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PEER REVIEWED PAPERS

COSMOGENIC CHLORINE-36 EXPOSURE AGES FOR TWO BASALT FLOWS IN THE NEWER VOLCANICS PROVINCE, WESTERN VICTORIA

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STONE, J., PETERSON, J. A., FIFIELD, L. K. & CRESSWELL, R. G., 1997:12:31. Cosmogenic chlorine-36 exposure ages for two basalt flows in the Newer Volcanics Province, western Victoria. *Proceedings of the Royal Society of Victoria* 109(2): 121–131. ISSN 0035-9211.

An exposure dating method based on the accumulation of cosmic-ray-produced ^{36}Cl has been applied to samples from the Newer Volcanics Province of western Victoria. Cosmogenic ^{36}Cl concentrations indicate exposure ages of approximately 32 kyr BP for the Harman Valley basalt flow from Mt Napier and 59 kyr BP for the basanite ring barrier at Mt Porndon. The results extend the chronology of volcanism at these sites back in time beyond minimum age limits so far obtained from ^{14}C dating of overlying peat deposits. The older ages imply slower rates of soil development on basalt and for re-establishment of drainage systems disrupted by eruptions, and suggest that both processes may also have been influenced by colder and more arid Late Pleistocene climatic conditions. Exposure dating complements dating methods based on soil maturity and ^{14}C and may be applied to good effect on other young volcanic rocks in eastern Australia. In particular, there is scope for dating material either too old to be dated with ^{14}C or lacking associated carbonaceous material, yet too young to be dated with the ^{40}K–^{40}Ar or ^{40}Ar–^{39}Ar methods.

DATING RECENT VOLCANIC ERUPTIONS—EXPERIENCE FROM WESTERN VICTORIA

The difficulties of dating young lavas and volcanic landforms are well known. The geochronological techniques most commonly applied, the radiocarbon and K–Ar/Ar–Ar methods, are not ideally suited to dating volcanic rocks in the 0–100 kyr age range.

The radiocarbon method cannot be used to date volcanic rocks directly. Instead, age constraints must be obtained from stratigraphically related carbon-bearing deposits such as buried soils, lake and river sediments overridden by lava, basal sediments in lakes and swamps dammed by ash or lava, and burned trees. Ages obtained from materials such as these provide only limiting constraints, that may bracket actual eruption ages very loosely. The demonstrated age limit for radiocarbon dating is ~50–60 kyr (*c.* 10 half-lives), a consequence of contamination in sample preparation and limits to measurement efficiency. Moreover, samples of this age and older are commonly found to give apparent ages as low as 30–40 kyr unless stringent care is taken to remove material contaminated by small amounts of younger carbon. Contamination with 'old' carbon is also possible, as in the case of hard water effects, and can also lead to incorrect age estimates.

There has been a long history of attempts to date the youngest volcanic landforms of the Newer Volcanics Province in western Victoria using the ^{14}C method. Gill and co-workers produced age estimates for two of the youngest volcanic features, Mt Eccles and Mt Napier, and their associated basalt lava flows. They obtained minimum limiting ages for the lavas by dating basal peat in Condah Swamp and Buckley's Swamp, drainage basins formed when lava dammed antecedent water-courses (Figs 1, 2). Ages of 6325±120 yr BP and 7240±140 yr BP were obtained for Mt Eccles and Mt Napier respectively (Gill & Gibbons 1969; Gill & Elmore 1973). As minimum limits, these have since proved to be far from close bounds. In a more recent study, Head et al. (1991) obtained minimum limiting dates of 26 240±480 yr BP and 27 510±240 yr BP from lake muds and underlying peat in Condah Swamp and Whittlebury Swamp, both dammed by the Mt Eccles flow. The difference between the two sets of limiting dates, obtained on similar materials from similar stratigraphic contexts can only be ascribed to diachronous onset of sedimentation across the irregular floors of the swamps. Sedi-

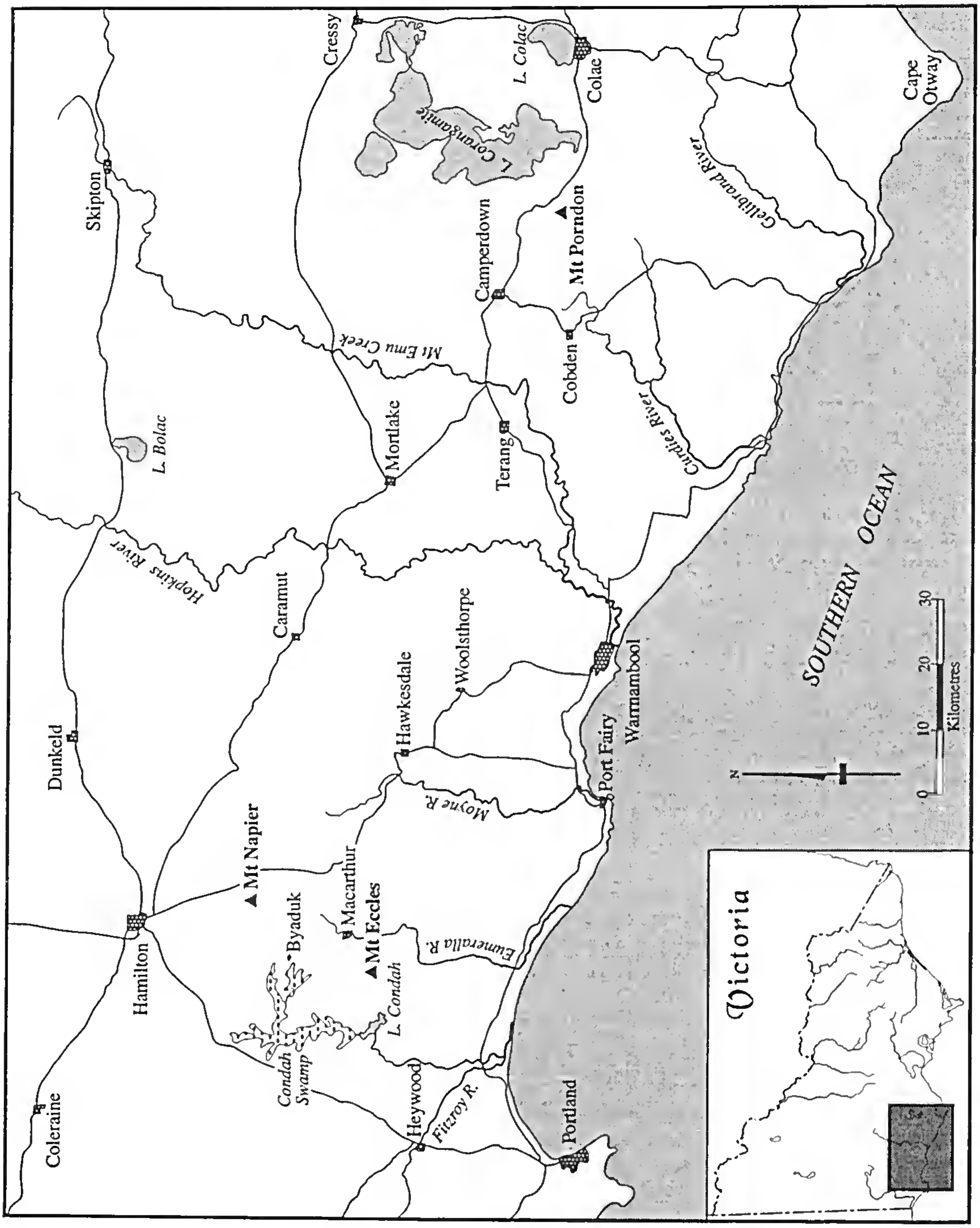

Fig. 1. Location map of western Victoria, showing field sites.

ment thicknesses are reported to vary by more than 4 m in the swamps surrounding Mt Eccles, and it must be assumed that Gill and co-workers were unfortunate in choosing to sample areas of comparatively recent sediment accumulation.

Peat near the northern margin of Condah Swamp is reported by Ollier (1981) to overlie the Harman Valley basalt from Mt Napier (Fig. 2). If this deposit is contemporaneous with the *c.* 27 kyr BP basal peats dated by Head et al., the Harman Valley basalt flow must also be older than 27 kyr BP. It is possible, however, that the onset of sedimentation following damming of the valley was delayed at this site too and that this peat is much younger than the flow which it overlies.

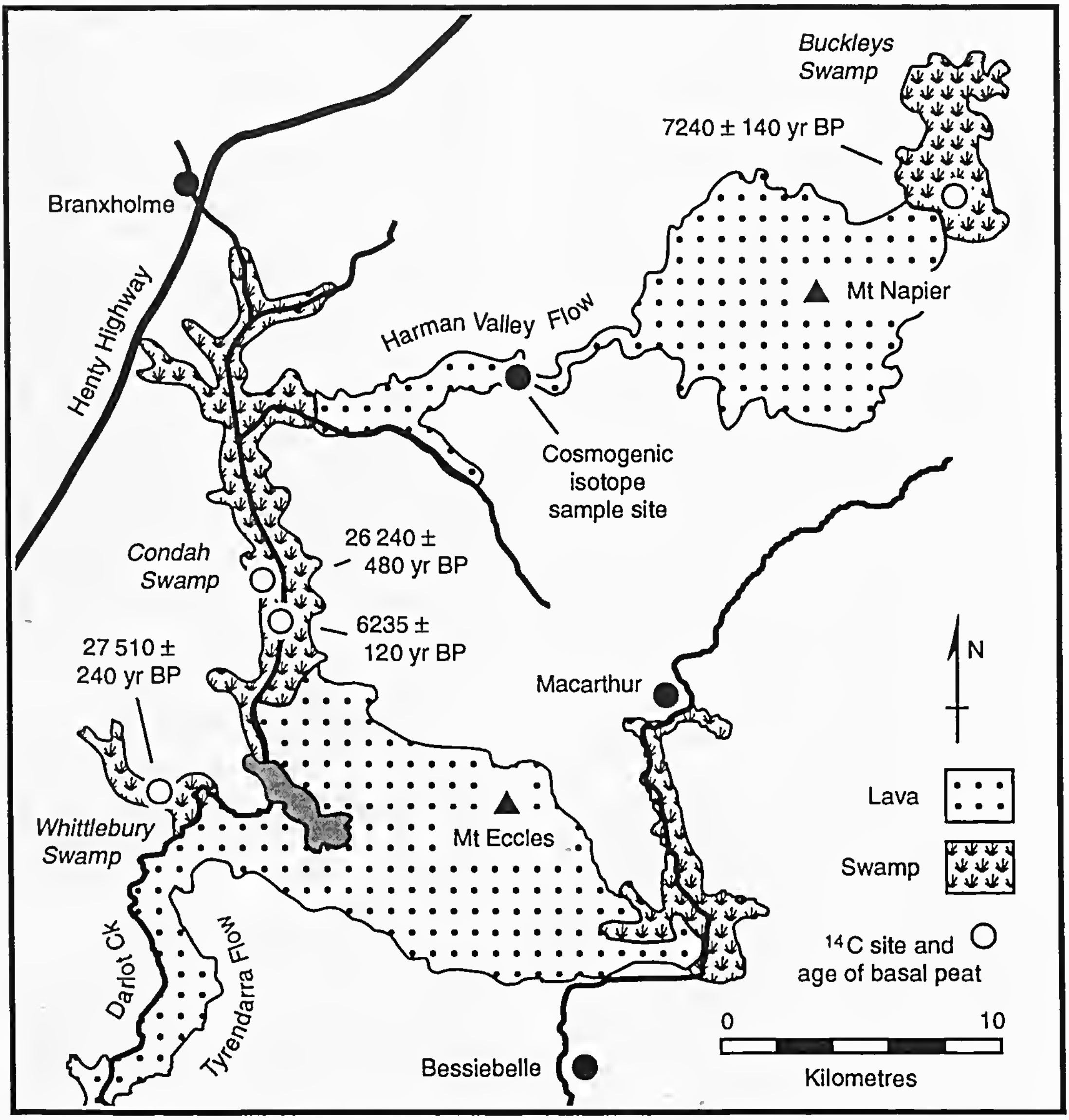

Fig. 2. Detailed site map of Mt Napier and Mt Eccles, showing sample site and sites of cores taken in previous studies for radiocarbon dating.

The 'old' ages obtained by Head et al. are in broad agreement with a very imprecise age of 28^{+21}_{-4} kyr BP for carbonaceous matter in soil beneath scoria from Mt Eccles (Ollier 1981), a maximum limiting age for this eruption. A final, unresolved puzzle in the radiocarbon story is an age of 19.3 kyr BP for wood recovered from fluvial gravels beneath the Tyrendarra lava flow from Mt Eccles (Gill 1979) (Fig. 2). This should represent a maximum age bracket for the Tyrendarra flow and thus conflicts with the 25–27 kyr BP minimum limits referred to above. Although the Tyrendarra flow is known to extend out to sea (and must therefore have been erupted at a time of lower sea-level; Gill 1979) the existence of a gravel bed-load stream at 19 kyr BP and the occurrence of wood in its gravels present a palaeoenvironmental puzzle which casts some doubt on the accuracy of this date. Environmental reconstructions for this period of peak glacial-stage conditions suggest a cold arid climate with lower streamflow than present, and a predominantly grassland vegetation with less tree cover from which the dated wood might have been derived (D'Costa et al. 1989). Whatever the resolution of the conflicting results, the difficulty of establishing consistent and closely-bracketing age constraints on volcanic landforms with the radiocarbon method is evident. This point is further emphasised by the lack of radiocarbon age control on the lava flow at Mt Porndon, the second site selected for study in this work.

The ^{40}K–^{40}Ar and ^{40}Ar–^{39}Ar methods have the advantage over the ^{14}C method of being directly applicable to volcanic rocks. However, there are a number of well-known problems in applying them to basalts in the ~10^4–10^5 yr age range, and few attempts have been made to use them to date the youngest lavas of the Newer Volcanics. Difficulties in dating very young lavas with K–Ar techniques stem from the minute amounts of radiogenic ^{40}Ar produced in such short time-spans. Even in alkali basalts such as those of Mt Porndon and Mt Napier, with K_2O contents of 1.2–1.3%, the amount of radiogenic ^{40}Ar produced in 10^4 years, ~10^8 atoms per gram, is likely to be small compared to the amount of atmospheric ^{40}Ar trapped by the basalt during eruption. Radiogenic ^{40}Ar may only amount to a few per cent of the total ^{40}Ar released from such samples during isotopic analysis. Quantifying such small amounts of radiogenic ^{40}Ar to obtain accurate age estimates requires accurate subtraction of the overwhelming non-radiogenic background. Moreover, simple subtraction procedures cease to be valid if the background component is isotopically fractionated, or if phenocrysts or xenocrysts containing an additional ^{40}Ar-rich mantle-derived component are present in the sample. Thus, although the ^{40}K–^{40}Ar and ^{40}Ar–^{39}Ar methods almost entirely underpin the chronology of the older lavas in the Newer Volcanics Province (McDougall et al. 1966; McDougall & Gill 1975), there has been little success in applying them to the youngest flows. For example, samples of olivine basalt from Mt Porndon analysed by Henley & Webb (1990) gave very low radiogenic and very high atmospheric Ar components, with apparent ages of 0.3±0.6 Myr and 0.26±0.6 Myr, to which the authors ascribed little chronological significance.

Several other dating methods can be applied to young volcanic landforms. Luminescence techniques (thermoluminescence and optically-stimulated luminescence) have been successfully applied to soils baked when over-run by lava, and to quartz in sub-volcanic sediments. Provided well-bleached sub-volcanic material is sampled, luminescence techniques can give direct age estimates for volcanic events. For example, Smith & Prescott (1987) obtained a thermoluminescence age of 4.9±0.5 kyr BP for baked dune sand over-run by basalt at Mt Schank. This result provides much tighter age control on the eruption of Mt Schank than a limiting radiocarbon date of 18.1 kyr BP on underlying charcoal (Polach et al. 1978) and marks what is likely to be the youngest activity in the Newer Volcanics Province. Another, even more direct dating technique which can be applied is surface exposure dating, based on the accumulation of rare, cosmic-ray-produced isotopes in volcanic rock surfaces.

EXPOSURE DATING WITH COSMOGENIC RADIOISOTOPES

Rock freshly exposed at the earth's surface begins to accumulate cosmic-ray-produced radionuclides such as ^{36}Cl, ^{26}Al and ^{10}Be, whose abundances can be used as the basis of an exposure dating method. The penetration depth of the radiation producing these nuclides is a few metres, hence lavas, extruded onto the earth's surface from much greater depths, arrive with initial isotopic concentrations essentially equal to zero. With this simplification, exposure ages can be determined by comparing cosmogenic nuclide concentrations to their production rates. Accumulation is described by the equation:

$$N = {}^{P}/_{\lambda}(1-e^{-\lambda t}) \tag{1}$$

where N is the abundance of the radioisotope (^{36}Cl in the cases described below), P its production rate, λ the decay constant and t the exposure age. Provided P and λ are known and N measured, the exposure age can be calculated directly. For equation (1) to be valid, the surface must have been continuously exposed in a stable orientation, without erosion, throughout the exposure period. In the case of basalt lavas, the preservation of glassy selvedges, pahoehoe and other distinctive textures can be used to identify surfaces which have suffered negligible erosion. Care must be taken, however, to ensure that these features mark the topmost surface of a flow and have not been uncovered from beneath overlying flow sheets. Likewise, the possibility of cover by younger soil or sediment, especially volcanic ash, must always be evaluated, because any cover of the sample surface in the past will have reduced the cosmic ray flux reaching it. To obtain accurate exposure ages, isotope production rates must also be known. Current calibrations are largely based on cosmogenic isotope measurements on independently dated surfaces (e.g. Nishiizumi et al. 1989; Cerling 1990; Kurz et al. 1990; Zreda et al. 1991; Stone et al. 1996). Details of the cosmic ray reactions responsible for ^{36}Cl production and their calibration are discussed in the Results section below.

Cosmogenic isotope methods have already been widely applied to dating basalts. The first measurements of terrestrial cosmogenic ^{3}He were made on Hawaiian lavas (Craig & Poreda 1986; Kurz 1986) and basalts have since been used extensively in calibrating ^{3}He, ^{21}Ne and ^{36}Cl production rates (e.g. Cerling 1990; Zreda et al. 1991; Poreda & Cerling 1992). Cosmogenic nuclide measurements on basalts have also been used to assess volcanic hazards (Zreda et al. 1993) and date catastrophic floods (Cerling 1990). To illustrate the potential of these methods for dating young Australian basalts and resolving ambiguous age estimates from ^{14}C dating, we present below exposure age estimates for two lavas of the Newer Volcanics Province in western Victoria.

SAMPLING AND METHODS

Sample sites

Samples were collected from the basalt ring barrier surrounding the Mt Porndon cinder cone near Colac and the Harman Valley flow from Mt Napier, south of Hamilton (Fig. 1). At Mt Porndon, a sample was collected from a high point on the crest of the western segment of the basaltic ring barrier surrounding the cinder cone (Fig. 3). The ring crest at the sample site rises steeply some 20 m above subdued stony rises on its outer side and a collapsed lava disc, partly overlain by scoria, on its inner side. Except in a few places on the eastern rim where the crest is mantled by cinders or overrun by small flows, the ring barrier consists of fresh, deeply-jointed outcrop with no regolith mantle. The steep flanks of the sample site would have ensured that any ash deposited on the top surface would have been shed rapidly. Although the Mt Porndon basalt is known to post-date both the Purrumbete maar eruption and early sediments in Lake Corangamite (Ollier & Joyce 1986), there are no precise numerical age constraints on its eruption. Ollier & Joyce (1986) assigned it to the Eccles regolith-terrain unit, for which they estimated an age younger than 100 kyr BP. It is clearly younger than surrounding, subdued, soil-covered (and cleared) stony rise country—the Rouse regolith-terrain unit of Ollier & Joyce (1986), broadly equivalent to the the Girringurrup Land System of Gibbons & Downes (1964). The age of this older landscape unit is estimated at between 0.3 and 2 Myr based on the K–Ar ages of McDougall & Gill (1975) and Ollier (1985), and is a loose upper limit to the age expected from exposure dating of the Mt Porndon basalt.

A second sample was collected from the Harman Valley flow, derived from Mt Napier (440 m). The sample was collected from the top of a regolith-free tumulus on the flow. As for the sample from Mt Porndon, it was collected from a surface judged likely to have rapidly shed any ash cover from subsequent eruptive activity. The series of events that formed the Mt Napier volcanic complex (see, for example, Whitehead 1991) disrupted local drainage to produce Buckley's Swamp, a ~30 km^{2} area upstream of the complex, and small swamps downstream where tributaries were blocked by the Harman Valley flow. If peat described by Ollier (1981) as overlying the Harman Valley flow is contemporaneous with basal peat in Condah Swamp to the south (Fig. 2), the ^{14}C age of 26.2±0.5 kyr BP obtained in Condah Swamp would provide a minimum age limit for the sample analysed here. However, it is also possible that peat overlying the Harman Valley flow is substantially younger than the basal deposits in Condah Swamp and places no strong constraint on the relative ages of the Mt Eccles and Mt Napier eruptions. Cosmogenic isotope methods may be useful in dating the full sequence of events in the area in future.

Both samples consist of frothy vesicular basalt with surface textures judged to indicate negligible erosion. Details of the sample locations, including latitude and altitude, which influence the intensity of the cosmic ray flux, and sample thicknesses, which determine cosmic ray attenuation and hence isotope production rates, are given in Table 1.

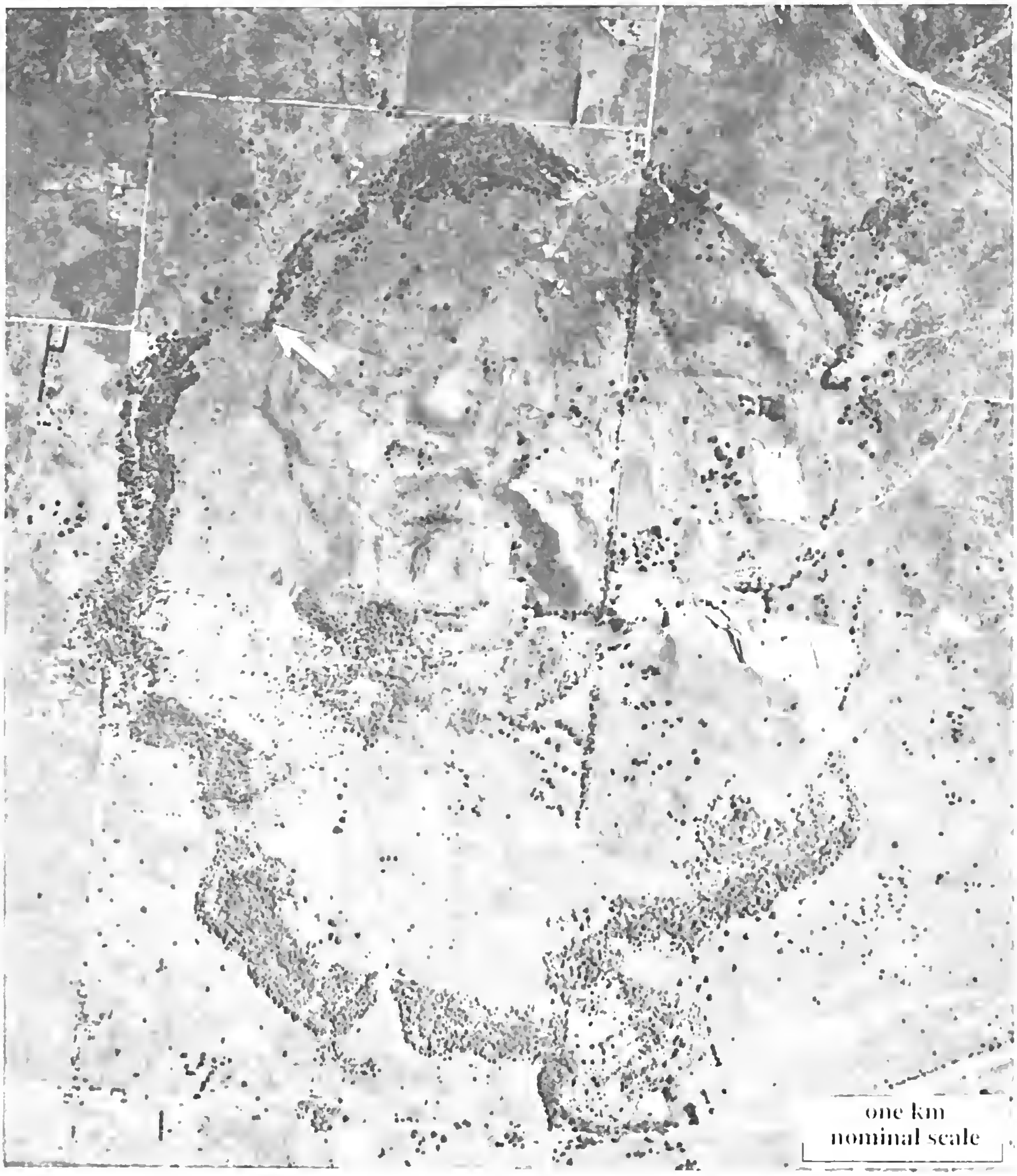

Fig. 3. Sample site and basaltic ring barrier at Mt Porndon. From a black-and-white vertical air photo (Heytesbury North Project, Run 3, 23 November 1969) reproduced by kind permission of Land Victoria, 1997.

Site	Latitude	Effective geomagnetic latitude^A	Longitude	Altitude (m)	Thickness (cm)/(g cm^{-2})
Mt Napier	37°55′S	42°45′S (0–32 kyr)	141°55′E	85 m	5.0/13.5
Mt Porndon	37°19′S	42°35′S (0–59 kyr)	143°16′30″E	190 m	5.5/15

Table 1. Site and sample details. ^{A}Latitude at which geomagnetic shielding of the cosmic ray flux equals the time-averaged shielding at the sample site. Chlorine-36 production rates have been scaled with respect to this latitude to correct for variation of the geomagnetic dipole strength during the sample exposure period (see text).

Chlorine-36 analyses

The method used to extract and purify chloride from the samples is described by Stone et al. (1996). Prior to extraction, the crushed samples were leached twice in hot 2% HNO_3 and rinsed thoroughly to remove secondary carbonate and all traces of meteoric chloride and ^{36}Cl contamination. Isotopic analysis of ^{36}Cl was performed by accelerator mass spectrometry (AMS), using the ANU 14 UD Pelletron (Fifield et al. 1990, 1994). Chloride was measured on the samples by ion chromatography after pyrohydrolytic extraction (Evans et al. 1981). Major element concentrations were measured by X-ray fluorescence. Trace neutron-producing and absorbing elements (U, Th, Gd, Sm, B) were measured by ICP-MS. A blank processed in parallel with the samples, using the same amount (~1.15 mg) of ^{36}Cl-free carrier and identical chemical procedures, was found to contain 2±1×10^4 atoms ^{36}Cl, negligible in comparison to the 2–5×10^6 atoms ^{36}Cl extracted from the samples.

	Mt Napier	Mt Porndon
Major elements (% wt)		
SiO_2	51.3	50.3
TiO_2	2.27	2.26
Al_2O_3	15.4	14.8
Fe_2O_3^{A}	9.29	10.4
MnO	0.11	0.12
MgO	6.54	8.43
CaO	9.68	8.94
Na_2O	3.87	3.68
K_2O	1.23	1.29
P_2O_5	0.10	0.03
H_2O	0.5	0.5
CO_2	0.0	0.0
Cl	16±3 ppm	26±5 ppm
Trace neutron producers and absorbers (ppm)		
B	10±2	10±2
Gd	6±2	10±2
Sm	6±2	10±2
U	0.3±0.2	0.3±0.2
Th	1.0±0.5	1.0±0.5

Table 2. Chemical composition of samples. ^{A}Total Fe as Fe_2O_3.

RESULTS

Chlorine-36 concentrations for the two samples and details of their target chemistry and neutron absorption properties are given in Table 2. In whole-rock samples such as these, ^{36}Cl is produced by high energy cosmic ray spallation reactions with K and Ca, capture of cosmic ray-produced secondary neutrons by ^{35}Cl, and to a small degree, by reactions involving cosmic-ray muons. To derive age estimates from the ^{36}Cl concentrations in Table 2, local production rates for these reactions are required. For high energy spallation reactions on Ca and K, we adopt the calibrations of Stone et al. (1996) and Evans et al. (1997) respectively. Production by thermal neutron capture on ^{35}Cl is based on the treatment of Liu et al. (1994), as calibrated by Phillips et al. (1996). A small fraction of the total ^{36}Cl production in the samples is due to negative muon capture by Ca and K isotopes. For the Ca reaction, we adopt the rate given by Stone et al. (1997). The analogous contribution from K has not yet been calibrated independently, and is taken as 5% of the total ^{36}Cl production from K at sea level, in keeping with the assumption used by Evans et al. (1997) when calibrating the K spallation rate. The accuracy of this assumption has a negligible effect (less than ±1%) on the calculated ages. The calibrations referred to above apply to production by the cosmic ray flux at sea level and latitudes >50°. Rates have been scaled to the altitude and latitude of the sample sites in Victoria using the procedures given by Lal (1991), and then corrected for variations in the cosmic ray flux due to changing geomagnetic dipole strength during exposure, as discussed below. Small corrections

	Mt Napier	Mt Porndon	
[^{36}Cl]	1.87±0.12×10^{5}	3.70±0.25×10^{5}	(atom/g)
$P_{\mathrm{Ca\ Spallation}}$	3.35±0.12	3.40±0.12	(atom/g/yr)
$P_{\mathrm{K\ Spallation}}$	1.82±0.12	2.10±0.14	(atom/g/yr)
$P_{\mathrm{Ca(\mu^-,\alpha)^{36}Cl}}$	0.32±0.06	0.31±0.06	(atom/g/yr)
$P_{\mathrm{^{39}K(\mu^-,p2n)^{36}Cl}}$	0.09±0.03	0.10±0.03	(atom/g/yr)
$P_{\mathrm{^{35}Cl(n,\gamma)^{36}Cl}}$ (thermal neutrons)	0.40±0.10	0.66±0.16	(atom/g/yr)
$P_{\mathrm{^{35}Cl(n,\gamma)^{36}Cl}}$ (epithermal neutrons)	0.09±0.02	0.15±0.03	(atom/g/yr)
P_{Total}	6.09±0.21	6.75±0.25	(atom/g/yr)
Altitude/Latitude scaling (spallation)[A]	1.04	1.14	
Altitude/Latitude scaling (muon reactions)[A]	1.00	1.05	
Thickness correction (spallation)[B]	0.96	0.96	
Thickness correction (thermal neutrons)[B]	1.32	1.32	
Thickness correction (epithermal neutrons)[B]	1.06	1.07	
Best estimate exposure age (including geomagnetic corrections)	31.9±2.4	58.5±5.0	(kyr)
Exposure age (uncorrected for magnetic variation)	33.6	62.3	(kyr)
Exposure age (Phillips/Liu production rates)	27.2±2.3	50.8±4.5	(kyr)

Table 3. Exposure dating results. [A]Scaling factors (relative to production rate at sea level and latitude >60°) calculated with respect to the effective geomagnetic latitude of the sample sites. Scaling factors with respect to geographic latitude of the sample sites are 0.99 and 1.08 for production by spallation at Mt Napier and Mt Porndon, respectively, and 0.95 and 0.99 for production by muons. [B]Production rate relative to 2Π, thin surface exposure.

have also been included to take account of cosmic ray attenuation within the 5–6 cm thick samples and to allow for disequilibrium between neutron production and absorption at the outcrop surfaces (Liu et al. 1994). Because both samples were collected from high-standing features above relatively flat horizons, no corrections are required for obstruction of the incoming cosmic-ray flux. The fully corrected production rates for the samples, P in equation 1, are given in Table 3.

With these values, equation 1 gives an age of 32±3 kyr BP for the Harman Valley lava, and 59±5 kyr BP for the Mt Porndon ring barrier (Table 3). The uncertainties in these ages reflect both the statistical precision of the AMS measurements (±5–7%) and remaining uncertainty in the calibration of the various ^{36}Cl production rates (±5–15%). An alternative set of values for the surface production rates of ^{36}Cl from Ca and K has been given by Phillips et al. (1996). These authors obtained a higher production rate from Ca and a lower rate from K than those underlying the rates shown in Table 3. Adopting the values of Phillips et al. (1996) gives slightly younger ages for the samples, which for completeness at this stage in our understanding of cosmogenic isotope production are also listed in Table 3. The two sets of ages calculated differ by 13–15%, which, though greater than the analytical uncertainties, is less than the discrepancies between the calibrations. Because the production rate from Ca estimated by Phillips et al. is higher, and that from K lower, than the rates used here, the discrepancies tend to cancel when applied to whole-rock samples containing both elements.

The ages have been calculated to allow for past changes in the earth's geomagnetic field intensity, which modulates the cosmic ray flux at low to mid latitudes (cf. Clark et al. 1995). At times of high dipole field strength, the cosmic ray flux decreases at these latitudes. Conversely, at times of low strength, a greater fraction of the primary cosmic ray flux reaches the atmosphere. (Similar changes occur through the 11-year solar cycle, but are well averaged over thousand-year calibration and sample exposures.) At the latitude of the sites in western Victoria, the ^{36}Cl production rate is likely to have varied by up to +12% and −10% relative to its present value for short periods in the past ~100 kyr, assuming the geomagnetic intensity record of Meynadier et al. (1992). The effect on time-averaged ^{36}Cl production is considerably smaller, due to the integrating nature of cosmogenic isotope build-up and the compensating effect of oscillations between high and low field intensity. To correct for changes in the cosmic ray flux we have used the method of Nishiizumi et al. (1989) to determine effective geomagnetic latitudes for the sites (i.e. latitude in the present field where the cosmic ray flux equals the time-average received at the sample site; see also Clark et al. 1995). Noting that the production rates of Stone et al. (1996) and Evans et al. (1997) are calculated with allowance for geomagnetic changes, we believe that the magnetically corrected results in Table 3 give the most accurate estimates of exposure age for the samples. These ages (31.9 and 58.5 kyr BP) are younger than the uncorrected estimates shown in Table 3, reflecting the fact that the dipole field strength averaged over the past 30–70 kyr BP was lower, and the cosmic ray flux higher, than at present.

The ages obtained for the basalts are consistent with existing, broad age constraints. The cosmogenic isotope age for the Harman Valley flow is older than the oldest radiocarbon age of 26 240± 480 yr BP obtained from basal peat in Condah Swamp (Head et al. 1991), which is consistent with the suggestion that deposits resulting from the damming of Condah Swamp overlie the Harman Valley basalt. If so, then a reasonably tight age bracket is obtained for the main eruption of Mt Eccles that blocked Darlot Creek to produce Condah Swamp. The timespan separating the Harman Valley eruption and the damming of Condah Swamp (bracketing the Mt Eccles eruption) would be less than the 6000 year apparent difference between the cosmic ray exposure age and radiocarbon age, because of the propagation of atmospheric Δ^{14}C variations into radiocarbon age estimates. Around 30 kyr BP, Mazaud et al. (1991) calculate that uncalibrated radiocarbon ages will underestimate true ages by ~2 kyr and Bard et al. (1990) present data indicating an offset of 2–3 kyr. This would place the eruption of the Mt Eccles basalt between the calibrated ^{14}C age of ~28 kyr BP and the ^{36}Cl age of the Harman Valley flow, 32 kyr BP. The age obtained for Mt Porndon is younger than, hence consistent with, the 100 kyr age limit suggested by Ollier & Joyce (1986) for the Eccles regolith-terrain unit and significantly younger than age estimates for the stony rise country which it overruns.

DISCUSSION

The exposure ages obtained in this study confirm the impression conveyed by ^{14}C re-dating in the Newer Volcanics Province (Head et al. 1991), that the youngest events in the province are significantly older than was originally believed. This follows a similar reappraisal of the age of phreatomagmatic activity at Mt Gambier, where an interpreted ^{14}C age of ~4.3 kyr BP (Blackburn et al. 1982) has been revised upwards to greater than 28 kyr BP (Leaney et al. 1995). The age revisions in the Western District have implications for the interrelationship between lavas and drainage patterns, the soils/weathering relative chronology for land surfaces in the region and for the study of past environments and human occupation.

The overall pattern of landscape evolution in the Newer Volcanics province shows many examples of lavas disrupting drainage (e.g. Ollier 1985). Many of the earlier episodes have been overcome and drainage re-established after millions of years of weathering. The effects around Mt Napier and Mt Eccles, involving lava damming and the creation of numerous swamps and lakes, remain prominent after ~30 kyr. On these flows, and in the older 'stony rise' landscapes into which they are set, drainage remains largely internal and broad-scale topographic control has not yet been re-established. Now that it is apparent that both the Mt Eccles and Mt Napier flows date back to ~30 kyr BP, the limited degree of drainage development can also be attributed to more arid climatic conditions that prevailed in the region from at least 20 kyr BP through to 11.5 kyr BP (D'Costa et al. 1989).

Time constraints on soil development in the district can also now be refined. Both the Napier and Mt Porndon basalt surfaces remain fresh and essentially soil-free, compared to a limited degradation of stony rises and infilling of hollows by weakly developed stony loam soils on surrounding land surfaces. The ~60 kyr BP age for the Mt Porndon lava demonstrates that the absence of soil development is not a consequence of an extremely young substrate, as would have been inferred when it was believed that the youngest flow surfaces in the district were Holocene in age (Gill & Gibbons 1969).

An additional conclusion that can be drawn from the ages now established for the Mt Napier and Mt Porndon eruptions is that the limited evidence for pre-late Holocene human occupation (e.g. Ross 1985) and the evidence for intensification of human activities in the district in the late Holocene (e.g. Lourandos 1983) cannot be attributed to volcanic activity.

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A MID-LATE HOLOCENE VEGETATION RECORD FROM AN INTERDUNAL SWAMP, MORNINGTON PENINSULA, VICTORIA

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JENKINS, M. A. & KERSHAW, A. P., 1997:12:31. A mid-late Holocene vegetation record from an interdunal swamp, Mornington Peninsula, Victoria. *Proceedings of the Royal Society of Victoria* 109(2): 133–148. ISSN 0035-9211.

Palynological analysis of swamp sediments from an interdunal swale provides a vegetation and environmental history from *c.* 4500 years BP to present. Although essentially the same vegetation communities of the site and surrounding area are recorded through the period, their distributions have changed due to regional climatic variation and human influence, particularly the impact of European land settlement. Changes in aquatic plant assemblages are related to localised fluctuations in the hydrological regime. *Melaleuca* and Cyperaceae have persisted as dominant taxa, with the hydrophyte *Villarsia* increasing in importance with a change from ephemeral swamp conditions to semi-permanent water about 1500 years ago. Disturbance to the hydrological regime in the European settlement phase has seen the proliferation of the aquatic herb *Myriophyllum* and increases in Restionaceae and *Melaleuca* as previously swamp margin communities expanded over the wetland. A *Eucalyptus* woodland with an open heath understorey characterised the dryland vegetation. *Allocasuarina* was a significant component of the regional vegetation. Increased plant diversity of the woodland understorey and an expansion of wetter forest elements were recorded after 3200 BP, probably due to an increase in climatic variability and associated higher burning levels, both natural and anthropogenic, and generally higher rainfall, respectively. Marked changes in the dryland record, which include a sharp decline in *Allocasuarina* percentages, the introduction of *Pinus* and exotic herbs, as well as an increase in the density of the shrub layer, are associated with European settlement and possibly alteration to fire regimes.

POLLEN preserved in swamp sediments provides a record of past vegetation and environmental change. A body of evidence from a range of palynological studies (see Dodson et al. 1992; Kershaw 1992, 1995) has provided a history of late Quaternary vegetation and climate for the Victorian region. Although major trends in environmental change between sites are similar, details of vegetation and climatic interactions reflect the range of topographic, geological and other local variables represented. The pollen analysis of accumulated swamp sediments from a wetland within Greens Bush on the Southern Mornington Peninsula, Victoria, details changes in vegetation during the mid to late Holocene and provides further evidence for regional variation in Victorian palaeoenvironments including that associated with the impact of human settlement.

THE STUDY AREA

Greens Bush (38°25′S,144°52′E) is part of Point Nepean National Park located about 75 km south of Melbourne. It is a 900 ha bushland remnant, 9 km south of Arthur's Seat on the Mornington Peninsula, Victoria (Fig. 1).

The climate of the study area is temperate with a maritime influence. Estimates from the climatic prediction system BIOCLIM (Busby 1991) indicate that Greens Bush receives an annual mean rainfall of 895 mm of which 273 mm falls in the winter quarter and 161 mm in the summer quarter. The annual mean temperature is about 13.4°C, with a mean minimum temperature in the coldest month of 5.4°C and a mean maximum temperature in the warmest month of 24.4°C. As with other Victorian coastal sites, westerly winds predominate and mean monthly wind speed varies from 10 to 30 km $hour^{-1}$. Relative humidity is moderately high throughout the year and ranges between 70–84% (Seaheti & Scott 1986).

Greens Bush lies approximately 120 m above sea level on an undulating topography of subdued siliceous dunes derived from Pleistocene calcarenite (Keble 1968). The soils are sandy podzols with humic podzols in low-lying areas.

The regional vegetation of the Mornington Peninsula has been described by Calder (1972, 1986). *Allocasaurina verticillata–Melaleuca lanceolata* woodland was the major association on the calcareous sands west of the study site. However, during the mid-Nineteenth Century timber cutters and limeburners depleted this community (Calder 1986). The *A. verticillata* community has been largely replaced by *Leptospermum laevigatum* scrub. Eucalypt woodland and heathland are dominant on the siliceous sands whereas open eucalypt forest characterises the heavier soils of the region. Wet sclerophyll forest is associated with the moist gullies and creek lines (Conn 1993).

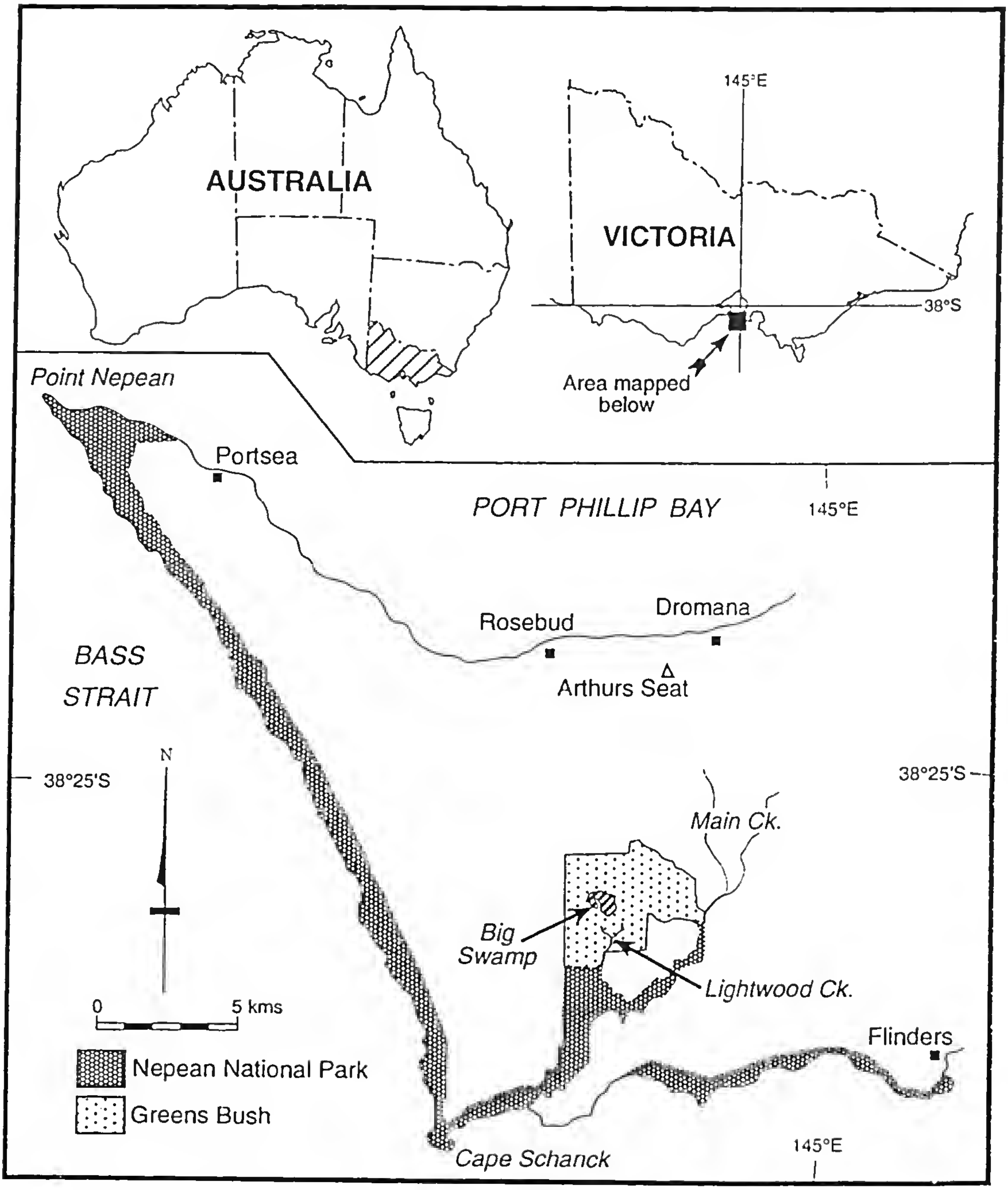


Fig. 1. The location of the study area.

In areas of poor drainage *Melaleuca squarrosa* scrub occurs. Calcarenite cliffs and unconsolidated coastal dunes between Cape Schanck and Point Nepean support a coastal flora which includes *Ozothamnus turbinatus*, *Leucopogon parviflorus*, *Alyxia buxifolia* and chenopods such as *Rhagodia candolleana* (Scaheti & Scott 1986; Barson & Calder 1981).

The vegetation of Greens Bush comprises heathland, woodland, forest, scrubs and swamps (Parr-Smith & Smith 1978). Heathland occurs on the drier sand dune crests and is dominated by *Xanthorrhoea australis*, *Leptospermum myrsinoides*, *Banksia marginata*, *Hypoleana fastigiata*, *Epacris impressa* and Fabaceae such as *Dillwynia glaberrima* and *Aotus ericoides*. Woodland communities are found on the sandy ridges and slopes. The woodland communities comprise a canopy of *Eucalyptus obliqua* with a heathy understorey of *Monotoca scoparia*, *Amperea xiphoclada*, *Leptospermum myrsinoides* and *Pteridium esculentum*. The heathland and woodland communities have affinities with *Leptospermum myrsinoides* heathland (WPC 8.3) described by Opie et al. (1984) and Conn (1993), sand heathland (LCC 1991) and tea-tree heath described by Cheal et al (1989) . The presence of *Xanthorrhoea australis* is a distinctive component of the Greens Bush communities. Forest units have a mixed canopy of *Eucalyptus obliqua* and *Eucalyptus radiata* with a lower stratum comprising *Acrotriche serrulata*, grasses such as *Poa labillardieri* and the herbs *Viola hederacea*, *Hydrocotyle hirta* and *Gonocarpus tetragynus*. Forest units are scattered on gentle, well drained slopes. In the incised valleys of Lightwood and Main creeks, wet sclerophyll communities are found. The community is characterised by a canopy of *Eucalyptus viminalis* and *Eucalyptus obliqua*, a mid-stratum of *Prostanthera lasianthos*, *Acacia melanoxylon*, *Olearia argophylla* and *Pomaderris aspera*, with the ferns *Dicksonia antarctica*, *Calochlaena dubia* and *Blechnum nudum* present in the lower stratum (Conn 1993). The wet sclerophyll community has some affinities to wet sclerophyll forest (Mel 9.2, 9.3) described by Cheal et al. (1989). In waterlogged sites a *Melaleuca squarrosa* scrub dominates over a closed layer of *Gleichenia microphylla* and the rush *Empodisma minus*. In areas of seasonally poor drainage, small remnants of wet heathland persist and comprise species such as *Sprengelia incarnata*, *Epacris obtusifolia* and *Allocasuarina paludosa*. Interdunal swamps are seasonally inundated and dominated by sedges such as *Lepidosperma longitudinale* and *Baumea rubiginosa*. In locations where sufficient water exists throughout the year, the swamps contain a suite of semi-aquatic species and often exhibit distinct zonation. The swamp communities of Greens Bush have close affinities to swamp sedgeland (WPC 14.2, 14.3) described by Opie et al. (1984), the Land Conservation Council (1991) and Conn (1993).

Greens Bush is a conservation area of significant ecological importance. With only 14% of the Peninsula supporting natural vegetation, about half in viable remnants, Greens Bush represents one of six remaining larger reserves. Several of the plant communities of Greens Bush are regionally rare, especially the swamp and wet sclerophyll communities. The swamp communities are reported to be of high ecological and conservation value (Larwill & Costello 1992). Similar swamp communities found in the Westernport Region are considered rare (Opie et al. 1984). Calder (1986) concluded the wet sclerophyll forests of the Peninsula, including those found in Greens Bush, to be of significant conservation and biological value for the occurrence of many species which are confined to this vegetation community on the Mornington Peninsula. Twenty-two per cent of the 144 species of indigenous flora identified in a preliminary survey of Greens Bush by Carr et al. (1988) were of State or regional significance. *Euphrasia collina* ssp. *muelleri*, an endangered species (Gullan et al. 1990), is found in the heathland community of Greens Bush.

Prior to European settlement the Mornington Peninsula and Westernport Region, including the area now designated as Greens Bush, was inhabited by a sub-clan of the Bunurong, the Mayone-Balluk, (baloke meaning swamp) (Barwick 1984). Archaeological research attests to the importance of swamps for aboriginals in the supply of food resources, potable water and raw materials. Evidence seems to suggest that the swamp environments of the hinterland were the long term focus of occupation (Sullivan 1981; Gaughwin 1981; Ellender & Weaver 1990). Gaughwin (1983) illustrated a pre-contact land use model in which the coastal margins were relatively unimportant in the food quest and the main focus was on the hinterland with campsites on the ecotone between woodland and wetland. It seems likely that local Bunurong used fire for manipulation of food resources and access purposes with the suggestion that tea-tree scrub was regularly burnt (Gaughwin 1981).

The European land use history and settlement of Greens Bush is sketchy. In the 1840s and 1850s the area in and around Greens Bush was taken up for large cattle runs. In 1926 Edward Green purchased much of the land now gazetted as national park. The land was used for grazing, associated land clearance and pasture improvement, with the central block retained in its 'natural' state. Anecdotal reports suggest that burning took place, and, although the extent and frequency of burning is unknown, there is evidence to support the notion of an increasing number of fires or increasing fire intensity immediately following European settlement (Muller 1993). The last major fire burnt Greens Bush in 1962.

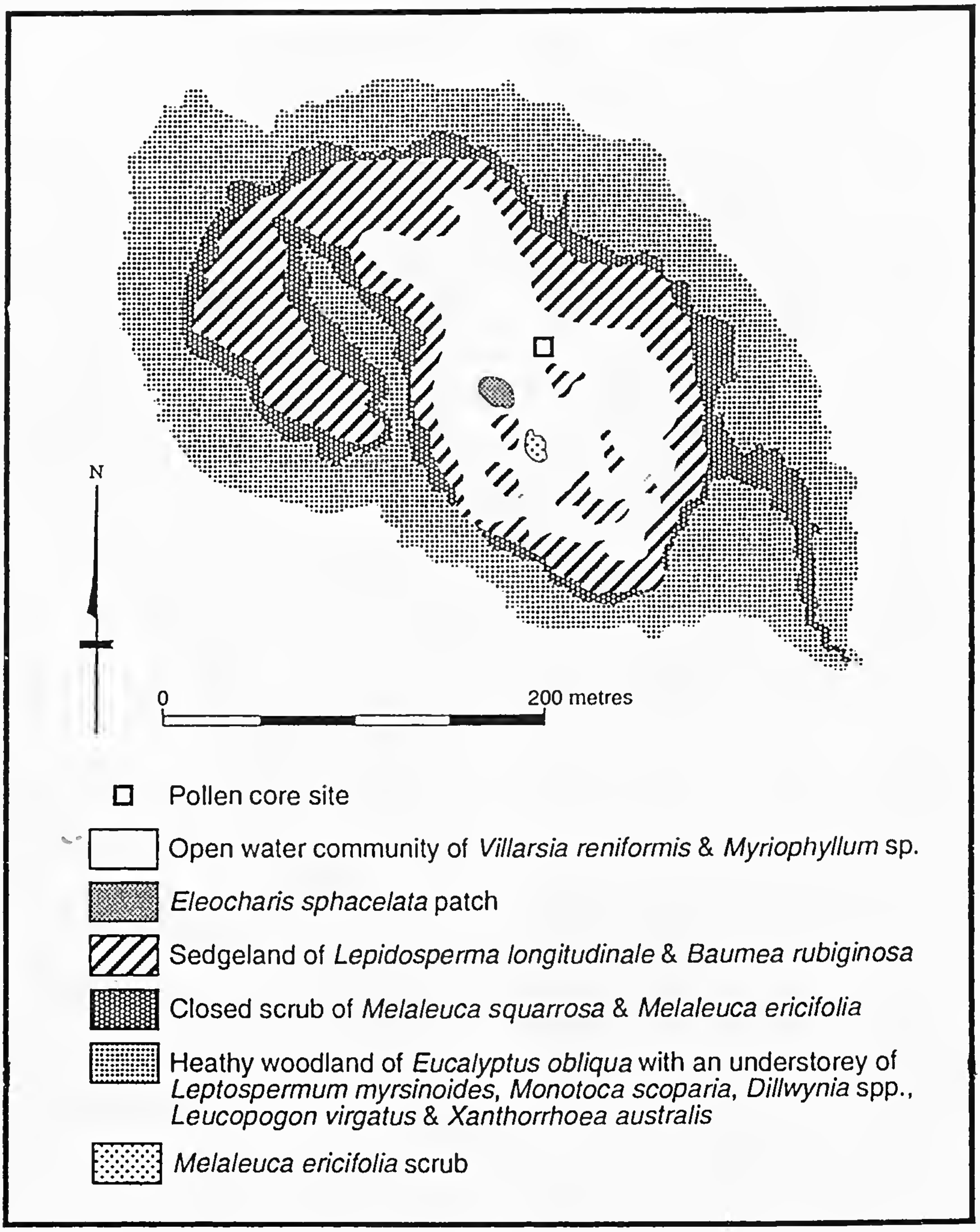


Fig. 2. The pollen core site in relation to the vegetation communities on and surrounding Big Swamp.

THE POLLEN SITE

Material for pollen analysis was obtained from Big Swamp, a shallow freshwater marsh (Corrick & Norman 1988) located in the headwaters of Lightwood Creek, in the western block of Greens Bush (Figs 1, 2). The swamp is about 260 m long and 150 m across at its widest point. Its long axis runs NW–SE. The surface of the swamp is relatively flat with only a slight slope toward a small outlet at its south-eastern end. The outlet flows into a tributary of Lightwood Creek. The swamp lies in an interdunal swale.

The hydrology of the swamp is affected by seasonal variations in precipitation and changes in the groundwater table. Similar hydrological patterns have been found on siliceous dunes in the region (Shugg 1991). In April 1991 the water table was 10 cm below the swamp surface, with surface water levels attaining a depth of 30–50 cm by August. Water levels fluctuated slightly through the summer of 1991–92 with permanent water remaining throughout 1992.

The vegetation of the swamp shows a distinct zonal pattern (Fig. 2). Swards of *Villarsia reniformis* and *Myriophyllum crispatum* characterise the open waters of the swamp with sporadic occurrences of *Amphibromus recurvatus* (Plate 1). A patch of *Eleocharis spachelata* has an isolated occurrence in the centre of the swamp. In the surrounding shallower waters, a sedgeland of *Lepidosperma longitudinale* and *Baumea rubiginosa* dominates with *Baumea tetragona* less prolific (Plate 2). The margins of the swamp are colonised by a closed scrub of *Melaleuca squarrosa* and *Melaleuca ericifolia*, with *Empodisma minus*, *Selaginella uliginosa* and *Sphagnum subsecundum* forming a dense, matted ground cover. Emergent *Eucalyptus ovata* occur in the closed scrub. The surrounding woodland community is dominated by *Eucalyptus obliqua* with a heath understorey of *Monotoca scoparia*, *Xanthorrhoea australis* and *Leptospermum myrsinoides* (Plate 3). *Leptospermum continentale* is a common species of both the heathy woodland and closed scrub communities. *Banksia marginata*, *Dillwynia glaberrima*, *Amperea xiphoclada*, *Leucopogon virgatus* and *Acacia suaveolens* are less prominent species in the

Plate 1. Open water community of Big Swamp with swards of *Villarsia reniformis* (January 1992; photo: M. Jenkins).

Plate 2. Sedgeland of *Lepidosperma longitudinale*, Big Swamp (August 1992; photo: M. Jenkins).

Plate 3. Heathy woodland of *Eucalyptus obliqua* with an understorey of *Leptospermum myrsinoides*, *Monotoca scoparia* and *Xanthorrhoea australis* surrounding Big Swamp (November 1992; photo: M. Jenkins).

heathy understorey. Herbaceous taxa of the woodland community include *Lagenifera stipitata* and *Burchardia umbellata*.

The swamp is considered of State conservation significance because of its high ecological and conservation value (Larwill & Costello 1992). The wetland plant communities are regionally rare (Carr et al. 1988; Fitzsimons 1989). The continuity of the ecological gradient between swamp sedgeland, surrounding *Melaleuca* scrub and heathland, make the mosaic of vegetation highly significant. Frood and Calder (1987) consider both *Melaleuca* scrub and swamp sedgeland as depleted in Victoria, and in need of conservation. A number of plant species recorded in and around the swamp are considered regionally significant in both the Melbourne and Westernport regions. These taxa include *Amphibromus recurvatus*, *Villarsia reniformis*, *Spiranthes sinensis*, *Utricularia* spp. and *Xyris gracilis* (Beauglehole 1983; Opie et al. 1984; Larwill & Costello 1993). The wetland is also of an important habitat for Latham's Snipe (listed on the Japan–Australia Migratory Bird Agreement).

METHODS

The sediment core for pollen analysis was taken within the open water community close to the centre of the swamp (Fig. 2). The core, 118 cm in length, was extracted in sections with a D section sampler (Moore & Webb 1978). It was described, in the laboratory, according to the Troels-Smith (1955) system of sediment stratigraphy.

The core was then sampled at 4 cm intervals from 2 cm to 118 cm depth with an additional sample taken from the surface. Slices of 1 cm thickness were removed and a 1 cm^3 subsample extracted from the uncontaminated centre of each slice for pollen and charcoal analysis. The remainder of each slice was used for moisture and organic determinations, which involved oven drying at 100°C for 24 h and furness ignition at 500°C for 2 h respectively.

The 1 cm^3 samples were treated by the standard potassium hydroxide, hydrogen fluoride digestion and acetolysis methods as described by Faegri & Iverson (1975) in order to remove the sediment matrix and thereby concentrate the pollen and charcoal. The residue from each sample was immersed in a known amount of silicone oil and stored in vials. A measured volume of each sample was then mounted on microscope slides for pollen counting and identification and for charcoal counting.

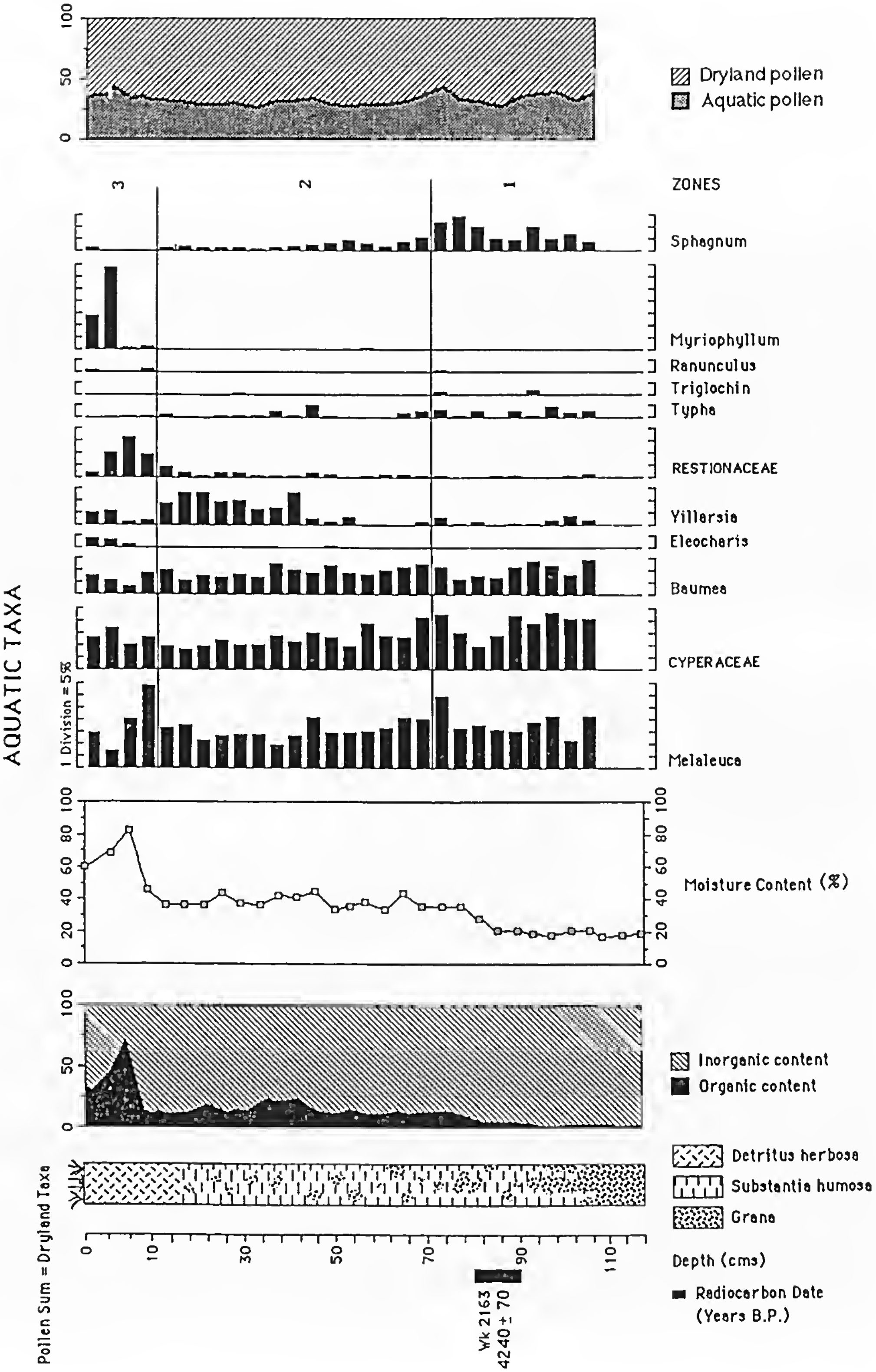
Identification of pollen grains and spores was made by comparison with reference slides and photographs located in the Department of Geography and Environmental Science, Monash University. The Myrtaceae were the most problematic group to identify because of considerable overlap in morphological features between genera and the presence of degraded grains. *Eucalyptus* pollen was distinguished from other genera by its equatorial diameter (17–24 µm), parasyncolpate apertures, thickened pores and the presence of a polar island. *Melaleuca* were classified according to their parasyncolpate/syncolpate apertures and equatorial diameter (16–20 µm). *Leptospermum* are thin pored, syncolpate grains with an equatorial diameter of 12–18 µm, sometimes with a faintly scabrate exine. Pollen grains with characteristics intermediate between *Leptospermum* and *Melaleuca* were classified as Myrtaceous shrubs. *Allocasuarina* pollen was separated into species based on grain size (Kershaw 1970; Dodson 1974; Hooley et al. 1980). *Allocasuarina* pollen grains with an equatorial diameter of >32 µm were classified as *Allocasuarina verticillata*. *Allocasuarina* pollen <32 µm was classified as *Allocasuarina littoralis*. Native and introduced species of *Plantago* were separated on the degree of aperture thickening.

Two hundred dryland pollen grains were counted on each slide using an Olympus binocular CHA microscope at a magnification of 600×. Pollen grains were counted along evenly spaced transects over the whole of each slide to account for the preferential distribution and behaviour of different sized particles in the oil medium. The number of transects required to count a minimum of 200 dryland pollen grains was recorded to allow an estimate of pollen density.

All opaque, black angular fragments greater than 10 µm were classified as charcoal. The abundance of charcoal as square millimetres per cubic centimetre was calculated by the Point Count Estimation Technique outlined by Clark (1982).

A radiocarbon (^{14}C) date for the core was determined from sediment taken at a depth of 80–90 cm. The low organic content of the basal sediments necessitated a bulk sample to obtain an accurate minimum age for initial swamp formation. Root fragments which may have been younger than the sediment matrix were removed. The sample was dispatched to the Radiocarbon Dating Laboratory at the University of Waikato, New Zealand for analysis.

Inferred dates for the pollen zones and basal sediments were determined from the radiocarbon date, the time of arrival of Europeans, and the


0
50
100
▨ Dryland pollen
▩ Aquatic pollen
3
2
1
ZONES
Sphagnum
Myriophyllum
Ranunculus
Triglochin
Typha
RESTIONACEAE
Villarsia
Eleocharis
Baumea
CYPERACEAE
Melaleuca
AQUATIC TAXA
1 Division = 5%
0
20
40
60
80
100
Moisture Content (%)
0
50
100
▧ Inorganic content
■ Organic content
Detritus herbosa
Substantia humosa
Grana
Pollen Sum = Dryland Taxa
0
10
30
50
70
90
110
Depth (cms)
Wk 2163
4240 ± 70
■ Radiocarbon Date (Years B.P.)

dryland pollen accumulation rate, on the assumption of a constant influx of pollen through time. The time of European arrival was identified by the first presence of exotic pollen in the record.

RESULTS

The results of pollen, charcoal, moisture and organic content analysis, along with the core stratigraphy are shown diagrammatically in Figs 3 and 4. Values for all individual pollen taxa are expressed as percentages of the native dryland plant pollen sum for each sample. Pollen and charcoal particle concentrations are shown as numbers per cm³ and mm² per cm³ respectively. Moisture content is shown as a percentage of the wet weight of the sample. Organic content is shown as a percentage of the dry weight of the sample after ignition at 500°C for 2 h.

The pollen diagram has been divided into zones on the basis of major changes in the representation of pollen taxa and the presence of taxa indicative of a particular vegetation type.

Description of the pollen zones including sediment stratigraphy

Zone 1 (118–70 cm) c. *4500 BP*–c. *3200 BP.* The basal sediments from 118 to 106 cm consisting of a mottled, light grey grana (sand) with a very low organic content (2–3%) and a moisture content of only 18–20% are devoid of pollen. Substantia humosa (decomposed peat) forms the matrix of the sediments between 106 and 70 cm with a grana component decreasing in representation toward the top of the unit.

The major aquatic pollen taxa within this zone are *Melaleuca*, *Baumea* and other Cyperaceae, with *Sphagnum* recording its highest representation in the diagram. *Typha*, *Triglochin* and *Villarsia* have low and variable percentages.

The dryland woody pollen taxa *Allocasuarina*, *Eucalyptus and Leptospermum* have consistently high percentages with *Allocasuarina* dominant except for a dip recorded at 86 cm. Asteraceae is the major woody/herbaceous taxon with Poaceae the major herbaceous taxon. Other dryland woody and herbaceous taxa, as well as pteridophytes have low and generally sporadic representation.

Pollen density is at its lowest level for the diagram in the basal part of the zone, where there are also many eroded grains, but increases sharply between 86 and 78 cm depth. Dryland taxa constitute greater than 50% of the pollen assemblage with woody taxa the most significant proportion of the dryland component. Charcoal values increase steadily through the zone.

Zone 2 (70–14 cm) c. *3200 BP*–c. *150 BP.* The sediments remain similar to those in the upper part of the last zone except towards the top where there is a change to more fibrous *Detritus herbosus* or peat. The organic content remains below 25% and water content, although increasing gradually through the zone, does not exceed 40% of wet weight.

Melaleuca, *Baumea* and Cyperaceae persist as the dominant aquatic taxa with *Villarsia* becoming an additional significant component in the top half of the zone. *Sphagnum* percentages decrease markedly while Restionaceae is consistently present and has an increased percentage in the top sample. The only other notable aquatic, *Typha* has low and variable representation.

Allocasuarina more clearly dominates the dryland component, particularly in the middle of the zone where values of both *Eucalyptus* and *Leptospermum* are relatively low. Asteraceae percentages are slightly reduced but the woody/herbaceous component is maintained by higher values of both Chenopodiaceae and *Amperea.* Poaceae maintains its representation. The zone shows generally high dryland pollen diversity with the more consistent presence of the woody taxa *Pomaderris*, *Dodonaea* and Epacridaceae, the herbaceous taxa *Plantago* (native), *Hydrocotyle* and *Gonocarpus* and the tree fern *Dicksonia.* Pollen density is highest close to the base of the zone with a gradual decline toward the top. Dryland taxa continue to dominate the pollen assemblage with woody taxa the major dryland component.

Within this zone, pollen density generally decreases from an early highest peak for the diagram. Overall charcoal abundance increases through the zone, though there are marked fluctuations in its representation.

Zone 3 (14–0 cm) c. *150 BP–Present.* This section of the deposit consists of a sub-fibrous, dark brown detritus herbosus (peat) with macro plant remains discernible in the top 10 cm. Organic content reaches its maximum of 72% at 6 cm with a corresponding peak in moisture content.

Fig. 3. Aquatic pollen diagram from Big Swamp. The values for all taxa are expressed as percentages of total dry land pollen for each sample.

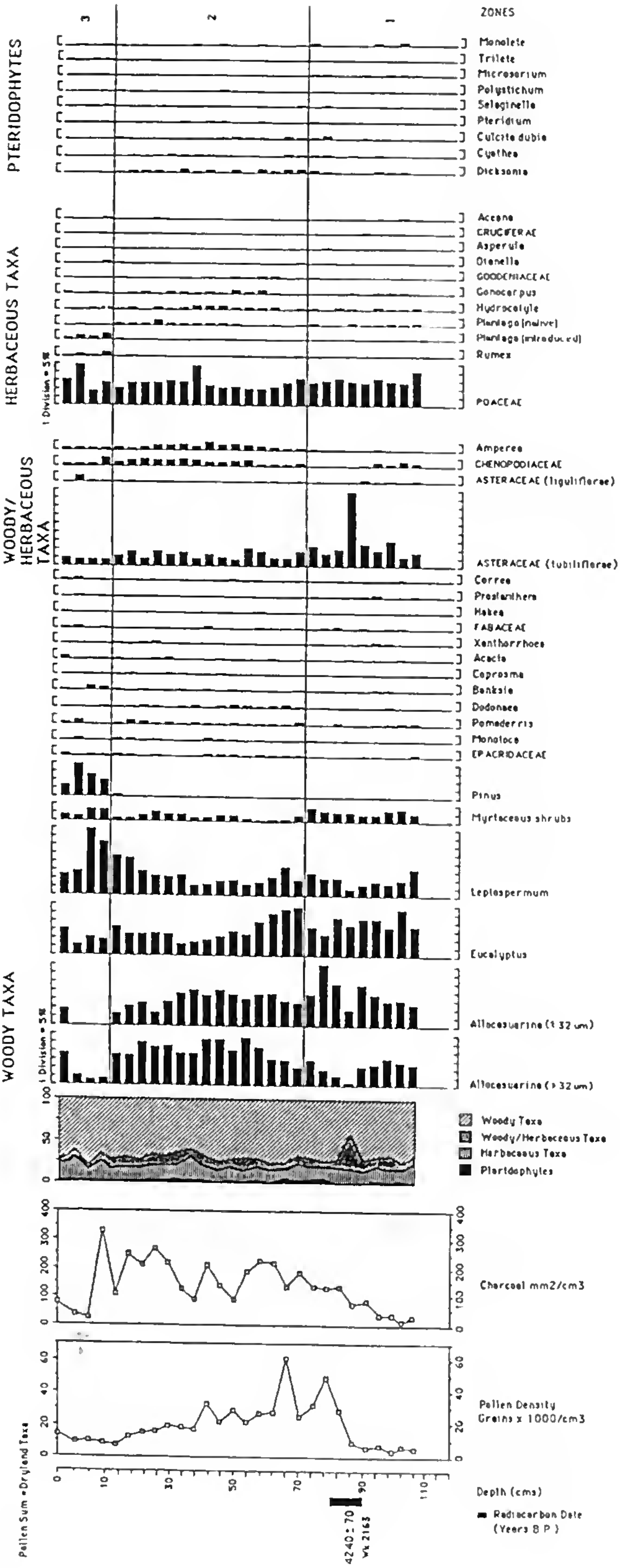


Fig. 4. Dry land pollen diagram from Big Swamp. The values for all taxa are expressed as percentages of total dry land pollen for each sample.

The base of the zone is characterised by a significant change in the composition and abundance of both aquatic and dryland pollen taxa while there are substantial variations within it. Within the aquatic taxa, *Melaleuca* records its highest value for the record at 10 cm depth before declining again, Restionaceae has high values through much of the zone while *Eleocharis* and particularly *Myriophyllum* become important components of the flora, for the first time, within the topmost sample. *Villarsia* values have declined and *Sphagnum* loses its consistent representation.

The dryland component is marked by very low values of *Allocasuarina*, except in the top sample, highest values for *Leptospermum* and *Banksia* within the diagram in the basal two samples of the zone, and the introduction of the exotic taxon *Pinus*. *Allocasuarina* (<32 µm) was only recorded in the topmost sample. Poaceae records its highest representation in this zone. *Plantago varia* declines in representation with the introduction of the exotic *Plantago lanceolata* while the herbaceous taxon *Rumex*, probably also from exotic plants, records low percentages. Ferns are poorly represented and no tree fern spores were recorded.

Pollen density declines further within this zone, before a slight increase toward the surface. The percentage of aquatic taxa remains relatively constant and dryland taxa continue to dominate the pollen assemblage. Charcoal abundance has a peak value for the diagram in the basal sample of this zone before declining to low levels.

DISCUSSION

Swamp development and aquatic vegetation

The swamp, which lies on a former drainage line of Lightwood Creek, began to accumulate polleniferous, organic sediments around 4500 BP. The reason for swamp initiation at this time is difficult to determine. It is possible that a decrease in effective precipitation after the mid-Holocene 'climatic optimum', dated generally to between 7000 and 5000 years BP (Kershaw 1992) led to a reduction in the erosive power of the stream allowing sediment to accumulate rather than being washed out of the system. Such an explanation has been suggested for the development of Tawonga Bog, a lowland site in the Kiewa valley, north-east Victoria (Kershaw & Green 1982), and Jackson's Bog in the Monaro Tablelands, New South Wales (Southern 1982) at this time. However, it is unlikely that Lightwood Creek ever had great erosive power and more feasible alternative explanations include the possibility that previously accumulated sediment was oxidised under dry conditions following the 'climatic optimum' and that some reorganisation of the dune system during this drier phase created a suitable basin for water and hence organic sediment accumulation. Other causal factors may include fire. Firing of the swamp and surrounding catchment may have contributed to the loss of pre-existing sediments through the combustion of peat layers and reorganisation of the dune sands through loss of stabilising vegetation.

The inorganic nature of the basal sediments together with a high proportion of eroded pollen grains in the basal part of zone 1 suggests that ephemeral swamp conditions prevailed. The relatively high percentages of *Sphagnum*, which is noted to undergo sporogenesis when under stress (Kershaw & Gell 1990), and the consistent representation of *Typha* which is able to establish from seed on exposed muds and can tolerate an inorganic substrate, add support to the proposal for the existence of ephemeral swamp. It is likely that the centre of the site was dominated by sedges with patches of *Typha* and open water containing *Villarsia* surrounded by marginal *Melaleuca* thickets. *Sphagnum* moss may have provided an understorey to many swamp communities.

Towards the end of the period represented by zone 1, the higher organic content of the sediment indicates more permanent swamp conditions. However, there is little indication of a vegetation change until the middle of zone 2, estimated to have been about 1500 years BP, when there is a further increase in the organic component and presumably a consistently higher water table. An increase in water level may explain the apparent expansion of *Villarsia* which may have been previously restricted to shallow water depressions due to the fact that it dies back when stranded (Aston 1973), and a decline in *Sphagnum* due to a reduction in water stress.

The European phase (zone 3) is marked by significantly increased variability in the aquatic pollen record. *Myriophyllum* makes a sudden appearance in the pollen spectra of this zone; its high representation possibly induced by nutrient loading of swamp waters and fluctuating water levels as a consequence of land clearance and cattle grazing. Orchard (1986) noted that the genus often grows prolifically in high nutrient waters and has a high propensity to flower when stranded. Other studies (Gell & Stuart 1989; Aitken & Kershaw 1993) have attributed an increase in *Myriophyllum* within very recent times to changes in water quality and yield. The increase in *Myriophyllum* may also be related to its phenotypic plasticity. This aquatic/paludal genus is able to produce erect, robust stems and spread by the formation of adventitious roots from nodes when stranded (Orchard 1986). The peaks in Restionaceae and *Melaleuca* are consistent with local fluctuations in water level as marginal swamp communities increased their extent, at least initially. Although the pollen spectra indicate some variation in swamp levels, the presence of the emergent macrophyte *Eleocharis* and the submerged hydrophyte *Villarsia* suggest the continued presence of open water communities. The increase in the organic content of sediments and the rapid sedimentation rate, implied by low pollen densities, are consistent with a productive swamp.

The aquatic pollen data indicates that the conservation of wetland plant communities in Greens Bush is reliant upon limiting degrading processes such as eutrophication and alteration of catchment hydrology. The weedy expansion of the aquatic herb *Myriophyllum*, in response to altered water quality and hydrology, may result in the exclusion of small, localised populations of significant species such as *Utricularia* spp. or *Spiranthes sinesis*, with a concomitant decrease in floral diversity. Similarly, the spread of *Melaleuca* thickets over the swamp surface, with changes in the hydrological regime through altered catchment processes, may lead to a reduction of sedge and open water communities and a decline in these regionally rare plant community types.

Terrestrial vegetation

The vegetation of the region was relatively constant during the pre-European period. An *Allocasuarina verticillata* (represented by *Allocasuarina* >32 µm) open woodland probably dominated the vegetation of the Nepean Peninsula west of Selwyn's Fault as evidenced by the relatively high percentages of this regional pollen type in the record and early historical accounts (Tuckey 1805). The constant background presence of Chenopodiaceae in the pollen spectra reflects the regional presence of coastal communities colonised by such taxa as *Atriplex cinerea* and *Rhagodia candolleana*. Similarly, the presence of *Pomaderris*, *Prostanthera*, *Coprosma* and the ferns *Dicksonia* and *Cyathea* in the record highlights the existence of wet sclerophyll communities in the entrenched gullies of Lightwood and Main Creek.

A *Eucalyptus* woodland with a dry, open heath understorey with a mix of herb taxa most likely characterised the dryland vegetation immediately surrounding the site over the last 4500 years (zones 1, 2). *Leptospermum* has been a major component of the understorey with Epacridaceae, *Banksia*, *Acacia* and *Amperea* comprising lesser components of the shrub strata. Taxa such as *Hydrocotyle*, Goodeniaceae and *Haloragis* make up the herb component. Significant percentages for *Allocasuarina littoralis* (represented by *Allocasuarina* <32 µm) suggest that this species may have been a more substantial component of the surrounding sclerophyll vegetation in the pre-European phase than indicated by its present distribution.

After 3200 BP, the dryland vegetation became more diverse with an increased representation of understorey and herbaceous taxa. Greater diversity in the vegetation during the period represented by zone 2 may be related to increased climatic variability with intensification of the El Nino–Southern Oscillation (ENSO) (McGlone et al. 1992; Aitken & Kershaw 1993) limiting competitive exclusion of taxa due to fluctuations in moisture regimes. Higher levels of charcoal in this zone suggests that increased burning, possibly due to the climatic variability, was also a contributing factor. Despite this evidence for climatic variability, the more consistent values for *Pomaderris* and *Dicksonia* in zone 2 suggest a slight expansion in wet sclerophyll elements during this period and support the aquatic evidence for generally higher precipitation levels. This feature of the climate also has regional support (Kershaw 1995). The synchronous increase in moisture dependent species and understorey taxa tolerant of disturbance are consistent with patterns described elsewhere in the Australasian region during the latter part of the Holocene (McGlone et al. 1992).

There is some ethnohistorical evidence for anthropogenic burning as a contributory explanation for increased fire and a more diverse vegetation at the site after 3200 BP. Deliberate burning by aboriginals for resource utilisation and access purposes has been noted with the suggestion that areas were regularly burnt (Gaughwin 1981). However, the extent and nature of the burning has not been fully determined. Ellender (1991) hypothesises that exploitation of hinterland swamps, similar in nature to Big Swamp, may have been associated with purposeful firing of the surrounding vegetation. It would seem that anthropogenic influence may in part be implicated in the vegetation dynamics of the site.

The European phase of the terrestrial record (zone 3) shows significant changes in pollen assemblages. The presence of *Pinus* pollen characterises the phase and corresponds with the establishment of softwood plantations and windbreaks on the southern Mornington Peninsula during the late 1800s. The sudden decline in *Allocasuarina* is probably related to land clearance and timber harvesting (Calder 1972). Decline in the abundance of *Allocasuarina* with European settlement has been documented in a number of palaeoecological studies (e.g. D'Costa et al. 1989; Head 1988). However the subsequent apparent recovery of the taxon has not been noted elsewhere in the region and it may be unwise to place too much significance on the evidence from one sample.

Leptospermum shows significant increases at the beginning of the European phase and is indicative of an increase in the density of the shrub layer. *Leptospermum myrsinoides* and, to a lesser extent, *Leptospermum continentale* are the dominant taxa in the heath understorey/heathland of the site and the most likely constituents of the *Leptospermum* sum given the limited dispersal of the genus (Dodson 1983). *Leptospermum myrsinoides* flowers profusely and its high representation may be attributed to post fire regeneration following the episode(s) of intense fire noted by the high charcoal level. An increase in the intensity and or frequency of burning in the late 1800s and early 1900s has been suggested (Muller 1993). The decrease in *Leptospermum* pollen toward the surface may indicate senescence of individual plants and a decline in the phenological capacity of *L. myrsinoides* as a consequence of more recent fire exclusion policies. The last major fire in Greens Bush was reported in 1962 (Muller 1993).

In the basal samples of the European phase of the terrestrial pollen record, taxa show differential response to fire. *Leptospermum* and *Banksia* increase their representation in response to fire, whereas *Pomaderris* and *Allocasuarina littoralis* (*Allocasuarina* <32 μm) decline. The decline in *Allocasuarina littoralis* may be related to its incapacity to resprout vegetatively following intense fire and/or lack of a nearby seed source as a consequence of timber harvesting. Similarly, the decline in *Pomaderris* may be related to its fire sensitivity.

As indicated by the pollen record, the management and conservation of plant communities in Greens Bush is in part related to fire regime. The ecological manipulation of fire needs to address the varied response of individual taxa and the differing fire requirements of wet sclerophyll and heathland communities alike. Strategies such as mosaic burning, the provision of buffer zones to protect from weed invasion, appropriate fire frequencies and monitoring programs (Gill & Nicholls 1989) are required. In heathland, fire is an integral component of the vegetation dynamics and important for the provision of regeneration opportunities. Frequency of heathland burning is a major determinant of persistence and regeneration possibilities of dominant taxa, with both long term absence and frequent fire capable of irreversible change in the heathland community (Cheal 1996). Mosaic burns provide the opportunity to assess the effectiveness of differing fire regimes, provide regeneration opportunities and limit the catastrophic effects of wildfire through variations in fuel load. In wetland communities the incidence of fire is rare, but fire protection may be needed to lessen the possibility of peat fires. In wet sclerophyll communities, an inappropriate fire regime could lead to a change in the composition of the understorey, an increase in weed invasion and the elimination of fire sensitive taxa. Ashton (1981) and Gill (1993) note the fire sensitivity of wet sclerophyll taxa such as *Prostanthera lasianthos* and *Pomaderris aspera* and changes in the floristics of wet sclerophyll forest in response to varied fire frequency. Logistical and park boundary considerations such as edge effects, and spread of fungal pathogens will affect the ecological manipulation of fire in Greens Bush. It is clear that management actions must respond to the results of monitoring and the observed response of plant taxa (Purdie & Slatyer 1976; Noble & Slatyer 1980) as well as conservation objectives and logistic constraints. The pollen record suggests that an inappropriate fire regime has the potential to lead to long term changes in plant community composition and structure.

Pasture and agricultural development in Greens Bush during the European period is indicated by the displacement of *Plantago varia* by the introduced *Plantago lanceolata*, the introduction and expansion of the herb *Rumex*, and increases in Poaceae and Asteraceae (Liguliflorae) in the most recent samples. The historical expansion of weedy herbaceous taxa with European land settlement may affect the integrity of the herb component of woodland/forest communities in Greens Bush with a resultant decline in plant diversity.

CONCLUSIONS

With the exception of the last 200 years, the vegetation on Big Swamp and within the Greens Bush region has been relatively stable through most of the last 4500 years. There is some evidence from the dryland vegetation of climate change resulting in increases in effective precipitation and climatic variability from about 3200 years BP, features which have broad regional expression in Australia and New Zealand. A general increase in the level of burning adds support to the proposed climatic variability. The local site evidence provides partial support for increased precipitation with gradual or stepwise increases in the water table and aquatic vegetation responses from about 3500 to 1500 years BP.

The question of aboriginal burning complicates the interpretation of the vegetation dynamics of the site. The limited evidence suggests that to some extent, anthropogenic burning may have affected the vegetation history of the site prior to European settlement.

Major changes in the vegetation of both the swamp surface and surrounding dry land vegetation have occurred during the time of European occupation. Many of these, such as the reduction in forest and woodland due to land clearance and the establishment of exotics are documented historically. Others such as the differential response of taxa to altered fire regimes and the impact on swamp vegetation of altered hydrology and water quality are revelations that have major implications for the management of 'natural' vegetation within this conservation area.

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FIRST RECORDS OF *SLAVINA* (OLIGOCHAETA : NAIDIDAE) IN AUSTRALIA AND DESCRIPTION OF A NEW SPECIES

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Pinder, Adrian M. & Brinkhurst, Ralph O. 1997:12:31. First records of *Slavina* (Oligochaeta: Naididae) in Australia and description of a new species. *Proceedings of the Royal Society of Victoria* 109(2): 149–155. ISSN 0035-9211.

Specimens of *Slavina appendiculata* d'Udekem, 1855 and *Slavina proceriseta* sp. nov., both from the state of Victoria, represent the first Australian records of this genus of freshwater oligochaetes. *S. proceriseta* sp. nov. from the La Trobe and Murray Rivers is the first naidid apparently restricted to Australia.

THE new *Slavina* material was identified from collections of previously unsorted oligochaete material held by the Museum of Victoria (MV), Melbourne, Victoria and the Murray Darling Freshwater Research Centre (MDFRC) in Albury, NSW. These are the first records of the genus in Australia and the new species is the first member of the cosmopolitan family Naididae known only from Australia.

Family NAIDIDAE

Genus **Slavina** Vejdovsky, 1883

Slavina Vejdovsky, 1883: 219.

Type species. *Nais appendiculata* d'Udekem, 1855.

The following diagnosis is derived from Sperber (1948) and Brinkhurst (1971b), roman numerals denote segmental position. Numerous sensory papillae arising from body wall. Body covered in foreign matter adhering to secretions produced by epidermal gland cells. Dorsal setae absent in II to III, IV or V. Hairs present, with non-serrate shafts, accompanied by needles without noduli, with tips finely or bluntly simple-pointed or bifid, often narrowest subapically and often slightly curved distally. Ventral setae fairly straight, with proximal to medial nodulus and usually with proximal bend. Stomach present. Clitellum absent between male pores. Vasa deferentia without prostate, joining atria above atrial duct. Atria with or without prostate. Penial setae present.

Slavina is a small genus of freshwater oligochaetes belonging to the Subfamily Stylarinae. Four species have been described. The type species, *Slavina appendiculata* (d'Udekem, 1855), is very widespread, occurring in Africa, North and South America, New Zealand, Asia and Europe (Brinkhurst 1971b) and now Australia. The remaining three species, *Slavina isochaeta* Cernosvitov, 1939, *Slavina sawayai* Marcus, 1944 and *Slavina evelinae* (Marcus, 1942) have only been found in South and/or Central America. Accounts of the genus and species include Harman (1965), Marchese (1986), Harman et al. (1988) and Grimm (1990).

Nemec & Brinkhurst (1987) divided the four species of *Slavina* into two groups for their analysis of naidid subfamilial relationships. Primarily, *S. evelinae* was separated from *S. appendiculata* because they differ in some aspects of their genital anatomies. Thus, *S. evelinae* has no atrial prostate and male ducts which empty into a common median pore, whereas *S. appendiculata* has atrial prostate and separate male pores. The other two species, whose genital anatomies have not been described, were allied with one or other of these two species according to similarities in setal morphology. Thus *S. isochaeta* was assumed to have the same genital anatomy as *S. evelinae* because it lacks elongate hairs anteriorly, while *S. sawayai*, which has long hairs in VI, was assumed to have the same genital anatomy as *S. appendiculata*.

The resulting trees suggested that *S. evelinae* and *S. appendiculata*, at least, might not be closely related. *S. evelinae* grouped with another subfamily, the Naidinae, because of its lack of atrial prostate and (in some analyses) slight difference in the form and size of the ventral setae between the anterior and posterior segments. The median male pore of *S. evelinae* emerged as an autapomorphy. However, the character 'anterior and posterior ventral setae different' is not one that any taxonomist would use to separate genera. This character appears to have been subject to homoplasy and reversion within the family, according to the same analyses, and even varies within other genera. In any case, the ventral setae of *S. appendiculata/S. sawayai* were scored as 'anterior setae not slightly different to posterior setae' whereas in fact they are slightly different in *S. appendiculata*. Furthermore, if the occurrence of papillae on the body wall had been included as a character in the Nemec & Brinkhurst analyses then all papillate species (*Vejdovskyella* and *Slavina*) might have grouped closer together, with the absence of prostate on *S. evelinae* then being considered a reversion in parallel to the Naidinae. The reason for excluding papillae from the analyses was that it was not considered an appropriate character for analyses of relationships at the subfamilial level.

At this stage, there seems to be little justification for acting on the suggestion from the Nemec and Brinkhurst (1987) study, as also discussed by Sperber (1948), that *S. evelinae* be classified separate from *S. appendiculata*, particularly when we lack information on the genital anatomy of some species.

Slavina appendiculata (d'Udekem, 1855)

Fig. 1A–D

Nais appendiculata d'Udekem 1855: 552, pl. 1, fig. 3.—d'Udekem 1859: 21.—Vaillant 1890: 371.—Bretscher 1896: 508.
Slavina appendiculata (d'Udekem) Vejdovsky 1883: 219.—Sperber 1948: 133, fig. 15.—Yamaguchi 1953: 293, fig. 11.—Harman 1965: 565.—Brinkhurst and Jamieson 1971: 344, figs 7.8R–S, 7.9A–C.—Naidu & Naidu 1981: 115, figs 8–9.—Brinkhurst 1986: 87.—Marchese 1986: 236, fig. 3.—Grimm 1990: 141, fig. 12.—Pinder & Brinkhurst 1994: 126.
Nais lurida Timm 1883: 153, pl. 11, fig. 25.
Slavina lurida (Timm) Bousfield 1886: 268.
Slavina punjabensis Stephenson 1909: 272, pl. 19, figs 41–45, pl. 20, figs 50–52.
Slavina montana Stephenson 1923: 84, fig. 30.
Slavina truncata Harman 1965: 566, figs 1–2.

Original authors of all synonyms are listed above, with the more significant citations of these names. A comprehensive list of pre-1971 citations is available in Brinkhurst (1971b).

Material. MV F78054–F78059, one immature specimen (with regenerating head) plus fragments in alcohol and five immature specimens mounted whole on slides, from fine sandy sediment in main channel of La Trobe River at Moe-Willow Grove Road Bridge (38°11′18″S,146°15′12″E), July 1980, coll. R. Marchant (MV); MV F78060 and F78061, two immature specimens mounted whole on slides from La Trobe River, 100 m below drain carrying treated sewage (38°13′28″S, 146°16′04″E), 5 Nov. 1979, coll. R. Marchant (MV); Returned to MDFRC, one immature specimen mounted whole on slide, from Murray River at Dora Dora (35°57′S,147°29′E), 24 Mar. 1994, coll. J. Hawking (MDFRC).

Description (primarily based on Australian specimens—see Remarks below). Length of preserved body 1.9–2.3 mm, width 170–242 µm when slide mounted, number of segments 25 to 35 plus regenerating tails.

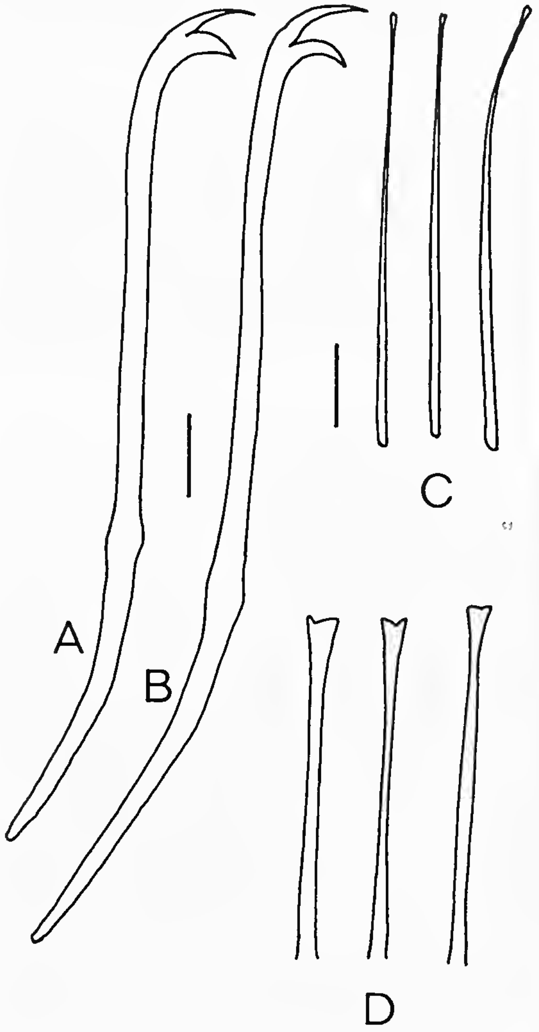

Fig. 1. A–D, *Slavina appendiculata*. A, ventral seta of II. B, ventral seta of posterior segment. C, needle setae. D, tips of needle setae. Bar scales: A–C, 9 µm; D, not drawn to scale. Illustrations drawn from Australian material.

Prostomium broad and flattened, up to three times wider at base than long in preserved specimens. Eyes present or absent (absent on all Australian specimens). Mouth ventral.

Ventral setae from II, (2)3–4(5) per bundle, moderately curved with nodulus located approximately $^1/_3$ of setal length from the proximal end, 2–3 µm wide, slightly longer in II (108–135 µm) than in rest (89–115 µm). Upper teeth thinner and 1.2 to 1.3 times longer than lower in all segments.

Dorsal setae from VI, each bundle with one (rarely two, except in VI and then up to three) long (195–290 µm, except in VI), stout (3.5–4 µm wide) hair setae and one or two thin (1 µm), short (40–56 µm) needles. Hairs of VI usually much longer (up to 630 µm) than those of other segments. Hairs with distended and flattened or minutely notched tips (visible at 400× magnification). Needles with narrow hair-like distal ends, usually terminating in slightly distended and flattened tips which may be notched in some instances (visible only when viewed at 1000× magnification).

Body wall with adhered layer of fine particulate organic material. Papillae projecting up to 30 µm (in preserved specimens) from the body wall and through foreign matter. Some specimens with regenerating tails.

Remarks. These Australian specimens closely fit previous descriptions of *S. appendiculata* such as Sperber 1948 and Brinkhurst (1971b). *S. appendiculata* is the only species with the combination of dorsal setae commencing in VI, elongate hair setae in VI, non-bifid needles and ventral setae with upper teeth slightly longer than lower. Since the new specimens are immature they do not have reproductive organs developed and so their genital anatomy cannot be compared to that described for *S. appendiculata*. Asexual reproduction predominates in the Naididae and it is rare to encounter specimens with the reproductive structures developed. Identifications of this species and other naidids, including first regional records, are usually made using sexually immature specimens for this reason. However, such specimens are fully developed in a somatic sense, apart from segments that are regenerating after asexual reproduction by budding.

While accepting this identification, some anatomical aspects of the Australian specimens should be discussed in relation to known variation within the species. First, there are no pigmented eye spots in any of the Australian specimens. However, other specimens without eyes, described as *Slavina montana* by Stephenson (1923) were attributed to *S. appendiculata* by Sperber (1948), who pointed out that the occurrence of eye spots is variable in some other naidid species (e.g. *Nais variabilis* and *Stylaria fossularis*). Similarly, Brinkhurst (1971b) concluded that eyeless specimens described as *Slavina truncata* by Harman (1965) were actually *S. appendiculata*.

Secondly, the needle setae of *S. appendiculata* are usually described and illustrated as being distended apically with bluntly rounded tips. By contrast, the needles of Australian specimens are similarly distended apically, but are usually flattened at the tip and, at high magnification, there occasionally appears to be a central notch. This is more noticeable on specimens temporarily mounted in alcohol. Yamaguchi (1953) described and illustrated similar tips to the needles of Japanese of *S. appendiculata*.

Thirdly, the hairs of Australian specimens are also slightly distended apically and often have roughly flattened tips (visible even at 400× magnification), which may also be notched as in the needles. This latter feature has not previously been noted for *S. appendiculata*, but similarly flattened hair tips have only recently been described for *S. isochaeta* by Harman et al. (1988), whereas this feature was not noted in the original description by Cernosvitov (1939).

A few specimens initially appeared to have dorsal setae from IV or V but upon closer examination these specimens were found to have single small ventral setae in the most anterior bundles and gaps between these bundles and the larger ventral setae of the first hair-bearing segment. This indicates that the anterior setae of these specimens have not fully regenerated after asexual reproduction, leading to incorrect counting of segments.

Lengths of the dorsal and ventral setae of the Australian specimens (Table 1) are similar to lengths reported previously for *S. appendiculata* from other regions (Sperber 1948; Harman et al. 1979; Naidu & Naidu 1981; Marchese 1986; Grimm 1990).

Thus, in almost all respects, the Australian specimens fall within the range of variation reported for specimens identified as *S. appendiculata* on other continents. The flattened hair tips have not been reported before but is of such a minor nature that it does not preclude us from identifying the Australian specimens as *S. appendiculata*.

Distribution. Cosmopolitan, but within Australia this species is known only from the La Trobe and Murray Rivers, Victoria.

	Ventral II–V (μm)	Ventral >V (μm)	Hairs >VI (μm)	Hairs VI[1] (μm)	Needles (μm)
S. appendiculata					
Lengths from literature[2]	111–147	90–135	228–450	600–800	30–70
Australian specimens	108–135	89–115	195–290	630	43–56
S. proceriseta	110–115	140–150	142–215	—	62–70

Table 1. Ranges of setal lengths for Australian and non-Australian specimens of *S. appendiculata* and for *S. proceriseta* sp. nov. [1]Maximum lengths recorded. [2]Sperber (1948), Harman et al. (1979), Marchese (1986), Naidu and Naidu (1981) and Grimm (1990).

Slavina proceriseta sp. nov.

Fig. 2A–G

Etymology. From the Latin *procerus* (long and thin) and seta, referring to the slender ventral setae.

Type material. Holotype MV F78063 mounted whole in Permount, from La Trobe River, 100 m below drain discharging treated sewage (38°13′28″S,146°16′04″E), 3 July 1979.

Other material. MV F78066, five fragments or specimens with only partially regenerated anterior ends in alcohol, from La Trobe River at Moe-Willow Grove Road Bridge (38°11′18″S,146°15′12″E), July 1980, coll. R. Marchant (MV); MV F78064–F78065, two fragments mounted whole in Permount with intact anal ends, from Acheron River at Glendale Lane (37°21′S,145°42′E), 1 Nov. 1993, coll. A. Pinder and P. Lillywhite (MV); MV F78067, one fragment in alcohol, with anal end intact from Murray River at Dora Dora (35°57′S, 147°29′E), 24 Mar. 1994, coll. J. Hawking (MDFRC).

Description. Length of complete holotype 1.95 mm and width 182 μm (at segment III) to 272 μm (in mid-body) when preserved, number of segments 23 (excluding regenerating tail). A specimen with an incompletely regenerated anterior end was 2.5 mm long, but is now in five pieces, and has 35 segments.

Prostomium short and bluntly rounded, half as long (19 μm) as wide at base (37 μm). Eyes absent. Brain semi-ovoid between pharynx and prostomium. Mouth of preserved holotype appearing to be directed anteriorly rather than ventrally. Pharynx slightly thickened in II and III, oesophagus narrower and gut widening abruptly in VII. Coelomocytes not observed.

Ventral setae from II, each bundle with 2 to 5 long, thin (2-2.5 μm) slightly curved bifid setae. Those of II–IV shorter (110–115 μm long) than the rest (which are 140–150 μm) and slightly thinner (1.5 μm instead of 2 μm). Upper teeth 2.5 to 3 times as long (12–15 μm) as the lower and slightly thicker and more curved. The lower teeth are fairly straight and diverge from the main shaft at an angle of about 10–15°. Nodulus poorly developed and located about $^1/_3$ of the length of the seta from the proximal end.

Dorsal setae from V, each bundle with 1 to 3 (2 or 3 anteriorly, reducing to 1 per bundle posteriorly) moderately long (142–215 μm) hairs per bundle with shafts 2–2.5 μm, gradually narrowing to a fine point. Hairs accompanied by an equal number of short (62–70 μm), fine (1–1.5 μm) needles which are broadest basally, narrowest subapically and terminate in a minutely bifid tip. The teeth of the needles are very short and equal, diverging at an angle of 15–30° and often appearing palmate or even simple pointed if viewed at a less than optimum angle.

Body wall with an adhered layer of fine particulate organic matter, which, in preserved specimens, may appear to be distributed in narrow (6–10 μm) bands around the body. Papillae, up to 5 μm wide and 12 μm long (in preserved specimens) project from the body wall and penetrate through the adhered organic material. Spacing of the papillae is variable but some occur as close together as 15 μm and 21 papillae project from one side of the body wall in profile along the length of the holotype. Papillae apparently occurring around the circumference of each segment, but the precise distribution not determined. Tips of papillae with numerous short fine hairs.

Remarks. The subfamily Stylarinae is defined (Nemec & Brinkhurst 1987) by the absence of noduli on the needle setae and (with the exception of some *Slavina*) an absence of prostate tissue on the atria, although the latter is considered to be a symplesiomorphy. The new specimens are immature but the needles definitely lack a nodulus. Of the seven genera assigned to the subfamily, only *Vejdovskyella* Michaelsen, 1903 and *Slavina* have a papillate body wall covered with adhering foreign matter, as in the new species. Other characteristics typical of *Slavina* displayed by the new species include dorsal bundles with few non-serrate fairly stout hairs starting between IV and

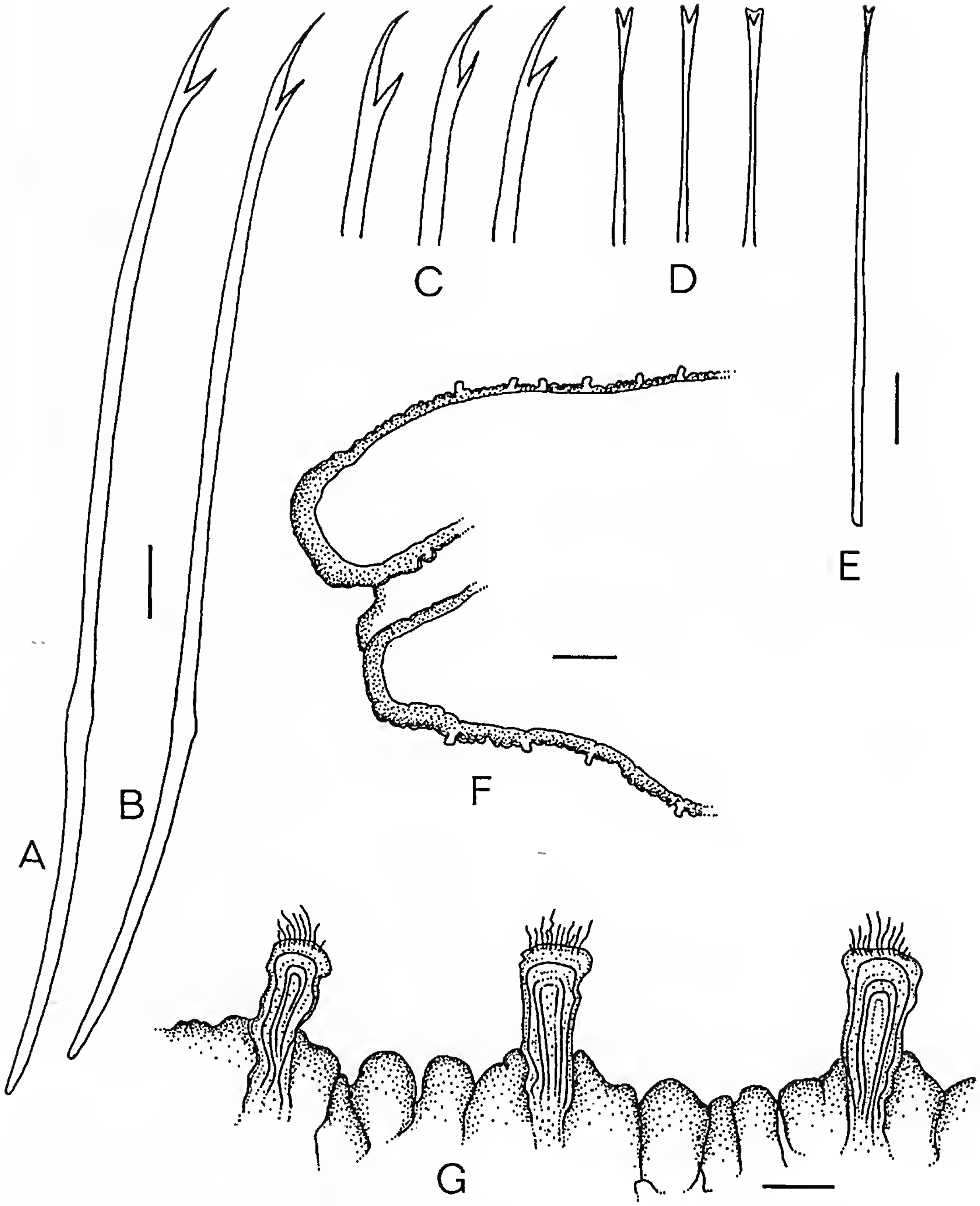

Fig. 2. A–G, *Slavina proceriseta* sp. nov. A, ventral seta of V. B, ventral seta of XI. C, examples of tips of ventral setae. D, tips of needle setae. E, needle seta. F, anterior of worm in profile showing short rounded prostomium and forward projecting mouth. G, section of body wall showing papillae. Bar scales: A, B, E, 9 µm; F, 28 µm; G, 5 µm; C, D, not drawn to scale. Illustrations drawn from holotype.

VI and a few fine needle setae which narrow sub-apically. *Vejdovskyella* also has stout dorsal setae from VI, possesses fine simple pointed needles and may have eyes present (as does *Slavina appendiculata*). However, *Vejdovskyella* is distinguished from *Slavina* by the more numerous hairs and needles (up to 9 and 12 per bundle respectively) and the much stouter hairs which are strongly serrated. The new species would thus appear to be correctly placed in *Slavina*.

Descriptions based on limited material can lead to taxonomic confusion, as has been the case for some other *Slavina* species. However, the form of the ventral setae of the new specimens are very different to those of any of the previously described *Slavina*, or indeed any other member of the subfamily, justifying in this case the description of a new species. Although the holotype is the only specimen with a completely regenerated anterior end, the other specimens have setae of identical form and almost certainly belong to the same species. However, in recognition of their incomplete nature they are not designated as paratypes.

In common with *S. isochaeta* and *S. evelinae*, *S. proceriseta* does not appear to have elongate hair setae anteriorly, although specimens of *S. appendiculata* which lack the usual elongate hairs are known (Grimm, in litt.). *S. proceriseta* is the only species of *Slavina* to have the upper teeth of the ventral setae so long compared to the lower. *S. isochaeta* and *S. sawayai*, which also have bifid needles, are the closest in this respect but even they have upper teeth at most half as long again as the lower and both have teeth that are much more curved than those of *S. proceriseta*. Commencement of dorsal setae in V is also unique to *S. proceriseta*, although that should be considered only tentatively diagnostic until further specimens can be examined.

The holotype consists of 23 segments plus a regenerating tail while some other specimens, which have a regenerating anterior end, consist of up to 35 segments. This suggests that the holotype is a recently separated anterior zooid, that the fission zone occurs around segment 23 and that specimens of at least 58 segments may occur.

Distribution. Recorded only from the riverine sites listed above.

DISCUSSION

Slavina proceriseta is one of only two naidid species known only from Australia. The other is a new species of *Dero (Allodero)* which will be published separately. Other specimens of *Dero* collected from the Northern Territory possibly represent a further new species but this cannot be described without further specimens. The other 29 naidid species that have been recorded in Australia are also known from other regions, including the Americas, Europe, Africa and Asia, although none are restricted to the Asian region (Pinder & Brinkhurst 1994). While there is a tendency for naidids to be globally widespread, other continents do seem to have a somewhat higher proportion of endemic naidids than is known from Australia so far, despite the examination of large numbers of naidids from all Australian states (Brinkhurst 1971a; Pinder & Brinkhurst 1994; unpublished data). For example, 12 of the 67 species recorded from North America by Brinkhurst (1986) are restricted to that region and 27 of the 84 naidid species found to occur in South and Central America by Brinkhurst & Marchese (1989) and subsequent authors are not known elsewhere. Similarly, the number of species considered to be restricted to Africa by Grimm (1987) was 10, out of a total of 48 for that continent.

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ASPECTS OF THE ECOLOGY AND BREEDING BIOLOGY OF *GALAXIAS FUSCUS* MACK, IN THE GOULBURN RIVER SYSTEM, VICTORIA

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The ecology of *Galaxias fuscus* Mack (1936), an endangered galaxiid which is listed on the Victorian Flora and Fauna Guarantee Act, was studied in the upper Taggerty River. Several differences in the ecology of *G. fuscus* and *Galaxias olidus* Gunther were found, further supporting claims for *G. fuscus* to be recognised as a taxon independent of *G. olidus*. *Galaxias fuscus* was found to have a spawning season from August until September, *G. olidus* in comparison began to spawn two weeks earlier and was completed in mid-September, earlier than that of *G. fuscus*. The size distribution of *G. fuscus* has a higher proportion of larger fish, than that of *G. olidus*, with *G. fuscus* being on average a larger fish. The microhabitat of *G. fuscus* was found to be slow (<0.20 ms^{-1}) deep (mean depth 434 mm) pools, adjacent to faster flowing sections of stream.

GALAXIIDS are a Southern Hemisphere salmoniform fish, which are found in a wide range of habitats throughout southern Australia (McDowall 1980). One of the more widespread species of galaxiids in Australia is the mountain galaxiid, *Galaxias olidus*, which inhabits fast flowing mountain streams through the eastern coastal region of Australia, from Queensland to South Australia (Cadwallader & Backhouse 1983). The ecology of *G. olidus* has been well studied by various authors (Cadwallader et al. 1980; Cowden 1988; Drayson 1989; Fletcher 1979; Harasymiw 1970; O'Connor & Koehn 1991) with considerable attention being focused on the taxonomy of this species (Frankenberg 1966; McDowall & Frankenberg 1981; Rich 1986; Terzis 1986). There are many morphological variants of *G. olidus*, with McDowall & Frankenberg (1981) recognising 10 of these. They stated that *G. olidus* was a phenotypically plastic species and consequently synonymised 10 species under *G. olidus*. *Galaxias fuscus* Mack is the most morphologically distinct variant of *G. olidus* (McDowall & Frankenberg 1981), and can be distinguished by its base colour and superficially dark surface bars in varying numbers on the sides of the fish. There continues to be uncertainty concerning the species status of *G. fuscus*, with Allen (1989) recently considering it as a distinct species. Originally described from the Rubicon River in 1936 (Mack 1936a, 1936b), only a few specimens of *G. fuscus* have since been collected in Victoria from few sites.

G. fuscus is recognised as an endangered taxon Australia wide (Jackson 1991; ANZECC 1996) and is currently listed on the Victorian Flora and Fauna Guarantee Act 1989 as being a rare and endangered taxon (SAC 1991). The only completed studies to date concerning *G. fuscus* have been intermittent distributional surveys by the Victorian Department of Natural Resources and Environment and a limited electrophoretic study with inconclusive results (Rich 1986). A research recovery plan has been developed by the Victorian Department of Natural Resources and Environment to guide management of *G. fuscus* (Raadik 1995).

Previously, no work had been conducted on the ecology of this taxon and the assumption has been that the ecology of *G. fuscus* was identical to the other variants in the *G. olidus* species complex. In this paper we present the results of a study on aspects of the ecology of *G. fuscus*, including spawning ecology, habitat preference and population size and structure, and compare these with the known ecology of *G. olidus*.

STUDY SITES

The restricted range of *G. fuscus*, which is found only in the upper reaches of the Goulburn River system in Victoria, limited the number of sites available for study. The Taggerty River system, a tributary of the Goulburn River in the southern highlands of Victoria, approximately 90 km north east of Melbourne, was selected as the primary region of study (Fig. 1). The river rises on the slopes of Lake Mountain and the upper reaches of the drainage are included in the Lake Mountain Alpine Reserve. The geography of the Lake Mountain region is described by Morris (1929). In its lower reaches, the river flows through State forest until its confluence with the Steavenson River near the town of Marysville. The study of the ecology of *G. fuscus* was undertaken between the months of April and October 1991, at seven sites on the Taggerty River and Keppel Hut Creek a tributary of the Taggerty River.

A study of the ecology of *G. olidus* was undertaken concurrently, to allow comparisons to be made between the two taxa, by monthly sampling of a population at one site on Little River also in the Marysville area. This site is at a similar altitude (900–1100 m), but about 7 km NNE of the *G. fuscus* sites (Fig. 1).

METHODS

Due to the endangered species status of the taxon, all data were obtained by non-destructive sampling methods. Electrofishing was the preferred method of collection of fish, although bait traps, seine nets and dip nets were used where access was difficult. Stop nets, with a mesh size of 1 mm, were set downstream of the sampling area when electrofishing during high stream flows.

Sampling of populations of *G. fuscus* was undertaken at two sites in Keppel Hut Creek (KHC3 and KHC5) (37°28′S,145°50′E) and four sites in the Taggerty River (TAG1–TAG4) (37°29′S, 145°51′E) fortnightly to monitor reproductive development and determine the time of spawning. Rotation of sites sampled was undertaken to minimise potential disturbance of fish and their habitat by reducing the frequency of electrofishing in specific regions. *G. olidus* was also sampled monthly in Little River (Site LR1) to monitor reproductive development.

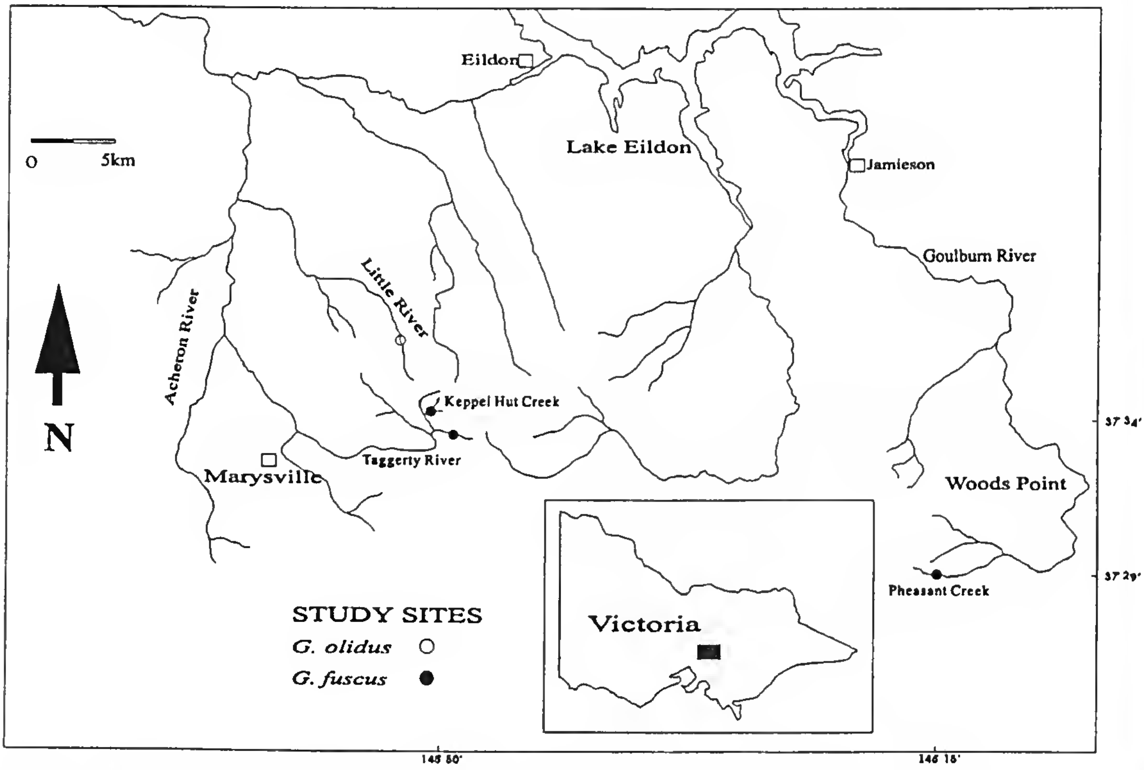


Fig. 1. The location of the study sites in the upper Goulburn River.

Prior to the collection of each fish sample water temperature and conductivity was measured mid flow.

All fish caught were measured as length to caudal fork (L.C.F.), and the microhabitat details of individual fish were recorded. Habitat use of *G. fuscus* was determined from microhabitat measurements at the point of capture of each individual. Variables which were measured included; mean water velocity (using a Tsurumi-Seiki Flow Meter suspended in the water at two-thirds of the water depth, for two minutes), type of substrate recorded on a descriptive scale [leaf litter, sand, silt, pebbles (<5 mm diameter), cobbles (5–20 mm diameter), rocks (>20 mm diameter)] and mean water depth. The mean water depth was calculated by measuring depths in the microhabitat area on a 1000 mm^2 square grid at 100 mm intervals. Reproductive state, sex and the number and pattern of full and partial bars on the sides of the fish was recorded for each specimen collected. All fish were then returned to the point of collection.

The states of reproductive development used by other authors (Pollard 1972; Humphries 1986) have been designed for studies involving dissection, consequently we used modified states more applicable for describing gonads visible through the body wall of live fish. They were: fully developed when gonads were visible through the body wall, running ripe being when eggs or milt were discharged with gentle pressure to the abdomen, spent when no gonadal material was visible after spawning and not ripe any other state.

Fecundity data was obtained from preserved museum specimens of 14 *G. fuscus* individuals (N.M.V. A8126, A84848, A7945, A7854, A7858, A7935: Arthur Rylah Institute for Environmental Research Collection, Department of Conservation and Natural Resources, 1987–92).

The endangered status of *G. fuscus* precluded the use of tag recapture studies or the removal method (Zippin 1958) to accurately determine population size. In order to limit stress and damage to the fish they were retained in buckets for the minimum time necessary and returned to the water as soon as possible. A determination of the population structure and an estimate of the population size of *G. fuscus* was obtained by counting the fish captured and excluding those recognised, by their size and the pattern of their bars, as having been recaptured.

After spawning had begun, egg searches were undertaken to determine the spawning sites. Methods employed included; visual searching, involving picking up instream rocks and other material and examining them for eggs; drift sampling, setting drift nets for 24 h periods; and kick sampling, taking drift samples downstream of areas when the substrate was being gently disturbed.

Photoperiod during the sampling period was determined from the records made at the Melbourne Planetarium.

The characteristics of each site were measured by measuring depth and recording substrate type at 0.25 m intervals on transects at 5 m intervals along the stream. The characteristics of *G. fuscus* habitat were compared to overall stream characteristics using analysis of variance.

RESULTS

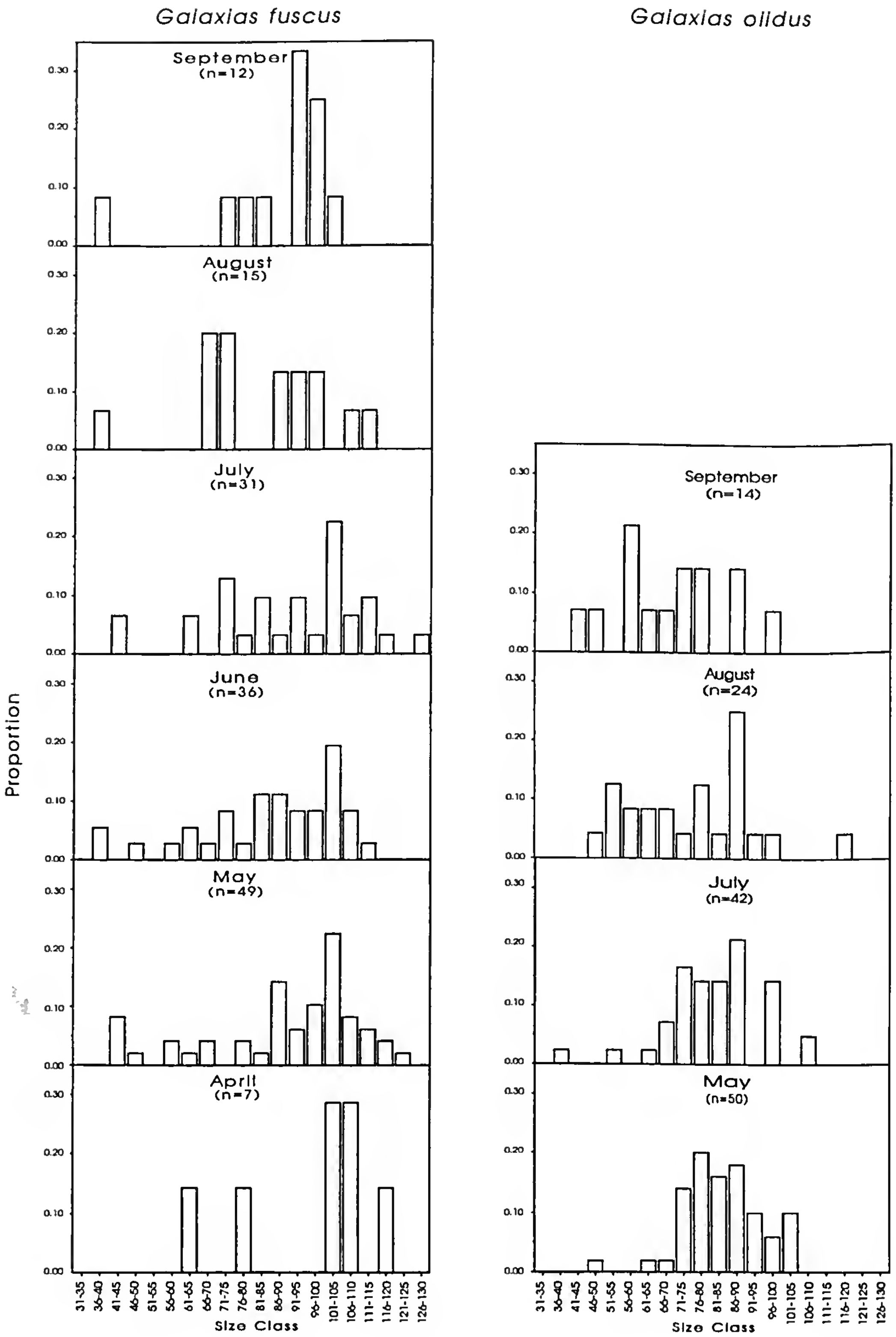
A total of 85 different individuals of *G. fuscus* were collected from the Taggerty River at the 4 sites during the study, whereas a total of 40 different individuals were collected from the two Keppel Hut Creek sites. Therefore, the total number of individuals collected from each stream is a minimum estimate of population size. Estimated population densities of *G. fuscus* ranged between 0.001 and 0.053 fish m^{-2} in the Taggerty River and from 0.010 to 0.036 fish m^{-2} in Keppel Hut Creek (Table 1). In comparison the densities of *G. olidus* in Little River ranged between 0.051 and 0.196 fish m^{-2} (Table 1).

Site	Species	Mean density±SE (fish m^{-2})	Range (fish m^{-2})
KHC3	*G. fuscus*	0.022±0.006	0.010–0.036
TAG1	*G. fuscus*	0.017±0.004	0.014–0.053
TAG2	*G. fuscus*	0.009±0.002	0.004–0.018
TAG3	*G. fuscus*	0.002±0.001	0.001–0.004
TAG4	*G. fuscus*	0.003±0.003	0.003–0.013
LR1	*G. olidus*	0.081±0.003	0.051–0.196

Table 1. Density of *G. fuscus* and *G. olidus* at sampling sites.

The observed sex ratio of females to males in the entire *G. fuscus* population sample (1.00 : 1.08) was not significantly different from 1 : 1 (χ^2=0.12, df=1, p>0.50).

It was not possible to determine size classes from our data because of the lack of clear cohorts and our inability to age the samples. Consequently *G. fuscus* and *G. olidus* data was fitted to size classes adapted from O'Connor & Koehn (1991) to allow comparison of population structure


Galaxias fuscus
Galaxias olidus
September
(n=12)
August
(n=15)
July
(n=31)
June
(n=36)
May
(n=49)
April
(n=7)
September
(n=14)
August
(n=24)
July
(n=42)
May
(n=50)
Proportion
0.00
0.10
0.20
0.30
31-35
36-40
41-45
46-50
51-55
56-60
61-65
66-70
71-75
76-80
81-85
86-90
91-95
96-100
101-105
106-110
111-115
116-120
121-125
126-130
Size Class

Length range (mm)	*G. fuscus* Number	*G. fuscus* Percentage	*G. olidus* Number	*G. olidus* Percentage
36–52	9	7.31	1	2.00
53–72	15	12.20	3	6.00
73–82	16	13.01	21	42.00
83–100	39	31.71	20	40.00
101+	44	35.77	5	10.00
Total	123		50	

Table 2. Length range and distribution of fish within size classes for *G. fuscus* and *G. olidus*.

(Table 2). A larger percentage of *G. fuscus* individuals were present in the larger size classes than *G. olidus* individuals (Table 2). The mean size of *G. fuscus* adults (95.4 mm) was significantly larger than that of *G. olidus* adults (84.6 mm) (ANOVA, F=23.377, df=1, $p<0.001$), with the mode of the *G. fuscus* population also being larger. The largest *G. fuscus* caught was 127 mm whereas 115 mm was the largest *G. olidus* caught at the Little River site.

Because of the low sample sizes it is difficult to differentiate cohorts from the size frequency graphs (Fig. 2). The size frequency distributions of *G. fuscus* are even with a tendency towards larger individuals (Fig. 2). The mode of the *G. olidus* size frequency is noticeably smaller than that of *G. fuscus* for most months excluding August (Fig. 2).

G. fuscus in the Taggerty River system during 1991 had an early spring spawning period extending over six weeks (Fig. 3), beginning in late August, and all fish were spent by early October. In comparison the Little River population of *G. olidus* had a four week spawning period starting a few weeks earlier than *G. fuscus*, in early August, and being completed by early September (Fig. 3).

G. fuscus appears to begin running ripe earlier than does *G. olidus* (Fig. 3). By the middle of May 90% of the *G. fuscus* population is in a ripe stage, whereas *G. olidus* are not running ripe until late June. *G. fuscus* starts to develop reproductively quite early, then appears to wait through most of winter before spawning (Fig. 3).

Spawning in *G. fuscus* and *G. olidus* occurred on the increasing photoperiod, with the change in seasons from winter to spring (Fig. 3). There did not appear to be any relationship between water temperature, conductivity or the onset of the snow melt with the spawning of *G. fuscus* or *G. olidus*. Water temperature during the spawning period varied between 4.5°C to 7°C (Fig. 3) showing no distinct trend, and the conductivity remaining very stable between 0–9 μs cm^{-1} for the length of the study. The major snow melt did not begin until early October, well after spawning of both species was complete.

Examination of the fecundity of *G. fuscus* revealed a mean egg number of 512 eggs (range 249–1002) the individuals examined had a mean length of 106 mm (range 83–142). Comparison of the fecundity of *G. olidus* (data from O'Connor & Koehn 1991) and *G. fuscus* (Fig. 4) revealed little differences in the fecundity of the two species. As with *G. olidus* (O'Connor & Koehn 1991) the number of eggs of *G. fuscus* is positively correlated with fish length ($r^2=0.748$, $p<0.001$).

A range of areas within the stream were sampled, both visually and with drift nets, for *G. fuscus* eggs, including spawning substrates known to be utilised by *G. olidus*, but no eggs of *G. fuscus* were found.

Limited spatial data, indicated a preference by *G. fuscus* for slow flowing areas of the stream with water velocity of between 0 and 0.20 m/s, compared to a mean stream velocity of 1.15 m/s. The microhabitat areas utilised were not isolated from the main stream but were usually immediately adjacent to faster flowing water (0.55 to 2.01 m/s). *G. fuscus* also showed a preference for the deeper areas of the stream, with the mean depth of microhabitat being 434 mm compared to a mean overall stream depth of 235 mm. The areas of *G. fuscus* habitat were significantly deeper than the mean stream depth (ANOVA, F=212.947, df=1, $p<0.001$). Substrate did not appear to be important in the choice of microhabitat as *G. fuscus* were found on all substrate types in similar proportions to the habitat availability.

DISCUSSION

G. fuscus were found to have a late winter early spring spawning period during 1991 extending from August until September. The population of *G. olidus* studied was also found to spawn during the late winter–early spring period,

Fig. 2. Length–frequency graphs for *Galaxias fuscus* in the Keppel Hut Creek and the Taggerty River and *Galaxias olidus* in Little River.

although spawning began two to three weeks earlier than for *G. fuscus*. O'Connor & Koehn (1991) reported *G. olidus* spawning at a similar time of year in Bruces Creek Victoria, although it extended into October, and populations of *G. olidus* in the ACT have been found to spawn

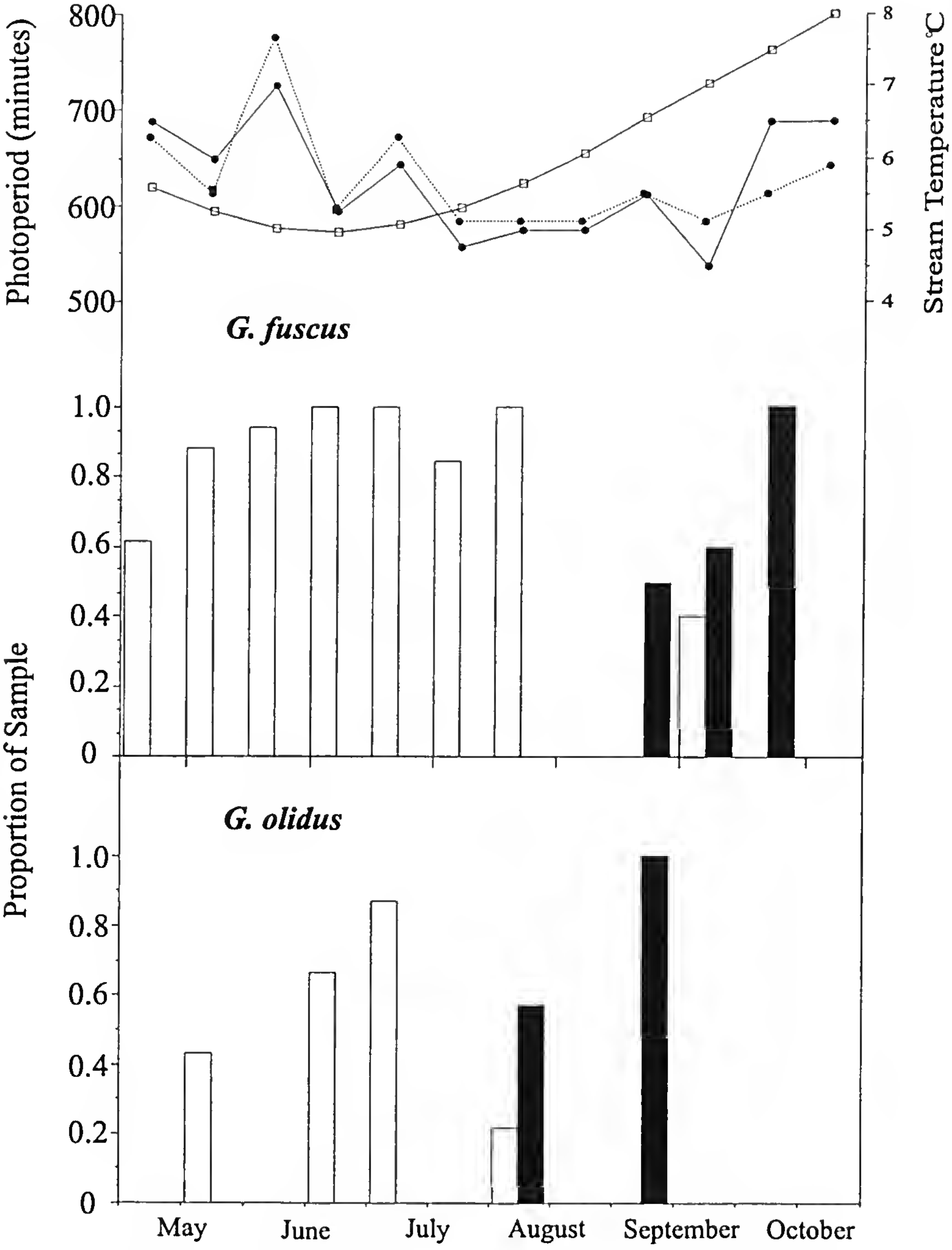


Fig. 3. The relative proportions of ripe (☐) and spent (■) *Galaxias fuscus* and *Galaxias olidus* collected during 1991. With photoperiod (–⊟–) and water temperature for the Taggerty River (–●–) and the Little River (....●....) for the same period.

over a similar period but beginning as early as July (Cowden 1988). There appears to be variability in the time of spawning between different populations of *G. olidus* across the geographic range of the species. There is a slight difference in the timing of spawning of *G. fuscus* and *G. olidus* but it is difficult to attribute this to differences between the taxa, because of the intraspecies variation in spawning time through the *G. olidus* complex.

G. fuscus spawned on the increasing photoperiod, with the increasing daylength possibly being the cue to initiate spawning. Changes in the duration of photoperiod have been linked to spawning in other species of endemic fish such as *Galaxias truttaceus* (Humphries 1989) and the gudgeon *Mogurnda adspersa* (Hansen 1988). Temperature has also been suggested as a cue for spawning (Backhouse & Vanner 1978; Tunbridge 1988; Humphries 1989). There were variations in water temperature in the habitat of *G. fuscus* and no clear temperature trend was apparent around the time of spawning. Hence it is not possible to say whether an increase or decrease in water temperature influenced the time of spawning. We suggest that it is the change from decreasing to increasing daylength which triggers spawning in *G. fuscus*, which then occurs on the increasing photoperiod. The *G. olidus* population in Little River also spawned on the increasing photoperiod, with no noticeable trend in water temperature.

There did not appear to be a significant difference in the fecundity of *G. olidus* and *G. fuscus*. *G. fuscus* were the larger individuals with more eggs but, as the closeness of the regression lines reveal, the ratio of fecundity to length seemed to be similar for the two species.

Our study found that *G. fuscus* had a distinct

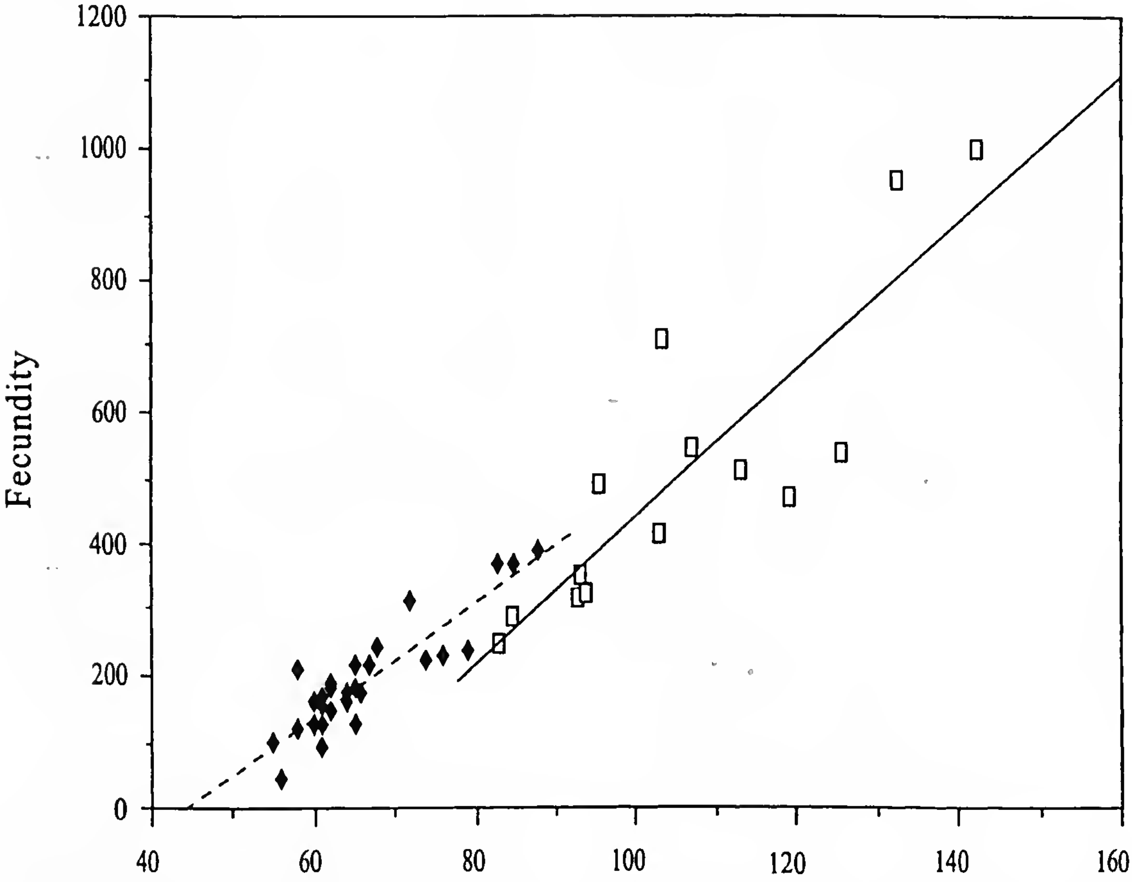


Fig. 4. Relationship between fecundity and length (L.C.F.) for *Galaxias fuscus* (□) with data for *Galaxias olidus* (◆) overlaid from O'Connor & Koehn (1991).

preference for the deeper slow flowing areas of the streams, that is for the pools rather than riffles or cascades. O'Connor & Koehn (1991) found that *G. olidus* were also found predominantly in pools. *G. olidus* inhabits riffles (O'Connor & Koehn 1991), whereas no *G. fuscus* were found in riffles in this study. The lack of *G. fuscus* in riffles may be because they are in lower densities and consequently are not forced into the less favoured riffle habitat, whereas *G. olidus* are forced into the riffle habitats because of their relatively higher instream densities.

G. fuscus is on average a larger fish than *G. olidus*, with more fish in larger size classes and a larger maximum size than *G. olidus* (Table 2). This indicates that *G. fuscus* has either a higher growth rate or a greater longevity in comparison to *G. olidus*. It is difficult to clarify the growth rates of *G. olidus* or *G. fuscus* due to the inconclusive nature of previous work using otoliths for ageing (Cowden 1988; Drayson 1989) and the lack of clear cohorts in our size frequency distributions. Because of the increased length of reproductive investment by *G. fuscus* and the energetic input involved, it is suggested that *G. fuscus*' greater size is attained through greater longevity rather than higher growth rates than *G. olidus*. Thus *G. fuscus* would grow at a similar rate as *G. olidus*, but live for a longer period.

Application of the size classes from O'Connor & Koehn (1991) to the *G. fuscus* population shows that there is a greater proportion of larger *G. fuscus* than there is *G. olidus*. The *G. fuscus* population supports a high proportion of large fish, whereas O'Connor & Koehn (1991) found relatively few *G. olidus* in the 3+ size class. Populations of *G. fuscus* appear to be able to sustain a greater proportion of larger fish than populations of *G. olidus*.

The lower instream density of *G. fuscus* relative to *G. olidus* may mean that *G. fuscus* is under comparatively less pressure for food and habitat space than *G. olidus*. Consequently the lower pressure upon *G. fuscus* may allow the taxon to live longer and attain the greater size recorded. The low instream density of *G. fuscus* may be as a result of high juvenile mortality or aggressive and territorial behaviour contributing to lower population densities of *G. fuscus*.

Because of sampling inefficiencies due to the equipment used, the extremely low conductivities and the constraints placed on sampling, because of the endangered status of *G. fuscus*, it is difficult to extrapolate much about the densities of *G. fuscus*. It is possible to compare the density of the *G. fuscus* populations in the Taggerty River and Keppel Hut Creek with the *G. olidus* densities in Little River because of a continuity of sampling techniques. The instream population densities of *G. fuscus* were significantly less than the densities of *G. olidus* found in Little River by this study (0.051–0.196 fish m^{-2}) or by other previous authors such as O'Connor & Koehn (1991) (1.31–1.70 fish m^{-2}), Tilzey (1976) (2.25–3.70 fish m^{-2}) and Jones et al. (1991) (14.90 fish m^{-1}).

The sex ratio of sexually mature *G. fuscus* did not differ significantly from 1:1, this is in agreement with both O'Connor & Koehn (1991) and Cowden (1988) who both found an overall sex ratio of 1:1. In our study it was not possible to accurately determine whether there was a change in the sex ratio over time particularly in the lead up to spawning, because of the limited size of our samples, as has been suggested for *G. olidus* by several authors (Cowden 1988; Drayson 1989; O'Connor & Koehn 1991).

Further work is required to fully understand the ecology of *G. fuscus* and its relationship within the *G. olidus* complex. Examination of the spawning period over several seasons at more sites is necessary and will increase the chance of finding the sites of egg deposition. An accurate determination of the age cohorts and growth rate of *G. fuscus* and also *G. olidus* is also required.

This initial study has shown that there are some ecological differences between *G. fuscus* and *G. olidus*. The two taxa have a slightly different spawning period, although the site of egg deposition remains unknown for *G. fuscus*. *G. fuscus* is on average a larger fish, which spends more time developing reproductive material. *G. fuscus* populations studied also exist in lower instream densities than known *G. olidus* population densities and *G. fuscus* is very specific in its microhabitat requirements. *G. olidus* prefers pools but is also found in riffles whereas *G. fuscus* was found solely in slow flowing deeper areas of stream (pools). The indications are that further work will show that the ecology of *G. fuscus* and *G. olidus* are further polarised. The differences found in this study lend support to the resurrection of distinct species status for *G. fuscus*.

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A LATE PALAEOCENE OSTRACODE FAUNA FROM THE PEBBLE POINT FORMATION, SOUTH-WEST VICTORIA

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Neil, John V, 1997:12:31. A Late Palaeocene ostracode fauna from the Pebble Point Formation, south-west Victoria. *Proceedings of the Royal Society of Victoria* 109(2): 167–197. ISSN 0035-9211.

Forty-four taxa are recorded from the Late Palaeocene Pebble Point Formation, Otway Basin, Victoria. The formation is diachronous. In the absence of diagnostic species, the age assessment of Late Palaeocene must be regarded as tentative. Fresh details are given of *Trachyleberis careyi*, *Margocythere* sp. and a number of previously described *Munseyella* species. Because of the poor preservation of much of the fauna, 23 taxa are left in open nomenclature. Two new species, *Pelecocythere parageois* and *Munseyella kleithria*, are described. The former is the oldest record of this genus and the first occurrence in a shallow-water fauna. The latter species is the most abundant of the substantial population of pectocytherids and one of the most common elements in the assemblage. The environment was of the marine, inner shelf type and not as high energy as previously thought. The earliest recorded species of *Pelecocythere*, a cosmopolitan deep-water genus in present-day waters, in a relatively shallow-water environment, adds strength to the proposal that many such species originated in shallow waters and have migrated to the deep sea environment subsequently.

Keywords: Ostracoda, Late Palaeocene, taxonomy, palaeobathymetry, Otway Basin, Victoria.

OSTRACODE faunas from the Palaeogene of south-east Australia have recently been described by McKenzie et al. (1991, 1993). Their papers discuss assemblages from the Late Eocene Gull Rock Member of the Blanche Point Formation in the Willunga Embayment of South Australia, the Late Oligocene Jan Juc Formation at Bell's Headland, Victoria and the Middle (?) and Late Eocene Brown's Creek Clay in the Aire River district of Victoria. Majoran (1995, 1996a, 1996b) also discusses Late Eocene ostracodes from the Blanche Point Formation, in South Australia. However, this paper is the first to describe Palaeocene Ostracoda from an Australian locality, and so extends the taxonomic work on south-east Australian faunas across almost the full range of the Tertiary. The Pebble Point Formation is the only fossiliferous marine Palaeocene formation in Victoria and is difficult to access in its coastal outcrops. Extensive picking has produced a substantial assemblage, though many specimens are broken, and adherent matrix makes identification frequently problematical. However, there are sufficient well-preserved specimens free of matrix to permit a reasonably comprehensive description of the fauna.

Evidence of a microfauna in the coeval inland outcrops of the 'Bahgallah Formation' (regarded as a junior synonym of the Pebble Point Formation [Abele et al. 1988]) has yet to be established. The writer examined core material from two bores in southwestern Victoria which penetrate the Pember Mudstone. Darragh (1994) found bivalves in this material (2125–2131 ft. Kaladbro 2; 1492–1502 ft. Mumbannar 1), though he misidentifies the Mumbannar 1 water bore as the Mersey Valley Oil Co.'s 1926 bore of the same name which bottoms out at 1100 ft. (Spencer-Jones & Kenley 1971). The Pember Mudstone is regarded as a little younger than the Pebble Point Formation (White 1996; Tickell et al. 1992). Kaladbro 2 and Mumbannar 1 (both Department of Mines water bores) yielded a microfauna of *Cyclammina* spp., but no ostracodes.

PREVIOUS WORK

There is no previous published work on the ostracode fauna of the Pebble Point Formation. Neither Wilkinson (1865), nor Murray (1875) makes any reference to a microfauna of this formation. Papers on the molluscs and nautiloids by Singleton (1943) and Teichert (1943) respectively are referred to by Baker (1943), and are the first published formal decriptions of fossils from this formation, apart from brief references in Dennant and Kitson (1903) and Dennant (1904). Parr and Glaessner list foraminifera in an appendix to Baker's 1943 paper, having had their attention drawn to the microfauna by Baker. They also refer to the occurrence of ostracodes. I have examined material collected by Parr in 1915 for ostracodes, but only two samples, both from Locality PL3003, yielded any specimens. McGowran (1965) refers to the Pebble Point Formation as 'renowned for the rarity and difficulty in extraction of its microfauna'. McGowran (1965, 1970) monographs the foraminiferal faunas of the Pebble Point Formation and the overlying Dilwyn Formation, and deals with their biostratigraphy in detail. Darragh (1985, 1986, 1994) has monographed the bivalves of the molluscan fauna.

LOCATION AND NATURE OF THE FORMATION

The Pebble Point Formation of Baker (1953) is exposed in coastal cliffs. These outcrops are generally sparsely fossiliferous, with the carbonate of the fossils unaltered. Inland outcrops are highly ferruginised and weathered, so that the macrofauna is usually very difficult to determine and often exists only as moulds (Darragh 1994). It is possible that the microfauna of these inland outcrops may have survived the diagenetic changes better than the larger shells, but no work has been done on it at present. Darragh's suggestion that the Palaeocene marine incursion in the Otway Basin may have been far more extensive than previously recognised could be tested by investigating for such a microfauna.

Most of the specimens referred to in this paper come from a cove between 'Buckley Point' and 'Point Pember' (unofficial names given by Baker [1950]), 4.5 km SE of Princetown (GR 894109 Princetown Topographic Map 1:25 000). This is No. PL 3003 in the Museum of Victoria Fossil Locality Register. The specimens occur in 'a dark greenish gray gravelly friable clay' (W. J. Parr's manuscript field notes, held in Museum of Victoria) in a fallen block. A small number of specimens was also recovered from a sample from 'the low cliff midway between Wilkinson's Locality 7 and the next point to the south-east of Point Ronald' (Parr's field notes) PL3001 in the register. This sample was described as 'a gray clay'.

AGE OF THE FORMATION

A tentative assignment of the Pebble Point Formation to the Palaeocene was made by Singleton (1943), although Baker (1953) was still undecided, and referred to it as 'Lower Eocene to Palaeocene'. Raggatt and Crespin (1955) were virtually convinced that the formation was Palaeocene. A decade later, McGowran's papers (1965, 1970) assign a Middle Palaeocene age, based on planktonic foraminifera. In a later paper (1991), he revises this age upwards to Late Palaeocene, which is accepted by Darragh (1994), although Tickell et al. (1992) state that rare planktonic foraminifers at the type locality indicate mid-Palaeocene Zone P3. The Pebble Point Formation extends in borehole sections into the Late Cretaceous, and so ranges through the whole of the Palaeocene (Tickell et al. 1992), but the outcrops sampled for this study are near the top of the Victorian section. White (1995, 1996) has shown the South Australian section of the Pebble Point Formation in the Gambier Basin ranging from P5 (Late Palaeocene) into P8 (middle Early Eocene), on the basis of pollen zonation and global sequence stratigraphy (McGowran 1991). However, this determination is based on correlating the start of Pebble Point sedimentation with the Pebble Point Ingression (McGowran 1991) in the latest Late Palaeocene. These differences in the age range attributed to the Pebble Point Formation are substantial, with the Cretaceous–Tertiary boundary unconformable in the South Australian sections (White 1995), and conformable in the Victorian sections (Tickell et al. 1992). The formation, as presently defined, is diachronous. In the absence of diagnostic fossils, and in view of the substantial number of taxa in the ostracode assemblage studied here which also occur in Eocene strata (McKenzie et al. 1991, 1993), an age assessment of Late Palaeocene must be regarded as tentative.

COMMENTS ON THE FAUNA

Although initial picking of the samples for this study seemed to indicate that the specimens would be limited both in number and variety, the size and diversity of the assemblage increased markedly as additional material supplied by Dr T. A. Darragh was examined. Over 1000 identifiable specimens were obtained, though many of these are broken or fragmentary.

Preservational characteristics

The preservation of the valves and carapaces is generally good from a broad morphological point of view, though detail at high magnification suffers because of replacement of shell material and/or pitting due to weathering and diagenetic processes. There is a relatively high proportion of carapaces (14%) in the assemblage, particularly of *Trachyleberis careyi* and *Munseyella* species, indicating rapid burial. Even *Pelecocythere parageois* has an occasional carapace, though the larger specimens of *Trachyleberis* and *Pelecocythere* are often broken or fragmentary. Because of the changes in shell structure referred to above, this breakage may have occurred in the preparation of the samples rather than in the environment of deposition.

Composition

The dominance of the fauna by the large trachyleberid *T. careyi* is quite marked (almost 25%). It is a real dominance, and not due to the large size and robustness of the valves, since substantial numbers of small and relatively fragile specimens have been found in the samples. However, there is a very small proportion of hemicytherids, which is in marked contrast to younger faunas such as that from the Miocene Muddy Creek Marl to the north-west (Neil 1992, 1994). This may reflect the later evolutionary development of hemicytherids in southeastern Australia, since the two most abundant genera in the range of assemblages of Late Oligocene to late Middle Miocene age from right across southern Australia are the hemicytherids *Hermanites* and *Quadracythere* (Neil 1995).

Munseyella species are the second most abundant group (>20%). McKenzie, Reyment & Reyment (1993) have commented on this abundance in relation to the faunas from the Eocene localities of Browns Creek and Castle Cove, which are quite close to Pebble Point. Because of the security of the pentodont hinge, and the lower energy environment, many *Munseyella* specimens are found as carapaces. In general, pectocytherids do not comprise a substantial component in other southeastern Australian assemblages studied by the writer (Neil 1992, 1994, 1995), although they do form a large proportion of the fauna occurring in the Miocene Upper Morgan and Pata Limestones of South Australia (McHenry, pers. comm. 1996), and the New Zealand Tertiary (Hornibrook 1952; Ayress 1995).

The relative abundance (6th most abundant species) of *Pelecocythere parageios* sp. nov. is a striking feature of the Pebble Point Formation fauna, since the genus has not previously been recorded from a shallow-water environment, nor from from other Tertiary faunas from southeastern Australia (see Neil 1992, 1993, 1995; McKenzie 1974; McKenzie et al. 1991, 1993; Warne 1987; Whatley & Downing 1983). It is also the earliest record of the genus, which is a distinctive element in deep-water faunas in the Pacific and Atlantic Oceans (Benson & Peypouquet 1983; Neale 1988; Whatley & Ayress 1988; Coles, Ayress & Whatley 1990; Whatley & Coles 1991; Correge 1993).

The absence of adult bairdiids, which are also large and robust, is unusual, given the presence of juvenile valves of *Neonesidea* spp. McKenzie et al. (1991, 1993) have not recorded large numbers of bairdiids in their Late Eocene faunas, nor has the common *Neonesidea australis* of the mid-Tertiary been recorded from strata older than the Late Oligocene. However, a complete absence of adult valves is an unusual circumstance. Loxoconchids are absent from the Pebble Point Formation. This contrasts sharply with their abundance in the Middle Miocene Muddy Creek Marl (Neil 1992, 1994) and in the southern Australian assemblages referred to above. The family Nunanidae with new species and genus *Nunana australiae* (McKenzie et al. 1993), is well represented in this assemblage. In diagnosing this new family, McKenzie et al. make reference to some similarities with Xestoleberididae, but the Nunanidae generally stand alone, particularly in relation to their small size.

Rare species, defined as comprising less than 1% of the total, aggregate more than half the number of identified species. This is somewhat surprising, since rare species are often the small fragile ones which have less chance of being preserved. Such small, fragile specimens represent a substantial component of the total assemblage, even allowing for broken and fragmentary material. Some of these rare genera which also occur in deep-water assemblages, and the relative abundance of *Pelecocythere parageois*, point towards a shallow-water origin for what later become diagnostic deep-water forms. This is referred to further in the conclusion to this paper.

The composition of the fauna is thus quite distinctive, even allowing for the occurrence of many species found in the Late Eocene faunas described by McKenzie et al. The dominance of *Trachyleberis careyi* and the notable presence of *Pelecocythere parageios* and ?*Nunana* sp. are positive factors in this distinctiveness, whilst the absence of hemicytherids, loxoconchids and adult bairdiids are negative factors.

CAPTIONS FOR THE PLATES

The specimens are housed in the invertebrate palaeontology collections of the Museum of Victoria, and are identified by numbers prefixed by the letter P. The following abbreviations are used: RV, right valve; LV, left valve; C, carapace; F, female; M, male; J, juvenile; ext., exterior; int., interior. Locations are indicated in the text. Magnifications are given for each micrograph.

SYSTEMATIC PALAEONTOLOGY

Note on taxonomic methodology

In dealing with a microfauna which includes many broken and fragmentary specimens, and which exhibits a wide range of preservational effects, it is necessary to make some modification to customary taxonomic procedure. Although a holotype (or type specimen) is designated for each new species which has been erected, the description makes reference to the hypodigm (Simpson 1940) in order to cover a wide range of taxonomic features. Since the fauna includes many broken or poorly preserved specimens with much adherent matrix, it is very difficult to choose a holotype which is sufficiently representative of the full range of taxonomic characters necessary for establishing a new species. On the other hand, choosing additional fragmentary or poorly preserved specimens as paratypes is unsatisfactory, since such specimens often display only one or two important taxonomic characters in an otherwise unrepresentative context. Measurements of the holotype are given in millimetres, together with the range of dimensions shown by the hypodigm, where appropriate. The classification followed is generally that put forward by Hartmann & Puri (1974).

A complete species/location list is available from the author.

Order PODOCOPIDA G. W. Mueller, 1894

Suborder PLATYCOPA Sars, 1866

Family CYTHERELLIDAE Sars, 1866

Cytherella Jones, 1849

Type species. Cytherina ovata Roemer 1840.

Cytherella cf. **pinnata**
McKenzie, Reyment & Reyment, 1993

Cytherella pinnata McKenzie, Reyment & Reyment 1993: 78, pl. 1, figs 1, 2.

Figured specimens. Fig. 4C (P146936); Fig. 9F (P146974).

Remarks. This species of *Cytherella* is very close in shape to *C. pinnata*, but it is smaller than that species. It constitutes a substantial proportion of the assemblage (7.9%). Since the muscle scars cannot be distinguished, though some specimens are well-preserved, these specimens can only be compared with *C. pinnata*. A relationship from the Late Palaeocene of Pebble Point to the nearby Late Eocene of Brown's Creek and Castle Cove is quite possible.

Measurements. P146936—L=0.56, H=0.36; P146974—L=0.78, H=0.50.

Material studied. 83 specimens, some broken, and including males, females, carapaces and juveniles.

Occurrence and age. 79 from PL3003; 1 from between Buckley's Point and Point Margaret; 3 from SE of Point Pember, PL3001 (W. J. Parr Collection). Late Palaeocene.

Cytherelloidea Alexander, 1929

Type species. Cythere (Cytherella) williamsoniana Jones 1849.

Cytherelloidea marginopytta
McKenzie, Reyment & Reyment, 1991

Cytherelloidea sp. McKenzie 1979: 90, p. 11, fig. 7.
Cytherelloidea marginopytta McKenzie, Reyment & Reyment 1991: 140, pl. 2, fig. 1; pl. 10, figs 2, 3.
Cytherelloidea marginopytta McKenzie, Reyment & Reyment 1993: 79, pl. 1, fig. 10.

Figured specimen. Figs 4A, B (P146935).

Remarks. McKenzie et al. (1993) allow a range of ornament in this species. The single specimen figured here is somewhat smaller, has a more marked marginal ridge and a slightly different pattern of pitting from those previously described, but is regarded as conspecific with them because of its basic pattern of ornamentation. Specimens of *C. marginopytta* occur in the collections of the writer from Fishing Point (Early Miocene); Point Addis (Late Oligocene) and Clifton Bank (late Early Miocene).

Measurements. P146935—L=0.59, H=0.36.

Material studied. 1 valve, possibly a juvenile.

Occurrence and age. PL3003. Late Palaeocene. *Cytherelloidea* sp. McKenzie 1979 from the Late Eocene Gull Rock Member, Blanche Point Formation of the Willunga Embayment, South Australia; specimens from the Late Oligocene at Bell's Headland and Point Addis and Miocene specimens referred to above give a range from Late Palaeocene to late Early Miocene.

Suborder PODOCOPA Sars, 1866

Family BAIRDIIDAE Sars, 1888

Neonesidea Maddocks, 1969

Neonesidea spp.

Figured specimen. Fig. 4G (P146940).

Remarks. A small number (8 specimens) of juvenile *Neonesidea* spp., mostly fragments, were recorded. A well-preserved specimen has been figured.

Measurements. P146940–L=0.53, H=0.30, W=0.12.

Material studied. 8 specimens.

Occurrence and age. PL3001; PL3003. Late Palaeocene.

Family CYTHERIDAE Baird, 1850

Subfamily CYTHERINAE Baird, 1850

Microcytherura Mueller, 1894

Type species. Microcytherura nigrescens Mueller, 1894

Microcytherura sp.

Figured specimens. Fig. 6A; Fig. 10D (P146950, P146979).

Remarks. The presence of several species from the *Loxocythere/Microcytherura* continuum (see Hartmann 1982) is a distinctive feature of this assemblage. These specimens have a closely punctate surface with some evidence of reticulation (Fig. 10D), reminiscent of the Recent form *M. peterroyi* Yassini and Jones 1995.

Measurements. P146950—L=0.36, H=0.20, W=0.12; P146979—L=0.34, H=0.19, W=0.12.

Material studied. 7 specimens.

Occurrence and age. PL3003. Late Palaeocene.

Loxocythere Hornibrook, 1952

Type species. Loxocythere crassa Hornibrook, 1952.

Loxocythere malzi
McKenzie, Reyment & Reyment, 1993

Loxocythere malzi McKenzie, Reyment & Reyment 1993: 84–86, pl. 2, fig. 5.

Figured specimens. Fig. 6D (P146953); Fig. 81 (P146971).

Remarks. This species is a relatively common component in the assemblages. Although McKenzie et al. (1993) illustrate only one specimen, a broken female carapace, from a total of 12 specimens, their description makes it clear that these Pebble Point specimens are conspecific.

Measurements. P146953—L=?, H=0.28; P146971—L=0.46, H=0.30, W=0.11.

Material studied. 37 specimens, many broken or fragmentary.

Occurrence and age. PL3003. Late Palaeocene.

Loxocythere sp. aff. **L. hornibrooki**
McKenzie, 1967

Loxocythere hornibrooki McKenzie 1967: 68–69, pl. 11, fig. 2.

Microcytherura (Loxocythere) hornibrooki Hartmann 1982: 120–121, text-figs 1, 2, pl. 1, figs 1, 2.

Figured specimens. Figs 6E, G (P146954, P146956).

Remarks. Although these specimens are Palaeocene, and McKenzie's and Hartmann's are from the Recent, there is a substantial similarity in the reticulation. Internal features cannot be compared because of poor preservation and adherent matrix, but McKenzie's (1967) comment '... reticulate carapace in which the reticules themselves are microreticulate or micropunctate' is borne out with these specimens. Sexual dimorphism noted—males longer and less high.

Measurements. P146954—L=?, H=0.26; P146956—L=0.51, H=0.25.

Material studied. 2 specimens.

Occurrence and age. PL3003. Late Palaeocene.

Loxocythere sp. cf. **L. ouyenensis**
(Chapman, 1914)

Cytherura ouyenensis Chapman 1914: 44–45, pl. 8, figs 35a, 35b.

Loxocythere ouyenensis McKenzie 1981: 106.

Figured specimen. Fig. 6C (P1469952).

Remarks. This specimen is more strongly reticulated than Chapman's species, which shows signs of abrasion that may have reduced the ornamentation. I have found specimens in the Miocene Muddy Creek Marl which are less markedly reticulate but in other respects very similar to the Pebble Point material. There is no evidence of microreticulation or micropunctation as in the material from this assemblage assigned to *L.* sp. aff. *hornibrooki*.

Measurements. P146952—L=0.49, H=0.26, W=0.15.

Material studied. 1 specimen.

Occurrence and age. PL3003. Late Palaeocene.

Family PECTOCYTHERIDAE Hanai, 1957

Remarks. Genera of this family are well represented in the assemblages described by McKenzie, Reyment & Reyment (1993) from the Eocene Browns Creek Clays of Brown's Creek and Castle Cove close to Pebble Point. The family is largely unrepresented in the assemblages from the Eocene of South Australia (no specimens) and the Oligocene of the Victorian coast further east from Pebble Point (three specimens), which these writers have also monographed, although Majoran (1995, 1996) records pectocytherids from the Eocene of the Port Willunga Embayment. The abundance of pectocytherids in the Cape Otway section of the Victorian coastal Tertiary deposits is therefore a distinctive provincial feature.

Premunseyella Bate, 1972

Type species. Premunseyella ornata Bate, 1972.

?Premunseyella imperfecta Bate, 1972

Figured specimen. Fig. 2F (P146926).

Remarks. A single valve, similar to those figured by Bate (1972) and Neale (1975), though exterior preservation is not as good.

Measurements. P146926—L=0.46, H=0.20.

Material studied. 1 specimen.

Occurrence and age. PL3003. Late Palaeocene.

Munseyella van den Bold, 1957

Type species. Munseyella hyalokystis (Munsey, 1953).

Munseyella kleithria sp. nov.

Etymology. From the Greek *kleithria*—a keyhole; a reference to the characteristic pierced area of the reticulation.

Types. Holotype—P146910 (LV); Paratypes—P146911 (carapace), P146912 (RV), P146913 (LV), P146914 (RV).

Figured specimens. Figs 2A, B, C (P146910, P146911, P146912); Figs 9D, E (P146913, P146914).

Type locality. PL3003. Late Palaeocene.

Diagnosis. A strongly reticulate *Munseyella*, with a pierced fossa subcentrally, and a marked, narrow marginal ridge on all sides.

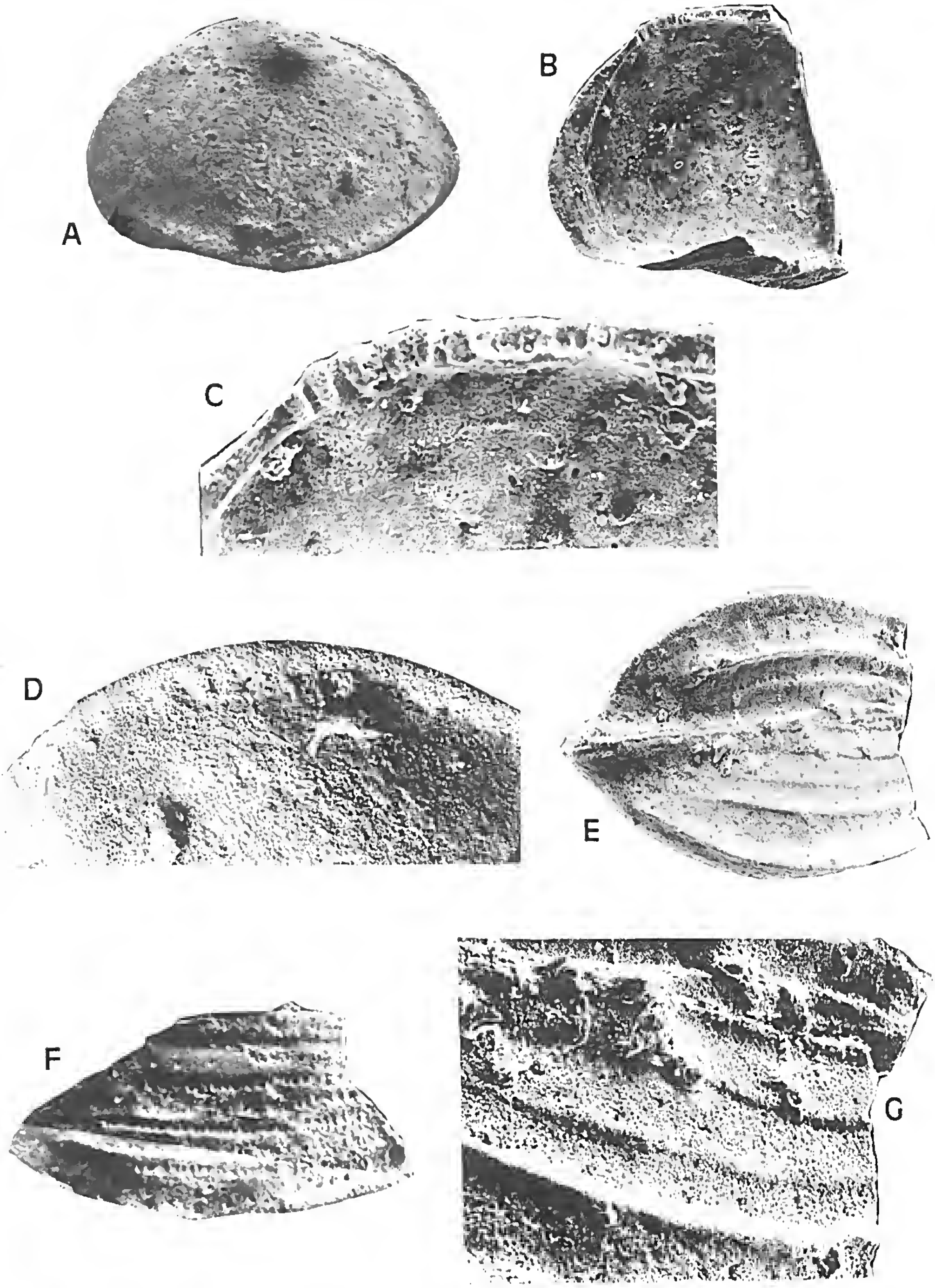
Description. Valves subquadrate, with females higher anteriorly than males. Reticulation strongly developed; sharp-edged muri; pierced fossa just below subcentral area; lateral lines of reticulation meander from anterior to posterior, with vertical borders of fossae not linked. Marginal flange almost complete from posterodorsal indentation clockwise through venter, anterior and dorsum, terminating with inclined ridge from posterodorsal angle to a postero-medial point behind posterior flange. Postero-dorsal angle marked by high, sharp, concavity of flange. Flange sharp-edged and concave inwards. Anterior groove behind flange. No eye tubercle.

Internal features not readily discerned. Inner lamella narrow in both anterior and posterior. No vestibules. Muscle scars not determined. Hinge pentodont, median bar probably crenulate.

Affinities. M. kleithria is the most strongly reticulate species of this genus from southeastern Australia. Most of those figured by McKenzie et al. (1991, 1993) are either punctate, punctate-reticulate or have large, rounded ridges. These latter species are represented in this assemblage (see below). *M. splendida* Whatley & Downing (1983) is also characterised by large, rounded ridges. *M.* sp. McKenzie (1974) is reticulate, but in broader style, as well as having two caudal projections, and in the author's view is better assigned to Keijia. McKenzie (1979) figured a punctate *Munseyella* from South Australia. *M. modesta* Swanson and *M. pseudobrevis* Ayress from the Eocene of New Zealand, and *Swansonites intermedia* Milhau, which is also a *Munseyella*, from the Miocene of New Zealand, are likewise not strongly reticulate *M. punctata* Yassini & Jones, from the Recent of Bass Strait, is a punctate form.

I found no reticulate *Munseyella* species in the Middle Miocene Muddy Creek Marl of south-western Victoria (Neil 1992).

Fig. 1. All figures are of *Pelecocythere parageois* sp. nov. A, P146905 LV ext. ×45. B, P146906 RV int. ×60. C, P146906 RV anterior hinge elements ×180. D, P146905 LV detail of alar flange ×90. E, P146907 C ventral surface (broken specimen) ×60. F, P146908 J ventral surface detail (broken specimen) ×90. G, P146907 C ventral surface detail ×135.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Remarks. The abundance of this species of *Munseyella* (and of other species of the genus) in this assemblage is noteworthy, and is congruent with the large numbers of specimens of the genus found in Victorian Eocene localities by McKenzie et al. (!993). Generally, pectocytherids are representative of shallow-water environments (McKenzie 1979).

Measurements. P146910 (Holotype)—L=0.52, H=0.28; P146911 (Paratype)—L=0.52, H=0.24, W=0.24; P146912 (Paratype)—L=0.51, H=0.28; P146913 (Paratype)—L= 0.48, H=0.24; P146914 (Paratype)—L=0.51, H=0.25.

Hypodigm ranges (adults). Length 0.50–0.52, height 0.24–0.28, width 0.11–0.12.

Material studied. 102 specimens, including 44 carapaces and some identifiable fragments.

Munseyella warringa
McKenzie, Reyment & Reyment, 1993

Munseyella warringa McKenzie, Reyment & Reyment, 1993: 96, pl. 4, figs 11–13; pl. 8, fig. 9.

Figured specimens. Fig. 2E; Fig. 10F (P146918).

Remarks. These specimens conform to the somewhat variable criteria set down by McKenzie et al. (1993). Polymorphism of the punctation is reflected in the absence of ridging between the punctae (as in fig. 13 of pl. 4). The medioventral ala is not marked, but the characteristic knob is evident.

Measurements. P146918—L=0.38, H=0.19.

Material studied. 16 specimens.

Occurrence and age. PL3001; PL3003. Late Palaeocene.

Munseyella dunoona
McKenzie, Reyment & Reyment, 1993

Munseyella dunoona McKenzie, Reyment & Reyment 1993: 96, pl. 4, figs 7–10.
Munseyella dunoona Majoran 1995: 77, fig. 3L.
Munseyella dunoona Ayress 1995: 909, fig. 8, nos 10, 11.

Figured specimens. Figs 2H, I (P146920, P146921).

Remarks. *M. dunoona* occurs in limited numbers in these assemblages. These specimens show the almost complete marginal ridge and branching 'crossroad' pattern referred to by McKenzie et al. (1993) making them conspecific. The specimen figured by Majoran (1995) does not clearly show these features.

Measurements. P146920—L=0.47, H=0.23, W=0.20; P146921—L=?, H=0.22,

Material studied. 12 specimens.

Occurrence and age. PL3001, PL3003. Late Palaeocene.

Munseyella sp. cf. M. adaluma
McKenzie, Reyment & Reyment, 1993

Munseyella adaluma McKenzie, Reyment & Reyment 1993: 94, 96, pl. 4, figs 3–6; pl. 8, fig. 8.

Figured specimens. Fig. 2D; Figs 8B, D; Fig. 10B (P146915, P146922, P146924).

Remarks. It is sometimes difficult to discern the pattern of ornament in the reticulate and punctate forms of *Munseyella* in this assemblage, because of the effects of weathering and diagenesis (Fig. 10B). These specimens are closest to *M. adaluma* with their deeply punctate lateral surfaces, and strongly developed anterior ridge with two deep arcuate loculi behind it. However, the absence of a postrodorsal projection and the random distribution of punctae make their assignment to *M. adaluma* tentative.

Measurements. P146915—L=0.48, H=0.23, W=0.18; P146922—L=0.41, H=0.21; P146923—L=0.46, H=0.21, W=0.18.

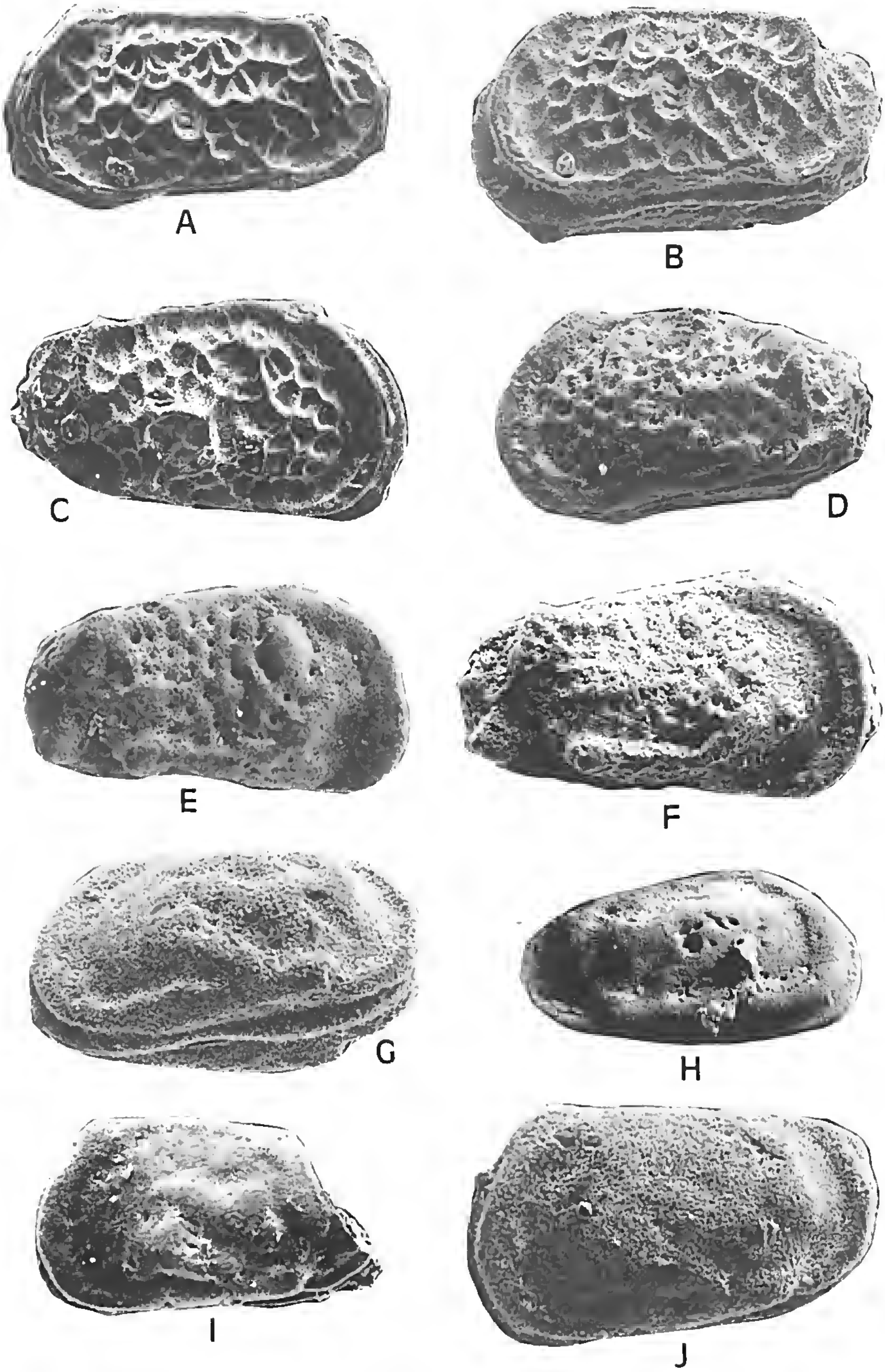
Material studied. 5 specimens.

Occurrence and age. PL3003. Late Palaeocene.

Munseyella sp. cf. M. bungoona
McKenzie, Reyment & Reyment, 1993

Figured specimens. Figs 2G, J; Fig. 9C (P146916, P146917, P146919).

Fig. 2. A, *Munseyella kleithria* sp. nov. P146910 LV ext. ×100. B, *Munseyella kleithria* sp. nov. P146911 C (LV) ext. ×100. C, *Munseyella kleithria* sp. nov. P146912 RV ext. ×110. D, *Munseyella* sp. cf. *M. adaluma* P146915 C (LV) ×120. E, *Munseyella warringa* P146918 RV ext. ×150. F, *?Premunseyella imperfecta* sp. P146926 F, RV ext. ×140. G, *Munseyella* sp. cf. *M. bungoona* P146916 C (LV) ×140. H, *Munseyella dunoona* P146920 RV ext. ×120. I, *Munseyella dunoona* P146921 LV ext. (broken specimen) ×120. J, *Munseyella* sp. cf. *M. bungoona* P146917 LV ext. ×150.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Remarks. These specimens form a significant part of the assemblage, being the seventh most abundant species. The relatively smooth surface makes comparison with *M. bungoona* somewhat difficult, especially since most specimens are preserved as carapaces, and the valves are not easily separable without breakage. The few separate valves do not show internal features clearly. Furthermore McKenzie et al.'s figures are somewhat indistict and the 'poorly expressed median ridge' can scarcely be regarded as a diagnostic feature. The greatest similarity is with the 'relatively plump' shape, and the rounded, subquadrate lateral aspect. Only tentative referral to *M. bungoona* is possible.

Measurements. P146916—L=0.44, H=0.19, W=0.19; P146917—L=0.43, H=0.23; P146919—L=0.42, H=0.23.

Material studied. 64 specimens.

Occurrence and age. PL3001; PL3003. Late Palaeocene.

?**Munseyella** sp. indet.

Figured specimen. Fig. 8E (P146925).

Remarks. This single specimen is tentatively assigned to *Munseyella* on the basis of size, shape and marginal ridging, which is similar to that of *Munseyella kleithria* sp. nov. However, the pentodont hinge is not clearly preserved, and the lateral surface suggests some taphonomic deformation.

Measurements. P146925—L=0.41, H=0.20.

Material studied. 1 specimen.

Occurrence and age. PL3003. Late Palaeocene.

Subfamily LEPTOCYTHERINAE Hanai, 1957

Callistocythere Ruggieri, 1953

Type species. Callistocythere littoralis (Mueller, 1894).

?**Callistocythere** sp.

Figured specimen. Fig. 6F (P146955).

Remarks. This single large specimen has well-preserved external features, but lacks detail internally. Valve shape is gently rounded anteriorly, with a straight venter, and an arched dorsal margin with greatest height forward of the mid-point. There is a narrow marginal ridge, marked in the posterior, but less so in the anterior. The ridged pattern is basically longitudinal, with a strong anterodorsal ridge paralleling the margin. The subcentral area is marked by a small fossa. There is a narrow trough forward of the posterior ridge. RV does not show diagnostic hinge features for *Callistocythere*. Muscle scars not detected. The specimen is tentatively assigned to *Callistocythere*, because of its general shape and ornamentation.

McKenzie, Reyment & Reyment (1993) figure a single valve which does not have the marked ridge pattern of this specimen. They comment on this Late Eocene occurrence being the earliest record for the genus in Australia. This range may well be extended to the Palaeocene if further material of ?*Callistocythere* sp. is found.

Leptocytherid gen. and sp. indet.

Figured specimen. Fig. 8C (P146923).

Remarks. One specimen, which has the characteristic leptocytherid shape, but is unlike ?*Callistocythere* sp.

Measurements. P146923—L=0.37, H=0.21.

Material studied. 1 specimen.

Occurrence and age. PL3003. Late Palaeocene.

Family EUCYTHERIDAE Puri, 1954

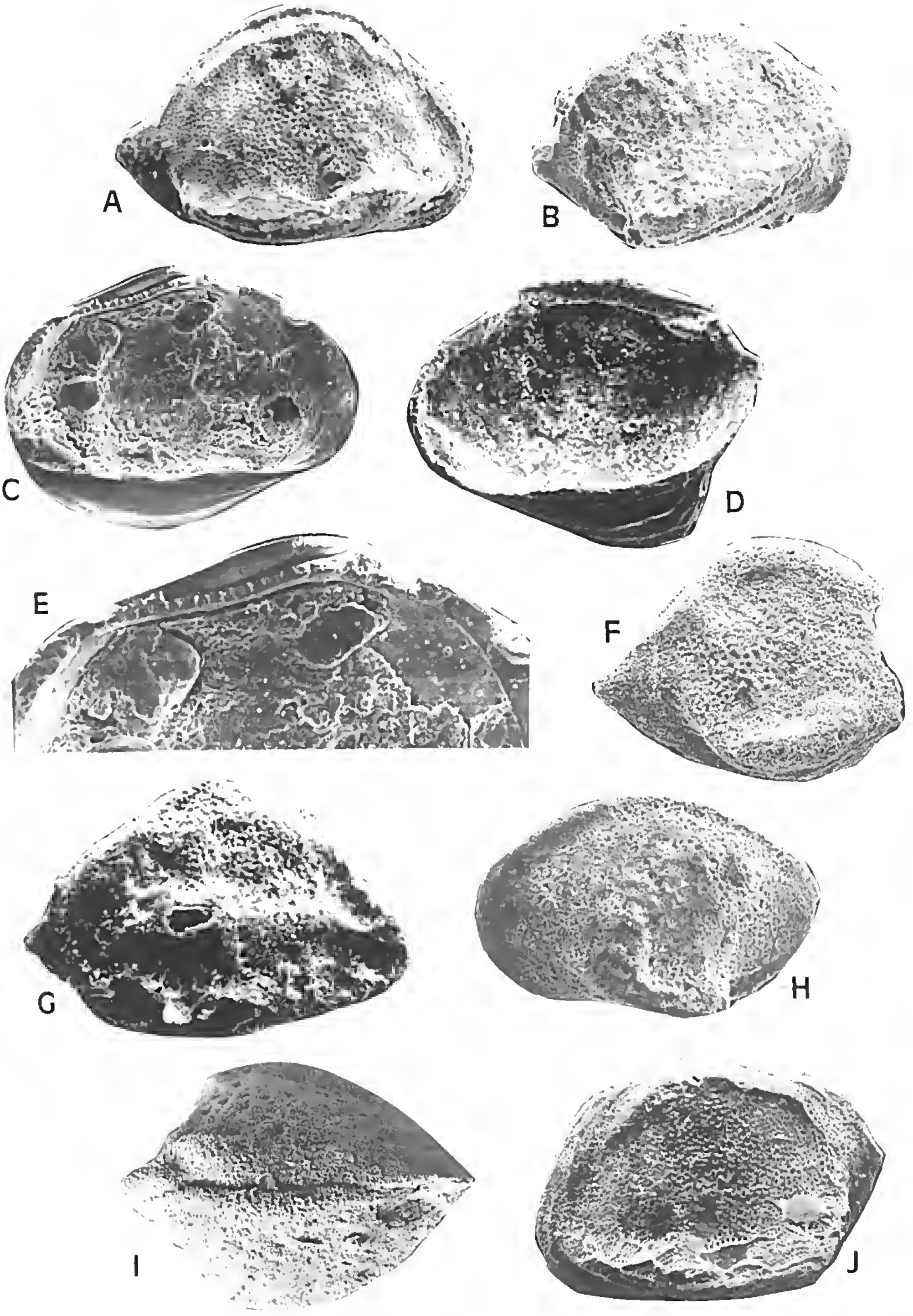
Eucythere Brady, 1868

Type species. Eucythere declivis (Norman, 1865).

Eucythere sp. 1

Figured specimen. Fig. 6H (P146957).

Fig. 3. A, *?Oculocytheropteron australopunctatarum* P146927 RV ext. ×100. B, *?Oculocytheropteron* sp. 2 P146928 RV ext. ×125. C, *Pelecocythere parageois* sp. nov. P146909 RV int. ×55. D, *?Oculocytheropteron* sp. 2 P146929 RV int. ×120. E, *Pelecocythere parageois* sp. nov. P146909 RV detail of hinge line ×100. F, *?Oculocytheropteron* sp. 1 P146930 RV ext. (broken specimen) ×140. G, *Kangarina* sp. P146931 RV ext. ×175. H, *Aversovalva* sp. P146932 LV ext. ×140. I, *Aversovalva* sp. P146933 C dorsal view ×120. J, *?Oculocytheropteron australopunctatarum* P146934 LV ext. (slightly crushed) ×130.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Remarks. This species is a common component of the assemblage from PL3003. The specimens are thin-shelled and show a lightly ribbed surface marked by deep punctae, and a compressed caudal extension. Other assemblages from south-eastern Australia have *Pseudeucythere* and *Rotundracythere*, both of which genera have a more acute dorsal angulation than *Eucythere*.

Measurements. P146957—L=0.29, H=0.18.

Material studied. 38 specimens, mostly fragmentary.

Occurrence and age. PL3003. Late Palaeocene.

Eucythere sp. 2

Figured specimens. Figs 8G, I; Fig. 10C (P146969, P146971).

Remarks. Although better preserved than *Eucythere* sp. 1, there are too few specimens to justify the erection of a new species. The specimens show a finely punctate surface (Fig. 10C), with some shallow depressions medially. There is no compressed caudal extension, and the posterior is more broadly rounded than in the generally smaller specimens of *Eucythere* sp. 1.

Measurements. P146969—L=0.36, H=0.20; P146971—L=0.46, H=0.30, W=0.11.

Material studied. 7 specimens (5 from PL3001 and 2 from PL3003).

Occurrence and age. Pl3001; PL3003. Late Palaeocene.

Rotundracythere Mandelstam, 1960

Type species. Rotundracythere rotunda (Hornibrook, 1952).

Rotundracythere rotunda (Hornibrook, 1952)

Eucythere rotunda Hornibrook, 1952: 30, pl. 2, figs 22, 23, 25.
Rotundracythere cf. *rotunda* Hornibrook, 1952.—McKenzie, Reyment & Reyment, 1993: 88–89, pl. 3, fig. 3.

Figured specimen. Fig. 6I (P146958).

Remarks. These specimens are similar to that figured by McKenzie et al. (1993), but show a more distict pattern of reticulation and punctation. The crenulate median hinge element places them in *Rotundracythere* rather than *Eucythere*, but the dorsum has a less marked angulation than that which characterises specimens figured by Hornibrook (1952), Swanson (1969, 1980) and Warne (1987). The male specimens are more elongate than is usual in *Rotundracythere*. One female specimen is more characteristically of *Rotundracythere* shape, but the reticulation and punctation clearly shown on the male specimens is not well-preserved here, though there is some suggestion of a slight anterior flange.

Hornibrook's original figures (1952) seem to show a distinct anterior flange, though this is not mentioned in the description. All subsequent figures by the later authors referred to here show flangeless valves. The surface reticulation, punctation and the median sulcus establish their conspecificity with the Hornibrook species and extend its range to the Late Palaeocene.

Measurements. P146958—L=0.36, H=0.21.

Material studied. 13 specimens.

Occurrence and age. PL3003. Late Palaeocene.

Family NEOCYTHERIDEIDAE Puri, 1957

Copytus Skogsberg, 1939

Type species. Copytus caligula Skogsberg, 1939.

Copytus sp. cf. **C. rara** McKenzie, 1967

Remarks. These four specimens are infilled with matrix, so internal features cannot be determined. Their smooth shells and characteristic shape suggest McKenzie's 1967 Recent species from Port Phillip Bay.

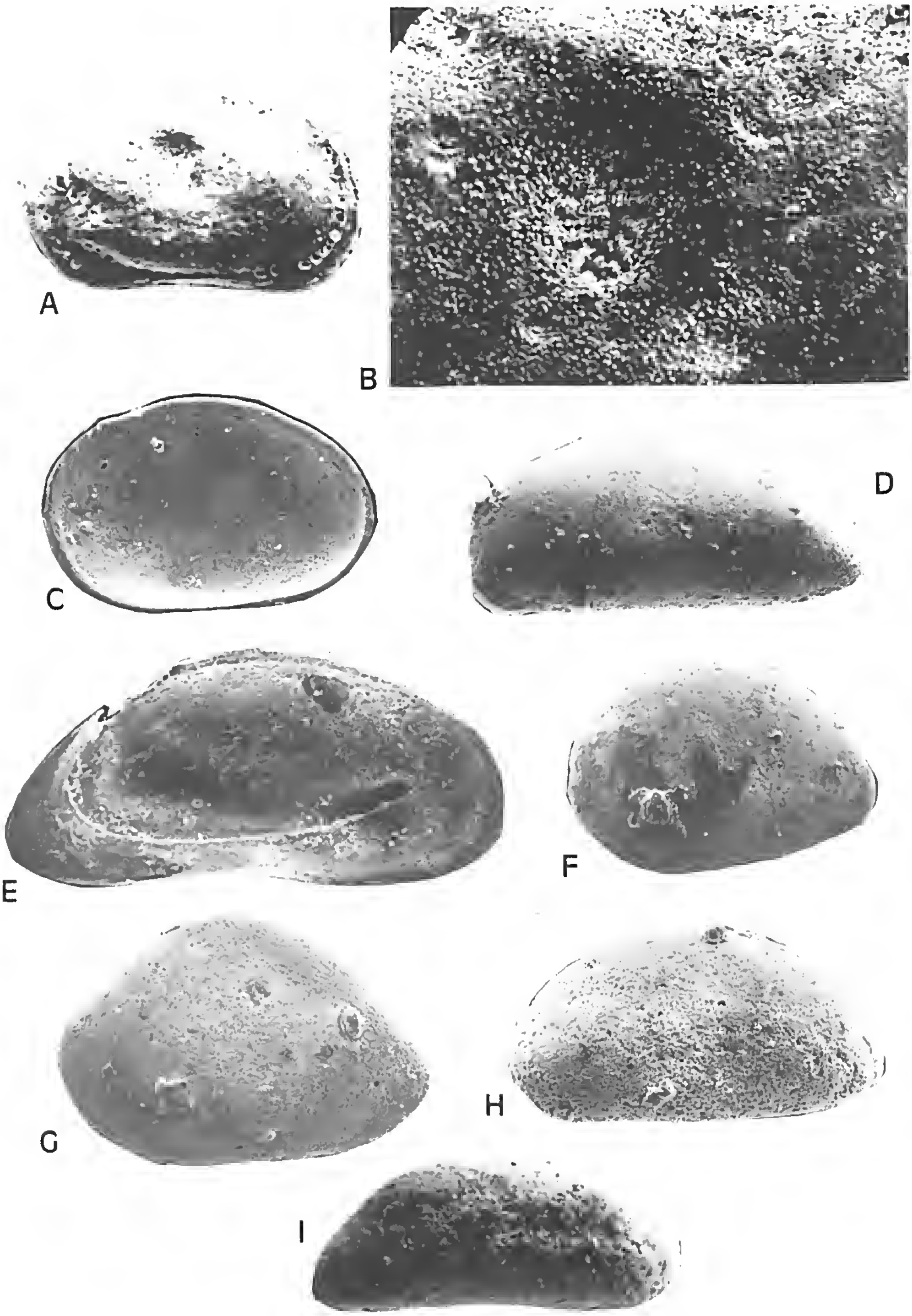
Material studied. 4 specimens, two broken.

Occurrence and age. PL3003. Late Palaeocene.

Neocytherideis Puri, 1952

Type species. Neocytherideis elongata Puri, 1952.

Fig. 4. A, *Cytherelloidea marginopytta* P146935 RV ext. ×80. B, *Cytherelloidea marginopytta* P146935 detail of muscle scars (ext.) ×350. C, *Cytherella pinnata* P146936 RV int. ×95. D, *Tasmanocypris* sp. P146937 LV ext. ×80. E, *Tasmanocypris* sp. P146938 LV int. ×100. F, *Xestoleberis* sp. P146939 RV ext. ×100. G, *Neonesidea* sp. P146940 LV ext. ×120. H, *Xestoleberis* sp. P146941 LV ext. ×115. I, *Macromackenzia porcelanica* P146942 RV ext. ×70.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Neocytherideis mediata Swanson, 1969

Figured specimen. Fig. 8J (P146972).

Remarks. These specimens are distinctly, but faintly reticulate, with fine punctation within the reticulations (see Fig. 8J). Swanson's illustrations do not show this but specimens of his species fall within the range of variation of this material (Ayress, pers. comm. 1997). Australian *Copytus* specimens, though rare in fossil faunas, are smooth-shelled (McKenzie 1974; McKenzie et al. 1990).

Measurements. P146972—L=0.68, H=0.23, W=0.11.

Material studied. 4 specimens, one a broken juvenile.

Occurrence and age. PL3003. Late Palaeocene.

Family TRACHYLEBERIDIDAE
Sylvester-Bradley, 1948

Subfamily TRACHYLEBERIDINAE
Sylvester-Bradley, 1948

Trachyleberis Brady, 1898

Type species. *Trachyleberis scabrocuneata* Brady, 1880.

Trachyleberis careyi
McKenzie, Reyment & Reyment, 1991

Trachyleberis careyi McKenzie, Reyment & Reyment 1991: 169–170, pl. 7, figs 11, 12.
Trachyleberis cf. *careyi* McKenzie, Reyment & Reyment 1993: 105, pl. 6, fig. 8.

Figured specimens. Figs 7A–F, H, J (P146960–P146964, P146966).

Remarks. This species forms the largest single component in the assemblage. The valves are larger and more elongate (especially the males) than those described by McKenzie, Reyment & Reyment (1991, 1993), and the anterior tooth is two-lobed rather than stepped. However, the pattern and polyfurcate nature of the spines, together with the thickened, spinose anterior margins with depressions behind them, establish these specimens as *T. careyi*. At higher magnification, the faint reticulation referred to by these authors is also visible. They claim the pattern, rather than the nature of the spines is the determining characteristic, since the specimens from Castle Cove and Browns Creek are tuberculate rather than spinose. The younger specimens from Bells Headland (McKenzie, Reyment & Reyment 1991) are sharply spinose.

Measurements. P146960—L=1.37, H=0.61; P146961—L=1.38, H=0.62; P146962—L=0.96, H=0.50; P146963—L=1.02, H=0.48, W=0.42; P146964—L=0.98, H=0.44.
Hypodigm range. L=0.86–1.38, H=0.44–0.62.

Material studied. 249 specimens, mostly broken or fragmentary, but including adults, juveniles and carapaces.

Occurrence and age. PL3003; PL3001; and W. J. Parr Collection slides 15006 and 15008. Late Palaeocene.

Idiocythere Triebel, 1958

Type species. *Idiocythere lutetiana* Triebel, 1958.

?Idiocythere nunkeri
McKenzie, Reyment & Reyment, 1993

Figured specimen. Fig. 7G (P146965).

Remarks. This fragmentary specimen, with its coarsely-punctate surface, its clearly-developed subcentral tubercle and its spinose anterior margin, is similar to *Idiocythere nunkeri* McKenzie et al. (1993: pl. VI, figs 16, 18). However, its small size and fragmentary condition make the assignment tentative.

Measurements. No measurements were possible.

Material studied. 1 specimen.

Occurrence and age. PL3003. Late Palaeocene.

Dumontina Deroo, 1966

Type species. *Dumontina puncturata* (Bosquet, 1854).

?Dumontina sp. cf. **?D. cratis** Neil, 1994

Figured specimens. Fig. 8A; Fig. 10A (P146967); Figs 9A, B (P146973).

Remarks. These specimens have the general shape, the fine reticulation and the sulcus behind the

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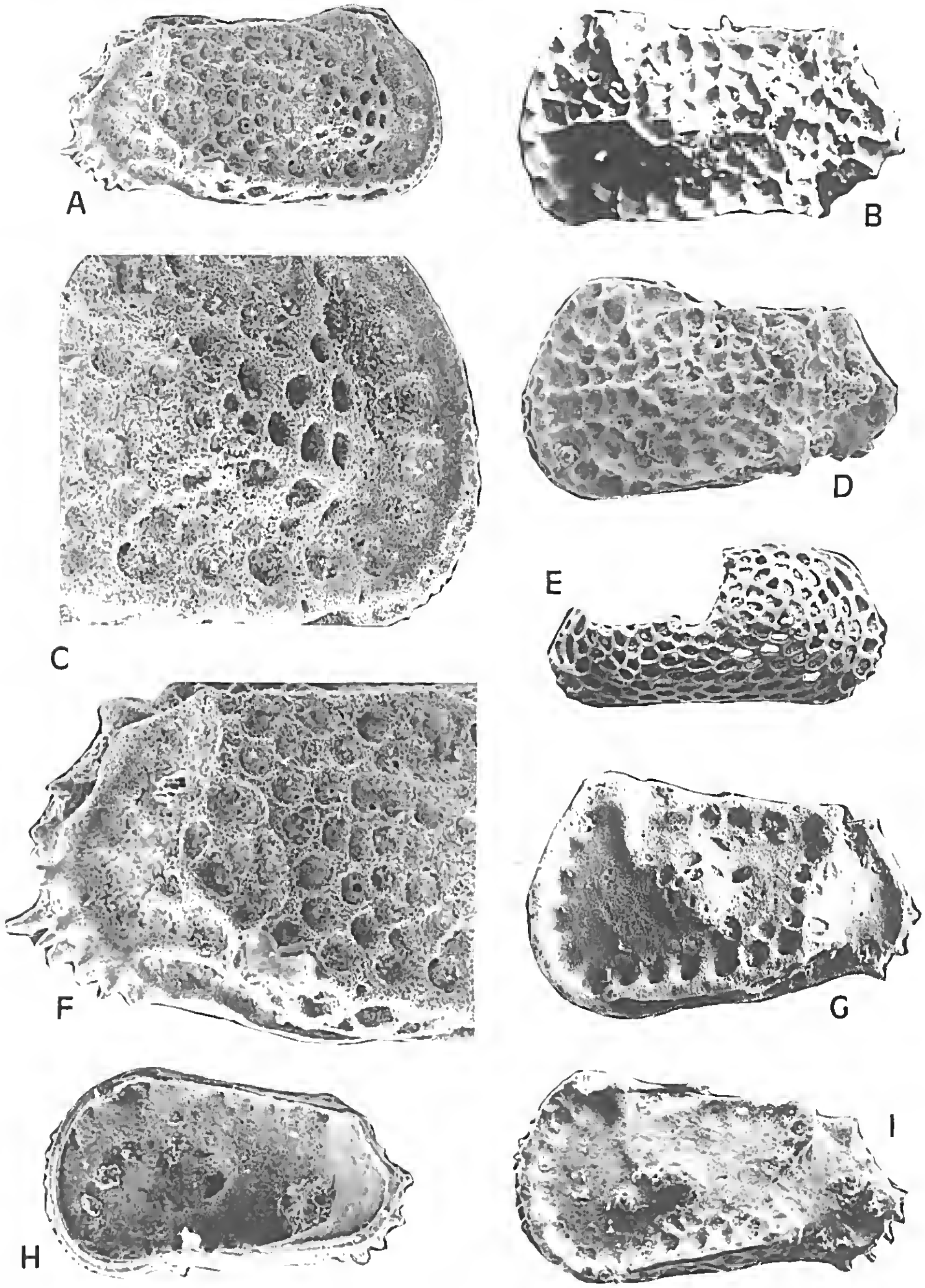
Fig. 5. A, *Margocythere* sp. P146943 RV ext. ×55. B, *?Oertliella* sp. P146944 LV ext. ×70. C, *Margocythere* sp. P146943 RV anterior detail ×130. D, *?Oertliella* sp. P146945 LV ext. ×95. E, '*Cythereis*' sp. P146946 LV ext. (broken specimen) ×70. F, *Margocythere* sp. P146146943 RV posterior detail ×130. G, *Bradleya semiarata anteropytta* P146947 J, LV ext. ×110. H, *Bradleya semiarata anteropytta* P146948 RV int. ×70. I, *Bradleya semiarata anteropytta* P146949 LV ext. ×85.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anterior margin which characterise ?*D. cratis* Neil, 1994. The broken valve, with a subcentral hole, suggests that the tubercle may have been more strongly developed than in ?*D. cratis*. However, internal details, apart from the hinge structure with the curved anterior socket (Fig. 9B), cannot be determined. The limited material means the assignment to *Dumontina* must remain tentative.

Measurements. P146967—L=0.78, H=0.40; P146973—L=0.72, H=0.40.

Material studied. 2 specimens.

Occurrence and age. PL3003. Late Palaeocene.

Oertliella Pokorny, 1964

Type species. Oertliella reticulata Pokorny, 1964.

?Oertliella sp.

Figured specimens. Figs 5B, D (P146944, P146945).

Remarks. The allocation of these specimens to *Oertliella* is tentative, because they are not well-preserved, and internal features are impossible to determine. They display a reticulation similar to that of both *Oertliella semivera* (Hornibrook, 1952), and *Spinobradleya echinata* McKenzie et al., 1993, but without the tubercles or spines, except along the dorsum. Small eyespots are present on both specimens. Valve shape is reminiscent of *Agrenocythere antiquata* as figured by Benson & Peypouquet (1983: pl. 1, fig. 7), with spines projecting above the slightly concave dorsal margin (not reproduced clearly in my figures), but the deep-sea genus is ruled out by the presence of eyespots.

Measurements. P146944—L=0.76, H=0.40, W=0.22; P1469945—L=0.61, H=0.32, W=0.14.

Material studied. 2 specimens.

Occurrence and age. PL3003. Late Palaeocene.

Cythereis Jones, 1849

Type species. Cythereis ciliata (Reuss, 1846).

'Cythereis' sp.

Figured specimen. Fig. 5E (P146946).

Remarks. This single, broken specimen is very similar in reticulation pattern and style to that figured by McKenzie et al. (1993: pl. 6, fig. 9), although a little smaller in size. Since both occurrences are limited to a single specimen, however, the definite allocation to *Cythereis* remains impossible. As McKenzie et al. note 'This could well be a new genus and species.'

Measurements. P146946—L=0.76, H=0.36.

Material studied. 1 specimen.

Occurrence and age. PL3003. Late Palaeocene.

Family HEMICYTHERIDAE Puri, 1953

Subfamily HEMICYTHERINAE Puri, 1953

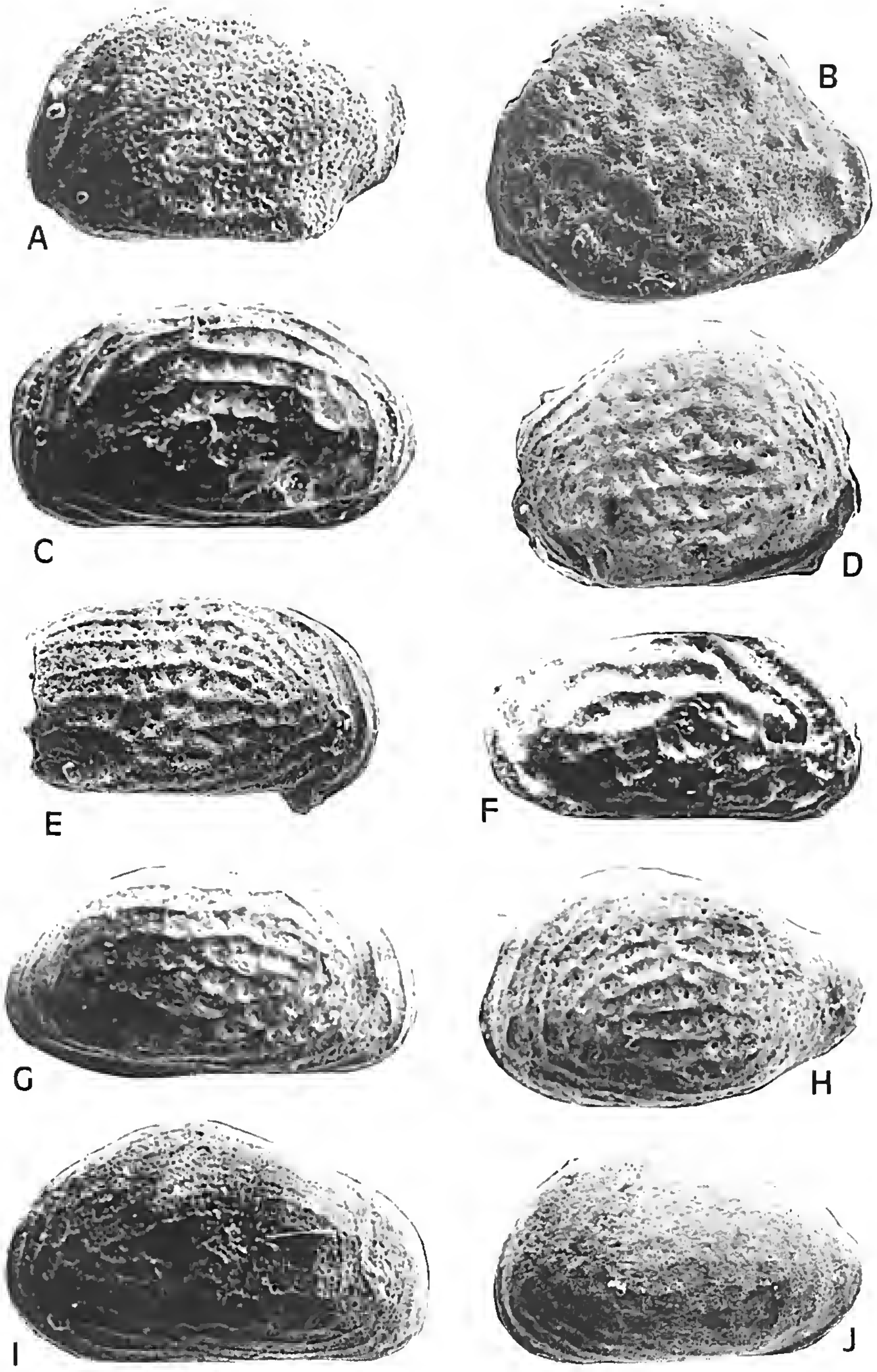
Margocythere
McKenzie, Reyment & Reyment, 1991

Margocythere sp.

Figured specimen. Figs 5A, C, F (P146943).

Remarks. This well-preserved carapace would warrant the erection of a new species if accompanied by additional specimens. However, a description of its main features will assist in that process should new material be found. *Margocythere* sp. is assigned to this genus because of its large size (length about 0.98 mm), its broad margin on the anterior, ventral and posterior of the valves, its ventral ridge and its ruggedly reticulate surface. It differs from the type species, *Margocythere aspreta*, in its very distinctive medio-anterior reticulate swelling (Fig. 5C) and its loculate ventral ridge and anterior marginal area. It differs strongly from *Margocythere latticina* (McKenzie, Reyment & Reyment, 1993) in lacking the criss-cross reticulation pattern of that species.

Fig. 6. A, *Microcytherura* sp. P146950 LV ext. ×150. B, *Kangarina* sp. P146951 LV ext. (broken specimen) ×140. C, *Loxocythere* sp. cf. *L. ouyenensis* P146952 LV ext. ×120. D, *Loxocythere malzi* P146953 RV ext. ×130. E, *Loxocythere* sp. aff. *L. hornibrooki* P146954 RV ext. (broken specimen) ×120. F, ?*Callistocythere* sp. P146955 RV ext. ×100. G, *Loxocythere* sp. aff. *L. hornibrooki* P146956 RV ext. ×110. H, *Eucythere* sp. 1 P146957 LV ext. ×175. I, *Rotundracythere rotunda* P146958 LV ext. ×175. J, ?*Nunana* sp. P146959 LV ext. ×140.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The internal features are not known, as preservation with some adherent matrix makes separation of the valves impracticable. The absence of a marked sub-central tubercle with a castrum, as in the thaerocytherid Bradleyinae, corroborates McKenzie et al.'s placement in the Hemicytheridae.

Measurements. P146943—L=0.98, H=0.52, W=0.56.

Material studied. 1 carapace.

Occurrence and age. PL3003. Late Palaeocene.

Family THAEROCYTHERIDAE Hazel, 1967

Subfamily BRADLEYINAE Benson, 1972

Bradleya Hornibrook, 1952

Type species. Cythere arata Brady, 1880.

Bradleya semiarata anteropytta McKenzie, Reyment & Reyment, 1993

Bradleya semiarata anteropytta McKenzie, Reyment & Reyment 1993: 112–113, pl. 7, figs 9–11.

Figured specimens. Figs 5G, H, I (P146947, P146948, P146949).

Remarks. Only two adult specimens, both broken, were found. The figured specimens are juveniles (A1 and A2). They show the concave posterodorsal lateral profile, and the shallow reticules of the subspecies. They differ in the greater prominence of the subcentral tubercle, and the presence of some pits on it. The eye tubercle is also less prominent than in the holotype of the subspecies. However, these differences are judged to be intraspecific.

Measurements. P146949—(A1) L=0.77, H=0.35, W=0.16; P146947—(A2) L=0.54, H=0.30, W=0.13; P146948—(A1) L=0.74, H=0.39, W=0.16.

Material studied. 11 specimens, some fragmentary—2 adults, 9 juveniles.

Occurrence and age. PL3003. Late Palaeocene. Hornibrook's nominate subspecies is Altonian–Early Miocene; this subspecies ranges from Late Palaeocene to Late Eocene.

Family CYTHERURIDAE G. W. Mueller, 1894

Subfamily CYTHERURINAE G. W. Mueller, 1894

Hemiparacytheridea Herrig, 1963

Type species. Hemiparacytheridea occulta Herrig, 1963.

Hemiparacytheridea sp.

Figured specimen. Fig. 7I (P146967).

Remarks. This single specimen has the characteristic extended cauda, and bitubercular alar structure of the emended diagnosis for *Hemiparacytheridea* of Ayress et al. (1995).

Measurements. P146967—L=0.36, H=0.16.

Material studied. 1 specimen.

Occurrence and age. Pl3003. Late Palaeocene.

Eucytherura Mueller, 1894

Type species. Cythere complexa Brady, 1867.

Eucytherura sp. 1

Figured specimen. Fig. 8F (P146968).

Remarks. This finely-ribbed specimen is unlike any of those figured by McKenzie et al. (1993) or Whatley & Downing (1983), being free of projections, spines and blades. It does have a general resemblance to *E. indianensis* Ayress et al. (1995), though lacking the aggradational outgrowths on the muri of the reticulation. It is interesting to note that *Eucytherura* is usually rare in any assemblage of which it is a component.

Measurements. P146968—L=0.30, H=0.20.

Material studied. 1 specimen.

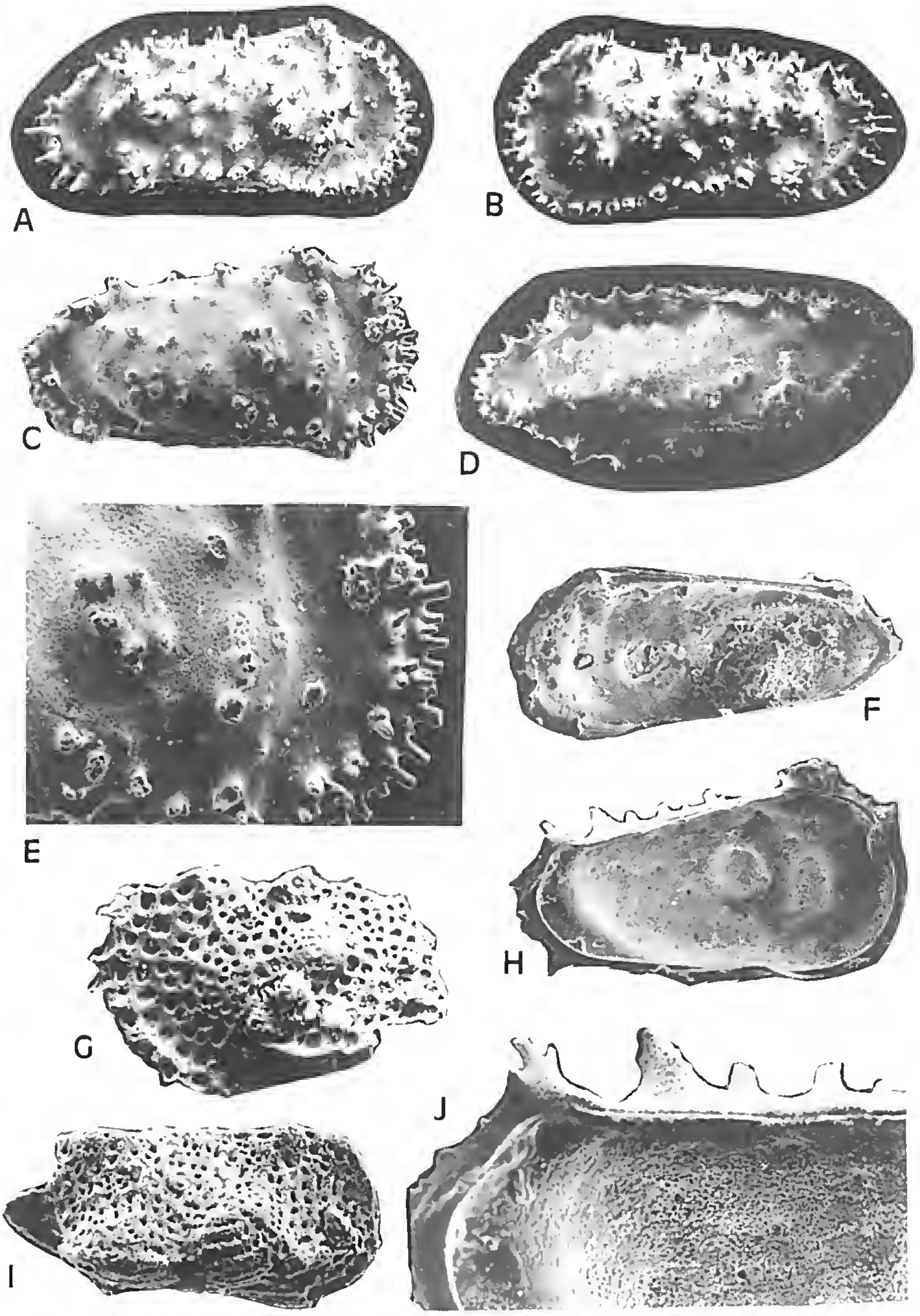
Occurrence and age. PL3003. Late Palaeocene.

Subfamily CYTHEROPTERINAE Hanai, 1957

Pelecocythere Athersuch, 1979

Type species. Pelecocythere sylvesterbradleyi Athersuch, 1979.

Fig. 7. All figures are of *Trachyleberis careyi* except G and I. A, P146960 RV ext. ×40. B, P146961 LV ext. ×40. C, P146962 J, RV ext. ×65. D, P146963 C (oblique) ×65. E, P1469962 RV anterior detail ×140. F, P146964 J, RV int. ×65. G, *Eucytherura* sp. indet. 1 P146965 LV ext. (broken specimen) ×110. H, P146966 J, LV int. ×65. I, *Eucytherura* sp. cf. *E.* sp. 1 Whatley & Downing P146967 RV ext. ×160. J, P146966 J, LV int. posterodorsal detail ×180.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Pelecocythere parageios sp. nov.

Etymology. Greek—*parageios* pertaining to shallow water; a reference to the first known shallow-water species of this hitherto deep-water genus.

Types. Holotype P146905; Paratypes P146906–146909.

Figured specimens. Figs 1A, D (P146905); Figs 1B, C (P146906); Figs 1E, G (P146907); Fig. 1F (P146908); Figs 3C, E (P146909).

Type locality. PL3003.

Diagnosis. A *Pelecocythere* species with two angularities on the dorsal margin, and an alar rim not reaching either anterior or posterior margins.

Description. [These characters are described from all the specimens, whole or fragmented, which can be confidently assigned to the species and so constitute the hypodigm.] Carapace large, alate, broadly elliptical in lateral view with greatest height slightly forward of mid-length, length greatest below mid-height. Dorsal margin of carapace narrow, except for a broad ridge in anterior. Dorsal margin of LV broadly rounded with two slight angularities, one anterior to mid-length and one just forward of posterior margin. Dorsal margin of RV with straight dorsum between angularities. Hinge line of LV below highest point of dorsum arch. LV over RV overlap, leaving sector-shaped projection of LV. Anterior broadly rounded; posterior less so, with angularity close to ventral margin. External surface of valves smooth with normal pores evenly distributed over entire lateral surfaces. Venter of each valve flat, marked by one thick ridge and two thinner ones sub-parallel to alar rim; punctate ridges and interareas, with normal pores as on lateral surfaces. Flat venters of RV and LV angled slightly towards the dorsal margin, giving an incurved base. Alar flange is relatively narrow, with 12 or more large, shallow punctae marking junction with lateral surface of valve. Edge of flange a narrow rounded ridge. No eye spots visible externally or interiorly.

Hinge antimerodont, as in type species, with five teeth anteriorly, and six posteriorly in RV and corresponding sockets in LV. Medial element with rounded crenulations in RV, locellate in LV.

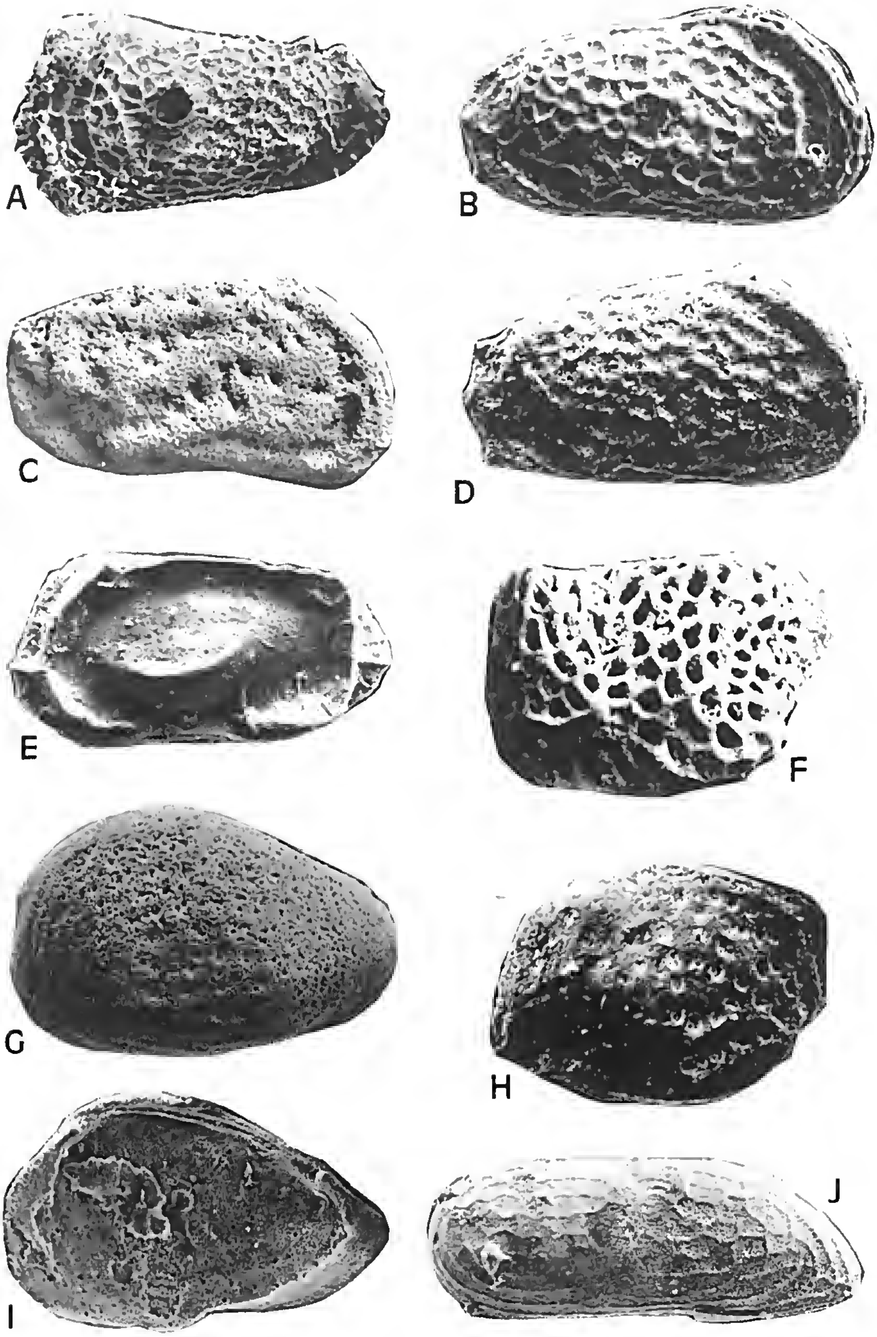
Muscle scars of characteristic cytherurid pattern —four adductors, aligned vertically with slight posterior tilt; dorsal scar small and rounded, subdorsal scar more elongate and slightly arcuate (concave down), sub-ventral scar elongate and ellipsoidal, ventral scar sub-rounded; frontal scars present but not determinable.

Interior of valve—inner lamella broad anteriorly, with narrow vestibule and numerous branched radial pore canals. Inner lamella very narrow dorsally and posteriorly.

Affinities. P. parageios differs from the type species, *P. sylvesterbradleyi* in its angular dorsal margin, its shorter, narrower and unornamented alar flange and its undivided adductor scars. Unlike *P. purii* Neale, 1988, it lacks a marked dorsal ridge, an acutely angled anterior and a caudal process. Its terminal hinge elements are not as strongly developed as in *P. purii*. *P. foramena* Whatley & Coles, 1987 differs from *P. parageios* in its more elliptical shape, its strongly curved ventral margin, its slit-like foramena along the alar margin and its short caudal process. *Pelecocythere* sp. Whatley & Coles, 1987 is probably conspecific with *P. purii*. *Pelecocythere* sp. 1 Whatley & Ayress, 1988 is rather similar to *P. foramena* and so differs from *P. parageios* for similar reasons. *P. trinidadensis* (van den Bold, 1960) ranging from the Middle Eocene to the Middle Miocene, is similar to *P. parageios*, but differs from it in the concavity of the posterodorsal margin, the breadth of the inner lamella posteriorly and the few, simple, straight radial pore canals. *Cytheropteron (Cytheropteron) carinoalatum* Bate 1972 from the Upper Cretaceous of the Carnarvon Basin in Western Australia may well be an ancestral form of *Pelecocythere*, since it shows most of the characteristic morphology of the genus, except for the smooth surface of the valves and the alar process. Its occurrence in relatively shallow basin deposits may support this evolutionary hypothesis. *Paraphysocythere riedeli* Swain, 1973 from the Maastrichtian of DSDP Site 48.2 bears a superficial resemblance in lateral view to *Pelecocythere* species, but has a marked peripheral ridge on all valve margins, and a different hinge structure.

Remarks. Pelecocythere parageios sp. nov. is the oldest recorded species of this genus. From its size and comparative abundance it forms a

Fig. 8. A, *?Dumontina* sp. cf. *D. cratis* P146967 LV ext. ×70. B, *Munseyella* sp. cf. *M. adaluma* P146922 RV ext. ×140. C, *Munseyella* sp. cf. *M. warringa* P146923 RV ext. ×130. D, *Leptocytherid* gen. and sp. indet. P146924 RV ext. ×140. E, *?Munseyella* sp. P146925 LV ext. (deformed?) ×140. F, *Eucytherura* sp. indet. 1 P146968 LV ext. ×150. G, *Eucythere* sp. 2 P146969 LV ext. ×170. H, *Eucythere* sp. 2 P146970 RV ext. ×110. I, *Loxocythere malzi* P146971 RV int. ×125. J, *Neocytherideis mediata* P146972 LV ext. ×95.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characteristic component of the Pebble Point fauna. The occurrence of *Pelecocythere parageios* in this Late Palaeocene shallow-water fauna is of particular significance because it is the earliest recorded occurrence of this genus, which is characteristic of deep-water ostracode assemblages ranging from the Early Eocene to the Recent (Benson & Peypouquet 1983; Coles, Ayress & Whatley 1988; Whatley & Ayress 1988; Whatley & Coles 1991). It is also significant because it is the only recorded shallow-water occurrence of *Pelecocythere*. Previous records of *Pelecocythere* spp. range in depth from 950 m (Correge 1993) to 4796 m (Neale 1988). Even the Early Eocene occurrence is recorded from >1000 m (Coles & Whatley 1989)

This change in depth habitat by the genus *Pelecocythere* over time reinforces the suggestion (Whatley & Dingle 1989) that some taxa presently inhabiting deep water (>1000 m) originated on the shelves of continental margins. These authors suggest that the deep-water genus *Poseidonamicus* Benson, 1972 probably arose in Australasia from shallow-water Late Cretaceous stock, though *Poseidonamicus* has not been found in the shallow water Tertiary record of either New Zealand or Australia. In fact they admit surprise that a sighted *Poseidonamicus* was encountered in waters off the southern African Atlantic coast rather than in Australasian waters. Unlike the ancestor of *Poseidonamicus*, *Pelecocythere*, and the possible ancestor of *Pelecocythere*, *Cytheropteron (Cytheropteron) carinoalatum* Bate, 1972, are both blind species. The occurrence of these earliest forms in the Australasian region, albeit in the widely separated Carnarvon Basin of Western Australia and the Otway Basin of southern Victoria, is consistent with the evolutionary hypothesis (Whatley et al. 1983) that SW Pacific shallow-water genera have given rise to cosmopolitan deep-water species of these genera right through the Tertiary to the Recent. Speculation by Coles, Ayress & Whatley (1990) that *Pelecocythere* may have originated in the North Atlantic was qualified by their proviso that additional sampling might produce new evidence. This is now the case.

The subsidence of the region between Australia and New Zealand allowed species to adapt to increasingly deeper habitats (Whatley 1983), though the rate of that subsidence has been claimed to be rapid by Ayress (1994). Unpublished work by Millson (1987) has illustrated material of Palaeocene age from DSDP cores in the Tasman which has affinities with *Pelecocythere*. In the light of these occurrences, further work is necessary if the evolutionary process suggested here is to be confirmed. The location of the Late Palaeocene *P. parageios* in the Otway Basin, which occupies one of a series of extensional basins which developed as an E–W trending trough in response to Cretaceous (Cenomanian) rifting between Antarctica and Australia (Veevers & Eittreim 1988), is generally consistent with this hypothesis. However, the present-day Otway Shelf (<100 km wide) remains a high energy environment, with continuous particle abrasion to 70 m, constant movement of calcareous sands to 130 m and occasional reworking of outer shelf and upper slope sediments (Boreen et al. 1993), so that the migration of the inner shelf fauna to deeper waters, perhaps through turbidity currents, seems feasible and would have been necessary for *P. parageios* to follow the evolutionary strategy referred to above. The patterns and rates of subsidence in the Otway Shelf area may not be related to those occurring in the Tasman Sea.

Measurements. Holotype, P146905—L=1.14, H=0.74, W=0.60; Paratypes, P146906—L=?, H=0.65; P146907—L=?, H=?, W=0.62; P146908 (Juvenile)—L=0.51, H=0.25.

Hypodigm specimens come within this range, with adults having length/height ratio of approximately 1.5:1, and juveniles having a length/height ration of 2:1.

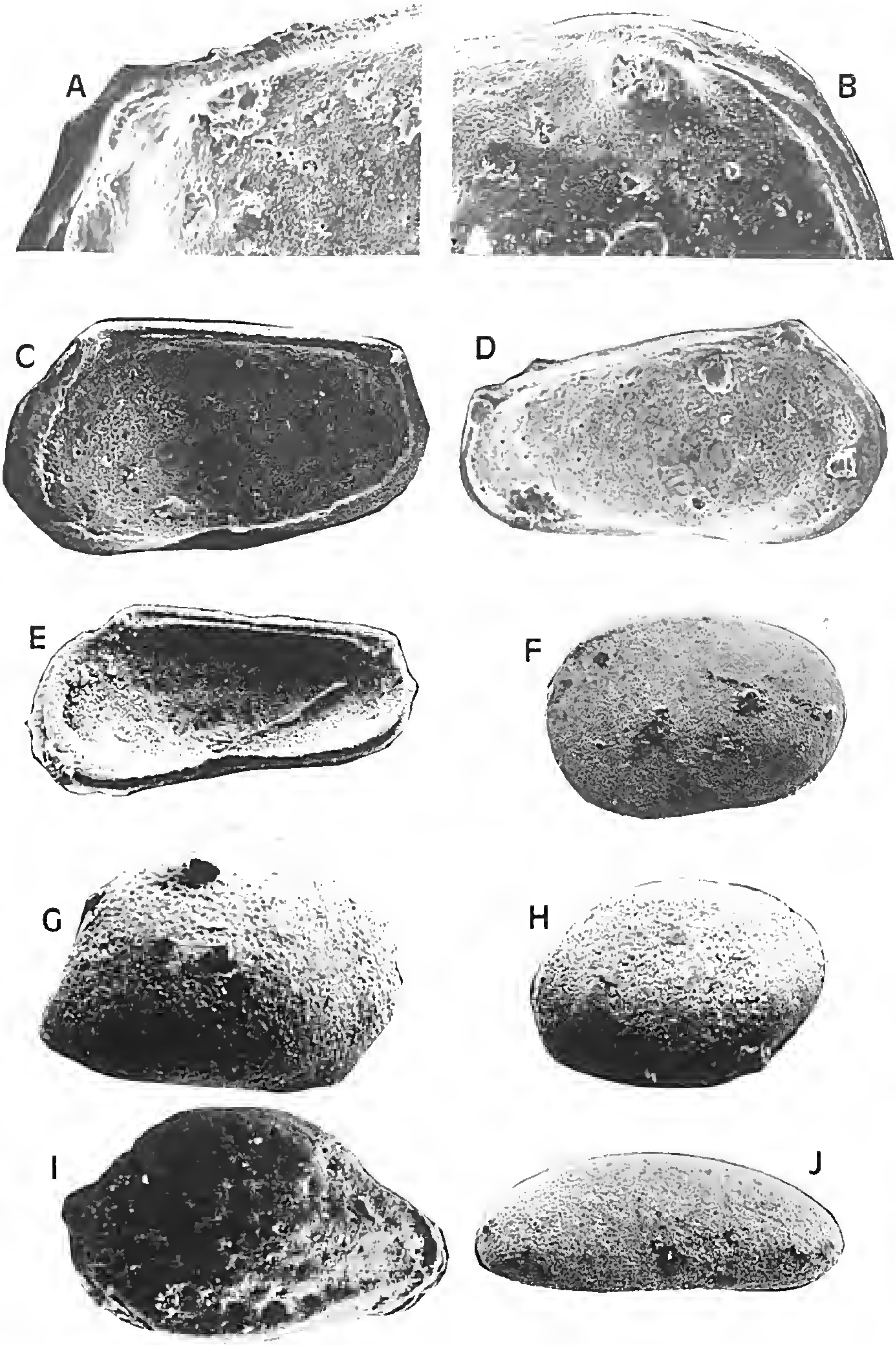
Material studied. 75 specimens, including single valves, carapaces, and identifiable fragments.

Age and occurrence. PL3001; PL3003. Late Palaeocene.

Oculocytheropteron Bate, 1972

Type species. *Oculocytheropteron praenuntiatum* Bate 1972.

Fig. 9. A, ?*Dumontina* sp. cf. *D. cratis* P146973 LV int. posterior hinge element detail ×200. B, ? *Dumontina* sp. cf. *D. cratis* P146973 LV int. anterior hinge element detail ×200. C, *Munseyella* sp. cf. *M. bungoona* P146919 RV int. ×150. D, *Munseyella kleithria* sp. nov. P146913 LV int. ×140. E, *Munseyella kleithria* sp. nov. P146914 RV int. ×110. F, *Cytherella pinnata* P146974 LV ext. ×50. G, *Neonesidea* sp. P146975 RV ext. ×110. H, Gen. et sp. indet. P146976 LV ext. (specimen lost) ×140. I, *Kangarina* sp. P146977 RV ext. ×140. J, ?*Argilloecia* sp. P146978 C (LV) ×80.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?Oculocytheropteron australopunctatarum McKenzie, Reyment & Reyment, 1991

Oculocytheropteron australopunctatarum McKenzie, Reyment & Reyment 1991: 154, pl. 6, fig. 1; pl. 7, figs 1, 2.

Oculocytheropteron australopunctatarum Majoran 1995: fig. 3P.

Figured specimens. Figs 3A, J (P146927, P146934).

Remarks. The surface punctation, shape and alar configuration of these specimens in both male and female valves is clearly conspecific with the Late Eocene species from the Blanche Point Formation of South Australia figured by McKenzie et al. (1991). The specimen figured by Majoran (1995) does not show the surface punctation very clearly. The diagnostic significance of the eyespot in the genus *Oculocytheropteron* is taxonomically debatable, and hence the assignment of all species in this fauna to this genus must be regarded as open to question.

Measurements. P146927—L=0.55, H=0.33, W=0.20; P146934—L=0.42, H=0.27, W=0.25.

Material studied. 2 specimens, one slightly crushed.

Occurrence and age. PL3003. Late Palaeocene.

?Oculocytheropteron sp. 1

Figured specimen. Fig. 3F (P146930).

Remarks. A finely reticulate species, which differs from *O. australopunctatarum* in having a finely ridged ornamentation, a longer and more pointed cauda and a convex venter. An unequivocal placement in *Oculocytheropteron* has not been made because an eye spot cannot be determined (see note above), though the nature of the alar process and the posterodorsal to subcentral ridge are said to be consistent *Oculocytheropteron* characteristics (Ayress, pers. comm. 1997).

Measurements. P146930—L=?, H=0.25; P146933—L=0.50, H=0.22, W=0.31 (Carapace).

Material studied. 1 specimen.

Occurrence and age. PL3003. Late Palaeocene.

?Oculocytheropteron sp. 2

Figured specimens. Figs 3B, D (P146928, P146929).

Remarks. A more coarsely punctate species than *O. australopunctatarum* with some longitudinal ribs posteriorly. Surface ornamentation of ribs and punctation and general shape are reminiscent of a Middle Miocene species occurring at Muddy Creek, near Hamilton (Neil 1992), but the poorer preservation of these specimens prevents close comparison. *?O.* sp. 2 has an eye, though it is not as strongly developed as in Bate's type species *O. praenuntatum* (in fact few described *Oculocytheropteron* species have prominent eye tubercles). *?O.* sp. 2 bears little resemblance to the other Australian oculocytheropteronids (Whatley & Downing 1983; Yassini & Jones 1995), but is rather similar to *Cytheropteron (C.) obtusalum* Hornibrook, 1952, which is described as ranging from Runangan (Late Eocene) to Recent in New Zealand.

Measurements. P146928—L=0.44, H=0.28; W=0.12; P146929—L=0.46, H=0.31, W=0.12.

Material studied. 38 specimens.

Occurrence and age. Pl3003; PL3001. Late Palaeocene.

Aversovalva Hornibrook, 1952

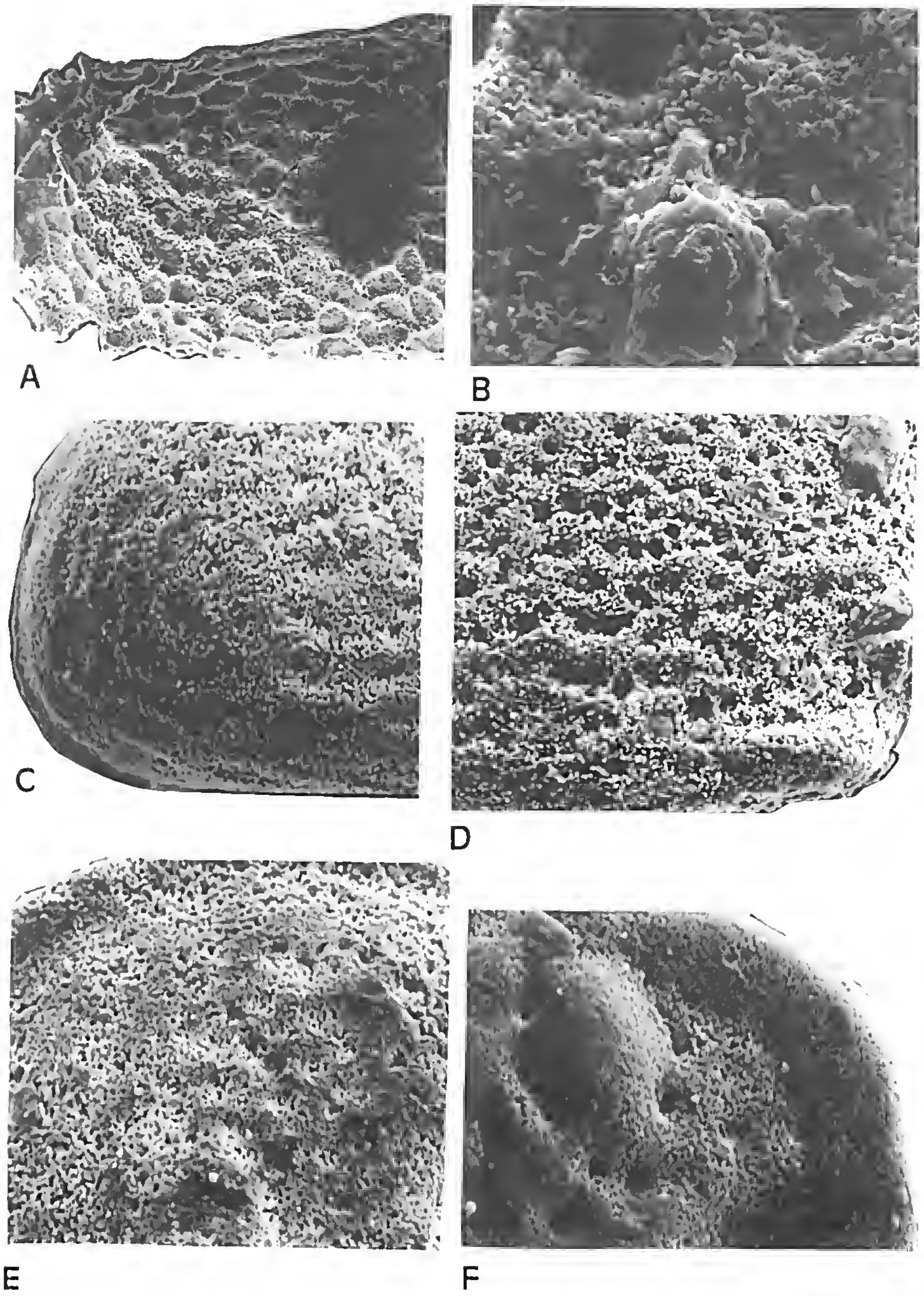
Type species. *Aversovalva aurea* (Hornibrook, 1952).

Aversovalva sp.

Figured specimens. Figs 3H, I (P146933); Fig. 10E (P146932).

Remarks. The small size, smoothly curved dorsum and straight hinge line of these specimens are diagnostic of the genus, though LV/RV overlap was not established. The alar process is relatively small and rounded for this genus and distinguishes it from the Late Oligocene *A. cooperi* McKenzie, Reyment & Reyment 1991. The surface is finely, but not uniformly, punctate (Fig. 10E). Majoran (1995) has figured a specimen, *Aversovalva* sp. 2, from the Late Eocene of the Tortachilla Limestone and the Blanche Point Formation in South Australia, which may be conspecific with *Aversovalva* sp.

Fig. 10. A, *?Dumontina* sp. cf. *D. cratis* P146967 detail of surface ornament ×130. B, *Munseyella* sp. cf *M. adaluma* P146915 detail of surface structure ×1200. C, *Eucythere* sp. 2 P146969 detail of surface ornament ×350. D, *Microcytherura* sp. P146979 detail of surface ornament ×450. E, *Aversovalva* sp. P146932 detail of surface ×350. F, *Munseyella warringa* P146918 detail of antero-dorsal margin ×425.


A
B
C
D
E
F

Measurements. P146932—L=0.40, H=0.24, W=0.18.

Material studied. 8 specimens.

Occurrence and age. PL3003. Late Palaeocene.

Kangarina Coryell & Fields, 1937

Kangarina sp.

Figured specimens. Fig. 6B; Fig. 91 (P146951, P146977).

Remarks. This species is characterised by a coarsely punctate surface free of ribs. It is unlike any other species of *Kangarina* figured from south-east Australia. Poor preservation prevents further assignment.

Measurements. P146951—L=?, H=0.30, W=0.12; P146977—L=0.44, H=0.30, W=0.13.

Material studied. 2 specimens.

Occurrence and age. PL3003. Late Palaeocene.

Subfamily CYTHERURINAE Mueller, 1894

Hemicytherura Elofson, 1941

Hemicytherura sp.

Figured specimen. Fig. 3G (P146931).

Remarks. This single specimen is poorly-preserved, but the shape is characteristic of *Hemicytherura.* There is some surface punctation but no clear connection with the hemicytherurids figured by McKenzie et al. (1991, 1993). A suggestion that this specimen may be linked with *Amphicytherura dinglei* McKenzie et al., 1993, and consequently with *Schizocythere* (McKenzie, pers. comm. 1997) is not borne out by the more strongly-arched dorsum of this specimen, and the absence of the schizodont hinge.

Measurements. P146931—L=0.32, H=0.21.

Material studied. 1 specimen.

Occurrence and age. PL3003. Late Palaeocene.

Family XESTOLEBERIDIDAE Sars, 1928

Xestoleberis Sars, 1866

Type species. Xestoleberis aurantia (Baird, 1838).

?Xestoleberis sp. 1

Figured specimen. Fig. 4H (P146941).

Remarks. These specimens differ from the xestoleberids figured by McKenzie et al. (1991, 1993). *Xestoleberis* sp. 1 has a more evenly rounded anterior than either *X. basiplana* or *Xestoleberis* sp., and is more elongate than *X. noccia.* Preservation and matrix infilling make it difficult to give a more detailed description, or assign to *Xestoleberis* other than tentatively.

Measurements. P146941—L=0.42, H=0.21.

Material studied. 17 specimens.

Occurrence and age. PL3003. Late Palaeocene.

Xestoleberis sp. 2

Figured specimen. Fig. 4F (P146939).

Remarks. These specimens are somewhat similar in shape to *Foveoleberis minutissima* (Chapman, 1926), but are not pitted, nor do they have the caudal process diagnostic of both *Foveoleberis* and *Uroleberis.* The slightly convex venter is unusual for this genus, and the highly-arched dorsum is unlike any other Australian fossil xestoleberids.

Measurements. P146939—L=0.50, H=0.31, W=0.13.

Material studied. 3 specimens.

Occurrence and age. PL3001, PL3003. Late Palaeocene.

Family NUNANIDAE
McKenzie, Reyment & Reyment, 1993

Nunana McKenzie, Reyment & Reyment, 1993

Type species. Nunana australiae Mckenzie, Reyment & Reyment, 1993.

?Nunana sp.

Figured specimen. Pl. 6, fig. J (P146959).

Remarks. The small size and poor preservation of these specimens, some infilled with adherent matrix, makes diagnostic features difficult to determine, but they are very tentatively assigned to *Nunana*, although the specimens are generally larger than those referred to by McKenzie et al. (1993). The ventral region is inflated and striate as in *N. australiae* and the anterior has a flange, but the presence of a subdued reticulation differentiates it from this smooth-shelled species. Where the hinge line can be examined, specimens are adont, but this may be a juvenile condition.

Measurements. P146959—L=0.41, H=0.22.

Material studied. 23 specimens.

Occurrence and age. PL3003, PL3001. Late Palaeocene.

Family MACROCYPRIDIDAE Mueller, 1912

Macromackenziea Maddocks, 1990

Type species. Macrocypris siliquosa Brady, 1887.

Macromackenzia porcelanica (Whatley & Downing, 1983)

Macrocypris porcelanica Whatley & Downing 1983: 383, pl. 1, figs 11–13.
Macromckenziea porcelanica (Whatley & Downing).—Maddocks 1990: 54.
Macromckenziea porcelanica (Whatley & Downing).—McKenzie, Reyment & Reyment 1991: 144, pl. 2, figs 5, 6.
Macromckenziea sp. aff. *porcelanica* (Whatley & Downing).—Yassini and Jones 1995: 311, figs 114, 116, 118, 120, 122.

Figured specimen. Fig. 4I (P146942).

Remarks. External and internal features, including shape, muscle scars and duplicature, establish these specimens as *M. porcelanica*, thus extending its range from Late Palaeocene through Middle Miocene probably to Recent (Yassini & Jones 1995). In shape, these Palaeocene specimens are closer to Recent forms illustrated by Yassini & Jones (1995) with a less acuminate posterior than the Miocene specimens figured by Whatley & Downing (1983) and McKenzie, Reyment & Reyment (1991).

Measurements. P146942—L=0.82, H=0.35.

Material studied. 38 specimens, some broken, and including carapaces. No juveniles.

Occurrence and age. 36 specimens from PL3003; 2 from PL3001. Late Palaeocene.

Family PONTOCYPRIDIDAE MUELLER, 1894

Argilloecia Sars, 1866

Type species. Argilloecia cylindrica Sars 1866.

?**Argilloecia** spp.

Figured specimen. Fig. 9J (P146978).

Remarks. Owing to the poor preservation and matrix-infilled condition of these specimens, only a tentative assignment to the genus is made on the basis of shape and size alone. At least two species are represented, one elongate with an evenly arched dorsum (Fig. 9J); the other smaller, with a more acutely arched dorsum.

Measurements. P146978—L=0.58, H=0.20.

Material studied. 9 specimens, including 2 carapaces.

Occurrence and age. PL3003. Late Palaeocene.

Maddocksella McKenzie, 1982

Type species. Bythocypris tumefacta Chapman 1914.

Maddocksella sp.

Remarks. Poorly preserved fragmentary or broken specimens preclude assignment beyond the generic level. However, the robust, relatively inflated valves, some showing the distinctive rosette muscle-scar pattern, are characteristic of *Maddocksella* which McKenzie et al. (1993) have recorded from the nearby Late Eocene Brown's Creek Clays.

Measurements. Specimens too fragmentary to measure.

Material studied. 10 specimens.

Occurrence and age. 7 from PL3003; 3 from PL3001. Late Palaeocene.

Family PARACYPRIDIDAE Sars, 1923

Subfamily PARACYPRIDINAE Sars, 1923 (*partim*)

Tasmanocypris McKenzie, 1979

Type species. Tasmanocypris dartnalli McKenzie 1979.

Tasmanocypris sp.

Figured specimens. Figs 4D, E, I (P146937, P146938, P146942).

Remarks. The limited number of specimens precludes the erection of a new species. However, the broad inner lamella and the muscle scars are diagnostic for the genus. These specimens differ from *T. eurylamella* McKenzie et al. (1991) in having a more evenly arched dorsum, and a less broad inner lamella ventrally. There is no anterodorsal convexity as in *T. dietmaykeyseri* (Hartmann, 1979). In lateral view, *T.* sp. is closest to *T. setigera* (Brady, 1880).

Measurements. P146937—L=0.78, H=0.35, W=0.32; P146938—L=0.76, H=0.36; P146942—W=0.82, H=0.35.

Material studied. 3 specimens.

Occurrence and age. PL3003. Late Palaeocene.

Family UNKNOWN

Genus and species indeterminate

Figured specimen. Fig. 9H.

Remarks. This fragile specimen was broken subsequent to being photographed, and has not been allocated a P number. It was of small size (H=0.20), smooth-shelled and of distinctive ovoid shape, which may indicate a juvenile cytherellid.

DISCUSSION

The composition of this assemblage presents a number of problems in palaeoecological and palaeobathymetric interpretation from a uniformitarian point-of-view.

The occurrence of a new species of *Pelecocythere* in the Palaeocene provides a substantial argument for the shallow-water origin of this otherwise cosmopolitan deep-sea index genus, since many of the characteristics of this assemblage point to a shallow-water or at least inner-shelf environment. However, as has been pointed out above, *Pelecocythere parageois* is a blind species. An ancestral sighted species from a shallow-water environment with blind descendant species in the deep sea is a persuasive combination of evidence. A blind ancestral species with blind descendants in the deep sea is less convincing, though blind species in shallow-water environments are common enough.

Dingle and Lord (1990—quoted in Szczechura 1995) point out that deep-water ostracodes may live in shallow waters if these are cold enough, relatively low saline and less oxygenated. Such cold, low saline, minimum oxygen waters may result from an upwelling or an influx from off the shelf, but there is insufficient palaeoecological evidence from this assemblage to warrant drawing that conclusion.

Whatley et al. (1983) refer to the SW Pacific area (and by extension, Bass Strait) as experiencing the invasion of the deep-water from the shallow by ostracode genera as essentially a one-way traffic. They illustrate this by reference to the genera *Poseidonamicus* and *Bradleya*, both of which have sighted, shallow-water ancestral species. It seems unlikely that *P. parageois* ran counter to this pattern, especially as it is the oldest species of the genus yet described. Inferences about palaeobathymetry on the basis of a uniformitarian interpretation of Recent ostracode genera will always be tentative. For instance, Whatley (1983) has indicated that 'a distinct species group of the normally phytal genus *Xestoleberis* occurs at both bathyal and abyssal depths'.

On balance, it seems that indicators of a shallow, marine shelf environment for this assemblage—the abundance of pectocytherids (McKenzie 1979), leptocytherids and some cytherurids including *Hemicytherura*; the macrofauna (Darragh 1994); the foraminiferida (McGowran 1965) and Baker's original (1950) investigation of the facies of the Pebble Point Formation—provide substantial evidence for proposing the beginning of the evolutionary development of the genus *Pelecocythere* from *P. parageois*.

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STUDIES ON WESTERN AUSTRALIAN PERMIAN BRACHIOPODS 14. THE FAUNA OF THE ARTINSKIAN HIGH CLIFF SANDSTONE, PERTH BASIN

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The brachiopod fauna of the Early Permian High Cliff Sandstone, Perth Basin, Western Australia is reviewed and described. The following new taxa are documented: *Neochonetes (Sommeriella) magnus* sp. nov., *Taeniothaerus quadratiformis* sp. nov., *Neospirifer (Quadrospira) woolagensis* subgen. et sp. nov., *Occidalia shahi* gen. et sp. nov., *Woolagia playfordi* gen. et sp. nov., *Cleiothyridina perthensis* sp. nov. and *Hoskingia skwarkoi* sp. nov. The age of the fauna, important for the biostratigraphy of the Permian of the Perth Basin, is reviewed and an age of Late Aktastinian (Artinskian) is preferred for the High Cliff Sandstone.

BRACHIOPODS of Permian age have been known from the basal High Cliff Sandstone since the early 1950s. Initial reports, discussed below, indicated that the specimens were from the underlying Fossil Cliff Formation. Nevertheless the analysis of these early collections by Dickins (1957) and the detailed stratigraphical study by Playford (1959) demonstrated their true stratigraphical source. The present review of available collections indicates the distinctive faunal features of the basal High Cliff Sandstone assemblage and confirms the importance of the faunal zone based on the assemblage, outlined by Archbold (1993a) and named formally herein as the *Neochonetes (Sommeriella) magnus* Zone. The High Cliff Sandstone fauna is a distinctive Westralian (Archbold 1983a) assemblage but does include an endemic component in the fauna, restricted to the Perth Basin.

STRATIGRAPHY

References to the regional geology of the Permian sequences of the Perth Basin are provided in Archbold (1996: 17) and are not repeated here. The stratigraphy of the High Cliff Sandstone (Clarke et al. 1951) is described as the unit of interbedded sandstones, conglomerates and siltstones, apparently lying conformably, but usually with an abrupt contact, on the Fossil Cliff Formation (Fossil Cliff Member of some authors) and conformably overlain by the Irwin River Coal Measures (Playford et al. 1976; Le Blanc Smith & Mory 1995). Marine fossils are only known from the basal unit of the formation in the Woolaga Creek area (Playford 1959; see Fig. 1 herein) 27 km south of the type section which is at High Cliff on the north branch of the Irwin River (see P. E. Playford and S. P. Willmott in McWhae et al. 1958: 77). The type section of the High Cliff Sandstone is 26 m thick but at Woolaga Creek the unit is up to 42 m thick. Dickins (1963: 145) has provided significant evidence in support of a break in sedimentation, with possible subaerial erosion, at the base of the High Cliff Sandstone at Woolaga Creek.

According to Playford (1959: 18) approximately 1.5 m of generally pale yellowish-grey fine grained silty sandstone occurs at the base of the section at Woolaga Creek. Above this is some 10 m of red brown, ferruginous, fine to medium sandstone with marine fossils. All marine fossils are from the surface outcrops at Woolaga Creek and are preserved as ferruginous internal and external moulds.

PREVIOUS BRACHIOPOD STUDIES

The first formal descriptions and illustrations of brachiopod specimens from the High Cliff Sandstone were provided by Coleman (1957). However Coleman followed earlier opinions (Fairbridge 1952; Johnson et al. 1954) and considered that the material described (aulostegid and linoproductid productids) was from a facies variant of the Fossil Cliff Formation. Dickins (1957) was the first worker to recognise the distinctive nature of the fauna and his brachiopod determinations were repeated by Playford (1959: 19) and Playford et al. (1976: 98, 100). Campbell (1965) described a terebratuloid species, *Gilledia woolagensis*, and Runnegar (1969) illustrated an ingelarellid speci-

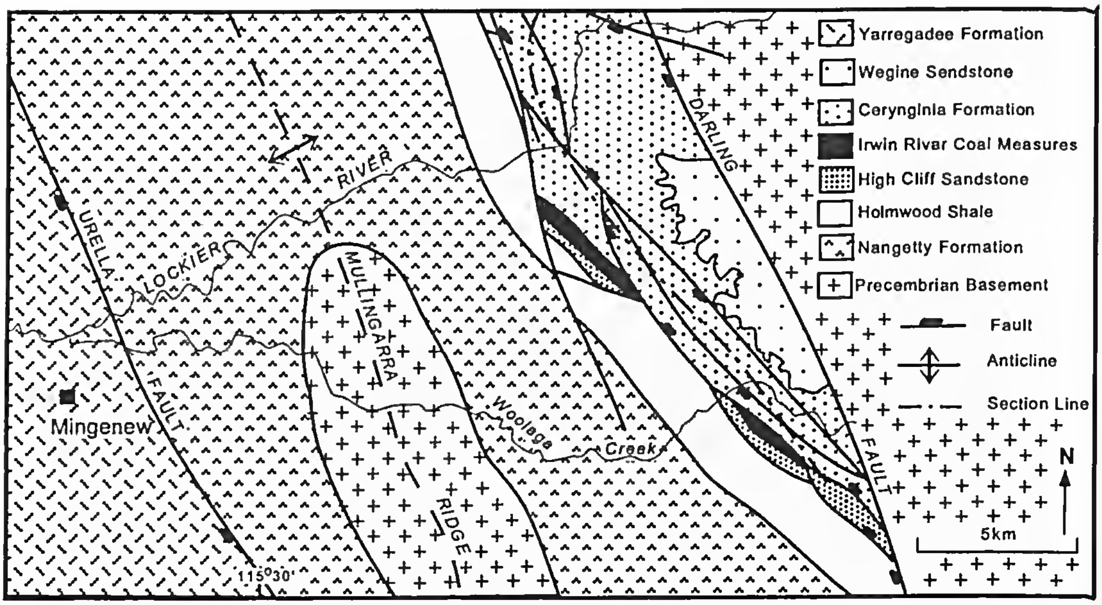


Fig. 1. Locality map of interpreted solid geology of the High Cliff Sandstone at Woolaga Creek (after Le Blanc Smith & Mory 1995: fig. 4).

men which was subsequently described as a new species, *Tomiopsis rarus*, by Archbold & Thomas (1986a). A revised list of the High Cliff Sandstone brachiopods was provided by Archbold (1988), used in part by Skwarko (1993) and several species were illustrated by Archbold et al. (1993) with brief diagnoses also being provided by those authors. A new species of the linoproductoid *Costatumulus* was described by Archbold (1993b). For the present study all previously described material was re-assessed.

COLLECTIONS

All specimens are registered with the Geological Survey of Western Australia (GSWA F), Perth; the Commonwealth Palaeontological Collections (CPC) of the Australian Geological Survey Organisation (AGSO), Canberra; the Western Australian Museum (WAM F), Perth or the University of Western Australia, Geology Department (UWA), Nedlands, Perth.

All illustrated specimens of new species, other than holotypes, are designated as paratypes.

AGE AND CORRELATION OF FAUNA

Dickins (1957) indicated that the fauna of the High Cliff Sandstone was intermediate in type between that of the Fossil Cliff Formation (and Callytharra Formation of the Carnarvon Basin) below and that of the Coyrie (Madeline) Formation of the Carnarvon Basin above. Archbold (1993a) proposed a zonation scheme based on brachiopods from the Permian of Western Australia. The *Neochonetes (Sommeriella)* sp. nov. A. Zone, now formally renamed the *Neochonetes (Sommeriella) magnus* Zone, was proposed for the fauna of the High Cliff Sandstone (also utilised in Archbold & Dickins 1996). However it was noted that the zone was not placed in an objective stratigraphical sequence (Archbold 1993a: 313) and that no direct correlatives of the zone were known elsewhere in Western Australian. The zone was placed provisionally, between the *Strophalosia jimbaensis* Zone, of the Jimba Jimba Calcarenite, above, and the *Strophalosia irwinensis* Zone of the Fossil Cliff Formation below.

The fauna of the Jimba Jimba Calcarenite of the Carnarvon Basin shares many species with the fauna of the Fossil Cliff Formation of the Perth Basin and the Callytharra Formation of the Carnarvon Basin (Archbold & Shi 1993) and includes four distinctive species that are related to Callytharra Formation species (see Archbold & Shi 1993: 189, for a list of Jimba Jimba species). One Jimba Jimba species (*Tomiopsis* cf *T. rarus* Archbold & Thomas) is closely related to a High Cliff Sandstone species. It appears likely that the Jimba Jimba Calcarenite can be considered to be a top member of an extended and redefined Callytharra Formation (Mory 1996; see also Table 2 herein). This may explain the relative similarity of the Fossil Cliff–Callytharra fauna with that of the Jimba Jimba Calcarenite.

However it is apparent from the present study that the brachiopod fauna of the High Cliff Sandstone (Table 1) is quite distinct from that of

Streptorhynchus sp.
Neochonetes (Sommeriella) magnus sp. nov.
Chonetinella sp.
strophalosiid indet.
Aulosteges ingens Hosking 1931
Taeniothaerus quadratiformis sp. nov.
Costatumulus occidentalis Archbold 1993
Neospirifer (Quadrospira) woolagensis subgen. et sp. nov.
Occidalia shahi gen. et sp. nov.
Woolagia playfordi gen. et sp. nov.
?Cyrtella sp.
Tomiopsis rarus Archbold & Thomas 1986
Cleiothyridina perthensis sp. nov.
Composita sp.
Gilledia woolagensis Campbell 1965
Hoskingia skwarkoi sp. nov.

Table 1. Brachiopod fauna of the High Cliff Sandstone.

STAGE/SUBSTAGE		ZONE	PERTH BASIN	CARNARVON BASIN
ARTINSKIAN	BAIGENDZHINIAN	*E. prideri*	/ / / / / /	Coyrie Fm.
		/ / / / / ?	Irwin River Coal	Wooramel Group
	AKTASTINIAN	*N.(S.) magnus* ?	High Cliff Sandstone	
		/ / / / / /	/ / / / / /	
		S. jimbaensis		Callytharra (upper)
SAKMARIAN	STERLITAMAKIAN	*S. irwinensis*	Fossil Cliff Fm.	Ballythanna Sandstone
				Callytharra Fm.
	TASTUBIAN	*T. occidentalis*	Woolaga L'stone M.	Carrandibby Fm. / / /
		L. lyoni	Holmwood Shale	Lyons Group
			Beckett M.	
			?	
ASSELIAN		?	Nangetty Fm.	
				?

Table 2. Revised Early Permian brachiopod zones of Western Australia and correlation of Early Permian strata of the Perth and Carnarvon Basins. The usage of upper Callytharra Formation follows that of Mory (1996) and includes the Jimba Jimba Calcarenite of previous authors.

the Fossil Cliff Formation and is, in fact, rather more closely related to that of the Mingenew Formation and, in part, the fauna of the Coyrie and Madeline Formations of the Carnarvon Basin. No species are shared with the fauna of the Fossil Cliff Formation, whereas one is shared with the fauna of the Madeline Formation (*Aulosteges ingens* Hosking 1931), and the distinctive new genus *Occidalia* is shared with the fauna of the Mingenew Formation. Hence on the basis of these relationships, it appears that the *Neochonetes (Sommeriella) magnus* Zone, typified by the fauna of the High Cliff Sandstone, should probably be placed between the *Strophalosia jimbaensis* Zone below and the *Echinalosia prideri* Zone above (Table 2). If correct, this would imply that there is a relatively short time break between the deposition of the Fossil Cliff Formation and the High Cliff Sandstone at Woolaga Creek, perhaps indicated by both the abrupt nature of the contact and the abrupt change in facies between the two units (see also Dickins 1963: 145).

International correlations of the Western Australian Permian sequences have traditionally relied on the sporadic distribution of ammonoid species (see references in Archbold 1993a) described from spot localities within the Western Australian sequences. The present author follows Glenister et al. (1993) and considers that no Aktastinian ammonoids are known from Western Australia but that the Baigendzhinian (including the Kungurian in the usage of Glenister et al. 1993) is well represented. On this basis, and given the nature of the High Cliff Sandstone brachiopod fauna, it is considered that the *Neochonetes (Sommeriella) magnus* Zone is probably Aktastinian in age with a Sterlitamakian fauna known from the underlying Fossil Cliff Formation (Archbold 1995b).

SYSTEMATIC PALAEONTOLOGY

Phylum BRACHIOPODA

Order STROPHOMENIDA Opik, 1934

Suborder ORTHOTETIDINA Waagen, 1884

Superfamily ORTHOTETOIDEA Waagen, 1884

Family STREPTORHYNCHIDAE Stehli, 1954

Genus **Streptorhynchus** King, 1850

Type species. *Terebratulites pelargonatus* Schlotheim, 1816.

Streptorhynchus sp.

Fig. 3A–B

Comments. One incomplete internal mould of a dorsal valve (WAM 69.753) indicates the presence of a moderately sized *Streptorhynchus* within the High Cliff fauna (estimated width, 46 mm; valve height, 34 mm). The dorsal muscle field and cardinalia are typical of the genus. Costellae (2 per mm at anterior margin of valve) are sharp and usually increase by intercalation. The valve was relatively thin; traces of costellae extend posteriorly to the muscle field. Material is inadequate for detailed comparison with other Western Australian species but the specimen appears to belong to the finely costellated, thin shelled group of species that is well represented in the Westralian Permian Province.

Order CHONETIDA Nalivkin, 1979

Suborder CHONETIDINA Muir-Wood, 1955

Superfamily CHONETOIDEA Bronn, 1862

Family RUGOSOCHONETIDAE Muir-Wood, 1962

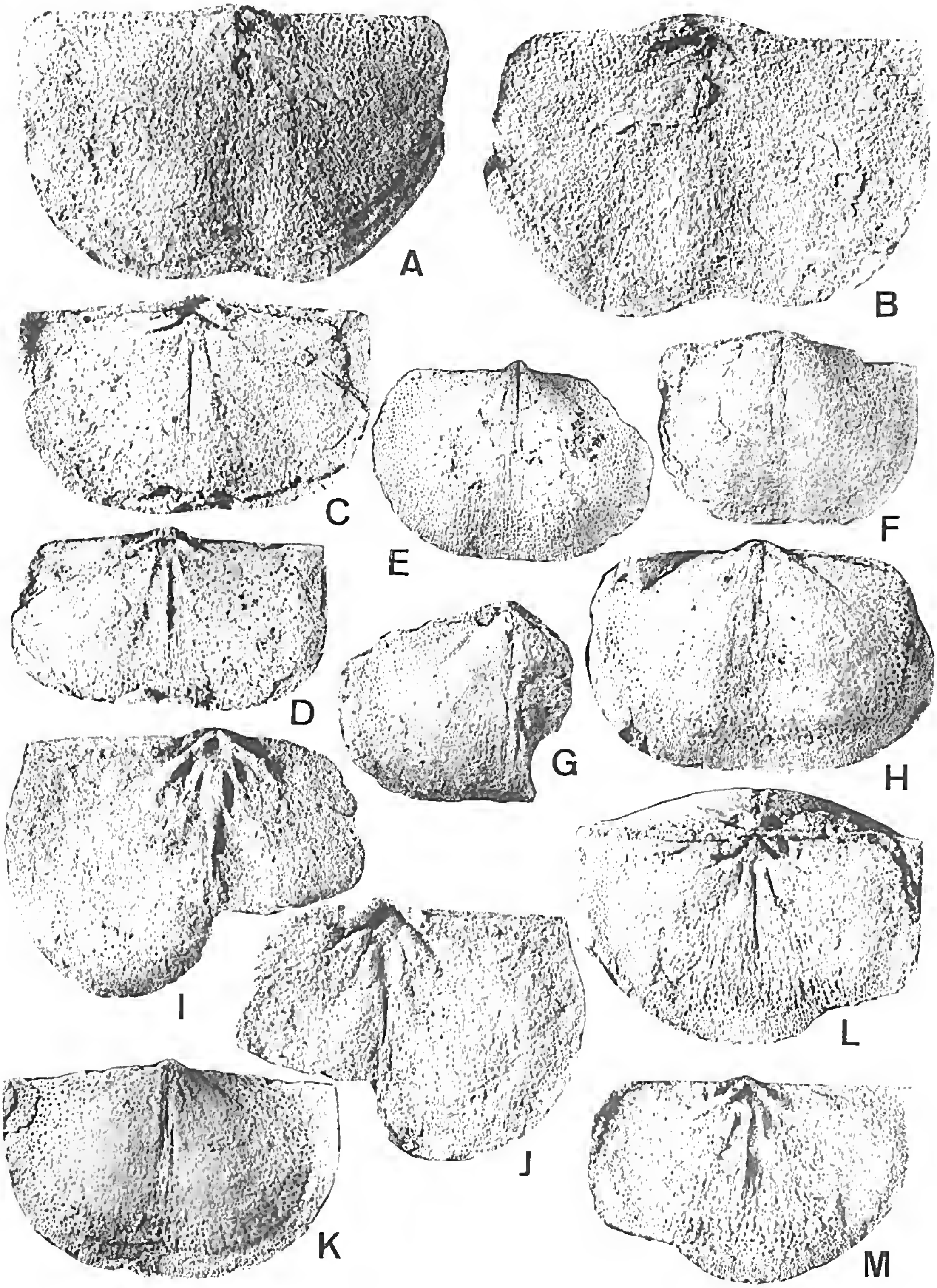
Subfamily RUGOSOCHONETINAE Muir-Wood, 1962

Genus **Neochonetes** Muir-Wood, 1962

Subgenus **Neochonetes (Sommeriella)** Archbold, 1982

Type species. *Chonetes prattii* Davidson, 1859.

Fig. 2. A–M, *Neochonetes (Sommeriella) magnus* sp. nov. A–B, WAM 69.754, holotype, latex cast of ventral valve external mould and the external mould, ×1.5. C–D, UWA 38552, internal mould of dorsal valve and latex cast from mould, ×1.5. E, UWA 32759, internal mould of ventral valve, ×1.5. F, UWA 31568, internal mould of ventral valve, ×1.5. G, WAM 69.756, internal mould of ventral valve. H, WAM 69.755, internal mould of ventral valve, ×1.6. I–J, UWA 33764, latex cast from mould of dorsal valve interior and the internal mould of dorsal valve, ×1.5. K–M, UWA 31566, internal mould of shell in ventral and dorsal views and latex cast of dorsal interior, ×1.5.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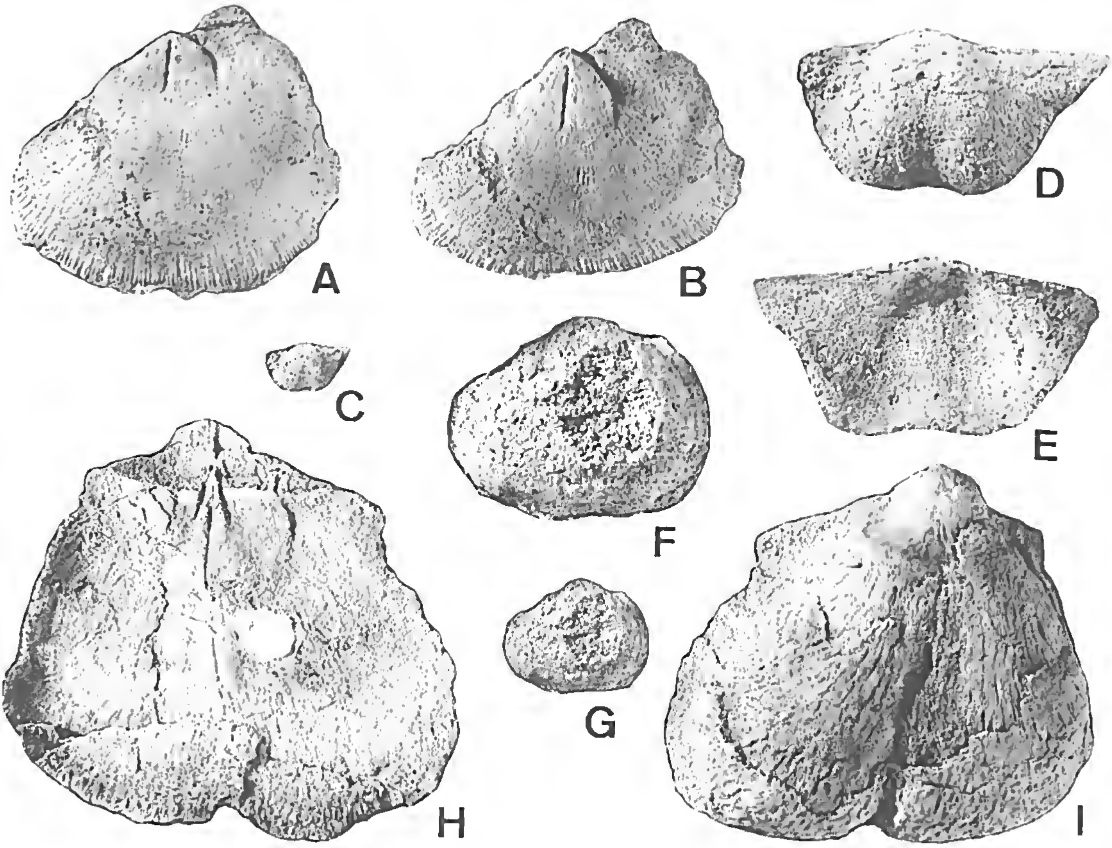


Fig. 3. A, B, *Streptorhychus* sp., WAM 69.753, internal mould of dorsal valve in dorsal and postero-dorsal views, ×1. C–E, *Chonetinella* sp., UWA 33763, latex cast of ventral valve external mould, ×1, ×3.5 and the external mould, ×4. F–G, strophalosiid indet., UWA 32755, internal mould of ventral valve, ×2 and ×1. H, I, *Aulosteges ingens* Hosking 1931, UWA 34433, internal mould of complete shell in dorsal and ventral views, ×1.

Neochonetes (Sommeriella) magnus sp. nov.

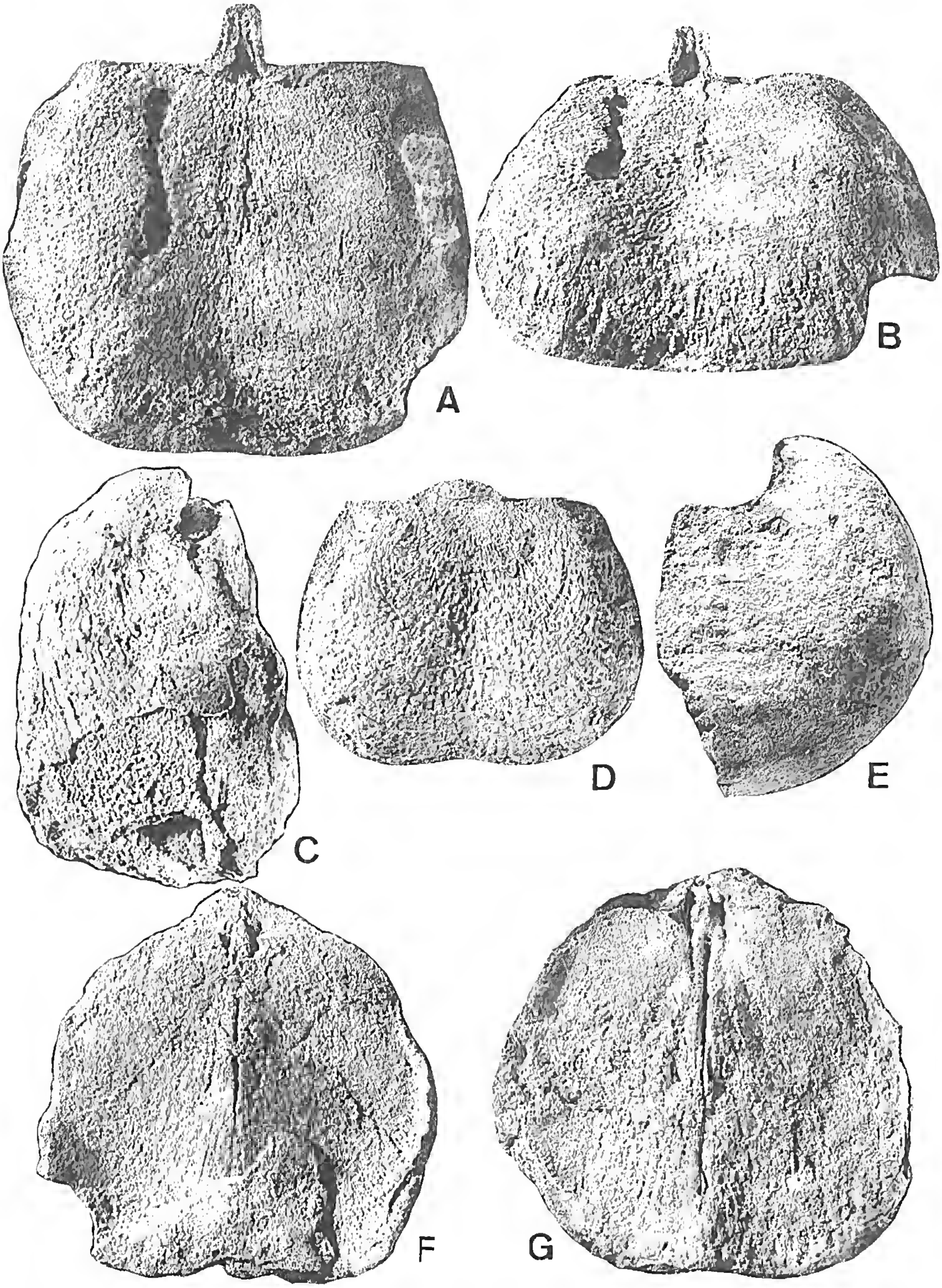
Fig. 2A–M

'Chonetes' sp., Dickins 1957: 2.—Playford 1959: 19.
Neochonetes sp., Playford et al. 1976: 100.
Neochonetes (Sommeriella) sp. nov., Archbold 1988: 46.—Archbold 1993a: 316.
Neochonetes (Sommeriella) sp. nov. A., Skwarko 1993: 91.

Holotype. WAM 69.754, an external impression of a large ventral valve from the High Cliff Sandstone, Woolaga Creek. Source of specimen, H. F. Broadbent, 1963–69, Scotch College Collection No. 179.

Paratypes. WAM 69.755–69.756, two ventral valve internal moulds. UWA 31568, UWA 32755, two ventral valve internal moulds. UWA 38552, UWA 33764, two internal moulds of dorsal valves and UWA 31566 and

Fig. 4. A–G, *Taeniothaerus quadratiformis* sp. nov. A, B, WAM 69.750, external mould of dorsal valve in ventral and antero-ventral views, ×1. C, CPC 34593, internal mould of shell in profile view, ×1. D, CPC 34594, external mould of dorsal valve, ×1. E, UWA 31557, internal mould of ventral valve in profile view, ×1. F, WAM 69.751, internal mould of shell in dorsal view, ×1. G, CPC 34595, internal mould of shell in dorsal view, ×1.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internal mould of a complete shell with valves open at 90°.

Size ranges. Maximum width, 27–44 mm; hinge width, 25–39 mm; shell height, 21–28 mm; length of ventral septum, 11–18.5 mm; length of dorsal septum, 10–13 mm.

Diagnosis. Very large *Neochonetes (Sommeriella)* with relatively flat lateral profile and a weakly developed, broad sulcus.

Description. Convexity of ventral valve usually gentle with shallow sulcus arising close to umbo with a weakly developed median valley. Dorsal valve flat to very gently concave, with no median fold. Greatest width of shell at midlength at maturity. External ornament of weakly developed growth lines, somewhat crowded at anterior of mature specimens. Capillae weakly developed (about 2 per mm at 1.5 cm from umbo on holotype). Interareas very low, marginal spines not known, ventral umbo small, low.

Ventral interior with fine, sharp median septum, up to two-thirds valve height, impressions of parallel vascular trunks weakly impressed. Muscle fields large, flabellate. Teeth small, sharp. Anterior of valve interior finely papillose.

Cardinal process poorly known, apparently internally bilobed. Alveolus prominent and deep at maturity. Median septum sharp, bladelike, arises anteriorly of alveolus, broadens and flattens posteriorly at maturity. Socket ridges distinct, sockets fine, lateral septa distinct, approximately half length of medium septum. Brachial ridges poorly known, weakly developed. Anterior of dorsal valve interior of submature individuals with parallel rows of radiating papillae. Posterior margin of valve smooth.

Discussion. Neochonetes (Sommeriella) magnus is the largest chonetoid known from the Western Australian Permian. The large size and shallow lateral profile of the species, the weakly developed sulcus and the overall flat appearance distinguish this species from all others of the genus.

Neochonetes (Sommeriella) cockbaini Archbold (in Archbold & Shi 1993) from the Jimba Jimba Calcarenite of Early Aktastinian age, is also a large species but possesses a deep, relatively narrow sulcus and a strongly convex ventral profile. *Neochonetes (Sommeriella) tenuicapillatus* Archbold (1981d) from Late Baigendzhinian units of Western Australia possesses very fine capillae and a distinctly concave dorsal valve. The Kungurian *Neochonetes (Sommeriella) afanasyevae* Archbold (1981d) from the Coolkilya Sandstone and correlative units of Western Australia is a smaller species, flattish in appearance but with a narrow dorsal fold.

Genus **Chonetinella** Ramsbottom, 1952

Type species. Chonetes flemingii Norwood & Pratten, 1855.

Comments. Species of *Chonetinella* can approach the morphology of species of *Neochonetes* (see Archbold 1991c: 289). *Chonetinella* is interpreted here as including small rugosochonetids, often subquadrate in outline, with a deep ventral sulcus and fine costellae as for the type species (see Muir-Wood 1962: pl. 9, figs 10–16).

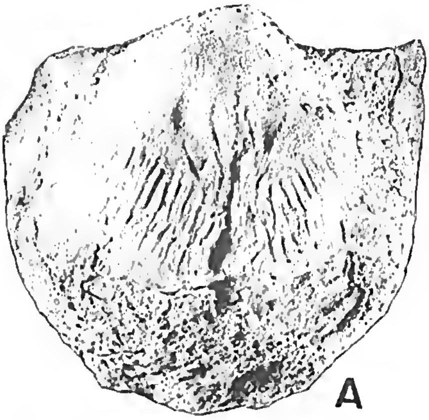
Chonetinella sp.

Fig. 3C–E

Comments. A single external mould of a ventral valve (UWA 33763) of a small chonetid (width, 10.1 mm; height, 6.3 mm) indicates the presence of a second chonetid in the High Cliff fauna. The specimen possesses a prominent sulcus that arises at the umbo. Ears are distinctly demarcated and impart a transverse outline to the valve. Indistinct traces of fine costellae are preserved. The profile of the valve is moderately convex.

The deep sulcus and demarcated ears of the valve, separate the specimen from juvenile *Neochonetes (Sommeriella)*. The most strongly sulcate species of *Neochonetes (Sommeriella)* from Western Australia, *Neochonetes (Sommeriella) cockbaini* Archbold (in Archbold & Shi 1993) from the Aktastinian of the Carnarvon Basin, does not develop a distinct, deep sulcus until later in ontogeny, unlike the present specimen.

Fig. 5. A–F, *Taeniothaerus quadratiformis* sp. nov. A, C, CPC 34596, internal mould of shell in postero-ventral and ventral views, ×1. B, UWA 34451, internal mould of ventral valve in profile view, ×1. D–F, WAM 69.749, internal mould of ventral valve in postero-ventral, ventral and posterior views, ×1.1.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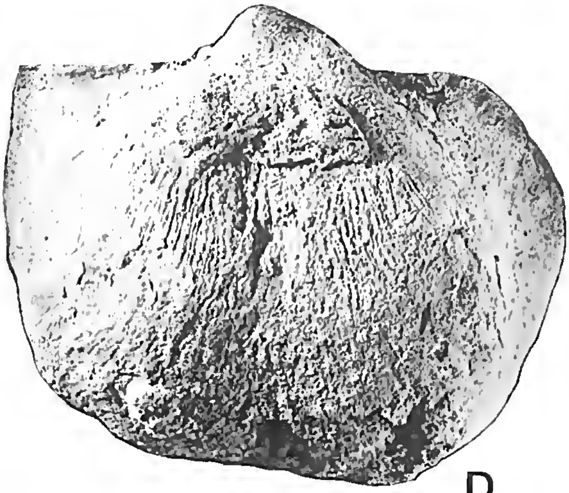
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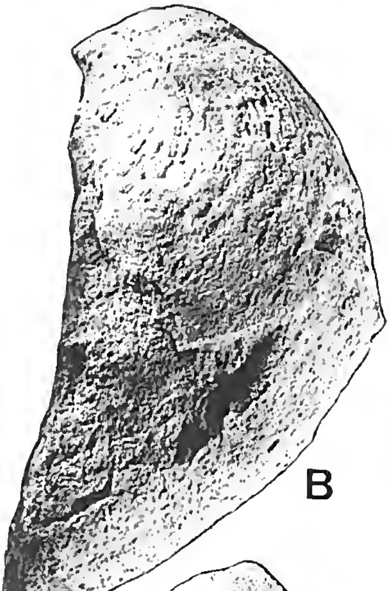
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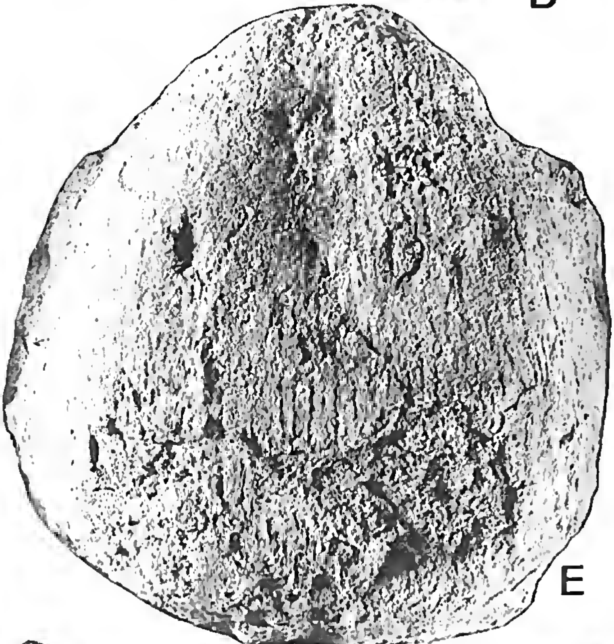
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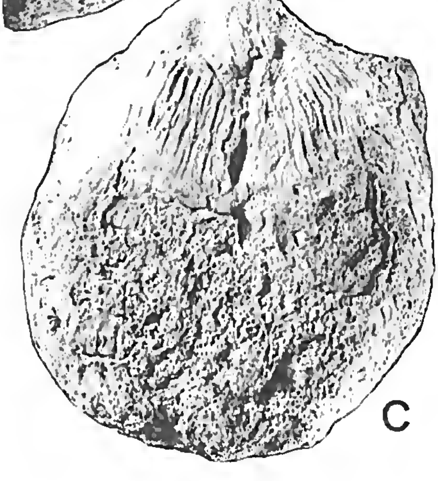
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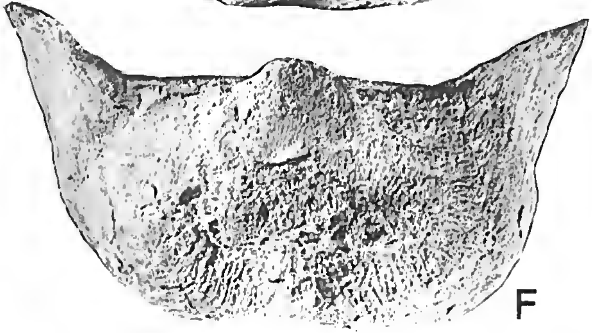
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This record of *Chonetinella* provides a minor additon to the imperfectly known record of the genus from Western Australia (see also Archbold 1981d). *Chonetinella* is also known from the Early Permian of Irian Jaya (Archbold 1982b, 1991c).

Order PRODUCTIDA
Sarycheva & Sokolskaya, 1959

Suborder STROPHALOSIIDINA
Waterhouse, 1975

Superfamily STROPHALOSIOIDEA
Schuchert, 1913

Family STROPHALOSIIDAE Schuchert, 1913

strophalosiid indet.

Fig. 3F, G

Comments. A single, small internal mould of a ventral valve, UWA 32755, indicates the presence of a strophalosiid in the High Cliff Sandstone assemblage. Traces of an interarea, a small adductor muscle field bisected by a median ridge and a transverse valve outline (width, 17 mm; height, 15 mm) are typical of submature strophalosiids. Lack of external details prevents generic assignment. The specimen is figured for the record.

Suborder PRODUCTIDINA Waagen, 1883

Superfamily AULOSTEGOIDEA
Muir-Wood & Cooper, 1960

Family AULOSTEGIDAE
Muir-Wood & Cooper, 1960

Subfamily AULOSTEGINAE
Muir-Wood & Cooper, 1960

Genus **Aulosteges** von Helmersen, 1847

Type species. Orthis wangenheimi de Verneuil, 1845 (=*Aulosteges variabilis* von Helmersen, 1847).

Aulosteges ingens Hosking, 1931

Fig. 3H–I

Aulosteges ingens Hosking 1931: 15, pl. 5, figs 1a–c; pl. 6, figs 2a–c.—Coleman 1957 (*partim*): 43, pl. 3, figs 1–4, 6, 8 (*non cet.*).—Archbold et al. 1993: pl. 29, figs 4–7, microfiche 4: 41 (with synonymy).—Skwarko 1993: 91, 98.
Aulosteges cf *ingens*.—Dickins 1957: 2.—Playford 1959: 19.
Aulosteges spinosus.—Coleman 1957 (*partim*): pl. 5, figs 1–3 (*non cet.*).
Aulosteges cf *A. ingens*.—Archbold 1988: 46.
Aulosteges sp. Archbold 1993a: 316.

Lectotype. GSWA 1/5000, a complete worn shell from the Coyrie Formation (*sensu* Skwarko, 1993), =upper part of Madeline Formation (*sensu* Archbold 1993a), Carnarvon Basin.

Comments. Coleman (1957) figured an internal mould of a complete shell from the High Cliff Sandstone as a representative of *Aulosteges spinosus* Hosking (1931), a species with a relatively low ventral intercarea, a gently curved ventral profile and based on a small, probably immature, holotype. Coleman's Woolaga Creek specimen UWA 34433, is a form with a distinct, moderately high, triangular, relatively flat ventral interarea, a somewhat twisted ventral umbo, a thin, sharp dorsal median septum and thin, sharp basal ridges of the cardinal process. Flattening of the ventral valve close to the umbo indicates the specimen possessed a cicatrix for attachment. The ventral profile, except for the anterior margin, is relatively flat.

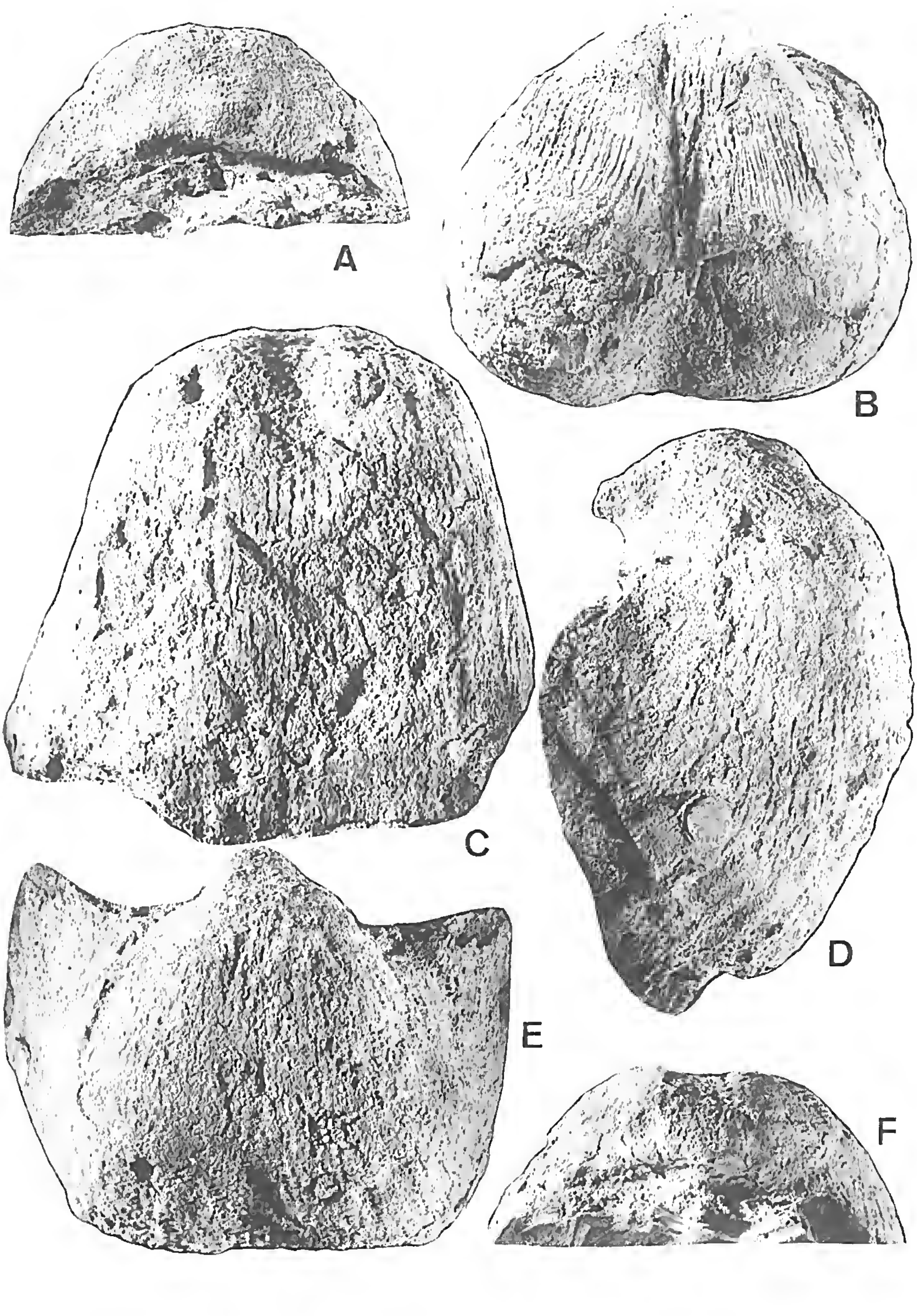
In view of the similarity of the specimen to the holotype of *A. ingens* Hosking, figured by Hosking (1931), Coleman (1957) and Archbold et al. (1993), UWA 34433 is referred to Hosking's species subject to the discovery of large collections which would permit more detailed comparisons.

Genus **Taeniothaerus** Whitehouse, 1928

Type species. Productus subquadratus Morris, 1845.

Comments. The lectotype of the type species (Natural History Museum, London, BM91171), from the Artinskian of Tasmania, was figured

Fig. 6. A–F, *Taeniothaerus quadratiformis* sp. nov. A, C–E, holotype, UWA 32316a, internal mould of ventral valve in posterior, antero-ventral, profile and postero-ventral valve views, ×1. B, F, UWA 34451, internal mould of ventral valve in postero-ventral and posterior views, ×1.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by Etheridge & Dun (1909), Hill (1950) and Coleman (1957). The type species has been most recently redescribed by Parfrey (1983) and is characterised by a relatively low ventral interarea and a relatively inflated and incurved ventral umbo. The new species described below is retained in *Taeniothaerus* despite possessing a curved interarea of moderate height, because of its large size, inflated and curved ventral profile and external spine features.

Taeniothaerus quadratiformis sp. nov.

Figs 4A–G, 5A–F, 6A–F, 7A–F

Taeniothaerus irwinensis Coleman 1957 (*partim*): 93.
Taeniothaerus sp. cf *T. subquadratus*.—Coleman 1957: 102, pl. 15, figs 8–12.
Taeniothaerus coolkiliensis Coleman 1957 (*partim*): 89, pl. 11, figs 11–12.
Taeniothaerus coolkiliensis.—Playford et al. 1976: 95.
Taeniothaerus sp. nov., Archbold 1988: 46.—Archbold et al. 1993: pl. 32, fig. 6, microfiche 4: 48.—Skwarko 1993: 91.—Archbold 1993a: 316.

Holotype. UWA 32316a, internal mould of mature ventral valve, from about 32 m west of Glendevon Homestead near Woolaga Creek.

Paratypes. WAM 69.750, CPC 34594 and UWA 32043, three external moulds of dorsal valves. CPC 34593, 34595, 34596, WAM 69.751, UWA 32042, 32043, six internal moulds of shells. UWA 31557, 34451, WAM 69.749, three internal moulds of ventral valves.

Size ranges. Measurements are estimates. Width of ventral valve, 49–77 mm; ventral valve height, 57–80 mm; dorsal valve height, 44–63 mm; height of ventral interarea, 5.5–8.5 mm; width of ventral interarea, 25.5–34.5 mm; shell thickness, 25–50 mm.

Diagnosis. Large *Taeniothaerus* with coarse ventral spines, fine dorsal spines, ventral interarea of moderate height for genus and anterior of mature shells with distinct radial crenulations.

Description. Shell large, length slightly exceeds width at maturity, maximum width somewhat anterior of mid-length. Ventral umbo distinct, usually pointed, often overhangs interarea. Ventral valve strongly convex with steep lateral flanks. Sulcus shallow, broad anteriorly, narrow posteriorly, arises close to umbo. Ears small, quadrate to rounded outline. Ventral interarea of moderate height for genus, flat or gently concave (in examples with higher interarea always concave), considerably narrower than width of shell, carries vertical and horizontal striations. Triangular elytridium narrow (up to 2 mm wide on UWA 32043). Ventral spines poorly known but coarse on lateral flanks, up to 1 mm wide.

Dorsal valve concave due to distinct geniculation. Visceral disc weakly convex with low, broad dorsal fold also present on trail. Dorsal valve with spines and dimples. Spines fine over visceral disc (0.3 mm wide), coarser anteriorly (0.5 mm wide). Dimples rounded on visceral disc, elongate on trail. Growth lines fine.

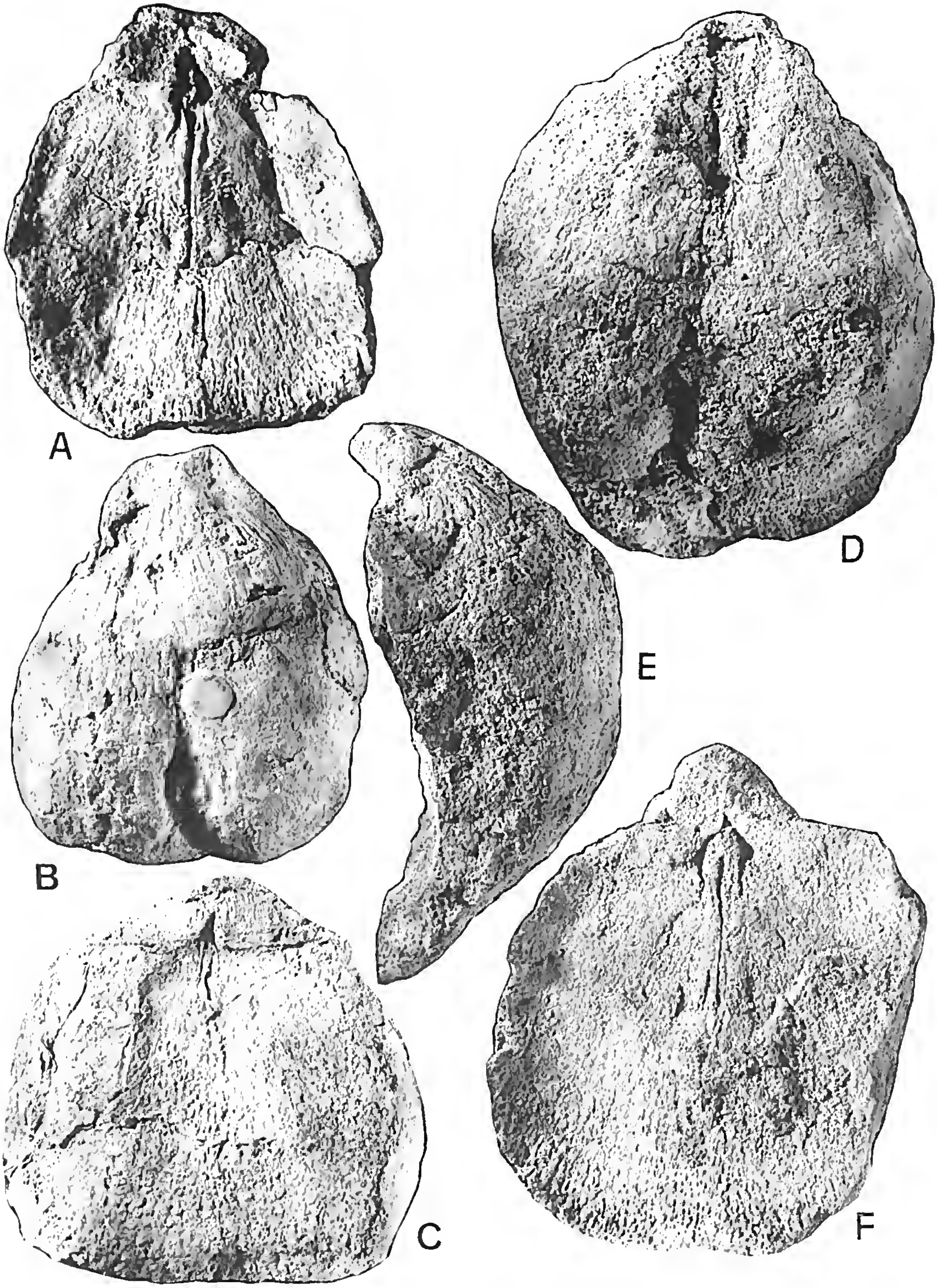
Ventral adductor scars narrow, often on gently raised platform. Diductor scars large, flabellate, strongly striate, deeply impressed.

Cardinal process pronounced, projects ventrally at low angle to visceral disc, trilobed with prominent alveolus at base. Two sub-parallel, low ridges continue anteriorly at base of process at posterior of adductor muscle scars. Brachial ridges absent. Median septum narrow, sharp, extends over three-quarters length of visceral disc in mature shells. Posterior of muscle scars dendritic, anterior essentially smooth.

Comments. Variably preserved specimens of this species were referred by Coleman (1957) to a number of species, including *T. subquadratus* (Morris), depending on their stage of ontogenetic development. Additional material now available permits a revised assessment of the interpretation of the High Cliff species.

Taeniothaerus quadratiformis sp. nov. is a large species distinguished from most Western Australian species referred to *Taeniothaerus* by Coleman (1957) by means of its coarse ventral spines, relative high ventral interarea and details of the ventral sulcus. *T. subquadratus* (Morris, 1845) and its allies from the Artinskian of the eastern Australian Permian (see Parfrey 1983; Waterhouse et al. 1983 and Briggs in Waterhouse 1986b) are a group of large, coarsely spinose species invariably with a low, concave ventral interarea (usually just a few mm high). The dorsal median

Fig. 7. A–F, *Taeniothaerus quadratiformis* sp. nov. A–C, UWA 32043, internal mould of shell in dorsal and ventral views and external mould of dorsal valve with ventral interarea, ×1.2. D–F, UWA 32042, internal mould of shell in ventral, profile and dorsal views, ×1.2.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septum appears to be shorter in the eastern Australian species and the dorsal adductor scars form a more transverse muscle field than that of *T. quadratiformis* sp. nov.

Superfamily LINOPRODUCTOIDEA Stehli, 1954

Family LINOPRODUCTIDAE Stehli, 1954

Subfamily AURICULISPININAE Waterhouse, 1986b

Genus **Costatumulus** Waterhouse, 1983a

Type species. Auriculispina tumida Waterhouse, 1983, in Waterhouse et al. 1983.

Costatumulus occidentalis Archbold, 1993

Fig. 8A–L

Linoproductus lyoni.—Coleman 1957 (*partim*): 76, pl. 8, figs 16–19, 22 (*non* 20, 21).
Linoproductus (Cancrinella) cf. *lyoni.*—Dickins 1957: 1.—Playford 1959: 19.
Linoproductus (Cancrinella) sp.—Dickins 1957: 2, 3.—Playford 1959: 19.
Cancrinella sp. cf. *C. lyoni.*—Playford et al. 1976: 98.
Cancrinella sp.—Playford et al. 1976: 98.
Lyonia lyoni.—Archbold 1983 (*partim*): 244.
Cancrinella sp. nov. Archbold 1988: 46.
Cancrinella sp. C.—Archbold et al. 1993, microfiche 4: 65.—Skwarko 1993: 91.
Costatumulus sp. nov. Archbold 1993a: 316.
Costatumulus occidentalis Archbold 1993b: 14, fig. 9A–I.

Holotype. UWA 32025, an internal mould of a complete shell and the external mould of the dorsal valve, from Woolaga Creek, Irwin River Area.

Comments. This species was originally described on the basis of three specimens (Archbold 1993b). Additional material illustrated in Fig. 8 provides details of specific variation that permits a broader understanding of the species.

The outline of the shell is rounded to transverse and the profile distinctly to gently concavo-convex. Ears may be indistinct to distinct. Ventral muscle scars weakly striate at maturity. Ear spines on ventral valve in distinct cluster. Rugae distinct on ventral valve lateral and anterior flanks but poorly developed over venter. Additional specimens confirm that dorsal spines are absent.

Costatumulus occidentalis is a large species, readily distinguished from other Western Australian species (Archbold 1983) by means of its size and details of ornament including weakly developed rugae over the venter and relatively coarse costellae.

Order SPIRIFERIDA Waagen, 1883

Suborder SPIRIFERIDINA Waagen, 1883

Superfamily SPIRIFEROIDEA King, 1846

Family SPIRIFERIDAE King, 1846

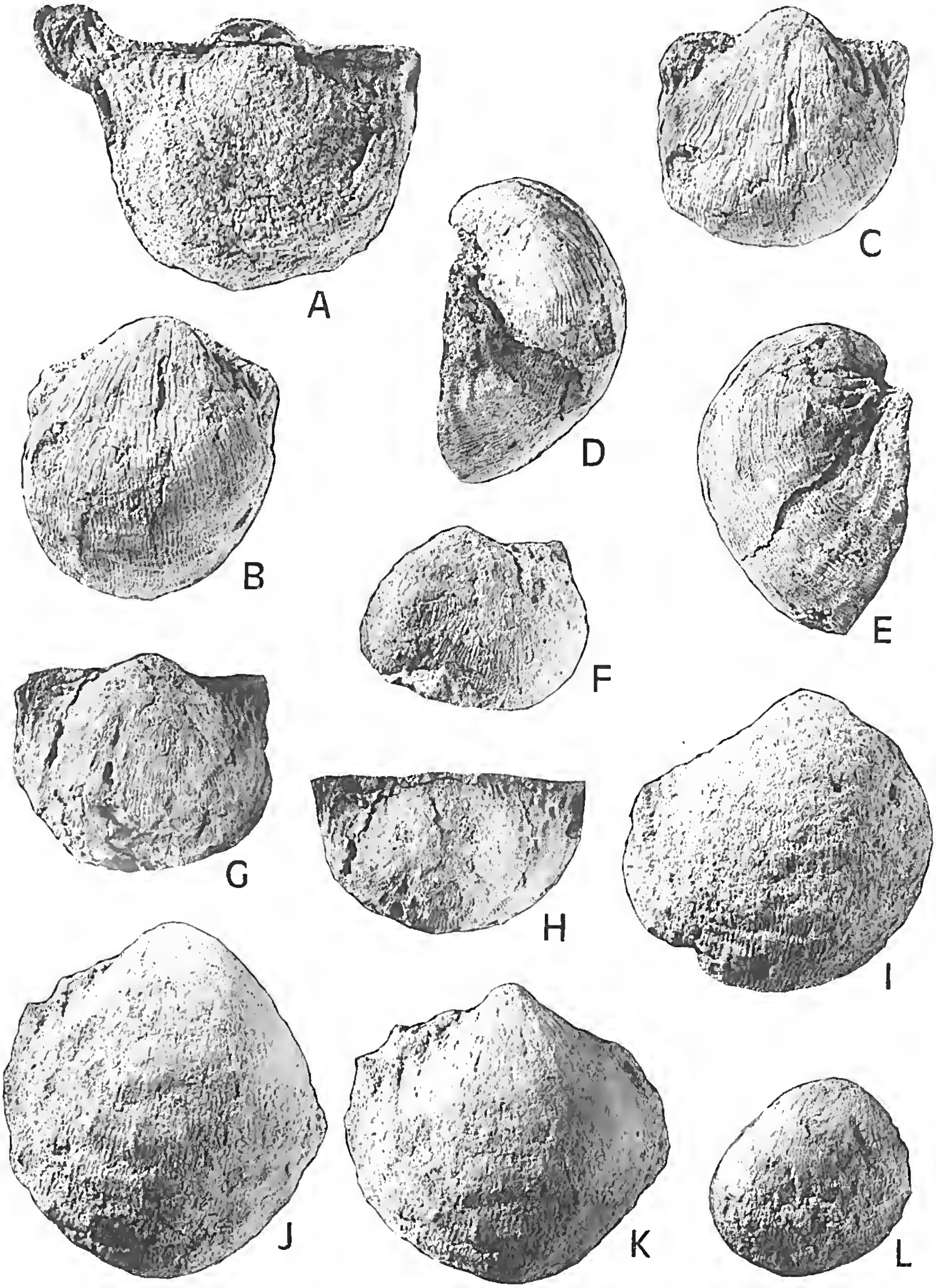
Subfamily NEOSPIRIFERINAE Waterhouse, 1968

Genus **Neospirifer** Fredericks, 1923

Type species. Spirifer fasciger von Keyserling, 1846.

Comments. Spiriferids with fasciculate costae are highly diverse during the Late Palaeozoic (eg. see Archbold & Thomas 1985, 1986, 1987) and numerous genera are recognised. Species and genera can demonstrate considerable morphological variability in terms of individual species and species groups within genera. Several distinctive groups (presumably representing incompletely understood 'clines') of *Neospirifer* are known for example in the rich Permian faunas of Western Australia (Archbold & Thomas 1986) and at least one of those is sufficiently well known to designate as a distinct group or subgenus. Recognition of such subgenera appear to be useful in aiding the recognition of palaeobiogeographical subgroupings of related species.

Fig. 8. A–L, *Costatumulus occidentalis* Archbold 1993. A, UWA 32755, external mould of dorsal valve, ×1.2. B–E, UWA 33677, internal mould of complete shell in ventral, postero-ventral and two profile views, ×1.2. F, UWA 32755, internal mould of ventral valve in ventral view, ×1. G, H, UWA 31552, internal mould of ventral valve in ventral and posterior views, ×1. I, UWA 33699, internal mould of ventral valve in ventral view, ×1.2. J, K, UWA 33765, internal mould of ventral valve in ventral and postero-ventral views ×1.2. L, UWA 33697, internal mould of ventral valve in ventral view, ×1.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Subgenus Neospirifer (Neospirifer) Fredericks, 1923

Type species. As for genus.

Comments. The date of authorship of *Neospirifer* by G. N. Fredericks is normally given as 1924 (see Archbold & Thomas 1984), the year when volume 38, number 3 of the Izvestiya of the Geologicheskogo Komiteta was published in Petrograd. Volume 38 of the journal was actually issued for the year 1919 but like many issues of the Izvestiya during the 1920s, was published some years later with individual numbers of the volume being issued out of sequence. It is of note that volume 39, number 2 of the Izvestiya, which contains a summary report of activities of the Geologicheskogo Komiteta for 1919 was published in 1923 in Peterburg. Within the summary report is a summary of G. N. Fredericks' theoretical studies the full text of which was later published in 1924 as his 'Paleontologicheskie Etyudy' in number 3 of volume 38. Within this summary, many of his new genera are listed with type species and brief diagnoses. One such genus is given as 'Neospirifer Frks—shell ribbed—plicate, Type: *Spirifer fasciger* Keys.;' which satisfies the criteria of publication for the date in question, ie. 1923. This date of publication of *Neospirifer* is used herein and the authorship is ascribed to G. N. Fredericks (cited as Fredericks 1923 in the references).

Neospirifer (Neospirifer) sp.

Fig. 14A

Comments. Specimen WAM 69.760, an external mould of a ventral valve, possessing fine costae and distinct growth lines resulting in a tegulate micro-ornament, is referred to *Neospirifer (Neospirifer)*. The specimen carries up to 6 pairs of relatively low lateral plications (including the sulcal bounding pair). The sulcus is relatively shallow, broadens anteriorly and possesses a pair of plications on its inner lateral flanks. The specimen is transverse (85 mm wide) and growth lines indicate a lack of attenuated ears or truncated hinge. In view of these morphological details it appears unlikely that the specimen is referable to *Neospirifer (Quadrospirifer)* subgen. nov. as described below.

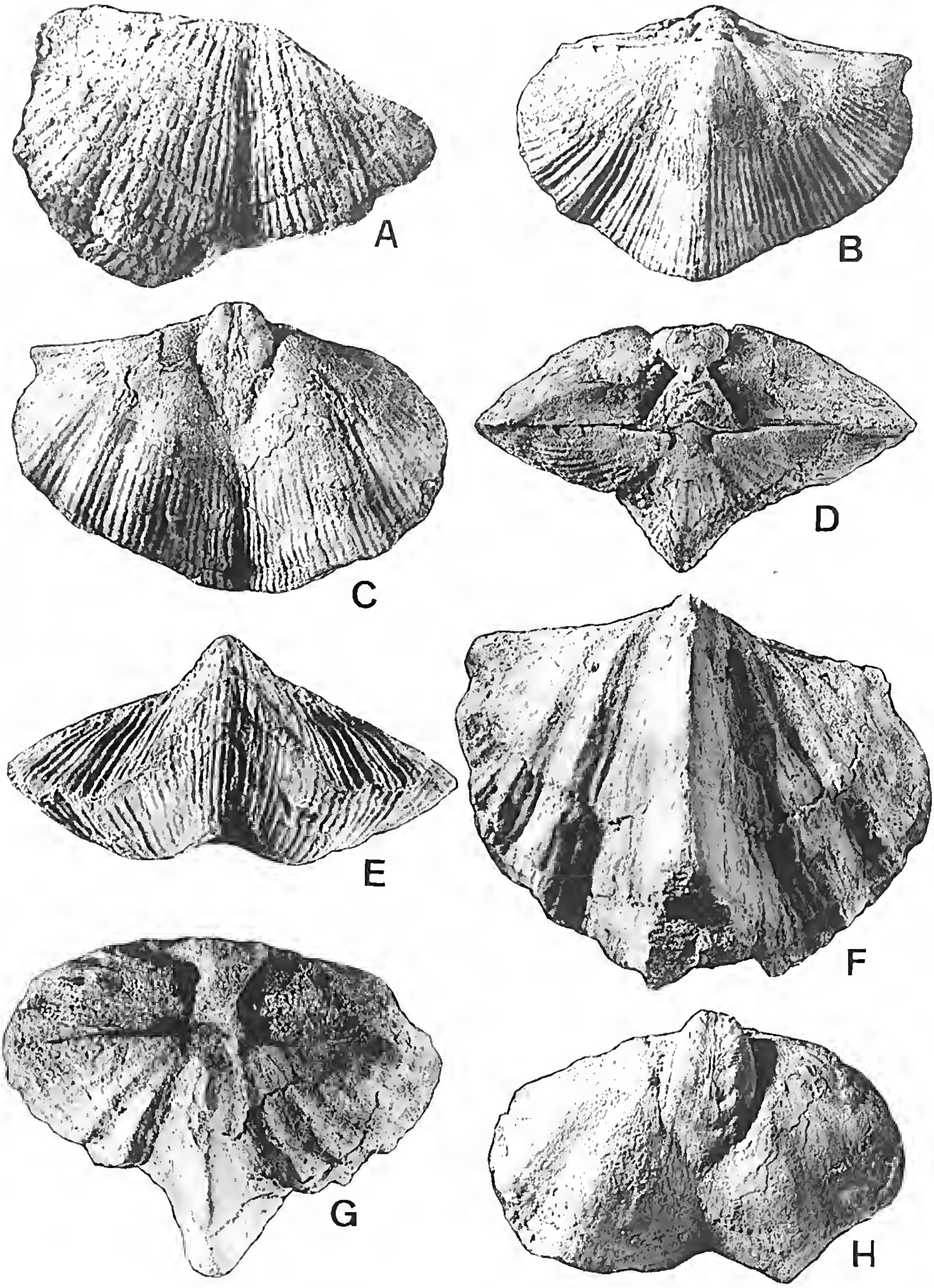
Neospirifer (Quadrospira) subgen. nov.

Type species. *Neospirifer plicatus* Archbold & Thomas, 1986.

Diagnosis. Medium to large *Neospirifer* with well-developed sulci and fastigia, low to prominent lateral plications and truncated hinge line and interareas at maturity with attenuated ears.

Discussion. In the Western Australian Early Permian, a distinctive group of species ranging in age from Sterlitamakian to Latest Baigendzhinian includes the species *Neospirifer hardmani* (Foord), *Neospirifer plicatus* Archbold & Thomas and *Neospirifer postplicatus* Archbold & Thomas. These species all possess truncated hinge lines and interareas at maturity and hence possess attenuated ears. The anterior fold is high, the fastigium pronounced and the sulcus distinct. Archbold & Thomas (1986) noted that these Westralian species shared these morphological features with a group of Permian species found throughout the Early and Late Permian of the Cimmerian Province as defined by Archbold (1983a). A current list of many of these records includes: *N. hardmani* as recorded by Hudson & Sudbury (1959), Sterlitamakian, Arabia; *Aperispirifer undatus* as recorded by Termier et al. (1974), Sterlitamakian, Afghanistan; possibly *Neospirifer trimuensis* (Reed, 1944), late Early Permian, Pakistan; *N. timorensis* (Martin, 1881; see also Archbold & Bird 1989), Permian, Timor; *Neospirifer* sp. (Garson et al. 1975), Early Permian, Peninsular Thailand; *Neospirifer* sp. nov. (Archbold et al. 1996), Aktastinian, Badhaura, India; and the Late Permian *Neospirifer tibetensis* Ting (1962; see also Yang & Zhang 1982) from southern Tibet and *Neospirifer kubeiensis* of Fang & Fan (1994) from Western Yunnan. All the above records are now referred to *Neospirifer (Quadrospira)*.

Fig. 9. A–H, *Neospirifer (Quadrospira) woolagensis* sp. nov. A, UWA 33743, latex cast of ventral valve external mould, ×1.2. B–E, UWA 34296, internal mould of shell in dorsal, ventral, posterior and anterior views, ×1. F, G, UWA 34294, holotype, internal mould of shell in dorsal and posterior views, ×1. H, UWA 31584, internal mould of ventral valve, ×1.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Neospirifer (Quadrospira) woolagensis sp. nov.

Figs 9A–H, 10A–E, 11A–F

Neospirifer sp. nov. A.—Dickins 1957: 2.—Playford 1959: 19.—Playford et al. 1976: 100.
Neospirifer sp. nov. Archbold 1988: 46.—Skwarko 1993: 91.—Archbold 1993a: 316.

Holotype. UWA 34294, an internal mould of a complete shell.

Paratypes. UWA 34296, 34311, 31581, three internal moulds of complete shells. UWA 33743, an internal mould of a shell with external mould of the ventral valve. UWA 31584, 38582, two internal moulds of ventral valves. CPC 34597, 34598, two incomplete internal moulds of shells.

Size ranges. Hinge width, 52–67 mm; maximum width, 62–71 mm; ventral valve height, 44–66 mm; dorsal valve height, 39–53 mm; thickness, 31–50 mm.

Diagnosis. Large *Neospirifer (Quadrospira)* with pronounced anterior fold, high fastigium, pronounced lateral plications at maturity and strong, relatively coarse but equidimensional costae.

Description. Large sized species, subquadrate and inflated at maturity, maximum width at approximately shell mid-length. Ears attenuated and interareas truncated at maturity.

Ventral umbo small, pointed, incurved, overhangs interarea. Sulcus broad, deep, U-shaped cross-section. Sulcal tongue long, inclined at 90° to plane of commissure. Three pairs of plications (including sulcal bounding pair) developed on ventral lateral flanks. Plications rounded to sharp. Costae moderately coarse (up to 1.0 mm wide at 3 cm from umbo, 1.5 mm wide at 5 cm from umbo) with narrow interspaces.

Delthyrium prominent. Dental plates strong, flanges stout and thickened, adminicula buried in valve thickening at maturity. Muscle field broad, rounded, adductor scars vertically striated, diductor scars with radial striations.

Dorsal fastigium high, anterior fold prominent. Lateral plications and costae as for ventral valve. Dorsal interarea low, cardinal process distinct, wider than long and vertically striated. Delicate myophragm bisects muscle field. Socket and crural plates typical of genus.

External micro-ornament poorly known, traces of radial capillae and distinct growth lines rarely preserved.

Discussion. The very pronounced fastigium, generally strong lateral plications and nature of the fold and sulcal tongue ally *N. (Q.) woolagensis* sp. nov. with *N. (Q.) plicatus* Archbold & Thomas (1986) from the Early Baigendzhinian of the Madeline Formation, Western Australia and *N. (Q.) timorensis* (Martin, 1881) from an unknown horizon, Timor. Both those species, however, possess fine costae and *N. (Q.) timorensis* possesses an additional pair of lateral plications.

Genus **Occidalia** gen. nov.

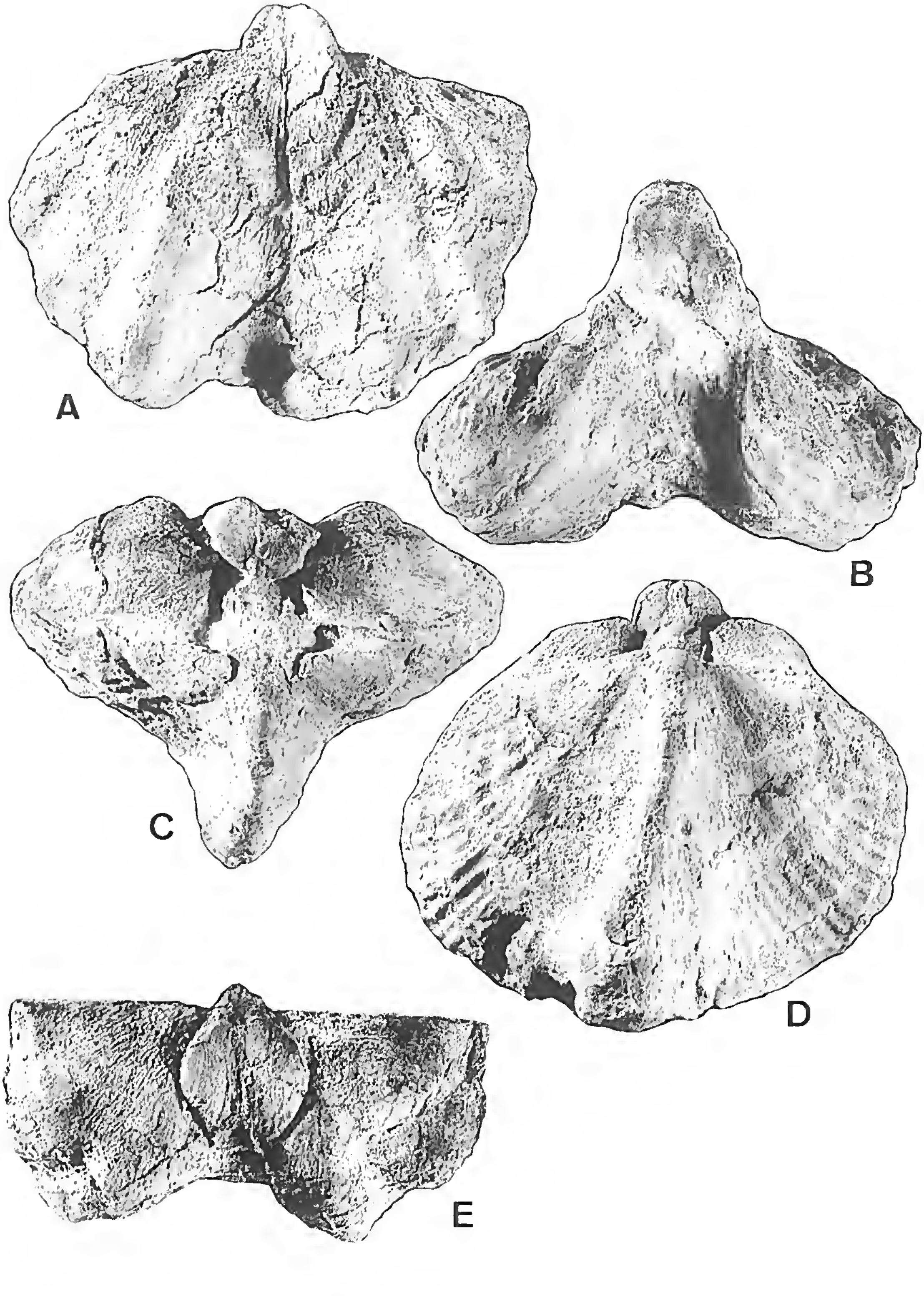
Type species. Occidalia shahi sp. nov.

Diagnosis. Moderately to strongly plicate transverse neospiriferids with high, sharp fastigia and pronounced anterior fold. Maximum width at hinge line. Sulcal tongue pronounced, at close to 90° to the plane of the commissure.

Discussion. This new genus was foreshadowed by Archbold (1996) when describing the somewhat less well known species *Crassispirifer mingenewensis* (see Archbold 1996: p. 36, fig. 10A–L). The Mingenew Formation species is now referred to *Occidalia* as is the species figured by Archbold et al. (1996) as *Crassispirifer* sp. nov. from the Aktastinian Badhaura Formation of Rajasthan, peninsular India.

Crassispirifer Archbold & Thomas (1985) is a closely related genus with lower lateral plications and broad, rounded fastigia and anterior fold of moderate height. Its sulcal tongue is distinct and at approximately 45° to the plane of the commissure. Both *Crassispirifer* and *Occidalia* may be descended from a smaller species such as *Crassispirifer condoni* Archbold & Shi (1993) from the Jimba Jimba Calcarenite (or upper Callytharra Formation in the extended sense of Mory 1996).

Fig. 10. A–E, *Neospirifer (Quadrospira) woolagensis* sp. nov. A, UWA 34294, holotype, internal mould of shell in ventral view, ×1.2. B–D, UWA 34311, internal mould of shell in anterior, posterior and dorsal views, ×1. E, UWA 38552, internal mould of ventral valve in postero-ventral view, ×1.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Occidalia shahi sp. nov.

Figs 12A–K, 13A–I

Neospirifer sp. nov. B, Dickins 1957: 2.—Playford 1959: 19.—Playford et al. 1976: 100.
neospiriferid gen. et sp. nov., Archbold 1988: 46.—Archbold 1993a: 316.

Holotype. UWA 34309, an internal mould of a shell and external mould of dorsal valve with ventral umbo and interarea region.

Etymology. For Shri Sumtilal C. Shah, retired Deputy Director of the Geological Survey of India and collector of the *Occidalia* species from Badhaura, India.

Paratypes. UWA 34310, internal mould of dorsal valve. UWA 33690, 34308, 33691, three internal moulds of shells. UWA 33754, internal mould of ventral valve.

Size ranges. Estimates only, due to preservation of material. Maximum width, 75–90 mm; ventral valve height, 35–42+ mm; dorsal valve height, 25–35 mm.

Diagnosis. Moderately plicate *Occidalia* with high, sharp fastigium, prominent fold and sulcal tongue close to 90° to the plane of the commissure.

Description. Moderate sized species, biconvex, transverse, maximum width at hinge line.

Ventral umbo small, sharp, arched over delthyrium. Interarea low, striated horizontally (growth lines) and, less regularly, vertically (denticular grooves). Delthyrium distinct, delthyrial grooves and ridges present. Sulcus arises at umbo, broadens anteriorly to incorporate first pair of plications. Sulcal tongue prominent, orientated close to 90° to plane of commissure. Lateral plications distinct, moderately low, up to five pair on valve flanks. Fasticulation of costae distinct, up to five costae per bundle. Costae sharp, equidimenstional, intercostal valleys narrow.

Dorsal umbo small, sharp, pointed; interarea very low. Fastigium arises at umbo, remains sharp, narrow, high, crest delineated by single costa. Anterior fold high, rounded but sharp crested. Lateral plications and fasciculate costae as for ventral valve.

External micro-ornament of growth lamellae giving tegulate appearance, with rare traces of radial capillae.

Ventral teeth stout with thickened dental flanges and adminicula. Ventral muscle field prominent, typically neospiriferid. Dorsal socket plates stout, cardinal process typically spiriferid.

Discussion. Occidalaia shahi sp. nov. is close to *Occidalia mingenewensis* (Archbold, 1996) from the Baigendzhinian Mingenew Formation, Perth Basin. The Mingenew species is differentiated by means of its more prominent lateral plications and longer sulcal tongue resulting in a higher dorsal fold. The new species from the Badhaura Formation, India (see Archbold et al. 1996: fig. 3J, L) possesses a rounded anterior dorsal fold and coarser, fewer costae than the Western Australian species.

Superfamily SYRINGOTHYRIDOIDEA
Fredericks, 1926

Family SYRINGOTHYRIDIDAE
Fredericks, 1926

Subfamily PERMOSYRINXINAE
Waterhouse, 1986

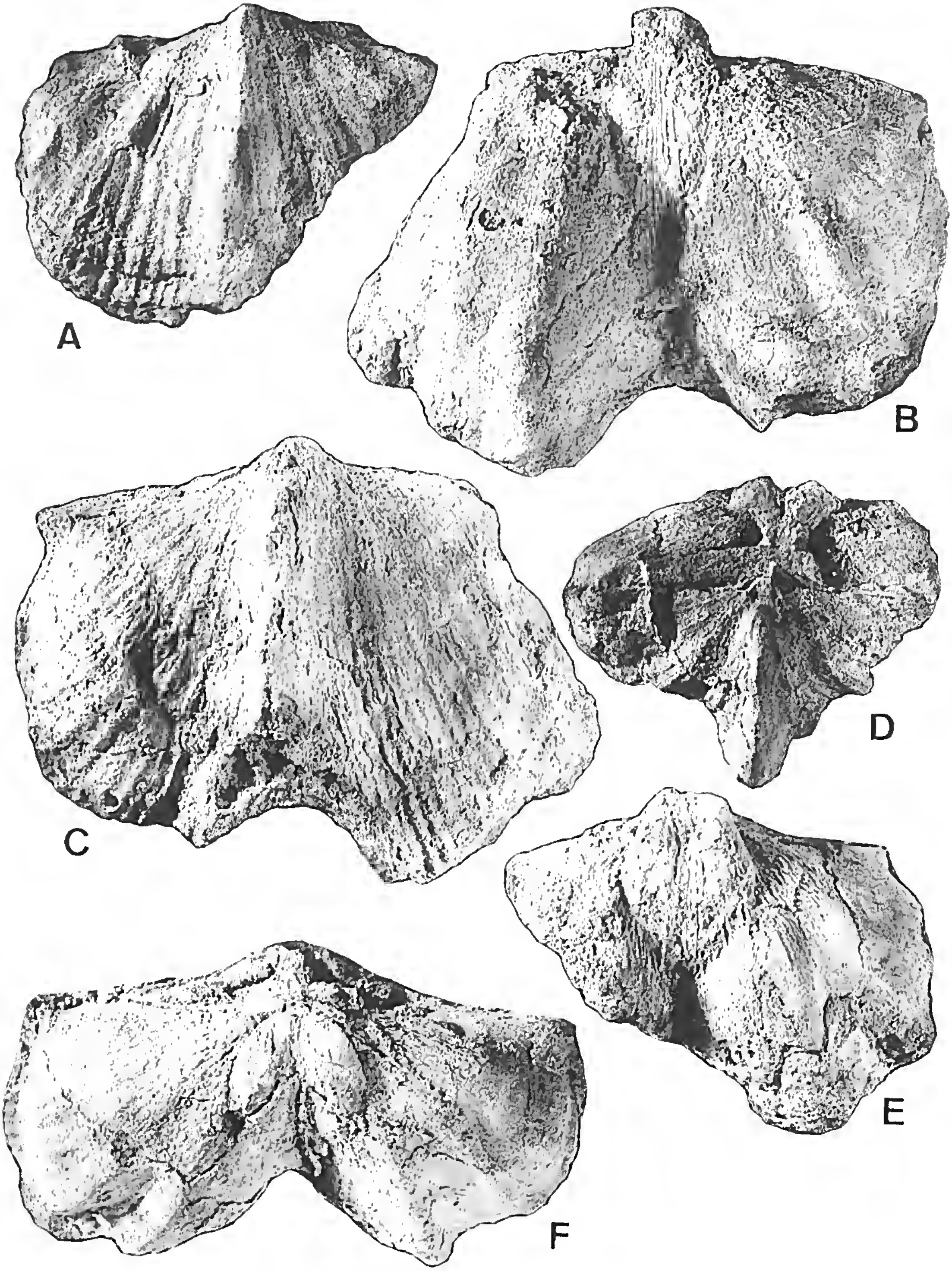
Genus **Woolagia** gen. nov.

Type species. Woolagia playfordi sp. nov.

Diagnosis. Transverse permosyrinxinid, normally with distinct broad groove in dorsal fastigium flanked by pair of low costae. Ventral sulcus shallow, deepens anteriorly at maturity, smooth or with low inconspicuous pair of costae on flanks. Costae simple on lateral flanks.

Discussion. A large and variable collection of specimens from the High Cliff Sandstone indicates the presence of a distinctive permosyrinxinid in the fauna. Many specimens are highly transverse while others grade to a somewhat less transverse outline at maturity. All possess typical spiriferid ventral muscle scars with simple, short ventral dental plates (flanges and adminicula thickened with no syrinx, additional septa or other structures).

Fig. 11. A–F, *Neospirifer (Quadrospira) woolagensis* sp. nov. A, D, E, CPC 34597, incomplete internal mould of shell in dorsal, posterior and ventral views, ×1. B, C, UWA 31581, internal mould of shell in ventral and dorsal views, ×1.2. F, CPC 34598, internal mould of shell in postero-ventral view, ×1.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The Permosyrinxinae are abundant in the cool and temperate Permian brachiopod faunas of the world (eg. see Grigoreva et al. 1989; Waterhouse 1987; Archbold 1996) but the genus *Woolagia* appears distinctive when compared with other genera reviewed and discussed by Waterhouse (1987).

Woolagia playfordi sp. nov.

Figs 14H–Q, 15A–Y

Spiriferidae sp. nov., Dickins 1957: 2.—Playford 1959: 19.—Playford et al., 1976: 100.
Punctocyrtella sp. nov. Archbold 1988: 46.
Cyrtella? sp. nov. Archbold 1993a: 316.

Holotype. UWA 34285e, an internal mould of a complete shell.

Etymology. Named for Prof. G. Playford, collector of much of the type material.

Paratypes. UWA 34285c, 33762, 33688, 33760, 34386, 34285h, six internal moulds of shells. UWA 38552, 31785, GSWA 49479, three internal moulds of ventral valves. UWA 33761, GSWA 49477, two ventral valve external moulds. GSWA 49476, UWA 34286, two external moulds of dorsal valves. UWA 33760, internal mould of dorsal valve. GSWA 49478, internal mould of dorsal valve and external counterpart.

Size ranges. Maximum width, 41–56 mm; ventral valve height, 14–28 mm; dorsal valve height, 13–24 mm; ventral interarea height, 5.0–5.5 mm. Some measurements are estimates due to preservation.

Diagnosis. Moderately to strongly transverse shells with broad dorsal fastigial groove flanked by pair of low costae. Sulcus may have weakly developed pair of costae. Costae simple. Ventral muscle field typically spiriferid.

Description. Transverse, invariably spindle shaped shells with low interareas. Ventral posterior moderately thickened with ventral muscle field projecting posteriorly into shell thickening. External ornament of simple costae, up to 10 pairs on dorsal and ventral lateral flanks of internal moulds (costae not visible on outer lateral flanks of internal moulds) whereas up to 20 costae on ventral lateral flanks on external moulds.

Dorsal fastigium distinct with broad median groove usually flanked by pair of broad, low, rounded costae. Anterior fold prominent, rounded. Ventral sulcus well rounded in cross-section, with short anterior sulcal tongue, which arises at umbo, carries one pair of low, indistinct costae on its lateral slopes.

Ventral interior with thick, delthyrial plate. Interarea apsacline, relatively low, horizontally striate. Dental plates strong, stout, adminicula thickened but short. Ventral muscle field equidimensional to slightly elongate. Adductor scars narrow, occupy centre of muscle field. Diductor scars weakly striate. Delicate, blade-like median myophragm rarely present in centre of muscle field. Dorsal interior with wide, short, thickened socket plates and typical spiriferid cardinal process. Delicate median myophragm may extend for half valve length.

Micro-ornament of delicate radial grooves. Pits and pustules not known. Punctae not confirmed.

Discussion. The nature of the dorsal fastigium, the short ventral adminicula and the lack of complex ventral delthyrial structures indicate the distinctiveness of *Woolagia playfordi* sp. nov. Relatively small specimens referred to *Primorewia reshetnikovi* by Pavlova (in Pavlova et al. 1991: pl. 31, figs 1–3), from the Kungurian of southern Mongolia, possess comparable costae, transverse outline and micro-ornament to *Woolagia playfordi* but ventral adminicula of the Mongolian specimens appear to be longer and surround the posterior of the ventral muscle field.

Genus **Cyrtella** Fredericks, 1924

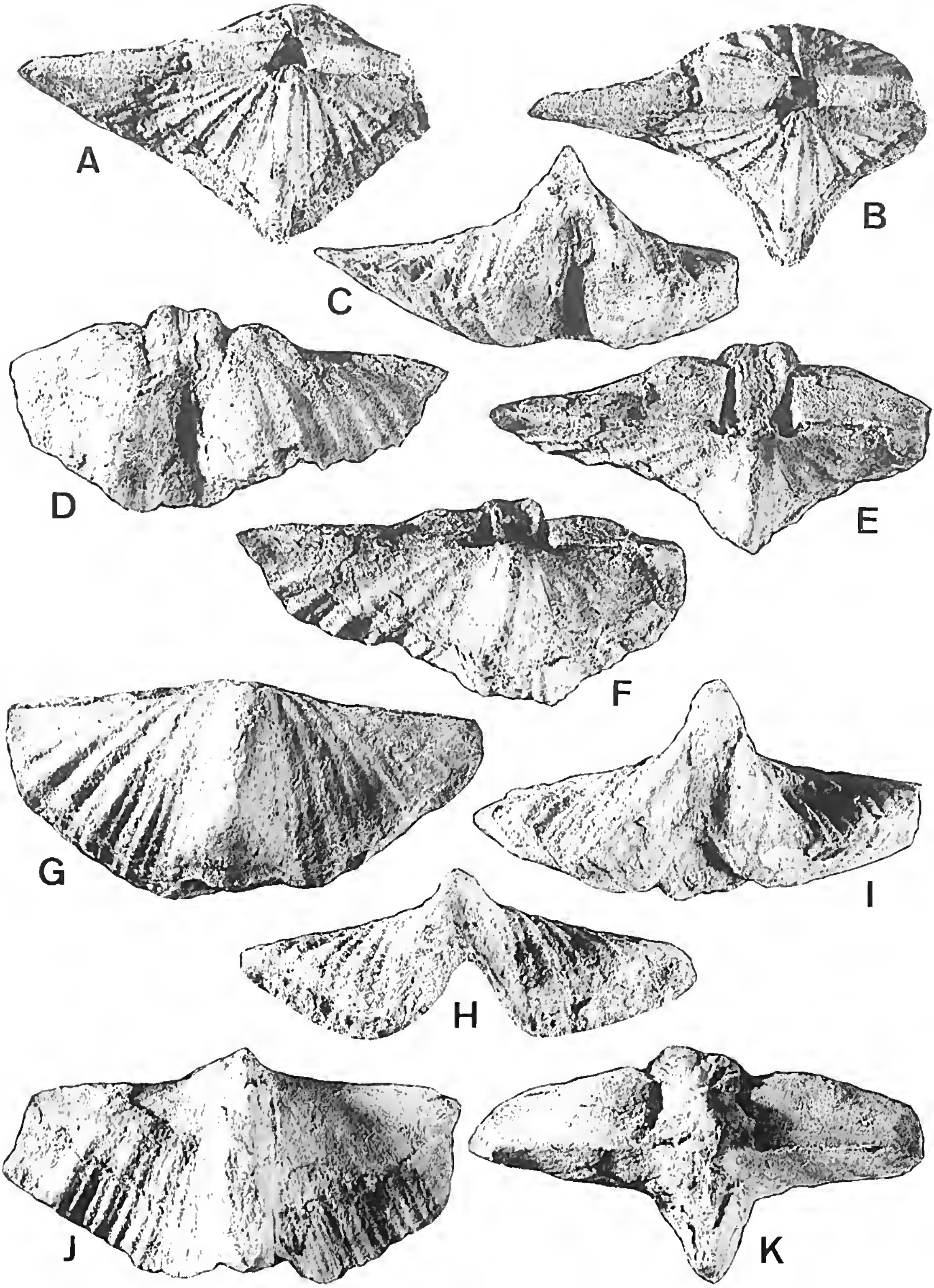
Type species. Cyrtia kulikiana Fredericks, 1916.

?Cyrtella sp.

Fig. 14B–G

Comments. Two specimens (CPC 34599, an in-

Fig. 12. A–K, *Occidalia shahi* gen. et sp. nov. A–F, UWA 34309, holotype, latex cast of external mould of dorsal valve in dorsal and postero-dorsal views, ×1, internal mould of shell in anterior, ventral, posterior and dorsal views, ×1. G, H, UWA 34310, internal mould of dorsal valve in dorsal and anterior views, ×1. I–K, UWA 33690, internal mould of shell in anterior, dorsal and posterior views, ×1.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ternal mould of a shell with counterpart external mould of dorsal valve and WAM 69.760a an external mould of a ventral valve) indicate the presence of a larger permosyrinxinid within the High Cliff fauna. The specimens indicate a form with a smooth V-sided sulcus, relatively low ventral interarea, smooth dorsal fastigium with virtually no central groove and strong, simple costae on the lateral flanks of both valves. Ventral adminicula are long and relatively fine (hence unlike those of *Woolagia playfordi*) and the ventral muscle field does not project posteriorly into ventral valve thickening.

Whether or not the specimens should be referred to *Cyrtella* is debatable, although that genus can be interpreted broadly (Waterhouse 1987) to include species with low ventral interareas. The specimens are figured for the completeness of illustrating the High Cliff fauna.

Family INGELARELLIDAE Campbell, 1959

Subfamily INGELARELLINAE Campbell, 1959

Comments. The family Ingelarellidae is now considered to include three subfamilies (Clarke 1992; Carter et al. 1994). Only the Ingelarellinae are reliably known outside the Permian of the Austrazean Province.

Genus **Tomiopsis** Benediktova, 1956

Type species. Brachythyris kumpani Yanishevskiy, 1935.

Comments. Of the Ingelarellinae, only *Tomiopsis* is reliably known from the Permian of Western Australia (Archbold & Thomas 1986a). *T. rarus*, from the High Cliff Sandstone, is the only Western Australian species for which the distinctive micro-ornament of the genus is not yet known (see Archbold & Thomas 1986a; Archbold 1993b).

Tomiopsis rarus Archbold & Thomas 1986a

Fig. 15Z, AA

'Martiniopsis' sp. A, Dickins 1957: 2.—Playford 1959: 19.—Playford et al. 1976: 100.

'Martiniopsis' sp. A?, Dickins 1957: 2.

Ingelarella branxtonensis.—Runnegar 1969: 88, pl. 1, figs 6–8 (*non cet.*).

Tomiopsis rarus Archbold & Thomas 1986a: 590, fig. 4—1–5.—Archbold 1988: 47.—Archbold et al. 1993: 254, pl. 43, figs 16–20, microfiche 5: 105.—Archbold & Shi 1995: 210, fig. 4—10, 11.

Ingelarella plana.—Dickins 1970: 22.

Comments. An incomplete internal mould of a ventral valve (UWA 38552) possesses the characteristic low lateral plicae and broad, moderately gentle sulcus of *Tomiopsis rarus* Archbold & Thomas (1986a), a species originally based on a single internal mould of a complete shell. The specimen is a submature individual with thin, diverging ventral adminicula (approximately 40°) and is an internal mould of an unthickened valve.

Order ATHYRIDIDA Dagys, 1974

Supermfamily ATHYRIDOIDEA McCoy, 1844

Family ARTHYRIDIDAE McCoy, 1844

Genus **Cleiothyridina** Buckman, 1906

Type species. Atrypa pectinifera Sowerby, 1840.

Cleiothyridina perthensis sp. nov.

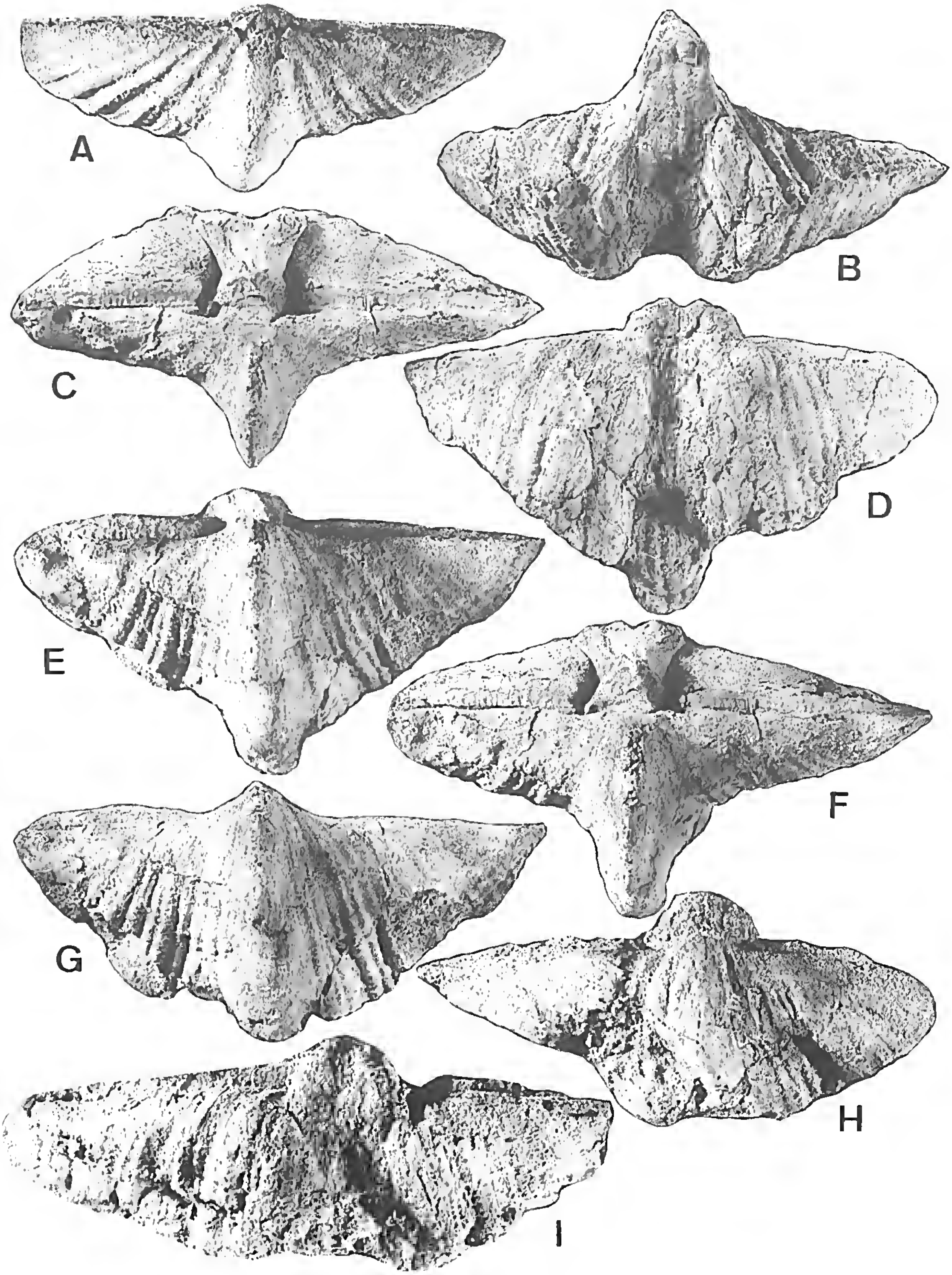
Fig. 16A–P

Cleiothyridina sp. Dickins 1957: 2.—Playford 1959: 19.—Playford et al. 1976: 100.—Archbold 1988: 47.—Skwarko 1993: 92.—Archbold 1993a: 316.

Holotype. UWA 31563, a complete internal mould of a conjoined shell.

Paratypes. GSWA 49480, external mould of posterior of shell, GSWA 49481, UWA 33366, 32753, 33761, 32755, 38552a, 31554, seven internal moulds of complete shells.

Fig. 13. A–I, *Occidalia shahi* gen. et sp. nov. A, UWA 34310, internal mould of dorsal valve in posterior view, ×1. B–G, UWA 34308, internal mould of shell in anterior, posterior, ventral, dorsal, postero-dorsal and antero-dorsal views, ×1. H, UWA 33754, internal mould of ventral valve, ×1. I, UWA 33691, internal mould of shell in dorsal view, ×1.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Size ranges. Maximum width, 25–34 mm; ventral valve height, 21–27 mm; dorsal valve height, 19.5–28 mm; thickness, 12–17 mm.

Diagnosis. Medium sized *Cleiothyridina*, transversely oval outline, biconvex at maturity. Robust and thick at maturity.

Description. Juveniles plano-convex, mature specimens biconvex. Outline transversely oval at maturity, maximum width close to mid-length. Mature shells relatively robust with thick profile.

Ventral valve flat in juvenile specimens, gently convex at maturity. Ventral umbo erect with apparently small foramen. Mature specimens with weakly developed sulcus anteriorly, resulting in weakly uniplicate commissure. Dorsal valve strongly convex, enhanced by very weakly developed median fastigium.

Exterior poorly known but growth lamellae well developed—spines unknown.

Ventral teeth short, thickened with dental plates fused into umbonal walls. Ventral muscle field large. Adductor scars posteriorly located with ridge extending anteriorly, bisecting the diductor scars. Diductor scars weakly striated or smooth, demarcated from valve floor by low, semi-circular ridge.

Dorsal interior with variably developed median septum. Muscle scars weakly impressed, valve floor variably striate.

Discussion. Most species of *Cleiothyridina* described by Etheridge (1889, 1903) and Foord (1980) from the Early Permian of Western Australia require modern description. This is being undertaken by the present author. Only *Cleiothyridina ovalis* Shi (in Archbold & Shi 1993) has received modern study. *Cleiothyridina perthensis* sp. nov. is distinguished from other Western Australian early Permian species by means of its robust, thick profile, virtually absent ventral sulcus, feebly uniplicate anterior margin and biconvex profile at maturity.

Genus **Composita** Brown, 1849

Type species. Spirifer ambiguus Sowerby, 1823.

Composita sp.

Fig. 16Q–W

Comments. Grant (1976: 204) noted that the genera *Composita* and *Spirigerella* are very similar and fully discussed both genera drawing attention to internal differences between them. Three internal moulds of ventral valves (UWA 31572a, 31572b, 31572c) and one external mould of a ventral valve (UWA 31572d) from the High Cliff fauna are referred to *Composita*. By comparison with *Composita advena* Grant (1976) from the late Early Permian of Thailand, present material is more rounded in outline but possesses comparable ventral muscle scars that are rounded in juvenile specimens and more elongate in larger specimens (accentuated by thickening of the shell in the valve posterior). Despite the specimens being inadequate for detailed species comparison, the High Cliff record does provide another example of a generic link between the Early Permian faunas of Western Australia and Peninsular Thailand (see Archbold & Shi 1995 for additional discussion).

Order TEREBRATULIDA Waagen, 1883

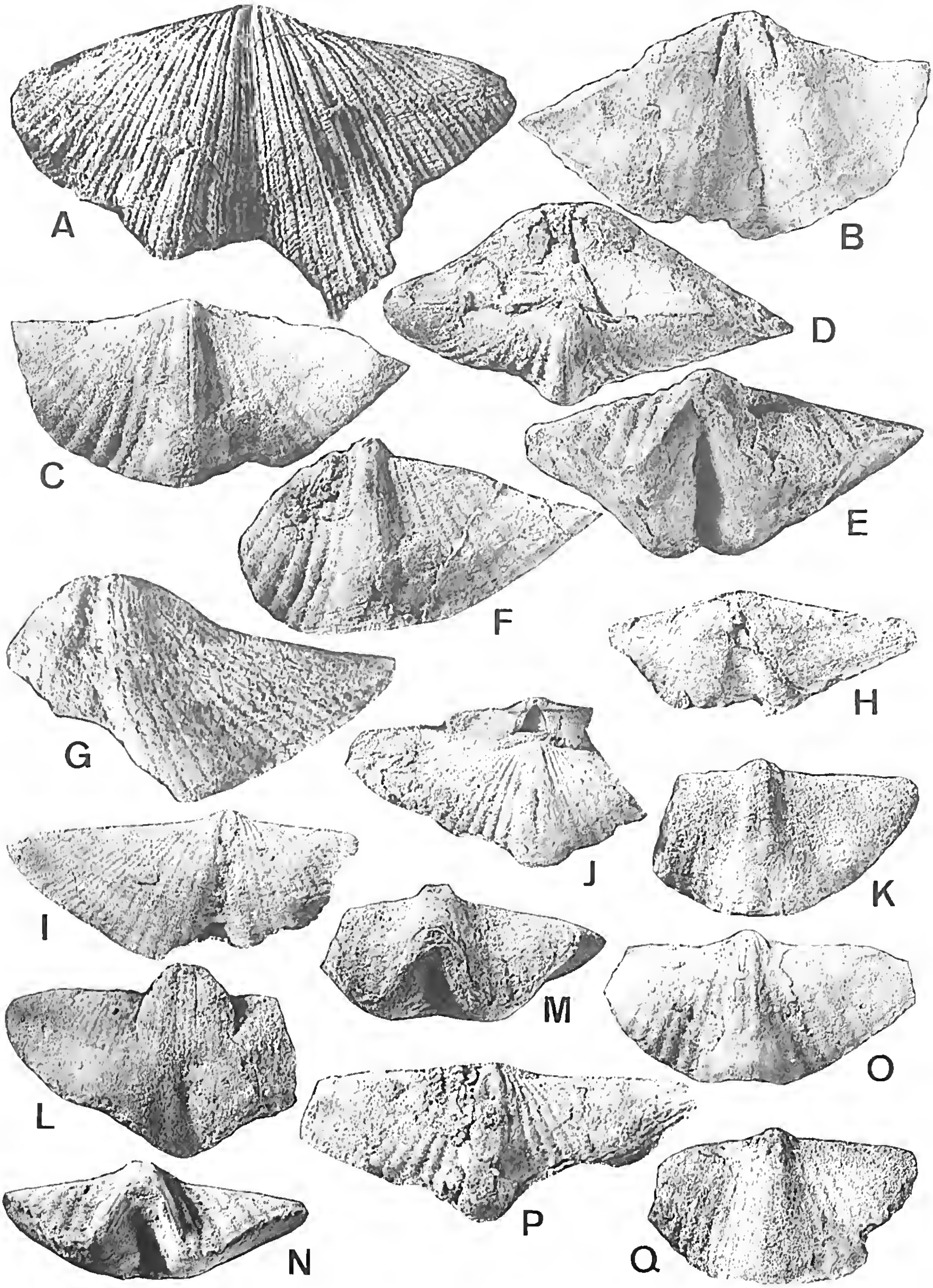
Suborder TEREBRATULIDINA Waagen, 1883

Superfamily DIELASMATOIDEA Schuchert, 1913

Family DIELASMATIDAE Schuchert, 1913

Subfamily DIELASMATINAE Schuchert, 1913

Fig. 14. A, *Neospirifer (Neospirifer)* sp., WAM 69.760, latex cast of ventral valve external mould, ×1. B–G, *?Cyrtella* sp. B–F, CPC 34599, internal mould of shell in ventral, dorsal, posterior and anterior views and latex cast of dorsal valve external mould, ×1. G, WAM 69.760a, latex cast of ventral valve external mould, ×1. H–Q, *Woolagia playfordi* gen. et sp. nov. H, UWA 33761, latex cast of ventral valve external mould, ×1. I, GSWA 49477, latex cast of ventral valve external mould, ×1. J, UWA 34286, latex cast of dorsal valve external mould, ×1. K–M, UWA 33762, internal mould of shell in dorsal, ventral and anterior views, ×1. N, O, UWA 34285a, internal mould of shell in anterior and dorsal views, ×1. P, GSWA 49476, latex cast of dorsal valve external mould, ×1. Q, GSWA 49478, internal mould of dorsal valve, ×1.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Genus **Hoskingia** Campbell, 1965

Type species. Dielasma trigonopsis Hosking, 1933a.

Hoskingia skwarkoi sp. nov.

Fig. 17A–L

'Dielasma' sp. nov. B Dickins 1957: 2.—Playford 1959: 19.
Hoskingia sp. nov. Archbold 1988: 47.—Archbold 1993a: 316.

Holotype. GSWA 49474, internal mould of complete shell.

Etymology. For Dr S. K. Skwarko, collector of the holotype and three paratypes of the species.

Paratypes. GSWA 49472,49473, two internal moulds of mature shells; GSWA 49475, anterior portion of external mould of ventral valve; UWA 33700, internal mould of complete juvenile shell.

Size ranges. Maximum width, 20–41.5 mm; length of ventral valve, 24–50.5 mm; length of dorsal valve, 22–46 mm; thickness, 10–18.5 mm; height of median fold, 0–4 mm.

Diagnosis. Large species with pronounced triangular posterior outline at maturity. Ventral internal median ridge distinct.

Description. Large species with ventral profile evenly convex, dorsal profile gently convex. Maximum width from 60 to 70% of shell length. Anterior outline rounded in juvenile specimens, tends to straight anterior margin at maturity. Lateral commissure weakly sinuate, anterior commissure sulciplicate at maturity. Ventral median fold distinct at maturity, feebly developed on juvenile specimens, slightly more than one-third valve width. Umbo sub-erect, foramen large (5.5 mm on holotype), mesothyrid.

Exterior with delicate growth lines, occasionally more prominent especially near anterior margin.

Pedicle collar strong, entire. Dental plates thin, widely spaced, short, located along outer shell wall. Muscle field elongate, suboval, slightly striate at maturity. Median ridge distinct, gently rounded crest.

Sockets distinct, crural bases distinct, thickened. Septalium sessile. Adductor scars elongate.

Comments. Hoskingia skwarkoi sp. nov. is a large species and is closest to *H. nobilis* (Etheridge, 1907a) from the Baigendzhinian Mingenew Formation of the Perth Basin (see Campbell 1965 and Archbold 1996 for recent descriptions of Etheridge's species). *H. nobilis* possesses a less triangular posterior outline, a lower ventral median ridge and a more rounded anterior outline at maturity than *H. skwarkoi.* Other Western Australian species of *Hoskingia* were well described by Campbell (1965).

Family GILLEDIIDAE Campbell, 1965

Subfamily GILLEDIINAE Campbell, 1965

Genus **Gilledia** Stehli, 1961

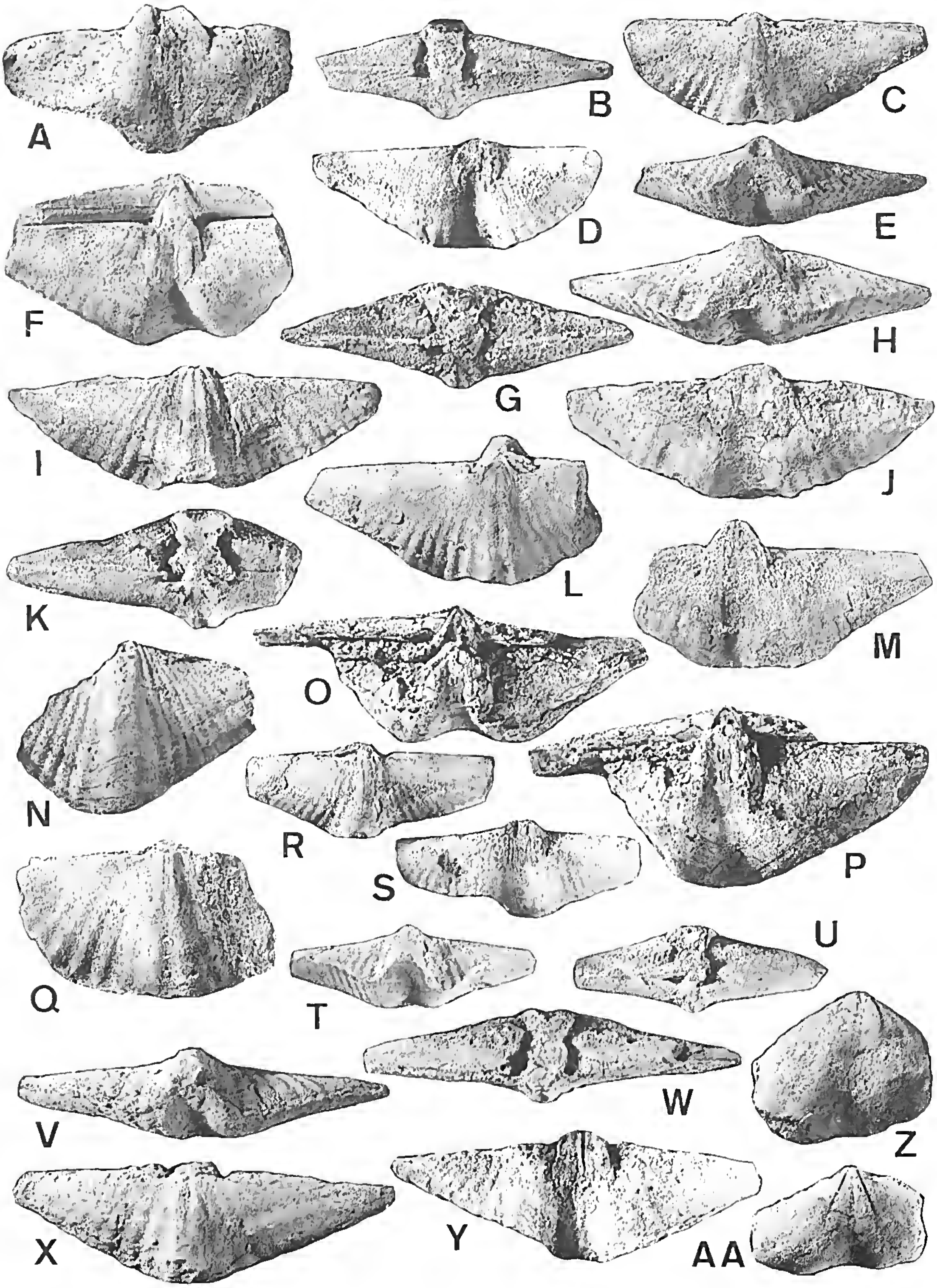
Type species. Terebratula cymbaeformis Morris, 1845.

Gilledia woolagensis Campbell, 1965

Fig. 17M–V

'Dielasma' sp. nov. A, Dickins 1957: 2.—Playford 1959: 19.
Gilledia woolagensis Campbell 1965: 82, pl. 9, figs 42–47.—Playford et al. 1976: 100.—Archbold 1988: 47.—Archbold 1993: pl. 45, figs 21, 24, 25, microfiche 5: 123.—Skwarko 1993: 92.—Archbold 1993a: 316.

Fig. 15. A–Y, *Woolagia playfordi* gen. et sp. nov. A, UWA 31795, internal mould of ventral valve, ×1. B–E, UWA 33688, internal mould of shell in posterior, dorsal, ventral and anterior views, ×1. F, GSWA 49479, internal mould of ventral valve, ×1. G–J, UWA 34285c, holotype, internal mould of shell in posterior, anterior, dorsal and ventral views, ×1. K–M, UWA 33760, internal mould of shell in posterior, dorsal and ventral views, ×1. N, GSWA 49478 counterpart, external mould of dorsal valve, ×1. O, P, UWA 38552, internal mould of ventral valve in posterior and ventral views, ×1. Q, UWA 33760, internal mould of dorsal valve, ×1. R–U, UWA 34386, internal mould of juvenile shell in dorsal, ventral, anterior and posterior views, ×1. V–Y, UWA 34285h, internal mould of shell in anterior, posterior, dorsal and ventral views, ×1. Z, AA, *Tomiopsis rarus* Archbold & Thomas, 1986, UWA 32552, internal mould of ventral valve, ×1.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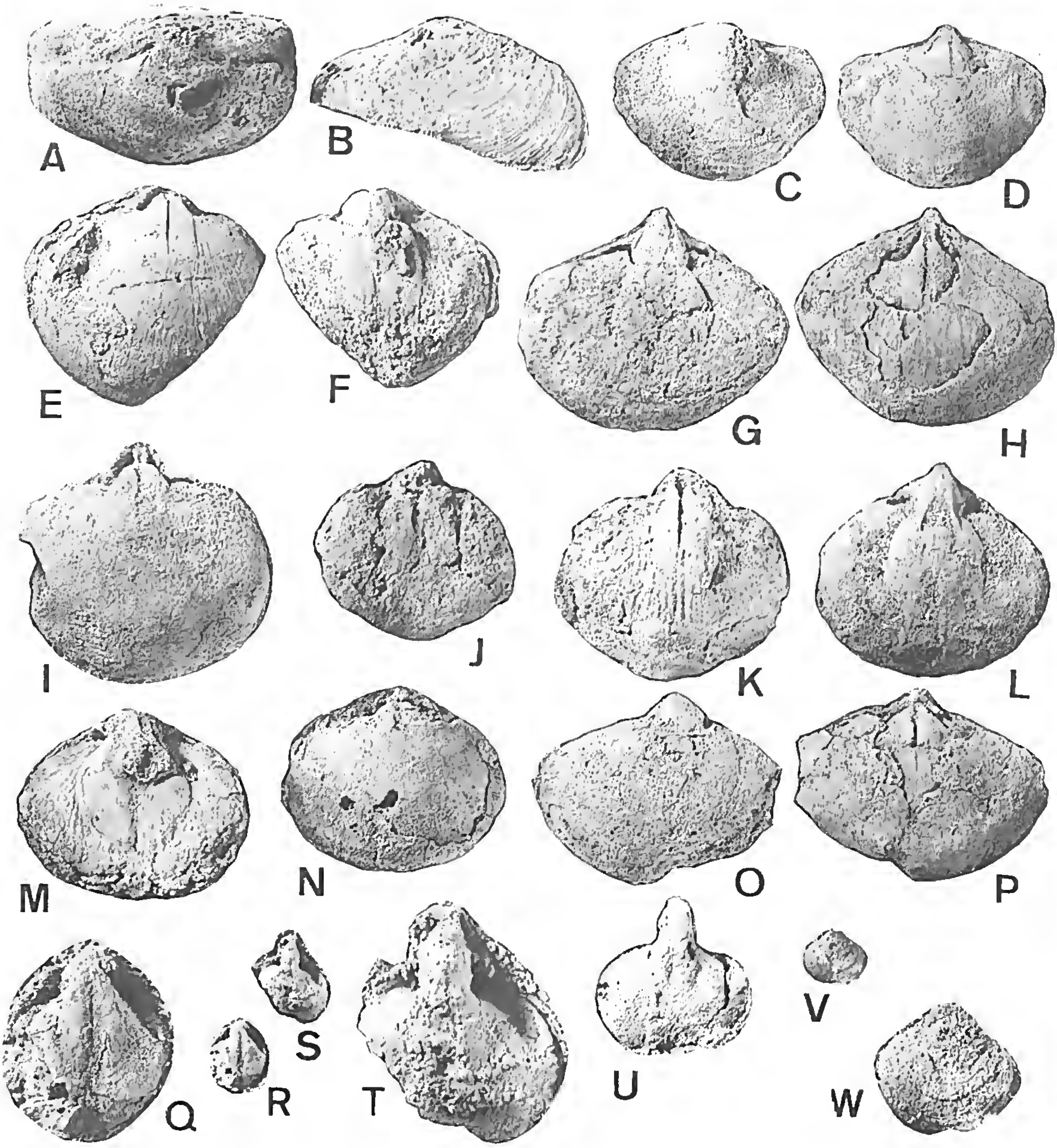

Fig. 16. A–P, *Cleiothyridina perthensis* sp. nov. A, B, GSWA 49480 latex cast of mould of posterior shell in posterior and ventral views, ×1. C, D, UWA 33366, internal mould of shell in ventral and dorsal views, ×1. E, F, GSWA 49481, internal mould of shell in dorsal and ventral views, ×1. G, H, UWA 32753, internal mould of shell in ventral and dorsal views, ×1. I, UWA 33761, internal mould of dorsal valve, ×1. J, K, UWA 32755, internal mould of shell in ventral and dorsal views, ×1 and ×1.2. L, UWA 38552a, internal mould of shell in ventral view, ×1.2. M, N, holotype, UWA 31563, internal mould of shell in ventral and dorsal views, ×1.2. O, P, UWA 31554, internal mould of shell in ventral and dorsal views, ×1. Q–W, *Composita* sp. Q, R, UWA 31572a, internal mould of ventral valve, ×3.5 and ×1. S, T, UWA 31572b, internal mould of ventral of valve, ×1 and ×4. U, UWA 31572c, internal mould of ventral valve, ×2.5. V, W, UWA 31572d, latex cast of external mould of ventral valve, ×1 and ×3.

Comments. This species was well described by Campbell (1965) on the basis of some 18 specimens, and 2 specimens were illustrated by him. Additional material (UWA 31563i–31563l, UWA 31564k) is illustrated herein in order to demonstrate the greater variability of the species with regard to shell outline and profile than indicated by Campbell's illustrations of the species.

ACKNOWLEDGEMENTS

For providing specimens and locality details the following are thanked: Dr S. K. Skwarko (formerly of the Geological Survey of Western Australia), Dr J. M. Dickins (Australian Geological Survery Organisation), Ms G. M. I. Rockett (Department of Geology, University of Western Australia) and Dr K. McNamara (Western Australian Museum). The author is grateful to Dr Shuzhong Shen for critically reading the manuscript. Mrs L. Archbold word-processed the manuscript and Ms E. Stagg draughted Fig. 1 and Table 1. Mr M. Grover assisted with photography. The author's work on Late Palaeozoic brachiopod faunas is supported by the Australian Research Council.

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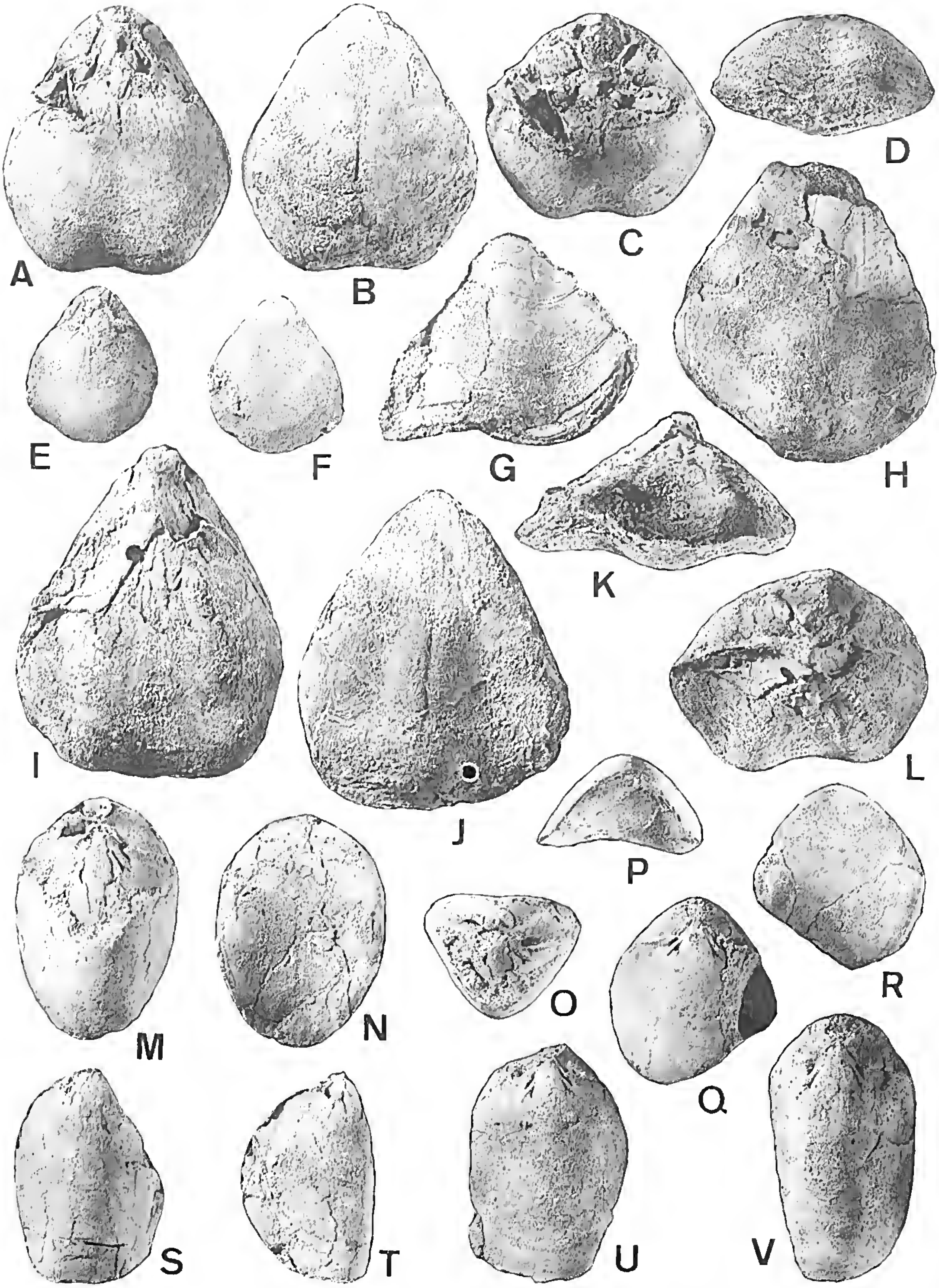
Fig. 17. A–L, ***Hoskingia skwarkoi*** sp. nov. A–D, GSWA 49472, internal mould of shell in dorsal, ventral, posterior and anterior views, ×1. E, F, UWA 33700, internal mould of juvenile shell in dorsal and ventral views, ×1. G, GSWA 49475, latex cast of external mould of anterior of ventral valve, ×1. H, GSWA 49473, internal mould of shell in dorsal view, ×1. I–L, GSWA 49474, holotype, internal mould of shell in dorsal, ventral, anterior and posterior views, ×1. M–V, *Gilledia woalagensis* Campbell, 1965. M–P, UWA 31563i, internal mould of shell in dorsal, ventral, posterior and anterior views, ×1. Q, R, UWA 31563j, internal mould of shell in dorsal and ventral views, ×1. S, T, UWA 31564k, internal mould of shell in dorsal and profile views, ×1. U, UWA 31563k, internal mould of shell in dorsal view, ×1.5. V, UWA 31563l, internal mould of shell in dorsal view, ×1.5.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G. J. HINDE'S (1899) DEVONIAN RADIOLARIANS FROM TAMWORTH, NORTH-EASTERN NEW SOUTH WALES: STRATIGRAPHIC AND CHRONOLOGIC CONTEXT

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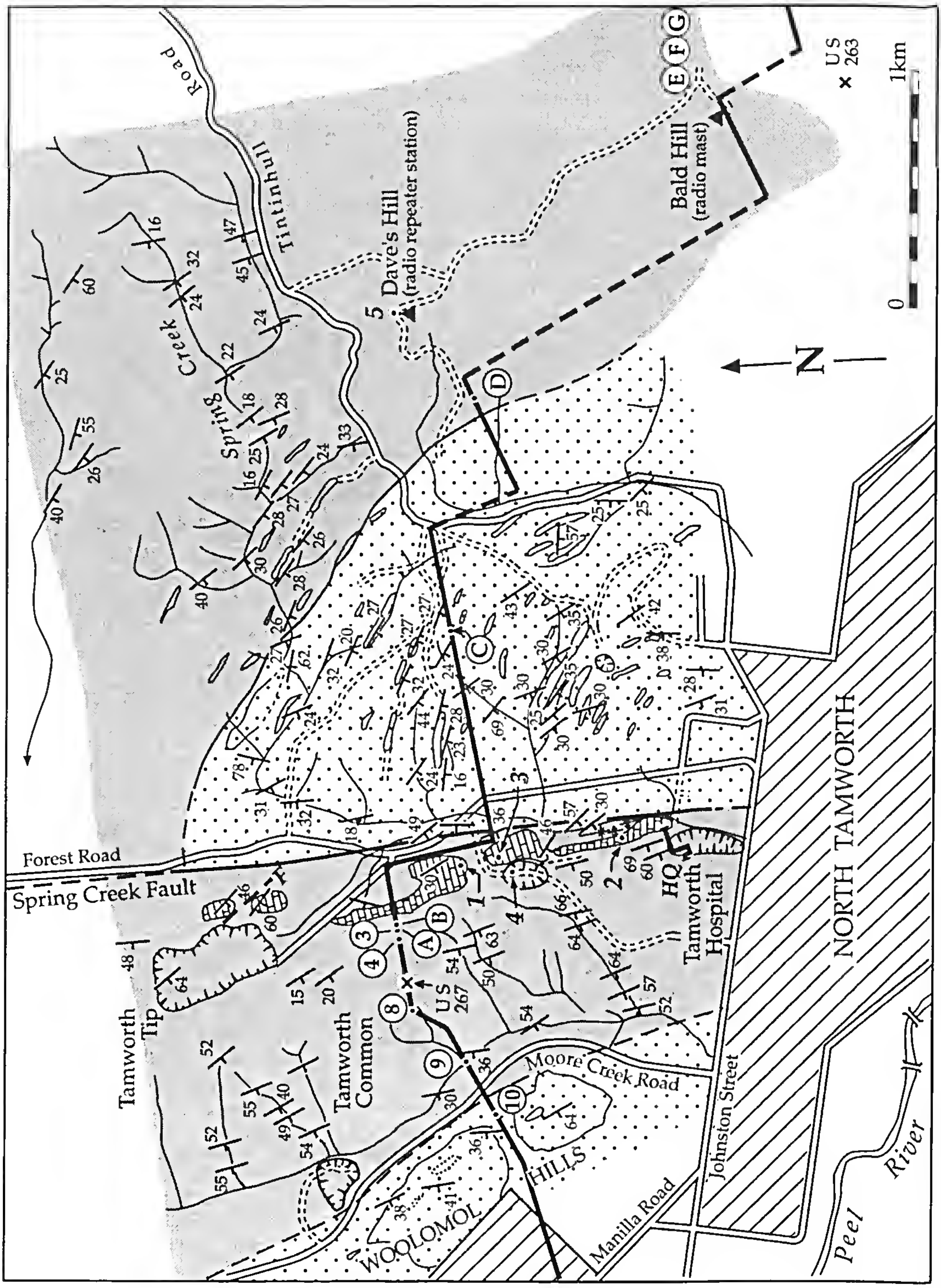
MAWSON, R., PANG, D. & TALENT, J. A., 1997:12:31. G. J. Hinde's (1899) Devonian radiolarians from the Tamworth area, north-eastern New South Wales: stratigraphic and chronologic context. *Proceedings of the Royal Society of Victoria* 109(2): 233–256. ISSN 0035-9211.

David & Pittman (1899) obtained Devonian radiolarians described by Hinde (1899) and revised by Aitchison & Stratford (1997) from the North Tamworth area of NE New South Wales. The host sequence is primarily fine-grained turbidites with minor horizons of debris-flow limestones, arenites, and thin ashfalls. The largest limestone bodies, formerly referred to as the 'Spring Creek limestone', are interpreted as olistoliths of Moore Creek Limestone emplaced during accumulation of the upper part of the Yarrimie Formation. Because of the demonstrably allochthonous nature of all limestones in the North Tamworth area, the conodont data from these olistoliths and from other limestones in that area are not tightly constraining as to chronology of the associated radiolarian horizons. The limestone horizons on David & Pittman's (1899) transect span an interval from early Emsian to late Frasnian and conceivably as young as the early Famennian–mid Famennian boundary (Late *rhomboidea* Zone to Early *marginifera* Zone). The taxonomically useful radiolarians (Aitchison & Stratford 1997) came from three horizons within the upper Yarrimie Formation. These horizons, stratigraphically above the olistoliths of 'Spring Creek limestone' (derived from Moore Creek Limestone, *australis* to *hemiansatus* Zones and perhaps Early *varcus* Subzone: late Eifelian–early Givetian), are argued to be late Givetian (*hermanni* Zone or younger) and late Frasnian respectively. A broader spectrum of mid-Palaeozoic ages (Pridoli to late Famennian) is indicated by conodonts occurring in association with radiolarians in cherts and siltstones from elsewhere in the region.

THE FIRST substantial investigation of the geology of the North Tamworth–Spring Creek area was by T. W. E. David and E. F. Pittman who constructed a detailed section extending some 7 km across this and adjoining areas (David 1896; David & Pittman 1899). Fossiliferous materials they collected were sent to G. J. Hinde and R. Etheridge, Jnr. Etheridge (1899) identified 19 species of corals from the 'Spring Creek limestone' and from adjacent limestone occurrences at Moore Creek and 'Moonbi' (see below). In a now classic paper, Hinde (1899) identified 53 species of radiolarians assigned to 29 genera from samples of black chert, limestone, claystone and tuffs from railway cuttings at Tamworth and, most importantly, from the Tamworth Common, an area extending northwards from the Tamworth Hospital and the adjacent Tamworth Hospital Quarry (Fig. 1).

As part of a much larger undertaking, W. N. Benson (1915) mapped the North Tamworth–Spring Creek area, recognising two stratigraphic sequences: an older or Tamworth Series (now Tamworth Group) considered to be Middle Devonian, overlain by a Late Devonian sequence, the Baldwin Agglomerates (now Baldwin Formation). Benson concluded that the 'Spring Creek limestones' were the same age as the Moore Creek Limestone *c.* 8 km to the N. His mapping was subsequently extended southwards to Loomberah (Benson 1918; Cawood 1980; Furey-Greig 1995), and northwards—to Attunga, Sulcor and Yarramanbully (Benson 1917; Brown 1942; Chappell 1961; White 1964, 1965; Pedder 1967, 1968; Marshall 1968; McMinn 1977, 1982; Pohler & Herbert 1993; Pohler, manuscript). These areas have been foci of studies of carbonate petrology (Pohler & Herbert 1993; Pohler, manuscript) and the chronologic implications of conodont data obtained from autochthonous and allochthonous limestones (Mawson & Talent 1994a; Mawson et al. 1995, 1996; Furey-Greig 1995; Klyza 1995), but they do not cover the North Tamworth–Spring Creek–Seven Mile Creek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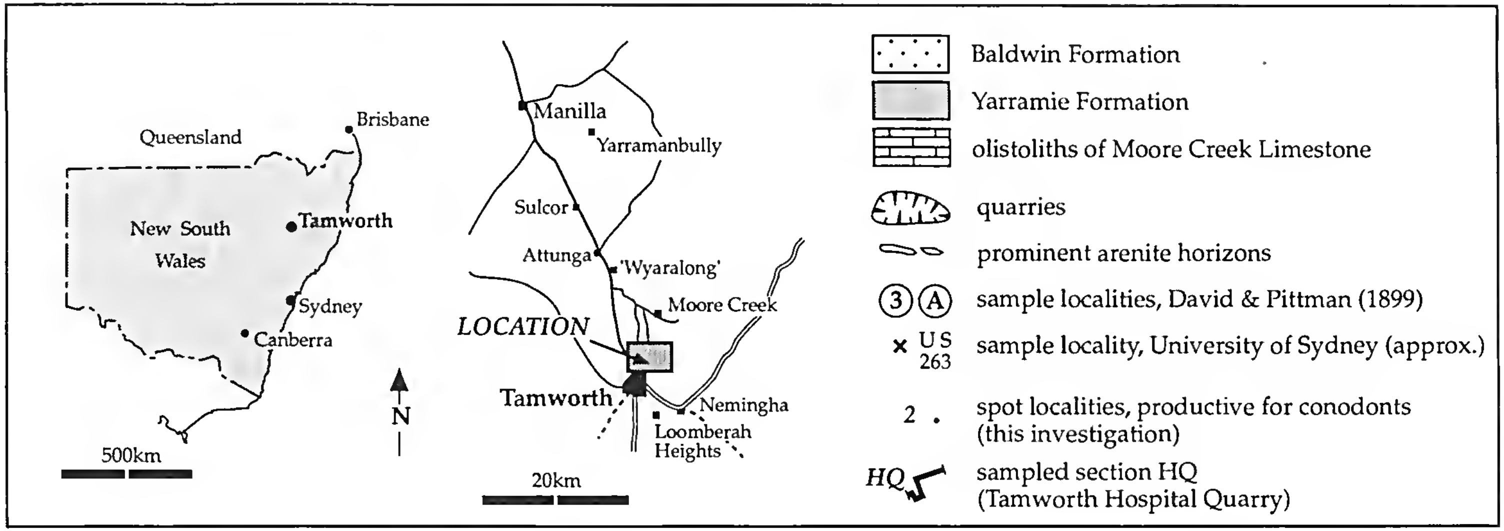


Fig. 1. Geology of the North Tamworth–Spring Creek area, New South Wales, showing the western part of David & Pittman's (1899) sampled section-line as well as the position of their localities, the Tamworth Hospital Quarry section (HQ), and other localities that have proved productive for conodonts.

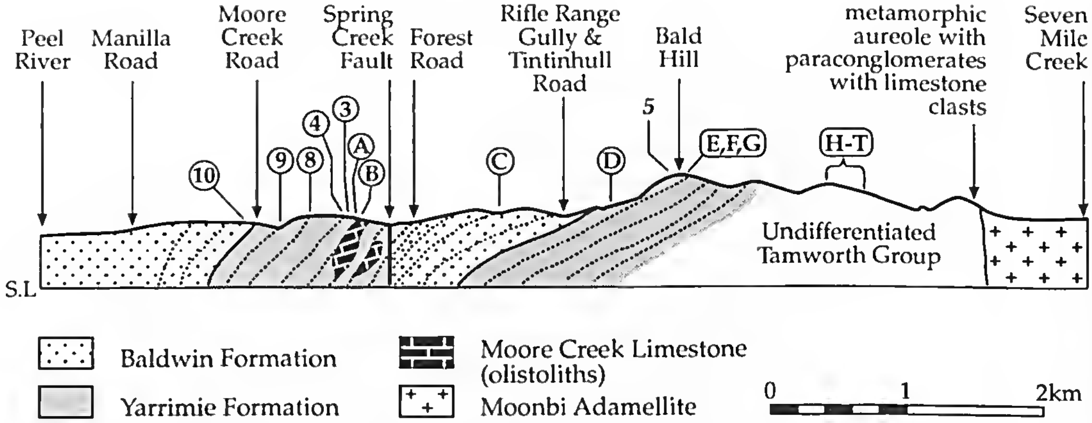


Fig. 2. Diagrammatic section following approximately the alignment of David & Pittman's (1899) North Tamworth section (natural scale). David & Pittman localities are shown circumscribed; locality 5 is a new locality. Other new localities 1–4 and the Hospital Quarry section have not been projected along strike onto the section line. Note that the section extends beyond the area shown in Fig. 1, from Bald Hill to the western flank of the Seven Mile Creek watershed where limestone cobble horizons occur in the metamorphic aureole marginal to the Moonbi Adamellite; these are suggested to represent the Drik Drik Formation or possibly the Silver Gully Formation. This interval is thought to be a repetition of David & Pittman's (1899) horizons H to T.

area, though it was included by Crook (1961a, 1961b, 1964) in a broad-scale synthesis of the geology of the Tamworth–Nundle–Timor area. Crook's work included a major rationalisation of stratigraphic nomenclature, and presentation of much new data on sedimentation. This work was extended by Pedder (1967) and Ellenor (1975). The areas considered in this report form part of what has been traditionally referred to as the Tamworth Belt. It has also been referred to as the Gamilaroi Terrane (Aitchison & Flood 1995, *q.v.* for earlier literature) and viewed as having sutured with 'cratonic' eastern Australia during the Late Devonian (Aitchison & Flood 1992).

Radiolarians have been documented from a scatter of localities through the Tamworth Belt (Hinde 1899; Aitchison et al. 1992, in press; Dongal 1995; Aitchison & Stratford 1997; Metcalfe et al. 1997; Stratford & Aitchison 1997) Corals have been described from the Moore Creek Limestone at North Tamworth and adjacent areas (Etheridge 1899; Hill 1942; Brühl & Pohler, manuscript) and from approximately coeval limestones farther afield at Timor (Pedder et al. 1970). Sponges have been described from Devonian limestones of the Tamworth Belt (Pickett 1969; Pickett & Pohler 1993). Stringocephalid brachiopods, characteristic of late Eifelian and Givetian rocks were noted almost a century ago from temporal equivalents of the Moore Creek Limestone at Crawney, S of Tamworth (Dun 1900: 195) and were documented subsequently from the Moore Creek Limestone at Sulcor (Brown 1944), 20 km N of the area under consideration.

All but two of David & Pittman's (1899) localities from which they obtained radiolarian-bearing Devonian sediments fall within the Tamworth Group (Fig. 1). The two exceptions, neither of these produced taxonomically useful radiolarians, are their localities C and 10; both are in the overlying Baldwin Formation. Horizons in the eastern (stratigraphically lower) part of their E-W section, in the Seven Mile Creek area, E of the area shown in Fig. 1, are from low in the Tamworth Group (see below); this interval is now well constrained by conodont data from elsewhere in the region (Mawson & Talent 1994a; Mawson et al. 1995; Furey-Greig 1995). According to Aitchison & Stratford (1997), the taxonomically useful material in the samples David & Pittman sent to Hinde came exclusively from 'radiolarian limestones 3 and 4' [samples 47 (3–4), HD4 and 45 (3)] low in the Yarrimie Formation [stratigraphically above David & Pittman's localities B and A; cf. Fig. 1] and from David & Pittman's horizon D [sample 387D] in the uppermost part of the Yarrimie Formation about 1.7 km E of the Spring Creek Fault (Fig. 1).

STRATIGRAPHIC CONTEXT

1. *Lower Tamworth Group Units* (area E of Fig. 1)

David & Pittman's (1899) section extended *c.* 2.3 km ENE from Bald Hill, beyond the area shown in Fig. 1, to the margin of the Moonbi Adamellite, just W of which is a belt of clastics with metamorphosed limestone clasts (David & Pittman 1899, horizons H to T). This belt falls within an area currently referred to as 'Seven Mile Creek Formation' (Crook 1961a) which is aligned with and lithologically resembles the Drik Drik Formation of the Nemingha–Piallamore area E of Tamworth (cf. Furey-Greig 1995). The latter area also has debris-flow deposits with abundant limestone clasts of early Emsian age, not older than *dehiscens* Zone (Furey-Greig 1995). Though our sampling of the Seven Mile Creek sequence along the alignment of David & Pittman's section, and N of it in allotment 173 parish of Moonbi, failed to produce conodonts, we suggest from the above that David & Pittman's horizons H to T are probably early Emsian in age, ie. considerably older than the limestone intervals of the Spring Creek area N of Tamworth. If equivalents of the post-Drik Drik/pre-Yarrimie units of the Tamworth Group—namely the Northcotte Formation, Wogarda Argillite and Silver Gully Formation—are indeed present along the eastern part of David & Pittman's section line, then these must be represented exclusively by clastics.

An alternative explanation is that these horizons H to T of David & Pittman (1899) are approximate equivalents of the late Emsian Silver Gully Formation. At Loomberah Heights, 16 km SE of Tamworth, the basal Silver Gully Formation, typically infested with debris flows with limestone clasts, has been shown from a thin autochthonous limestone interval to be very late Emsian—*serotinus* Zone or possibly *patulus* Zone, though the definitive form *Polygnathus costatus patulus* was not obtained (Mawson et al. 1995: 422). Limestones of approximately the same age are remarkably widespread within the Tamworth Belt, occurring in allochthonous blocks in the Bog Hole Formation on the island in Chaffey Dam 34 km SE of Tamworth (Mawson & Talent, unpubl. data), and in limestones an uncertain distance above the base of the Silver Gully Formation on the upper Barnard River near 'Chittick', about 55 km SE of Tamworth (Allen & Leitch 1992). Co-occurring *Polygnathus serotinus* and *P. costatus patulus* at the latter locality confirm a horizon early in the *patulus* Zone (Mawson et al. 1995: 424), ie. not far below the Emsian–Eifelian boundary. Approximately the same horizon has been reported from an autochthonous limestone-shale sequence at Bralga Tops on 'Glenrock' Station (Metcalfe et al. 1997), *c.* 75 km SE of Tamworth. At 'Chittick', the Silver Gully Formation is overlain by the Folly Spilite and, at least in that area, the onset of volcanism seems to have occurred close to the Emsian–Eifelian boundary. The Pitch Creek Volcanics (early Emsian) of the Pigna Barney area, *c.* 95 km SE of Tamworth, proven from conodonts from the overlying Bennys Tops Limestone (Dongol 1995) to be early Emsian *dehiscens–perbonus* Zones or older, are therefore interpreted as a volcanic episode significantly pre-dating the Folly Spilite.

The broad 'Silver Gully' interval referred to above is represented by the presently unnamed (L. Salem, unpubl. data) clastic sequence with minor limestones intervening between the Sulcor and Moore Creek Limestones in the Sulcor and Yarramanbully areas 25–35 km NW of Tamworth (S. Pohler, in prep.); conodont data (Mawson et al. 1996, 1998; Mawson & Talent, in prep.) suggest that this interval spans the Emsian–Eifelian boundary. Conodont data are already published for portion of this interval from the Attunga area, 18 km NW of Tamworth, by Mawson & Talent (1994a). Their section WY at 'Wyaralong', up to and including their sample WY148.5, includes debris flows with large limestone clasts. If the age indicated by conodonts from these clasts approximates the age of the enclosing sediments, this interval may equate with some of the upper part of the Silver Gully Formation. The presence of *Polygnathus costatus partitus* and *P. angustipennatus* from cobbles from sample WY91–96 is indicative of earliest Eifelian *partitus* Zone. The presence of *P. costatus costatus c.* 16 m stratigraphically higher in the WY section in sample WY 139, still in allochthonous limestone clasts, indicates the *costatus* Zone. This is about 15 m stratigraphically below the base of the Moore Creek Limestone. The *costatus* Zone is not known from any occurrences of Moore Creek Limestone, though Mawson & Talent's (1994a) samples OKE 62.9 and their Loc 1 in nodular limestones and siltstones low in the Moore Creek Limestone are indicative of an interval that spans broadly the upper third of the *costatus* Zone into the *australis* Zone. The 'Silver Gully' interval or 'unnamed formation' or 'lower Yarrimie Formation' (Pohler & Herbert 1993; Mawson & Talent 1994a) thus includes part and conceivably all of the *costatus* Zone. We suggest that, until such time as firm evidence to the contrary might be forthcoming, the base of the Moore Creek Limestone should be provisionally drawn at the *costatus–australis* boundary.

2. *Moore Creek Limestone*

Large bodies of Moore Creek Limestone outcropping in the watershed of Spring Creek, North Tamworth (Fig. 1), earlier referred to informally as the 'Spring Creek limestone', consist of buff grey to dark grey fossiliferous wackestones and grainstones, occasionally stylolitic. Rugose and especially tabulate corals are relatively common in these as well as in all other occurrences of Moore Creek Limestone. The rugose corals *Dohmophyllum* sp., *Xystriphyllum mitchelli* (Etheridge), *'Campophyllum'* cf. *lindstroemi* (Frech), *Disphyllum robustum* (Etheridge), *Phacellophyllum porteri* (Etheridge) and *Sanidophyllum davidis* Etheridge have been reported (Hill 1942) from the 'Tamworth Common, 1 mile north of Tamworth'. All of the above forms, except the first, are known from what we take to be the stratotype for the Moore Creek Limestone, immediately S of the hamlet of Moore Creek, or from other stratigraphically equivalent outcrop-tracts N of Tamworth. There can be little doubt, therefore, on the basis of rugose corals, that accumulation of the 'Spring Creek limestones' was coeval with the Moore Creek Limestone *sensu stricto* and should bear the same stratigraphic name.

Etheridge's coral collections, incidentally, included materials labeled 'Woolomol limestone'. These are believed by us to be from the typical Moore Creek Limestone outcropping boldly in the reserve on the S side of Moore Creek (in the parish of Woolomol) opposite the hamlet of Moore Creek. Areas of limestone outcrop farther S extend from the parish of Woolomol into the adjoining parish of Moonbi and are thought to be the source of old collections labeled 'parish of Moonbi'.

An age-range *kockelianus–ensensis* zones for at least part of the Moore Creek Limestone at Moore Creek follows from re-interpretation (Mawson & Talent 1994a: 45) of conodonts documented by Philip (1966a). The presence of the *australis* and *kockelianus* in the Moore Creek Limestone at Yarramanbully was demonstrated by Sloan (in Mawson et al. 1989: 500). The same interval, but with extension up into the *ensensis* Zone *sensu lato* [ie. without clear discrimination between *hemiansatus* Zone and the brief unnamed latest Eifelian post-*kockelianus* interval] was reported by Mawson & Talent (1994a) from the 'Wyaralong' outcrop-tract at Attunga, 11 km NW of the stratotype at Moore Creek. The *australis–hemiansatus* zones have also been reported from a small, partly fault-bounded, anticlinal occurrence of Moore Creek Limestone at 'Warrawilla' 4.5 km E of Attunga (Klyza 1995).

Despite large parts of the North Tamworth–Spring Creek area lacking outcrop, the following observations may be made regarding the limestones of that area:

1. The limestone tract does not map out as a coherent body, but as 5 major and apparently discrete bodies of limestone 130 to 600 m in length with, despite paucity of outcrops, evidence of intervening Yarrimie Formation sediments.
2. The two northernmost bodies appear to be discordant to the strike of adjacent Yarrimie Formation clastics, though this could be due to local flexure or fault displacement as Benson (1915) suggested.
3. The top of the Moore Creek Limestone (sample HQ 0 on our Hospital Quarry section) produced a sparse conodont fauna indicative of the *kockelianus* Zone, revealing the absence of horizons expected high in the Moore Creek Limestone, namely the brief 'rump *ensensis*' Zone [after excision of the *hemiansatus* Zone], the *hemiansatus* Zone and possibly some of the Early *varcus* Subzone.
4. Additionally and importantly, the 5 bodies of Moore Creek Limestone are conspicuously devoid of the 'transitional intervals' above the Moore Creek Limestone, well expressed at Attunga, Sulcor and Yaramanbully (Pohler & Herbert 1993; Mawson & Talent 1994a, unpubl. data; Pohler, manuscript).

We conclude that the Moore Creek Limestone occurrences in the Spring Creek area are olistoliths, dislodged after lithification, that have become incorporated downslope in clastics of the Yarrimie Formation.

3. *Yarrimie Formation*

The Yarrimie Formation, the uppermost unit of the Tamworth Group, consists of 880 m or more (Crook 1961a) of typically colour-banded dark grey to black and white argillites, often of cherty appearance and containing radiolarians, with subordinate cream to white feldspathic ashfalls (relatively quartz poor), minor beds of lithic sandstone, particularly in the upper part of the formation, and uncommon intervals of conglomeratic limestone with pebble- to cobble-sized clasts of various limestone lithologies, mudstone and, rarely, igneous rocks. Exposures, although generally poor, are excellent in the quarries of the North Tamworth area.

No unequivocally autochthonous limestones were encountered in the Yarrimie Formation of the North Tamworth area; almost all are pebble- or cobble-sized clasts in conglomerates, though larger isolated clasts, rarely exceeding a cubic metre in size, have been encountered during quarrying in the Tamworth Hospital Quarry. Autochthonus limestone horizons nevertheless occur low in the Yarrimie Formation elsewhere in the Tamworth Belt, eg. at Sulcor (Mawson & Talent, in prep.) and Attunga (Mawson & Talent 1994a). In the latter area, Early and Late *varcus* zones (and by inference Middle *varcus* Zone) have been demonstrated in the interval of limestones and clastics transitional to the Yarrimie Formation immediately overlying the Moore Creek Limestone at Attunga. The Moore Creek Limestone was thus demonstrated to be 'sandwiched' between the *costatus* Zone (below—see earlier) and the Early *varcus* Zone above, but with the possibility of it including minor intervals referable to one or both of these zones.

4. *Baldwin Formation*

The Baldwin Formation (Crook 1961b) has not been a principal focus of the present investigation. It consists of 945 m or more of massive, medium to coarse grained, thick bedded, green-grey feldspatho-lithic arenites with interbeds of thinly bedded sandstone and siltstone. Its lower boundary is gradational from the underlying Yarrimie Formation. Famennian conodonts (Late *rhomboidea* Zone to Early *marginifera* Zone) have been reported (Marshall 1968; McMinn 1977, 1982) from limestone horizons at two localities in the Yarramanbully area (see below); conodonts and radiolarians of somewhat younger Famennian age (*postera* to Early *expansa* Zones) have been reported (Naka et al. 1988) from outcrops in the Peel River about 3 km downstream from Nundle.

SAMPLING OF THE NORTH TAMWORTH AREA

An attempt was made to locate and sample all limestone horizons on David & Pittman's (1899) section as well as other limestone horizons in the North Tamworth area, including the sequence exposed along the N face of the Tamworth Hospital Quarry. The latter section has excellent exposures and equates fairly well with the poorly exposed sequence immediately above the 'Spring Creek limestone' along David & Pittman's (1899) section line through their horizons B, A, 3 and 4 in ascending order stratigraphically (Fig. 1). Their horizon B equates approximately with the Tamworth Hospital horizon HQ 1 and, of special importance as regards radiolarians figured by Aitchison & Stratford (1997), David & Pittman's horizon 3 equates approximately with HQ 4, and their horizon 4 either with HQ7 or a somewhat higher horizon now covered by quarry fill.

David & Pittman's horizon D, also of significance for radiolarians, is inferred to correlate with a horizon high in the upper Yarrimie Formation possibly with their horizon 9 or between it and locality 10 (low Baldwin Formation, Fig. 1). If this assumption is correct, horizon D would be *c.* 470–500 m stratigraphically above David & Pittman's horizon 3.

Limestones E, F and G of David & Pittman, on Bald Hill, failed to produce conodonts, but one horizon (M&T 5, Fig. 1) among what is inferred to be the same swarm of conglomeratic limestones along strike near the radio repeater station on Dave's Hill (Fig. 1), *c.* 200–240 m below the base of the Baldwin Formation, produced broken, unidentifiable conodonts. A lithologically similar group of conglomeratic limestones in the vicinity of David & Pittman's locality 8, recently exposed by bulldozing during tree-planting and fencing, is thought to represent a repeat of the Dave's Hill and Bald Hill conglomeratic limestones; these failed to produce conodonts.

David & Pittman's stratigraphically highest limestone, at locality 10 just W of the Moore Creek Road (Fig. 1), consists of fist-sized limestone cobbles in arenites, and irregular, poorly defined patches of calcareous arenite, very low in the Baldwin Formation. These limestones failed to produce conodonts.

NOTES ON CONODONTS AND THEIR CHRONOLOGIC IMPLICATIONS

1. *North Tamworth area*

Most sampled horizons in this area gave low yields (Fig. 1) or proved barren of conodonts. Conodonts (Table 1) from clasts from the various limestone-bearing horizons, and isolated clasts in the Yarrimie Formation exposed in the Tamworth

Formation		Moore Creek Limestone						Yarrimie Formation								
Conodont taxa / Sample No.		near D&P-A	near D&P-B	M&T-1	M&T-2	M&T-3	HQ 0	HQ 1	HQ 1 (loose)	HQ 2	HQ 2A	HQ 3A	HQ 4	HQ 5	HQ 6	HQ 7 (loose)
Belodella resima			10	9	4		2	2	1	1	3			1	1	1
Drepanodus sp.					2				1		1				1	
Dvorakia sp.									1							
Icriodus struvei																1
Neopanderodus aequabilis										1				1	1	2
Neopanderodus sp.														1		
Panderodus unicostatus		1			4		2		1		1					2
Polygnathus aequalis									1							
Polygnathus cooperi cooperi														1		
Polygnathus cristatus											1					
Polygnathus hemiansatus													2		1	
Polygnathus linguiformis linguiformis														1	1	1
Polygnathus linguiformis klapperi											1					
Polygnathus cf. *ovatinodosus*											1					
Polygnathus pennatus									1							
Polygnathus xylus xylus									1		1		2			
Polygnathus sp. A				1												
Polygnathus sp.		2		1								1				
Prioniodina sp. A	Pa					1										
	Pb					2										
	Sb					1										
	Sc					3										
Tortodus kockelianus kockelianus							2									
Unassigned elements	Pa	2		1				1			1					
	Pb	2	2	4							1	1	1			2
	M	1										1				
	Sa							1								
	Sb	3		2				2			1					
	Sc	5	2	2			3	1	1		2	1	1	3		2

Table 1. Distribution of conodonts, arranged stratigraphically, from measured stratigraphic section across the back/north) wall of Tamworth Hospital Quarry, and from spot localities in the North Tamworth-Spring Creek area, NE New South Wales. HQ=productive horizons in the Tamworth Hospital Quarry section (Fig. 2). D&P= localities from David & Pittman (1899; cf. Fig. 1 of this report). M&T=other limestone horizons sampled for this report and which proved productive of conodonts (see Fig. 1).

Hospital Quarry (Fig. 3), as well as from blocks excavated during quarrying and left lying on the floor of the quarry, accord with a spectrum of intervals from Eifelian to late Givetian: *costatus* Zone to *kockelianus* Zone; *kockelianus* Zone; *hemiansatus* Zone to Middle *varcus* Subzone; Middle *varcus* Subzone to Late *varcus* Subzone; and *hermanni* Zone. This considerable age-spectrum is consistent with the allochthoneity of the limestones. Comments on specific horizons sampled (see Table 2 for conodont faunas) are:

Conodonts from the top of the large Moore Creek Limestone olistolith at HQ 0, and conodonts (too sheared for determination) from a small olistolith 'near D&P-A' both had high CAI: 5 to 6, equating with >300°C. Conodonts from a limestone clast 'near D&P B' (dominated by belodellids) had remarkably low CAI: 1.5 to 2, equivalent to <140°C. contrast in thermal history of the source rocks for the clast at these three localities.

Belodellids were the main conodont group represented in 'M&T 1' but among them were two polygnathids, *Polygnathus* sp. A and the anterior portion of another form of *Polygnathus* with steep anterior margins of the platform resembling *P. parawebbi*. The latter ranges in age from *australis* Zone to Late *varcus* Zone (Mawson & Talent 1989). Although several limestone conglomerate horizons in the vicinity of 'D&P 8' failed to produce conodonts, one of the samples produced radiolarians tentatively identified as *Trilonche elegans* Hinde 1899.

No age-constraining conodonts were recovered from 'M&T 2' other than simple cones, although the fauna contained a large number and variety of well preserved ostracods. Several elements from a *Prioniodina* apparatus were the only conodonts from 'M&T 3'. Although similar to the Middle Devonian *P. tortoides* Sparling 1981, the exact age of the species of *Prioniodina* from the Tamworth area is uncertain.

All samples from along the section line at the Tamworth Hospital Quarry (Table 1) appear to be from allochthonous clasts. Conodonts from HQ 4, 5, 6 and 7 give ages from *kockelianus* Zone to Early *varcus* Subzone, and are therefore consistent with being clasts derived from Moore Creek Limestone. Samples HQ 1 [loose] and HQ 2A are younger in age, Late *hermanni* Zone. Horizons HQ 1, 2 and 3A failed to produce age-constraining conodonts.

Interestingly, the sharp contrast in CAI values between the Moore Creek Limestone occurrences (5 to 6) and younger horizons in the Yarrimie and Baldwin Formations (1.5 to 2), indicative of a rapid decrease in regional heat flux, occurred contemporaneously with a similar swift decrease in heat flux in the Burdekin Basin of NE Queensland (Talent & Mawson 1994) 1400 km away. This we associate with near cessation of, or a profound decrease in the Tabberabberan tectonism.

2. *Age of uppermost Yarrimie Formation*

Palmatolepis hassi Müller & Müller, *Ancyrodella curvata* Branson & Mehl and *Ancyrognathus* sp. have been reported by McMinn (1982) from a locality high in the Yarrimie Formation at Yarramanbully. McMinn's materials could not be located, but we have obtained *P. hassi* from essentially the same locality at 927_0920_5 on 1:25 000 topographic map 9036-II-N, Klori (Mawson & Talent, in prep.). The association is indicative of the later half of the Frasnian, specifically the Late *hassi* to *linguiformis* zones (cf. Sandberg & Ziegler 1990), ie. in terms of the former zonal scheme an interval extending from late in the Zone of *Ancyrognathus triangularis* to somewhere in the Uppermost *gigas* Zone, or about zones 6–13 in terms of Klapper's (1989) system based on sections in the Montagne Noire of southern France. Because there is at least 250 m of Yarrimie Formation between this locality and the faulted boundary with the Baldwin Formation. it is conceivably older than David & Pittman's locality D and possibly older even than their locality 8, but this is speculative.

We suggest accordingly that the best approximation of age for the radiolarian fauna from horizon D is not older than late Frasnian. An inevitable corollary from the above is that accumulation of the uppermost Yarrimie Formation of the Tamworth–Yarramanbully area was coeval with accumulation of the Mostyn Vale Formation (Wright et al. 1990; Winchester-Seeto & Paris 1995) of the Keepit area, *c.* 50 km NW of Tamworth.

3. *Age of the Baldwin Formation*

As noted earlier, David & Pittman's (1899) stratigraphically highest limestone, very low in the Baldwin Formation at their locality 10, failed to produce conodonts, but autochthonous limestones in the Baldwin Formation at Yarramanbully (Marshall 1968), outside the area mapped for this report and, it is stressed, much higher in the formation at 898_5916_5 on 1:25 000 topographic map 9036-II-N, Klori, produced conodonts including *Palmatolepis glabra glabra* Ulrich & Bassler. Our collections from this locality (Mawson & Talent, in prep.) include *Icriodus chojnicensis* Matya. McMinn (1977) reported a similar fauna from the Baldwin Formation E of Yarramanbully and E of the Namoi Fault at 951_0919_5 on the same topographic sheet. In terms of presently known ranges of conodonts, the age indicated is somewhere in the interval Late *rhomboidea* Zone to Early *marginifera* Zone. These limestone intervals may well be representative of the widespread Early *marginifera* Zone transgression in eastern Australia (Talent 1989; Mawson & Talent 1997).

4. *Devonian conodonts from cherts in the Tamworth Belt and adjoining regions*

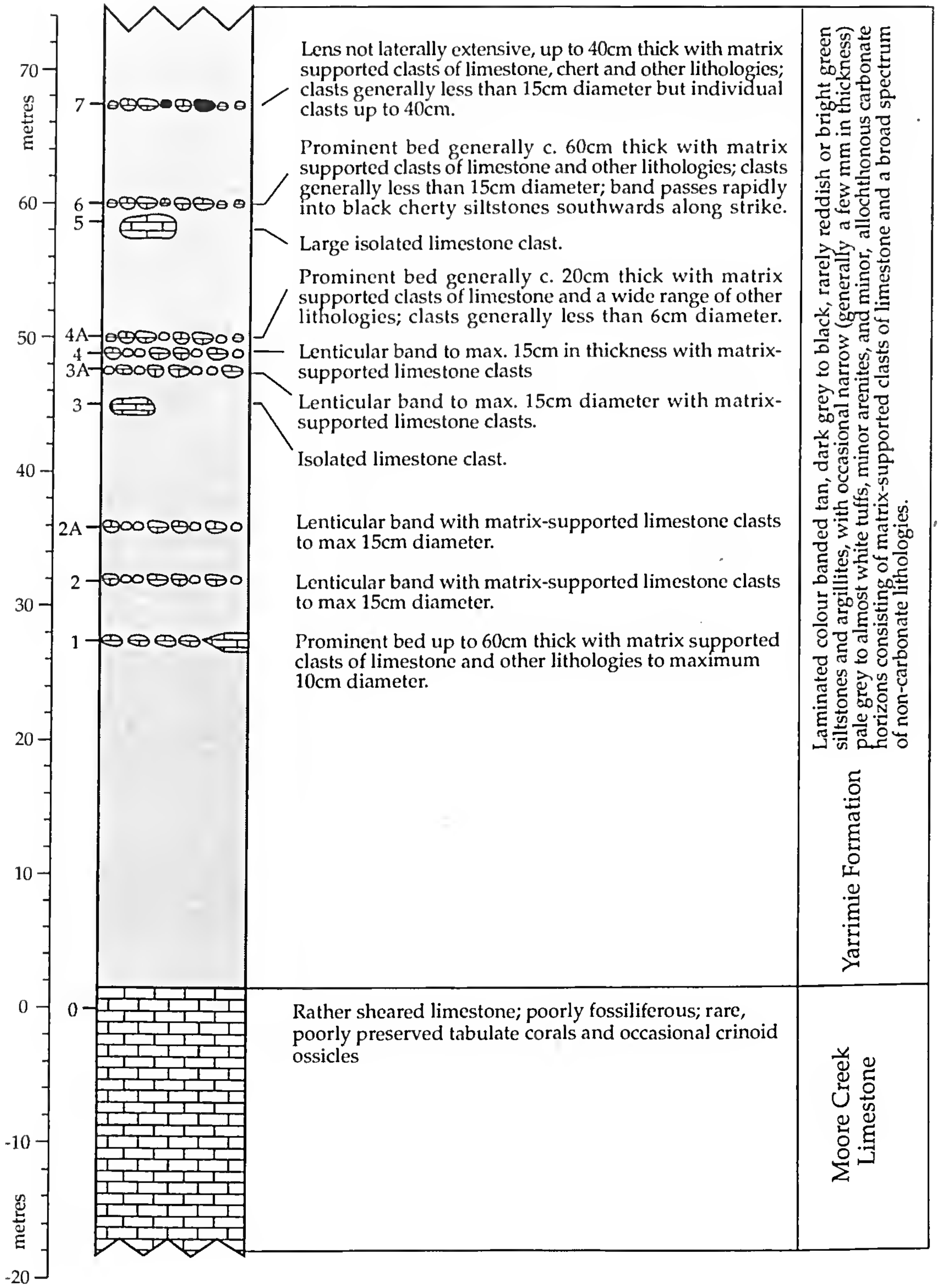
(i) Late Devonian conodonts, obtained as a by-product of hydrofluoric acid leaching in quest of radiolarians, have been reported but not illustrated by Naka et al. (1988) from low in the Baldwin Formation but possibly from high in the Yarrimie Formation (cf. Ishiga & Leitch 1988: fig. 3) from the Tamworth Belt SE of the area considered here. They reported *Polygnathus styriacus*, characteristic of the Famennian Early *postera* to Early *expansa* zones from their samples 2-3-4 and 2-3-5 from an outcrop on the left bank of the Peel River opposite the junction of Burrows Creek, 3 km NNE of Nundle. If this determination is correct, it indicates major diachronism of at least 4 conodont zones (and possibly more) for the Yarrimie–Baldwin boundary between North Tamworth and Nundle: at least Middle *marginifera* Zone to Early *postera* or Early *expansa* zones. This possibility of diachronism needs clarification.

(ii) A latest Silurian/Early Devonian (Pridoli–Pragian) fauna has been documented by Ishiga, Leitch et al. (1988) and Ishiga, Leitch & Watanabe (1988) from the Woolomin Formation in the Macdonald Block at their locality WA-50 approximately 5 km NNW of Dungowan at grid reference 179494 on 1:25 000 topographic sheet 9135-4-S Dungowan. The conodonts indicate that this horizon aligns stratigraphically to somewhere within the Glencairn Limestone of the Willow Tree Creek area, 10 km ENE of Attunga (Leitch et al., manuscript).

(iii) A conodont fauna from the western margin of the Hastings Block obtained by Ishiga & Leitch (1988a) from siltstone at their locality 39-i at Yarras Post Office includes several conodont species. Their fig. 1, identified as *Polygnathus asymmetricus*, is a specimen of *Palmatolepis rhomboidea* Sannemann, a species that may occur from Early *rhomboidea* Zone to Early *marginifera* Zone. Their fig. 2, identified as *Polygnathus asymmetricus*, is a *Palmatolepis* cf. *rhomboidea*. It has the same shagreen ornament and the anterior blade is high, but the orientation of the photograph does not allow positive identification. Their figs 3 and 4, identified as *Polygnathus asymmetricus* Bischoff & Ziegler, are *Polygnathus* sp. indet. The basal pit appears to be symmetrical unlike the basal pit of *Mesotaxis asymmetricus* (Bischoff & Ziegler). Their figs 5 and 6, identified as *Polygnathus* spp., are *Polygnathus communis communis* Branson & Mehl 1934. This species is known to extend through most of the Famennian, commencing in the Middle *crepida* Zone; it extends to the *anchoralis/latus* Zone in the Tournaisian. Their fig. 7 was identified as *Polygnathus* sp. indet.; we accept this identification. Their fig. 8 was referred to *Kockelella* sp., a genus restricted to the Silurian. Its identification is problematic, but it resembles *Ancyrodella*, a genus not known from horizons younger than *triangularis* Zone. If it is indeed *Ancyrodella* it is likely to be a reworked specimen. Their fig. 11 was identified as *Panderodus* sp.; we accept this identification. There were 5 unnamed elements: fig. 9, a Pb element, fig. 12, possibly an M element, figs 10 and 13, Sb elements, and fig. 14 an M element. Based primarily on the co-occurrence of *Palmatolepis rhomboidea* and *Polygnathus communis communis*, the age is inferred to be *rhomboidea* Zone or Early *marginifera* Zone. It therefore equates approximately chronologically with the limestones in the Baldwin Formation of the Yarramanbully area discussed earlier.

(iv) Nondescript mid-Palaeozoic conodonts have been reported but not documented from cherts of the Port Macquarie Block (Ishiga et al. 1988: 56).

Fig. 3. Stratitgraphic column for measured and sampled section across the Tamworth Hospital Quarry showing horizons sampled in quest of conodonts (cf. Table 1). Note that all horizons proved allochthonous; horizon 0 was 60 cm below the top of the Moore Creek Limestone olistolith; horizon 4A proved barren.



Lens not laterally extensive, up to 40cm thick with matrix supported clasts of limestone, chert and other lithologies; clasts generally less than 15cm diameter but individual clasts up to 40cm.

Prominent bed generally c. 60cm thick with matrix supported clasts of limestone and other lithologies; clasts generally less than 15cm diameter; band passes rapidly into black cherty siltstones southwards along strike.

Large isolated limestone clast.

Prominent bed generally c. 20cm thick with matrix supported clasts of limestone and a wide range of other lithologies; clasts generally less than 6cm diameter.

Lenticular band to max. 15cm in thickness with matrix-supported limestone clasts

Lenticular band to max. 15cm diameter with matrix-supported limestone clasts.

Isolated limestone clast.

Lenticular band with matrix-supported limestone clasts to max 15cm diameter.

Lenticular band with matrix-supported limestone clasts to max 15cm diameter.

Prominent bed up to 60cm thick with matrix supported clasts of limestone and other lithologies to maximum 10cm diameter.

Rather sheared limestone; poorly fossiliferous; rare, poorly preserved tabulate corals and occasional crinoid ossicles

Laminated colour banded tan, dark grey to black, rarely reddish or bright green siltstones and argillites, with occasional narrow (generally a few mm in thickness) pale grey to almost white tuffs, minor arenites, and minor, allochthonous carbonate horizons consisting of matrix-supported clasts of limestone and a broad spectrum of non-carbonate lithologies.

Yarrimie Formation

Moore Creek Limestone

5. *Conclusions*

David & Pittman's limestone horizons are inferred to have been of various ages from early Emsian to late Frasnian, with the youngest horizon (their locality 10) being conceivably as young as the early Famennian–mid Famennian boundary (Late *rhomboidea* Zone to Early *marginifera* Zone). A broader spectrum of mid-Palaeozoic ages (Pridoli to late Famennian) is indicated by conodonts occurring in association with radiolarians in cherts and siltstones from elsewhere in the region. A summary of the alignments of North Tamworth limestone horizons in relation to the regional stratigraphic pattern and relevant chronologic date is given in Table 2.

NOTES ON CONODONT TAXA

For nomenclature of localities for conodonts in the North Tamworth–Spring Creek area see the map (Fig. 1), stratigraphic column (Fig. 3) and distribution chart (Table 1). The faunas include several chronologically compelling forms that, in autochthonous contexts, would warrant extended discussion. Because of allochthoneity of all limestone horizons sampled, comment is minimal. Abbreviations: AMF=Australian Museum; D&P= sample localities indicated by David & Pittman (1899) on their section line (these are shown within circles in Figs 1 and 2); HQ=Hospital Quarry section; M&T=spot localities located away from David & Pittman's section, and away from the Hospital Quarry section (these are shown without circles in Fig. 1).

Order **CONODONTOPHORIDA**
Eichenberg, 1930

Family **Belodellidae** Khodalevich & Tschernich, 1973

Genus *Belodella* Ethington, 1959

Type species. Belodus devonicus Stauffer, 1940.

Discussion. Two multi-element interpretations for *Belodella* are presently in use. Klapper & Barrick (1983) distinguish M, Sa, Sb, Sc and Sd elements. Jeppsson's (1989) 'f' element equates with the falciform M element of Klapper & Barrick, additional 'u' and 'a' elements are short and robust with denticulate posterior margins and 'd' elements form a symmetry-transition series thus equating with the S series proposed by Klapper & Barrick (1983). Terminology of Klapper & Barrick (1983) is used herein as the faunas are not sufficiently large to unequivocally identify the elements suggested by Jeppsson (1989).

Belodella resima (Philip, 1965)

Fig. 5M, O, P

Discussion. See Mawson, Talent & Furey-Greig (1995: 424–427) for synonymy. Following Klapper & Barrick (1983) and Stauffer (1940), S elements of *B. resima* may be differentiated from those of *B. devonica* by the absence of longitudinal costae.

Specimens of *Belodella resima* originally described from Tyers, Victoria (Philip 1965), were from horizons dated as *sulcatus* and *kindlei* zones (Mawson & Talent 1994b). Elsewhere in Australia, elements of *B. resima* have been reported and/ or illustrated from the Buchan area, Victoria [*dehiscens* to *serotinus* zones] (Philip 1966b; Mawson 1987b), the Broken River area, N Queensland [*pesavis* Zone to Late *varcus* Subzone] (Telford 1975; Mawson 1987a; Mawson & Talent 1989; Sloan et al. 1995) and Attunga, NSW [*patulus* to Late *varcus* zones] (Mawson & Talent 1994a).

Genus *Dvorakia* Klapper & Barrick, 1983

Type species. Dvorakia chattertoni Klapper & Barrick, 1983.

Dvorakia sp.

Fig. 5N

Discussion. As the element illustrated has a

Table 2. Suggested stratigraphic allocation of David & Pittman's (1899) and other limestone horizons in the North Tamworth area in the context of stratigraphic and biochronologic information from the Attunga–Tamworth–Nundle portion of the Tamworth Belt. Not included is the Sulcor Limestone (late Emsian), outcropping in the Sulcor–Yarramanbully area, 4–10 km N of Attunga (for location see inset, Fig. 1); it is inferred (Mawson & Talent, in prep.) to have been a major source of the limestone clasts in the Silver Gully Formation. D&P=David & Pittman (1899). U of S=University of Sydney. M&T=Mawson & Talent, this report.

Baldwin Formation	**D&P C** (not re-located) **D&P 10** limestone clasts (perhaps Moore Ck Limestone Member; barren of conodonts)
Yarrimie Formation	**D&P 9** (barren of conodonts) and **D** (not re-located). These horizons may be approximate correlates of McMinn's (1982) locality at Yarramanbully which produced late Frasnian *hassi* Zone conodonts **D&P 8** - several conglomeratic limestone horizons (sparse radiolarians), equating approximately with lithologically similar conglomeratic limestone horizons in the Dave's Hill and Bald Hill areas; = **D&P E, F & G**, and **M&T 5.** **U of S 267** **D&P 3**, equating approximately with **HQ 6** **D&P B**, equating approximately with **HQ 2 & 2A**, and with **M&T 4** **M&T 3** (clast of Moore Creek Limestone very low in Yarrimie Formation Lowest Yarrimie horizons are Early (perhaps not earliest part of the subzone) and Late *varcus* Subzones at Attunga (Mawson & Talent 1994)
Moore Creek Limestone	**M&T 1 & 2** (olistoliths in North Tamworth area); *costatus* and *australis* Zones are represented in the interval transitional from below into the Moore Creek Limestone (Mawson & Talent 1994), massive limestones at Attunga and Yarramanbully extending the age-span through the *kockelianus* Zone to the *hemiansatus* Zone and perhaps into the Early *varcus* Subzone (Mawson & Talent, 1994 & unpub. data).
Unnamed Unit	Not clearly differentiated on David & Pittman's (1899) North Tamworth-Seven Mile Creek traverse, but well-defined in the Yarramanbully and Sulcor areas as clastic and subordinate carbonate interval between Sulcor and Moore Creek Limestones. Referred to as "Lower Yarrimie Formation" by Mawson & Talent (1994) and shown to include *patulus* and *partitus* zones (i.e. straddling the Emsian-Eifelian boundary) at Attunga and be transitional to the Moore Creek Limestone. Laterally equivalent (at least in part) with Silver Gully Formation
Folly Spilite	Well expressed in areas south of Tamworth (e.g. Allen & Leitch 1992) but not identified on David & Pittman's (1899) North Tamworth-Seven Mile Creek traverse; inferred to be late *patulus* Zone or early Eifelian (see text)
Silver Gully Formation	Not clearly differentiated on David & Pittman's (1899) North Tamworth-Seven Mile Creek traverse, but demonstrated to be late *serotinus* - *patulus* Zone at Loomberah Heights (Mawson et al. 1995); Bog Hole Formation includes the same interval (Mawson et al 1995 & unpub. data)
Wogarda Argillite	Not clearly differentiated on the eastern part of David & Pittman's (1899) North Tamworth-Seven Mile Creek traverse
Northcotte Formation	Not clearly differentiated on the eastern part of David & Pittman's (1899) North Tamworth-Seven Mile Creek traverse
Drik Drik Formation	**D&P H-T** - suggested to possibly align with lithologically similar(matrix-supported limestone cobble horizons) in the metamorphic aureole associated with the Moonbi Adamellite west of Seven Mile Creek (cf. Fig. 2), and with generally not strongly metamorphosed developments in the Nemingha-Nundle area inferred (Furey-Greig 1995) to be *dehiscens* Zone; includes interstratified Copes Creek Andesite (Morgan 1997)

slightly asymmetrical, round to triangular cross section, it is designated an Sb element. It closely resembles a specimen illustrated by Klapper & Barrick (1983: fig. 8J) from Salisbury, Howard County, Iowa, from the Middle *varcus* Subzone.

Family **Acanthodontidae** Lindström, 1970

Genus ***Drepanodus*** Pander, 1859

Type species. Drepanodus arcuatus Miller, 1889.

Drepanodus sp.

Fig. 5C

Discussion. Although species of *Drepanodus* are generally taken to be confined to the Ordovician (Sweet 1988), several acostate, long, generally robust, slightly reclined coniform elements occurring in Devonian faunas have been referred to this genus (eg. Philip 1966b; Telford 1975).

Genus ***Panderodus*** Ethington, 1959

Type species. Paltodus unicostatus Branson & Mehl, 1933.

Panderodus unicostatus (Branson & Mehl, 1933)

Fig. 5J

Discussion. See Simpson & Talent (1995: 118–119) for synonymy. Various reconstructions of this species are summarised in Smith et al. (1987), for example those of Bergstrom & Sweet (1966), Cooper (1975) and Barrick (1977).

Genus **Neopanderodus** Ziegler & Lindström, 1971

Type species. Neopanderodus perlineatus Ziegler & Lindström, 1971.

Neopanderodus aequabilis Telford, 1975

Fig. 5K

Discussion. See Mawson et al. (1995: 428) for synonymy. Mawson et al. (1995: 428) suggested that the multielement reconstruction of the *Neopanderodus* may be analogous to that of *Panderodus*. A slender element, possibly an Sc element (pl. 2, fig. 19), has a groove on the inner lateral face running two-thirds the length of the cone, with longitudinal, parallel striae covering the area from the groove to the outer lateral margin, and oblique striae covering the area from the inner margin to the groove.

Neopanderodus sp.

Fig. 5L

Discussion. One neopanderodid specimen with relatively coarse striations developed from the tip of the cone to its base has not been assigned to *Neopanderodus aequabilis* because of the nature of the striations and lack of a lateral groove on the cone.

Family **ICRIODONTIDAE** Müller & Müller, 1957

Genus ***Icriodus*** Branson & Mehl, 1938

Type species. Icriodus expansus Branson & Mehl, 1938.

Icriodus struvei Weddige, 1977

Fig. 5A, B

Discussion. See Mawson (1987a: 258) for synonymy. This narrow form of *I. struvei* is somewhat similar to specimens of *I. regularicrescens*, for example, those illustrated by Weddige (1977: pl. 2, figs 31–32). The latter, however, can be distinguished from *I. struvei* in having a platform

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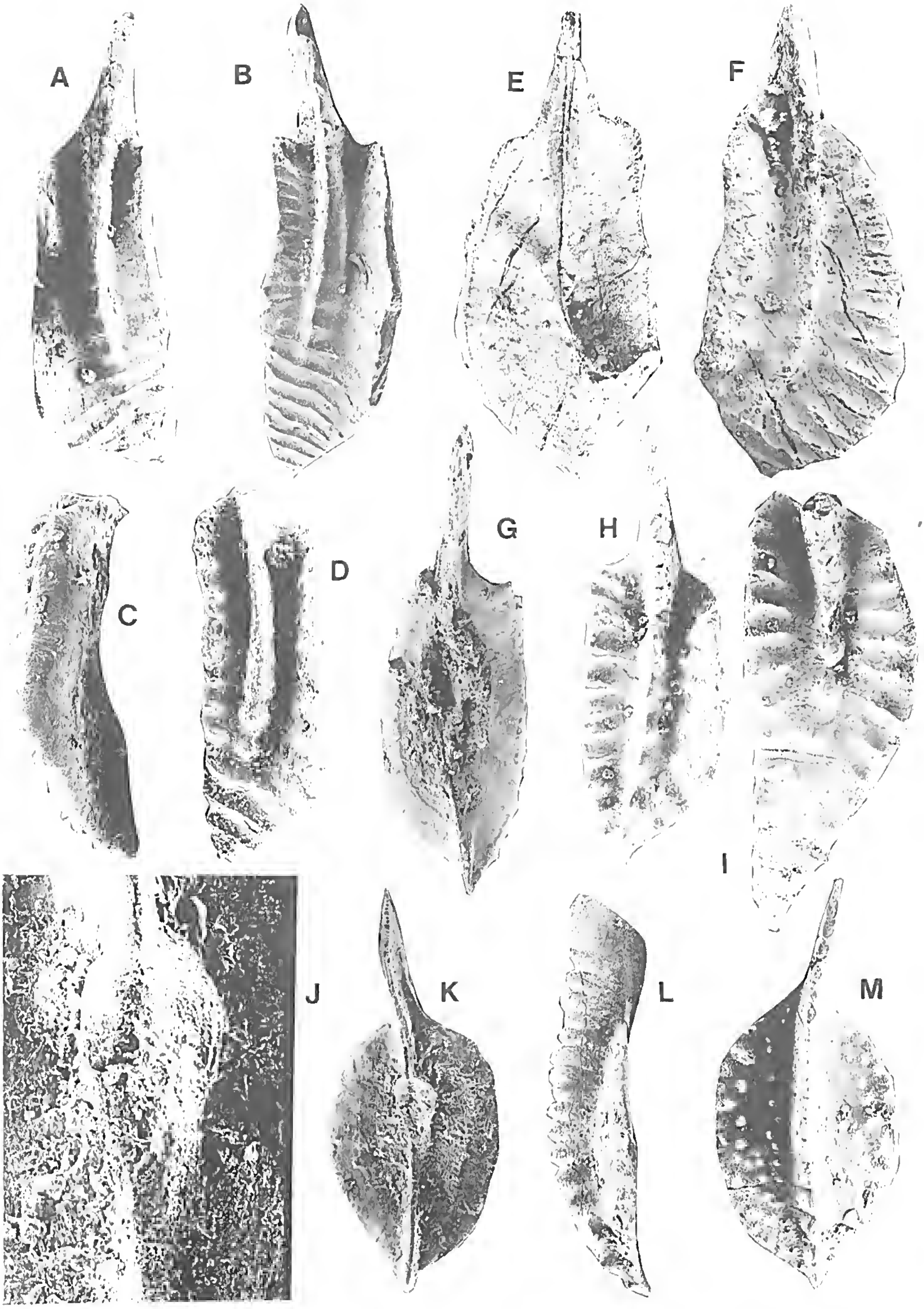
Fig. 4. A–D, *Polygnathus linguiformis linguiformis* Hinde 1897. A, upper view of AMF99074, ×35, HQ 5. B, upper view of AMF990975, ×45, HQ 6. C, D, lateral and upper views respectively of AMF990976, ×60, HQ 7 (loose). E, F, *Polygnathus aequalis* Klapper & Lane 1985. Lower and upper views respectively of AMF990978, ×35, HQ 2A. G, H, *Polygnathus aequalis* Klapper & Lane 1985. Lower and upper views respectively of AMF990979, ×60, HQ 1 (loose). I, *Polygnathus cooperi cooperi* Klapper, 1971. Upper view of AMF990977, HQ 5. J–M, *Polygnathus cristatus* Hinde 1879. J, enlargement showing asymmetry of basal pit of AMF99083, ×300, HQ 2A. K–M, lower, lateral and upper views respectively of AMF99083, ×60, HQ 2A.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that is narrower posteriorly. In Australia, *I. struvei* occurs in horizons ranging in age from *costatus* Zone to *hemiansatus* Zone (Mawson & Talent 1989).

Family **Prioniodontidiae** Bassler, 1925

Genus ***Prioniodina*** Bassler, 1925

Type species. Prioniodina subcurvata Bassler, 1925.

Prioniodina sp. A

Fig. 5F–I

Discussion. Several elements with similar denticulation and occurring in a single fauna (sample M&T-1 from the Moore Creek Limestone), have been assigned to *Prioniodina* sp. A. In lateral view, the slightly damaged prioniodellan (Pa) element is weakly arched in lateral view and has tall, closely packed but discrete denticles, round in cross section and tilted towards the posterior. The basal cavity is expanded in the anterior third of the unit and extends as a narrow groove to the posterior. The prioniodinan (?Pb) element is characteristically twisted with the basal cavity inverted anteriorly. It is far less angulate than the prioniodinan element of *Pri. subcurvata* as illustrated by Huddle (1968). The ?Sb element (longidensiform element of Sparling 1981) and the Sc element (ligonodinan element) have denticles that are similarly rounded to those of the P elements, but they are not as closely packed.

Family **Spathognathodontidae** Hass, 1959

Genus *Tortodus* Weddige, 1977

Type species. Tortodus kockelianus (Bischoff & Ziegler, 1957).

Tortodus kockelianus kockelianus
(Bischoff & Ziegler, 1957)

Figs 4L, M; 3D, E

Discussion. See Klapper & Johnson (1980: 455) for basic synonymy. The smooth, platform-like bulges on either side of the central row of denticles distinguishes *T. k. kockelianus* from *T. k. australis*. Despite damage to both specimens recovered from horizon HQ-0, they are readily identified as specimens of *T. k. kockelianus* by the characteristic platform bulges, the inward twist of the posterior part of the platform and the accompanying inclination of the denticles. The incoming of *T. k. kockelianus* marks the beginning of the *kockelianus* Zone *sensu stricto*; ie. it extends into the post-*kockelianus*/pre-*hemiansatus* interval that remained after excision of the *hemiansatus* Zone.

Family **Polygnathidae** Bassler, 1925

Genus ***Polygnathus*** Hinde, 1879

Type species. Polygnathus dubius Hinde, 1979.

Polygnathus aequalis Klapper & Lane, 1985

Fig. 3G, H

Discussion. See Klapper & Lane (1985: 930) and Bultynck & Martin (1995: 19) for synonymy of the species. A right curved specimen of *P. aequalis* was recovered from sample HQ 1 (loose) in the Hospital Quarry. It is a right-hand form having anterior margins of equal height and ridged ornamentation and platform dimensions very similar to those of the specimen figured by Klapper & Lane (1985: fig. 16.10) and the specimen figured by Bultynck & Martin (1995: pl. 8, fig. 8).

Fig. 5. A–E, *Polygnathus xylus xylus* Stauffer 1940. A, B, upper and lower views respectively of AMF990984, ×90, HQ 2A. C, upper view of AMF990985, ×30, HQ 4. D, E, upper and lateral views respectively of AMF990986, ×60 and ×55 respectively, HQ 1 (loose). F, G, *Polygnathus hemiansatus* Bultynck 1987. Lateral and upper views respectively of AMF99082, ×45, HQ 4. H, I, *Polygnathus* cf. *ovatinodosus* Ziegler & Klapper 1976. Upper and lower views respectively of AMF990988, ×35, HQ 2A. J, K, *Polygnathus* sp. A. Lateral and upper views of AMF99091, ×45, M&T 1. L, M, *Tortodus kockelianus kockelianus* (Bischoff & Ziegler 1957). Lower and upper views respectively of AMF990980, ×60, HQ 0. N, O, *Polygnathus pennatus* Hinde 1879. Lateral and upper views respectively of AMF990990, ×60, HQ 1 (loose).


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Polygnathus cooperi cooperi Klapper, 1971

Fig. 3I

Discussion. See Mawson et al. (1995: 431) for synonymy. One polygnathid is referred to *P. c. cooperi* because of its shallow depressions paralleling the carina, the gradual rounding of the posterior platform that forms a tongue, the short, discrete ridges on the margins of the platform and the ridges on the tongue that are partly interrupted as a continuation of the carina. It is generally agreed that the youngest specimens of *P. c. cooperi* occur in the *costatus* Zone. Bultynck & Hollard (1980) and Ziegler et al. (1976) recorded this subspecies as occurring in horizons as old as *serotinus* Zone.

Polygnathus cristatus Hinde, 1879

Fig. 3J–M

Discussion. See Klapper & Johnson (1980: 452) for synonymy. The leaf-like, nodose, arched platform and the basal pit surrounded by slightly asymmetrical lips that extend as a keel both posteriorly and anteriorly identify this as being a specimen of *P. cristatus*. The occurrence of this species in the HQ 2A fauna indicates an age no older than the upper half of the *hermanni* Zone (late Givetian), but possibly as young as the middle *asymmetricus* Zone (early Frasnian) (Higgins & Austin 1985; Sweet 1988; Barskov et al. 1991).

Polygnathus hemiansatus Bultynck, 1987

Fig. 4F, G

Discussion. See Bultynck (1987: 161) for basic synonymy. This species is recognised by having an almost straight inner platform margin contrasting with the outer platform margin with its pronounced constriction along the anterior margin. Bultynck et al. (1993) proposed that the definition of the Eifelian–Givetian boundary should be based on the entry of the species *P. hemiansatus* as defined by them; this has now been ratified by the International Union of Geological Sciences.

Polygnathus linguiformis linguiformis Hinde, 1879

Fig. 3A–D

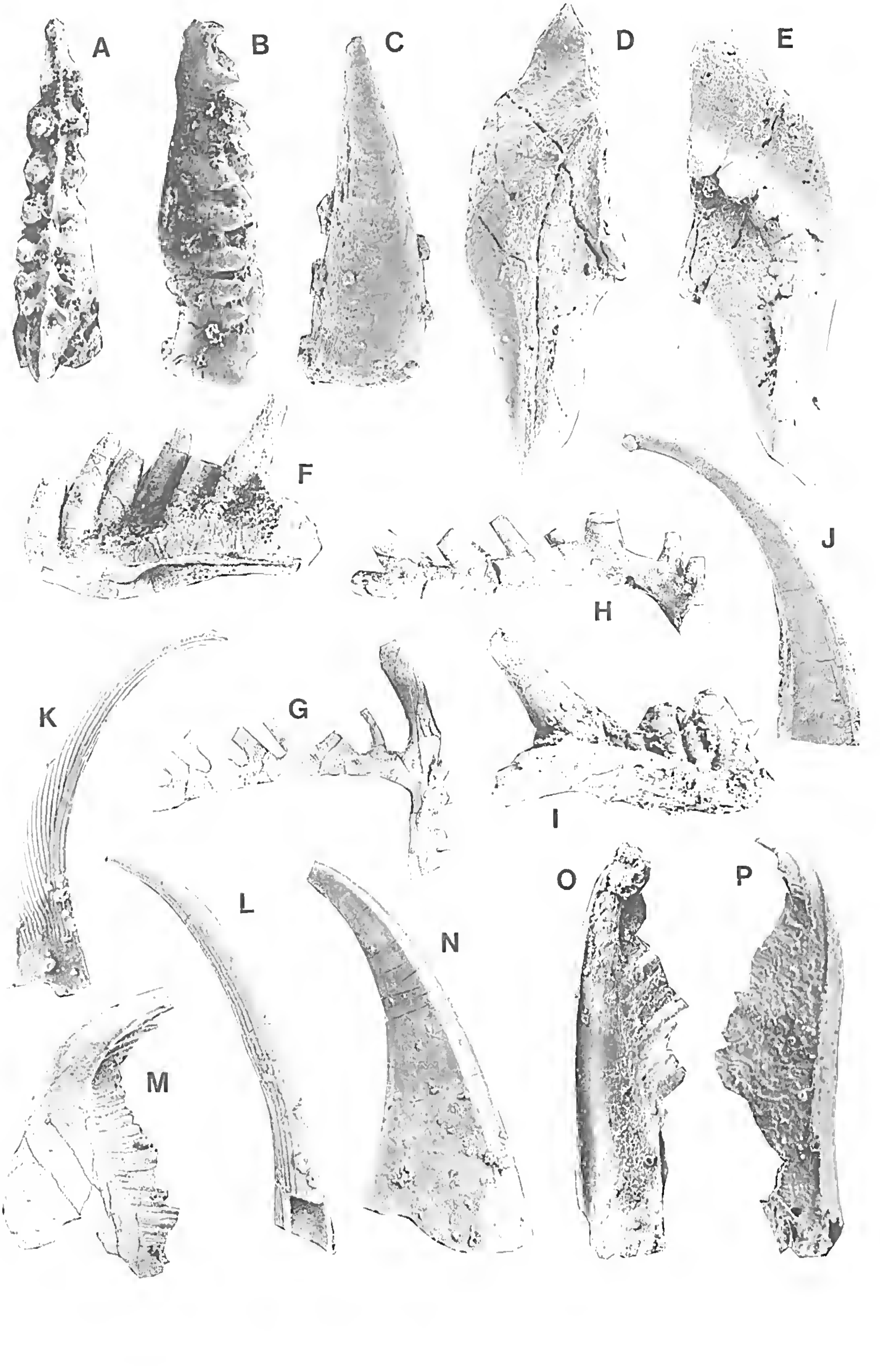
Discussion. See Mawson et al. (1995: 432) for synonymy. Also known in the literature as *Polygnathus linguiformis* gamma morph (eg. Bultynck 1970), this polygnathid is a long-ranging form. In Australia it is known from latest *serotinus* Zone through to the Middle *varcus* Subzone (Mawson & Talent 1989), but it could be expected from still younger horizons. Higgins & Austin (1985) have it extending from the *costatus* Zone through to the Lower *asymmetricus* Zone; Barskov et al. (1991) show the range to be *costatus* Zone to *asymmetricus* Zone. Klapper (in Ziegler et al. 1977) gives the range as from early Middle Devonian to early Upper Devonian (*asymmetricus* Zone).

Polygnathus linguiformis klapperi Clausen et al., 1979

Fig. 3E, F

Discussion. See Olivieri (1985: 303) for synonymy. Originally recognised as *P. linguiformis* epsilon morph (eg. Klapper in Ziegler 1977), Clausen et al. (1979) raised this form to subspecies level. Barskov et al. (1991) show this subspecies ranging from horizons dated as upper *ensensis* (=*hemiansatus*) Zone to *hermanni*–

Fig. 6. A, B, *Icriodus struvei* Weddige 1977. Upper and lateral views respectively of AMF990989, ×50, HQ 7. C, *Drepanodus* sp. Lateral view of AMF99087, ×60, HQ 2A. D, E, *Tortodus kockelianus kockelianus* (Bischoff & Ziegler 1957). Lower and upper views respectively of AMF990981, ×60, HQ 0. F–I, *Prioniodina* sp. A. F, lateral view of Pa element, ×45, AMF99092, M&T 3. G, lateral view of Sc element, AMF99095, ×25, M&T 3. H, lateral view of ?Sb element, AMF99094, ×35, M&T 3. I, lateral view of ?Pb element, AMF99093, ×35, M&T 3. J, *Panderodus unicostatus* (Branson & Mehl, 1933a). Lateral view of ?tortiform element, AMF99100, ×60, HQ 2A. K, *Neopanderodus aequabilis* Telford 1975. Lateral view of AMF99096, ×60, HQ 5. L, *Neopanderodus* sp. Lateral view of AMF99097, ×90, HQ 5. M, O, P, *Belodella resima* (Philip 1965). M, lateral view of Sc element, AMF99098, ×75, HQ 2A. O, lateral view of Sa element, AMF99099, ×60, HQ 1. P, lateral view of Sa element, AMF99101, ×60, HQ 2. N, *Dvorakia* sp. Lateral view of Sb element, AMF99102, ×90, HQ 1 (loose).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cristatus Zone. Klapper & Johnson (1980) indicate this form to be present in the Lowermost *asymmetricus* Zone in Indiana.

Polygnathus cf. **ovatinodosus**
Ziegler & Klapper, 1976

Fig. 4H, I

Discussion. See Klapper & Johnson (1980: 453) for basic synonymy of *P. ovatinodosus*. The specimen from HQ 2A is compared to *P. ovatinodosus* as there is a suggestion of the outer anterior trough bowing outwards, a feature not usual in *P. ovatinodosus*. It has, however, a relatively flat platform, the typical nodose ornamentation on the platform, and a short rostrum; the platform and blade are of equal length and the pit is located in the rostral area. These features identify *P. ovatinodosus*. Barskov et al. (1991) and Klapper & Johnson (1980) gave the range of this species as Middle *varcus* Subzone to Lowermost *asymmetricus* Zone.

Polygnathus pennatus Hinde, 1879

Fig. 4N, O

Discussion. See Norris et al. (1992: 78–79) for synonymy. This specimen has a lanceolate platform, a high carina that reaches the posterior extremity of the platform, and distinct marginal ridges, typical of *P. pennatus*. Barskov et al. (1991) show this species to occur only in horizons of Lowermost *symmetricus* to Middle *asymmetricus* age. Klapper (in Ziegler 1973) noted the occurrence of this species in the upper part of the *hermanni–cristatus* Zone in the Rhenish Slate Mountains (Ziegler 1966).

Polygnathus xylus xylus Stauffer, 1940

Fig. 4A–E

Discussion. See Sparling (1995: 1137) for synonymy. *P. xylus xylus* differs from *P. x. ensensis* in having fewer serrations developed along the anterior part of the platform margins slightly posterior of the geniculation points. In some specimens of *P. x. xylus*, a slight serration may be seen, eg. Fig. 4E. The latter specimen also lacks the strong downward arching of the platform posterior to the serrations, another feature of characteristic of *P. x. ensensis*. *P. x. xylus* is known to occur in faunas of varcus to Lower *asymmetricus* age (Barskov et al. 1991; Sweet 1988).

Polygnathus sp. A.

Fig. 4J, K

Discussion. A single Pa element is recorded from locality M&T-1. The narrow, slightly curved platform is highly arched for its size and is ornamented with nodes or short ridges for the length of the platform. The blade is high and is equal in length to the platform. The platform is a little too asymmetrical for it to be a small specimen of *P. decorosus* Stauffer.

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TRANSACTIONS

OF THE

ROYAL SOCIETY OF VICTORIA

CLIMATE VARIABILITY AND CHANGE—SCIENCE AND INDUSTRY

Royal Society of Victoria Symposium, Melbourne, 21 October 1997

INTRODUCTION

A symposium, which included lively debate, was held at the Royal Society's Hall in Melbourne on 21 October 1997. The topic was 'Climate Variability and Change—Science and Industry'. A range of speakers from diverse backgrounds including the solid-earth sciences, the atmospheric sciences, industry, government and the university sectors provided a spectra of presentations and viewpoints which initiated considerable debate and discussion.

Several of the speakers have provided short summaries of their presentations which are included in these *Transactions* in order to stimulate further research, debate and the exchange of information and opinion concerning one of the major global issues of the close of the Twentieth Century and of the new millennium.

ICE *VERSUS* ATMOSPHERE AS CLIMATE-CHANGE DRIVER

R. J. Foster*

Over the past many tens of thousands of years, surging of Northern Hemisphere ice sheets was a far more important driver of mega-regional climate change than was variation in atmospheric composition. The likely sequence was iceberg launching, sea-level rise, and ocean circulation change resulting in heat transport changes—with the outcome of regional climate change. This was natural variability on a millennial scale.

At a time-scale relevant to humans, past climate changes were not 'global'.

For the last two decades, the Southern Hemisphere has cooled relative to the Northern—contrary to climate-model predictions. Could natural variability as a result of changes in oceanic heat transport, perhaps including the influence of Antarctic ice movements, be of a greater magnitude than the human-induced warming which has been predicted? This is a question whose answer would have major economic and environmental implications.

1 *Learning from the past*

1.1 *Descent into the Ice Age*

For a quarter-billion years, ours was a warm, wet world. However, we have now entered an Ice Age of Glacials and Interglacials, alternating on a hundred-thousand-year (100 ky) cycle. Glacials comprise the larger part of this cycle; although we have the good fortune to be alive during an Interglacial.

The world was kept warm and wet by an atmosphere containing several times the carbon dioxide (CO_2) concentration which existed in the immediate pre-industrial past. Mountain-building arising from India's collision with Asia resulted in intensified erosion over the last 50 million years (50 my), incorporation of atmospheric carbon in new carbonate sediments, consequent depletion of atmospheric CO_2, and global cooling as an outcome. This is natural variability of our climate on a truly grand scale.

However, decreasing CO_2 levels were not a sufficient explanation for the Ice Age now with us. A likely trigger was the opening of Drake Passage some 40 million years before the present (40 my BP). Breaching of the Andean Cordillera enabled the giant circum-South-Polar cold current to begin, thus creating the conditions which led on to the establishment of the great East Antarctic ice-sheet by 14 my BP.

The Northern Hemisphere was slow to follow, and it was not until closure of the seaway between the Americas at Panama about 3 my BP that the Greenland ice-cap became established. Thereafter, sea-ice spread over the Arctic Ocean in winter; and by 2 my BP the Ice Age had begun.

1.2 *A time of Glacials and Interglacials*

It is only in the past 700 ky that Arctic sea-ice has survived an Interglacial such as that we now enjoy, and the Ice Age has revealed its full force. Since then, there has been a striking correlation between *c.* 100 ky-period variations in solar insolation caused by orbital factors, and major fluctuations in global climate—the Glacial–Interglacial cycle. This is still natural variability on the grand scale.

Antarctic ice-core records available over the last 400 ky show that variations in CO_2 content of the atmosphere have tracked these variations in climate. Because the Glacial–Interglacial cycles are orbitally-induced, the associated major variations in atmospheric CO_2 must be an outcome of climate change—not its driver.

There is a pronounced hemispheric asymmetry to the Globe. The Antarctic continent is set in a great ocean, carries 90% of the world's continental ice volume, and promotes long-term climatic stability in its region. On the other hand, the

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Arctic Ocean is almost land-locked, bordered by continents, and covered by sea-ice; and its surrounding region suffers great variation between Glacials and Interglacials.

This notable asymmetry condemned the Northern Hemisphere, particularly the North Atlantic Basin region, to a more abrupt and more extreme response to any global-scale climate stimulus in the past—thus providing an important analogy for the present.

1.3 *The last Glacial*

For most of the last 110 ky the world has cooled, and sea level has fallen as ice accumulated on northern continents. At the Last Glacial Maximum (LGM), say 20 ky BP, continents adjoining the North Atlantic were covered by kilometre-thick ice-sheets extending down beyond 45°N in north-eastern America and 55°N in western Europe. Since then, world sea-level has risen by 120 m.

While Australia was cold (10°C colder at Lake Eyre) and very dry (dunes as far south as Bass Strait) at the LGM, even Tasmania was spared major glaciation.

There is compelling evidence that surges of continental icesheets, mostly originating in North America, and the consequent launching of iceberg armadas, had a dramatic influence on climate in the North Atlantic Basin mega-region during the last Glacial.

These 'Heinrich Events' appear to have been internally-triggered, rather than be a response to contemporaneous external factors. Each left a footprint of some trillion tonnes of ice-rafted detritus (IRD) spread across the floor of the North Atlantic, including on the tops of sea-mounts. The Events correlate with periods of cooling and subsequent abrupt warming (up 7°C in less than a century) observed in Greenland ice-cores, Atlantic sea-bed cores and European lake sediments.

Shorter-duration episodes of abrupt warming, also recorded in Greenland ice cores, follow the deposition of more-plentiful thin layers of IRD in the North Atlantic between the massive Heinrich Events.

Over many tens of thousands of years during the last Glacial, the surging of continental ice-sheets, consequent sea-level rise, and subsequent adjustments to the great oceanic water movements were the driver of mega-regional climate change. This was natural variability on a millennial scale—and it was not caused by contemporary variations in the composition of the atmosphere.

2 *Model of climate change*

Based on evidence from the past 75 ky, a plausible explanation for the major natural variations in observed climate in that locus of abrupt climate change has been the North Atlantic Basin region, is as follows:

internally-triggered surging of continental ice-sheet;
rapid rise in global sea-level;
resultant increase in Earth's radius of gyration;
deceleration of global spin to maintain level of angular momentum;
exchanges of momentum between solid Earth and mobile oceans;
contemporaneous increase in vulcanism;
complex changes in movement of oceanic water masses;
changed heat transport, because oceans are a massive store of heat;
atmospheric response to changes in oceanic temperatures;
translation by the atmosphere of ocean changes into regional climate changes
resonance effects persist in that mobile store of heat—the oceans;
long after sea-level has stabilised, climate fluctuations persist;

and

changed oceanic movements most notable in North Atlantic;

therefore,

climate change most pronounced in northern lands of the Atlantic Basin;

3 *'Global' climate change*

The worldwide Glacial–Interglacial transition about 16–13 ky BP appears always to have been rapid when it came, although its arrival was not contemporaneous everywhere. But the return to near-Glacial conditions of the Younger Dryas at 12.8 ky BP was a Northern Hemisphere event, as was the abrupt reinstatement of warm conditions (7°C in 50 years) at 11.6 ky BP; these remarkable events had only an attenuated Southern reflection.

Even the peak of our current Interglacial (the Holocene Maximum) appears to have been staggered. In the Northern Hemisphere, the zenith of the Interglacial was about 6 ky BP; but in eastern Australia it was nearer 4 ky BP.

In Queensland, the hot oblique wet zenith of the current Interglacial was marked by extensive rainforest, with a mean annual temperature some 3.5°C warmer than today, persisting from about 5 to 3.5 ky BP.

In the Northern Hemisphere, the Holocene Maximum lay between two intervals of increased mountain glaciation at about 8 and 5 ky BP. Since then, the North has experienced two stronger glacial advances at 3300–2400 BP and during the Little Ice Age. Between these glacial episodes have been warmer periods marked by advances in the tree-line.

The Little Ice Age which began in *c.* 1300 AD, although traumatic (even fatal) for those who were subjected to it, was one of a series of North Atlantic Basin—not global—events. Its last episode of severe cold was in the 1810s and 1820s, and temperatures had returned to near-modern levels by 1920. The tree-line is now readvancing.

However, here in southeastern Australia, a 3700-year Tasmanian tree-ring record shows that our coolest period was in the late Nineteenth Century.

Similarly, more-recent multi-decadal climate-related events are not global. A warm to cold to warm cycle recognised in North Atlantic sea-surface temperature since the 1940s, and the dramatic loss of summer sea-ice in the Antarctic in the 1950s and 1960s are presumably ocean-related and not human-induced. But these events are natural variability on a human time-scale.

4 *Today's trends*

Numerical model studies predict that long-lived anthropogenic greenhouse gases (GHGs) such as CO_2 provide hemispherically-symmetric warming of the lower atmosphere. However, aerosols from the burning of fossil fuels mostly originate in the temperate latitudes of the Northern Hemisphere; and because of a short residence time, their impact is local and regional—not global. Aerosols act as a coolant.

Therefore, these models predict that human actions are warming the lower atmosphere of the Southern relative to Northern Hemisphere.

Temperature trends in the lower atmosphere are available from data collected by weather satellite over 17 years (1979–95), and from direct measurements by radiosonde over 38 years (1958–95). The run of satellite data and the last 24 years of the radiosonde measurements show relative cooling in the Southern Hemisphere.

Is this record long enough to be a reflection of multi-decadal natural climate variability on a mega-regional scale? And if so, are there natural forcings—perhaps including past or present movements of the Antarctic ice-sheet—which are sufficiently large to mask the predicted human-induced warming for the Southern Hemisphere?

5 *Critique of the IPCC Report*

The Intergovernmental Panel on Climate Changes *Climate Change 1995: the Science of Climate Change* is its current assessment of climate-change science (Houghton et al. 1996).

The Report comprises *Preface, Summary for Policymakers* and *Technical Summary* of 50 pages, followed by a substantial text. It is implausible that 'policymakers', whether politicians or public servants, would have the time to read much beyond page 50.

The IPCC Report is tested in two ways:

> Against its own assertion that the Technical Summary presents a 'comprehensive, objective, and balanced view of the subject matter'.
>
> Against the criterion (Fisk 1997) that to be 'sound science' an 'assessment has to be free of omissions and bias'.

The Report, as represented by its first 50 pages, fails these tests because:

*It promotes the dubious concept of 'global' climate change. The available evidence indicates that past climate changes have not been global at the decade/century scale relevant to humans.

*It ignores ice as a past driver of climate change, and it offers the spurious explanation of 'precipitation and runoff' for wild fluctuations in the climate of the North Atlantic Basin mega-region during the last Glacial.

*It ignores the continuing role of the oceans, with their huge store of heat and momentum, as the major source of natural climate variability on a regional scale. On the contrary, the Report emphasises the atmosphere as the driver of natural climate variability; and therefore, the potential for changes in regional climate on a multi-decadal scale is under-emphasised by default.

*It ignores observed cooling of the lower atmosphere in the Southern relative to the Northern Hemisphere over the past two decades. This relative cooling contradicts model predictions which IPCC uses as a basis for its claim of 'a discernible human influence on global climate'. Granted, it would be surprising if there were yet no human influence on climate, considering the world's skyrocketing GHG emissions. But has IPCC cried 'wolf' here?

6 *Imagination block*

Under the heading 'imagination block' Fisk states that:

> 'One of the most difficult areas in an assessment is to be sure that all the possible interpretations of the data have been explored.'

The IPCC Report suffers from imagination block in at least two crucial areas. These are identified below:

> *First*, its fixation with the atmosphere as primary driver of climate change. This leads it to ignore the much larger store of heat in the mobile oceans. Whether or not influenced by past or present ice movements, changes in ocean circulation have the potential to provide regional climate changes over decades-to-centuries. This is natural variability on a scale relevant to humans;

and

> *Second*, its tacit assumption that natural variability is currently limited to changes with a duration of up to a decade or so. Thus, observed regional warmings of multi-decadal duration must be human-induced.

Analogy with the past demonstrates ample scope for IPCC to be wrong on both counts. In short, 'all the possible interpretations of the data' have not been explored.

7 *Extending the conclusions*

At present, there is insufficient justification for claiming that GHG emissions deriving from human activity are the sole, or even the largest, factor influencing mega-regional climate change. Natural variability has a crucial but unsung role.

Those relying on the IPCC Report for their knowledge are not being properly informed; and matters can not be put right until IPCC abandons its fixation with the atmosphere. The Report is single-issue science, at a time when we need to look at climate-change science in the round.

If it can be established that anthropogenic warming is only a second-order element of the climate-change equation, the effort which has to be applied to the task of limiting sky-rocketing world CO_2 emissions could be safely reduced—with far-reaching and positive implications for the growth of living standards in the Third World.

This is not an academic issue even for wealthy Australia, because:

> *First*, any severe limiting of Australia's industrial CO_2 output will give rise to the export of jobs to countries which do not so encumber their industries;

and

> *Second*, the erosion of national wealth which will be a likely outcome of weakening our industrial base, must reduce the funds available for pressing conservation needs—such as the protection of Australian habitat from further degradation, and hence the preservation of our biodiversity. Australians are custodians for the world of our large endemic flora and fauna—and this is a job which we need to do better.

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THE SURGING WEST ANTARCTIC ICE SHEET

THE KEY DYNAMIC OPERATOR ON PRESENT GLOBAL SEA LEVEL RISE AND RAPID CLIMATE CHANGE

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THE Little Ice Age, in the Middle Ages, and previous cold periods, centred around 2900 and 5300 BP, together with the mid-Holocene warm period, *c.* 6000 BP, are evidence of a dynamic atmosphere–ocean–cryo-sphere system, which, in the Northern Hemisphere, at least, sets up a climate oscillation with a period of 2500 years (approximately) (Dansgaard 1993; Broecker 1994).

The Younger Dryas, lasting from 11 000 to 10 000 years BP, interrupted the return to warm conditions, after the collapse of the Northern Hemisphere ice sheets over North America and Northern Europe, ending about 14 000 years BP. Until recently, the precise cause of the Younger Dryas has been obscure.

The present changes in the West Antarctic Ice Sheet (WAIS) are believed to be the effects of residual dynamics built into the polar icecaps of Antarctica and Greenland as the result of the rapid rise in sea level and temperature, which occurred worldwide, as the earth emerged from the ice age, *c.* 14 000 a BP (Alley & Whillans 1991).

The possibility that marine ice shelves attached to continental ice sheets disappear very quickly was first suggested by Denton & Hughes (1981). Hughes (1992) later suggested that climate changes were initiated by ice sheet collapse, and these changes were related to the life cycles of ice streams.

Very recent research based on satellite imagery presented to the July 1997 Conference of the International Glaciological Society, at Hobart, Tasmania, by Dr Robert Bindschadler, of NASA Goddard Space Center, Maryland, USA, indicates that the West Antarctic Ice Sheet, between the Ross and Weddell Seas, has, in fact, been disintegrating, or surging, since 6000 BP, when there was a major climatic shift on the Antarctic Peninsula (Hjoort 1997, pers. comm.). The ice streams, in particular Ice Stream B, which appears to be accelerating in flow volume and velocity, are the vehicle for the rapid draw-down of the ice sheet, and its ultimate collapse. Ice Stream C apparently stopped in the early Nineteenth Century (MacAyeal 1995), whereas Ice Streams A, D and E may also be surging (Bindschadler 1997, pers. comm.).

Bindschadler (1997, pers. comm.) estimates that the recession of the headward margin is 140 m/a, and he estimates the time that the ice streams will take to extend to the continental divide are 800 and 1200 a in two directions. An integration of the recession rate over the headward margin of the ice streams leads to an evaluation of the mass of ice, and subsequently water, upon melting of icebergs, lost to the icecap, and hence, gained to the volume of the oceans. The result indicated by Bindschadler (1997, pers. comm.), is a sea level rise of 0.9 mm per annum, which matches the 'missing' component in other calculations of sea level rise in relation to observed changes.

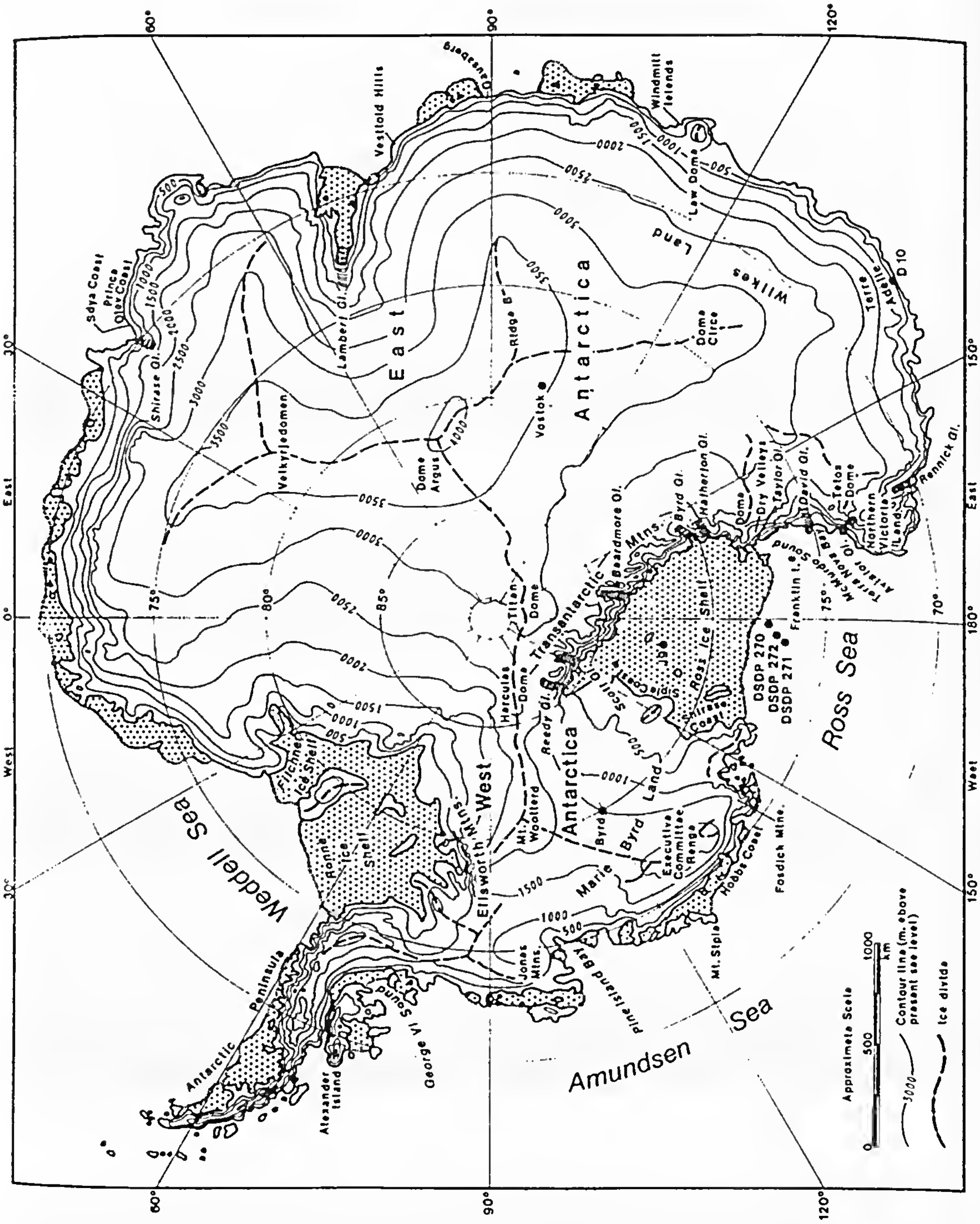
THE PARADIGM SHIFT INITIATED BY HEINRICH'S DISCOVERIES

The tracks of massive discharges of icebergs were discovered in the sediments of the North Atlantic Ocean, by Heinrich in 1988. These events occurred at intervals of 7–13 000 a (approx.) back to halfway through the last interglacial (MacAyeal 1993). The frequency slowed slightly backwards in time. The iceberg outbursts occurred independently of solar insolation (Milankovitch) cycles.

Studies of the corals in the Barbados Islands (Fairbanks 1989), revealed two stages of massive influx of freshwater to the Atlantic, centred around 9500 and 12 000 a BP. Sea level rises detected by radiocarbon dating of 28 and 24 m occurred over time spans of 1 kyr (approx.). As the ice sheets collapsed, there was an initial cooling of 2°C for 100 a (approx.), and subsequently, a rapid rise in atmospheric temperature of as much as 7°C over periods as short as a decade.

The evidence of the Greenland Ice Core (GRIP Project) (Johnsen 1992; Bond 1993), is that ice sheet collapse is driving shifts in climate.

The stratigraphy of the annual layers, and that of the palaeo-climate information derived therefrom, back to the last interglacial, 115 000 to 135 000 a BP, by analyis of the oxygen isotope



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Source: Denton, G. H. & Hughes, T. J., 1986. Global ice-sheet system. *Quaternary Research* 26: p. 7.

ratio, indicates that the spikes in the ice core temperature recorded were preceded by the massive influx of icebergs into the polar oceans, the Heinrich events (Heinrich 1988; Broecker 1993; Broecker 1994; Majewski 1997, pers. comm.). Thereafter, on a much longer time frame, occurred slow variations in atmospheric carbon dioxide content.

Ice stream surges in Antarctica and Greenland activate ocean currents, bringing up warm bottom water, eg. the Antarctic Bottom Water (ABW), and the North Atlantic Deep Water (NADW), which in turn causes atmospheric warming (Bond et al. 1993).

Hence, there occurs a glacial carbon dioxide oscillation, which may still be operating and contributing to the presently observed increase in atmospheric content. Because the mass content of carbon dioxide in the oceans is sixty times that in the atmosphere, very small perturbations in ocean currents, may cause large oscillations in the carbon dioxide content of the atmosphere (Berger 1982).

TECTONIC PROCESS IN GLACIERS AND ICE SHEETS

The theory of glacier and ice sheet surging, which is related to the catastrophic collapse of the Northern Hemisphere ice sheets marking the end of the Ice Age, is still in its infancy, and presents a challenge in resolving a major unsolved problem of geophysics. The topic of deformation in continental shear zones, in tectonics, employs the notion of 'thermal runaway'. Finite element models are used to demonstrate the occurrence of similar features in the analogous ice mass (continental ice sheet, ice stream, or mountain glacier).

The precise cause of the initiation of fast motion in ice masses is a controversial issue in glaciology. The topic is significant in that ice surging may affect climate.

The decadal scale surges of fast motion in glaciers in the temperate regions, such as in Alaska, Yukon Territory and Central Asia, and the flow of ice streams in polar ice sheets (Antarctica and Greenland), both may have origins in the development of tectonic structures, or zones of high mobility, within the ice mass, at a location at some small height above the ice–bedrock interface. The time scale of the life cycles of ice streams is longer because of the colder temperatures at the poles. A 20-year surge interval for a mountain glacier which is comprised of temperate ice may correspond to a 3-kyr cycle of ice streams in polar ice.

The 'pulling force' (Hughes 1992), exerted on the headward part of an ice sheet (a consequence of the horizontal differential in body forces between the hydrostatic force of the oceans, and the overburden force of the ice), actuates the slow recession headwards of the margin, marked by intense crevassing, between the fast moving ice, within an ice stream, and the slow moving continental ice. (The ratio of ice velocities between the two fields may be two or even three orders of magnitude.) The spatial variation in ice flow is characterised by intense shear.

The dominant paradigm in glaciology has been that ice to bedrock 'lubrication' governs the behaviour of ice masses, in particular, the behaviour during surging, and, by a convoluted argument, that environmental factors dominate flow in ice sheets. The emphasis on basal sliding in glaciology is likely to be regarded as not so important and a renewed interest is possible for such surging mechanisms as 'creep instability' and 'explosive shear heating' (Jarvis & Clarke 1975). The difficulties of the hypothesis of deforming till (which is saturated, unstable and highly non-linear in its rheological properties), underlying the fast moving ice in ice streams, causing surging, have been discussed by Kamb (1991).

Photogrammetric mapping of ice streams permits the calculation of velocity fields. Inverse methods are used to estimate the basal flow field. MacAyeal et al. (1995) determined that ice stream resistance is concentrated at bedrock 'sticky points'. The implication is that shear heating and deformation in highly mobile shear zones is controlling the dynamics of ice flow, within ice streams.

DISCUSSION AND CONCLUSIONS

Three independent lines of evidence, sediment studies of the North Atlantic, the Greenland ice core and stratigraphy and dating of the Barbados' corals, all point to the same conclusion; that ice sheet collapse by the process of massive

Fig. 1. Present-day Antarctic Ice Sheet. The ice sheet in East Antarctica is largely terrestrial, whereas that in West Antarctica is largely marine. The stippled pattern shows ice shelves.

reorganisation of ocean currents by melting icebergs in the past induced climate cycles (Hughes 1992; MacAyeal 1993). It is probable that these processes are still occurring, in polar areas and explain the anomalies of climate dynamics.

The fact that the Heinrich events have occurred at only a slowly changing frequency, going backward in time, in the North Atlantic, varying from 7 to 13 kyr, indicates that they are not triggered by environmental, or solar insolation, factors. This has elevated internal forcing as the most likely determinant of ice sheet collapse. If an internal mechanism of triggering the surge events can be found, many heretofore inexplicable aspects of ice flow may be explained.

The weakest of the solar orbital cycles (the Milankovitch cycles), is the 100-kyr variation in orbital eccentricity. The 100-kyr cycle of the ice ages, on the other hand, represents a very strong signal in ice sheet areal extent and volume. Previously, non-linearities in the ice-sheet structure and lithospheric response have been suggested as amplifying the solar signal (Muszynski & Birchfield 1987). More recent explanations (Muller 1997) have suggested variation in the inclination of the solar orbits relative to the galaxy and corresponding variations in the incidence of stellar dust as the cause of the 100-kyr ice ages.

The implication from computer modelling and field studies (Raymond 1996; Heinrichs et al. 1996; Hambrey et al. 1996; Rowden-Rich & Wilson 1996; Payne & Dongelmans 1997), is that ice sheet collapse is internally forced. The ramification of the internal forcing hypothesis is that climate cycles are initiated by dynamics ice re-crystallisation and shear heating. This has significance for related branches of science, oceanography and meteorology, in that field experiments and associated mathematical modelling will have to take account of the possibility that ice sheet disintegration processes are, in fact, the main driver in rapid climate change.

It is possible that solar insolation cycles are introduced as an operator on the rate of reforming of ice sheet volume after intermittent surging at varying frequencies has depleted ice sheet volume. This would account for the observed 10 000-year lag in ice volume following solar cycles (Budd & Rayner 1993).

This process is active in the West Antarctic Ice Sheet (Bindschadler 1997, pers. comm.). The advance of the ice of the Ross Ice Barrier northward (Vaughan 1997, pers. comm.) may be a manifestation of an accelerating drawdown of the ice in the ice sheet appurtenant to the marine ice shelf. The behaviour of the divideward margins of the ice streams until recently has been obscured, owing to the difficulty of ground and air reconnaissance. The development of satellite altimetry and synthetic aperture radar has enabled a precise estimate of the rate of recession. This rate of recession is likely to accelerate in time leading to the incursion of the ocean and the eventual removal of the bulk of the grounded continental ice of the West Antarctic Ice Sheet. The implications for this scenario of events is that there will be a worldwide rise in sea level of 3–5 m (Hughes 1977, 1992).

The surprising explanation of sea level rise since the Middle Ages of approximately one metre, by the mass removal of ice from the West Antarctic Ice Sheet, currently at the rate of 0.9 mm per annum, but likely to accelerate to 4 mm per annum (Bindschadler 1997, pers. comm.), has ominous portents for the future environmental regime of the coastal parts of the earth.

Attempts to limit sea level rise by control of carbon emissions will be of no avail, at least in limiting flooding of islands, and in fact, may be counter-productive, in that such misguided efforts may tie up scarce capital resources that may be better directed at dealing with the actual problem, rather than pseudo-problems.

The lessons from the palaeo-climate record are that climate has fluctuated rapidly, as a response to surges in polar ice sheets. This process is still active.

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OBSERVED CLIMATE VARIABILITY AND CHANGE

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The evidence that the climate of the Australian region has changed over the last century is reviewed. There are uncertainties due to changes in observational techniques, incomplete data coverage and urbanisation. Nevertheless the near-surface atmospheric temperature does appear to have warmed, with overnight temperatures increasing about 1°C since mid-century, while daytime (maximum) temperatures appear to have increased about 0.5°C. The evidence of warming from instrumental data is supported by a wide variety of proxy evidence. No clear, long-term precipitation trend is evident across the region.

The question of whether the climate is becoming more extreme or variable is addressed. Although there is evidence of changes in variability or extremes on a regional scale, some of these changes are towards increasing variability while some other extremes are becoming less frequent. Overall, there is no evidence that the climate is becoming more (or less) extreme or variable. However, this may simply reflect the inadequacy of the analyses conducted so far. The behaviour of the El Niño–Southern Oscillation has been unusual since the mid-1970s, compared with its behaviour in the previous 100 years. Some of the trends in extreme weather events (eg. decrease in numbers of tropical cyclones) simply reflect the changed behaviour of the El Niño–Southern Oscillation.

THE Intergovernmental Panel on Climate Change (IPCC), in their Second Assessment of Climate Change, judged that 'Global mean surface air temperature has increased by between about 0.3 and 0.6°C since the late Nineteenth Century', and that 'Recent years have been among the warmest since 1860, ie., in the period of instrumental record, despite the cooling effect of the 1991 Mt Pinatubo eruption'. On the subject of climate change extremes (Nicholls 1995), the IPCC concluded that on 'regional scales there is clear evidence of changes in some extremes and climate variability indicators ... Some of these changes have been toward greater variability; some have been toward lower variability'. How does the pattern of recent climate change in Australia fit with this global IPCC picture? And what else can we say about climate change in the region?

PROBLEMS WITH MONITORING CLIMATE CHANGE

Although we have instrumental meteorological data starting from last century, there are many problems with these data, if we wish to use them to examine how the climate of Australia has changed. Karl et al. (1995) provides a comprehensive discussion of problems with monitoring climate change. Last century the number of stations recording climate data were small and mainly concentrated in the southeast of the country. Even now we have large data gaps in the drier regions of the west and centre of the country. This lack of complete spatial coverage generally restricts us to looking at climate change since about the start of the Twentieth Century. A second problem with the data from the Nineteenth Century is that temperature measurements were often taken in an open stand, instead of the Stevenson Screen which became standard throughout Australia by 1910. So the Nineteenth Century measurements are biased warm, relative to modern measurements (Nicholls et al. 1996).

Other problems have continued through the Twentieth Century. Temperatures are usually warmer in cities than in the surrounding countryside, so care is needed to exclude stations from our analyses where urbanisation may have caused a local warming. As well, changes in observing practices, and even less-than-perfect observers, can lead to doubts about the ability to monitor climate change accurately. We have spent a lot of time developing high-quality historical temperature and rainfall data sets to avoid these problems, by restricting our analysis to the period with consistent exposures in Stevenson screens, and avoiding the use of stations likely to be affected by urbanisation, station shifts, or poor observational practices (Lavery et al. 1992, 1997; Torok & Nicholls 1996).

HOW HAS CLIMATE CHANGED AROUND AUSTRALIA?

These high-quality instrumental data have been used to examine Australian climate variations.

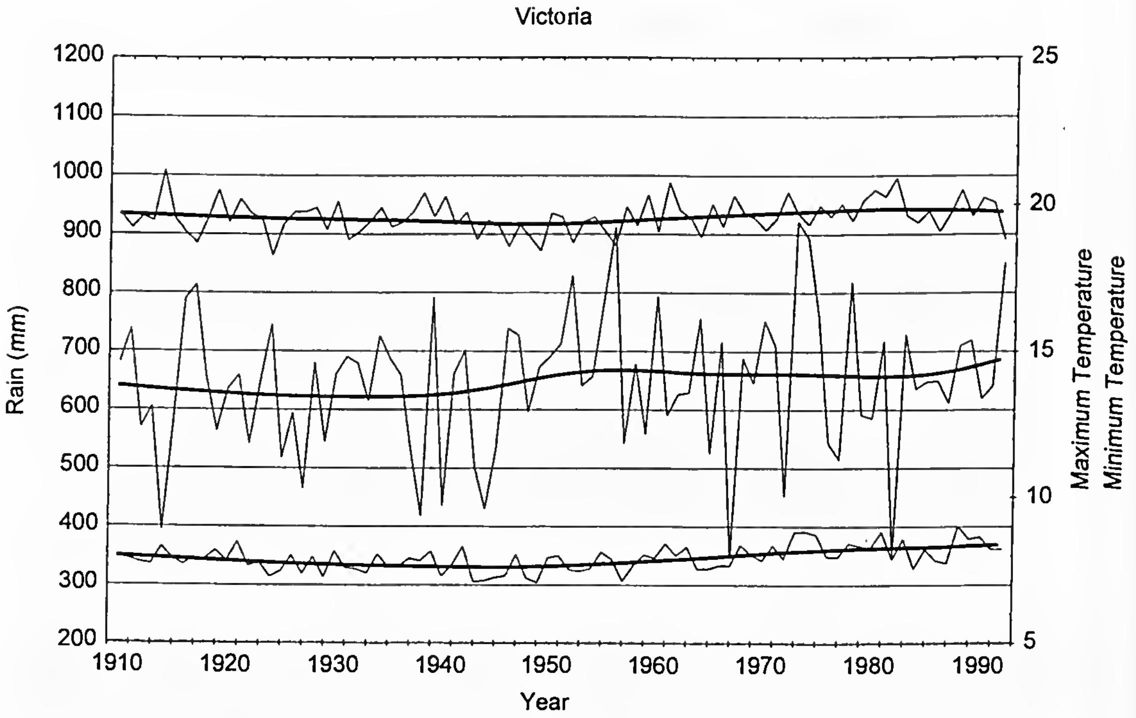

Fig. 1. Annual average maximum (top lines) and minimum (bottom lines) temperature and rainfall (middle lines), averaged across Victoria. Thin lines show annual averages; thick lines show results of smoothing the annual data.

Averaged across the country, daytime (maximum) temperatures have increased about 0.5°C since mid-century, while night-time (minimum) temperatures have increased about 1.0°C (Torok & Nicholls 1996). Average Australian rainfall has not exhibited any clear trend this century (Lavery et al. 1997). There are clear regional variations in these patterns. In New South Wales for instance, maximum temperatures have actually decreased through the century (Torok & Nicholls 1996) and rainfall increased abruptly around mid-century (Nicholls & Lavery 1992).

Fig. 1 shows maximum and minimum temperatures, and rainfall, averaged across Victoria. The rather abrupt increase in rainfall mid-century is evident, as is the smaller warming of daytime (maximum) temperatures since mid-century, relative to the night-time (minimum) temperatures. Similar graphs are available for all states and for the country as a whole.

But can we believe these changes, given the deficiencies of our observations noted earlier? There is considerable other evidence supporting the increased temperatures in the Australian region. Similar trends have been observed in New Zealand and the small islands of the southwest Pacific, as well as in sea surface temperature and night-time air temperatures measured from ships (Salinger et al. 1996).

Further evidence comes from proxy data. For instance:

the well-documented retreat of the New Zealand and New Guinea glaciers;
increased growth in Tasmanian Huon Pine (Cook et al. 1992);
retreat of Antarctic sea ice (de la Mare 1997); and
increased temperature inferred from isotope measurements in corals (Charles et al. 1997) and ice cores in the Andes (Thompson et al. 1995).

All the instrumental and proxy evidence of surface temperatures produce a similar message, that throughout the Indian and South Pacific Oceans and the countries surrounding them, temperatures have increased substantially through this century. The Tasmanian tree rings and the Andes ice cores suggest that temperatures in recent decades have been the highest for some hundreds of years.

HAS THE CLIMATE BECOME MORE EXTREME OR VARIABLE?

As was the case with the global situation surveyed by the IPCC, there have been some increases and some decreases in the frequency of extreme weather and climate events. The total number of tropical cyclones in the Australian region has decreased, although the number of intense cyclones (those with an 'eye') has decreased slightly (Nicholls et al. 1998). The decrease in the total number reflects the impact of the recent downward trend in the Southern Oscillation Index which, in turn, reflects the fact that the El Niño–Southern Oscillation has been behaving unusually in recent decades (Trenberth & Hoar 1996), with a greater than usual frequency of El Niño events. As well, the impact of the El Niño–Southern Oscillation on Australia has been unusual (Nicholls et al. 1997a, 1997b), with a tendency for El Niño events to be less dry across the country than was the case prior to about 1970.

On shorter time-scales there has been some evidence of decreased numbers of frosts and low temperatures, at least in inland eastern Australia (Stone et al. 1996). In eastern Australia, where the total rainfall increased through the century, this generally reflected an increase in the number of rainfall events, rather than an increase in the average intensity of events (Nicholls & Kariko 1993). There is, however, evidence that heavy rainfall events have become more frequent (Suppiah & Hennessy 1996).

CONCLUSIONS

The Australian region has warmed since the 1950s.

Warming has been larger at night than during the day.

Rainfall, averaged across Australia, has not changed substantially.

There are regional variations in all these trends.

Some trends have been seen in extreme weather events.

The El Niño–Southern Oscillation and its Australian impacts have been unusal since the mid-1970s.

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DETECTING A HUMAN INFLUENCE ON CLIMATE

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AN important conclusion from the recent scientific assessment of climate change by the Intergovernmental Panel on Climate Change (IPCC) (Houghton et al. 1996) was that 'the balance of evidence suggests a discernible human influence on climate'. This conclusion was not possible in earlier assessments and has attracted some controversy. Here, a brief review is presented of some of the evidence which led to this conclusion, based on the chapter 'Detection of Climate Change and Attribution of Causes' (Santer et al. 1996a) in this scientific assessment.

Identifying a human influence on climate has two parts; detecting significant changes in the global climate system and then attributing at least part of these changes to human influence. The detection problem involves separating any climate change signal (such as due to increasing greenhouse gases) from natural climate variability. A 'significant' climate change is one which is large relative to changes expected from natural variability. Next, the cause of this climate change must be established, which is the attribution problem. Attribution of a detected climate change to a particular causal mechanism has usually involved a series of climate model simulations with different forcing mechanisms and comparison with the observed climate change. Unique attribution of climate change to human activity requires the consideration and elimination of all other plausible non-anthropogenic mechanisms. This is feasible only in the sense of demonstrating that the observed change is consistent or inconsistent with the climate response to specified forcing mechanisms.

The most common type of climate change detection study has involved detection of significant warming trends in global mean near-surface temperatures and then comparison of these trends with climate model simulations. A number of studies have shown that the observed global warming over the last century is significant relative to estimates of century time-scale natural variability (Santer et al. 1996a). However, this result is dependent on the magnitude of the estimated natural variability, which is uncertain. Attribution of the observed warming requires comparison with model simulations. An example, in Fig. 1, shows the simulated global mean warming from 1860 to 1990 in a coupled ocean-atmosphere climate model with increasing greenhouse gases only and with increasing greenhouse gases and sulphate aerosols (Mitchell et al. 1995), compared with observed changes over the same period. The simulations with increasing greenhouse gases only show a warming trend which increases with time. The observed global mean temperatures show marked variability on interannual and interdecadal time-scales (due to internal climate processes), with an overall warming trend that is less than in the model simulations with greenhouse gases alone. Sulphate aerosol concentrations have been increasing over the industrial areas of Europe, North America and Asia, mainly due to emissions from power stations. The direct effect of these aerosols is to reflect some of the incident solar radiation back to space, reducing that received at the surface. Including the effects of increasing sulphate aerosols in the climate model simulations, together with increasing greenhouse gases, reduces the magnitude of the simulated warming and brings the simulated temperature changes close to those observed.

Despite the apparent similarity between the observed and modelled warming trends in the above example, it is difficult to eliminate the possibility of natural climate variability on century time-scales or other forcing processes leading to similar climate change, when a simple detection parameter, such as global mean near-surface temperature is used. More complex climate change detection studies have sought to compare the spatial patterns of observed temperature change with those simulated by models, since different forcing mechanisms are likely to lead to different patterns or 'fingerprints' of warming and cooling. Attribution of observed changes to a specific cause should be easier using this 'fingerprint' detection approach.

A number of pattern-based detection studies are described by Santer et al. (1996a). They have used the horizontal patterns of near-surface temperature change (eg. Hegerl et al. 1996; Santer et al. 1995) or the vertical patterns of zonal-mean temperature change in the troposphere and lower stratosphere (eg. Karoly et al. 1994). In general, they have shown significant similarity between the

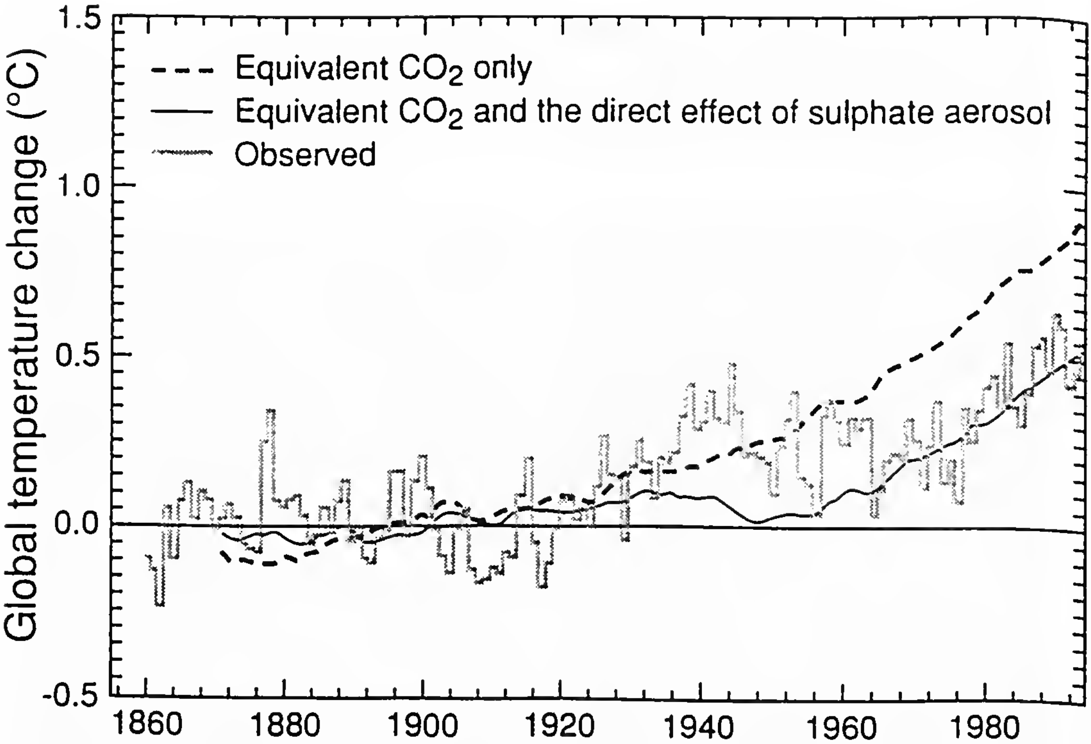

Fig. 1. Observed global-mean near-surface air temperatures over the period 1860–1990 together with climate model simulations for forcing by increasing greenhouse gases alone, and increasing greenhouse gases and sulphate aerosols. Reproduced from Houghton et al. (1996), from Mitchell et al. (1995).

observed changes over about the last 40 years and simulations forced by both increasing greenhouse gases and sulphate aerosols.

More recent studies by Santer et al. (1996b) and Tett et al. (1996), published after the IPCC scientific assessment, have provided the most convincing evidence yet of a human influence on climate. Both these studies used the vertical pattern of zonal-mean temperature change observed over the last 30 years and compared this with climate model simulations forced by increasing greenhouse gases and sulphate aerosols, together with decreasing stratospheric ozone concentrations. The novel aspect of these studies was including the effects of reductions in stratospheric ozone since about 1975 due to increasing concentrations of chlorine in the stratosphere, another human-induced change. Pattern comparisons revealed that the observations were in better agreement with the temperature-change patterns due to combined forcing in the models than for greenhouse gas forcing alone. Part of this improvement was due to the effect of sulphate aerosols leading to a smaller warming in the Northern Hemisphere than in the Southern Hemisphere, and to the role of ozone decreases leading to a stronger cooling in the lower stratosphere, as observed. Natural climate variations in very long simulations with unforced climate models were used to test the significance of the observed-model pattern similarity. They showed that this similarity was unlikely to have occurred due to natural variability, suggesting a human influence on climate.

In addition to the quantitative methods mentioned above for detecting and attributing climate change, there are a number of areas of qualitative agreement between model simulations of climate change and observations. Some of these include retreat of mountain glaciers, warming of near-surface ocean temperatures, reduction in the diurnal temperature range, and reduction of Northern Hemisphere snow cover in spring. These, together with the results from many other studies, led the IPCC to reach the conclusion that 'the balance of evidence suggests a human influence on climate'. Research is continuing around the world to quantify the extent of this human influence.

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IPCC AND THE SCIENCE POLICY INTERFACE

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Intergovernmental Panel on Climate Change (IPCC)

FEW, if any, other scientific issues have raised such complex and far-reaching policy implications for national governments and the entire global community as the prospect of long-term climate change from the build up of greenhouse gases in the atmosphere as a result of human activities.

Although relatively well understood in the meteorological community for more than a century, it was not until the 1950s that the greenhouse effect began to acquire a political dimension. And it was 1979 before the (First) World Climate Conference and the Eighth World Meteorological Congress set in place the World Climate Programme (Zillman 1980) and the international scientific and policy framework that was to lead to the so-called Villach Statement (Zillman 1986) and the Toronto Conference (Pearman et al. 1989) and the establishment of the Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Negotiating Committee (INC) for a Framework Convention on Climate Change (FCCC).

In view of the speed with which the FCCC was eventually concluded and the significance it has assumed in world affairs as nations proceed to negotiate a legally binding 'Kyoto Protocol' that can be expected to impact dramatically on the world order in the Twenty-first Century, it is important to understand the nature of the science-policy mechanisms which, within a decade, generated hitherto unprecedented political concern for global environmental issues and propelled the greenhouse effect on to the front pages of virtually every newspaper in the world. Fig. 1 provides a schematic overview of the international developments through the 1980s and early 1990s.

THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

In 1988, in response to the increasingly strident statements of concern from within the international climate science community through both governmental and nongovernmental fora (Fig. 1), the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) jointly established the Intergovernmental Panel on Climate Change (IPCC), to provide governments with a comprehensive, objective assessment of the scientific evidence for possible future climate change and an analysis of its potential impacts and possible response strategies. The IPCC's 1990 First Scientific Assessment (Houghton et al. 1990) reaffirmed the reality of the scientific basis for international concern and provided the scientific underpinning for the negotiation of the FCCC which was concluded in May 1992, opened for signature at the Rio Earth Summit in June 1992 (Zillman 1992) and came into force in March 1994.

The IPCC is both an intergovernmental and a scientific and technical assessment body. Throughout its existence, it has operated with three main Working Groups (Fig. 2), the first of which (Working Group I) has dealt with the science of climate change. The main work of this Group has been carried out by teams of 'lead authors' consisting of key members of the international climate research community who have agreed to coordinate the preparation of state-of-the-art reviews of the scientific literature in each of the specialised fields of climate science relevant to determination of future climate change. Their draft reports have been comprehensively peer-reviewed by the climate research community and by experts nominated by national governments. The Working Group has then met in formal intergovernmental session. Its most important task has been the presentation of the most policy-relevant aspects of the scientific findings in non-technical 'Summaries for Policymakers' which are aimed at providing essential understanding of the policy-relevant science to those involved in formulating response strategies at both the national and international levels.

The main outputs of IPCC Working Group I have been:

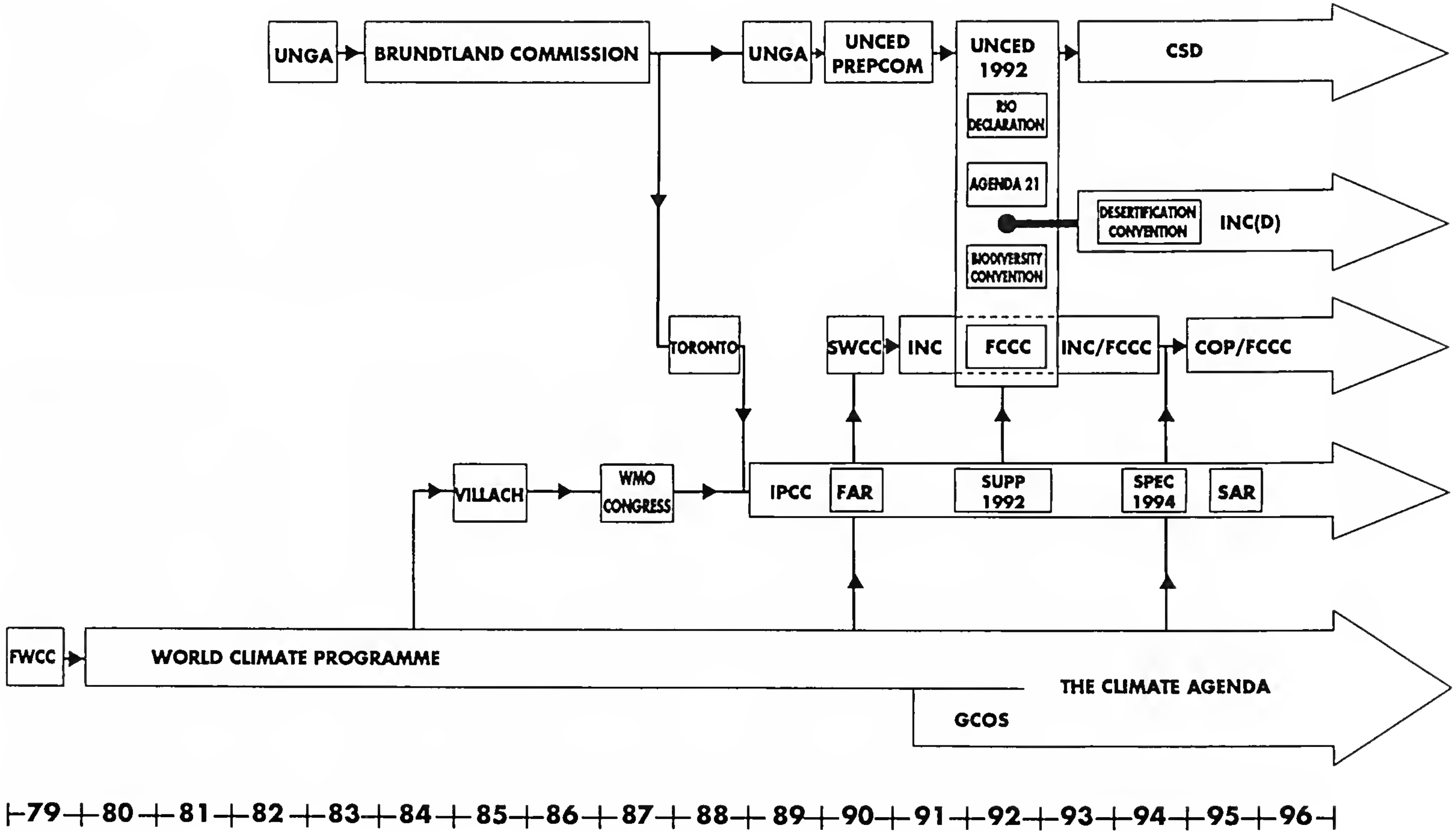
Climate Change: The IPCC Scientific Assessment (Houghton et al. 1990);

Climate Change: The 1992 IPCC Supplement (Intergovernmental Panel on Climate Change, 1992);

Climate Change 1994: Radiative Forcing of Climate Change (Houghton et al. 1995);

Climate Change 1995: The Science of Climate Change (Houghton et al. 1996);

INTERNATIONAL DEVELOPMENT OF THE CLIMATE ISSUE



An Introduction to Simple Climate Models Used in the IPCC Second Assessment Report (Houghton et al. 1997a);

Stabilisation of Atmospheric Greenhouse Gases: Physical, Biological and Socioeconomic Implications (Houghton et al. 1997b).

THE IPCC'S SECOND SCIENTIFIC ASSESSMENT

The 1995 Second Assessment Report on the science of climate change (Houghton et al. 1996) focused on six key conclusions set down in the Working Group I Summary for Policymakers (SPM):

Greenhouse gas concentrations have continued to increase.

Anthropogenic aerosols tend to produce negative radiative forcings.

Climate has changed over the past century.

The balance of evidence suggests a discernible human influence on global climate.

Climate is expected to continue to change in the future.

There are still many uncertainties.

The justification for, and interpretation of, several of the statements in the SPM and the formulation of the more extensive Technical Summary and the detailed 572-page underlying report have been the subject of some controversy within the scientific community (see eg. Tucker 1997), as well as in the media, but a recent meeting of some 300 of the world's leading climate scientists in Geneva (WMO–ICSU–IOC, 1997) agreed that the 1995 Second Assessment Report still provides the best available consensus view on the overall state of greenhouse science.

THE CURRENT STATE OF THE SCIENCE

It is clear from the full text of the Second Assessment Report that climate change science has developed rapidly over the past decade through both national and international research programmes such as the World Climate Research Programme (WCRP) and the International Geosphere–Biosphere Programme (IGBP) and especially through the development and application of global climate models to simulate the behaviour of the climate system under a range of scenarios of future greenhouse gas emissions. As the science has developed, some aspects have become more confidently understood and, in other areas, the uncertainties have increased. While the definitive position is that set down in the SPM, the essential message from the IPCC's Second Assessment of climate change science may be summarised as follows:

> The overwhelming majority of the world's mainstream climate scientists believe that increased concentrations of carbon dioxide and other greenhouse gases in the atmosphere should lead, other things being equal, to some global warming and probably to other changes in global and regional climate. Based, *inter alia*, on the observed 30% increase in the atmospheric concentration of carbon dioxide over the past century, the science-based climate models suggest that there should already have been a globally averaged warming of approximately 1°C over the period as a result of the enhanced greenhouse effect.
>
> Though not all of the actually observed historical data (including some satellite data) give a consistent picture, there is a high level of confidence that the global average surface temperature has risen by about 0.5°C over the past century. There is much less certainty

Fig. 1. The key influences and events in the international development of climate as a major issue of international public policy 1979–1996. Beginning with the (First) World Climate Conference (FWCC) in 1979 and the establishment of the World Climate Programme by the Eighth World Meteorological Congress, the international scientific effort led into the 1985 Villach Conference Statement on the role of carbon dioxide and other greenhouse gases in climate variations and associated impacts. The parallel activity of the Brundtland Commission established by the United Nations General Assembly (UNGA) and the 1988 Toronto Conference on the Changing Atmosphere lifted the profile of the global threat of human-induced climate change and reinforced the urgency of the work of the Intergovernmental Panel on Climate Change (IPCC). Its First Assessment Report (FAR) and the Ministerial Declaration of the Second World Climate Conference (SWCC) which it inspired led in to the work of the Intergovernmental Negotiating Committee (INC) on the development of the Framework Convention on Climate Change (FCCC) as a centrepiece of the 1992 United Nations Conference on Environment and Development (UNCED). Through its 1992 Supplementary Report (SUPP), its 1994 Special Report (SPEC) and its 1995 Second Assessment Report (SAR), the IPCC has continued to provide scientific input to the ongoing policy and political processes proceeding under the auspices of the Conference of the Parties (COP) to the FCCC.

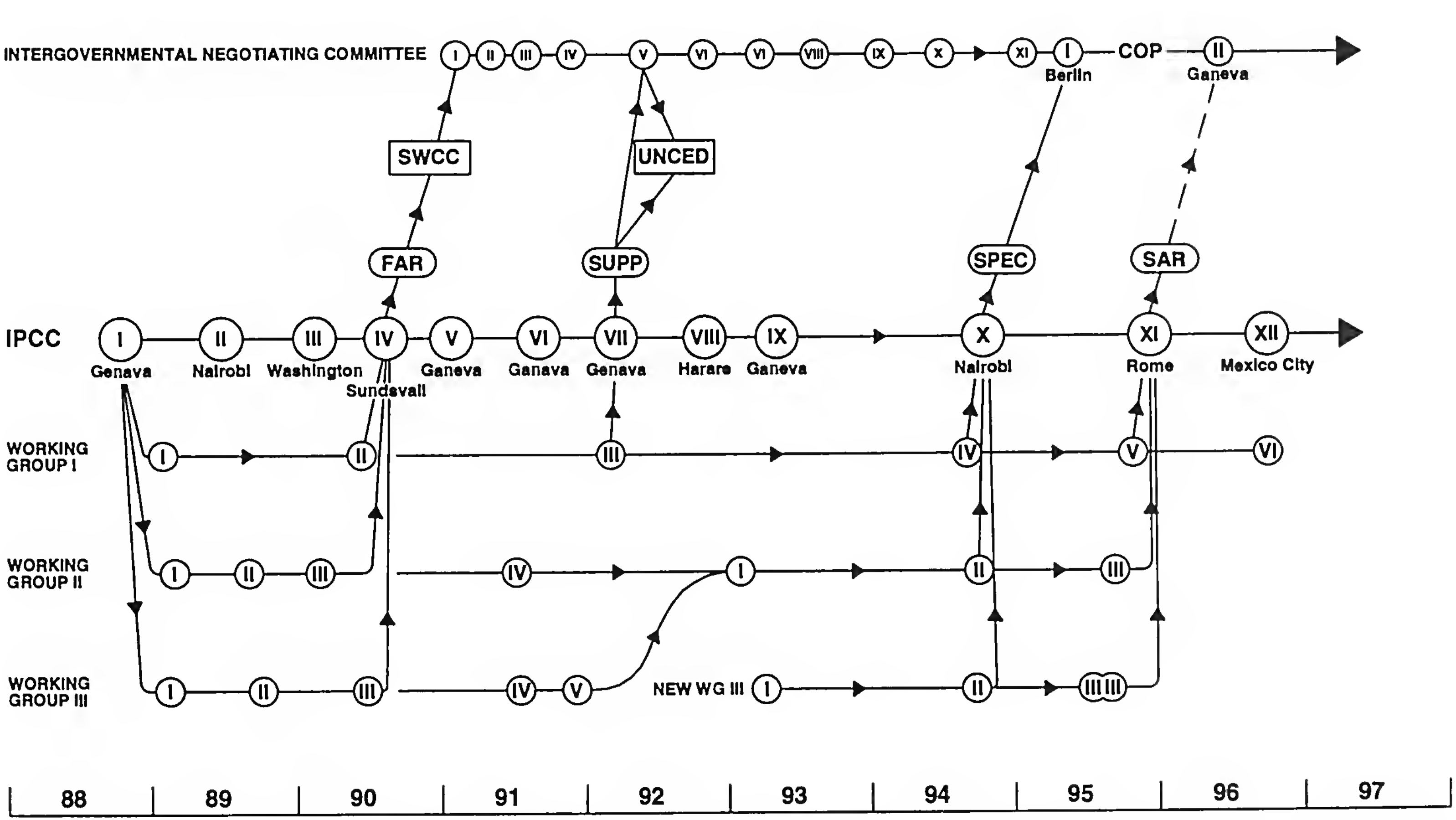


Fig. 2. A schematic representation of the IPCC (Intergovernmental Panel on Climate Change) process 1988–96. The sessions (numbered in Roman numerals) of the IPCC and its three Working Groups, initially on Science (Working Group I), Impacts (Working Group II) and Response Strategies (Working Group III), are shown in the bottom half of the diagram with its major outputs [1990 First Assessment Report (FAR), 1992 Supplementary Report (SUPP), 1994 Special Report (SPEC) and the 1995 Second Assessment Report (SAR)] feeding into the negotiating sessions of the Intergovernmental Negotiating Committee and the Conference of the Parties (COP). The sessions of the Bureaux of the IPCC and its Working Groups and the numerous IPCC scientific workshops and lead author drafting sessions are not shown.

in the climate science community, however, that the observed warming (and the various other less-confidently-detected long-term trends in climate patterns) can be unambiguously attributed to the enhanced greenhouse effect. Some scientists argue that the observed warming trend can be explained as a result of changes in the incoming radiation from the sun or alternatively as part of the natural long-term variability of the global climate system. Others argue that the observed warming is almost certainly due to greenhouse but is less than the expected 1°C because of offsetting cooling resulting, *inter alia*, from sulphate haze (from coal burning, etc.) reflecting some of the sun's energy back to space. After weighing all the evidence, the IPCC Working Group I reached a consensus in November 1995 on the cautious statement (above) that 'The balance of evidence suggests a discernible human influence on global climate'.

Given that the climate models are soundly based and that they appear to have been able to reasonably satisfactorily explain the observed warming trend of the past century, they may legitimately be used to estimate how the global climate might evolve over the next century for a range of possible future rates of emission of carbon dioxide and other greenhouse gases. Allowing for the various uncertainties in both the carbon cycle and the climate models and *for a plausible range of greenhouse gas emission scenarios for the next century*, the models suggest a global mean temperature rise by 2100 of between about 0.8°C and 4.5°C with corresponding rises in sea level of between 15 and 95 cm.

New scientific research results (both new analysis of historical data and improved model projections) are being published all the time, some of which add weight to the IPCC's 1995 conclusions and some of which raise new questions and new uncertainties. However, while there is a fairly high level of confidence and unanimity in the scientific community on the expectation of a continued global warming trend due to greenhouse influences, the models are not yet good enough to indicate with any certainty how climate (temperature, rainfall, frequency of severe events, etc.) might change at the regional or local level. Although CSIRO has issued, and regularly updates, climate change 'scenarios' for Australia, it must be understood that these are *not predictions*—merely internally consistent projections based on the current state of the art in climate modelling and plausible global emission scenarios. They are a legitimate tool for sensitivity analysis but not for confident planning.

On the local scene, the basic conclusions of a joint Academies assessment of climate change science completed in February 1995 by a team of Australia's leading climate scientists under a broadly-based steering committee (Steering Committee of the Climate Change Study, 1995) also remain valid. While many uncertainties remain, the balance of evidence still suggests that the impacts of past increases in greenhouse gas concentrations are beginning to become discernible in the behaviour of climate; and that, even with substantial reductions in global emissions, significant changes in climate are inevitable over the next century (Zillman 1995).

It is important to make clear, in summarising the current state of greenhouse science, that media and other suggestions that the IPCC has progressively decreased its estimates of future greenhouse warming are not correct. The IPCC has not, at any stage over the past nine years, attempted to make a *forecast/prediction* of how much greenhouse warming will actually occur by any particular future date. Rather, it has used climate system models to project what warming might be expected to occur *for each of a number of emission scenarios* given also a range of estimates of the sensitivity of the climate system to increases in greenhouse gas concentrations. The emission scenarios, however, depend entirely on basic assumptions on future global population increase and the like and the IPCC has not attempted to assign any particular probability of occurrence to the emission scenarios. The IPCC has, however, offered, as a 'best estimate' of the *sensitivity* of the climate system, an equilibrium warming of 2.5°C for an effective doubling of the concentration of carbon dioxide concentration. This 'best estimate' put forward in the First Assessment Report (Houghton et al. 1990) remains as the IPCC's currently valid best estimate.

The IPCC has, however, in its more recent reports, attempted to quantify the offsetting cooling effects of sulphate aerosol which were treated qualitatively in its early reports.

THE SCIENCE-POLICY INTERFACE

By far the most complex and difficult aspects of the international handling of the greenhouse issue over the past decade have been those associated with the maintenance of effective dialogue across the science-policy interface in attempting to

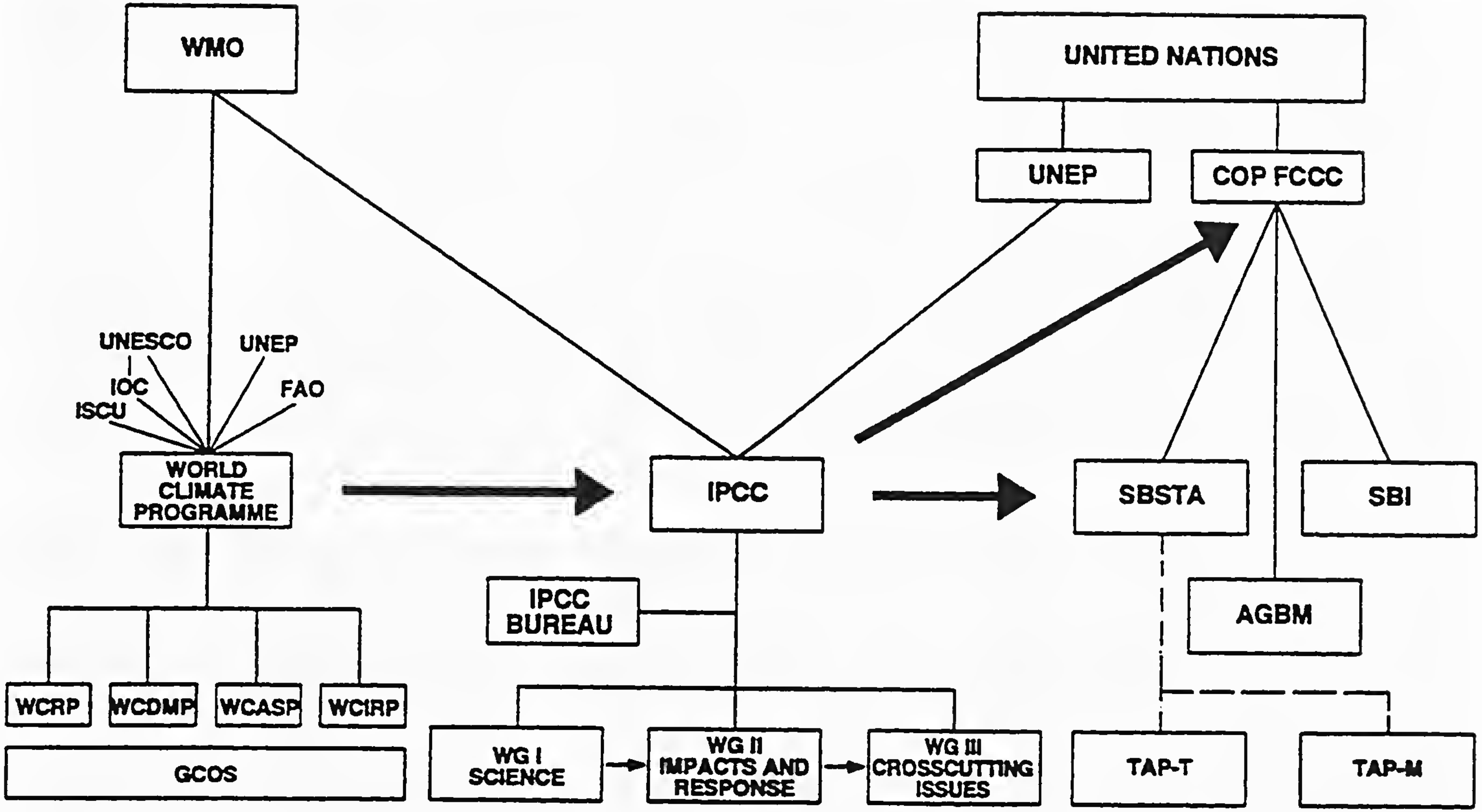


Fig. 3. The role of the World Climate Programme and its components [WCRP (World Climate Research Programme), WCDMP (World Climate Data and Monitoring Programme), WCASP (World Climate Applications and Services Programme), WCIRP (World Climate Impacts and Response Strategies Programme)] and the associated Global Climate Observing System (GCOS) in providing the scientific basis for the assessment work of the Intergovernmental Panel on Climate Change (IPCC) and its three Working Groups (WG) as input to the political negotiation processes under the Conference of the Parties to the Framework Convention on Climate Change (COP FCCC). The COP Subsidiary Body for Scientific and Technological Advice (SBSTA) and the Subsidiary Body for Implementation (SBI) have already been established along with an Ad Hoc Group on the Berlin Mandate (AGBM) but the SBSTA's technical advisory panels on technologies (TAP-T) and methodology (TAP-M), though formally authorised, have not yet been established.

identify what is warranted, and what is possible, by way of national and international political response to the advice emanating from the expert climate science community. Attitudes range from advocacy for acceptance of the science as a 'given' requiring no further attention so that the world can now focus on aggressive strategies for greenhouse gas emission reductions on the one hand, to that of arguing that, with so much doubt and uncertainty still surrounding the science, any action beyond 'no regrets' measures (ATSE, 1995) would be irresponsible at this stage on the other. The scientific community themselves have been divided as to how best to contribute to the policy process—with some going far beyond where their personal scientific credentials suggest they should in arguing the case for political action; and others highly reluctant to provide advice beyond their own restricted areas of specialisation within climate science.

In purely structural terms, the IPCC operates as a bridging mechanism between the research carried out under the auspices of the World Climate Programme and a range of other associated international monitoring and research programmes on the one hand and the political processes and subsidiary bodies of the Convention on the other (Fig. 3). The major dilemma within the IPCC has been in finding the right balance between its 'intergovernmental' and its 'expert scientific and technical assessment' dimensions. Notwithstanding a firm IPCC position that its role is to produce policy-relevant rather than policy-prescriptive advice, this balancing act has generated considerable tension (Zillman 1996). Probably the most successful feature of the international climate change machinery has been the arrangement under which significant numbers of experts within national delegations have tended to operate horizontally across the mechanisms shown schematically in Fig. 3. The fact that the key players in the climate research community have been willing to participate in the IPCC assessment process as lead authors; and the inclusion of IPCC experts in national delegations to sessions of the subsidiary bodies of the Conference of the Parties and of the Conference of the Parties itself, has ensured that the political process has not become completely decoupled from the science as has, at times, appeared a real danger. In many respects, however, the difficult part is only just beginning as nations contemplate actions that go beyond 'no regrets' and those who would be impacted adversely by such actions properly demand evidence of higher levels of certainty than the science can deliver.

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All manuscripts should be written in clear and concise English. Use double spacing throughout; leave 30 mm margins around the text; number all pages. Underline only those words to be italicised in running text. All measurements are to be expressed in SI units (e.g. μm, mm, m, km, but not cm) and standard symbols used. Authors should follow the layout of headings, tables and illustrations as presented in a recent issue of the *Proceedings*. Papers should be organised as follows:

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Refer to illustrations of the paper in the text as 'Fig. 1A, B', 'Figs 1, 2' or 'Figs 1–4', and indicate in the margins where the illustrations should be placed. Refer to references in the text as Birch (1985), (Birch 1985) or (Birch 1985: 2, fig. 1); multiple citations of references should be arranged chronologically. All references cited in the text must be listed at the end of the paper. Footnotes in the main text are not allowed.

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non *Eudendrium generale*.—Watson 1982: 89, pl. 10, fig. 3.
Eudendrium lendenfeldi Briggs 1922: 150.—Rosler 1978: 104, 120, pl. 20, figs 1–3.

Note that plate and figure numbers, etc. originally given in Roman numerals should be transliterated into Arabic figures; this is also the case in the main text and in the references.

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MacPherson, J. H. & Gabriel, C. J., 1962. *Marine Molluscs of Victoria*. Melbourne University Press, Melbourne, xv+475 pp.

Parsons, W. T., 1982. Weeds. In *Atlas of Victoria*, J. S. Duncan, ed., Victorian Government Printing Office, Melbourne, 122–125.

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