AMf68606, latex cast of paratype showing doublure and vincular furrow, x3. **H**, AMf68607, latex cast of paratype pygidium, x4. **I**, AMf68608, latex cast of paratype pygidium, x4. **J**, AMf68609, latex cast of paratype pygidium, x 4. **K**, AMf68610, lateral view of mould of paratype pygidium showing doublure, x4 approx.


A
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Maximova (1972) and *P. (Angulophacops)* Maximova (1978) — differ from *Ananaspis* in a number of important aspects.

Ananaspis ekphyma sp. nov.
Fig. 6**A-K**

Types. AMf68600, holotype; AMf68601-68610, paratypes. All from the Tangerang Formation, grid reference 648262, Kooringaroo 8828-II-S 1:25,000 sheet. Early Devonian (probably Lochkovian). All material housed in the Australian Museum, College Street, Sydney.

Diagnosis. *Ananaspis* with long (exsag.) postocular area; long lateral border furrow; short genal spine; eye with up to 17 files with about 9 lenses per file; relatively numerous glabellar tubercles as well as only sparse granules; long (tr.) lateral occipital lobe; vincular furrows weakly notched laterally.

Derivation of Name. From the Greek word ekphyma, meaning an eruption of pimples.

Description. Outline of cephalon elongate to transversely semi-oval. Prominent glabella globose, expanding forward at about 60°; maximum width at anterior border furrow, at about mid-length; anterior margin overhanging narrow furrow. Axial furrows weak across wide (sag.) occipital ring (producing a wide (tr.) lateral occipital lobe), diverging immediately in front on 1s; lateral extremities of 1p almost completely isolated by short (exsag.) furrows. 1s furrows deep laterally, reaching almost to mid-line, transverse laterally, but adaxial portions anteriorly directed at low angle; 2s furrows gently convex forward, shorter and shallower than 1s; 3s furrows gently convex forward in adaxial portion, making slight angle with 2s, and lateral portion (anterior ramus) shorter and trending anteriorly towards axial furrow. Eye with up to (approx.) 17 files with about 9 lenses per file; anterior end close to axial furrow and level with anterior end of 3s; posterior end level with anterior end of 2s, well anterior of posterior border furrow. Palpebral lobes below level of glabella, with well-defined furrow running across lobe and down around base of eye to meet broad anteriorly weakening lateral furrow. Posterior limb narrows lateral to occipital ring, then widens abruptly level with the base of the eye, and the broad margin thus formed extends around genal angle with short spine, narrowing forward to the level of the front of the eye. Deep and rounded posterior border furrow turns inside genal angle at about 90°, becoming shallower and wider anteriorly, giving rise to slightly upturned margin beneath overhanging glabella. Margin bears granules on both dorsal and ventral surfaces; doublure wide anteriorly, vincular furrow not developed anteriorly, and only weakly notched. Tubercles developed abundantly on glabella, rings, cheeks inside border furrow, palpebral ridge and posterior limb. Granules are also developed sparsely on the glabella, where ornament becomes finer anteriorly.

Hypostome and thorax not found.

Pygidium transversely semi-oval, with marked facets accounting for ½ of width of pleural fields. 8(?9) axial rings plus a terminal piece; 6 ribs, with interpleural furrows deeper and longer than pleural furrows, both being slightly curved. Crests of axial rings (slightly W-shaped) and ribs bear low tubercles which reduce in size laterally to granules on the wide margin; doublure wide.

Remarks. This *Ananaspis* material is tectonically deformed so morphological features such as glabellar form must be assumed to be not in their pristine condition. Further, the material is somewhat silicified. Nevertheless, *A. ekphyma* sp. nov. is quite different from other species assigned to *Ananaspis*, either in the restricted sense used by Campbell (1967) and Chlupac (1977) or in the wider interpretation followed by Holloway (1980). In particular, the species is distinct in its glabellar prosopon which includes close-set and numerous tubercles and only very sparse granules, in which it resembles *Paciphacops (Viaphacops).* From the Australian species *Phacops serratus* Foerste, 1888; *Phacops crosslei* Etheridge and Mitchell, 1896; and *Phacops latigenalis* Etheridge and Mitchell, 1896, *A. ekphyma* differs in having anteriorly no trace of the vincular furrow. From species referred to *Ananaspis* by Campbell (1967, 1977) and Chlupac (1977), *A. ekphyma* differs in one or more of the following characters: the anteriorly placed eye; the long lateral border furrow; and the abundance of glabellar tubercles and rarity of glabellar granules. Material assigned to *Ananaspis f. fecunda* Barrande, 1846 has eyes placed anteriorly as in *A. ekphyma.* The dimorphism in eye development discussed by Campbell (1977) has not been observed in the Windellama material, in which the eyes are very poorly preserved. Holloway (1980) noted that '*Ananaspis* is presently known from the Late Llandovery to the Ludlow'; therefore the Windellama species considerably extends the known range of *Ananaspis.* Holloway and Neil (1982) assigned to *Ananaspis* the species *Phacops claviger* Haas, 1969 from the Pragian Wenban Limestone of Nevada; the assignment is not followed here. *A. ekphyma* n. sp. thus appears to be the first described *Ananaspis* from Australia and also the youngest known species of the genus.

This species is associated with: *Pleurodictyum* sp.; cf. *Nucleospira* sp., indeterminate rhynchonellids; ?*Crotalocephalus* sp. A, ?*Acanthopyge (Lobopyge)* sp., a proetid, indeterminate scutelluids, odontopleurids; fenestellids and favositid corals.

Notes and Discussion

THE CAMBALONG COMPLEX: A NEW METAMORPHIC COMPLEX IN SOUTHEASTERN N.S.W.

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A regional metamorphic complex has recently been mapped 12km west of Bombala in southeastern New South Wales. The complex is centred on Cambalong station (Fig. 1), and we have named it the Cambalong Complex. High grade metamorphic rocks have not previously been described from this area, although McRoberts (1948) mentioned two isolated occurrences of biotite-bearing metasediments to the west and southwest of Bombala and suggested that the metamorphic belt at Cooma could possibly extend south into this general region. This paper describes the field relationships of the complex and outlines its petrography and structure, as a basis for future more detailed studies.

Detailed mapping has revealed an elongate, north-south trending area of regional metamorphism, up to 7km wide and over 25km long. This is developed in a flysch sequence of probable Mid to Late Ordovician age (Bombala Beds). The metamorphic complex contains zones of progressively lower grade schists and phyllites on either side of a central belt of coarse-grained schists and gneisses. The central belt also contains foliated and unfoliated hornblende-bearing rocks and felsic dykes. Metamorphic zones are broadly concordant with the major structural trends in the area and the central belt lies in the core of an anticlinorium. The complex is asymmetric with zones on the western side being wider than equivalent zones in the east (Fig. 1). Much of the northeastern end of the complex is covered by Cainozoic basalts and sediments.

The metamorphism of the complex probably occurred in the Silurian, by analogy with the Cooma Complex to the north.

The lowest grade rocks in the area are sandstones, slates and chloritic phyllites, with minor interbedded cherts and pyritic black slates. Bedding and other sedimentary structures are well preserved and at least three phases of folding can be recognized.

Fine-grained mica schists and interlayered quartzites mark the start of the main metamorphic complex. Metapelites in this zone consist dominantly of quartz, biotite, muscovite, minor albitic plagioclase and retrograde chlorite. They generally show a domainal schistosity defined by aligned mica aggregates which anastomose around recrystallized quartz and plagioclase grains.

Further into the complex, particularly on the western side, there is a well-developed zone of knotted mica schists. Rocks here include medium to coarse, foliated assemblages of quartz-biotite-muscovite and quartz-muscovite-chlorite with a variety of knot types including mica-rich aggregates, small porphyroblasts of partly retrogressed cordierite and large altered idioblasts of andalusite. Porphyroblasts generally predate the mica foliation and have retrogressed during or after foliation development.

Metasedimentary rocks in the central belt are mainly coarse-grained mica schists with a wavy foliation, and finely-banded quartz-mica gneisses. Locally there are some more massive micaceous quartzites and unfoliated metapelites with a coarse decussate texture. The central belt metasediments contain quartz, biotite, and muscovite with

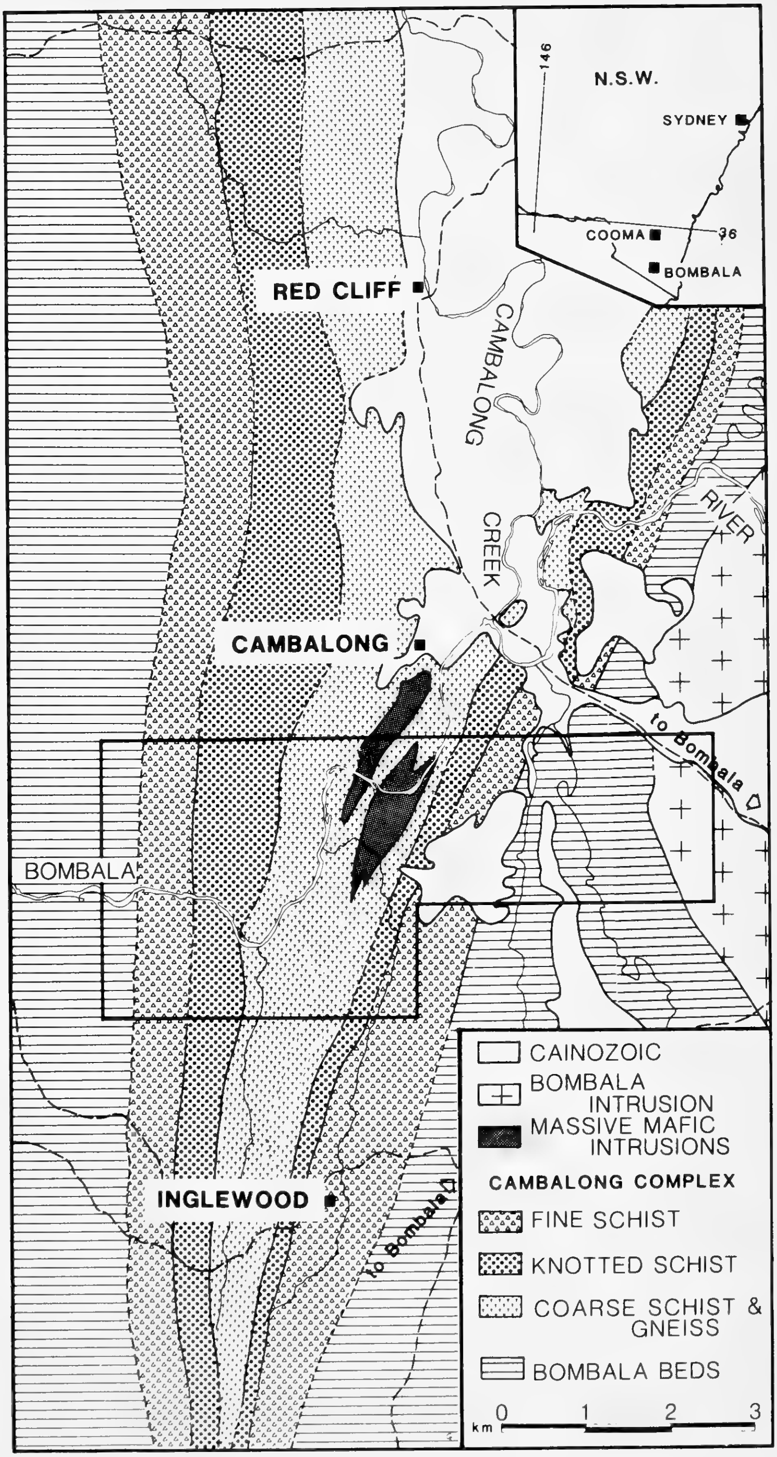

Fig. 1. General geology and location of the Cambalong Complex, west of Bombala. Outlined area is shown in more detail in Fig. 2.

variable amounts of plagioclase, andalusite, and cordierite. Some of the biotite has retrogressed to chlorite, and cordierite is replaced by fine-grained micas and amorphous material with low relief. Only a few acicular grains of sillimanite, enclosed in muscovite in one thin section have been identified. Aplite and pegmatite veins and dykes of centimetre and larger widths intrude the central belt metasediments. Where the metasediments are foliated, the foliation continues through these dykes and veins. It is unlikely that the numerous aplite and pegmatite veins could have been intruded if the metasediments had been at a temperature much lower than the solidification temperature of these felsic melts, i.e. at temperatures corresponding to high grade amphibolite facies metamorphism. This is also consistent with the mineral assemblages in the more mafic gneisses which have a close spatial association with the metasediments of the central belt.

Various foliated rocks, apparently derived from igneous precursors, and elongate bodies of massive tonalite, diorite and hornblendite are interlayered with, or intrude, the central belt metasediments (Fig. 2). The foliated rocks include hornblende-bearing types of acid to basic composition and more felsic rocks. The hornblende-bearing rocks contain granulated plagioclase, hornblende, biotite, quartz and epidote. The plagioclase (An_{40-60}) shows normal and oscillatory zoning. The rocks typically show a coarse gneissic banding of darker and paler layers and elongate lenticles. This banding is steeply dipping and parallel to foliation in surrounding metasediments. The paler bands and lenses are of tonalitic composition and are coarser and less granulated than the darker bands and lenticles of more mafic (gabbroic) composition. In some areas foliated hornblende-bearing rocks can be seen veining surrounding metasediments parallel to layering. They also contain metasediment rafts. Foliated felsic rocks consist of microcline, quartz, zoned oligoclase, biotite and muscovite, with accessory tourmaline, apatite and zircon. They have a granulated fabric with a foliation defined by anastomosing mica-rich bands. These rocks occur both as large mappable bodies elongate parallel to the regional foliation trends and as the aplite and pegmatite dykes and veins described above.

The presence of andalusite and cordierite and the absence of dense phases such as kyanite, staurolite, and garnet in the complex together with the narrow metamorphic zones, suggest a high geothermal gradient when the complex was forming. High geothermal gradients are typical of other early Palaeozoic metamorphic complexes in the southeastern highlands of Australia, such as the Cooma Complex, 75 kilometres to the north (Joplin, 1942; Hopwood, 1976), metamorphics at Jerangle (Hayden, 1980), and the Wagga Metamorphic Belt (Vallance, 1953). Detailed comparisons of pressure/temperature relationships in the Cambalong Complex with these other occurrences must await more detailed and careful sampling and petrographic studies on the Cambalong rocks. The apparent paucity of sillimanite at Cambalong, even in aluminous metapelites which are intimately veined with felsic igneous rocks, is something of an enigma. Original sillimanite may have been destroyed by retrograde metamorphism, which has affected most of the rocks thus far examined in thin section. Alternatively the rocks of the central belt at Cambalong may have been metamorphosed at temperatures not quite as high as those of high grade zones at Cooma and the Wagga Belt where sillimanite is more abundant.

The significance of the igneous rocks and metamorphosed igneous rocks in the complex is uncertain. The felsic rocks clearly intrude the metasediments. Aplite and pegmatite veins and perhaps also the larger dykes could represent products of partial melting of the metasediments. However, unlike the anatectic granite at Cooma (Flood and Vernon, 1978), they are relatively free of xenoliths and do not apparently contain cordierite or Al-silicates. The more mafic hornblende-bearing rocks could be

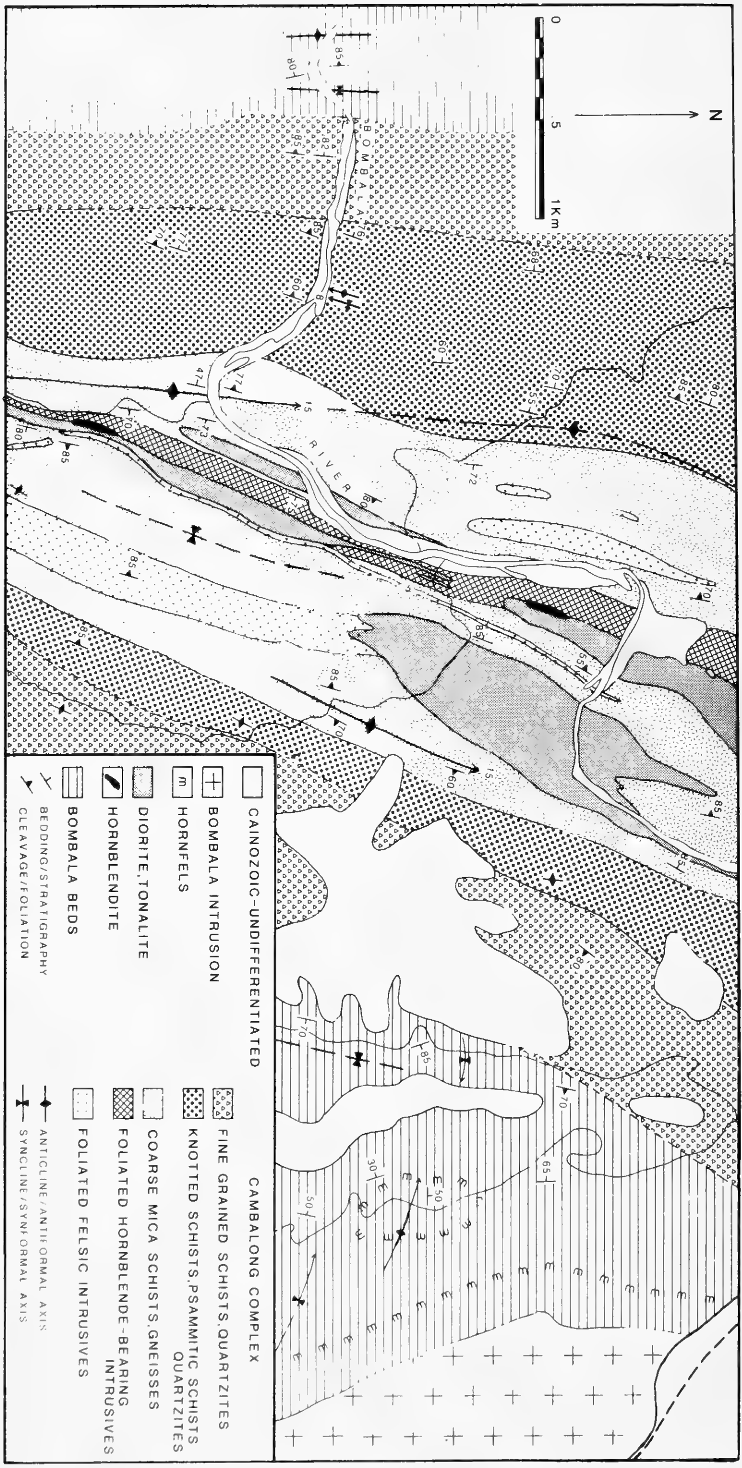

Fig. 2. Detailed geology of part of the Cambalong Complex. For locality refer to Fig. 1.

interpreted as synkinematic intrusives, emplaced during and/or soon after the main metamorphic episode, perhaps derived from more extensive areas of underlying mafic magmas. This could in turn account for the high geothermal gradient (cf. Miyashiro, 1982). They could also be interpreted as a pre-metamorphic complex of volcanics and associated intrusives at or near the base of the metasedimentary sequence. This latter interpretation would imply that the massive diorite and hornblendite bodies have largely escaped the imprint of later metamorphic events.

In the Cooma Complex, an S-type anatectic granite with associated migmatites is the major igneous component of the high grade core. More mafic hornblende-rich rocks are a very minor component, restricted to a few outcrops of amphibolite less than $1000m^2$, and xenoliths of hornblende-pyroxene granulite in the anatectic granite. Joplin (1942) interprets these as metamorphosed small gabbroic intrusives with perhaps some associated mafic volcanics, emplaced before the main metamorphic event. Hornblende-bearing xenoliths in the biotite-rich Murrumbucka Tonalite, north of the main Cooma Complex were interpreted by Snelling (1960) as being derived from the same suite of mafic rocks.

Tectonic features in the complex are best understood in the western low-grade and knotted schist zones. Here beds dip steeply west and are mostly west facing with some overturning. Structures include large sub-horizontal, steeply-inclined folds with a well-developed axial plane cleavage, steeply-plunging mesoscopic folds which affect both bedding and cleavage, and microscopic to mescopic kink folds with associated crenulation cleavage. Structures appear more complex in the central belt. Bedding and stratigraphic layering are preserved in some areas, but the dominant surface is a steeply-dipping metamorphic foliation. This shows isoclinal folding and locally contains a mineral lineation. Folded differentiated layering and a later axial plane fracture cleavage are common in some of the gneisses. Relationships between deformation and metamorphism in these higher grade rocks are currently being investigated. To the east, the complex grades rapidly into low-grade rocks which show more moderate west dips, much less penetrative deformation and some cross folding. These rocks have been intruded by largely undeformed, high-level plutons with well-developed contact metamorphic aureoles (Fig. 2). The structural relationship between these more gently dipping rocks and the metamorphic complex is not yet clear.

The Cambalong Complex is significant in that it is a regional metamorphic complex of considerable size whose possible existence was only hinted at in earlier publications and which is not shown on published regional maps. Its high-grade central core includes large areas of hornblende-bearing rocks of tonalitic, dioritic, and more mafic compositions — rock types which are poorly represented in the better known Cooma Complex to the north.

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