PROCEEDINGS

OF THE

ROYAL SOCIETY OF VICTORIA

ESTABLISHMENT OF THE ROYAL SOCIETY OF VICTORIA

The Publications of the Royal Society of Victoria and of the Societies amalgamated with it

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VICTORIAN INSTITUTE FOR THE ADVANCEMENT OF SCIENCE
Transactions and Proceedings, Vol. 1, 1854/55.

PHILOSOPHICAL SOCIETY OF VICTORIA
Transactions, Vol. 1, 1854/55.

These two Societies then amalgamated and became—

PHILOSOPHICAL INSTITUTE OF VICTORIA
Transactions, Vol. 1–4, 1854/56–1859.

The Society then became—

ROYAL SOCIETY OF VICTORIA
Transactions and Proceedings (Vol. 5, *entitled* Transactions), Vol. 5–24, 1860–1887.
Transactions, Vol. 1, 2, 3 (Pt 1 only was published), 4, 5 (Pt 1 only), 6, 1888–1914.
Proceedings (New Series), Vol. 1–82, 1888–1969.
Proceedings, Vol. 83, ... 1969 ...
('New Series' deleted from Title Page)

MICROSCOPICAL SOCIETY OF VICTORIA
Journal (Vol. 1, Pt 1, *entitled* Quarterly Journal), Vol. 1 (Pt 1 to 4), 2 (Pt 1), title page and index [all published], 1879–82.
[The Society then combined with the ROYAL SOCIETY OF VICTORIA]
Note—*Most of the volumes published before 1890 are out of print.*

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Vol. 46, Part 2, contains an author index of the Royal Society of Victoria and of the Societies amalgamated with it from 1855–1934.
Vol. 73 contains an author index of the Proceedings of the Royal Society of Victoria, Vol. 47 (1934/5)–70 (1958).
Vol. 84, Part 2, contains an author index of the Proceedings of the Royal Society of Victoria, Vol. 71 (1959)–84 (1971).
Vol. 99, Part 4, contains an author index of the Proceedings of the Royal Society of Victoria, Vol. 85 (1972)–98 (1986).

PROCEEDINGS

OF THE

ROYAL SOCIETY OF VICTORIA

INCLUDING

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Volume 112

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CONTENTS OF VOLUME 112, NUMBER 1

EDITORIAL POLICY

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PROCEEDINGS

ROYAL SOCIETY OF VICTORIA

PEER REVIEWED PAPERS

TETHYOCHONETES GEN. NOV. (CHONETIDA, BRACHIOPODA)
FROM THE LOPINGIAN (LATE PERMIAN) OF CHINA

Z. Q. Chen, G. R. Shi, Shuzhong Shen & N. W. Archbold

School of Ecology & Environment, Deakin University, Rusden Campus, 662 Blackburn Road,
Clayton, Victoria 3168, Australia

Chen, Z. Q., Shi, G. R., Shen Shuzhong & Archbold, N. W., 2000:06:30. *Tethyochonetes* gen. nov. (Chonetida, Brachiopoda) from the Lopingian (Late Permian) of China. *Proceedings of the Royal Society of Victoria* 112(1): 1–15. ISSN 0035-9211.

A new rugosochonetid genus, *Tethyochonetes* gen. nov., is proposed for several species from the Lopingian (Late Permian) of China previously assigned to *Waagenites* Paeckelmann, 1930. Five species of *Tethyochonetes* are described, including two new species, *Tethyochonetes? liaoi* sp. nov. and *Tethyochonetes chaoi* sp. nov., and three revised species, *Tethyochonetes quadrata* (Zhan), *Tethyochonetes longtanensis* (Liao) and *Tethyochonetes wongiania* (Chao).

WAAGENITES Paeckelmann, 1930, with *Chonetes grandicosta* Waagen (1884) as the type species, was proposed without a description of dorsal internal features. *Waagenites* has subsequently been widely applied to numerous species showing a variety of morphological features (Muir-Wood 1962, 1965; Waterhouse & Piyasin 1970; Grant 1976). The generic name has been widely applied to many chonctid specimens from the Late Permian (Wuchiapingian and Changhsingian) of China. Some authors have noted distinct differences between these species and the type species (Waterhouse & Piyasin 1970; Grant 1976; Liao 1979: 200, 1987: 99; Zhan 1979: 71; Xu 1987: 119–220; Zeng et al. 1995: 48–49). In this study, we re-examine several of these Chinese species and compare them with published information of *Waagenites grandicosta* (Waagen) and *Waagenites* species from western Yunnan. We note distinct differences between the Late Permian Chinese species and *Waagenites grandicosta* and its allied species, and therefore propose *Tethyochonetes* gen. nov. for the Late Permian Chinese species.

All described material is deposited in the following institutions: the Nanjing Institute of Geology and Paleontology, Chinese Academy of Sciences, China (NIGP); and Museum Victoria, Melbourne, Australia (NMV).

STRATIGRAPHY OF THE NEW MATERIAL

The described specimens were collected from four sections within Late Permian sequences of China (Fig. 1). The sequence across the Permian–Triassic boundary in the Selong section (Section A,

Fig. 1) of Nyalam County, southern Tibet, has been subdivided into five informal lithological units, namely (in ascending order) the Coral Bed, the Caliche Bed, the '*Waagenites*' Bed, the *Otoceras* Bed and the *Ophiceras* Bed (Jin et al. 1996). Of these, the Coral and Caliche Beds (beds 1–2 in Section A, Fig. 1, respectively) have been lithologically assigned to the Selong Formation, while the '*Waagenites*', *Otoceras* and *Ophiceras* Beds (beds 3–5 in Section A, Fig. 1, respectively) have been referred to the Kangshare Formation (Jin et al. 1996). One specimen described herein was collected from the '*Waagenites*' Bed. The conodont *Clarkina orchardi* Zone of latest Changhsingian age has been recorded from the same bed (Wang et al. 1989; Jin et al. 1996; Mei 1997). In this section the Permian–Triassic boundary is defined by the first occurrence of the conodont *Hindeodus parvus* at the base of the *Otoceras* Bed (Jin et al. 1996). '*Waagenites*' from the '*Waagenites*' Bed is distinct from the type species of *Waagenites*, and is referred to herein as *Tethyochonetes liaoi* sp. nov. Accordingly, the '*Waagenites*' Bed could now be renamed the *Tethyochonetes* Bed.

One specimen of *Tethyochonetes wongiania* (Chao) was collected from the Lungtan Formation in the Baizuyuan section of Nantong County of Chongqing City, southwest China (Section B, Fig. 1). The Lungtan Formation in this area is of Wuchiapingian age (Sheng & Jin 1994).

The Meishan section of the Changxing area, Zhejiang Province, eastern China, (Section C, Fig. 1), a prime candidate of the Global Stratotype Section and Point of the Permian–Triassic Boundary (Yin et al. 1996), has yielded several *Tethyochonetes* specimens from Bed 26 (the Black Clay Bed) of latest Changhsingian age.
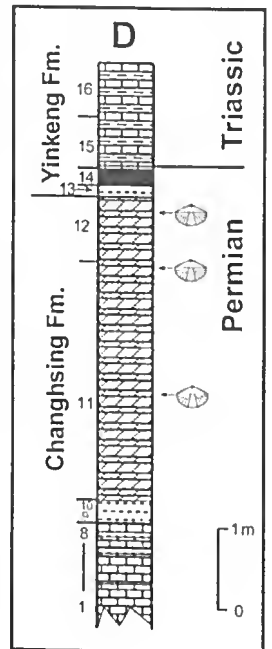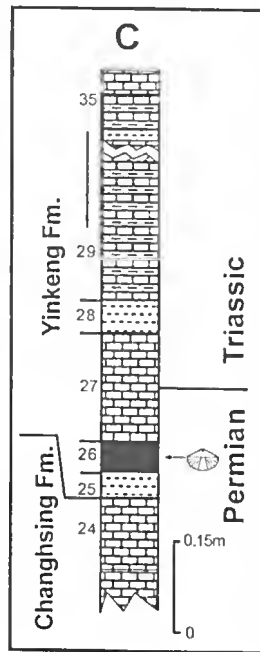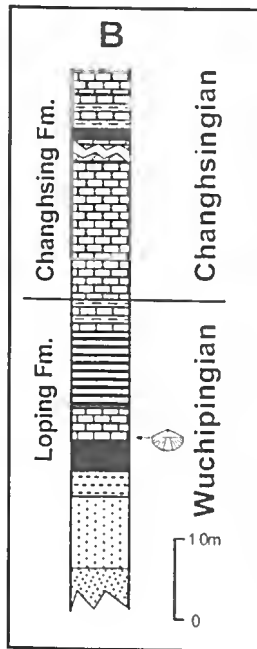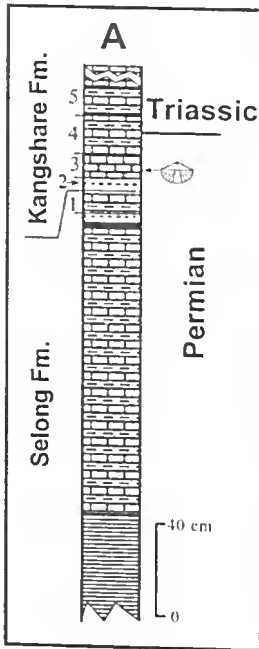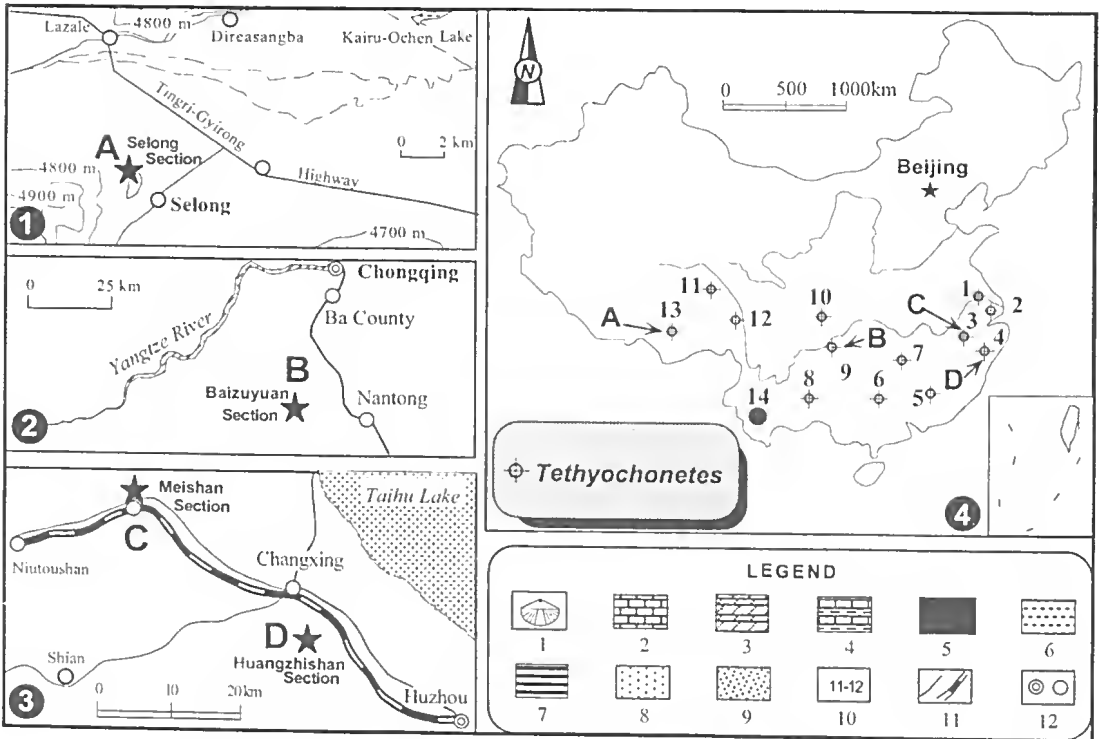
The remaining material of *Tethyochonetes* described in this paper was obtained from Beds 11 and 12 of the Huangzhishan section (Section D, Fig. 1) of Huzhou City, Zhejiang Province, eastern China. Bed 12 is of earliest Triassic age because of the appearance of the associated bivalve species: *Pteria ussurica variabilis* Chen & Lan, *Towapteria scythica* (Writh) and *Eumorphotis* sp. The underlying Bed 11 is characterised by abundant brachiopods including *Neochonetes convexa* Liao, *Spinomarginifera kueichowensis* Huang, *Spinomarginifera alpha* Huang, *Haydenella chianensis* (Huang), *Crurithyris flabelliformis* Liao and *Araxathyris araxensis* Grunt, all common elements of the Changhsingian in South China (Liao 1979). The late Changhsingian conodont species *Clarkina changxingensis* Wang & Wang is also present in the underlying limestone beds (Zhang 1995), therefore constraining the age of Bed 11 to be most likely latest Changhsingian.

In addition, several specimens of true *Waagenites* from the Middle Permian of the Xiaoxinzai section (Locality 14, Fig. 1) in the Gengma area, western Yunnan are also figured herein for comparison with the new genus.

STRATIGRAPHIC AND GEOGRAPHIC DISTRIBUTION OF *TETHYOCHONETES* GEN. NOV.

Nine species of *Tethyochonetes* have been reported from different areas of China (Table 1). In addition, *Tethyochonetes soochowensis* (Chao) has been reported from the Changhsingian Yenduyet Formation of the Son La area of northwest Vietnam (Shi & Shen 1998). Species of *Tethyochonetes* range from Wuchiapingian to latest Changhsingian age and are palaeogeographically confined to the Cathaysian and Himalayan Provinces as defined by Shen et al. (1999).

SYSTEMATIC PALAEONTOLOGY

The supra-orderinal classification follows Williams et al. (1996). The classification of the Rugosochonetidae is after Archbold (1982). All morphological terms are in current use, as in Williams & Brunton (1997).

Phylum BRACHIOPODA Dumeril, 1806

Subphylum RHYNCHONELLIFORMEA Williams, Carlson, Brunton, Holmer & Popov, 1996

Class STROPHOMENATA Williams, Carlson, Brunton, Holmer & Popov, 1996

Order PRODUCTIDA Waagen, 1883

Suborder CHONETIDINA Muir-Wood, 1955

Superfamily CHONETOIDEA Bronn, 1862

Family RUGOSOCHONETIDAE Muir-Wood, 1962

Subfamily RUGOSOCHONETINAE Muir-Wood, 1962

Fig. 1. Fossil localities and geographic distribution of *Tethyochonetes* gen. nov. in China. ❶ Selong section, Nyalam County, southern Tibet. ❷ Baizhuyuan section, Nantong County, Chongqing City, southwest China. ❸ Meishan section, Changxing County, and Huangzhishan section, Huzhou City, Zhejiang Province, eastern China. ❹ Distribution of *Tethyochonetes* gen. nov. in China. 1. Longtan section, Nanjing City, Jiangsu Province, eastern China. 2. Miaojiao section, Suzhou City, Jiangsu Province, eastern China. 3. Meishan section, Changxing County, and Huangzhishan section, Huzhou City, Zhejiang Province, eastern China. 4. Huangzhishan section, Huzhou City, Zhejiang Province, eastern China. 5. Fushi section, Yongding County, Fujian Province, southeastern China. 6. Shuizutang section, Lianxian County, northern Guangdong Province, South China. 7. Loping coal mine section, Loping City, Jiangxi Province, South China. 8. Jiazhishan section, Anshuan City, Guizhou Province, southwestern China. 9. Huayinshan section, Huayin City, Sichuan Province, southwestern China. 10. Shangsi section, Guangyuan City, Sichuan Province, southwestern China. 11. Yikebiqueisi and Delingha sections, Tianjun County, Qinghai Province, China. 12. Yinba section, Changdu City, eastern Tibet. 13. Selong section, Nyalam County, southern Tibet. 14. Locality of *Waagenites*: the Xiaoxinzai section, Gengma County, western Yunnan, China. Legend: 1, fossil horizon; 2, limestone; 3, argillaceous limestone; 4, marl; 5, black shale; 6, clay bed; 7, sandy mudstone; 8, siltstone; 9, sandstone; 10, bed number; 11, highway and railway; 12, city and county. Stratigraphic columns A–D provide details of lithological successions across several Permian–Triassic boundary sections in China. A. The Selong section (Fig. 1.1). Bed 1: the Coral Bed; Bed 2: the Caliche Bed; Bed 3: *Tethyochonetes* Bed (='*Waagenites*' Bed of Jin et al. 1996); Bed 4: *Otoceras* bed; Bed 5: *Ophiceras* Bed. B. The Baizhuyuan section (Fig. 1.2). C. The Meishan section (Fig. 1.3). D. The Huangzhishan section (Fig. 1.3). (Legends see above, the left numbers of Sections A, C and D represent beds.)

Species	Author	Formation and age	Locality see Fig. 1	Revision
Chonetes barusiensis (Davidson)	Hayaskaya 1922; Wang et al. 1964	? Late Permian	Loc. 8	*Tethyochonetes chaoi* gen. et sp. nov.
C. cf. *barusiensis* (Davidson)	Chao 1928	*Lytouia* bed, Late Permian	Loc. 7	*T. chaoi* gen. et sp. nov.
Waagenites barusiensis (Davidson)	Jin & Liao 1974; Feng & Jiang 1978	Lungtan Fm., Wuchiapingian	Loc. 10	*T. chaoi* gen. et sp. nov.
	Zhang & Jin 1976	Selong Group, Late Permian	Loc. 13	*T. chaoi* gen. et sp. nov.
	Yang et al. 1977	Shuizutang Fm., Changhsingian	Loc. 6	*T. chaoi* gen. et sp. nov.
W. barusiensis (Davidson)	Xu 1987	Changhsing Fm., Changhsingian	Loc. 9	*T. chaoi* gen. et sp. nov.
	Zhan 1989	Talung Fm., Changhsingian	Loc. 8	*T. chaoi* gen. et sp. nov.
Tethyochonetes chaoi sp. nov.	This paper	Changhsing Fm., Changhsingian	Loc. 3, 4	*T. chaoi* gen. et sp. nov.
Waagenites barusiensis (Davidson)	Liao 1979, 1980a,b	Changhsing Fm., Changhsingian	Loc. 8	*Tethyochonetes liaoi* gen. et sp. nov.
	Zhao et al. 1981; Liao 1984	Talung and Yinkeng Fms.. Changhsingian	Loc. 1, 3, 5	*T. liaoi* gen. et sp. nov.
	Zhan 1979.	Shuizutang Fm., Changhsingian	Loc. 6	*T. liaoi* gen. et sp. nov.
	Wang et al. 1982	Talung and Yinkeng Fms	Loc. 2, 3	*T. liaoi* gen. et sp. nov.
	Wang et al. 1989	Kanshare Fm. Changhsingian	Loc. 13	*T. liaoi* gen. et sp. nov.
Tethyochonetes liao sp. nov.	This paper	Changhsing and Kangshare Fms.. Changhsingian	Loc. 3, 13	*T. liaoi* gen. et sp. nov.
Chonetes soochowensis Chao	Chao 1928	? Late Permian	Loc. 2	*Tethyochonetes soochowensis* (Chao)
	Huang 1932	? Late Permian	Loc. 8	*T. soochowensis* (Chao)
Waagenites soochowensis (Chao)	Yang et al. 1977; Zhan 1979	Shuizutang Fm., Changhsingian	Loc. 6	*T. soochowensis* (Chao)
	Liao 1979, 1980a. b; Feng & Jiang 1978	Changhsing Fm., Changhsingian	Loc. 13	*T. soochowensis* (Chao)
	Zhao et al. 1981; Liao 1984	Talung and Yinkeng Fms.. Changhsingian	Loc. 3, 5	*T. soochowensis* (Chao)
	Wang et al. 1982	Changhsing Fm.. Changhsingian	Loc. 3	*T. soochowensis* (Chao)
	Xu 1987	Changhsing Fm.. Changhsingian	Loc. 9	*T. soochowensis* (Chao)
	Zhan 1989	Changhsing Fm.. Changhsingian	Loc. 10	*T. soochowensis* (Chao)
	Zeng et al. 1995	Luntan Fm.. Wuchiapingian	Loc. 10	*T. soochowensis* (Chao)
Chonetes wongiania Chao	Chao 1928	? Late Permian	Loc. 1	*Tethyochonetes wongiania* (Chao)
	Wang et al. 1964	? Late Permian	Loc. 8	*T. wongiania* (Chao)
Waagenites wongiania (Chao)	Yang et al. 1977; Zhan 1979	Shuizutang Fm., Changhsingian	Loc. 6	*T. wongiania* (Chao)
	Liao 1980a, b; Feng & Jiang 1978	Changhsing Fm., Changhsingian	Loc. 8	*T. wongiania* (Chao)
	Wang et al. 1982	Lungtan Fm., Wuchiapingian	Loc. 1	*T. wongiania* (Chao)
	Xu 1987	Changhsing Fm., Changhsingian	Loc. 9	*T. wongiania* (Chao)
	Zhan 1989	Changhsing Fm., Changhsingian	Loc. 10	*T. wongiania* (Chao)
	Zeng et al. 1995	Luntan Fm., Wuchiapingian	Loc. 10	*T. wongiania* (Chao)
Tethyochonetes wongiania (Chao)	This paper	Lungtan Fms.. Wuchiapingian	Loc. 9	*T. wongiania* (Chao)
W. soochowensis quadruta Zhan	Zhan 1979	Shuizutang Fm., Changhsingian	Loc. 6	*Tethyochonetes quadrata* (Zhan)
Tethyochonetes quadrata (Zhan)	This paper	Changhsing Fm., Changhsingian	Loc. 4	*T. quadrata* (Zhan)
Waagenites pigmaea Liao	Liao 1979, 1980a, b	Changhsing Fm., Changhsingian	Loc. 8	*Tethyochonetes pigmaea* (Liao)
	Zhao et al. 1981; Liao 1987	Talung and Yinkeng Fms.. Changhsingian	Loc. 1, 2, 3, 5	*T. pigmaea* (Liao)
	Wang et al. 1982	Changhsing Fm., Changhsingian	Loc. 3	*T. pigmaea* (Liao)
Waagenites guizhouensis Liao	Liao 1980a	Changhsing Fm., Changhsingian	Loc. 8	*Tethyochonetes guizhouensis* (Liao)
Waagenites longianensis Liao	Liao 1984	Talung Fm., Changhsingian	Loc. 1	*Tethyochonetes longtanensis* (Liao)
Tethyochonetes longtanensis (Liao)	This paper	Changhsing Fm., Changhsingian	Loc. 4	*T. longtanensis* (Liao)
Waagenites convexa Fan	Yang et al. 1962	? Late Permian	Loc. 11	*Tethyochonetes convexa* (Fan)
	Jin & Sun 1981; Jin 1985	Yinba & Toba Fms.. Late Permian	Loc. 12	*T. convexa* (Fan)

Table 1. Geographic and stratigraphic distributions of species of *Tethyochonetes* gen. nov.

Discussion. Archbold (1982) formally grouped the rugosochonetid genera into six subfamilies. Of these, the Rugosochonetinae was restricted to include only the externally capillated to costated genera. In addition to external ornament, the subfamily can also be distinguished from other rugosochonetids in embracing a feebly to strongly developed ventral median sulcus, usually low-angle hinge spines, and well-developed brachial ridges in the dorsal valve.

Genus **Tethyochonetes** gen. nov.

Etymology. Latin. *Tethy-* Tethys, referring to the Sister and Consort of Oceanus (the god of the ocean in Greek mythology) (the first English publication, Suess 1893: 183). The genus is limited to the Lopingian of the Tethyan region of the Palaeoequatorial Realm.

Type species. Waagenites soochowensis quadrata Zhan 1979.

Diagnosis. Small and transversely rectangular Rugosochonetidae, profile strongly concavo-convex; cardinal extremities varying from acute to slightly semi-elliptical; ears smooth, broad, flattened or slightly swollen. Ventral sulcus varying from deep, broad and distinct to shallow, narrow and indistinct; sulcal bounding flanks distinct to depressed. Dorsal fold slightly raised to flattened. External ornament with robust and rounded costae, sometimes bifurcating. Ventral median septum thin and high, extending anteriorly for half valve length. Cardinal process rounded and blunt, bilobed internally, trilobed externally; dorsal median septum stout, raised at its middle to anterior part, originating anterior to alveolus, continuing forward for half valve length; lateral septa stout, short and distinct; brachial scars strongly swollen and semi-circular in shape.

Other included species. As shown on Table 1.

Discussion of specific variation. Of nine species currently assigned to *Tethyochonetes* gen. nov., the older species such as *T. wongiana* (Chao), flourishing at the Wuchiapingian, usually embrace larger size and extremely coarse costae (see below). In comparison, the younger species often are much smaller and have finer ribs. In particular, two younger species, *T.? liaoi* sp. nov. and *T. longtanensis* (Liao), both from the latest Changhsingian, are significantly smaller, usually less 10 mm in width, and possess finer ribs than others (see below). However, all of them embrace

highly convex ventral valve, and more importantly, share the same internal characteristics. Accordingly, they are tentatively referred to the new genus.

Comparison. Species of *Waagenites* Paeckelmann, 1930 invariably possess subquadrate and strongly concavo-convex shells, with large inflated ears and coarse costae (Figs 2A–C, 3Q, T). As discussed by Fang (1983) and Archbold (1988), the ventral interior is characterised by strong teeth, a short but distinctive median septum and a median ridge. The median ridge commences at the anterior of the median septum and is high anteriorly because of the presence of taleolae (Figs 2D, 3F–G). The cardinal process is trilobate externally with a deep alveolus; the myophore faces ventrally through the open delthyrium (Fig. 3J–K, R–S). A thin, high median septum arises anterior to the alveolus and is highest at its middle-anterior part; the lateral septa are short, strong and distinct; the brachial scars are strongly convex and semi-circular in shape (Figs 2E, 3L).

Morphologically, *Waagenites* is closest to *Tethyochonetes* in both external and internal features. However, the new genus is distinguished by the possession of distinct but finer costae, less strongly concavo-convex shells and less distinct sulcus and fold. In addition, *Waagenites* has a prominent median ridge and a rather short ventral median septum, often shorter than one fifth of the valve length (Figs 2D, 3F–G). In contrast, *Tethyochonetes* gen. nov. bears a long ventral median septum, usually longer than half of the valve length (see Yang et al. 1962: 48, pl. 14, fig. 14). The dorsal interior of *Waagenites* is characterised by a broad, deep alveolus, and a thin, high, blade-like median septum (Fig. 2E), whereas *Tethyochonetes* has a shallow alveolus, and a stout median septum and lateral septa (Fig. 2F).

The younger species of *Tethyochonetes* somewhat resemble *Neochonetes* in terms of fine ribs, however, *Neochonetes* is easily separated from the new genus by its paucicostellae, paucicostellate ears and pair of well-developed vascular trunks in the ventral valve.

Tethyochonetes shares features with other genera notably *Fusichonetes* Liao (in Zhao et al. 1981), *Fanichonetes* Xu & Grant (1994), *Waterhouseiella* Archbold (1983) and *Rugaria* Cooper & Grant (1969). A comparison of these genera with *Tethyochonetes* is provided in Table 2. Diagnostic features of *Tethyochonetes* are a relatively long ventral median septum, a strong, long dorsal median septum, arising anteriorly of the alveolus, and brachial scars that are strongly convex and semicircular.
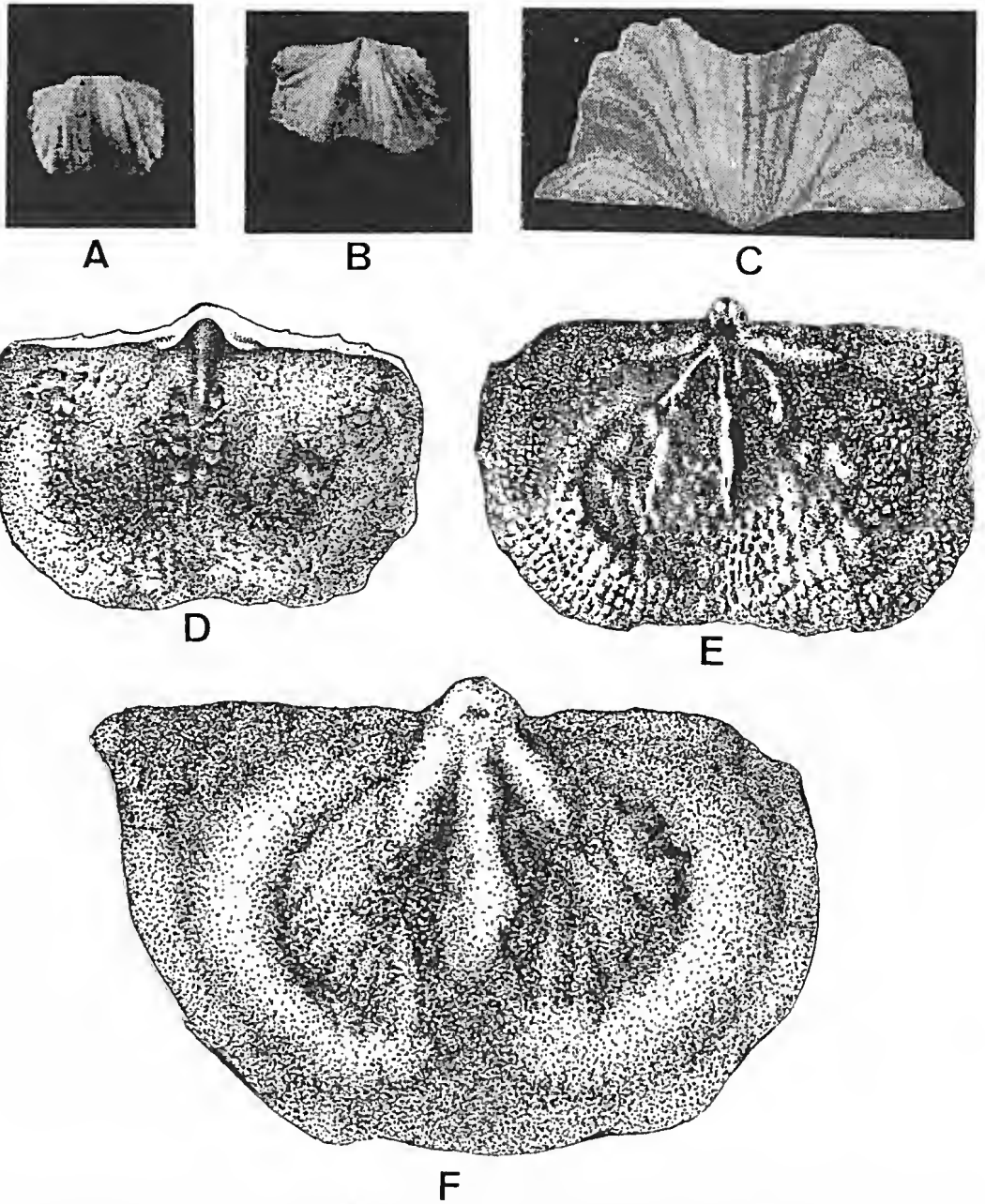
Fig. 2. External features of topotype specimen and internal features of *Waagenites* Paeckelmann, 1930 and *Tethyochonetes* gen. nov. A–C, *Waagenites grandicosta* (Waagen), type species of the genus. A–B, two ventral valves from the Chhidru Formation of Punjab, Salt Range, Pakistan (after Muir-Wood 1965: H433, fig. 288, 3b, c), ×1.5, ×2, respectively. C, posterior view of a ventral valve from the Chhidru Formation of the Salt Range, Pakistan (after Waagen 1884: pl. 61, fig. 7a), ×4. D–E, *Waagenites yunnanensis* Fang. D, a ventral valve interior (drawing based on specimen NMV P1456843; see also Fig. 3N, P), showing a short median septum, ×5. E, a dorsal valve interior (figure based on specimen 81111 illustrated by Fang [1983: 96, pl. 2, fig. 3] from the Middle Permian of the Xiaoxinzai section [Locality 14, Fig. 1.4]), ×5. F, the dorsal internal features of *Tethyochonetes quadrata* (Zhan) (figure based on specimen K-0066 [Zhan 1979: 70–71, pl. 4, fig. 16], housed in the Chinese Academy of Geological Sciences, Beijing), ×6.
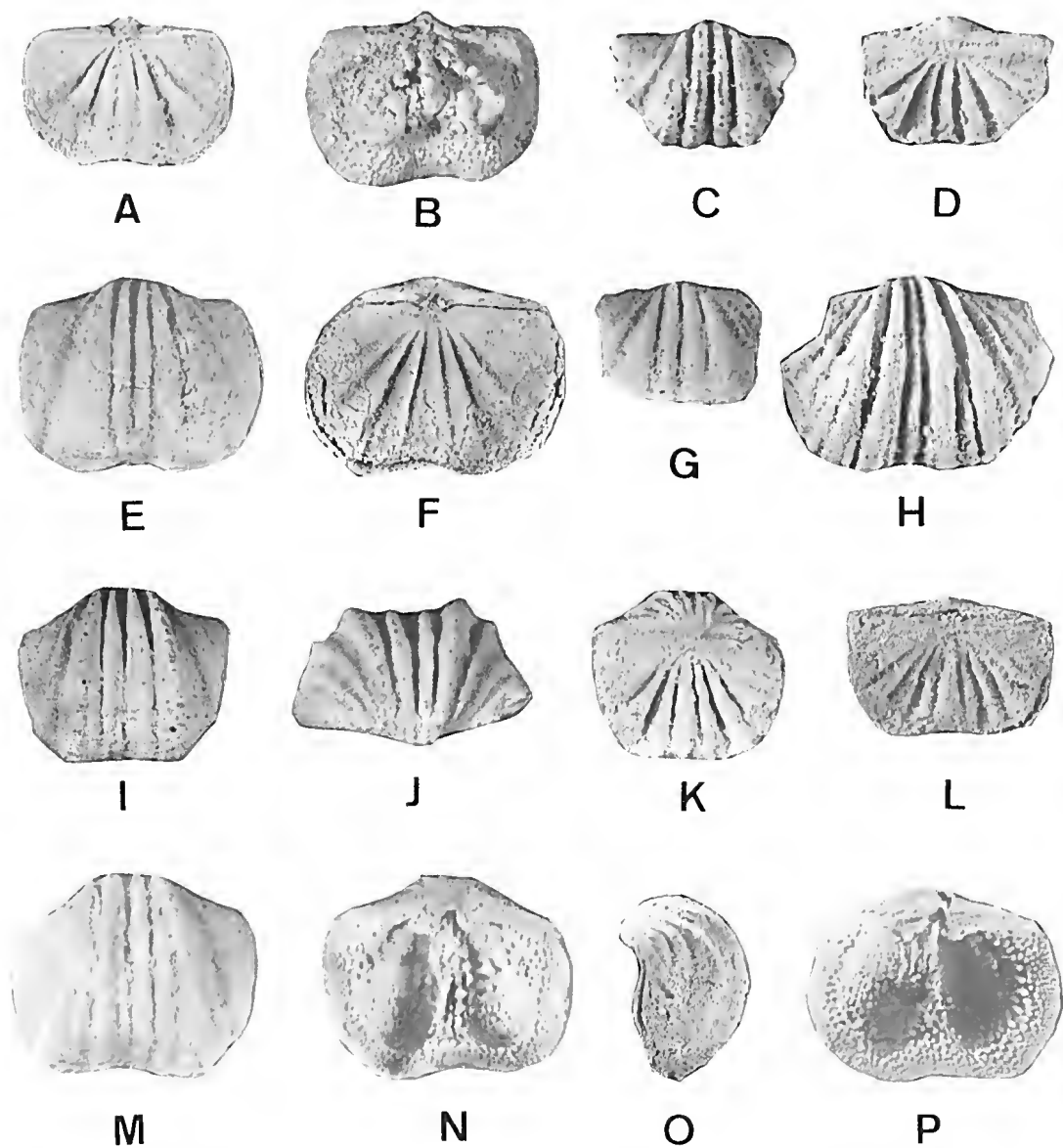
Fig. 3. Waagenites yunnanensis Fang. A–B, NMV P149270, a dorsal valve exterior and interior, ×3.5, ×4. C–D, NMV P149271, a complete specimen in ventral and dorsal views, ×3.5. E–F, NMV P1456843, a complete specimen in ventral and dorsal views, ×4. G–H, NMV P149272–273, two specimens in ventral views, ×3.5. I–K, NMV P149274, a complete specimen in ventral, posterior and dorsal views, ×3.5. L, NMV P149275, a specimen in dorsal view, ×3.5. M–N, NMV P1456848, a ventral valve exterior and interior, ×4. O–P, NMV P149276, a ventral valve in lateral and interior views, ×4. All from the Middle Permian of the Xiaoxinzai section (Locality 14, Fig. 1.4).

	Characteristic	Waagenites Paeckelmann	Tethyochonetes gen. nov.	Fusichonetes Liao	Fanichonetes Xu & Grant	Waterhouseiella Archbold	Rugaria Cooper & Grant
Exterior	Hinge spine	4-5 pair, extending latero-posteriorly	2-4 pair, extending latero-posteriorly	3-4 pair, extending latero-posteriorly	6-8 pair, inclined toward midline	7-8 pair, extending latero-posteriorly	5-6 pair, extending latero-posteriorly
	HW/SW	1 or <1	1	1	1.0-1.2	1	0.9-1.1
	SW/SL	1.4-1.7	1.2-1.9	3.2	1.2-1.4	1.4-1.6	1.3-1.5
	SW/ST	2.0-2.5	1.5-3.5	?	?	3.1-3.6	5.1-5.3
	Ears	moderate size, inflated	large, flat	large, flat	large, flat	large, flat	small or undeveloped
Costation pattern — density (per 5 mm at midvalve)		2-3	8-10	12	11-13	6-7	16
Costation pattern — interspace		deep, wide & angular	moderately deep, wide and rounded	deep, angular	narrow & shallow	deep, rounded	moderately deep, rounded
Costation pattern — subdivision		bifurcation	bifurcation	simple	bifurcation	branching or intercalation	bifurcation
Interior — Ventral valve — median septum		short,	long, up to midlength	?	short	high, thin, long up to midlength	short
Ventral valve — vascular trunks		distinct	no	no	no	variably developed	no
Dorsal valve — cardinal process		small, trilobate	broad & strong, trilobate	?	bifid	low	broad
Dorsal valve — median septum		blade like, up to midlength arising anteriorly	strong, long arising anteriorly	?	?	develop at midvalve	excavated anteriorly
Dorsal valve — lateral septa		strong and short	strong and short	?	?	long	undeveloped
Dorsal valve — brachial scars		strongly convex, semicircular	strongly convex, semicircular	?	?	no	no

Table 2. Comparison of *Tethyochonetes* gen. nov. with allied genera. HW/SW: the ratio of hinge width and greatest width of shell; SW/SL: the ratio of valve width and valve length; SW/ST: the ratio of valve width and thickness. Question marks indicate information that was not provided by the original authors when the genera were proposed.

Discussion. Most of the costate, rugosochonetid specimens from the Late Permian of China, considered previously to belong to *Waagenites*, possess the diagnostic features of the new genus and are different from true *Waagenites* as characterised above. We therefore refer these Chinese species to *Tethyochonetes* gen. nov.

Tethyochonetes quadrata (Zhan 1979)

(Fig. 4A–D, G)

Waagenites soochowensis quadrata Zhan 1979: 70, pl. 4, figs 16–19.

Holotype. Designated by Zhan (1979: 70), Specimen K-0063 from the Late Permian Shuizutang Formation of
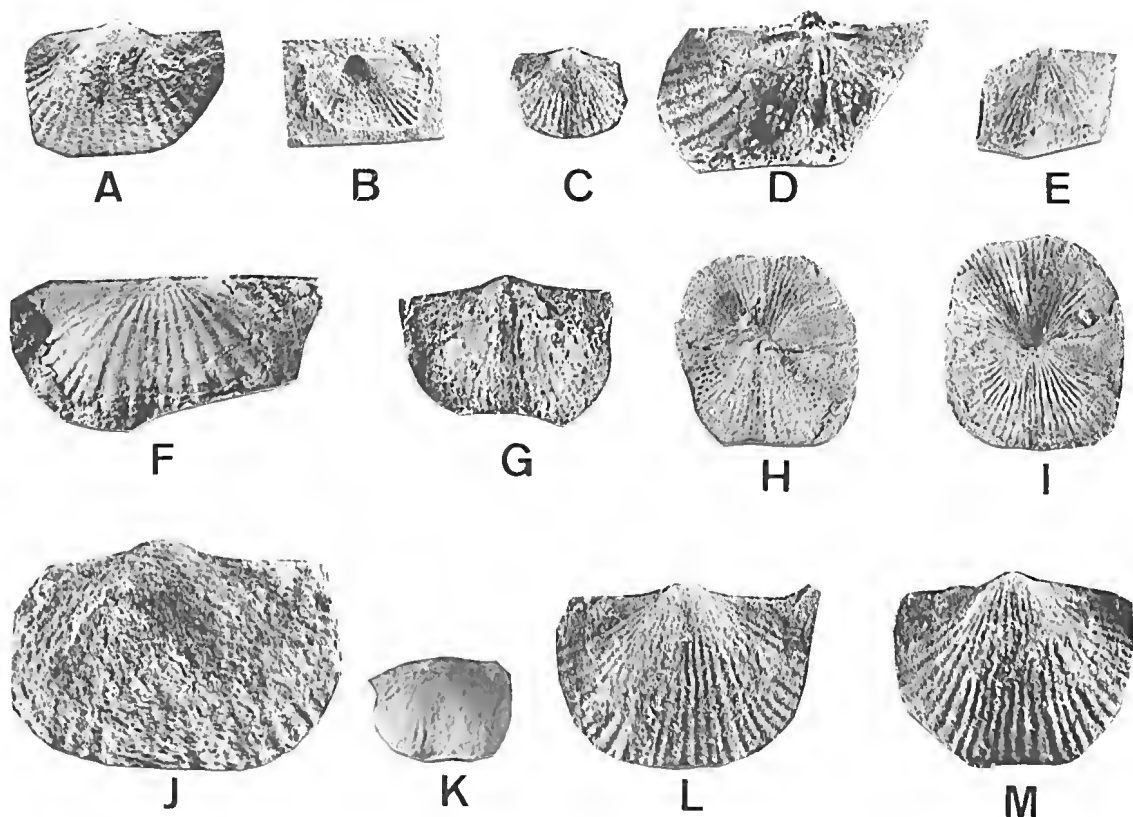
Fig. 4. A–D, G. *Tethyochonetes quadrata* Zhan. All specimens from the Changhsingian Changhsing Formation of the Huangzhishan section (Locality 4, Fig. 1.4). ×3. A, a ventral valve (NIGP 130460). ×3. B–C, views of an external mould of a ventral valve and a shelly ventral valve (NIGP 130462). ×1.5. D, a dorsal internal mould (NIGP 130459). ×3. G, a ventral internal mould (NIGP 130461). ×3. E, H–I. *Tethyochonetes? liaoi* sp. nov. E, a ventral external mould (NMV P149277). ×2, from the Kangshare Formation of the Selong section (Locality 13, Fig. 1.4). H–I, two ventral valves and external moulds (NIGP 130464–130465). ×3, from the Changhsingian Changhsing Formation of the Huangzhishan section (Locality 4, Fig. 1.4). F. *Tethyochonetes wongiania* (Chao). A dorsal external mould (NMV P149278). ×2, from the Wuchiapingian Lungtan Formation of the Baizuyuan section (Locality 9, Fig. 1.4). J–K. *Tethyochonetes chaoi* sp. nov. All specimens from the black shale (Bed 26 in Section C, Fig. 1) of the latest Changhsingian Yinkeng Formation of the Meishan section (Locality 3, Fig. 1.4). J, a ventral valve (NIGP HZ 130475). ×5. K, a ventral valve (NMV P1456860). ×2. L–M, *Tethyochonetes longtanensis* (Liao). Two ventral valves (NIGP 130471–130472). ×3, from the Changhsingian Changhsing Formation of the Huangzhishan section (Locality 4, Fig. 1.4).

Lian Xian, Northern Guangdong, figured by Zhan (1979: pl. 4, fig. 17a–b), and housed in the Chinese Academy of Geological Sciences, Beijing, China.

Material. Figured specimens include two ventral valves, a ventral internal mould, a ventral external mould, and a dorsal internal mould (NIGP 130459–130462).

Measurements (in mm)

Specimens	Valve length	Hingeline width	Midvalve width	Thickness
NIGP 130459	3.73	7.02	7.05	2.03 ♠
NIGP 130460	4.72	7.75	7.55	2.68 ♥
NIGP 130461	5.61	8.48	7.99	2.84 ♥
NIGP 130462	3.89	4.41	4.22	2.95 ♥

♥ only ventral valve; ♠ only dorsal valve (the same legend hereafter)

Diagnosis. Small and subquadrate *Tethyochonetes*; ventral umbo rounded; median sulcus variously developed; costae moderately coarse. Shell internally pustulose.

Description. Transversely quadrate to rectangular in outline; hingeline straight and equal to shell width; cardinal extremities varying from acute to slightly semi-elliptical; ears smooth, large, flattened or slightly swollen, distinct; separated from body of shell by grooves.

Ventral valve strongly to moderately convex; beak broadly, evenly convex and strongly incurved, overhanging hingeline; interarea narrowly triangle-shaped, about 5 mm in width; umbo broadly rounded, convex, moderately steeply sloping to flanks; median sulcus varying from deep, broad, and distinct, to shallow, narrow and indistinct, originating anterior to beak and extending anteriorly with increasing width; flanks bounding sulcus vary from distinctly to weakly developed.

Dorsal valve deeply concave, median fold slightly raised to flattened, originating at beak, extending to anterior margin.

External surface ornamented by distinct and rounded costae, occasionally increasing in number near anterior margin by bifurcation; about 25 costae on external surface and 6 costae per 3 mm near anterior margin; costae in median sulcus slender and finer than those on other parts of shell. Posterior margin usually marked by about 2–4 oblique cardinal spines on each side.

Delthyrium distinct; hinge teeth well-developed; ventral median septum thin and high, originating under delthyrium and extending anteriorly to about half valve length. Cardinal process rounded and blunt, alveolus shallow; socket ridges parallel to hinge margin; dorsal median septum moderately

high and strong, originating at anterior of alveolus and continuing forward for half of valve length, higher at middle-anterior part; lateral septa short, strong and distinct; brachial scars strong, swollen, and semi-circular in shape (Fig. 2F). Shell internal surface covered by abundant pustoles in radial rows.

Discussion. This species was first proposed as the subspecies *Waagenites soochowensis quadrata* based on specimens from the Late Permian Shuizutang Formation of Lian Xian, North Guangdong (Locality 6, Fig. 1). Compared with the holotype of *Chonetes soochowensis* Chao (1928: 31, pl. 1, figs 14–16), the Guangdong specimens are distinguished by their rectangular outline, more convex ventral valve, larger number of costae, and a more strongly elevated dorsal median septum. *Chonetes soochowensis* is also highly transverse, with a width/length ratio close to 2, more projecting cardinal extremities, and 16–18 costae on both valves. Therefore, Zhan's subspecies is regarded by us as a distinct species and assigned to *Tethyochonetes*.

Tethyochonetes quadrata has a similar dorsal median septum to that of *Waagenites yunnanensis* Fang (1983), being higher at its anterior-middle part, but the median septum of *T. quadrata* is more strongly developed and robust. *T. quadrata* possesses denser and finer costae, a longer ventral median septum, stronger lateral septa, and more strongly convex brachial scars than *W. yunnanensis*.

Tethyochonetes quadrata differs from *T.? liaoi* sp. nov. by its quadrate outline, moderately convex ventral valve and shallower median sulcus. The latter species has relatively larger, more inflated ears, and greater number of costae.

Tethyochonetes convexa (Fan in Yang et al. 1962: 48, pl. 14, figs 11–14) from the Late Permian of the Tibet–Qinghai region, western China (Jin & Sun 1981: 131, pl. 1, fig. 6; Jin 1985: pl. 5, figs 4–5; pl. 7, fig. 12) may be distinguished from the present species by its narrower and deeper median sulcus, broader and more distinctive ventral interarea, and a longer ventral median septum.

Tethyochonetes guizhonensis (Liao 1980) [= *Waagenites guizhouensis* Liao 1980b: 258, pl. 5, figs 5–7; Zhan 1989: 25, fig. 5; = *Sulcirugaria guizhonensis* (Liao), Waterhouse 1983: 117] is distinct in being more transverse, twice as wide as long, and having broader ears, and unbranching costae.

Age and locality. Changhsingian; Huangzhishan section, Huzhou City, Zhejiang Province, eastern China.

Tethyochonetes chaoi sp. nov.

(Fig. 4J, K)

Etymology. Named for the late Dr Yah-Tseng Chao, a pioneer worker on the Permian brachiopods of China.

Chonetes barusiensis (Davidson), Hayaskaya 1922: 100, pl. 5, figs 7–10.—Wang et al. 1964: 240–241, pl. 27, figs 27, 33.
Chonetes cf. *barusiensis* (Davidson), Chao 1928: 30, pl. 1, fig. 18.
Waagenites barusiensis (Davidson), Jin & Liao 1974: 311, pl. 164. fig. 8.—Yang et al. 1977: 332, pl. 135, fig. 4.—Feng & Jiang 1978: 244, pl. 88, fig. 6.—Xu 1987: pl. 8, figs 17, 18; pl. 9, figs 7, 8, 21.—Zhan 1989: pl. 25, fig. 9.
Waagenites cf. *barusiensis* (Davidson), Zhang & Jin 1976: 65, pl. 1, fig. 7.

Holotype. Specimen (NIGP 22489) from the Lungtan Formation of the Late Permian of the Wenxing area, Chongqing City, selected herein, figured by Jin & Liao (1974: 311, pl. 164, fig. 8), and housed in the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences.

Material. Two ventral valves (NIGP 130475 and NMV P1456860) are illustrated.

Measurements (in mm)

Specimens	Valve length	Hingeline width	Midvalve width	Thickness
NMV P1456860	5.58	6.98	6.96	2.30 ♥
NIGP 130475	5.61	7.31	7.31	2.45 ♥

Diagnosis. Small and trapezoidal *Tethyochonetes*, with broad, deep ventral median sulcus, sculptured with robust, simple, unbranching costae.

Description. Hingeline straight and equal to shell width; ears broad, smooth, flat or slightly inflated and projecting laterally, separated by a trough or shallow concavity from lateral flanks of ventral valve.

Ventral valve more or less strongly convex; beak arched, and extending slightly beyond hingeline; umbonal region broad and convex, flanked by steep lateral slopes; distinct median sulcus originating at beak, extending anteriorly and greatly increasing in width and depth, bounded by pronounced flanks. Dorsal valve deeply concave; median fold indistinct.

External surfaces ornamented by 16 robust costae with rounded crests; costae originating at beak, simple and unbranching.

Internal features are normal for genus.

Discussion. *Waagenites barusiensis* (Davidson 1866) was based on a Himalayan specimen. The original description and illustration provided by Davidson (1866: 42, pl. 2, fig. 7) indicates that the species should be referred to *Waagenites* Paeckelmann (1930) although its incomplete preservation hinders a full diagnosis (Waterhouse & Piyasin 1970: 117).

Many Chinese Late Permian chonetid specimens have been compared or identified with *W. barusiensis*, but differ from the type material of true *W. barusiensis* in possessing relatively less strongly concavo-convex shell, a narrower and shallower median sulcus and a differing number of costae. The large morphological variations of these various Chinese reports allows us to propose two new species, *T. chaoi* sp. nov. and *T.? liaoi* sp. nov.

Tethyochonetes soochowensis (Chao 1928), a common species in the Late Permian in Asia (Table 1), may be distinguished from the present species by its very transverse outline, shell width double shell length, flat and postero-laterally projecting ears and acute cardinal extremities.

Age and locality. Changhsingian; Meishan section, Changxing, Zhejiang Province, eastern China.

Tethyochonetes? liaoi sp. nov.

(Fig. 4E, H–I)

Etymology. Named for Professor Liao Zhuoting of the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences.

Waagenites barusiensis (Davidson), Zhan 1979: 71, pl. 4, figs 15, 20.—Liao 1979: pl. 1, figs 16, 17.—Liao 1980a: pl. 5, figs 24–26.—Liao 1980b: 292, pl. 2, fig. 14.—Zhao et al. 1981: pl. 8, figs 9–12.—Wang et al. 1982: 197, pl. 96, figs 13, 30.—Liao 1984: pl. 1, fig. 12.—Wang et al. 1989: pl. 1, fig. 6.

Holotype. Designated herein, Specimen AJ12/43567 from the Lungtan Formation of Jiazhishan section of Anshuan City, Guizhou, figured by Liao (1980a: pl. 5, fig. 26) and housed in the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences.

Material. Three figured ventral valves (NMV P1456859, NIGP 130464 and NIGP 130465).

Measurements (in mm)

Specimens	Valve length	Hingeline width	Midvalve width	Thickness
NMV P1456859	6.13	9.48	8.37	3.12 ♥
NIGP 130464	3.85	7.21	6.33	3.80 ♥
NIGP 130465	3.94	7.56	6.87	3.91 ♥

Diagnosis. Small to medium sized *Tethyochonetes*, with trapezoidal outline; ears inflated; median sulcus narrow, deep; external ribs fine, occasionally bifurcate.

Description. Widest at straight hingeline; ears broad, smooth and inflated, bounded by shallow troughs from body of shell.

Ventral valve less strongly convex; beak strongly incurved and extending slightly beyond hingeline; umbo moderately convex; median sulcus originating at beak as a groove, greatly increasing width and depth anteriorly, bounded by distinct flanks. Dorsal valve deeply concave; median fold distinct, commencing at beak.

External ornamentation consisting of costellae with rounded crests, originating at beak, occasionally bifurcate anteriorly; about 5 costae per 10 mm near anterior margin.

Ventral interior with pair of strong teeth; median septum thin, long. Cardinal process strong, trilobed externally; alveolus circular and deep; dorsal median septum strong, raised at anterior; brachial scars distinct.

Discussion. *Tethyochonetes liaoi* sp. nov. is proposed for specimens referred by Zhan (1979), Liao (1979, 1980a, 1980b, 1984), Zhao et al. (1981), Wang et al. (1982), and Wang et al. (1989) to *Waagenites barusiensis* (Davidson) (see above synonymy list). The new species is distinct from other members of the genus by its relatively narrower, deeper median sulcus, and significantly finer ribs. As a result, the present new species may be separated generically. However, strongly convex ventral valve, broad and smooth ears, and comparable internal structure allow the present tentative generic assignment.

The most allied species to the new species is *T. chaoi* sp. nov., both having a trapezoidal outline, broad, inflated ears, and deep, distinct ventral median sulcus, however, relatively finer, occasionally bifurcate capillae and slightly more strongly inflated ears distinguish the new species from the latter.

Tethyochonetes pigmaea (Liao 1979) [= *Fusichonetes pigmaea* Liao 1979; pl. 1, fig. 14; 1980b; pl. 1, figs 5–6; Zhao et al. 1981; pl. 8, fig. 7; Wang et al. 1982: 200, pl. 96, figs 8–9; = *Plicochonetes pigmaea* (Liao), Liao 1980a: 257, pl. 4, figs 4–6; =*Waagenites pigmaea* (Liao), Liao 1984: 279, pl. 1, fig. 7; 1987: 100, pl. 3, fig. 24] is distinguished by being much smaller and having smaller, less inflated ears, simple, unbranching, smaller number of costae, and a less well-developed ventral median septum.

Tethyochonetes convexa (Fan in Yang et al. 1962) is separated by means of its broader ventral umbonal region and prominent teeth. *T. convexa* is also lamellose near its anterior margins.

Age and localities. Changhsingian; Selong section, Nyalam County, southern Tibet and Huangzhishan section of Huzhou City, Zhejiang Province, eastern China.

Tethyochonetes longtanensis (Liao 1984)

(Fig. 4L, M)

Waagenites longtanensis Liao 1984: 279, pl. 1, figs 8–9.

Holotype. Designated by Liao (1984: 279, pl. 1, fig. 9). Specimen 71125 from the Talung Formation of the Longtan section, Nanjing, Jiangsu Province, housed in the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences.

Material. Two ventral valves are figured (NIGP 130471–130472).

Measurements (in mm)

Specimens	Valve length	Hingeline width	Midvalve width	Thickness
NIGP 130471	7.45	10.71	10.07	3.61 ♥
NIGP 130472	7.33	10.16	9.85	3.59 ♥

Diagnosis. Medium sized *Tethyochonetes*, with transversely quadrate outline, highly convex ventral umbo, and flat ears.

Description. Widest at hingeline, cardinal extremities acute; ears large, smooth or ornamented by weak costae, forming generally an acute extension at cardinal extremities and demarcated shell flanks by pronounced concavity.

Ventral valve strongly convex; greatest convexity at umbo; beak strongly arched, slightly extending beyond hingeline; umbonal region high and narrow, triangular-shaped; median sulcus well-developed, deep but narrow. Dorsal valve slightly concave; beak indistinct; median fold distinct.

External costae dense, with narrower costal interspaces, commencing at beaks, about 3–4 per 2 mm at anterior margin; posterior margin marked by 3–4 pairs of spines on each side, projecting laterally.

Ventral median septum low but long. Cardinal process low; sockets open and distinct; median septum thin and long, originating from anterior of alveolus and extending forward to midvalve, arising slightly at its anterior end; lateral septa strong and short.

Discussion. The most allied species is *T. guizhouensis* (Liao), which possesses unbranching, coarse costae, but *T. guizhouensis* is relatively more transverse, with shell width double the shell length, and embraces more laterally projecting cardinal extremities.

The present species resembles *T. quadrata* (Zhan) in embracing a subquadrate outline, closely spaced costae, but has a relatively shallower ventral median sulcus, a more highly convex ventral umbo, which have steeper slopes to flanks, and a thinner median septum in the dorsal interior.

T. chaoi sp. nov. is distinguishable from the present species by the possession of a broader, less strongly convex ventral umbonal region, a broader median sulcus, and relatively coarser, a smaller number of costae.

The present species is differentiated from *T.? liaoi* sp. nov. by possessing a narrower and more strongly convex ventral umbonal region, juvenile stages, and a narrower ventral median sulcus.

Age and locality. Changhsingian; Huangzhishan section, Huzhou City, Zhejiang Province, eastern China.

Tethyochonetes wongiania (Chao 1928)

(Fig. 4F)

Chonetes wongiania Chao 1928: 28, pl. 1, fig. 17.—Wang et al. 1964: 242, pl. 37, fig. 28.
Waagenites wongiania (Chao), Yang et al. 1977: 332, pl. 136, fig. 8.—Zhan 1979: 72, pl. 11, fig. 7.—Liao 1980a: pl. 5, fig. 4.—Liao 1980b: pl. 1, fig. 2; pl. 2, fig. 7.—Feng & Jiang 1978: 243, pl. 88, fig. 5.—Wang et al. 1982: 198. pl. 91, figs 1–2; pl. 95, fig. 6.—Xu 1987: 220, pl. 9, figs 1, 2. 5–6, 10–12.—Zhan 1989: pl. 25. fig. 10.—Zeng et al. 1995: pl. 3, fig. 18.

Holotype. Designated by Chao (1928: 31), Specimen Cat. No. 539 from the Luntan Formation of Miaojiao section, Suzhou City, Jiangsu Province, figured by Chao (1928: pl. 1, fig. 14), housed in the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences.

Material. Figured specimen, a ventral valve (NMV P1456861).

Measurements. Length 8.17 mm, width 17.04 mm, thickness 3.03 mm.

Diagnosis. Medium to large *Tethyochonetes*, with subtrapezoidal outline; ears rather broad; costae robust.

Description. Hingeline straight and equal maxi-mum shell width; cardinal extremities acute; ears large and flat, demarcated from remainder of shell by a pronounced concavity.

Ventral valve strongly convex; beak strongly incurved, slightly extending beyond hingeline; umbonal region high, flanked by steep umbonal slopes; median sulcus well developed, broad and deep. Dorsal valve slightly concave; beak indistinct; median fold weakly developed.

External costae with relatively broader costal interspaces, simple throughout and unbranching, originating at beaks, becoming coarser near anterior margin, costae within median sulcus slender numbering about 16–20.

Internal features are similar to those of *T. quadrata* (Zhan).

Discussion. The present species bears relatively most robust costae than any other members of the genus, and thus, apparently resembles species of *Waagenites*. However, apart from the differences of internal structures documented in the above generic comparison, *T. wongiania* has a less highly convex ventral valve, relatively broader ears and slightly greater number of costae, which usually have more flattened crests.

T. wongiania is remarkably similar to *T. soochowensis* (Chao) in outline, external ornament and dorsal internal features, but differs from the latter in possessing a broader and deeper ventral median sulcus, and simple, unbranching, less closely spaced costae.

T. guizhouensis (Liao) is also comparable with the present species in many details, but can be differentiated by being more transverse, and having slightly finer, greater number of costae and a less developed ventral sulcus.

Horizon and locality. Wuchiapingian; Baizuyuan section, Nantong County, Chongqing City, southwestern China.

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EOCENE BIVALVES AND GASTROPODS FROM THE PALLINUP SILTSTONE, WESTERN AUSTRALIA, WITH NEW RECORDS FROM THE EOCENE AND OLIGOCENE OF SOUTHEASTERN AUSTRALIA

Thomas A. Darragh[1] & George W. Kendrick[2]

[1] Department of Invertebrate Palaeontology, Museum of Victoria, Box 666E,
Melbourne, Victoria 3001, Australia
[2] Department of Earth and Planetary Sciences, Western Australian Museum,
Francis Street, Perth, Western Australia 6000, Australia

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New species and new records of bivalves and gastropods (Patellogastropoda, Vetigastropoda) from the Middle Eocene to Early Oligocene of southern Australia are presented. The study material is mostly from the Pallinup Siltstone (Late Eocene) with supplementary contributions from the Werillup Formation, Blanche Point Formation, Browns Creek Formation, Glen Aire Clay and Jan Juc Formation. Extensions of stratigraphic range and/or first Eocene records for Australia are recorded for 15 genera, including a first possible fossil record for the Thysanodontinae. A post-Eocene age for the Quagering Beds is indicated from fossil evidence. A neotype is selected for *Liotia lamellosa* Tenison Woods, 1877 and *L. roblini* Johnson, 1880. Newly described and named taxa from the Pallinup Siltstone are *Plicatula (P.) emaciata*, *Homalopoma (H.) limnaios*, *Tricolia psilia*, *Danilia vialis*, *Micrelenchus (Plumbelenchus) armulatus*, *Calliostoma (Fautor) mumapunt*, *Trochachlis stillata*, *Leucorhynchia rotulina* and *L. ventricosa*, *Pseudoninella? squarrosa*, *Collonia variabilis* (Browns Creek Formation), *Danilia euglypta* (Jan Juc Formation) and *Micrelenchus (Plumbelenchus) lirulatus* (Glen Aire Clay) are described from the Otway Basin, Victoria.

Key words: Mollusca, Late Eocene, southern Australia, taxonomy, new taxa.

EOCENE MOLLUSCA are common in the Plantagenet Group of the Bremer Basin, southwestern Western Australia. This paper presents new records and descriptions of new species of bivalve and gastropod (Patellogastropoda, Vetigastropoda) molluscs, principally from the Pallinup Siltstone of that group, together with supplementary contributions from other regions of southern Australia. It enlarges upon an earlier study (Darragh & Kendrick 1980), which was confined to bivalves from the Pallinup Siltstone of North Walpole, Western Australia. That locality has provided most of the new material described below. Remaining gastropod groups (Mesogastropoda, Neogastropoda, etc.) will be the subject of a further paper.

Our previous contribution (1980) recorded 23 bivalve species from the North Walpole deposit. Further collecting has produced an additional seven species from that locality, making a new total of 30 bivalve species. We also report 21 vetigastropod and one species of caenogastropod from North Walpole (including one species described by Beu & Ponder 1979: 20–21), giving a progressive total of 51 species of Mollusca from that source. Of these, one bivalve and eight gastropod species from North Walpole are described and named below.

Four other gastropod species, all congeneric with particular North Walpole taxa, are also formally described. These are from the Browns Creek Formation, Glen Aire Formation (both Otway Basin) and Jan Juc Formation (Port Phillip Basin) in Victoria.

The study material has been drawn from seven localities in the Plantagenet Group (one reworked), Bremer Basin and others from the Otway, Port Phillip and Bass basins. Distributional data for each species is summarised in Table 1. All specimens cited herein are registered in the collections of the Western Australian Museum (WAM) and Museum of Victoria (NMV).

PRESERVATION

North Walpole fossil molluscs are mostly preserved as siliceous replacements, with or without distortion, of the original carbonate structures, as has been described in detail by Darragh & Kendrick (1980). Some specimens are not well preserved, so that fine details such as protoconch sculpture are missing. New material from the Lucky Bay deposit, east of Esperance, Western Australia, is

	A		B			C	D					E		F
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
BIVALVES														
1. *Nucula tatei* Finlay		x			x		x	x						
2. *Nuculana (Saccella) chapmani* Finlay		x			x		x	x						
3. *Sarepta planiuscula* (Tate)		x			x				x					
4. *Arca pseudonavicularis* Tate		x			x			x						
5. *Barbatia (B.) limatella* Tate	x	x			x			x						
6. *Barbatia (Acar) gunsoni* Darragh & Kendrick	?	x			x									
7. *Notogrammatodon cainozoicus* (Tate)	x	x			x	x	x	x	x	x	x			x
8. *Arcopsis dissimilis* (Tate)		x			x		x							
9. *Limopsis (L.) chapmani* Singleton	x	x			x		x	x	x					
10. *Limopsis (L.) multiradiata* Tate		x			x		x	x						
11. *Tucetona lenticularis* (Tate)	x	x	x		x		x	x	x					
12. *Limarca angustifrons* Tate		x			x				x					
13. *Septifer (S.) subfenestratus* Basedow		x			x									
14. *Vulsella laevigata* Tate		x		x										
15. *Plicatula (P.) enuciata* sp. nov.		x												
16. *Anomia (A.) cymbula* Tate		cf			x									
17. *Spondylus gaderopoides* McCoy		cf		x				x				x		
18. *Dimya sigillata* Tate		x			x			x	x					
19. *Limea (Gemellima?)* sp.		x												
20. Limid, genus and species undetermined		x												
21. *Epicodakia* sp.		x												
22. *Venericardia (Rotundicardia) latissima* (Tate)		x			x		x	x						
23. *Cyclocardia (Vimentum?)* sp.		x												
24. *Salaputium communis* (Tate)		x			x		x	x	x					
25. *Vepricardium (Hedecardium) moniletectum* (Tate)		?			x									
26. *Glossus (Miocardiopsis)* sp.		x												
27. *Dosinia multilamellata* (Tate)		x			x			x				x		x
28. *Corbula (Caryocorbula) pixidata* Tate		x			x		x	x	x					
29. *Verticordia* sp. A		x												
30. *Verticordia* sp. B		x												
GASTROPODS														
31. *Nacella (?) jutsoni* (Chapman & Crespin)		x												
32. *Emarginula (?)* sp.		x												
33. *Liotina lamellosa* (Tenison Woods)	x	x					x		x		x	x		x
34. *Pseudoninella? squarrosa* sp. nov.								x						
35. *Pseudoninella?* sp.	x	x												
36. *Collonia variabilis* sp. nov.								x						
37. *Homalopoma (H.) linmaios* sp. nov.		x												
38. *Euninochilus otwayensis* (Pritchard)	x	x			x		x	x						
39. *Turbo (Euninella)* sp. cf. *T. (E.) hamiltonensis* Harris		x												
40. *Bolma (B.) flindersi darraghi* Beu & Ponder		x					x							
41. *Astralium?* sp.		x												
42. *Tricolia psilia* sp. nov.		x												
43. *Danilia vialis* sp. nov.		x												
44. *Danilia euglypta* sp. nov.												x		
45. *Agathodonta (?)* sp.		x												
46. *Micrelenchus (Plumbelenchus) armulatus* sp. nov.		x			x									
47. *Micrelenchus (P.) lirulatus* sp. nov.									x					
48. *Clanculus* (s.l.) sp.		x												
49. *Calliostoma (Fautor) numapuu* sp. nov.		x												

Table 1 continued next page

	A		B			C	D					E		F
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
GASTROPODS (*continued*)														
50. *Calliostoma* (s.l.) sp.		x												
51. *Carinastele* (?) sp.		x												
52. Trochid, genus undetermined Species A		x												
53. Trochid, genus undetermined Species B		x												
54. *Trochaclis (?) stillata* sp. nov.		x												
55. *Leucorhynchia rotulina* sp. nov.	x	x												
56. *Leucorhynchia ventricosa* sp. nov.		x												
57. *Circulus* sp.		x												
Totals	8	53	1	2	22	1	12	17	11	1	2	4	1	2

Table 1. Stratigraphic ranges (Middle Eocene to Middle Miocene) of selected bivalves and gastropods from southern Australia. Sources: Ludbrook (1961, 1965); Darragh & Kendrick (1980); Darragh (1985, this paper); WAM collections. A, Bremer Basin; B, St Vincent Basin; C, Murray Basin; D, Otway Basin; E, Port Phillip Basin; F, Bass Basin. 1, Werillup Formation; 2, Pallinup Siltstone; 3, South Maslin Sand; 4, Tortachilla Limestone; 5, Blanche Point Formation; 6, Morgan Limestone (Cadell Marl Member); 7, lower Browns Creek Formation; 8, upper Browns Creek Formation; 9, lower Glen Aire Formation; 10, Gellibrand Formation; 11, Muddy Creek Formation; 12, Jan Juc Formation; 13, Fyansford Formation; 14, Freestone Cove Sandstone.

similarly preserved, likewise a small collection of specimens from a locality east of Northcliffe, Western Australia. All of this siliceous material is assigned to the Pallinup Siltstone.

Specimens from two other Pallinup localities, Green Range and Lort River, are moulds, which is the more usual form of preservation of molluscan fossils at these localities. Latex casts have provided the figures in these examples.

Specimens from the Ocumup No. 1 deep well, located near Bremer Bay, are assigned to the Werillup Formation and occur as undeformed carbonate shells, in which the original aragonite seems essentially unmodified.

All other material described from sources in southeastern Australia occur as unmodified aragonitie shells.

PALAEOECOLOGY, PALAEOGEOGRAPHY, CORRELATION

Relevant comments on palaeoecology, palaeogeography and correlation have been noted in the discussion of individual species below and we defer a comprehensive account of these questions until taxonomic evaluation of the remaining gastropods is completed. By way of some preliminary observations, it is noted (see Table 1) that of the 30 bivalve species now recorded by us from the Plantagenet Group, about 20 (67%) also occur in the Blanche Point Formation of the St Vincent Basin; about 14 (47%) are known from the upper Browns Creek Formation, 10 (33%) from the lower Browns Creek Formation and 8 (27%) from the lower Glen Aire Formation, all Otway Basin. Eight of the bivalve species (27%) are as yet known only from the Pallinup Siltstone.

Distributional patterns of the gastropods reported here differ somewhat from those of the bivalves. Of the 23 species recorded below from the Plantagenet Group, no less that 19 (83%) are as yet unknown elsewhere, suggesting a much higher degree of endemism when compared with the bivalves (Table 1). However, this may reflect collection and other bias, in view of the small to minute size of some of the Vetigastropoda and the difficulties in establishing identifications for many of them.

Extensions of stratigraphic range and/or first Eocene records for Australia are presented for 17 genera or subgenera. These are: *Nacella, Vimentum, Emarginula, Angaria, Euninella, Astralium, Tricolia, Homalopoma, Danilia, Agathodonta*(?), *Micrelenchus (Plumbelenchus), Clanculus, Calliostoma (Fautor), Carinastele*? (first 'fossil record for the Trochidae : Thysanodontinae), *Trochaclis*(?) and *Leucorhynchia*.

Definitive correlations of the Middle and Late Eocene of the Bremer Basin, based on local and standard planktonic foraminiferal biostratigraphy, are yet to be established and this is particularly true for the Pallinup Siltstone (McGowran 1989). However, the Nanarup Limestone Member of the Werillup Formation is associated by McGowran (1989: 50–52, figs 2, 8) with the Tortachilla Transgression of the Middle to Late Eocene, straddling the Johannian–Aldingan Stages boundary.

Foraminifera in the coarse residues from Ocumup No. 1 include *Lenticulina* and *Operculina* as the most common forms. Less common are *Pseudo-polymorphina carteri* Quilty and *Linderina glaessneri* Quilty. The assemblage characterises the Tortachilla transgression (McGowran 1989) of late Middle Eocene age, cycle TA4.1, ~39 Ma. (B. McGowran, pers. comm., 21 January 1997).

We report for the first time fossil material from the Quagering Beds of Finkl & Fairbridge (1979), which occur typically as sheet deposits of quartz gravels in a coarse sandy matrix, located widely across the Ravensthorpe Ramp (Cope 1975) of southern Western Australia, often in proximity to occurrences of the Plantagenet Group.

Fossils collected from the Quagering Beds near Northcliffe comprise a sponge and silicified gastropods of Eocene character, including the sponge-associated *Tenagodus* sp. and *Nacella jutsoni* (Chapman & Crespin), the latter examined below. These have been reworked into the Quagering Beds presumably from an adjacent Pallinup Siltstone source, yet to be located. The reduced level of this locality lies within the range of 120–140 m above sea level. A post-Eocene age for these quartz gravels is therefore indicated, apparently subsequent to the silicification of the Pallinup, which may have occurred in the Oligocene. At that time, the Darling Plateau experienced epeirogenic uplift of *c.* 50 m (Cope 1975) with consequent erosion and stream incision.

Spondylus gaderopoides, additional to the above, is recorded from the Wilson Bluff Limestone, Abrakurrie Limestone and Colville Sandstone, all of the Eucla Basin (Lowry 1970; Darragh & Kendrick 1980). *Venericardia (Rotundicardia) latissima* is cited in Darragh & Kendrick (1980) as *Glaus (Fasciculicardia) latissima* and in Darragh (1985) as *Glaus latissima*.

LOCALITIES

(see Fig. 1)

(a) Western Australian Museum

Bremer Basin

1. North Walpole. For a detailed locality description see Darragh & Kendrick (1980: 7). Located in a poorly drained sandy depression 26 km north along Thompson Highway from Walpole townsite. Map reference: Deep River (1:100 000 series) 743486. Reduced level 124 m above AHD. Collected V. A. Ryland, T. A. Darragh and G. W. Kendrick, 14–16 October 1981. Pallinup Siltstone, Late Eocene.

2. Lucky Bay via Esperance. Track surface (ripped prior to revegetation) 4.3 km SE from Frenchman Peak and 0.1 km downslope (NW) from road to Lucky Bay, Cape Le Grand National Park. Map reference: Merivale (1:100 000 series) 264386. Collected V. A. Ryland, A. F. Longbottom and G. W. Kendrick, 7 October 1980; A. F. Longbottom, 11 July 1983 and 29 January 1984. Pallinup Siltstone, Late Eocene.

3. Green Range. Plantagenet Location 6475 on Litho 350/80. Collected P. G. Quinn, 1975. Pallinup Siltstone, Late Eocene.

4. Lort River. Near farm dam *c.* 0.5 km E of River and 0.1 km S of Albany–Esperance Highway. Map reference: Stokes Inlet (1:100 000 series) 388648. Collected J. Pas, June 1986. Pallinup Siltstone, Late Eocene.

5. Northcliffe. Nine miles (14.5 km) E of North-cliffe townsite on W side of Eggling Road, Nelson Location 10366, W side Canterbury River; quartz-ose gravel in shallow excavation and adjacent creek bed. Collected G. Gardner, 1967; G. Gardner and A. Jackson, June 1968 and 1 March 1970; G. Gardner, T. A. Darragh and G. W. Kendrick, 15 March 1969. Gravel contains reworked silicified fossil material (sponges, molluscs) apparently derived from unknown Eocene source, presumably Pallinup Siltstone. Gravels represent Quagering Beds of Finkl & Fairbridge (1979). An attempt to relocate this locality in 1995 was unsuccessful, due to extensive road construction and track realignments; area is mostly heavily forested.

6. Ocumup No. 1 deep well. Exploratory well (tenement E-68), drilled June 1976 by SILFAR, located at 34°23′45″S,119°12′53″E. Map reference: Bremer (1:100 000 series) QG 036918. Log details copied from the Index Sheet are:

depth (m)	lithology	stratigraphy
0–12	sand, clay	Quaternary
12–34	spongolite	Pallinup Siltstone
34–73	siltstone, calcarenite, sand, lignite	Werillup Formation
73–81	sandstone	basal sandstone
81	granite, gneiss	Precambrian

Twenty-seven samples from this bore are held at the Western Australian Museum, of which eight are assigned to the Pallinup Siltstone and 17 to the Werillup Formation.

7. Nanarup Lime Quarry, near head of Taylor Inlet, beside road to Nanarup, east of Albany. Map reference: Manypeaks (1 : 100 000 series) 967285. Werillup Formation, Nanarup Limestone Member, Middle (?) Eocene.

(b) Museum of Victoria

Otway Basin

8. PL 3011 BCI, 9.6 m dark clay with *Turritella* below greensand in Washout 1, nearest mouth of Browns Creek, Johanna, Victoria. Map reference: Glen Aire (1 : 25 000 series) 079058. Browns Creek Formation, Late Eocene (Aldingan).

9. PL 3013 BCIII, dark gritty clay 16 m above greensand in Washout 1 nearest mouth of Browns Creek, Johanna, Victoria. Map reference: Glen Aire (1 : 25 000 series) 079058. Browns Creek Formation, Late Eocene (Aldingan).

10. PL 3014 BCIII, dark gritty clay in Washout 2, forked gully nearest mouth of Johanna River, Johanna, Victoria. Map reference: Glen Aire (1 : 25 000 series) 079059. Browns Creek Formation, Late Eocene (Aldingan).

11. PL 3019 G.S.V. loc. Awl, slips immediately north of Point Flinders, near Cape Otway, Victoria. Map reference: Glen Aire (1 : 25 000 series) 162983. Glen Aire Clay, Early Oligocene.

12. PL 3024. Cliff section opposite Bird Rock, below Bird Rock cap, Torquay, Victoria. Map reference: Torquay (1 : 25 000 series) 642518. Jan Juc Formation, Late Oligocene (Janjukian).

St Vincent Basin

13. Silicified specimens from cherty band about 2.5 m above base of formation at Uncle Toms Cabin, Maslin Bay, South Australia. Map reference: Noarlunga (1 : 50 000 series) 696970. Blanche Point Formation, Late Eocene (Aldingan).

SYSTEMATIC PALAEONTOLOGY

Class Bivalvia Linnaeus, 1758

Subclass Palaeotaxodonta Korobkov, 1954

Order Nuculoida Dall, 1889

Superfamily Nuculanoidea H. & A. Adams, 1858

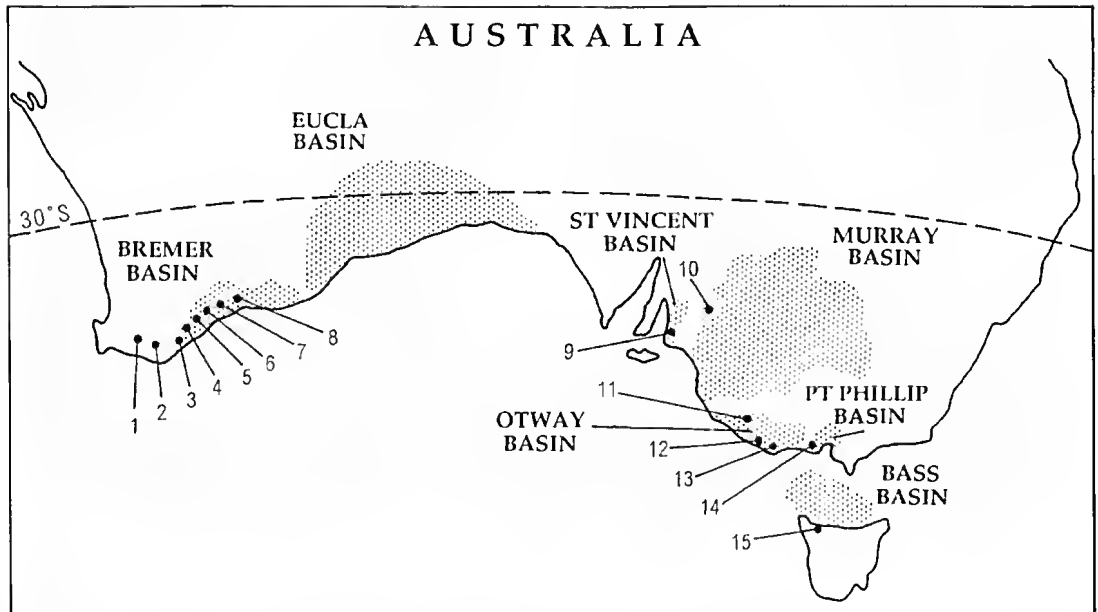Family Sareptidae A. Adams, 1860

Fig. 1. Onshore sedimentary basins of southern Australia. Localities: 1, Northcliffe; 2, North Walpole; 3, Albany; 4, Nanarup; 5, Green Range; 6, Ocumup; 7, Lort River; 8, Lucky Bay; 9, Blanche Point–Maslin–Aldinga; 10, Morgan; 11, Hamilton; 12, Browns Creek–Johanna River; 13, Pt Flinders; 14, Torquay; 15, Table Cape.

Subfamily Sareptinae A. Adams, 1860

Genus **Sarepta** A. Adams, 1860

Type species. Sarepta speciosa A. Adams, 1860. By monotypy. Recent, Korea Strait.

Sarepta planiuscula (Tate, 1886)

Fig. 21

Leda planiuscula Tate, 1886: 130, pl. 5, fig. 2.
Sarepta planiuscula—Chapman & Singleton, 1927: 116, pl. 10, figs 8–12; Darragh, 1985: 111, table 1.
Ovaleda planiuscula—Ludbrook, 1961: 61, pl. 3. figs 3, 4.

Material. WAM 83.2606. Two conjoined pairs.

Description. The species agree in external characters with the revised description of the species in Ludbrook (1961). Internal characters not seen.

Dimensions	Length	Height	Inflation
WAM 83.2606, pair	4.91	3.69 (est.)	1.75

Discussion. This rare species, widely distributed across southern Australian waters during the Late Eocene–Early Oligocene, is as yet unknown from the Browns Creek Formation. In New Zealand, the genus is recorded from Middle to Late Eocene and Early Miocene (Beu & Maxwell 1990: 393). It is included in the Tethyan–Indo Pacific element by Darragh (1985: 90–91, 111, table 1).

Occurrence. Otway Basin: lower Glen Aire Clay, Early Oligocene. St Vincent Basin: 'Adelaide Bore' (= Kent Town Bore), Kent Town (type), Blanche Point Formation, Late Eocene. Bremer Basin: North Walpole, Pallinup Siltstone, Late Eocene.

Subclass Pteriomorpha Buerlen, 1944

Order Arcoida Stoliczka, 1871

Superfamily Arcoidea Lamarck, 1809

Family Arcidae Lamarck, 1809

Genus **Arca** Linnaeus, 1758

Type species. Arca noae Linnaeus, 1758. By subsequent designation of Schmidt, 1818 (I.C.Z.N. Opinion 189).

Arca pseudonavicularis Tate, 1886

Fig. 2A–B

Arca pseudonavicularis Tate, 1886: 139, pl. 11, fig. 8; Ludbrook, 1965: 94, pl. 3, figs 30, 31; Darragh & Kendrick, 1980: 9, fig. 2G; Darragh, 1985: 101, 111, table 1.

Material. WAM 83.2577, 2 LVs, 1 deformed pair, 3 fragments. Six specimens all from North Walpole.

Description. Walpole specimens agree closely with the revised description of the species by Ludbrook (1965).

Dimensions	Total length	Length hinge margin	Height	Inflation
WAM 83.2577a, LV	13.52	9.82	5.35	3.18

One fragment in the study material would have an estimated original length in excess of 30 mm and probably larger than that of the holotype.

Discussion. The new material from North Walpole allows a better illustration of the species than was previously possible (Darragh & Kendrick 1980). The genus, which persisted until the Pliocene in southern Australian waters (Ludbrook 1954) and in New Zealand up to the Castlecliffian (Beu & Maxwell 1990), has been regarded as a tropical element by Ludbrook (1954) and by Beu & Maxwell (1990); however Darragh (1985) groups it with cosmopolitans.

Occurrence. Otway Basin: upper Browns Creek Formation, Late Eocene. St Vincent Basin: Blanche Point Formation (type), Late Eocene. Bremer Basin: North Walpole, Pallinup Siltstone, Late Eocene.

Genus **Notogrammatodon** Maxwell, 1966

Type species. Pseudogrammatodon (Notogrammatodon) inexpectatus Maxwell, 1966. By original designation. Late Eocene, New Zealand.

Notogrammatodon cainozoicus (Tate, 1886)

Fig. 2C

Macrodon cainozoicus Tate, 1886: 143, pl. 10, fig. 4.
Arca (Plagiarca) cainozoica—Harris, 1897: 335.
Barbatia (Plagiarca) cainozoica—Ludbrook, 1965: 101, pl. 5, figs 1–9.
Notogrammatodon cainozoica—Darragh, 1985: 100, 111, table 1.

Material. WAM 83.2580, one juvenile LV, one medium-sized LV (lacking antero-ventral area) and one fragment (LV). Three specimens.

Description. The material agrees with the revised description of the species in Ludbrook (1965). The posterior teeth are horizontal, anterior convergent on a point well below the beak and median area edentulous. The distinctive external sculpture of predominant transverse ribs and finer, discontinuous radials is well preserved.

Dimensions	Length of shell	Length hinge margin	Height	Inflation
WAM 83.2580a	17.33	13.50	8.42	2.92

Discussion. Rare at North Walpole, the species is here recorded from the Bremer Basin for the first time. The two smaller specimens have dissimilar gastropod boreholes, one bevelled—naticiform, the other of cylindrical form.

N. cainozoicus is closely related to the only known congener, *N. inexpectatus* Maxwell, 'differing in being less oblique, in having the anterior end sloping backwards sharply and in details

of dentition' (Maxwell 1966: 440). The genus is included in Darragh's Australian–New Zealand element (Darragh 1985: 88–90, fig. 6).

Occurrence. Port Phillip Basin: Fyansford Formation, Balcombian. Otway Basin: lower and upper Browns Creek Formation, Late Eocene; lower Glen Aire Clay, Early Oligocene; Gellibrand Formation, Bairnsdalian: Muddy Creek Formation (type), Balcombian. Murray Basin: Morgan Limestone (Cadell Marl Member), Balcombian. St Vincent Basin: Blanche Point Formation, Late Eocene. Bremer Basin: Ocumup No. 1 deep well, 71.7 m. Werillup Formation, Middle Eocene; North Walpole, Pallinup Siltstone, Late Eocene.
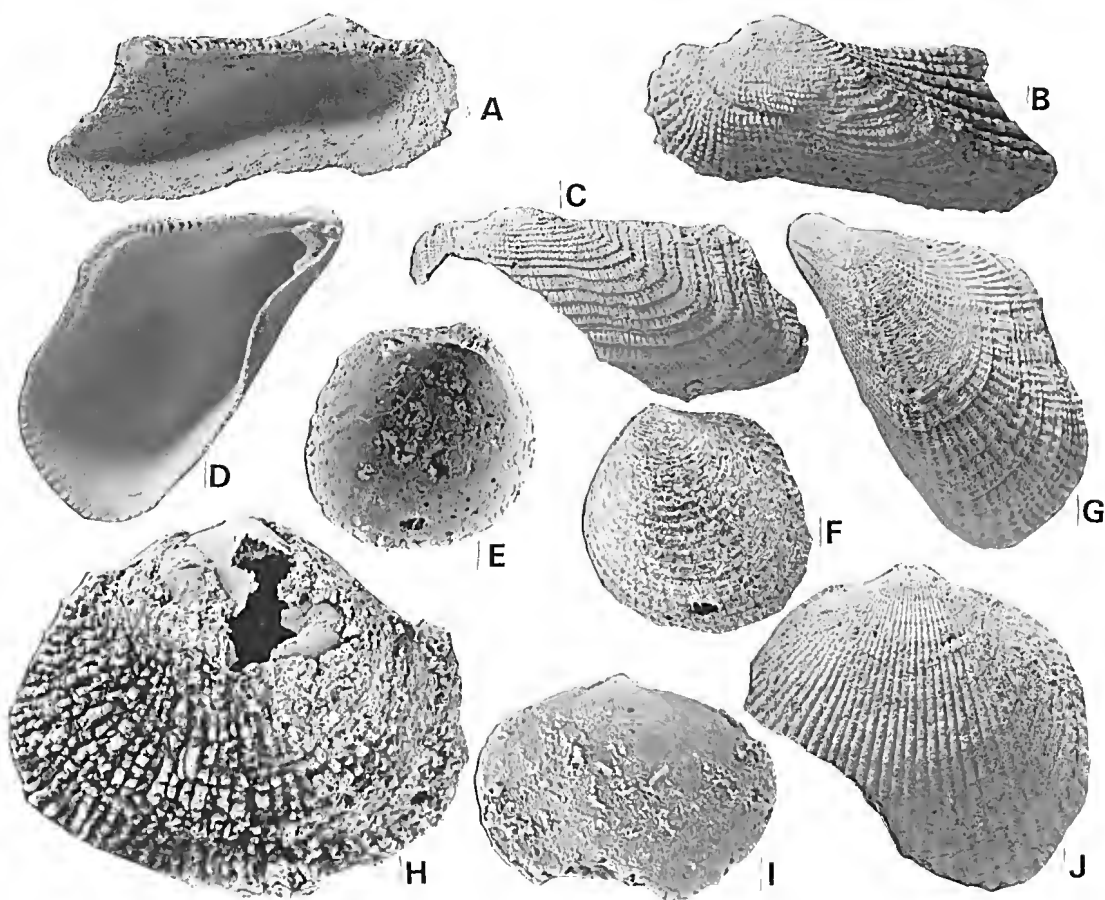

Fig. 2. A–B, *Arca pseudonavicularis* Tate, WAM 83.2577a, LV interior, exterior, × 4. C, *Notogrammatodon cainozoicus* (Tate), WAM 83.2580a, LV exterior, × 3. D, G, *Septifer (Septifer) subfenestratus* Basedow, WAM 83.2586a, LV interior, exterior, × 3. E–F, *Limarca angustifrons* Tate, WAM 83.2600, LV interior, exterior, × 8.2. H, *Anomia (Anomia)* sp. cf. *A. (A.) cymbula* Tate, WAM 83.2592, LV exterior, × 6.4. I, *Sarepta planiuscula* (Tate), WAM 83.2606a, LV, exterior, × 8. J, *Tucetona lenticularis* (Tate), WAM 86.1632, LV exterior (latex peel), × 2.1.

Superfamily Limopsoidea Dall, 1895

Family Limopsidae Dall, 1895

Genus **Limopsis** Sassi, 1827

Type species. Arca aurita Brocchi, 1814. By original designation. Pliocene–Recent, N. Atlantic–Mediterranean.

Subgenus **Limopsis**

Limopsis (Limopsis) chapmani Singleton, 1932

Limopsis chapmani Singleton, 1932: 296–299, pl. 24, figs 12–14, pl. 25, fig. 16; Ludbrook, 1965: 83–84, pl. 1, figs 1–9. Synonymy; Darragh, 1985: 111, table 1.
Limopsis (Limopsis) chapmani—Darragh & Kendrick, 1980: 13, fig. 2O–R.

Material. WAM 95.391, 95.403, 95.429. Four juvenile valves.

Discussion. Specimens from the Plantagenet Group are invariably smaller and thinner than those from other regions. The species, which is the most common bivalve at North Walpole, is here recorded for the first time from the Werillup Formation.

Occurrence. Port Phillip Basin: Jan Jue Formation (type), Late Oligocene–Early Miocene. Otway Basin: lower and upper Browns Creek Formation, Late Eocene; lower Glen Aire Clay, Early Oligocene. St Vincent Basin: Blanche Point Formation, Late Eocene. Bremer Basin: Ocumup No. 1 deep well, 53.4–68.6 m, Werillup Formation, Middle Eocene; North Walpole, Pallinup Siltstone, Late Eocene.

Family Glycymerididae Newton, 1922

Genus **Tucetona** Iredale, 1931

Type species. Pectunculus flabellatus Tenison Woods, 1878. By original designation. Recent, southeast Australia.

Tucetona lenticularis (Tate, 1886)

Fig. 2J

Pectunculus lenticularis Tate, 1886:138, pl. 11, fig. 1.
Glycymeris lenticularis—Chapman & Singleton, 1925: 31, pl. 1, fig. 8a–b, pl. 4, fig. 6; Darragh, 1985: 111, table 1.
Glycymeris (Tucetona) lenticularis—Ludbrook, 1965: 93, pl. 3, figs 11–13.

Material (Bremer Basin). WAM 83.2583, 86.1632, 95.417, 95.425. One external mould, one incomplete juvenile valve and 12 fragments.

Discussion. The type material from the Blanche Point Formation has been redescribed and figured by Ludbrook (1965). Specimens identified with this species from the Plantagenet Group are here recorded for the first time; there it appears to be uncommon and poorly preserved. Rib counts are 36 and 44 (Pallinup Siltstone) and 33 and 35 (Werillup Formation), within the range of variation ('usually from 30 to 50') reported by Ludbrook (1965).

Occurrence. Otway Basin: lower and upper Browns Creek Formation, Late Eocene; lower Glen Aire Clay, Early Oligocene. St Vincent Basin: South Maslin Sand, Middle Eocene; Blanche Point Formation (type), Late Eocene. Bremer Basin: Ocumup No. 1 deep well, 71.7–73.2 m, Werillup Formation, Middle Eocene. North Walpole and Lort River district, Pallinup Siltstone, Late Eocene.

Family Philobryidae Bernard, 1897

Genus **Limarea** Tate, 1886

Type species. Limarca angustifrons Tate, 1886. By monotypy. Late Eocene, Adelaide district, South Australia.

Limarca angustifrons Tate, 1886

Fig. 2E–F

Limarca angustifrons Tate, 1886: 135, pl. 8, fig. 5a–b; Darragh, 1985: 111, table 1.

Materials. WAM 83.2600, one LV.

Description. Shell small, roundly sub-rhomboidal, slightly higher than long, extended and slightly alate posteriorly; umbone moderately inflated, slightly prosogyrate, projecting above dorsal margin; beak incurved, prosogyrate, close to anterior end of straight dorsal margin; prodissoconch small; anterior and ventral margins evenly rounded; posterior margin obliquely and roundly subtruncate, meeting dorsal margin at obtuse angle; sculpture of low, flattened, transverse costellae and incised, linear interspaces, numbering *c.* 20 in height of 3.9 mm; radial sculpture obscure, poorly preserved, confined to ventral area; hinge comprises three raised, slightly oblique, parallel teeth below beak and about three short, sub-horizontal, posterior teeth, well spaced from anterior series and set on a narrow hinge plate; posterior and postero-ventral margin internally crenulate, elsewhere poorly preserved; adductor scars not seen.

Dimensions

	Length	Height	Inflation
WAM 83.2600, LV	3.78	3.90	1.08

Discussion. The single specimen to hand from North Walpole of this rare species compares satisfactorily with Tate's description and figures, despite imperfect preservation in some parts. The genus, apparently monotypic, belongs with Darragh's (1985: 92) Southern Australian Endemic Element. It is unknown after the Early Oligocene. The genus *Limarca* differs from the speciose *Philobrya* Carpenter in features of the hinge, shape and sculpture. In the latter genus, the anterior and posterior series of teeth are more or less proximate on a wide hinge plate; the shell is sub-mytiliform and carries spaced radial sculpture across the disc; the prodissoconch is also larger.

Occurrence. Otway Basin: lower Glen Aire Clay, Early Oligocene. St Vincent Basin: Blanche Point Formation (type), Late Eocene. Bremer Basin: North Walpole, Pallinup Siltstone, Late Eocene.

Order Mytiloida Férussac, 1822

Superfamily Mytilodea Rafinesque, 1815

Family Mytilidae Rafinesque, 1815

Subfamily Mytilinae Rafinesque, 1815

Genus **Septifer** Récelz, 1848

Type species. Mytilus bilocularis Linnaeus, 1758. By subsequent designation of Stoliczka, 1871. Recent, Indo-SW Pacific.

Subgenus **Septifer** s. str.

Septifer (Septifer) subfenestratus
Basedow, 1904

Fig. 2D, G

Septifer subfenestratus Basedow, 1904: 251–252, text fig.
Septifer (Septifer) sp. cf. *S. (S.) fenestratus* Tate. Darragh & Kendrick, 1980: 13, fig. 3A–C.

Material. WAM 67.84, 69.109, 69.110, 74.551, 76.1, 83.2586. Total of three RVs, one LV, one conjoined pair (deformed), associated internal and external moulds and 21 fragments. NMV P40639, P40655.

Description. Small for genus, thin, triangularly mytiliform, compressed and sub-acute anteriorly, expanded dorso-posteriorly; umbone compressed, high, rostrate, with slight spiral twist; beaks terminal; postero-dorsal area alate; ventral area short, almost normal to commissural plane and bordered by angulate shoulder; dorsal margin straight, meeting slightly concave postero-dorsal margin at 125–145°; posterior margin roundly sub-truncate; ventral margin sinuate with prominent byssal sinus at anterior fourth; sculpture of fine, close, divaricate, bifurcating radial costellae, strongest and about as wide as interspaces on median area, elsewhere finer and narrower than interspaces; on unworn specimens, fine transverse growth striae crowd intercostal spaces, usually much reduced on worn specimens; juvenile shell up to 7 mm long, fenestrate with fine, crowded, radial and transverse costellae, persisting in adult on ventral area; elliptical area around byssal gape with reduced sculpture, mainly transverse, or smooth; resilifer a shallow sub-marginal groove below anterior half of dorsal margin; anterior extremity with strong internal septum bearing two low dysodont teeth; amphidetic teeth present behind ligament, grading into very fine internal crenulation around posterior and ventral margins, much reduced ventrally especially around byssal gape; anterior adductor scar weakly defined, beneath septum on dorsal side; posterior adductor scar obscure; pallial line thin, entire, close to margin,; margin everted posteriorly; interior faintly nacreous.

Dimensions

	Length beak–posterior	Length dorsal margin	Height	Inflation
WAM 83.2586a, LV	17.12	9.50	8.83	4.91
WAM 83.2586h, RV	12.44	7.48	7.50	3.33

Discussion. In a previous study (Darragh & Kendrick 1980), based on inferior material, we were unable to establish a positive determination for the Walpole Septifer. Specimen WAM 69.109, figured by us (1980: fig. 3A–C) is now seen to be deformed by dorso-ventral compaction and is not a good representation of the species. Subsequent collecting has produced well preserved material, which permits a revised description and determination. Our material agrees reasonably well with the description and figure of *Septifer subfenestratus* Basedow, erected on a 'pseudomorphous cast in glauconite', a possible equivalent of the Blanche Point Formation of the Adelaide District (Basedow 1904: 251–252, text fig.). Walpole specimens differ from the Balcombian *S. fenestratus* Tate in having a broader umbone, greater postero-dorsal flair, fewer stronger ribs on the median area and a more angulate shoulder bordering the ventral area.

Septifer subfenestratus and *S. fenestratus* appear to represent an endemic southern Australian lineage of this essentially tropical to subtropical genus, which lineage is not known to have survived beyond the Middle Miocene. In New Zealand, the genus has a recorded range of from Early Eocene to Middle Miocene (Beu & Maxwell 1990: 33).

Occurrence. St Vincent Basin: Royal Vale Vineyards, Happy Valley, glauconitic sandstone (type), probably Blanche Point Formation, Late Eocene. Bremer Basin: North Walpole; Green Range, Plantagenet Location 6475; Pallinup Siltstone, Late Eocene.

Superfamily Plicatuloidea Watson, 1930

Family Plicatulidae Watson, 1930

We follow Waller (1978) in according superfamilial status to the Plicatuloidea, equal to and separate from the Dimyoidea.

Genus **Plicatula** Lamarck, 1801

Type species. Spondylus plicatus Linnaeus, 1758. By subsequent designation of Schmidt, 1818. Recent, Indo-SW Pacific.

Subgenus **Plicatula** s. str.

Plicatula (Plicatula) emaciata sp. nov.

Fig. 3A, C, E, G–J

Plicatula (Plicatula) sp. Darragh & Kendrick, 1980: 15, fig. 3I–L.

Material. Holotype WAM 67.79, separate paired valves, from 26 km along Thompson Highway north from Walpole, Western Australia. Paratypes WAM 69.112a, 69.113, 72.267a–b, 74.552a–b, 78.4092a, 83.2589a–b. Total of five LVs two pairs. NMV P302328 (left valve), P302329 (pair).

Other material. WAM 67.93, 69.108, 69.117, 72.268, 74.537, 74.539, 88.153, 83.2589. Total of 56 valves. NMV P52337 (8 valves), P40638 (11 valves), P301957 (30 valves). Total 49 specimens.

Description. Small, thin-shelled, compressed, inequivalve, extended posteriorly, irregularly folded, ostreiform, without marginal gape, higher than long; RV the more convex with large attachment area; LV more or less flat in juvenile, becoming slightly concave or convex with growth; LV margin slightly everted to fit RV margin; auricles absent; sculpture more or less similar on each valve, transversely lamellose with hollow, raised, incurved scales and from 15–20 irregular, often bifurcate, radial costae of variable width, weakly to moderately developed; costae absent from attachment area (RV) and corresponding part of LV; adductor scars of both valves oval, centred in postero-dorsal quadrant; crura thick, erect, with points directed out as in *Spondylus*; weakly serrated; crura of RV close to resilium pit, those of LV more spaced; cardinal area present on RV, absent on LV.

Dimensions

	Length	Height	Inflation
WAM 67.79a holotype, RV	11.90	13.65	4.45
WAM 67.79b holotype, LV	11.35	12.48	2.70
WAM 72.267 paratype, LV	13.30	18.13	3.94
WAM 74.552a paratype, pair	17.34	18.78	7.80
WAM 78.4092 paratype, LV	13.90	15.47	3.12

The largest specimen to hand, paratype WAM 69.112a, is broken but the estimated height *c.* 20 mm.

Discussion. Previously described species of *Plicatula* from the Australian Tertiary (Early and Middle Miocene) all differ from the present in their relatively thicker shells and fewer, more spaced, wider radials (Tate 1898; Chapman 1922). This is the first Australian Eocene record for the genus, which has a long record in Australia, an undescribed species being present in the Bajocian Newmarracarra Limestone of the northern Perth Basin (Playford 1959; WAM, unpub. records). Cretaceous records of *Plicatula* from Western Australia (Feldtmann 1963) are considered to belong with the genus *Atreta* Étallon (Darragh & Kendrick 1991), a genus subsequently relocated in the Dimyidae (Hodges 1991). As noted previously (Darragh & Kendrick 1980), single LVs (64 valves) greatly outnumber single RVs (nine valves) in the study material, indicating differential post-mortem transportation.

Gastropod boreholes are present on 22 valves, a predation rate of 35%. Twenty of these are on the LV, all but one of the non-bevelled 'muriciform' type. Both RVs have been bored well clear of the attachment area.

The specific name is derived from the Latin *emacio*—to waste away, in view of the notably small thin shell of this species.

The genus, in modern seas restricted to tropical and subtropical waters, is recorded from the Early Eocene of New Zealand (Beu & Maxwell 1990: 90, pl. 3d, g). It is included in Darragh's (1985) cosmopolitan element.

Occurrence. Bremer Basin: North Walpole (type), Pallinup Siltstone, Late Eocene.

Superfamily Anomioidea Rafinesque, 1815

Family Anomiidae Rafinesque, 1815

Genus **Anomia** Linnaeus, 1758

Type species. Anomia ephippium Linnaeus, 1758. By subsequent designation of Schmidt (1818). Recent, Atlantic-Mediterranean.
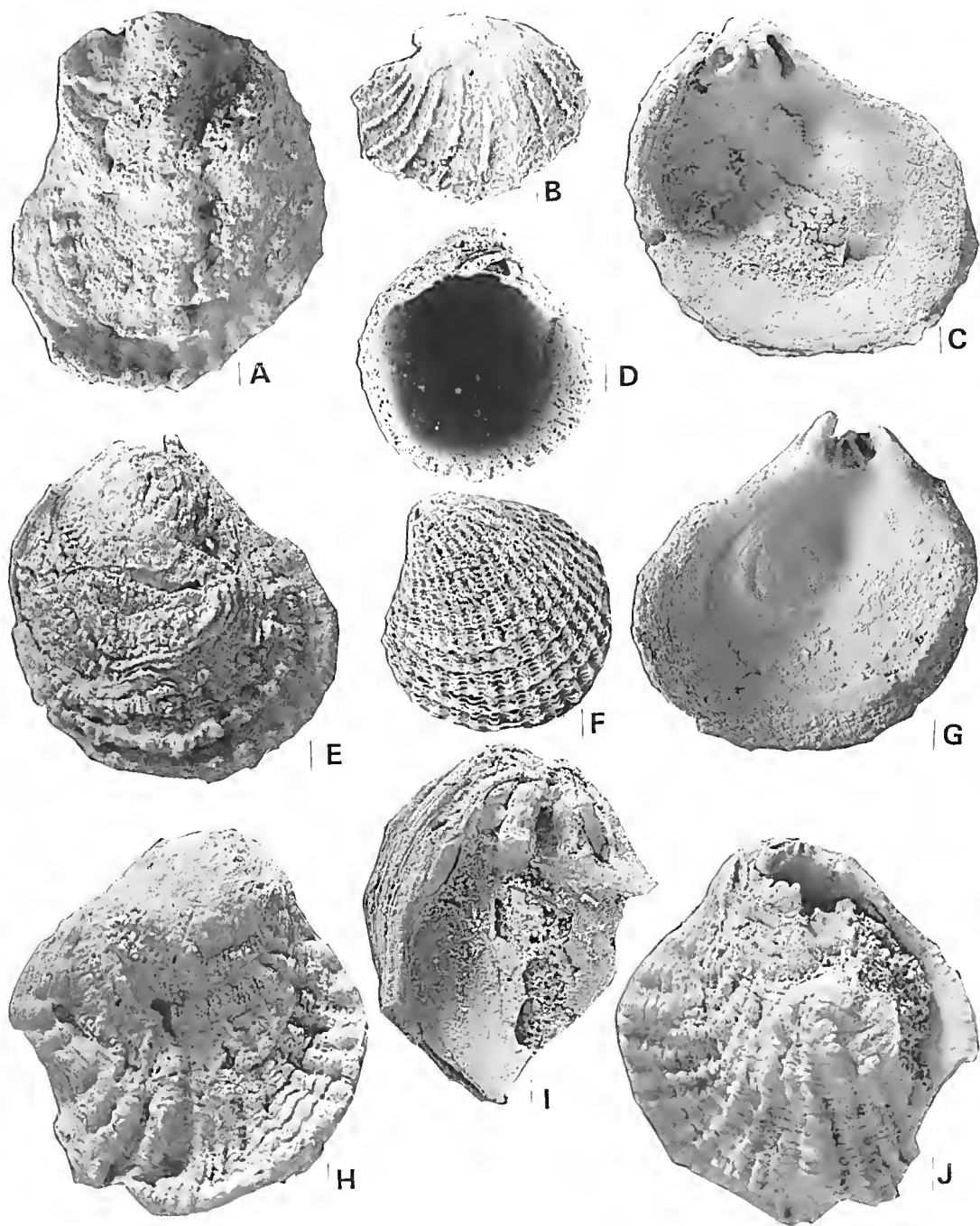
Fig. 3. A, C, E, G–J, *Plicatula (Plicatula) emaciata* sp. nov. A, C, E, G, WAM 67.79, holotype: A, RV exterior; C, interior; E, LV exterior; G, LV interior; all × 4. H, J, WAM 74.552a, paratype, conjoined pair: H, RV exterior; J, LV exterior; both × 3. I, WAM 69.117, RV interior, fragment attached to a sponge, × 4. B, *Verticordia (Verticordia)* sp. WAM 83.2610, LV exterior, × 8.4. D, F, *Cyclocardia (Vimentum?)* sp. WAM 83.2599, LV interior, exterior, × 6.

Subgenus **Anomia** s. str.

Anomia (Anomia) sp. cf. A. (A.) cymbula
Tate, 1886

Fig. 2H

cf. *Anomia cymbula* Tate, 1886: 101, pl. 11, fig. 5.

Material. WAM 83.2592. One LV.

Description. Small for genus, thin, of irregular outline and profile, possibly deformed a little by compaction; longer than high; umbone broad, more or less orthocline, inflated, broken in median area; without foramen; anterior and posterior slopes oblique, former being slightly convex on margin, latter slightly concave on margin; ventral margin broadly rounded; axis of greatest length located in ventral half; sculpture of numerous, fine, crowded radial costellae, bearing packed, irregular, erect scales, variously aligned; margin somewhat abraded; body cavity with large dorsal callosity; muscle scars not preserved.

Dimensions

	Length	Height	Inflation
WAM 83.2592, LV	9.26	7.89	2.66

Discussion. In proportions, the sole specimen to hand (from North Walpole) appears to be unlike Tate's figure of *Anomia cymbula* (Tate 1886: 101, pl. 11, fig. 5) from 'Turritella-clays at Blanche Point, Aldinga Bay'. In neither specimen (apparently both LVs) are the muscle scars known; however the finely scaled radial costellae of our specimen are anomiid in character and suggest at least an affinity between the Blanche Point and North Walpole specimens.

Collection of more material from both sources may confirm the generic determination and indicate the range of variation in each. The present species is rare at North Walpole.

Occurrence. Bremer Basin: North Walpole, Pallinup Siltstone, Late Eocene.

Subclass Heterodonta Neumayer, 1884

Order Veneroida H. & A. Adams, 1856

Superfamily Carditoidea Fleming, 1820

Family Carditidae Fleming, 1828

Subfamily Carditamerinae Chavan, 1969

Genus **Cyclocardia** Conrad, 1867

Type species. Cardita borealis Conrad, 1831. By subsequent designation of Stoliczka, 1871. Recent, North Atlantic.

Subgenus **Vimentum** Iredale, 1925

Type species. Cardita dilecta E. A. Smith, 1885. By original designation. Recent, southern Australia.

Cyclocardia (Vimentum?) sp.

Fig. 3D, F

Material. WAM 83.2599. One LV.

Description. Small, robust, ovate-subtrigonal, inflated, higher than long, subequilateral, very slightly extended anteriorly; posterior area weakly defined; umbone broad, elevated, slightly prosogyrate; beak slightly posterior of centre; lunule shallow, weakly defined, elliptical; antero-dorsal margin concave; anterior and ventral margins evenly curved in outline; posterior margin slightly truncate; posterodorsal margin slightly convex; hinge plate broad, tooth 2 short, erect; tooth 4 long, massive; cardinals subtend 90° angle below beak; posterior lateral PII weak, poorly indicated; ligamental attachment groove submarginal, shallow; sculpture of 24 radial costellae, about as wide as interspaces except for six narrower radials on posterior area; radials and interspaces overlain by numerous fine, transverse threads, combining to form weak plicae on crests of costellae; internal margin strongly crenulate corresponding to external radials; anterior adductor scar large, close to anterior extremity; posterior adductor scar larger and close to posterior extremity; pallial line entire, distanced from margin.

Dimensions

	Length	Height	Inflation
WAM 83.2599, LV	5.32	5.79	2.32

Discussion. This rare and evidently undescribed species is assigned provisionally to the subgenus *Vimentum* from a broad similarity in sculpture and hinge structure to the type species *Cardita dilecta* E. A. Smith and other related species, such as *V. excelsior* (Verco), from the Recent of southern Australia. It differs from these in the apparent presence of a weak posterior lateral tooth (PII), in the spacing and number of ribs, the transverse microsculpture, height exceeding length and greater inflation.

Further determination of this species must await the collection of a RV. The subgenus is hitherto not recorded from the Eocene according to Chavan (in Moore 1969: N551, fig. E49, 7).

Occurrence. Bremer Basin: North Walpole, Pallinup Siltstone, Late Eocene.

Superfamily Crassatelloidea Férussac, 1822

Family Crassatellidae Férussac, 1822

Subfamily Crassatellinae Férussac, 1822

Genus **Salaputium** Iredale, 1924

Type species. Crassatella fulvida Angas, 1871. By original designation. Recent, Australia.

Salaputium communis (Tate, 1896)

Crassatella astartiformis Tate, 1886: 147, pl. 11, figs 12, 15 *non* Nyst, 1847.
Crassatella corrugata Tate, 1886: 147, pl. 2, fig. 14 *non* Adams & Reeve, 1850.
Crassatella communis Tate in Tate & Dennant, 1896: 129 *nom. nov.* for *Crassatella astartiformis* Tate, 1886 (*non* Nyst, 1847).
Salaputium aldingensis Finlay, 1930: 38, *nom. nov.* for *Crassatella corrugata* Tate, 1886 (*non* Adams & Reeve, 1850).
Salaputium communis—Darragh & Kendrick, 1980: 18, fig. 5A-C; Darragh, 1985: 100, 111, table 1.

Material. WAM 88.155, an external mould (RV) in bryozoal calcarenite; 95.419, an incomplete LV. Two specimens.

Discussion. The synonymy above follows Darragh & Kendrick (1980: 18) in recording the species from the Pallinup Siltstone at North Walpole. The additional material reported here is from the Werrilup Formation and resembles the fine, closely ribbed form of shell characteristic of Walpole specimens. The genus in New Zealand is recorded from the Late Oligocene to Early Miocene (Beu & Maxwell 1990: 398).

Occurrence. Otway Basin: lower and upper Browns Creek Formation, Late Eocene; lower Glen Aire Clay, Early Oligocene. St Vincent Basin: Blanche Point Formation (type), Late Eocene. Bremer Basin: Ocumup No. 1 deep well, 71.7 m, Werillup Formation, Middle Eocene. North Walpole, Pallinup Siltstone, Late Eocene.

Subclass Anomalodesmata Dall, 1889

Order Pholadomyoida Newell, 1965

Superfamily Poromyoidea Dall, 1886

Family Verticordiidae Stoliczka, 1871

Genus **Verticordia** Sowerby, 1844

Type species. Hippagus? cardiiformis Sowerby, 1844. By monotypy. Pliocene, England.

Subgenus **Verticordia** s. str.

Verticordia (Verticordia) sp. B
Fig. 3B

Material. WAM 83.2610. One LV. P301941. Pair, crushed and poorly preserved.

Description. Shell minute, thin, fragile, transversely ovate, longer than high, moderately inflated; umbone broad; beak strongly prosogyrate above recessed lunule; margin mostly poorly preserved, ventral margin missing; cardinal area thickened along margin behind beak; apical area more or less smooth, developing sculpture of 11 thin, spaced radial costellae, weakly spinose on crests; intercostal spaces broad, smooth; internal layer faintly nacreous; interior filled with spicular silica.

Dimensions

	Length	Height	Inflation
WAM 83.2610, LV	4.02	3.27*	1.35

*ventral margin is lost and original height was probably closer to length.

Discussion. The present species differs markedly from *Verticordia (Verticordia)* sp., also from North Walpole, recorded by Darragh & Kendrick (1980: 19), in its fewer (11 against 16) and more widely spaced radials.

Sculptural features likewise distinguish the Walpole species from those from the Miocene of Morgan, Hamilton and Balcombe Bay described by Tate (1887: 149–150, pl. 14, figs 4, 13) and by Pritchard (1901: 30).

Occurrence. Bremer Basin: North Walpole, Pallinup Siltstone, Late Eocene.

Class Gastropoda Cuvier, 1797

Order Patellogastropoda Lindberg, 1986

In limpet systematics, we follow the classification of Lindberg (1986, 1988), in which the name Patellogastropoda replaces Docoglossa Troschel, 1866 and incorporates the families Patellidae, Nacellidae, Lepetidae, Acmaeidae and Lottiidae. By long custom regarded as 'Archaeogastropoda', the patellogastropods are now ranked as a distinct order of the Prosobranchia.

Suborder Nacellina Lindberg, 1988

Superfamily Nacelloidea Thiele, 1891

Family Nacellidae Thiele, 1891

Genus **Nacella** Schumacher, 1817

Type species. Nacella mytiloides Schumacher, 1817 (= *Patella mytilina* Helbling, 1779). Recent, southern Chile.

Nacella (?) jutsoni (Chapman & Crespin, 1934)

Fig. 4L. N

Cellana jutsoni Chapman & Crespin, 1934: 122, 126, pl. 11, fig. 28; Darragh, 1985: 110, table 1.

Material. Holotype NMV P14634 (internal mould) and P14635 (external mould). WAM 67.733. One specimen.

Description. Holotype comprises internal and external moulds in brown siltstone representing small limpet of oval outline, longer than wide; apex low, at anterior fourth, tip small, well defined, directed anteriorly; apical angle (left–right cross-section) *c.* 115°; midline profile gently convex posteriorly, slightly concave anteriorly; apical area smooth; sculpture confined to periphery, of *c.* 48 radial costellae of variable strength and spacing but generally narrower than interspaces; very fine transverse growth striae cross interspaces; margin internally crenulate; muscle scar not apparent.

WAM 67.733 from the Northcliffe district is a small conical-patelliform shell, outline oval, apex at about anterior third, not deflected; apical angles— left–right cross-section *c.* 90°, antero-postero cross-section *c.* 120°; apex to anterior and posterior profiles both very slightly convex; sculpture of up to 40 fine, spaced, radial costellae of variable strength and spacing; apical area without radial sculpture, possibly abraded; no discernible transverse sculpture or siphonal notch; margin probably finely crenulated; internal characters unknown.

Dimensions	Length	Max. width	Height
NMV P14635 holotype, ext. mould	19	13.5	2.5 (est.)
WAM 67.733	13 (est.)	10 (est.)	3.8

Discussion. The holotype and hitherto only known specimen of '*Cellana*' *jutsoni* Chapman & Crespin is a pair of moulds in brown siltstone from the Albany district. A second specimen, WAM 67.733, from the Northcliffe area is a silica replacement of a small limpet with a probably abraded apex, broken anteriorly and along much of the left margin; interior solidly infilled. Despite some differences in relative heights, apical angles and rib totals, we consider them to be probably conspecific, subject to confirmation from further material.

In both specimens, radial ribbing is confined to the periphery, the rest of the exterior being essentially smooth; apex on both specimens is located well anteriorly. These characters are consistent with the Southern Hemisphere offshore genus *Nacella*, to which the species is provisionally referred. The range of variation within *Nacella jutsoni* cannot be established adequately until further material becomes available.

Occurrence. Bremer Basin: Albany, W.A., 'in fine spicular ooze' (type), ie., Pallinup Siltstone, Late Eocene. Northcliffe district, W.A. (see Localities). Quartz gravel (Quagering Beds) containing sparse fossils, presumably reworked from unknown outcrop of Pallinup Siltstone. Late Eocene.

Order Vetigastropoda Salvini-Plawen, 1980

Superfamily Fissurelloidea Fleming, 1822

Family Fissurellidae Fleming, 1822

Subfamily Emarginulinae Gray, 1834

Genus **Emarginula** Lamarck, 1810

*Type species. Emarginula conica* Lamarck, 1810. Recent, North Atlantic.

Emarginula (?) sp.

Fig. 4K, M

Material. WAM 83.2628, 83.2644. Eleven fragments, two with parts of the selenizone. NMV P302011, P302012 nine very incomplete fragments.

Description. Fragments of a robust emarginuline shell with strong sub-cancellate sculpture; apex imperforate, low, blunt, gently inclined posteriorly; selenizone narrow, not elevated, between two narrow ribs, terminating at slit; sculpture of numerous straight, raised, radial costellae, generally alternately stronger and finer, with stronger costae weakly subspinose adapically; transverse sculpture lamellose, adapically only present between costae, toward margin passing across costae to form low scales on their crests; margin unevenly crenulated within, corresponding to radial sculpture; other internal characters unknown.

Fig. 4. A, D–G, *Pseudoninella? squarrosa* sp. nov. A, E–F, NMV P302268, holotype, × 4. D, G, NMV P302269, paratype, × 4. B–C, *Eutinochilus otwayensis* (Pritchard). NMV P134100, lectotype: B, × 9; C, × 7.5. H–J, *Liotina lamellosa* (Tenison Woods). NMV P302173, neotype, × 7.5. K, M, *Emarginula* (?) sp. K, WAM 83.2628a, fragment with marginal sculpture, × 3. M, WAM 83.2644a, anterior fragment with apical part of selenizone (arrow). L, N, *Nacella* (?) *jutsoni* (Chapman & Crespin). L, WAM 67.733, exterior, × 4.9. N, NMV P14635, holotype, external mould (latex peel), × 3.
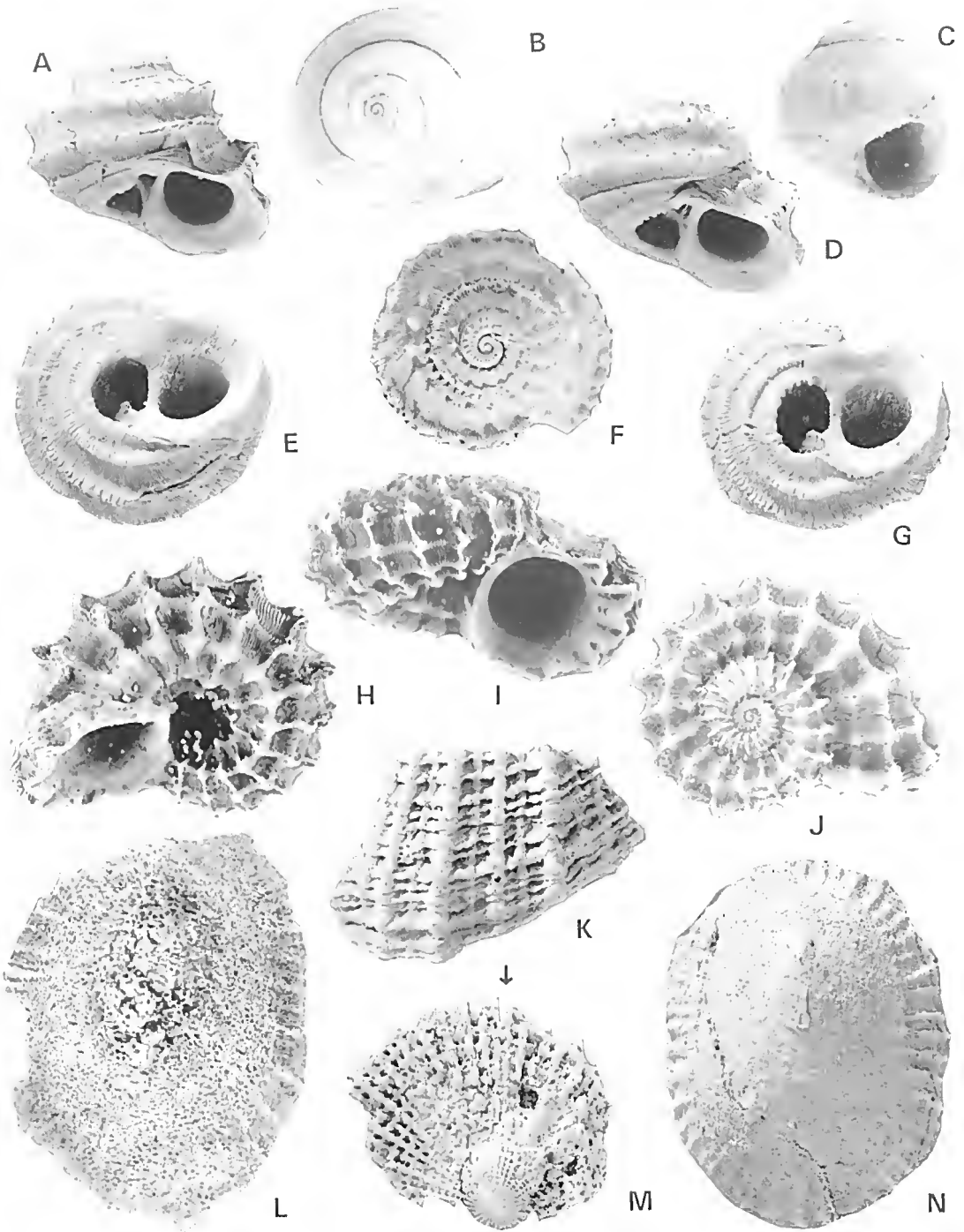
Dimensions. Unobtainable from the fragmentary condition of the material but comparable in size with *Emarginula wannonensis* Harris (1897), ie., up to 20 mm in length.

Discussion. The species is referred with reservations to *Emarginula* from the presence on two fragments (WAM 83.2644) of a clear selenizone, bordered by two narrow ribs. The selinizone on one fragment terminates at a slit. The apical characters are atypical of *Emarginula*, rather more resembling those of the genus *Tugali* Gray, as does the sealed transverse sculpture of the more mature shell. So far as can be seen, the specimen does not closely resemble any known emarginuline from the Australian Tertiary.

Occurrence. Bremer Basin: North Walpole, Pallinup Siltstone, Late Eocene.

Other records of Emarginulinae. Two samples (WAM 83.2645, 83.2646) from North Walpole comprise small, poorly preserved and fragmentary specimens consistent with one or two species of *Emarginula*, additional to the above. The shells are finely sculptured with an incurved, low and posteriorly overhanging apex; dimensions of an internal mould (83.2645) are L 6.5, W 2.6, H 2.3, indicating a shell with a length about twice the width and three times the height. In shape and fineness of sculpture, this material recalls *E. clypeata* Lamarck from the Paris Basin Eocene. A further fragmentary specimen (WAM 95.382) from the Werillup Formation in the Ocumup No. 1 deep well, 53.4 m, may represent a third species of *Emarginula* from the Plantagent Group.

Superfamily Trochoidea Rafinesque, 1815

Family Turbinidae Rafinesque, 1815

Subfamily Liotiinae H. & A. Adams, 1854

Genus **Liotina** Fischer, 1885

Globarena Iredale, 1929.

Type species. Delphinula gervillei Defrance, 1818 by subsequent designation of Cossmann (1888). Lutetian, France.

In according full generic rank to *Liotina* and in the above synonymy, we follow Hickman & McLean (1990: 37).

Liotina lamellosa (Tenison Woods, 1877)

Fig. 4H–J

Liotia lamellosa Tenison Woods, 1877: 96. Table Cape.
Liotia roblini Johnston. 1880: 39. Table Cape; Tate, 1885: 211; Harris, 1897: 284, pl. 8, fig. 4a–c.
Munditia lamellosa—Darragh, 1985: 100, table 1.

Material. WAM 67.105, 69.129, 72.279, 83.2629, 83.2648, 85.633, 95.405, 95.436. Total 118 specimens. NMV P301962, P301963, P301983, P301984, P302173 (neotype). Total 99 specimens.

Description. Shell small, robust, diameter exceeding height; juveniles almost planispiral, adults subdiscoidal; spire low, whorls about four; protoconch of 0.7–1.0 smooth whorls, concordant with shell axis and terminating at onset of very fine axial threads; apical 2.5 whorls depressed, subsequently descending; whorls strongly convex, with subsutural, channelled shelf and impressed suture; peripheral edge of penultimate whorl almost vertical (slightly overhung); periphery of last whorl convexly rounded between projecting axial plicae; base excavate, umbilicus open, broad, deep, on some specimens narrower in adult; aperture circular, peristome continuous, attached to parietal surface; outer and basal lips thickened to form prominent varix; columellar margin free, projecting, evenly rounded; teleoconch sculpture predominantly axial, of three orders; first 0.7 whorls with *c.* 14 simple, close, axial costellae, thereafter becoming stronger, more spaced and plicate at intersections with spirals; on last whorl, primary axials (including apertural varix) number 12–16, on penultimate whorl 16–17; axials continuous onto base, entering umbilicus; spiral sculpture subordinate, beginning as raised points on post-brephic axials, subsequently forming continuous lirae between and across axials; spirals number three or four on penultimate whorl (three on topotypes) and five on last whorl (six on topotypes); another circumumbilical spiral on base and smaller one within umbilicus; tertiary microsculpture of very fine, crowded, axial striae on entire teleoconch, entering umbilicus. Operculum poorly preserved, circular, with concentric growth lines; nucleus not preserved.

Dimensions	Height	Max. diameter	No. whorls
NMV P302173, neotype	4.13	6.69	4.2
WAM 95.436a	5.73	6.96	4.2
WAM 95.436b	3.85	5.26	4.3
WAM 95.436c	4.31	4.84	3.9

Discussion. Johnston (1880: 39) acknowledged the 'marked resemblance' of his species *Liotia roblini* to *L. lamellosa* Tenison Woods and the two were considered to be conspecific by May (1919: 71). May also noted that the type of *L. roblini* was missing from the collection of the Tasmanian Museum but made no mention of the type of

L. lamellosa. Ludbrook (1967) included neither of the above in an inventory of Tertiary molluscan primary types from the same repository, remarking (1967: 65) 'Although the collection represents only a small percentage of the material described by Tenison Woods and Johnston, it appears to be all that remains in Hobart'. Mr Noel Kemp, Tasmanian Museum, advises that neither specimen has been found since Ludbrook's paper was published. We presume therefore that the type material of both *Liotia lamellosa* Tenison Woods and *Liotia roblini* Johnston are now irretrievably lost.

Comparing the descriptions of the above species of Tenison Woods and Johnston (there were no figures), we concur with May's (1919) opinion that they relate to the same species. The former's specimen apparently was a juvenile, about half the size of Johnston's. However to stabilise the names, we propose to designate as neotype, jointly for both *Liotia lamellosa* Tenison Woods and *Liotia roblini* Johnston, NMV specimen P302173 (Fig. 4) from the common type locality of both species, the Longfordian Freestone Cove Sandstone (= *Crassatella* bed of Johnston, 1877: 84), lower bed, Table Cape, north of Wynyard, Tasmania; specimen ex. F. A. Cudmore Collection, 'lower bed, Table Cape'.

Topotypes of *L. lamellosa* from the Freestone Cove Sandstone of Table Cape (NMV collection) are rather thick, heavy shells, some relatively wider and lower in the spire compared with specimens from the Late Eocene of the Bremer Basin but are otherwise very similar and, in our view, conspecific. Small, immature specimens (NMV P302175) from the Browns Creek Formation (lower shell bed), Otway Basin, are identical with those from the Bremer Basin. Other records of the species from Museum Victoria collections are from the lower Glen Aire Clay (Early Oligocene; rare), Jan Jue Formation (Janjukian; rare) and Muddy Creek Formation (Balcombian; common). These records suggest that *L. lamellosa* was more common in relatively shallow waters; however it is common at North Walpole, where water depths are estimated at about 160 m.

L. lamellosa is related, probably ancestrally, to *Liotina tasmanica* (Tenison Woods), which ranges from Kalimnam to Recent according to Ludbrook (1956: 22, pl. 2, fig. 6). The modern specimen from Tasmania attributed to *L. lamellosa* by Tenison Woods (1877: 97) is probably the extant *L. tasmanica*, which differs from *L. lamellosa* in its bicarinate periphery, weaker radials and wider umbilicus (Wilson 1993: 100).

The present species is related to the New Zealand Early Eocene (Mangaorapan?) *Liotina*

turua Maxwell, 1978, Kauru Formation, New Zealand (South Island) (Beu & Maxwell 1990: 94–96, pl. 4, figs l–m). On *L. lamellosa*, the axial costae are more numerous and closer together and the whorl profile is less angulate, compared with Maxwell's species. The prominences at the intersection of the radials and spirals are lower in *L. lamellosa*.

The present species and its congener *L. tasmanica* (Tenison Woods) appear to be a lot closer in shell characters to *Delphinula gervillei* Defrance, the type species of *Liotina* Fischer, 1885 than to *Liotina tryphenensis* Powell, the type species of *Munditia* Finlay, 1927, Recent, New Zealand.

The genus *Liotina* ranges from Eocene to Recent and is recorded from Europe, North and East Africa, Pakistan, Indo-SW Pacific, Japan, South America and Australasia, according to Keen (in Moore 1960: 1267), Morley Davies (1971: 297) and Wenz (1938: 338, fig. 787). It is included among Darragh's (1985: 91) Tethyan Indo-Pacific element.

In the material from Walpole, eight specimens out of 212 (3.8%) have gastropod boreholes, mostly on the spire whorls. Many of the Walpole specimens have been deformed by sediment compaction.

Occurrence. Bass Basin: Freestone Cove Sandstone (type), Early Miocene. Port Phillip Basin: Jan Jue Formation, Early Oligocene. Otway Basin: lower Browns Creek Formation, Late Eocene; lower Glen Aire Clay, Early Oligocene; Muddy Creek Formation, Middle Miocene. Bremer Basin: Ocumup No. 1 deep well, 68.6 m, Werillup Formation, Middle Eocene; North Walpole and Lucky Bay, Pallinup Siltstone, Late Eocene.

Subfamily Angariinae Thiele, 1921

Genus **Pseudoninella** Sacco, 1896

Type species. Delphinula miosolarioides Sacco, 1896.

Pseudoninella? squarrosa sp. nov.

Fig. 4A, D–G

Material. Holotype NMV P302268 from uppermost bed, washout nearest Browns Creek, Johanna, Victoria. Locality PL 3013. Paratype NMV P302269 from uppermost bed, washout nearest Johanna River, Johanna, Victoria. Locality PL 3014. NMV P31006–7. Total 2 specimens.

Description. Shell small, robust, turbinate, diameter exceeding height with about four gradate whorls; apex depressed; suture adpressed, attached immediately anterior to lesser of two prominent

peripheral cords; protoconch of one smooth whorl, concordant with shell axis, terminating at onset of fine radial lamellae, which persist over entire teleoconch (including umbilicus) as prosocline microsculpture; first teleoconch whorl depressed, subsequent whorls strongly gradate with broad concave shelf; last whorl strongly biangulate about periphery, adapical cord stronger; base convex; whorl profile concave between cords; aperture circular, tangential, peristome continuous, extended across parietal area; inner lip recessed; outer lip prosocline, internally smooth and bevelled; umbilicus deep, of moderate width, partly constricted by thickened, crenulate circumumbilical rim. Spiral sculpture initiated on second teleoconch whorl as double row of nodules, which become raised cords bearing scales and tubercles on crest formed by grouping of axial microsculpture; first subsutural cord fine, initially with spaced nodules on crest, changing to elevated scales; second cord strongest, bearing erect scales; third cord peripheral and scaled like second but slightly weaker; fourth cord on base, like third but finer; fifth cord on base, nodose, finer than fourth; one spiral with raised scales within umbilicus; inner layer of shell nacreous.

Dimensions

	Height	Max. diameter	No. whorls
NMV P302268, holotype	8.93	10.20	4.5
NMV P302269, paratype	8.56	10.18	4.3

Discussion. Species of *Pseudoninella* occur widely in the European Tertiary from Paleocene to Miocene but have not been recorded hitherto from Australia. The present species resembles *Pseudoninella raulini* Cossmann & Peyrot, Miocene, France (Cossmann & Peyrot 1917: 75, pl. 3, figs 21–24); *P. depressa* Ravn, Danian, Denmark (Ravn 1933: 29, pl. 2, fig. 3a–c); and *P. bronni* (Philippi), Early Oligocene, Germany (Koenen 1892: 871, pl. 56, fig. 1a–c), but seems to be more depressed apically than any of these.

The syntype of *Delphinula miosolarioides* Sacco (Middle Miocene, Italy) is a poorly preserved specimen, of which the original figure conveys little. This specimen, refigured by Ferrero Mortara et al. (1984: 274, pl. 50, fig. 2), appears to be an internal mould retaining remnants of shell, which leaves some uncertainty as to the essential diagnostic characters of *Pseudoninella*. However, there seems little doubt that the present species, together with that which follows, are closely related to the species cited above.

Small turbiniform opercula of circular to subcircular outline occur in the upper levels of the Browns Creek Formation. Most of these are probably referrable to *Bolma*, which is common there, but some may be derived from the present species. This can only be settled by the collection of an associated shell and operculum.

A second species of *Pseudoninella* is reported below from the Plantagenet Group of the Bremer Basin. It differs from the present species in being wider relative to height and in having a more depressed spire and more numerous spiral cords (nine).

The specific name is derived from the Latin *squarrosa* (feminine), rough, with scales or processes, etc.

Occurrence. Otway Basin: upper Browns Creek Formation, Late Eocene.

Pseudoninella? sp.

Fig. 8C–E

Material. WAM 69.131, 72.237, 83.2651, 95.366, 96.249. Five juvenile specimens.

Description. Shell minute, subdiscoidal, diameter exceeding height, spire low, apex depressed for initial 2.5 whorls; suture initially incised, becoming canaliculate on last whorl, attached just below bicarinate periphery; base convex with deep, moderately wide umbilicus; protoconch of one smooth whorl, terminating at a weak varix and succeeded by very fine, crowded axial threads, persisting over entire teleoconch (including umbilicus) as orthocline microsculpture; from c. 1.7 whorls, initially two, then four spiral cords develop, which are, at first, nodulose, becoming finely scalar by penultimate whorl; new cords arise by intercalation; last whorl with four scaled cords above periphery, two stronger scaled cords form bicarinate periphery with five scaled cords on base, of which fifth (circumumbilical) is strongest; within umbilicus are two additional fine cords with recurved scales; aperture broken, internally smooth, circular; peristome probably continuous; columella smooth, everted at apertural margin; innermost shell layer nacreous.

Dimensions

	Height	Max. diameter	No. whorls
WAM 72.237	1.81	3.62	3.5+

Discussion. All specimens to hand are minute and none has an intact aperture. We consider them to be juveniles of a species distinct from but closely related to *Pseudoninella? squarrosa* sp. nov., described above.

The principal differences with the foregoing are, most obviously, the greater number of spiral cords (nine against five) on the last whorl and the presence of two cords within the umbilicus. The circumumbilical cord is distinct and well developed in the present species but reduced to a thickened, crenulate rim in the other. The apex is more depressed, the umbilicus narrower and less constricted and the periphery less bicarinate in the present species. Otherwise, particularly in the nature of the axial microsculpture and its elaboration on the crests of the spiral cords, the two species are rather similar and, in our view, congeneric.

Further determination of this species depends on the collection of mature specimens.

Occurrence. Bremer Basin: Ocumup No. 1 deep well, 56.4 m, Werillup Formation, Middle Eocene; North Walpole, Pallinup Siltstone, Late Eocene.

Subfamily Colloniinae Cossmann, 1916

Genus **Collonia** Gray, 1850

Type species. Delphinula marginata Lamarck, 1804. By subsequent designation of Cossmann (1888). Lutetian, France.

We utilise the genus in the broader sense adopted by Hickman & McLean (1990).

Collonia variabilis sp. nov.

Fig. 8A–B, G

Material. Holotype NMV P302634, from PL3014, uppermost shell bed, washout nearest Johanna River, Johanna, Victoria. Paratypes NMV P302263; WAM 94.664a–e. Total of 11 specimens, all from type locality.

Other material. NMV P302256, P302257, P302259, P302261. Total of 40 specimens.

Description. Small for genus, depressed–turbinate, wider than high; spire usually low, occasionally slightly elevated; whorls to 3.5, convexly rounded; last whorl evenly rounded or faintly subangulate above periphery; suture lightly impressed, becoming adpressed and terminally descending in maturity; protoconch of one smooth whorl, not set off from teleoconch; aperture (mature) circular, peristome continuous with narrow adaxial internal thickening; adapical margin near-tangential to previous whorl; columella concave, thickened at parietal attachment and anteriorly by low umbilical keel; umbilicus wide to narrow (immature), becoming entirely sealed (mature) by expansion of umbilical keel;

spire sculpture with or without short prosocline axial folds, strong to faint or absent and confined to subsutural shelf; fine spiral thread borders suture; spire otherwise smooth, polished; base with weak spiral striae and on some specimens, weak short axial folds radiating from umbilicus (if open); circumumbilical keel weak, weakly nodulose; internally strongly nacreous.

Dimensions	Height	Max. diameter	No. whorls
NMV P302634, holotype	1.7	2.2	3.3
WAM 94.664a, paratype	1.59	2.62	4.3

Discussion. With its rather variable umbilical features and sculpture, the present species does not agree readily with any of the subgenera of *Collonia* in either Cossmann (1918: 53–63) or Keen in Moore (1960: 1269–1270) and we defer subgeneric assignment.

The species superficially recalls *Crossea parvula* Tenison Woods from the Early to Middle Miocene of Victoria (Tenison Woods 1880: 4, pl. 1, fig. 7); however that species is widely umbilicated and is not internally nacreous. The present species lacks the strong granose circumumbilical spiral of *C. marginata* (Lamarck). It is more rounded in whorl profile than *C. canalifera* (Lamarck) from the French Middle Eocene and lacks the thickened, slightly reflexed outer lip of that species.

Of the 51 specimens to hand, 4 (8%) bear naticiform boreholes, three on the base, one on the spire.

Occurrence. Otway Basin: upper Browns Creek Formation, Late Eocene.

Genus **Homalopoma** Carpenter, 1864

Type species. Turbo sanguineus Linnaeus, 1758. Recent, Mediterranean.

Our location of *Homalopoma* within the subfamily Colloniinae follows Hickman & McLean (1990).

Subgenus **Homalopoma** s. str.

Homalopoma (Homalopoma) limnaios sp. nov.

Fig. 5G–H, K, N

Material. Holotype WAM 83.2620a, from 26 km along Thompson Highway north from Walpole, Western Australia. Paratypes WAM 83.2620b–d, 83.2632a–c, 95.562. NMV P302031. Total of 8 specimens, all from the type locality.

Other material. WAM 67.101, 69.119, 72.238, 72.275, 80.1329, 82.1481, 83.2620, 83.2624, 83.2625, 83.2631, 83.2632, 85.629, 85.1458, 95.547, 95.548. Total of 118 specimens. NMV P302013, P302014, P302015, P302016, P302028, P302039, P302030. Total of 95 specimens.

Description. Shell small for genus, of about five whorls in a height of 6 mm, thick, robust, roundly trochiform, squat, height slightly exceeding diameter; spire short, truncated, apical area, comprising first 2.5 whorls, slightly sunken; last and penultimate whorls swollen, the former contracted towards aperture. Protoconch paucispiral, depressed, initially smooth for about 1.3 whorls, then gradually developing very fine, close axial threads; at 1.7 whorls, weak nodules appear, to form three primary, nodose, spiral lirae (2.0 whorls); at about 2.5 turns, whorl begins to descend, acquiring by intercalation two more nodose spirals; lirae total five above periphery on penultimate whorl and two below, latter lirae scaled, not nodose; last whorl with 11–14 spirals from suture to base, all finely nodose to scabrous and becoming obsolete abapically; lirae about as wide as interspaces except on base where they are narrower; lirae and interspaces crossed by very fine, close, prosocline growth striae; suture canaliculate, descending at aperture; aperture continuous, circular and with thick, internally bevelled, recessed rim, presumably to receive operculum; outer lip prosocline with narrow marginal rim; columella smooth, evenly rounded; narrow callus extending continuously over parietal area to columellar area; umbilicus open and spirally striate in juvenile, becoming sealed in adult; umbilical area bordered by slightly more prominent nodose spiral. Inner shell layer weakly nacreous. Operculum not seen.

Dimensions	Height	Max. height	No. whorls
WAM 83.2620a, holotype	5.9	5.2	5.0
WAM 83.2620b, paratype	5.9	5.2	5.0
WAM 83.2620c, paratype	5.7	5.1	4.9
WAM 83.2620d, paratype	6.1	4.9	4.7
WAM 83.2632a, paratype	6.0	5.3	4.8
WAM 83.2632b, paratype	5.2	4.7	4.7
WAM 83.2632c, paratype	5.4	5.0	4.5
WAM P302021, paratype	5.4	4.8	4.5

Discussion. The present species differs from all congeners known to us, eg., *H. sanguineum* (Linnaeus), *H. obtusalis* (Baudon), *H. inermis* (Deshayes) (the two latter from the Lutetian of the Paris Basin), in its abbreviated spire, depressed apex, narrower whorls relative to height and deeply canaliculate suture. The Walpole species is similar in size and shape to *H. eugenii* (Deshayes), also from the Paris Basin Lutetian but differs in having scabrous rather than smooth lirae.

This is the first record from the Australian Tertiary of this wide-ranging Cenozoic genus *sensu stricto*, which, according to Hickman (1974) was 'well defined ... in shallow waters throughout the Eocene'. The ex-Australian stratigraphic range of the genus s. str. is Paleocene–Recent in Europe and Eocene–Recent in the Americas (Keen, in Moore 1960: 1270). Modern records are from warm temperate to tropical seas, excluding southern Australia.

Of the 222 specimens available for examination, 38 had one gastropod borehole and three each had two boreholes, in all cases on the base and usually close to the umbilical area; predation rate is 18%.

The specific name is from the Greek *limnaios*, of a marsh, descriptive of the type locality.

Occurrence. Bremer Basin: North Walpole (type) and Lucky Bay, Pallinup Siltstone, Late Eocene.

<div align="center">

Genus **Eutinochilus** Cossmann, 1918

</div>

pro *Homalochilus* Cossmann, 1892 *non* Fischer, 1856.

Type species. Collonia miliaris Cossmann, 1892. Lutetian, France.

<div align="center">

**Eutinochilus otwayensis** (Pritchard, 1904)

Fig. 4B–C

</div>

Collonia otwayensis Pritchard, 1904: 331, pl. 18, figs 6, 7.
Collonista otwayensis—Darragh, 1985: 101, table 2: 113.

Material. NMV P134100 lectotype, P301985, P301986, P302176, P302177, P302178, P302179, P302180. Total 147 specimens. WAM 67.102, 69.125, 72.281, 95.387, 95.598. Total 124 specimens.

Fig. 5. A, E–F, P–Q, *Bolma (Bolma) flindersi darraghi* Beu & Ponder. A, P, operculum WAM 95.611a, exterior: A, × 8.7; P, × 9.3. E–F, WAM 78.922d, juvenile, × 8.6. Q, WAM 83.2623a, showing unworn sculpture, × 4. B–D, *Astralium?* sp., WAM 85.1446, juvenile, × 4. G–H, K, N, *Homalopoma (Homalopoma) limnaios* sp. nov. G–H, WAM 83.2620a, holotype, × 6.2. K, N. 83.2632a, paratype, × 6.5. I–J, *Tricolia (Tricolia) psilia* sp. nov. I, WAM 67.107a, holotype, × 6.3. J, WAM 83.2619a, paratype showing operculum *in situ*, × 6.5. L–M, O, *Turbo (Euninella)* sp. cf. *T. (E.) hamiltonensis* Harris. L–M, WAM 85.631a, operculum, internal, external, × 6.8. O, WAM 83.2639, fragment opposite aperture showing sculpture, × 4.
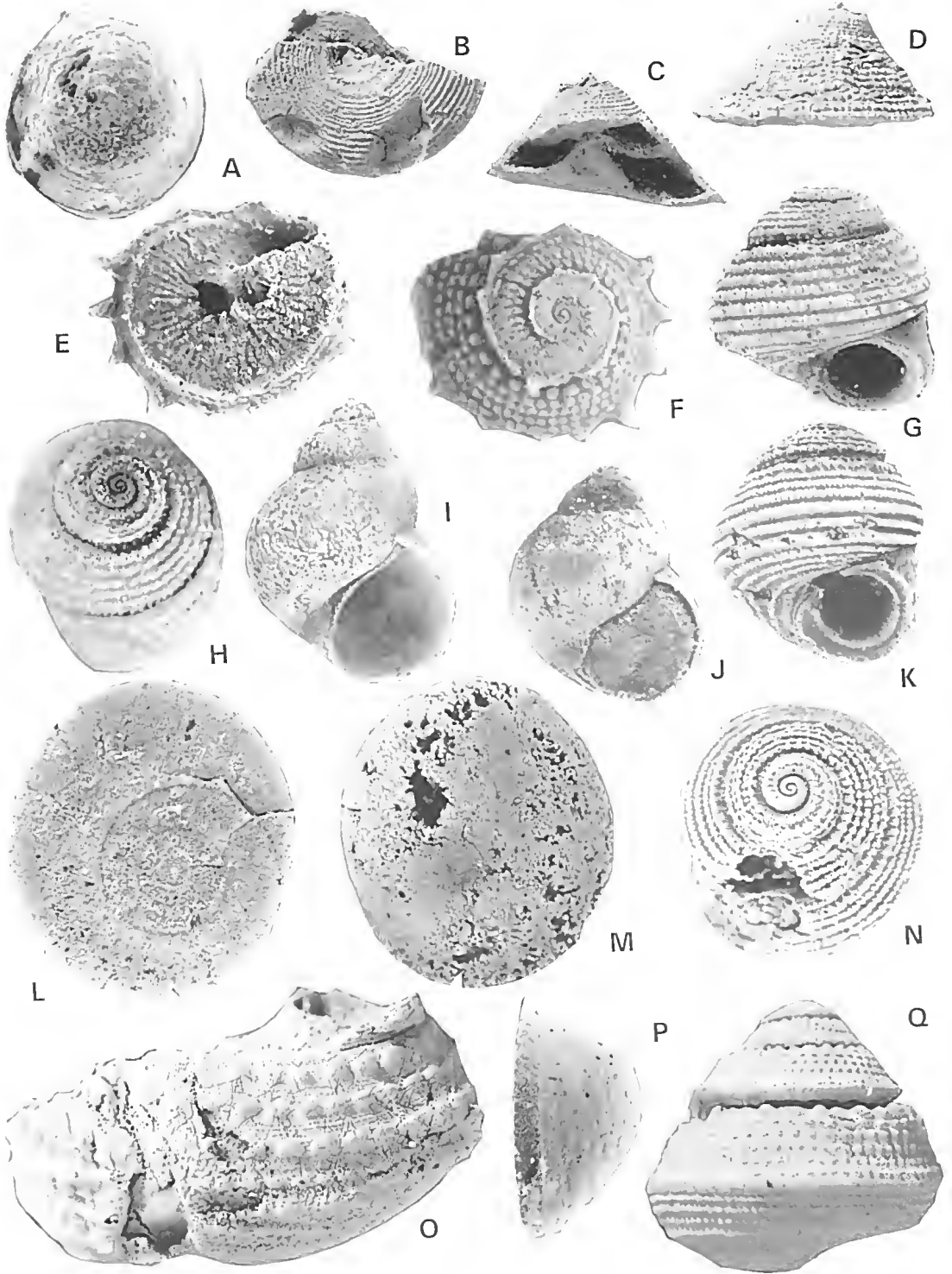
Description. Shell small to minute, robust, sub-globose–turbiniform, diameter usually exceeding height when immature, tending to reverse when fully grown; apex bluntly rounded; protoconch usually somewhat flattened, of 1.0–1.5 whorls, on well-preserved specimens seen to be separated from teleoconch by very fine axial thread; spire low to moderately elevated; whorl profile slightly to moderately convex according to position of sutural plane relative to periphery; whorls very slightly depressed below (anterior to) suture; suture incised, weakly offset below by a spiral thread, more apparent near aperture; teleoconch sculpture variable, either with light to very faint spiral striae or smooth; apical whorls on some specimens (NMV P302179) weakly to moderately axially ridged; base a little flattened and bordered by weak angulation in immature specimens, more convexly rounded in adult, with or without faint spiral striae; with or without small, shallow, umbilical recess; aperture ovate, higher than wide, slightly oblique, peristome discontinuous, adapically descending and projecting; outer lip prosocline and internally bevelled, forming (adult) sharp edge; columellar lip thickened and with callus extending onto base, occasionally with weak tubercle (mature shells) and joining with basal rim of aperture; small parietal glaze extends to columellar area; interior not nacreous; operculum unknown.

Dimensions	Height	Max. diameter	No. whorls
NMV P134100, lectotype	4.00	3.90	5.0
NMV P302176, topotype	4.06	3.13	5.0
NMV P302177	3.59	2.92	4.8
NMV P302178	3.04	2.44	4.5
NMV P302179	2.39	3.07	4.2
NMV P302180	2.44	2.88	4.0
WAM 67.102	2.66	2.72	4.3
WAM 69.125	2.45	2.69	4.2
WAM 72.281	2.78	3.01	4.2
WAM 95.387	2.51	2.61	4.12

Discussion. Pritchard's type material appears to have comprised three specimens (Pritchard 1904), only one of which (his figured specimen) has been located in this study. Because Pritchard did not choose a holotype and to ensure that the species name continues to be used as before, we now designate his extant specimen, NMV P134100 (MUGD 1818), as lectotype of *Collonia otwayensis* Pritchard. The type locality is 'Point Flinders' (PL 3019), near Cape Otway, Victoria, from the lower Glen Aire Clay.

The materials to hand, drawn from the Browns Creek Formation, Glen Aire Clay, Blanche Point Formation, Pallinup Siltstone and Werillup For-mation, vary somewhat, both within and between samples but we view this as intraspecific variation, reflecting perhaps environmental, predation and clinal factors, singly or in combination and we see no justification for the taxonomic separation of any of these.

The largest specimens in our material (H >4 mm, W *c.* 5) are from the Glen Aire Clay and present a more exert spire than those from elsewhere. This arises from the tendency of the plane of sutural attachment to change direction with growth so that the suture shifts from being at or slightly above the periphery to slightly below, thus generating a more convex whorl profile, a more elevated spire and rounded base. Specimens with a height of up to 3 mm and less than 4.5 whorls tend to have a gently convex whorl profile, low spire, slightly flattened base and a maximum diameter greater than the height. This latter is the more common form of shell in our material overall, particularly (though not exclusively) that from the Bremer Basin.

Fine, close, spiral sculpture on spire and/or base varies in strength and persistence in all of the samples to hand and may be absent altogether. Specimens from the Browns Creek Formation and Pallinup Siltstone tend to be lightly sculptured or smooth, though poor replication may have diminished this character to a degree among the latter. A single shell (WAM 95.398) from the Werillup Formation entirely lacks spirals. Low axial ridges are present on the spire whorls of some Browns Creek specimens, becoming obsolete on the last whorl.

Most specimens from the Glen Aire Clay have a sealed umbilicus (some retaining, nevertheless, a distinct umbilical depression), one has an open immature umbilicus. Shells from Browns Creek Formation, Blanche Point Formation and Pallinup Siltstone have closed or narrowly open umbilici, depending on individual variable growth parameters.

Specimens somewhat similar to the present occur in the Fishing Point Marl (Early Miocene) and Muddy Creek Formation (Middle Miocene). The latter resemble in shape specimens from the Glen Aire Clay but are even larger. Taxonomic con-sideration of these is deferred.

A high predation rate seems to have been a factor influencing shell size and hence proportion. The largest single source of specimens, North Walpole (Pallinup Siltstone), contributed 75% of the study material and of these 44 shells or 22% showed gastropod boreholes, almost all of bevelled–naticiform type, the shell base being the preferred site of attack. The overall predation rate

is 22%. The likely principal predator is the small naticid *Friginatica aldingensis* (Tate), which is not uncommon at North Walpole and elsewhere.

The present species compares well with the description and figures of *Collonia utiliaris* Cossmann 1892 from the Lutetian of Parnes, Paris Basin, which is type species of *Eutinochilus* Cossmann (Cossmann 1918; 129–130, pl. iv, figs 13–14). The genus *Argalista* Iredale, 1915 has been utilised in Australia and New Zealand for species resembling the present but its type species is dissimilar, being more umbilicate and having a lower spire. Umbilical size, however, varies somewhat among other species assigned to that genus, eg., *Argalista kaipareusis* Finlay, Early Miocene, New Zealand (Beu & Maxwell 1990; pl. 53f, i). The type species of *Collonista* Iredale, 1918, *Collonia picta* Pease, 1868 (Recent) has a turbiniform shell with very strong spiral lirae, again quite unlike our study material.

From topotypic material kindly lent to us by the New Zealand Institute of Geological & Nuclear Sciences, we consider the present type species to be very close indeed to '*Argalista' proimpervia* Laws, 1935 from the Kaiatan–Whaingaroan (Late Eocene–Oligocene) of New Zealand (Beu & Maxwell 1990: 113, 404). This seems to be a little larger than the Australian specimens and more consistently marked with fine spirals; the two species are unquestionably congeneric.

The genus (as *Collonista*) is included among Darragh's (1985: 91) Tethyan Indo-Pacific element.

Occurrence. Otway Basin: upper Browns Creek Formation, Late Eocene; lower Glen Aire Clay (type), Early Oligocene. St Vincent Basin: Blanche Point Formation, Late Eocene. Bremer Basin:

Ocumup No. 1 deep well, 54.8 m, Werillup Formation, Middle Eocene. North Walpole, Pallinup Siltstone, Late Eocene.

Subfamily Turbininae Rafinesque, 1815

Genus **Turbo** Linnaeus, 1758

Type species. *Turbo petholatus* Linnaeus, 1758. By subsequent designation of Montfort (1810). Recent, Indo-SW Pacific.

Subgenus **Euninella** Cotton, 1939

Type species. *Turbo gruneri* Philippi, 1846. By original designation. Recent, southern Australia.

Turbo (Euninella) sp. cf. T. (E.) hamiltonensis Harris, 1897

Fig. 5L–M, O

cf. *Turbo hamiltonensis* Harris, 1897: 274, pl. 8, fig. 3a–c.

Material. WAM 83.2639, 85.631. One incomplete shell and two opercula.

Description. The shell comprises part of the last whorl and columella, possibly a little deformed by compaction. Small for genus and subgenus, whorl profile convexly rounded, with weak peripheral carina; sculpture (suture to base) of 14 spiral ribs of diverse strengths; three subsutural ribs are prominently beaded, fourth narrower and more lightly beaded; these four ribs are well spaced,

Formation	Catalogue Nos	No. of specimens	No. bored	% bored
Glen Aire Clay	NMV P302176	12	4	33
Glen Aire Clay	NMV P302177	9	3	33
Browns Creek Formation	NMV P302179	4	1	25
Browns Creek Formation	NMV P302180	5	4	80
Blanche Point Formation	NMV P302178	17	3	18
Pallinup Siltstone	NMV P301985	1	1	100
Pallinup Siltstone	NMV P301986	98	20	20
Pallinup Siltstone	WAM 67.102	16	4	25
Pallinup Siltstone	WAM 69.125	10	4	40
Pallinup Siltstone	WAM 72.281	1	—	—
Pallinup Siltstone	WAM 95.598	96	15	16
Werillup Formation	WAM 95.387	1	—	—
	Totals	270	59	22

Table 2. Gastropod predation in *Eutinochilus otwayensis*.

occupying adapical shoulder of whorl between suture and periphery; latter bears a strong, continuous, slightly irregular spiral rib; below periphery are ten spirals, some beaded and becoming obsolete toward umbilical area; intercostal spaces bear very fine spiral striae (1–3) and weak, spaced, transverse, slightly prosocline growth ridges; columella evenly rounded, thick and callused over umbilical area; apertural profile a little wider than high, probably due to deformation; internal shell in places faintly nacreous. Operculum small, oval, higher than wide, exterior finely pustulose, asymmetrically convex with shallow eccentric depression, bordered by low spiral rib and narrow peripheral flange; interior flat, spiralled, nucleus eccentric.

Dimensions. Standard dimensions are unobtainable from this incomplete specimen; the aperture from columella to outerlip measures 8 mm, vertically about the same. Estimated original height 25 mm. The larger operculum measures 7.24 × 6.29 (diameters) and 1.76 max. thickness.

Discussion. As far as can be observed from the available characters, the present species appears to be related closely to the Balcombian *T. (E.) hamiltonensis* Harris. It differs in that the whorl profile is more rounded with reduced angulation. The beaded spirals between suture and periphery are similar but a little stronger on the Walpole shell, recalling this aspect of *T. (E.) tenisoni* Finlay. The basal sculpture is closer to that of *T. hamiltonensis* than of *T. tenisoni*. Both species are figured by Harris (1897: 273–274, pl. viii, figs 2–3), the latter as *T. etheridgei* Tenison Woods, 1877 [*non* Lycett, 1857].

Our association of the shell from North Walpole with opercula from Lucky Bay is circumstantial and subject to confirmation from the collection of further material.

The subgenus is included among Darragh's (1985) Southern Australian Endemic element. This record extends the first appearance of *Euminella* back from the Late Oligocene to the Late Eocene.

Occurrence. Bremer Basin: North Walpole and Lucky Bay, Pallinup Siltstone, Late Eocene. The type locality of *T. (E.) hamiltonensis* is Muddy Creek, Victoria (= Muddy Creek Formation, Middle Miocene, Balcombian).

Genus **Bolma** Risso, 1826

Type species. Turbo rugosus Linnaeus, 1767. Pliocene–Recent, Mediterranean.

Subgenus **Bolma** sensu stricto

Bolma (Bolma) flindersi darraghi
Beu & Ponder, 1979

Fig. 5A, E–F, P–Q

Bolma flindersi darraghi Beu & Ponder, 1979: 20–21, fig. 5a–h.

Material. WAM 67.108, 69.127, 78.922, 80.1332, 83.2623, 83.2640 (opercula), 83.2641, 85.630, 85.1448, 88.157, 95.611 (opercula). Total 20 shells, four opercula. NMV P47775, P47776, P47777, P301961, P302000 (operculum). Total eight shells, one operculum.

Description (Walpole material). Shell small, robust, trochiform, a little wider than high, 6.2 whorls in a height of 10.7 mm; spire whorls flattened in profile, subtending an angle of about 70°; last whorl with rounded but distinct peripheral keel and lesser basal carination, profile between these slightly concave; plane of attachment a little below periphery, to form canaliculate suture; base slightly convex; aperture subcircular, slightly wider than high, discontinuous with small parietal callus; columella thick, rounded, smooth and somewhat varicose at base; outer lip rounded, prosocline; umbilicus perforate and bounded by a gemmate cord in juvenile specimens, closed in adults; protoconch smooth, lobate, initial 1.5–2.0 whorls sunken, thereafter becoming emergent, astraeiform and spinose at raised periphery; at third whorl, fine radial costellae and more distinct peripheral spinosity appear as whorl begins to descend; at 3.5 whorls, a strong subsutural gemmate spiral appears, followed by others of variable prominence (up to eight including peripheral carina) on subsequent whorls; spinosity variable, usually present on early whorls and may persist weakly or be absent from mature whorls; between peripheral and basal carinae, two or three beaded spirals occur; base smooth in juveniles (up to five whorls), acquiring up to seven weak, beaded spirals on adult shells (6.2 whorls); operculum subcircular, nucleus slightly eccentric, sunken, internal surface slightly concave, external strongly convex, slightly pustulose centrally, elsewhere transversely wrinkled and with distinct marginal rim.

Dimensions	Height	Max. diameter	No. whorls
WAM 83.2623a	10.7	11.2	6.4
WAM 83.2641b	7.1	8.3	5.4

Remarks. The Western Australian specimens of *B. (B.) flindersi darraghi* from Walpole differ consistently from those from the type area (Browns

Creek Formation, Johanna River district, Otway Basin) in their more depressed apex, greater spire angle, reduced spinosity on the adult whorls and more numerous, gemmate (non-scalar) spirals. The reduced spinosity appears, from several well-preserved examples (eg., WAM 83.2623a, 83.2641c), to represent an authentic morphological variant and not a consequence of abrasion. Three incomplete specimens from near Lucky Bay, east of Esperance (WAM 80.1332, 85.630, 85.1448) are closer, both geographically and morphologically, to Victorian material in their more elevated, pagodiform spire, lesser apical angle and greater spinosity (extending to the periphery of the last whorl). These differences between the Walpole–Lucky Bay and Victorian material we regard as intraspecific, possibly clinal.

The present subspecies appears to be ancestral to *B. (B.) flindersi flindersi* (Tenison Woods), described from the Early Miocene (Longfordian Stage) of Table Cape, Tasmania (Beu & Ponder 1979). The genus is included in Darragh's (1985: 91) Tethyan Indo-Pacific element.

Occurrence. Otway Basin: lower Browns Creek Formation (type), Late Eocene. Bremer Basin: North Walpole and Lucky Bay, Pallinup Siltstone, Late Eocene.

Genus **Astralium** Link, 1807

Type species. Turbo calcar Linnaeus, 1758. By subsequent designation of Fischer, 1873. Recent, Indo-SW Pacific.

Bellastraea Iredale, 1924.

Astralium? sp.

Fig. 5B–D

Material. WAM 85.1446. One juvenile shell.

Description. Shell small, immature, lacking apex and part of last whorl; robust; broadly conical, wider than high; spire profile slightly coeloconoid; spire angle almost 90°; sutures adpressed, attached at periphery which is projecting, carinate, not spinose; peripheral angle 55°; base flat with open, shallow umbilical depression; aperture poorly preserved, wider than high; columella short, oblique; sculpture of fine, close, gemmate, spiral lirae, seven per whorl, that below suture with more prominent beading; a few very fine intercalary spirals present; base with 14 fine, non-gemmate spirals, about equal in width to interspaces; umbilical depression bordered by a thicker spiral and with a finer one within.

Dimensions	Height	Max. diameter	No. whorls
WAM 85.1446	6 (est.)	8.8	3+

Discussion. Previous records of *Astralium* from the Australian Tertiary are from the Longfordian Freestone Cove Sandstone, Balcombian Muddy Creek Formation and Pliocene Dry Creek Sands and Roe Calcarenite (Ludbrook 1967; Tenison Woods 1879; Ludbrook 1941, 1956, 1978). The present species, as far as can be seen from the limited material, differs from all of these in its finely gemmate spiral sculpture (spire), near-flat spire profile and absence of spinosity, the latter notwithstanding its juvenile state. This appears to be a true character, not a consequence of abrasion, to which the shell has certainly been subjected.

The sculpture of the shell is not unlike that of *Trochus virgatus* Gmelin, type species of the subgenus *Tectus (Cardinalia)* Gray, 1847 and of other trochid species. However, the keeled periphery and umbilical configuration are very much like those of *Astralium*.

Occurrence. Bremer Basin: Lucky Bay, Pallinup Siltstone, Late Eocene.

Subfamily Tricoliinae Woodring, 1928

Assignment of the Tricoliinae to subfamilial rank within the Turbinidae follows Hickman & McLean (1990).

Genus **Tricolia** Risso, 1826

Type species. Turbo pullus Linnaeus, 1758. Recent, North Atlantic.

A synonymy of the genus was given by Robertson (1985).

Tricolia psilia sp. nov.

Fig. 5I–J

Material. Holotype WAM 67.107a, from 26 km along Thompson Highway north from Walpole townsite, W.A. Paratypes WAM 67.107b, 83.2619, 83.2630a, 83.2650a–f. Total of 12 specimens. NMV P302253. One specimen. All specimens from type locality.

Other material. WAM 67.107, 69.128, 72.280, 83.2619, 83.2630, 83.2650. Total of 153 specimens. NMV P301989–92. 119 specimens.

Description. Shell small, robust, higher than wide, subglobose, naticoid (juvenile) to bulimoid (maturity); height relative to width increasing with

growth; spire equal to about half total height; spire angle 55°; whorls evenly rounded; suture impressed, attached below periphery; protoconch smooth, merging imperceptibly with teleoconch; aperture ovate, higher than wide, angulate above; peristome discontinuous, joined (maturity) by parietal callus; outer lip thin, prosocline, not expanded; columella narrow, raised, evenly curved and extending across but not sealing narrow umbilical fissure (maturity); surface smooth; colour pattern not retained; operculum subpyriform, externally concave, angulate above, rounded below, thickened along adaxial margin; abaxial margin narrowly ridged (paratype WAM 83.2619a).

Dimensions	Height	Max. diameter	No. whorls
WAM 67.107a, holotype	6.97	4.68	5.6
WAM 67.107b, paratype	4.91	3.68	4.9
WAM 83.2630, paratype	5.95	4.26	5.3
NMV P302253, paratype	6.1	4.3	5.3

The height : maximum diameter ratios of the above are 1.48, 1.33, 1.39 and 1.42 respectively, demonstrating the change of shape with growth.

Discussion. The genus *Tricolia* is well represented (as '*Phasianella*') in the Eocene of the Paris Basin (Cossmann & Pissarro 1910: pl. 5, figs 35-1–12) and the Walpole species is broadly comparable with several of these, eg., *T. parisiensis* (d'Orbigny). We have compared our material with specimens (WAM 80.1444, 82.1378) of (Lamarck), type species of the subgenus *Phasianochilus* Cossmann, 1918, noting that both species share a moderately elevated spire with well-impressed sutures. Both have a minute but distinct umbilical fissure but in the Walpole species this develops only in mature specimens and is absent in juveniles. Our largest specimen, the holotype, is much smaller than shells of Lamarck's species.

Robertson (1985) has revised the Indo-West Pacific species of *Tricolia*, all extant; the oldest record of these, *T. variabilis* (Pease), is from the Early Miocene of Bikini Atoll (Ladd 1966). Specimens of *T. variabilis* are deeply grooved beside the columella and do not greatly resemble the Walpole species. According to Robertson (1985), sexual dimorphism occurs in the shells

of some species of *Tricolia*, including *T. variabilis*, in which the males are smaller than females and have a flared outer lip. We have been unable to recognise this in the present species.

There are no previous records of *Tricolia* from the Tertiary of either Australia or New Zealand (Beu & Maxwell 1990), though the genus is represented in WAM collections from the Roe Calcarenite of the Eucla Basin. The genus *Pellax* Finlay, 1926 (type species *Phasianella huttoni* Pilsbry) has sometimes been associated with *Tricolia* (eg., Ludbrook 1956: 25) but has been shown by Ponder (1965) to be a mesogastropod and a synonym of *Eatoniella* Dall, 1876 of the Eatoniellidae. *Pellax jejuna* Ludbrook from the Dry Creek Sands of the St Vincent Basin is not a phasianelline, according to Robertson (1985: 23, fig. 15).

The specific name is from the Greek *psilos*, bare, smooth.

Occurrence. Bremer Basin: North Walpole, Pallinup Siltstone, Late Eocene.

Family Trochidae Rafinesque, 1815

Subfamily Eucyclinae Koken, 1897

Genus **Danilia** Brusina, 1865

Olivia Cantraine, 1835 *non* Bertholoni, 1810.
Craspedotus Phillippi, 1847 *non* Schoenherr, 1844.

Type species. *Monodonta tinei* Calcara, 1835. Recent, Mediterranean.

In the above taxonomic arrangement, we follow Wenz (1938) and Hickman & McLean (1990).

Danilia vialis sp. nov.

Fig. 6E–I

Material. Holotype WAM 67.103, from 26 km along Thompson Highway north of Walpole townsite, W.A. Paratypes WAM 72.276, 83.2635, 85.1447, 95.612. Total of nine specimens. Paratype NMV P302183. One specimen.

Fig. 6. A, *Calliostoma* (s.l.) sp. WAM 95.613a, × 6.5. B–D, *Circulus* sp. WAM 67.104, × 8.2. E, I, *Danilia vialis* sp. nov. E, WAM 67.103, holotype, × 5.6. I, WAM 83.2635a, paratype, × 6.5. F, *Micrelenchus (Plumbelenchus) lirulatus* sp. nov. NMV P302185, holotype, × 4. G, *Danilia euglypta* sp. nov. NMV P302208, holotype, × 6.7. H, *Carinastele* (?) sp. WAM 80.1330, × 6.6. J–K, *Micrelenchus (Plumbelenchus) annulatus* sp. nov. J, WAM 83.2622c, paratype, × 6.7. K, WAM 83.2622a, holotype, × 6. L–M, *Clanculus* (s.l.) sp. WAM 95.573a, × 4. N, *Agathodonta* (?) sp. WAM 67.99, × 5.7.
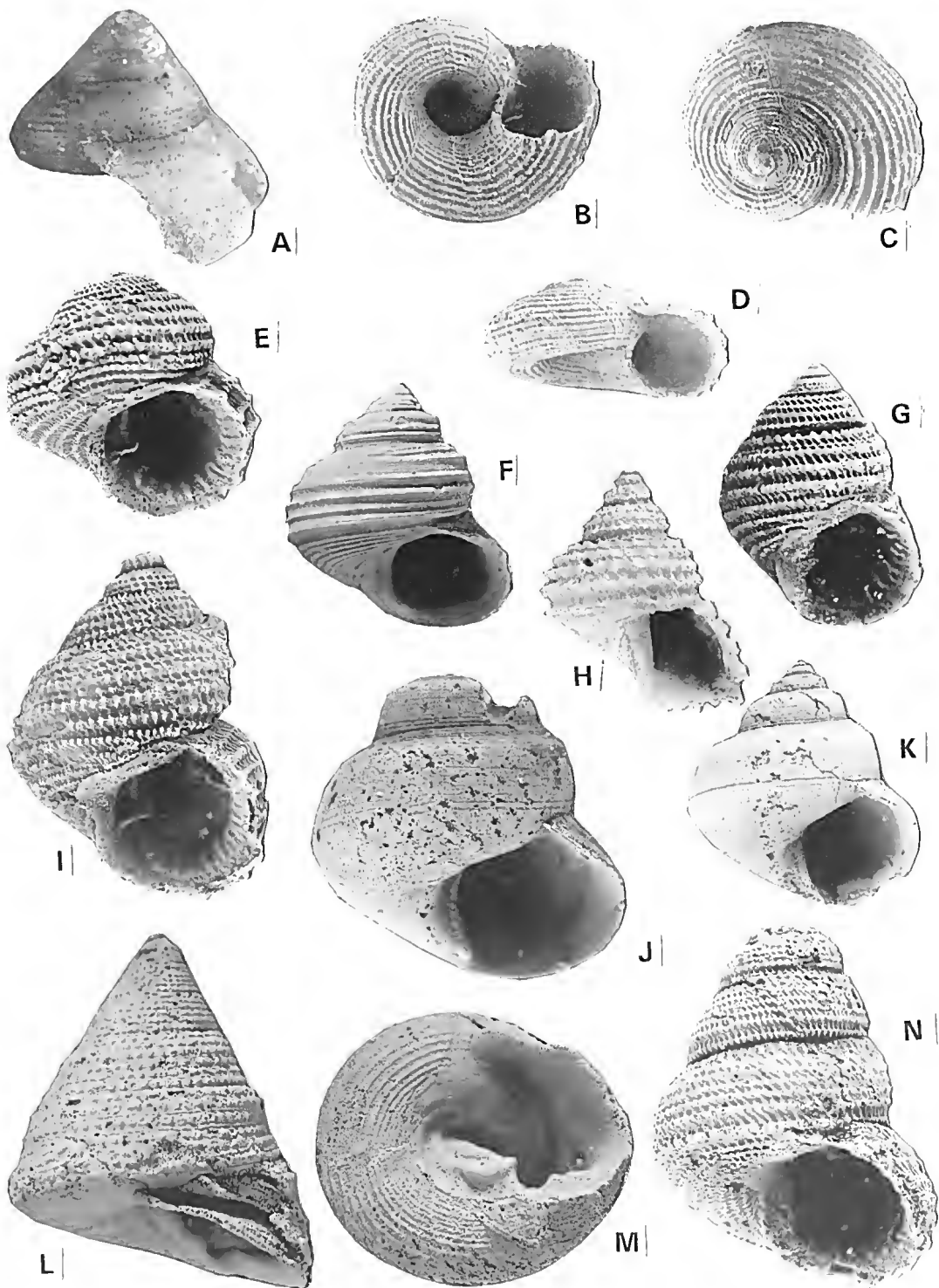
Other material. NMV P301997, P301998, P301999. Total of five specimens.

Description. Shell small, robust, turbiniform, higher than wide, of about 4.5 tumid whorls; spire equal to about half total height; apex sub-acuminate, subtending with spire angle of about 75°; whorls convexly rounded; suture impressed, narrowly canaliculate and attached below periphery, particularly on apical whorls; protoconch of about 1.5–2.0 smooth, elevated, convex whorls, tip slightly sunken, coiled in axis of shell; aperture moderately large, subcircular, about as wide as high; peristome discontinuous; on mature shell, thin callus extends across parietal area; outer lip strongly prosocline with strong external varix (slightly behind apertural lip) and weaker internal thickening, latter finely crenulate; columella concave, merging evenly with basal margin of aperture and buttressed with strong plate bearing one prominent tooth and notch; false umbilicus a prominent vertical groove on plate; imperforate; sculpture of first teleoconch whorl of very fine close axial costellae, extending over and beyond periphery as short spines; three or four very fine spiral lirae appear at about 1.5–2.0 whorls, increasing to five or six on second whorl and six to eight on penultimate whorl, all finely nodulose (almost scabrous) at intersections with axials, latter strongly prosocline and finer than spirals; on last whorl, spirals number 12–15 from suture to umbilical area, of which fourth is strongest and peripheral, sixth and seventh form doublet and eighth to fifteenth are on base; axial sculpture intensifies on apertural varix and also on base with reduced nodulation on spirals; innermost shell layers weakly nacreous.

Dimensions	Height	Max. diameter	No. whorls
WAM 67.103, holotype	7.5*	6.7	3.0+
WAM 72.276, paratype	8.0*	6.8	3.2+
WAM 83.2635a, paratype	8.4*	5.7	4.6
NMV P302183, paratype	7.8*	6.0	3.0+

* denotes estimated heights; holotype and NMV P302183 lack two apical whorls; others deformed.

Discussion. One deformed and incomplete specimen (85.1447) from Lucky Bay has 15 spirals on the last whorl (suture to umbilical area), of which the seventh is peripheral and strongest. Further material may widen the range of variation in sculpture from that given above.

The Walpole material compares well with a specimen of *Danilia tinei* (Calcara) from Piacenza (WAM 82.1473) and there is no doubt as to their congeneric status. Spiral sculpture on our species is finer and more numerous and it seems to be

a little wider relative to height, albeit mostly deformed. From the extant southern Australian *D. telebatha* Hedley, the present species differs in its much stronger columellar plate and tooth.

Danilia vialis is readily distinguished from the Janjukian *D. euglypta* sp. nov. (see below) by its more numerous spirals, stronger apertural varix and by the deep groove on the ventral surface of the columellar plate, a character absent from the latter species. *Danilia neozelanica* Laws from the Runangan (Late Eocene) of New Zealand (Laws 1935: 30, fig. 2) is of comparable age with *D. vialis* but differs in its substantially fewer spiral lirae. The Walpole species has some resemblance to *Danilia perelegans* (Deshayes) from the French Lutetian (figured in Cossmann & Pissaro 1910: pl. 3, fig. 22-2), differing in its finer and more numerous spiral lirae.

Ryckholt (1862) listed 38 nominal, mostly fossil, species of *Craspedotus* (=*Danilia*), most of which were assigned to stages of the Late Cretaceous. The status of these nomina are for the most part subject to confirmation but it is unlikely that any is directly relevant to the present species.

The specific name is from the Latin *vialis*, of roads, in view of the close proximity of the type locality to a public highway.

Occurrence. Bremer Basin: North Walpole (type) and Lucky Bay, Pallinup Siltstone, Late Eocene.

Danilia euglypta sp. nov.

Fig. 6G

Material. Holotype NMV P302208 from Spring Creek, near Torquay, Victoria; ledge and above ledge, Bird Rock Cliffs. J. Dennant Coll. Paratypes NMV P302204, P302205. Two specimens. Other material P302206, P302207*, P302209*, P302210*, P302211*. Five specimens. * denotes specimen from type locality.

Description. Shell small for genus, robust, ovate-turbiniform, higher than wide; spire slightly exceeds half total height; apex subacuminate; spire angle 60°; whorls tumid; sutures impressed, canaliculate, attached below periphery, descending slightly at aperture; base rounded, anomphalous; aperture moderately large, subcircular; peristome discontinuous, weakly angulate above and joined by a thin parietal glaze; other lip prosocline, thin, bevelled and denticulate within and with weak external varix behind; peristome slightly effuse, more so on basal and columellar margins where reflected over umbilical area; columella thick with strong vertical plate with basal tooth and notch anterior to it; protoconch smooth, of about

1.5 whorls, coiled in axis of shell; subsequent 1.3 whorls bear fine, close, prosocline axial threads; three fine spiral cords appear at *c*. 2.0 whorls, becoming four on third whorl; spirals stronger and more spaced than axials; points of intersection nodose, more strongly on spiral below suture which is gemmate; four or five spirals on penultimate whorl, 11–12 on last whorl of which fifth (from suture) is strongest; spirals narrower than interspaces; intercalary spirals occasionally present; axials almost lamellate on last whorl.

Dimensions	Height	Max. diameter	No. whorls
NMV P302208, holotype	6.03	4.14	5.2
NMV P302204, paratype	5.43	3.90	5.0
NMV P302205, paratype	5.48*	4.15	3.7+

* denotes apex slightly truncated.

Discussion. The present species differs from both *Danilia tinei* (Calcara) and the Late Eocene *D. vialis* (see above) in its less gradate spire, its reduced post-apertural varix, the absence of a deep groove on the columellar plate and a tendency to finer sculpture. It differs from the extant *D. telebatha* Hedley in its less gradate spire and stronger columellar plate; it appears to be smaller than all of the above three species.

No post-Janjukian fossil records of *Danilia* are as yet known from Australia; the genus is not recorded as a fossil from New Zealand after the Runangan (Late Eocene) (Beu & Maxwell 1990: 403), but is represented in the modern fauna by *D. insperata* Beu & Climo, 1974.

The specific name is from the Greek *eu*, good, well, true, etc., and *glyptos*, carved, engraved, etc., from the elaborate sculpture of the shell.

Occurrence. Port Phillip Basin: Jan Juc Formation, Late Oligocene–Early Miocene (Janjukian Stage).

Genus **Agathodonta** Cossmann, 1918

Agnathodonta—Wenz, 1938: 298, fig. 653 (obj.).

Type species. Trochus dentigerus d'Orbigny, 1843. By original designation. Neocomian, France.

Agathodonta (?) sp.

Fig. 6N

Material. WAM 67.99. One specimen.

Description. Shell small, robust, elevated-turbiniform, spire acute, estimated at about two-thirds total height; spire angle *c*. 45°; whorls gently convex; suture impressed, attached below periphery; aperture roundly subquadrate, slightly higher than wide; peristome discontinuous; outer lip strongly prosocline, slightly thickened but without a varix; internally bevelled and weakly crenulate; columella thick, vertical, with single small, projecting median-low tooth and wide basal notch; columella merges into slightly effuse basal margin; base rounded, imperforate. Sculpture of fine, spiral lirae, about equal to interspaces, numbering seven on penultimate whorl and 14 on last whorl (seven each on shoulder and base), of which seventh from suture is strongest; subordinate sculpture of very fine, axial/prosocline threads forming very fine, close nodulations at intersections with spirals; axials intensify on abapical side of suture, around aperture and on base.

Dimensions	Height	Max. diameter	No. whorls
WAM 67.99	11.5 (est.)*	7.51	3.8+

*Several apical whorls have been lost by breakage.

Discussion. In the general form of the shell and its sculpture, the specimen resembles both *Agathodonta dentigera* (d'Orbigny), type species of the genus and also *A. nortoni* McLean, Recent, Philippines (Cossmann 1918: 193, 200, 201; Cox, in Moore 1960: 1249, fig. 160,2; McLean 1984: 121–123; Hickman & McLean, 1990: 78, fig. 40E) and is referred provisionally to that genus. It differs from both of the above mentioned species in having only a single columellar tooth, in contrast to the prominent double teeth of the others.

Further taxonomic evaluation of the present species is deferred until more specimens are to hand.

Occurrence. Bremer Basin: North Walpole, Pallinup Siltstone, Late Eocene.

Subfamily Trochinae Rafinesque, 1815

Genus **Micrelenchus** Finlay, 1926

Type species (monotypy). *Trochus sanguineus* Gray, 1843. Recent, New Zealand.

In according full generic status within the Trochinae to *Micrelenchus*, we follow Hickman & McLean (1990) and Marshall (1998b).

Subgenus **Plumbelenchus** Finlay, 1926

Type species. Trochus capillacus Philippi, 1848, Recent, New Zealand.

Micrelenchus (Plumbelenchus) armulatus
sp. nov.

Fig. 6J–K

Material. Holotype WAM 83.2622a from 26 km along Thompson Highway north from Walpole townsite, W.A. Paratypes WAM 67.100, 67.106, 83.2622b–c, 83.2636a–c. Total of ten specimens. NMV P301184. One specimen.

Other material. WAM 69.124, 72.277, 83.2622d–f, 83.2627, 83.2636d–r, 85.632. Total of 30 specimens. NMV P301993, P301994, P301995, P301996. Total of 28 specimens.

Description. Shell small, robust, turbiniform, higher than wide, spire equal to about half total height; whorls usually stepped with distinct subsutural shelf and roundly subangulate shoulder; second shoulder corresponds with plane of sutural attachment; last whorl contracted basaly, usually subangulate to (less often) rounded in profile; apical angle 60°; aperture subquadrate to subcircular, peristome discontinuous, outer lip strongly prosocline, on some specimens contracted at suture, bevelled within, lacking varix and internal crenulation; columella short, obliquely concave, expanded and thickened toward base, merging evenly with basal margin of aperture, lacking tooth; base rounded, anomphalous; protoconch smooth, of one whorl, slightly deviated from axis of shell, tip sunken; succeeded by convex, shouldered whorl with three spiral lirae, of which adapical forms angulate edge of subsutural shelf; sculpture, where present, entirely spiral, of very fine striae, intensified on shelf, mostly faint to obscure elsewhere; spirals occasionally stronger and extending over most or all of shell, including base. Traces of remnant nacre sometimes present within aperture and on exposed inner shell layer.

Dimensions	Height	Max. diameter	No. whorls
WAM 83.2622a, holotype	5.90	5.76	5.4
WAM 83.2622b, paratype	5.80	5.18	5.2
WAM 67.100a, paratype	6.41	5.96	5.3
WAM 83.2636a, paratype	6.51	5.90	5.3
NMV P302184, paratype	5.8	5.0	5.0

One poorly preserved, slightly deformed specimen (83.2636, part) has a height of 7.68 mm, MD 7.47 mm.

Discussion. Variation in the present species is to be noted both in the whorl profile and in the strength and persistence of the sculpture, the latter noted above. The holotype and most other specimens have a distinct subsutural shelf and a roundly biangulate profile to the last whorl. Paratype WAM 83.2622b has a less well defined

shelf and more rounded whorl profile and is relatively a little higher in the spire. All other characters are shared and we regard these differences, including sculptural, as intraspecific.

Shell characters of *Micrelenchus* Finlay and *Plumbelenchus* Finlay are weakly differentiated according to Marshall (1998b), who evaluated the latter as a subgenus of the former, followed herein. Compared with the figures of the type species of each taxon (Marshall 1998b: figs 17–19, 34–39), the present species more closely resembles *M. (P.) capillaceus* (Philippi) in sculpture and whorl/apertural profiles.

As presently understood, the genus is centred on New Zealand with a stratigraphic range of Duntroonian to Recent (Beu & Maxwell 1990: 31, 36, 138, 403–404). The Australian stratigraphic range—Late Eocene to Early Oligocene—thus predates its trans-Tasman counterpart. The specific name is from the Latin *armus*, a shoulder, a salient character of the whorl profile.

Occurrence. Bremer Basin: North Walpole (type) and Lucky Bay. Pallinup Siltstone, Late Eocene. St Vincent Basin: Uncle Tom's Cabin, Maslin Bay, South Australia, Blanche Point Formation, Late Eocene.

Micrelenchus (Plumbelenchus) lirulatus
sp. nov.

Fig. 6F

Material. Holotype NMV P302185, from slips at Station Beach, north of Point Flinders near Cape Otway, Victoria (locality Pl 3019). Paratypes NMV P302186, P302187, from type locality. Total of three specimens.

Other material. NMV P133326, P133338, P302286, 20 specimens.

Description. Small, robust, turbiniform, slightly higher than wide; spire about equal to half total height; whorls regularly convex with narrow subsutural shelf, on some specimens shouldered; spire of variable height, angle 60–80°; suture impressed, inserted below periphery; aperture subcircular, peristome discontinuous, outer lip prosocline; columella regularly concave, bounded by narrow parallel groove, merging into basal margin of aperture; protoconch smooth, of about one whorl, tip depressed, slightly deviated and weakly offset from teleoconch; sculpture of prominent spiral lirae of variable strength and spacing, five or six on penultimate whorl, 14–20 on last whorl; lirae more or less spaced above periphery, stronger on

periphery and crowded on base; microsculpture of very fine, crowded spiral threads and prosogyrate axials on lirae and interspaces; interior nacreous.

Dimensions	Height	Max. diameter	No. whorls
NMV P302185, holotype	10.74	8.32	5.9
NMV P302186, paratype	11.27	8.33	6.9
NMV P302187, paratype	8.55	8.50	5.7

Discussion. The species varies somewhat in proportions of height (and also spire height) to diameter, in the spire angle, width of subsutural shelf and number and spacing of the primary spiral lirae. It is larger and much more strongly sculptured than the Late Eocene *M. (P.) armulatus* (see above) and the two are morphologically well differentiated. This species bears some resemblance to *M. (P.) mortenseni* (Odhner, 1924), Recent, New Zealand, but has fewer spiral lirae and the lirae are not nodulate as in *M. (P.) mortenseni*.

Occurrence. Otway Basin: lower Glen Aire Clay, Early Oligocene.

Genus **Clanculus** Montfort, 1810

Type species. Trochus pharaonius Linnaeus, 1758. By monotypy. Recent, Indo-West Pacific.

Subgenus **Paraclanculus** Finlay, 1926

Type species (monotypy). *Paraclanculus peccatus* Finlay, 1926, Recent, New Zealand.

Clanculus (Paraclanculus) sp.

Fig. 6L–M

Material. WAM 95.573. Two specimens. NMV P302001. Two specimens.

Description. Shell small, robust, trochiform, higher than wide; spire profile almost straight, very slightly attenuated apically; spire angle 60°; suture linear, lightly impressed, inserted at periphery; base almost flat; periphery roundly angulate; aperture wider than high, discontinuous, outer lip strongly prosocline, internally bevelled, smooth but neither crenulate, dentate nor costate within; parietal glaze thin; columella oblique, twisted, emerging from shallow false umbilicus; one very weak adapical tooth and strong, projecting, basal-terminal tooth and sinuate notch, the former being termination of strong, smooth spiral rib which emerges from false umbilicus; second, weaker, smooth spiral borders umbilical area, terminating at notch; basal margin thickened with small, recurved, internal shelf;

sculpture of finely granose spiral cords, six on each whorl, those on apical four whorls weakly cancellate and showing radial alignment of granules; last and penultimate whorls with additional very fine interealary spiral threads; base with eight fine, non-granulose, spiral threads; interior nacreous.

Dimensions	Height	Max. diameter	No. whorls
WAM 95.573a	13.60	11.65	7.2

Discussion. The species is at present known from only four specimens, two of which are poorly preserved; one only has an intact aperture. Of the available trochine genera, the species agrees generally with *Clanculus sensu lato* but does not match closely any of the known subgenera, including those of Iredale (1924) and Cotton & Godfrey (1934), based on southern Australian species. The nearest of these seems to be *Euclanculus* Cotton & Godfrey (type species *Clanculus leucomphalus* Vereo, Recent, South Australia), which has a spiral 'funiele' emerging from the pseudumbilicus and terminating at the basal columellar tooth (Vereo 1905: 168–169, pl. 31, figs 9–11). Differences on the present species from *C. leucomphalus* include the almost straight spire/whorl profile (recalling that of *Calliostoma*), the absence of any circumumbilical nodulation, the entirely smooth outer lip and interior and the much finer overall sculpture, particularly on the base.

In its spire profile, the present species resembles a number of extant Australian species of *Clanculus*, eg., *C. brunneus* A. Adams, *C. comarilis* Hedley, *C. margaritarius multipunctatus* Jansen and *C. septenarius* Melvill & Standen, differing from all of these in its simple apertural, umbilical and columellar features and fine sculpture (Jansen 1995). This species bears a close resemblance to *C. (Paraclanculus) peccatus* Finlay, 1926, Recent, New Zealand (Marshall 1998a: 100, figs 54–56).

The present species, which appears to be new, is the first record of the genus from the Eocene of Australia. Further determination is deferred until more material comes to hand.

Occurrence. Bremer Basin: North Walpole, Pallinup Siltstone, Late Eocene.

Subfamily Calliostomatinae Thiele, 1924

Genus **Calliostoma** Swainson, 1840

Type species. Trochus connlus Linnaeus, 1758. By subsequent designation of Herrmannsen, 1846. Recent, western Europe.

Subgenus **Fautor** Iredale, 1924

Type species. *Ziziphinus comptus* A. Adams, 1855. Recent, Australia.

Calliostoma (Fautor) numapum sp. nov.

Fig. 7A

Material. Holotype WAM 83.2633a, from 26 km along Thompson Highway north from Walpole townsite, W.A. Paratypes WAM 67.95a–b, 67.96, 72.236, 83.2621a–b, 83.2626a, 83.2633b–c, 96.249. Total of eleven specimens. NMV P302254. One specimen.

Other material. WAM 67.95c–f, 67.182, 69.120, 69.122, 69.130, 72.278, 83.2621c–i, 83.2626b–g, 83.2633d–z. Total of 53 specimens. NMV P301958, P302002, P302003, P302004. Total of 38 specimens.

Description. Shell small, robust, trochiform-conical, higher than wide; spire moderately elevated, whorls up to seven, early whorls convexly rounded, by third whorl flat in profile; last whorl a little contracted; spire angle 51°; suture lightly impressed; periphery carinate in immature shell, roundly subcarinate in adult; base gently convex, without umbilicus; aperture roundly quadrangular, peristome discontinuous; outer lip strongly proso-cline, attached slightly below periphery; basal lip
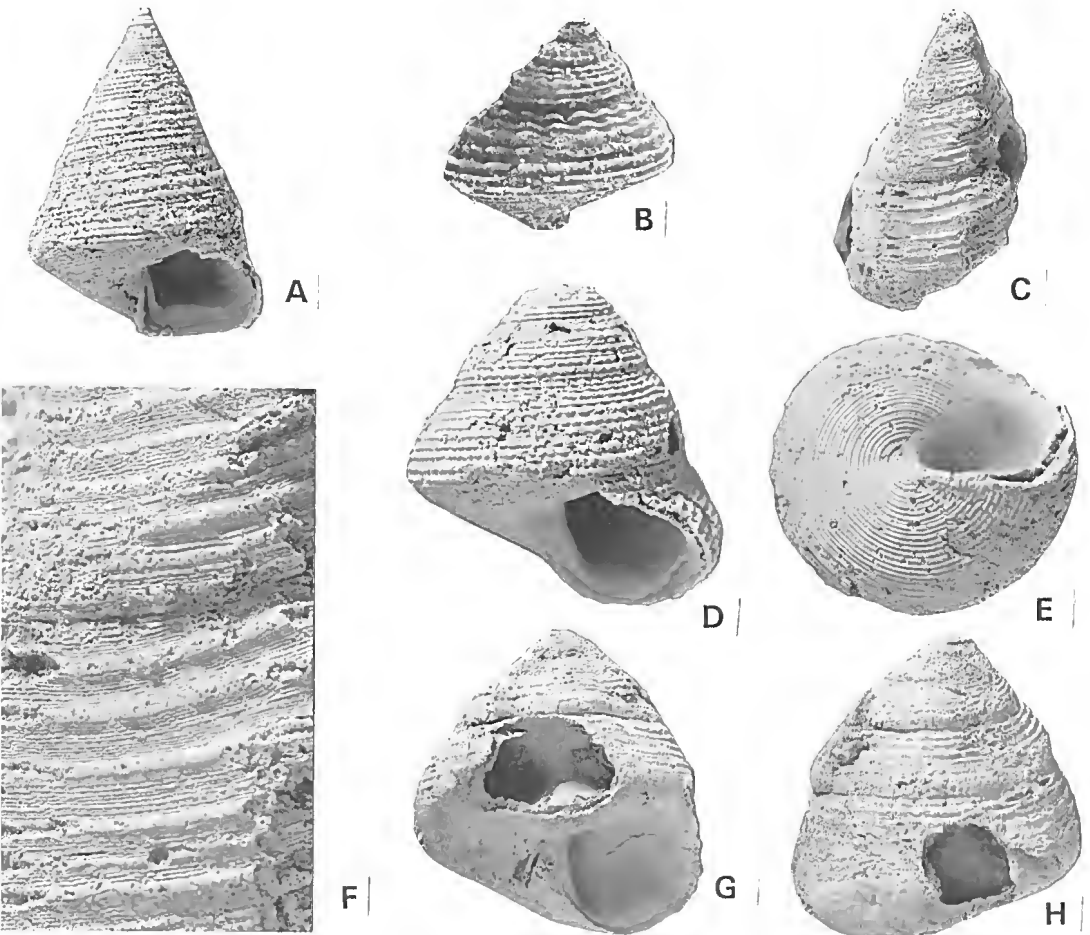
Fig. 7. A, *Calliostoma (Fautor) numapum* sp. nov. WAM 83.2633a, holotype, × 4. B, Trochid, genus undetermined, species B, WAM 67.98, × 6.8. C, F, G–H, *Calliostoma* (s.l.) sp. WAM 83.2634, deformed shell: C, G–H, × 1.3; F, × 6.5. D–E, Trochid, genus undetermined, species A, WAM 95.614, × 4.

thickened internally, slightly reflected; columella short, thick without tubercle, oblique, meeting base at angle of c. 100°; protoconch paucispiral, of one whorl, slightly oblique to shell axis; reticulate microsculpture occasionally preserved; teleoconch sculpture of fine, close, spiral lirae and subordinate, prosocline axials, all rather variable in number, spacing and persistence; first two whorls cancellate with two or three spiral lirae and finer, prosocline axial threads, weakly nodulose at the intersections; on subsequent whorls, spirals increase by intercalation up to six/nine, all finely nodulose, those about suture more prominent than others; axials tend to weaken after fourth whorl but may persist onto last whorl and base as axially aligned rows of nodules (eg., paratype WAM 83.2633b); last whorl with seven/nine spirals above periphery and 16/22 spirals on base, latter of variable strength, with or without nodules; inner layers nacreous (eg., WAM 69.130, paratype 83.2633b).

Dimensions	Height	Max. diameter	No. whorls
WAM 83.2633a, holotype	10.74	7.30	7.7
WAM 72.236, paratype	10.76	6.81	7+
WAM 83.2626a, paratype	8.35	6.27	7.1
WAM 83.2633b, paratype	9.93	6.38	7.2
NMV P302254, paratype	8.4	6.4	6+

Discussion. In size and proportions, the present species recalls *Calliostoma waiareka* (Laws) from the Kaiatan (Late Eocene) of New Zealand (Laws 1935: 32, fig. 5; Beu & Maxwell 1990: 116, pl. 7, fig. m). The Walpole species differs from that of Laws in sculptural details, particularly in its more numerous basal spirals, which may or may not bear fine nodules.

A somewhat similar species of *Calliostoma* occurs in the Glen Aire Clay, Otway Basin, having thin, widely spaced spiral lirae which are prominently gemmate at intersections with thin axial costellae. The shell is much wider relative to height than that from Walpole.

The specific name, from the Nyoongar (southwest Australian) Aboriginal *nu-map*, small, little, diminutive (Bindon & Chadwick 1992: 382), alludes to the small size of the species.

Occurrence. Bremer Basin: North Walpole, Pallinup Siltstone, Late Eocene.

Calliostoma (s.l.) sp.

Figs 6A; 7C, F, G–H

Material. WAM 83.2634, 95.613. Three specimens.

Description. Shell of medium size for genus, robust, trochiform, height and width approximate; spire probably exceeding half height; spire probably coeloconoid; apex bluntly rounded; whorls exceeding five in height of about 30 mm; suture linear, lightly impressed, attached at or slightly below periphery; whorls almost flat in profile; periphery of last whorl roundly subangulate; aperture large, discontinuous, roundly quadrangular, outer lip prosocline and internally bevelled; columella oblique, concave, without tooth, bordered by a rim, which is continuous with margin of outer lip; base anomphalous, probably gently convex; protoconch apparently smooth, of c. 0.8 whorl, tip sunken; primary spiral thread appears on first teleoconch whorl, followed by other spirals on second and third whorls; no axial sculpture; on fourth and subsequent whorls, spirals become six or seven weakly nodulose, ridge-like cords with very fine, crowded, spiral threads in interspaces; eight spirals on base.

Dimensions	Height	Max. diameter	No. whorls
WAM 83.2634	32	30/15	5+
WAM 95.613a, juvenile	5.72	6.06	5.2

Of the two measured specimens, the larger is strongly deformed by compaction; the other is a juvenile.

Discussion. The material to hand permits only a limited description, establishing little more than the presence of another, rare and apparently unnamed species of *Calliostoma* at North Walpole. It is distinguished readily from the associated congeners by its greater size and somewhat atypical sculpture.

The combination of weakly nodulose spirals and interspaces crowded with very fine spiral threads is uncommon in *Calliostoma*. The subordinate sculpture (and also shell size and proportions) resemble those of *Calliostoma moniliferum* (Lamarck) from the Bartonian (Late Eocene) of France and England (eg., WAM 82.1204) but Lamarck's species (figured by Cossmann & Pissarro 1910: pl. 4, fig. 30-1) has fewer and more strongly nodulose spirals than the present species. Further determination of this species is subject to the collection of additional material.

Occurrence. Bremer Basin: North Walpole, Pallinup Siltstone, Late Eocene.

Subfamily Thysanodontinae Marshall 1988

The subfamily was erected by Marshall (1988b) for three extant trochid genera, the species of which, all modern, are from New Zealand, New

Caledonia, southern Australia and South Africa. The shells are calliostomatine in form and share with that subfamily a protoconch microsculpture described as 'a network of interconnected hexagons' (Marshall 1988: 215). The thysanodontines are characterised by a highly distinctive, specialised jaw and radular structure, interpreted as adaptions to a suctorial mode of feeding. A Mesozoic origin for the subfamily is postulated by Marshall (1998: 217).

Genus **Carinastele** Marshall, 1988

Type species. *Carinastele kristelleae* Marshall, 1988. By original designation. Recent, Cook Strait and Macquarie Ridge, New Zealand, 126–274 m, on coarse substrata.

Carinastele (?) sp.

Fig. 6H

Material. WAM 80.1330. One deformed specimen.

Description. Shell small, robust, trochiform, higher that wide; whorls convexly rounded, without median carination; spire slightly coeloconoid, spire angle *c.* 70°; suture impressed, canaliculate, attached below periphery; apex and protoconch abraded, protoconch of about 0.8 whorls, terminated by weak varix; base almost flat, anomphalous; aperture subrectangular (deformed); peristome discontinuous; outer lip slightly prosocline; columella extended, mostly straight but slightly twisted at base, meeting basal margin of aperture at *c.* 90° (deformed); basal margin effuse near columella; sculpture of first teleoconch whorl initially of faint axial threads crossing weak subsutural shoulder, latter becoming on second whorl primary spiral cord, to be joined by others; on third whorl three spirals are cancellated at intersections with finer axial threads; penultimate and last whorls strongly cancellate with five strong, raised spirals, narrower than interspaces and crossed by weaker axials, nodulose at intersections; no intercalary spirals present; base bordered by carinate angulation corresponding to plane of sutural attachment; basal sculpture finer than that of spire, comprising six narrow spiral cords with wide interspaces crossed by numerous fine axial threads, scabrous at intersections; internal nacreous lustre not observed.

Dimensions	Height	Max. diameter	No. whorls
WAM 80.1330	5.9	4.0	5.5

Discussion. Of the trochid subfamilies revised by Hickman & McLean (1990), the present species seems best located in the Thysanodontinae, a provisional assignment in view of the limited nature of the material to hand. The specimen shares a suite of characters with *Carinastele kristelleae* Marshall, the type species of *Carinastele*, eg., the whorl profile and general form, channelled suture, the cancellate sculpture (dissimilar on spire and base) and apertural shape. Differences include the much more nodulose spire sculpture with a stronger axial component, the absence of intercalary spirals and any carination on the early teleoconch; the basal twist of the columella is present but weaker than in *C. kristelleae* and its new Zealand congeners. The present species lacks the conspicuous nacreous lustre of other thysanodontines but this may be a consequence of the silica replacement process. SEM examination of this specimen shows that the protoconch and apical 2.5 whorls, site of several diagnostic thysanodontine characters, are much abraded. Consequently, the present identification, possibly the first fossil record for the subfamily, remains subject to confirmation.

Occurrence. Bremer Basin: Lucky Bay, Pallinup Siltstone, Late Eocene.

Trochid, genus undetermined

Species A

Fig. 7D–E

Material. WAM 95.614. One specimen.

Description. Shell small, robust, trochiform, higher than wide; spire angle 68°; whorls slightly convex, periphery subangulate, becoming rounded toward aperture; sutures lightly impressed, attached slightly below periphery; base rounded, anomphalous; aperture roundly subquadrate; peristome discontinuous; outer lip broken, probably strongly prosocline; no parietal glaze apparent; columella curved, without tooth; apex missing; sculpture of fine, close, gemmate spirals, increasing by intercalation, 11 on penultimate whorl and above periphery of last whorl; on base, 21 finer spirals, not gemmate; aperture and interior faintly nacreous.

Dimensions	Height	Max. diameter	No. whorls
WAM 95.614	12 (est.)	10.2	4+

Discussion. The specimen lacks the apex and appears to be an immature shell. Its proportions and sculpture set it apart from all other trochids

in the assemblage. Further determination of this rare species depends on collection of additional specimens.

Occurrence. Bremer Basin: North Walpole, Pallinup Siltstone, Late Eocene.

Species B

Fig. 7B

Material. WAM 67.98. One shell.

Description. Shell very small, probably juvenile, trochiform with gradate spire and deeply impressed suture, attached at periphery; spire angle almost 90°; base gently convex with narrow umbilical fissure; aperture rectangular, peristome discontinuous, no parietal glaze; columella straight, a little effuse at base where meeting apertural margin; periphery roundly subangulate; sculpture of apical whorls poorly preserved; protoconch with tip depressed; by third whorl, sculpture of five, narrow, slightly undulating and weakly scalar spiral cords; on last whorl, these number seven, all wider than interspaces with scales expanding into low axial plicae; base sculptured with *c.* 13 regularly spread lirae, slightly narrower than interspaces.

Dimensions	Height	Max. diameter	No. whorls
WAM 67.98	4.32	4.50	4.6

Discussion. The identity of this rare species remains to be clarified from further, better preserved material. The distinctive sculptural combination (base and apex) resembles that of no other species in the study material.

Occurrence. Bremer Basin: North Walpole, Pallinup Siltstone, Late Eocene.

Family Trochaclididae Thiele, 1928

Genus **Trochaclis** Thiele, 1912

Type species. Trochaclis antarctica Thiele, 1912. By monotypy. Recent. Antarctica.

The systematics and taxonomy of the trochaclidid gastropods have been discussed recently by Hickman & McLean (1990) and by Marshall (1995). We follow the latter in according them full family status. Generic arrangement of the family relies primarily on anatomical, particularly radular, characters, not available with fossil material, so that determinations of the latter are, to some extent, subjective.

The shell characters of *Trochaclis* have been summarised by Marshall (1995: 93) thus: 'Shell turbiniform, up to about 2.00 mm wide, narrowly umbilicate or anomphalous, white. Interior surface set with scattered platelets, presumably aragonite, and representing vestigial nacreous layer. Protoconch of less than one whorl, sculptured with fine network of crisp threads that enclose irregularly polygonal spaces, tip of apical fold pinched. Teleoconch whorls convex, a rounded varix early on first whorl, with or without shoulder angulation on first one or two whorls or (one species) with shoulder and peripheral keel on all whorls, with or without a few basal spiral threads.' From the available characters, the species described below seems best located in this genus.

The distribution of the family (or subfamily of the Trochidae in the view of Hickman & McLean 1990) is Antarctica, NE Pacific, North Atlantic–Mediterranean, New Caledonia, New Zealand and southern Australia. Living animals have been found to be sponge-associated (Hickman & McLean 1990) and abundance of sponges throughout the Pallinup Siltstone, including the North Walpole site, suggests that this association has persisted at least since the Late Eocene.

Trochaclis (?) stillata sp. nov.

Fig. 8H, J

Material. Holotype WAM 83.2649a, from 26 km along Thompson Highway north from Walpole townsite, W.A. Paratypes WAM 67.188, 69.123, 83.2638, 83.2649b–d. Total of 15 specimens. NMV P302216. One specimen.

Other material. NMV P301959. Total 12 specimens.

Description. Shell minute, robust, turbiniform, slightly wider than high, of up to four smooth whorls with broad subsutural shelf, descending a little at maturity and strongly convex periphery; suture linear, impressed, attached below periphery; apex flattened; protoconch poorly preserved, apparently smooth, weakly distinguishable from teleoconch by obscure varix; tip slightly sunken; base roundly convex; umbilicus a narrow fissure; aperture subcircular, in maturity, peristome continuous across parietal area, discontinuous in immature shell; outer lip prosocline; columella short, vertical, slightly reflected across umbilical fissure and curving evenly into basal peristome; surface smooth, without visible sculpture.

Dimensions	Height	Max. diameter	No. whorls
WAM 83.2649a, holotype	2.04	2.40	4.0
NMV P302216, paratype	2.1	2.5	4 (est.)

Discussion. Marshall (1995) has recorded nine species of *Trochaclis* from the southwest Pacific region, five from the Recent of New Zealand, three from the Early Miocene (Otaian) of New Zealand and one from the Middle Miocene (Balcombian) of Victoria. The present species, possibly the first record of genus and family from the Eocene, differs from all of the foregoing in its combination of a notably wider than high shell, devoid of sculpture, with broad subsutural shelf and narrow umbilical fissure. From *Trochaclis antarctica* Thiele (figured by Dell 1990: 119, 120, fig. 201), it differs in its wider base and lower spire.

The present species differs from the trochaclidids *Acremodontina translucida* (May), Recent, southern Australia and from *A. balcombiana* Marshall, Middle Miocene, Victoria (Marshall 1995) in its greater width relative to height, broader subsutural shelf and absence of spiral sculpture.

The specific name is from the Latin *stillo*, a drop, alluding to the minute size of the shell.

Occurrence. Bremer Basin: North Walpole, Pallinup Siltstone, Late Eocene.

Family Skeneidae Clark, 1851

Genus **Leucorhynchia** Crosse, 1867

Type species. Leucorhynchia caledonica Crosse, 1867. By monotypy. Recent, SW Pacific.

This genus is recorded from the Paleocene–Miocene of Europe, Eocene–Miocene of Australia. Modern records are from the SW Pacific.

Leucorhynchia rotulina sp. nov.

Fig. 8F, I, K–N, P-Q, T

Material. Holotype WAM 83.2642a, from 26 km along Thompson Highway north from Walpole townsite, W.A. Paratypes WAM 83.2642b–p. Total of 16 specimens. NMV P302255. One specimen.

Other material. WAM 67.178, 69.126, 83.2642, 95.371, 95.392, 95.426, 95.430. Total of 88 specimens. NMV P301960. Total of 64 specimens.

Description. Shell minute, robust, of few whorls, subdiscoidal–rotelliform, wider than high; spire very low, apex flattened; last whorl with broad subsutural shelf, on some specimens slightly sunken; periphery convexly rounded, smooth to subangulate according to sculpture; suture linear, impressed, attached above periphery but descending on last whorl; protoconch lobate, of about one smooth whorl, not readily distinguished from teleoconch (Walpole specimens); base gently convex; immature umbilicus open, reduced to fissure or almost closed in maturity; aperture circular, peristome continuous; outer lip slightly prosocline, thin; adapical lip projecting beyond abapical lip; columella short, concavely arched with parietal callus and stronger, expanded, basal callus extending over umbilical area; sculpture variable— from almost smooth with faint spiral threads, continuous or otherwise, on spire and/or last whorl— to fine, close, spiral cords of uneven strength and spacing over entire adapical surface; cord below suture on some specimens stronger than others and axially gemmate; base without spirals, most specimens show pinched, axial folds crowding umbilical area; operculum calcareous, circular, spiral, nucleus central. Nacreous lustre not observed.

Dimensions	Height	Max. diameter	No. whorls
WAM 83.2642a, holotype	1.60	2.48	3.2
WAM 95.430a	1.42	2.56	3.2
NMV P302255, paratype	1.9	2.5	3.3

Discussion. The above description is based on topotypic material, all siliceous replacements, from North Walpole. Six well preserved specimens (WAM 95.371, 95.392, 95.426, 95.430) from the Werillup Formation in the Ocumup No. 1 deep well (53.4–73.2 m), though quite similar, differ slightly in being more consistently spirally striate on spire and base, subsutural beading may extend to become weak axial plicae across the shelf and the umbilicus becomes sealed earlier in growth by extension of the basal apertural callus directly into the umbilicus; the protoconch is prominent, smooth, lobate, of 0.8 whorls, terminated by the abrupt onset of spiral teleoconch sculpture (two threads).

Fig. 8. A–B, G, *Collonia variabilis* sp. nov. NMV P302634, holotype, × 16. C–E, *Pseudoninella?* sp. WAM 95.366, × 7. F, I, K–N, P-Q, T, *Leucorhynchia rotulina* sp. nov. F, I, K, WAM 83.2642c, paratype. L–M, P, WAM 83.2642d, paratype. N, Q, T, WAM 83.2642a, holotype, × 15. H, J, *Trochaclis (?) stillata* sp. nov. H, WAM 83.2649a, holotype. J, WAM 67.188, paratype, × 15. O, R–S, *Leucorhynchia ventricosa* sp. nov. WAM 83.2643a, holotype, × 15.
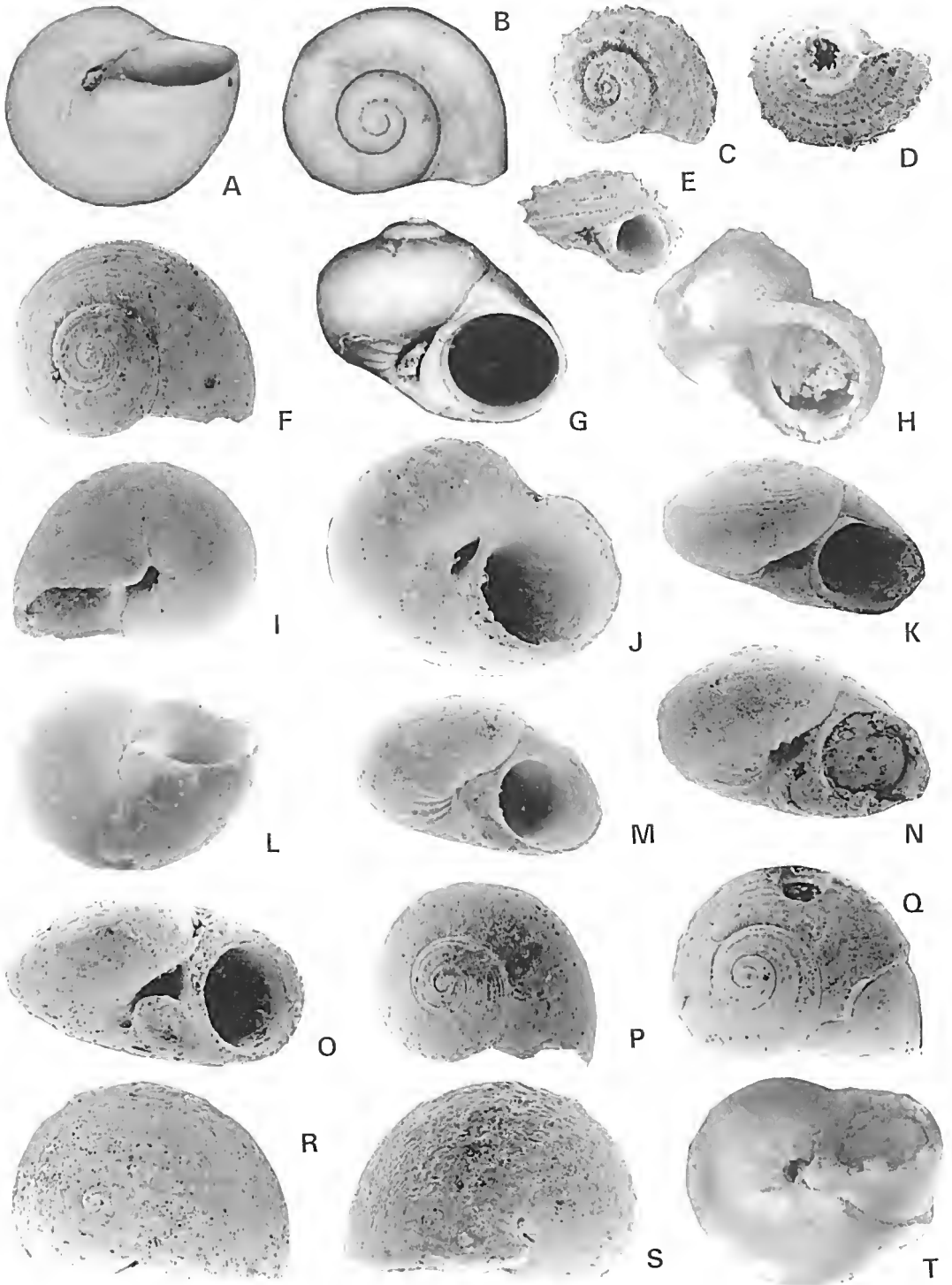
Both Crosse (1867) and Cossmann (1918) refer to a nacreous interior for species of *Leucorhynchia*, including its type species *L. caledonica* Crosse, but this has not been observed on any of our material, whether siliceous replacements (Walpole) or carbonate shells (Ocumup No. 1 deep well). The latter we refer provisionally to the present species.

In general form, the present species resembles *L. callifera* (Deshayes) from the Lutetian of France and Hungary, figured by Cossmann & Pissaro (1910: pl. 4, fig. 33-8) and by Strausz (1966: 104, pl. 2, figs 7, 10, 11), differing in its smaller size, stronger circumumbilical folds and in the presence of well-defined spiral sculpture on many shells. From *L. nitida* Briart and Cornet, Calcaire de Mons (Montian, Belgium) the present species differs in its much stronger circumumbilical folds (Glibert 1973: 28, pl. 3, fig. 16).

L. caledonica Crosse has a circular, multispiral operculum with a central nucleus. Two specimens of the present material (holotype and paratype WAM 83.2642b) retain opercula within the aperture. As far as can be seen, these show spiral rather than concentric growth.

Variation in the present species is observed in the strength, persistence and distribution of spiral sculpture and occasionally axial plications on the adapical surface, on the presence or absence of beading below the suture and on the degree of constriction or infilling of the umbilicus. The latter is open in the juvenile, closing with growth.

Of the 163 shells to hand, 31 (19%) show naticiform gastropod boreholes. No preferred borehole position has been observed.

The specific name is from the Latin *rota*, a wheel, referring to the shell profile.

Occurrence. Bremer Basin: Ocumup No. 1 deep well, 53.4–73.2 m, Werillup Formation, Middle Eocene; North Walpole, Pallinup Siltstone (type), Late Eocene.

Leucorhynchia ventricosa sp. nov.

Fig. 8O, R–S

Material. Holotype WAM 83.2643a from 26 km along Thompson Highway north from Walpole townsite, W.A. Paratypes WAM 67.177, 83.2643b–f. Total of eight specimens. NMV P302251. One specimen.

Other material. NMV P301960. Six specimens.

Description. Shell minute, robust, wider than high, subdiscoidal–lenticular; spire low, of few, rapidly enlarging whorls; spire profile smoothly and evenly rounded, apex flattened, not projecting; protoconch poorly preserved, lobate, apparently smooth; periphery subangulate; suture adpressed, attached well above periphery, descending at aperture (maturity); aperture subcircular, tangential to last whorl; peristome continuous, thickened at periphery and with strong parietal callus and short, thick columella, at base of which massive, bluntly rounded fold projects across (without sealing) umbilicus; umbilicus narrow, partly concealed, on some specimens with few weak circumumbilical wrinkles; base convex, ventricose; with sculpture (preservation permitting) of very fine, close, spiral striae on spire and base; operculum unknown. Nacreous lustre not observed.

Dimensions	Height	Max. diameter	No. whorls
WAM 83.2643a, holotype	1.62	3.09	3.0
WAM 83.2643b, paratype	1.72	2.92	3.5
NMV P302251, paratype	1.3	2.70	4.0

Discussion. This second species of *Leucorhynchia* in the Pallinup Siltstone at North Walpole is distinguished from the preceding and all other congeners known to us by its lower, more smoothly rounded spire, tangential aperture, subangulate periphery, reduced circumumbilical wrinkling and prominent trans-umbilical fold at the base of the columella. In shape, the species resembles *L. caledonica* (Crosse), differing in the very fine, close spiral striae, which are lacking in Crosse's species.

None of the specimens shows evidence of gastropod predation.

The specific name is from the Latin *ventricosa* (feminine), swollen, bulging, referring to the base.

Occurrence. Bremer Basin: North Walpole, Pallinup Siltstone, Late Eocene.

Superorder Caenogastropoda Cox, 1959

Superfamily Rissooidea Gray, 1847

Family Vitrinellidae Bush, 1897

Genus **Circulus** Jeffreys, 1865

Type species. Delphinula duminyi Requien, 1842 = *Solarium philippi* Contraine, 1842. By monotypy. Recent, Atlanti–Mediterranean.

Circulus sp.

Fig. 6B–D

Material. WAM 67.104, 95.599. Two shells. NMV P301988. One shell.

Description. Shell minute, sub-discoidal, of few convex whorls; spire very low with broad subsutural shelf and rounded periphery; suture incised, channelled, attached close to periphery, in maturity descending at aperture; protoconch poorly preserved, apparently smooth, lobate; aperture sub-circular with continuous, thin peristome, attached by thin parietal callus; columella thin, not differentiated from margin of aperture; base concave, widely and deeply umbilicate exposing to apex adaxial surfaces of whorls; entire shell sculptured with very fine, raised, narrow, spiral lirae with smooth interspaces, six on penultimate whorl, last whorl with 12 spirals from suture to broader intercostal space just below periphery and a further 16 extending across base and deeply into umbilicus; sculpture of first teleoconch whorl poorly preserved but resembles that of later whorls; no axial sculpture evident.

Dimensions	Height	Max. diameter	No. whorls
WAM 67.104	1.93	4.58	3.5

Discussion. Early records for the genus are from the Thanetian Calcaire de Mons of Belgium (Glibert 1973: 29, pl. 4, fig. 2-4). By the Middle Eocene, it was dispersed widely throughout the Tethyan Realm to Australasia. Possible occurrences from the Paleocene to Recent of Western Europe, the Americas, North Africa and East Asia are listed in Cossmann as *Adeorbis* species (1918: 97–99). Miocene species from The Netherlands are described by Janssen (1984: 129–131, pl. 45).

The Walpole species resembles *'Adeorbis' intermedius* Deshayes from the Lutetian of the Paris Basin, as figured in Cossmann & Pissarro (1910: pl. 8, fig. 59-11) and is not unlike *Circulus mitorraphes* Gardner from the Miocene Alum Bluff Group of Florida (Gardner 1947: 599, pl. 61, figs 1, 2, 27). In its rounded whorl profile and multiple spiral lirae, the present species recalls *Partubiola varilirata* Ludbrook from the Dry Creek Sands of the St Vincent Basin (Ludbrook 1941: 87, pl. 4, fig. 17; 1956: 21), differing in its more numerous spirals on the last whorl and in the complete absence of axial microsculpture. A probable *Circulus* from the New Zealand Late Eocene (Kaiatan) in Maxwell (1992: 89, pl. 9, figs a–c, e) is similar to the Walpole species, differing in its peripheral keel and finer more numerous basal sculpture.

This species bears some resemblance to *Elachorbis subtatei* (Suter, 1907), Recent, New Zealand, so it may well be a cyclostrematid and not a vitrinellid.

This appears to be the first record of the genus from the Australian Eocene. We believe it to be new but defer full determination in view of the limited material to hand.

Occurrence. Bremer Basin: North Walpole, Pallinup Siltstone, Late Eocene.

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CHECKLIST OF VICTORIAN DRAGONFLIES (INSECTA : ODONATA)

I. D. Endersby

56 Looker Road, Montmorency, Victoria 3094, Australia

ENDERSBY, I. D., 2000:06:30. Checklist of Victorian dragonflies (Insecta : Odonata). *Proceedings of the Royal Society of Victoria* 112(1): 59–64. ISSN 0035-9211.

An annotated checklist is given for the dragonfly fauna currently known from Victoria. The fauna comprises 74 species: 26 Zygoptera and 48 Epiproctophora (formerly Anisoptera). New distribution records and taxonomic nomenclatural changes since 1974 are detailed.

SINCE the publication of a checklist of Victorian dragonflies by Hutchinson (1975) a number of nomenclatural changes and additional distribution records have been made. Hutchinson's list was based on that of Watson (1974) to which he added his own observation of a specimen of *Austrolestes aridus* (Tillyard). The species which he lists as 'Caliagrion lyelli' is a typographical error for the two species *Caliagrion billinghursti* (Martin) and *Coenagrion lyelli* (Tillyard).

Watson (1977) published a supplement which added Hutchinson's *Austrolestes aridus* record and one of *Trapezostigma loewii* (Kaup) to the Victorian fauna. In his key to larvae of south-eastern Australia, Hawking (1986) provided a checklist of adults based on the nomenclature of Watson (1974), covering 'Victoria and eastern South Australia and new material ... from throughout the River Murray catchment' and adding a number of new records. The Odonata volume of the Zoological Catalogue (Houston & Watson 1988) recognised the family Protoneuridae, some genus name changes and new records. Watson et al. (1991) gave the most comprehensive Australian review of the Order Odonata since that of Fraser (1960), describing new species and providing keys to species, distribution data and ecological notes. Major phylogenetic studies have been undertaken recently, particularly in Germany, America and Australia, and Hawking & Theischinger (1999) provided a new Australian checklist recognising these works, particularly the familial and higher level classification of Bechly (1996). Hawking & Theischinger (1999) recognise that Bechly's analyses are not universally accepted with the caveat that 'it is not, however, our intention to support or criticise'. Similarly, this checklist uses their classification purely as a framework to record those species known to have been found within Victoria to date and the nomenclatural changes that have occurred since 1974.

CHANGES TO FAMILIAL NOMENCLATURE

Protoneuridae

Hutchinson (1975), following Watson (1974), retained the genera *Isosticta* Selys and *Oristicta* Tillyard in the family Protoneuridae. Fraser (1960) recognised two subfamilies, Protoneurinae (containing *Nososticta* Hagen) and Isostictinae, and Hawking (1986) acknowledged this within his key to the larvae. Watson & Theischinger (1984) still maintained these two subfamilies but they were accorded familial rank by Davies (1981) and subsequent Australian authors have followed him. Bechly (1996) regards the Isostictinae as a subfamily of Protoneuridae but Hawking & Theischinger (1999) retain it at family level.

ANISOPTERA

Traditionally three suborders of Odonata have been recognised: Zygoptera, Anisoptera and the Anisozygoptera with extant species only in Japan and Nepal. Bechly (1996) renamed the Anisozygoptera to Epiophlebiidae and combined it with the Anisoptera to form a new suborder Epiproctophora, used by Hawking & Theischinger (1999) and, therefore, in this summary of Victorian species.

Austropetaliidae

Victoria's only representative of the family Austropetaliidae is *Austropetalia tonyana* Theischinger. At the time of Hutchinson's (1975) checklist it was still considered to be a member of the Aeshnidae but Houston & Watson (1988) placed it in Neopetaliidae, following Davies (1981). The family Neopetaliidae was restricted to Australia, New Zealand and Chile. Relocation of the genus *Neopetalia* Cowley to the Libelluloidea by

Carle & Louton (1994) caused them to erect a new family, Austropetaliidae, which contains the Australian species.

Aeshnidae

One of Bechly's (1996) revisions was to remove a number of genera from the family Aeshnidae to a new family Telephlebiidae. The effect for Victorian species was to retain only *Aeshna brevistyla* (Rambur) and *Hemianax papuensis* (Burmeister) in Aeshnidae. Hawking & Theischinger (1999) agree that the split is consistent with a major character state in their key: the larval epiproct is concave at the tip for Aeshnidae but pointed in Telephlebiidae.

Corduliidae

Watson (1974) recognised Synthemidae as a separate family from the Corduliidae, as did Hutchinson (1975). Davies (1981) retained it as the family Synthemistidae, but Theischinger & Watson (1984) relegated it to subfamilial status as Synthemistinae within Corduliidae.

Major changes have occurred with the division of the former family Corduliidae. Of the new families, those found in Victoria are the Synthemistidae, Austrocorduliidae, Cordulephyidae and Hemicorduliidae. These groupings are not inconsistent with the field appearance of the relevant species.

CHECKLIST

Ensynthemis tillyardi Theischinger 22
Ensynthemis virgula (Selys)
Parasynthemis regina (Selys) 23
Synthemis eustalacta (Burmeister)
Family Austrocorduliidae (formerly part of Corduliidae)
Apocordulia macrops Watson 24
Austrocordulia refracta Tillyard 25
Family Cordulephyidae (formerly part of Corduliidae)
Cordulephya pygmaea Selys
Family Hemicorduliidae (formerly part of Corduliidae)
Hemicordulia australiae (Rambur)
[*Hemicordulia novaehollandiae*] 26
Hemicordulia tau (Selys)
Procordulia jacksoniensis (Rambur)
Family Libellulidae
Austrothemis nigrescens (Martin)
Cracothemis nigrifrons (Kirby) 25
Diplacodes bipunctata (Brauer)
Diplacodes haematodes (Burmeister)
Diplacodes melanopsis (Martin)
Nannophlebia risi Tillyard 28
Nannophya australis Brauer 29
Nannophya dalei (Tillyard)
Orthetrum caledonicum (Brauer)
Orthetrum villosovittatum (Brauer)
Pantala flavescens (Fabricius) 30
Trapezostigma loewii (Kaup) 31

DISCUSSION

Paragraph numbering follows the notes shown in the Checklist table.

1. In spite of its type locality being given as Port Denison (now Bowen, Queensland) *Hemiphlebia mirabilis* Selys has long been considered to be endemic to Victoria. However, Trueman et al. (1992) recorded it from north-east Tasmania and Endersby (1993) recorded its discovery on Flinders Island.

2. *Synlestes weyersii* and *S. tillyardi* were recognised as good species in all Australian references until Watson et al. (1991) who treated *tillyardi* (and *nigrescens* from the Sydney region) as subspecies of *S. weyersii*.

3. Hutchinson (1975) reported one sighting (presumably his own) from the Big Desert as the only known occurrence of *Austrolestes aridus* in Victoria. Subsequently, Hawking (1994) recorded it from Middle Creek, 5 km SE of Wodonga (September 1988).

4. All Victorian species in the family Megapodagrionidae, at the time of Hutchinson's (1975) checklist, were considered to be in the genus *Argiolestes*. In a review of the genus Theischinger & O'Farrell (1986) resurrected the name *Austroargiolestes*, and *A. calcaris* and *A. icteromelas* were included in it, the others remaining in *Argiolestes*.

5. *Argiolestes griseus* had been divided into a number of subspecies, primarily by Tillyard (1912). Watson et al. (1991) considered four of these to be specifically distinct, the Victorian members being *Argiolestes eboracus* and *A. intermedius*. Theischinger (1998) divided the Australian species previously in the genus *Argiolestes* into three genera, those in the *A. griseus* complex becoming *Griseargiolestes*.

6. In a revision of the Isostictidae, Watson et al. (1991) erected the new genus *Labidiosticta* for *Oristicta vallisi*.

7. Watson, in Watson et al. (1991), in his revision of the Isostictidae transferred the Australian species of *Isosticta* to a new genus *Rhadinosticta*.

8. *Rhadinosticta banksi* (as *Isosticta banksi*) was listed by Watson (1974), and therefore Hutchinson (1975) and Hawking (1986), as occurring in Victoria. Houston & Watson (1988) do not list it for Victoria but Watson et al. (1991) do, with a question mark against the entry. Except for this doubtful Victorian record the distribution is south-eastern Queensland, north-eastern Queensland, Cape York Peninsula, 'Top End' Northern Territory and the Kimberley region of Western Australia. Hawking & Theischinger (1999) do not include it their checklist for New South Wales and it is highly unlikely to have been found in Victoria.

9. After viewing the type of *Pseudagrion cyane* Selys, Lieftinck (1982) recognised that it was synonymous with the Western Australian species *Austroagrion coeruleum* Tillyard, thus requiring a new name for the eastern species, *Austroagrion watsoni*. Hutchinson (1975) and Watson (1974) predated this change but Hawking (1986) lists both *A. watsoni* and *A. cyane*, the latter only from south-eastern South Australia. Houston & Watson (1988) and Watson et al. (1991) recognise it from that region.

10. Hawking (1986) adds *Pseudagrion aureofrons* to the Victorian list and this is maintained by subsequent authors. It is very common in the Ovens, Campaspe and Broken rivers (Hawking, pers. comm. 1999).

11. Theischinger (1995a) considered the specimens of *Austropetalia patricia* from the Blue Mountains to be specifically different from those inhabiting the southern highlands, which includes Victorian specimens. He named the southerly group *A. tonyana* but acknowledged that more material is required to clarify the status of populations from southern Victoria. Carle (1996) also recognised two forms of *A. patricia* and he raised the name *A. victoriae*, but the distribution patterns show sympatry and differ from those of Theischinger (1995a). Lohmann (1996) considered *A. victoria* to be a synonym of *A. tonyana*.

12. Although Lieftinck (1951) attempted to show that *Acanthaeschna* had priority over *Austroaeschna* for the known species in this genus, Allbrook & Watson (1978) studied new material of *Acanthaeschna victoria* and found it not to be congeneric. As *A. victoria* was the type species for *Acanthaeschna* they resurrected *Austroaeschna* for the other species.

13. After reviewing the history of *Austroaeschna* nomenclature Theischinger (1982) realised that '… what has been called *longissima* is really *unicornis*, and what has been called *unicornis* is really *pulchra*'. So, the *A. longissima* in Hutchinson's (1975) list disappears and *A. pulchra* is added. All subsequent authors agree.

14. Theischinger (1982) separated a new species, *Austroaeschna subapicalis*, from specimens previously identified as *A. atrata*.

15. Although Martin (1901) did not list *Acanthaeschna victoria* for Victoria he did so in Martin (1909) (*fide* Hutchinson 1975). Watson (1974) queried the Victorian record and no author since has included it in the Victorian fauna. Hawking & Theischinger (1999) have only two records for the 20th Century and give as its distribution northern New South Wales and southern Queensland. It is highly likely that Martin's (1909) record was an error.

16. The first reference to *Dendroaeschna conspersa* as a Victorian species is Houston & Watson (1988), based on specimens of larvae collected in 1983 and 1985. Hawking (1991) documents the discovery.

17. Theischinger (1982) moved *Austroaeschna tripunctata* into a new genus *Spinaeschna*.

18. Hawking (1986) includes *Austrogomphus angeli* in his list but as it covers 'adults from Victoria and eastern South Australia …' he is quoting Watson's (1974) south-eastern South Australia locality (Hawking, pers. comm. 1999). Houston & Watson (1988) and Watson et al. (1991) quote it directly from Victoria but Watson (1991) notes that it has been found only in the Murray River, listing specimens from New South Wales— Wentworth and Corowa.

The species was named by Tillyard (1913) in recognition of the two brothers (S. & F. Angel) who discovered it. Consequently Peterson (1993) emended the specific epithet to the plural form of *angelorum*. Peterson (1993) also states that only twenty adult specimens have been collected to date.

19. Hutchinson (1975) listed *Austrogomphus* sp. 'e' following Watson (1974) who included a number of undescribed genera and species using code letters. The Zoological Catalogue (Houston & Watson 1988) referred to *Austrogomphus doddi* Tillyard as *Austrogomphus* sp. 'e' but Watson (1991) described it as a new species *Austrogomphus cornutus*. Watson (op. cit.: 393) discusses the confusion between *A. doddi* and *A. cornutus*.

20. Houston & Watson (1988) include *Hemigomphus heteroclytus* as a Victorian species as do Watson et al. (1991), noting its similar appearance to *H. gouldii*. Watson (1991) gives precise collection localities for both species.

21. From a major phylogenetic study, Carle (1995) placed three species of *Synthemis*, including *Synthemis macrostigma*, in a new genus *Archaeosynthemis*. Hawking & Theischinger (1999) state that the eastern Australian *A. macrostigma orientalis* is possibly a distinct species.

22. Whilst unravelling the *Eusynthemis guttata* group of sibling species Theischinger (1995b) raised *Metathemis guttata* (Selys) var. *pallida* (Tillyard 1910) to full species status and named it *Eusynthemis tillyardi*.

23. In the same study in which he named the genus *Archaeosynthemis*, Carle (1995) recognised *Synthemis regina* as monotypic at generic level and placed it in a new genus as *Parasynthemis regina*.

24. *Apocordulia macrops* was raised from larvae to maturity by Watson (1980) and named in a new genus and species. Their crepuscular flight times are probably the cause of them remaining unrecognised for so long. It is now known to occur in small stretches of the Broken, Campaspe and Loddon rivers and also in Gippsland (Hawking, pers. comm. 1999).

25. Thieschinger & Watson (1984) did not list any Victorian localities for *Austrocordulia refracta* but Watson (1974) includes it in southern New South Wales. Hawking (1986) records it from Gippsland and subsequently Watson et al. (1991) and Hawking & Theischinger (1999) list it from Victoria.

26. Watson (1974) included *Hemicordulia novaehollandiae* in the Victorian fauna, marked with a question mark. Hutchinson (1975) followed him but commented that the species is known from one imperfect female and is of doubtful specific status. Fraser (1960) is the source of the comment and Houston & Watson (1988) give for its distribution 'Australia, no known locality'.

27. Hawking (1986) records *Crocothemis nigrifrons* from eastern Gippsland and has now found it in billabongs in northeast Victoria (Hawking, pers. comm. 1999). Hawking & Theischinger (1999) have a category VIC in their distribution list but none of the intervening authors (eg. Houston & Watson 1988; Watson et al. 1991) have recognised it for the state.

28. *Nannophlebia risi* was added to the Victorian fauna by Hawking (1986) from records from the Kiewa River and Hawking & Theischinger (1999) have a map showing a collection locality from the Murray River near Jingellic.

29. The first reference to *Nannophya australis* as a Victorian species is that of Houston & Watson (1988).

30. *Pantala flavescens* is the most recent addition to the Victorian list (Hawking & Ingram 1994) from larvae which are probably the progeny of migratory adults.

31. Hutchinson (1977) gives the first record of *Trapezostigma loewii* from Victoria. Watson (1977) incorporated this observation into his first supplement and Hawking (1986) listed it from billabongs in northeast Victoria.

SUMMARY

Hutchinson (1975) listed 64 species of Odonata for Victoria (26 Zygoptera and 38 Anisoptera) but the total now stands at 74 (26 Zygoptera and 48 Epiproctophora). The changes for the Zygoptera are due to one new sighting (*Pseudagrion aureofrons*), a net gain of one from taxon splitting (*Argiolestes griseus* revealed *Griseargiolestes eboracus* and *G. intermedius*), one species was lost by taxon lumping (*Synlestes tillyardi*), and one was an incorrect

record (*Isosticta banksi*). For the Epiproctophora, 9 new sightings occurred (*Austrocordulia refracta*, *Austrogomphus angelorum*, *Crocothemis nigrifrons*, *Dendroaeschna conspersa*, *Hemigomphus heteroclytus*, *Nannophlebia risi*, *Nannophya australis*, *Pantala flavescens* and *Trapezostigma loewii*), one new species was discovered (*Apocordulia macrops*), two species arose from taxon splitting (*Austroaeschna subapicalis* and *Eusynthemis tillyardi*), and there were two incorrect or unsubstantiated records (*Austroaeschna victoria* and *Hemicordulia novaehollandiae*).

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VICTORIAN PALEOGENE AND NEOGENE MACROFLORAS: A CONSPECTUS

D. R. Greenwood[1], A. J. Vadala[2] & J. G. Douglas[3]

[1] School of Life Sciences and Technology, Victoria University of Technology,
St Alban's Campus (S008), PO Box 14428, Melbourne City MC, Victoria 8001, Australia
[2] School of Botany, The University of Melbourne, Parkville, Victoria 3052, Australia
[3] 41 Grieve Street, Warrnambool, Victoria 3280, Australia

Victoria has a rich record of Paleogene and Neogene vegetation represented in a diverse range of macrofloras ranging in age from Paleocene to Pliocene. These macrofloras are present in deposits ranging from the laterally extensive and thick brown coal and associated interseam clays of the LaTrobe Valley, to small clay lenses with leaf impressions or scattered plant fragments preserved under the basalts of the Dargo and Bogong High Plains. Most floras are composed of leaf compressions (or mummifications) or leaf impressions. There are also significant accumulations of seeds, fruits or silicified wood fragments in placer deposits known as 'deep leads'. Rare sites include tree stumps in growth position, in some instances representing 'fossil forests'. Amber containing fossil insects and leaves is known from a single site. The Victorian Paleogene and Neogene macrofloras provide an extensive yet largely unexploited database for palaeoenvironmental, biostratigraphic and palaeoclimatic analysis.

AUSTRALIA'S Paleogene and Neogene macrofloras are a primary record of the evolution of vegetation and climate; they reflect a Gondwanan conifer- and angiosperm-dominated floristic heritage established after the dominant pteridosperm and ginkgophyte floral elements of the mid-Cretaceous were replaced by angiosperms. Duigan (1951) listed 129 macrofloras in a catalogue of the Australian Tertiary floras known at that time, of which 55 were found in Victoria. Douglas (1990) noted that in addition to the floras listed by Duigan, another 30 Victorian Cenozoic (Paleogene and Neogene) macrofloras had been discovered since the 1950s, and that the actual number of floras may exceed 100. Some of these floras were listed by Hill (1988a) and Greenwood (1994). Publication of two successful non-specialist books on palaeobotany (White 1986, 1994) and a specialist edited volume (Hill 1994) indicates great interest in Australian palaeobotany, and in the floras of the Cenozoic in particular, but also indicates the greater variety of previously largely unknown or unreported macrofloras. This paper is an attempt to redress the lack of review and summation of information regarding the Cenozoic macrofossil record of Victoria.

Victoria figured early and prominently in Australian Cenozoic macrofossil palaeobotany, with Mueller (1874, 1883), McCoy (1876, 1878), and Ettingshausen (1883, 1886, 1888, 1891) describing Victorian plant fossils. This work was maintained with descriptions of macrofloras under 'auriferous drifts' or deep leads (Deane 1923; Chapman 1926a)

and those associated with coal deposits (Deane 1902b, 1902d, 1925; Paterson 1935; Cookson 1947; Cookson & Duigan 1950; Patton 1958; Duigan 1965). Researchers identified several important geographical areas with numerous fossil floras, including the Victorian High Plains (eg. Murray et al. 1878) and many close to Melbourne (Deane 1902c, 1904; Patton 1919, 1928; Paterson 1934; Gill 1949; Gill & Baker 1950). Research described not only leaf floras (eg. Deane 1902a), but also fruits (Chapman 1914; Pike 1952) and wood (Chapman 1918). Individual elements of these macrofloras were identified as significant early on, including *Eucalyptus* (Chapman 1926b), *Casuarina* (Patton 1936), *Acacia* (Cookson 1954), Banksieae (Cookson & Duigan 1950), cycads (Cookson 1953), *Dacrydium* (Cookson & Pike 1953b) and other podocarps (Cookson & Pike 1953a, 1954). Reviews of this large body of research were produced by Deane (1900); Chapman (1921); Howchin (1928); Duigan (1951) and Gill (1952). A number of Cenozoic localities have subsequently achieved prominence (eg. Christophel et al. 1987; Christophel 1989, 1993, 1994; Greenwood 1987, 1994; Pole et al. 1993). Some localities such as Berwick were extensively studied due to the presence of significant taxonomic entities such as the 'earliest' *Eucalyptus* macrofossils (Deane 1902b; Chapman 1926a, 1926b; Pole et al. 1993), or by virtue of their scale, as evidenced by continuing interest in the macrofloras of the LaTrobe Valley coals and associated sediments (Chapman 1925a, 1925b; Deane 1925; Cookson &

Duigan 1950; Cookson & Pike 1953a, 1953b, 1954; Pike 1952; Patton 1958; Duigan 1966; Blackburn 1981a, 1981b, 1985; Greenwood 1981; Blackburn & Sluiter 1994).

This paper is a compilation of information on most known Paleogene and Neogene macrofloras in Victoria. Earlier catalogues of Paleogene and Neogene macrofossil localities produced by Duigan (1951) and Hill (1988a) provided details of validly published taxonomic entities. Previous syntheses of Australian Cenozoic macrofloras have provided 'overviews' (eg. Chapman 1921; Gill 1952, 1975; Barlow 1981; Christophel 1981, 1989, 1993; Christophel & Greenwood 1989; Hill 1990a, 1992b) but generally included little specific information on the sites, and omitted some macrofloras. The value of collating and assessing site information for individual 'floras' is shown by a stratigraphic evaluation of the Vegetable Creek and Elsmore macrofloras, which indicated a series of sites spanning the Late Eocene to Early Miocene, each with a characteristic 'flora' (Pickett et al. 1990).

Information on the Paleogene and Neogene macrofloras of Victoria has been derived from museum records, personal communications, field reconnaisance, published literature and from detailed maps and reports produced by the Geological Survey of Victoria over more than 100 years. These Geological Survey publications provide a wide range of information, ranging from the Casterton 1:63 360 sheet describing the Eocene Duntroon Formation and noting the presence of carbonised plant remains, the Colac 1:50 000 sheet that first noted the Lake Colac macroflora (see below), and the Report of Progress (Murray et al. 1878) that provided specific locality information and the first descriptions of the Paleogene macroflora at Bundara River (see below). Where possible, we have provided information on stratigraphic arrangement of macrofloras, including information on spore-pollen zones and stratigraphic nomenclature. It is hoped this compilation will encourage study of Paleogene and Neogene macrofloras not in isolation, but as individual samples of a continuum of past vegetation. As previously stated by Douglas (1990), the variety and temporal and geographic spread of Victorian macrofloras affords opportunities for broad regional syntheses.

A HISTORY OF VICTORIAN PALEOGENE AND NEOGENE MACROFOSSIL PALAEOBOTANY

Research on Victorian Cenozoic macrofossil palaeo-botany is here divided into four periods: late 19th Century, 1900 to 1940, 1940 to 1970 and 1970 to 1999. The most recent period has included a shift in emphasis to pre-Cenozoic Victorian floras, and to macrofloras outside Victoria (see Douglas 1969, 1973, 1990; Gould 1975, 1981). Significant advances were made in descriptive and stratigraphic palynology by Victorian palaeobotanists such as Cookson from the 1920s to the 1970s. These advances combined with research relating to commercial oil exploration in the Gippsland Basin contributed to the palynostratigraphic framework currently used for most of the Cenozoic macrofloral record (eg. Stover & Partridge 1973; MacPhail et al. 1994; Partridge, in prep.).

Late 19th Century

Earliest descriptions of the Cenozoic flora of Australia, for example those of Mueller (1874, 1883), Ettingshausen (1883, 1886, 1888, 1891), McCoy (1876, 1878), Johnston (1885, 1887) and Schimper & Schenk (1890) must be viewed with an understanding of the limitations of their times. These researchers assigned many Australian Cenozoic plant fossils to Northern Hemisphere taxa such as *Quercus*, *Laurus* and *Fagus*, or implied relationship to such genera, such as *Psendopinns wilkinsoni* Ett. from Vegetable Creek (syn. *Podocarpus wilkinsoni* (Ett.) Selling 1950). Although more recent researchers (eg. Deane 1900; Selling 1950; Christophel 1981, 1993) were to decry this practice, it was probably the consequence of a more thorough knowledge of European rather than Australian plant morphology, systematics and ecology at that time. An extension of early palaeobotanical research was the perception of an Australian Paleogene '*Cinnamonum* flora', typified by large-leaved Lauraceae with acrodromous venation (eg. *Cinnamonum polymorphoides* McCoy) and other leaves of the 'brush type', a reference to similarity with vegetation now termed subtropical to tropical rainforest.

Of greater controversy at the time was Ettingshausen's 'Cosmopolitan Theory' (Ettingshausen 1888), which proposed that all continents had originally supported essentially the same community of taxa, and that evolution and extinction had subsequently led to differentiation of the distinctive floras of Australia and other parts of the world. This theory was criticised by palaeontologists at the time (eg. Deane 1900; Andrews 1916); however it was largely ignored by researchers in areas other than palaeontology (Hill 1994).

Principal Victorian macrofloras discovered and described in this early period were mostly associated with gold diggings and included Daylesford, Eldorado, Foster, Haddon, Maddingley, Tanjil, Thorpdale, Werribee Creek and the High Plains. The bias towards descriptions of fossil seeds in the taxonomic research of Mueller reflects the macrofloras associated with deep lead deposits. This research is still considered to have some systematic value (eg. Rozefelds & Christophel 1996a, 1996b). A fossil seed of *Xylocaryon lockii* F. Muell. from Haddon near Ballarat figured by Mueller (1883) was recently recognised as equivalent to extant *Eidothea zoexylocarya*, a previously undescribed monotypic genus of Proteaceae assigned to the monogeneric subfamily Eidotheoideae (Douglas & Hyland 1995). *Penteune clarkei* F. Muell., common in Victorian deep leads, was subsequently matched with endocarps of extant *Elaeocarpus* (Selling 1950; Rozefelds & Christophel 1996b). Other common seed or fruit types described by Mueller from the deep lead floras, such as *Spondylostrobus* F. Muell., remain enigmatic although some affinity with Cupressaceae was suggested by him at the time.

1900–1940

Significant palaeobotanical studies in this period were produced by Deane (1900, 1902a, 1902b, 1902c, 1902d, 1904, 1923, 1925), who described important leaf floras at Berwick, Sentinel Rock and Mornington, and a deep lead flora at Foster in South Gippsland. The most important work (Deane 1900) was a brief account of Australian Cenozoic floras, including an extensive critique of Ettingshausen's (1883) 'Cosmopolitan Theory' of plant evolution and a discussion of problems relating to the use of leaf venation as a diagnostic tool in macrofossil taxonomy. Deane (1900) recognised that many identifications of Australian Cenozoic macrofossils as Northern Hemisphere genera, such as *Quercus* (Fagaceae; Ettingshausen 1883), were based on apparently limited comparisons of leaf morphology, and were more likely to represent extant Australian genera. Significantly, Deane (1900) argued that leaf venation and general leaf architecture were so variable within genera as to be almost useless as a diagnostic tool, and thus many identifications based on leaf features, such as *Cinnamomum* (Lauraceae), were suspect.

Other researchers active in this period included Chapman (1914, 1918, 1921, 1925a, 1925b, 1926a, 1926b), Patton (1919, 1928, 1936), and Paterson (1934, 1935). Anecdotal records from several sites were also published (eg. Keble 1925; Thomas 1932; Ewart 1933), some of which indicated the existence

of Cenozoic floras in the Eastern Highlands and East Gippsland (Chapman 1918; Kenny 1937). The open-cut coal mine at Morwell provided the first plant fossil material (primarily seeds and wood) from the extensive thick brown coals of the LaTrobe Group sediments in the LaTrobe Valley (Deane 1923; Chapman 1925a, 1925b; Nobes 1922). Material from several sites near Melbourne was also described (Armitage 1910; Chapman 1914; Patton 1919; Paterson 1934), reflecting increased roadworks and the construction of the new Melbourne sewerage system. Deane (1902a) and other workers also published accounts of Cenozoic floras from outside Victoria at this time. Research by European workers continued on from Mueller's work, and included description or reclassification of seeds from deep lead floras (Kubart 1922; Kirchheimer 1935). Reviews of Australian Cenozoic floras were included in papers by American (Andrews 1916) and Australian (Chapman 1921; Howchin 1928) researchers. Both Maiden (1922) and Chapman (1926b) reviewed the Paleogene and Neogene macrofossil record of *Eucalyptus*, based largely on Victorian material.

1940–1970

This period saw very active palaeobotanical research into Victorian Cenozoic macrofloras, largely through the efforts and influence of Isabel Cookson and her associates, based mainly in the School of Botany at The University of Melbourne. Cookson researched macrofloras and microfloras (pollen, spores and plankton) ranging from Silurian to Pleistocene, and a thorough account of her achievements is beyond the scope of this paper (see Baker 1973 for a complete bibliography). The hallmark of Cookson's research was an appreciation of the importance of establishing taxonomic relationships based on detailed comparison of anatomical diagnostic features of both fossil and extant taxa (eg. Cookson & Duigan 1950).

Few additional Cenozoic macrofloras were described in this period, although major advances were made in understanding the systematics of many macrofloras, particularly those of the LaTrobe Valley coal measures, by Cookson (1947, 1953), Cookson & Duigan (1950, 1951), Pike (1952), Cookson & Pike (1953a, 1953b, 1954), Clifford & Cookson (1953) and particularly by Duigan (1965). Gill and co-workers documented Cenozoic macrofloras near Melbourne, such as Lilydale (Gill 1942) and within the Melbourne metropolitan area, such as Pascoe Vale and Maribyrnong (Gill 1949; Gill & Baker 1950). They also provided the solitary report of a Cenozoic fungus from the LaTrobe

Valley coals (Willis & Gill 1965). Gill (1952, 1961, 1965, 1975) proposed hypotheses regarding the evolution of the Australian flora and climate through the Cenozoic. The sole Australian record of amber containing plant or animal remains was also described during this time (Hills 1956). Selling (1950) described *Araucaria balcombensis* Selling from the Mornington macroflora, and also referred *Penteune clarkei* F. Muell. from the deep lead floras to extant *Elaeocarpus*, and other fossil seeds to extant tropical Australian taxa. Fossil woods described from Victorian localities by Nobes (1922) were transferred to *Podocarpoxylon* by Krausel (1949). Florin (1963) referred to Victorian macrofossils in his major monograph on fossil conifers.

1970–1999

Research on Victorian Cenozoic palaeobotany during this period has been dominated by workers based outside Victoria, with a focus on a small number of floras, particularly the Anglesea Eocene flora (Christophel 1993). This period is dominated by research completed or initiated at The University of Adelaide by Christophel (Christophel 1980, 1981, 1984, 1986, 1989, 1993, 1994) and his associates, for example in Christophel & Basinger (1982), Basinger & Christophel (1985), Blackburn (1985), Christophel & Lys (1986), Christophel et al. (1987), Greenwood (1987, 1991, 1994), Christophel & Greenwood (1988, 1989), Rozefelds (1988), Barrett & Christophel (1990), Scriven & Christophel (1990), O'Dowd et al. (1991), Rozefelds et al. (1992) and Rozefelds & Christophel (1996a, 1996b). Significant long-running research into Victorian Cenozoic maco-floras was also conducted initially in Adelaide but mainly at The University of Tasmania by Hill (1978, 1980, 1988a, 1989, 1990a, 1990b, 1994) and his associates, for example in Hill & Christophel (1989), Hill & Carpenter (1991), Hill & Pole (1992), Pole et al. (1993) and Scriven & Hill (1995). In addition to these two main research groups there have been reports by other individuals (eg. Douglas 1977, 1983; Leisman 1986).

Significant advances in biostratigraphic analyses of the Otway and Gippsland basins were completed over this period (eg. Harris 1971; Stover & Partridge 1973; McGowran 1991; MacPhail et al. 1994). These improved the potential for placing Victorian Cenozoic macrofloras into stratigraphic context, particularly when combined with con-comitant radiometric analyses of volcanic rocks (Wellman 1974, 1983).

PALEOGENE AND NEOGENE SEDIMENTARY BASINS OF VICTORIA

There are three main Paleogene and Neogene onshore sedimentary basins in Victoria (Fig. 1), which are primarily of marine origin but also include significant terrestrial sequences. The Otway Basin covers much of southwestern Victoria including the Otway Ranges and coast, and extends offshore. The Murray Basin encompasses most of northwestern Victoria. The Gippsland Basin covers much of southeastern Victoria and includes the laterally extensive and thick coal-bearing sequences of the LaTrobe Valley (Douglas 1993). Biostratigraphic dating of macrofloras is primarily based on palynostratigraphic schemes derived from the Gippsland Basin (Stover & Partridge 1974) and Otway Basin (Harris 1971, 1985) as summarised by MacPhail et al. (1994). Age controls on palyno-stratigraphic zones are based on correlations with assemblages of cosmopolitan marine nannofossils and microfossils. Radiometric dating of interleaved volcanic sediments and detailed sequence strati-graphy of onshore exposures of the LaTrobe Group sediments of the Gippsland Basin is providing greater refinements in the chronostratigraphic place-ment of some floras (Holdgate et al. 1995). Stratigraphic positions of floras outside the main basins, such as those from the Eastern Highlands, are problematic: key stratigraphic marker pollen types may be lacking or may show different patterns of first and last appearance than seen in the type sections (MacPhail et al. 1994; Partridge, in prep.).

Duigan (1951) listed 55 Paleogene and Neogene macrofloras from Victoria. A summary of floristic and stratigraphic information on the majority of these floras is presented below, together with an overview of floras reported since that initial catalogue. Macrofloras are primarily grouped according to stratigraphic stage within sedimentary basins (Fig. 2). Macrofloras of the Eastern High-lands and those of the deep leads are also discussed under separate headings. Very little macrofossil material has been reported from the Murray Basin and so this material is discussed with the floras of the Eastern Highlands.

MACROFLORAS OF THE OTWAY BASIN

South-western Victoria

A number of significant Paleogene and Neogene macrofloras have been reported from sites in the Otway Basin, in the Otway Ranges and coast, and

from near Hamilton and Casterton in western Victoria (Chapman 1921; Paterson 1935; Douglas 1983, 1990; Abele et al. 1988). The Eocene macroflora at Anglesea is the most significant of these in terms of the amount of published detail (discussed below). Early reports on the Victorian Cenozoic discussed the following floras from the Otway Basin: Lookout Hill near Aireys Inlet

(Eocene); Sentinel Rock and Pitfield (Miocene); Redruth Ironstone near Casterton (Miocene or Pliocene); Wannon Falls (Pliocene); and Grange Burn or Hamilton (Pliocene or Early Pleistocene). Crespin (1954) and Kenley (1971) reported leaves of cf. *Cinnamomum* and cf. *Banksia* from bore samples of the Dartmoor Formation (considered a junior synonym of Dilwyn Formation; Abele et al.
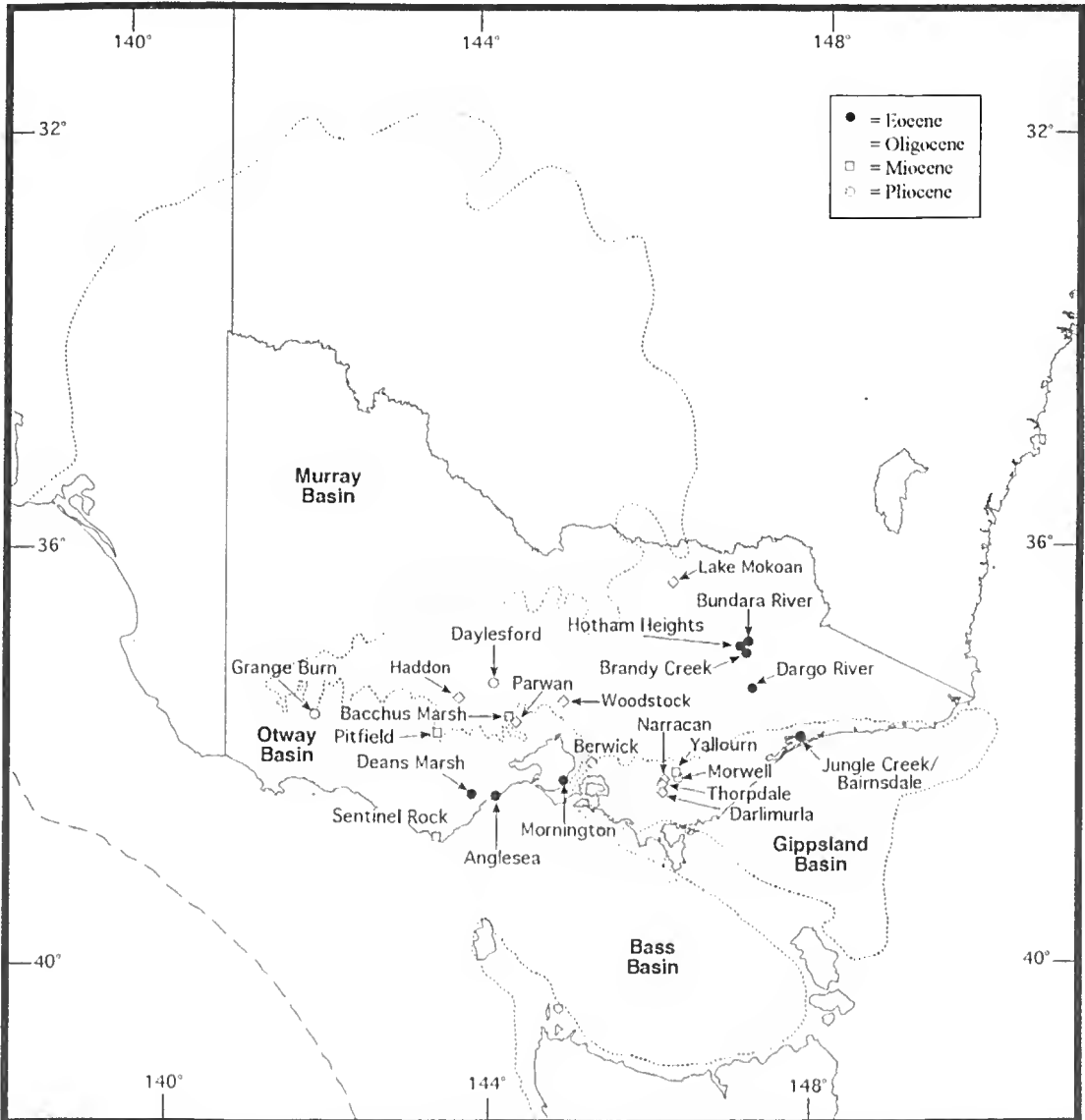
Fig. 1. Principal Paleogene and Neogene macrofloras in Victoria. Fine dashed lines indicate approximate limits of Paleogene and Neogene sediments in the major sedimentary basins; wider dashed line indicates inferred limit of continental crust. (Basin details after Abele et al. 1988.)

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Nothofagaceae

Banksieae

Proteaceae

Eucalyptus

Casuarinaceae

Lauraceae

Podocarpaceae

Araucariaceae

Gippsland Basin

Morwell

Yallourn

Narracan/
Darlimurla

Traralgon

Jungle Creek/
Bairnsdale

Otway Basin (including Melbourne and area)

Grange Burn

Sentinel Rock

Pitfield

Bacchus Marsh

Berwick

Parwan

Pascoe Vale

Anglesea

Mornington

Lookout Hill

Deans Marsh

Eastern Highlands
& Deep Leads

Stony Creek /
Daylesford

Eldorado
& Haddon

Bundara
River

Woodstock /
Loddon

Brandy
Creek

Hotham
Heights

5
10
15
20
25
30
35
40
45
50
55
60
65

Tortonian
Serravallian
Langhian
Burdigalian
Chattian
Rupelian
Priabonian
Bartonian
Lutetian
Ypresian
Danian

Late
Middle
Early
Late
Early
Late
Middle
Early
Late
Early

Miocene
Oligocene
Eocene
Paleocene

Neogene
Paleogene

1988) near Nelson. Carbonised plant remains in Dilwyn Formation sediments in outcrop in the Glenelg and Stokes River valleys north of Dartmoor indicate a Late Paleocene to Early Eocene flora, as the sediments contain a microflora correlated with the *Cupanieidites orthoteichus* Zone of the Otway Basin (Harris 1985; Abele et al. 1988). Rare plant fragments have also been reported from the Late Miocene to Early Pliocene Dorodong Sand at Red Cap Creek (Abele et al. 1988), and leaf impressions of possible Proteaceae, *Eucalyptus* and 'tea trees' (*?Leptospermum*) are known from volcanic tuff at Lake Colac that has been radiometrically (K/Ar) dated at 2 million years (J. G. Douglas, unpub. data).

Melbourne and metropolitan area

A substantial number of known Victorian Cenozoic macrofloras occur within 100 km of Melbourne (Fig. 1; Table 1). These macrofloras were commonly collected from fluvial or fluvio-lacustrine facies below Newer Volcanics or Older Volcanics, depending on location and site stratigraphy. Macrofloras considered important to one generation of palaeobotanists occasionally appear to have been either overlooked by subsequent generations, or displaced from their former position of importance by later discoveries. For example, whereas some recent papers on Australian Cenozoic macrofloras (Christophel 1981, 1989, 1993; Christophel & Greenwood 1989; Greenwood 1994; Pole et al. 1993; Hill 1994) mention only the Berwick and Bacchus Marsh (Maddingley) macrofloras, Douglas (1967, 1983) and earlier researchers (eg. Chapman 1921; Gill 1950) cite additional floras.

Several other localities close to Melbourne (eg. Flemington) are now beneath suburbia and are uncollectable. Material representative of most of such floras is housed in the National Museum of Victoria. Providing ages for these floras is problematic, as host sediments were often in suberop, and the stratigraphic units (eg. Werribee Formation and equivalent units) were time-transgressive across the Melbourne area (Abele et al. 1988). Sediments associated with basalt flows to the east of Melbourne are generally older (Late Eocene to Oligocene) than sediments so associated to the west (Early Miocene to Pliocene). In many cases, no further analysis of the

stratigraphic position of these floras has been undertaken since their original description.

Pascoe Vale

The macroflora locality at Pascoe Vale has been described in varying degrees of detail by numerous authors includung Hanks (1934), Paterson (1934), Gill (1949), Douglas (1967, 1983) and Abele et al. (1988). This flora is worthy of detailed systematic study as both high quality impressions and mummified leaves have previously been collected. Indeed, Paterson (1934) recorded leaf impressions of three taxa of *Nothofagus* in addition to *Eucalyptus kitsoni*, Proteaceae, Lauraceae and other dicot leaf taxa of the 'brush type', in addition to mummified leaf fossils possibly representing *Nothofagus* and *Eucalyptus*. Gill (1949) considered the Pascoe Vale flora to be of Paleogene age (underlying Older Volcanics) and likely contemporaneous with the Late Oligocene Berwick flora. However, Abele et al. (1988) suggested the Pascoe Vale macroflora occurred in the Werribee Formation, indicating a Late Eocene to Early Oligocene age (Fig. 2).

Berwick

The Berwick flora was originally described by Deane (1902), and was recollected and redescribed by Pole et al. (1993). This macroflora crops out in a series of sub basaltic fluvio-lacustrine lenses (Deane 1902; Pole et al. 1992). The palynoflora associated with these sediments is correlated with the Middle *Proteacidites tuberculatus* Zone of the Gippsland Basin (Stover & Partridge 1974), indicating a Late Oligocene to Early Miocene age (Fig. 2). Macrofossils are preserved as impressions in a pale grey matrix with organic preservation of leaf cuticle, or as impressions with no organic preservation.

Deane (1902) recorded several taxa of *Eucalyptus* as leaves from Berwick; however Pole et al. (1993) described only one taxon, using both leaf venation and cuticular information, and amended the diagnosis of *Eucalyptus kitsoni* Deane. Pole et al. (1993) interpreted the Berwick flora as reflecting a transitional phase in Victoria, suggesting the mixture of temperate rainforest forms (eg. *Nothofagus*) and sclerophyllous plants (eg. *Eucalyptus*) reflected initial drying of the regional climate and the early development of tall open eucalypt forests.

Fig. 2. Stratigraphic arrangement of Victorian Paleogene and Neogene macrofloras with constraining spore–pollen zones for south-eastern Australia (Gippsland and Otway basins). Palynostratigraphic scheme adapted from MacPhail et al. (1994).

Basin/locality	Age	Stratigraphy/pollen zone	Taxa	References
OTWAY BASIN				
1. *South-western Victoria*				
A. Red Cap Creek/Dorodong Sand	Late Miocene–Early Pliocene	Dorodong Sand	Plant fragments (rare)	Abele et al. (1988)
B. 'Redruth' (=Wannon Falls)	Pliocene		Leaf impressions including *Eucalyptus* and *Banksia*	Chapman (1910, 1921)
C. Sentinel Rock*	Middle Miocene–Pliocene	Sentinel Rock Clay	Leaves of *Casuarina, Acacia,* Proteaceae Myrsinaceae, Rubiaceae, Fabaceae, *Phyllocladus;* fruits	Deane (1902d); Paterson (1935); Cookson (1954); Douglas (1983); Abele et al. (1988)
D. Wannon Falls	Late Miocene–Early Pliocene	Wannon River Beds	Leaf impressions	Chapman (1911); Abele et al. (1988)
E. Nintingbool		Deep lead	Fruits and seeds	Mueller (1875); Selling (1950); Duigan (1951)
F. Pitfield*	Neogene		Diverse rainforest flora: mainly leaves including: *Cinnamomum, Sterculia, Eucalyptus,* Mollinedia, Sapindaceae, Winteraceae, Araliaceae	Deane (1902); Paterson (1935)
G. Grange Burn*	Pliocene		*Phyllocladus* wood; dicot and conifer leaves; *Acacia* phyllodes	Douglas (1983); Abele et al. (1988); Rich et al. (1991)
H. Hamilton	Late Pliocene		*Phyllocladus* wood	Gibbons & Gill (1964)
I. Lillicur	Pliocene–Pleistocene		Algae fossils	Krause (1887)
J. Ouyen (Murray Basin)			Algae and fungi fossils	Chapman (1913)
2. *Melbourne and Metropolitan Area*				
A. Lookout Hill/Aireys Inlet	Early–Middle Eocene	'Boonah Sandstone'/Eastern View Formation; Lower *Nothofagidites asperus*	Leaf impressions	Gill (1952); Abele et al. (1988); Douglas (1983)
B. Flinders	Late Middle Eocene	Flinders Basalt	Stems and dicot leaves	Deane (1923); Douglas (1983); Abele et al. (1988)
C. Flemington	Late Eocene–Early Oligocene	Yaloak/Werribee Formation	Leaf impressions	Paterson (1934); Abele et al. (1988)
D. Pascoe Vale	Late Eocene–Early Oligocene	Werribee Formation/Older Volcanics	Dicot leaves including *Eucalyptus, Nothofagus* and leaves of 'brush-type'	Paterson (1934); Gill (1949); Douglas (1983); Abele et al. (1988)
E. Berwick*	Late Oligocene–Early Miocene	Middle *Proteacidites tuberculatus*	Conifer leaf impressions; *Eucalyptus kitsoni* leaves and capsules; *Nothofagus* leaves	Deane (1902); Pole et al. (1993)

Location	Age	Formation	Fossil content	References
F. Bulla	Neogene		*? Eucalyptus* leaves	Patton (1919); Douglas (1983)
G. Keilor	Neogene		Leaf impressions, including *Eucalyptus*	Patton (1919); Douglas (1983)
H. Clifton Hill			*Casuarina* wood	Armitage (1910); Gill & Baker (1950)
I. Altona			Conifer (*Mesembrioxylon* sp.) wood	Chapman (1921)
J. 'Balcombe Bay' (=Mornington)			*Araucaria balcombensis*	Selling (1950)
K. Mornington*			*Eucalyptus praecoriacea* leaves	Deane (1902b); Chapman (1921)
L. Gisborne			Legume fruits and flowers	Thomas (1932)
M. Lilydale			*Betschmiedia* wood; *Nothofagus* leaves	Gill (1942)

3. Werribee Gorge: Parwan and Bacchus Marsh/Maddingley

Location	Age	Formation	Fossil content	References
A. Parwan*/Parwan Creek	Late Paleocene to Early Miocene	Werribee Formation/ 'Yaloak Formation'	Leaf impressions, including *Eucalyptus kitsoni*, rainforest taxa	Hanks (1934); Paterson (1934); Gill (1949); Douglas (1983); Abele et al. (1988)
B. Bacchus Marsh*/ Maddingley	Early Miocene	Upper *Proteacidites tuberculatus*	*Cinnamomum polymorphoides* impressions; leaves of *Nothofagus*, Myrtaceae, *Araucaria*, *Dacrycarpus*; *Casuarina* and *Acacia* foliage; *Elaeocarpus* fruits; *Eucalyptus* fruits, flowers and leaves	Cookson & Duigan (1951); Christophel (1985; Abele et al. (1988); Greenwood (1994); Blazey (1994)

4. Deans Marsh. Anglesea and surrounding area

Location	Age	Formation	Fossil content	References
A. 'Benwerrin' (=Deans Marsh)	Late Paleocene/Early Eocene	Eastern View Formation; *Lygistepollenites balmei*	Fossil leaves	Abele et al. (1988); Douglas (1983)
B. Deans Marsh*	Early Eocene	Eastern View Formation; *Proteacidites asperopolus*	*Cinnamomum*-type mummified leaves; *Nothofagus* leaves and cupules; *Eucalyptus* fruits	Christophel & Greenwood (1989); Greenwood (1994); Greenwood & Christophel (1994); Partridge (1998)
C. Wensleydale	Eocene	Eastern View Formation	Leaf impressions	Cookson (1954); Abele et al. (1988)
D. Anglesea*	Late Middle Eocene	Eastern View Formation; Lower/Middle *Nothofagidites asperus*	Leaf impressions and compressions, including taxa of: *Lygodium*, *Bowenia*, *Pterostoma*, *Dacrycarpus*, *Fulcatifolium*, *Podocarpus*, *Prumnopitys*, *Austrodiospyros*, *Myrtaciphyllum*, *Banksiaeaphyllum*, *Musgraveinanthus*, *Megahertzia*, *Brachychiton*, *Gymnostoma*, *Lauraphyllum*, *Sloanea*, *Petermanniopsis*, *Linnospadix*, Loranthaceae, Sapindaceae and Rutaceae	Christophel (1981, 1984, 1988; Christophel & Lys (1986); Christophel & Greenwood (1988, 1989); Greenwood (1993)
E. Lookout Hill	Early–Middle Miocene	Boonah Sandstone	Seeds, stems; impressions of broad-leaved taxa and Banksieae-like leaves	Gill (1952); Abele et al. (1988)

(Legend to Table 1 and table continued overleaf)

Basin/locality	Age	Stratigraphy/ pollen zone	Taxa	References
GIPPSLAND BASIN				
1. Darlimurla, Narracan and other South Gippsland floras				
A. Hazelwood			Leaf impressions	Cookson (1947); Duigan (1951)
B. Tanjil River			Fruits and seeds	Selling (1950); Duigan (1951)
C. Bruthen	Eocene		*Eucalyptus* wood	Chapman (1918)
D. Jungle Creek*/Bairnsdale	Late Eocene–Early Oligocene		Wood of Lauraceae (*Cryptocaryoxylon gippslandicum*)	Chapman (1918); Leisman (1986)
E. Narracan*	Late Early Oligocene–Early Miocene	Childers Formation. LaTrobe Group	Leaf impressions including; Lauraceae, Sterculiaceae, *Nothofagus*, Cunoniaceae, Moraceae, Proteaceae, Myrtaceae (including *Eucalyptus*), Monimiaceae Loganiaceae, Casuarinaceae, *Podocarpus*, *Dacrycarpus*	Howchin (1923); Chapman (1926); Paterson (1935); Douglas (1983)
F. Darlimurla*	Late Oligocene		Leaf impressions including: Lauraceae, Sterculiaceae, *Eucalyptus*, *Nothofagus*	Paterson (1935); Thomas & Baragwanath (1951)
2. Thorpdale				
A. Thorpdale*	Paleogene		*Spondylostrobus smythii* fruits and seeds	Duigan (1951); A. J. Vadala (unpub. data)
3. Macrofloras of the brown coals				
A. Traralgon	Late Middle Eocene		Leaf impressions and compressions	
B. Gelliondale	Early Oligocene–Late Miocene	Overlying LaTrobe Unconformity	Coal seam	Thomas & Baragwanath (1950); Gloe et al. (1988)
C. Morwell* coal	Late Oligocene–Early Miocene	Middle/Upper *Proteacidites tuberculatus* (Morwell 1A and 1B seams)	Leaf compressions, impressions (including *Eucalyptus*); fruits; seeds	Chapman (1925); Duigan (1965); Blackburn & Sluiter (1994)
D. Morwell* clay	Late Oligocene–late Early Miocene	Middle *Proteacidites tuberculatus*	Leaf compressions and impressions	Duigan (1965); Blackburn & Sluiter (1994)
E. Yallourn* clay	late Early Miocene–early Middle Miocene	Upper *Proteacidites tuberculatus*– *Triporopollenites bellus* (Yallourn Clays)	Dispersed cuticle: leaves of *Pterostoma*, *Gymnostoma*, *Diospyros*, *Ceratopetalum*, Lauraceae, Myrtaceae, *Podocarpus/ Prumnopitys*, *Dacrycarpus*, *Phyllocladus*, *Agathis*, *Araucaria*; *Wilkinsonia* seeds	Greenwood (1981, 1993); Rozefelds & Christophel (1995)
F. Yallourn* coal	early–mid Middle Miocene	*Triporopollenites bellus* (Yallourn Seam)	Dispersed cuticle; leaves; seeds of *Elaeocarpus cerebriformis*	Duigan (1965); Blackburn (1985); Blackburn & Sluiter (1994); Christophel (1994b); Rozefelds & Christophel (1996)
G. Hazelwood			*Oleinites* leaves	Cookson (1947)

4. Deep lead floras

A. Woodstock*/Loddon	Oligocene	Dicot leaves and fruits	Douglas (1983); Partridge & Wilkinson (1982)
B. Foster	? Oligocene	Seeds; *Elaeocarpus clarkei* fruits	Mueller (1874); Deane (1925); Rozefields & Christophel (1996)
C. Eldorado/Chiltern	Early/Middle Miocene	*Banksia* infructescences; *Elaeocarpus clarkei* and *E. angularis* fruits	Selling (1950); Pike (1953); Abele et al. (1988); Rozefields & Christophel (1996)
D. Haddon*	Early–Middle Miocene	*Eucalyptus* leaves; *Elaeocarpus clarkei*, *Xylocaryon lockii* fruits; legume fruits.	Mueller (1874, 1883); McCoy (1874); Selling (1950); Rozefields & Christophel (1996)
E. Nintingbool		*Xylocaryon lockii, Spondylostrobus smythii* fruits; legume and other fruits	Mueller (1875); Selling (1950)

Table 1. Victorian Paleogene and Neogene macrofossil localities, with age (where known), stratigraphy/pollen zone (where known) and details of taxonomic composition as recorded in the associated reference(s). Locality information is derived mainly from Duigan (1951), with additional data from Douglas (1983) and from sources examined for the current survey. Where a locality has been described by two or more authors using different names (eg. Benwerrin and Deans Marsh), both are listed separately. Those localities shown on Fig. 1 are indicated by an asterisk (*).

Several poorly documented macrofloras are known from localities close to Melbourne. The Flemington macroflora is largely undocumented but is recorded from the Yaloak Formation, a probable equivalent of the Werribee Formation (Douglas 1967, 1983; Abele et al. 1988). The Maribyrnong and Clifton Hill macrofloras are known from records of impressions of *Casuarina* twigs in basalt (Armitage 1910; Gill & Baker 1950), and are unlikely to be important. Additional largely undocumented macrofloras from St Kilda and Cranbourne are represented by collections held at Museum Victoria. The Cranbourne macroflora is likely coeval with the Berwick flora (below). Plant remains have also been reported from the Late Miocene to Early Pliocene (Cheltenhamian) Black Rock Sandstone, which crops out from Beaumaris to Black Rock in metropolitan Melbourne.

Little has been published on the Miocene Mornington–Balcombe Bay macroflora since the original description by Deane (1902), and the specimens in Museum Victoria are largely unusable due to previous heavy use of varnish as a preservative. The Flinders locality is associated with the Flinders Basalt (Middle Eocene; Abele et al. 1988), and consists of plant stems and leaf impressions (Douglas 1982). Deane's (1902) description of *Eucalyptus praecoriacea* from Mornington provoked some debate over its systematic position (Christophel 1981; Hill 1994). Maiden (1922; see Chapman 1926) accepted the fossil as *Eucalyptus*, but Hill (1994) noted that Patton (1919) considered the original identification doubtful. Indeed, Hill (1980) considered the specimen likely to be a pinnule of a zamioid cycad. Foliage of *Araucaria balcombensis* Selling (1950) has also been described from Balcombe Bay, probably from the same sediments as the Mornington flora.

Deans Marsh, Anglesea and surrounding area

The Deans Marsh macroflora was collected from overburden at the abandoned Wensleydale brown coal open-cut mine south of Winchelsea in sediments towards the base of the Eastern View Formation, above its contact with the Demons Bluff Formation. The collection used in the analyses of Christophel & Greenwood (1989), Christophel (1993), Greenwood (1994) and Greenwood & Wing (1995) represents a single large block of sediment from which 128 whole or near whole mummified leaves were extracted. These leaves probably represents the only collection of the macroflora as the site is now flooded. The Deans Marsh

macroflora is of Early Eocene age based on palynological correlations (Abele et al. 1988; Christophel & Greenwood 1989; Fig. 2) although Rowett & Sparrow (1994) indicated an early Middle Eocene age was possible. An unstudied Eocene macroflora at Benwerrin in the Otway Ranges has been noted to contain conifer shoots (Douglas 1983; J. G. Douglas, unpub. data).

The Lookout Hill macroflora is known from sites on a ridge overlooking Aireys Inlet, in sediments of the Boonah Sandstone of Early to Middle Eocene age (Gill 1952; Abele et al. 1988). Gill (1952) reported seeds, stems and impressions of broad leaves and *Banksia*-type (*Banksieaeformis*) leaves. Poorly preserved leaf impressions in coarse sandstone can still be collected from a roadside quarry near the locality (J. G. Douglas & D. R. Greenwood, unpub. data).

Douglas (1977) first noted the Anglesea macroflora. Abundant, taxonomically diverse and well preserved plant macrofossils have been described in a number of publications (Hill 1978, 1980; Christophel 1980, 1981; Greenwood 1987; Hill & Christophel 1988; Rowett & Christophel 1988; Rozefelds 1988; Rozefelds et al. 1991; Conran et al. 1994). Macrofossils have been collected from the Eastern View Formation in a series of fluvio-lacustrine lenses in overburden from the Anglesea open-cut brown coal mine (Christophel et al. 1987). The associated microflora indicates a mid–late Middle Eocene Age (Lower *Nothofagidites asperus* Zone of Stover & Partridge 1974; Fig. 2). Macrofossils are preserved as impressions in a pale grey matrix with minor organic (cuticle) preservation, as impressions with no organic preservation, and as mummifications comprising laterally extensive horizons of leaf mats preserved in a mudstone matrix.

Mummified material from Anglesea is unimpressive in hand specimen; however maceration using a hydrogen peroxide bath typically releases large numbers of organically intact leaf, fruit and flower fossils with good cellular detail (eg. Christophel & Lys 1986). Flowers, staminate conifer cones containing pollen and fern sporangia with spores have previously been recovered (Basinger & Christophel 1985; Christophel 1984; Greenwood 1987; Rozefelds et al. 1992). Barrett & Christophel (1990) reported that lateral and vertical variations in the composition of macrofloras was significant between and within discrete

'lenses', but that macrofossils belonging to the major identified taxa were encountered throughout the locality following extensive sampling (see also Christophel et al. 1987; Rowett & Christophel 1989). Palaeoecological interpretation of the Anglesea macroflora indicates a diverse, laterally heterogeneous rainforest of similar floristic and foliar physiognomic character to extant upland tropical rainforests (Simple Notophyll Vine Forest *sensu* Webb 1959) of northeastern Queensland in the Daintree River area. Christophel (1993, 1994) suggested analogy with rainforest at Noah Creek, where many rare taxa (eg. *Megahertzia* and *Gymnostoma*) with close matches to Anglesea fossil taxa can be found in close proximity.

Christophel (1994) suggested over 100 taxa were present in the Anglesea macroflora. Although a complete taxonomic list is not yet available, the following taxa have been recorded: the fern *Lygodium*; foliage of the cycads *Bowenia eocenica* Hill and *Pterostoma zamioides* Hill (Zamiaceae), and the conifers *Dacrycarpus eocenica* Greenwood, *Falcatifolium australis* Greenwood, *Podocarpus platyphyllum* Greenwood, *Prumnopitys tasmanica* (Townrow) Greenwood and *P. lanceolata* Greenwood (all Podocarpaceae). Angiosperms include leaves of rainforest trees such as *Austrodiospyros eocenica* Basinger & Christophel (Ebenaceae; flowers and leaves), *Myrtaciphyllum douglasii* Christophel & Lys (Myrtaceae), two *Banksieaephyllum* spp. (Banksieae, Proteaceae), *Musgraveinanthus alcoensis* Christophel (Musgraveinae, Proteaceae; flowers), *Megahertzia*[1] sp. (Oriticae, Proteaceae), *Brachychiton* sp. (Stereuliaceae), *Gymnostoma* sp., at least 5 *Laurophyllum* spp. (Lauraceae), Elaeocarpaceae cf. *Sloanea*, leaves of the monocot *Petermanniopsis anglesaeensis* Conran et al. (Petermanniaceae), and a palm attributed to *Linospadix* (Arecaceae). Escalloniaceae (cf. *Quintinia*), Loranthaceae, Sapindaceae and Rutaceae have also been recorded as present (Christophel 1981, 1989, 1993, 1994; Basinger & Christophel 1985; Christophel & Basinger 1982; Christophel & Greenwood 1988, 1989; Christophel et al. 1987; Rozefelds et al. 1992; Conran et al. 1994). O'Dowd et al. (1991) noted the presence of oribatid mites in domatia of Elaeocarpaceae (cf. *Sloanea*) leaves from Anglesea, indicating the persistence since the Middle Eocene of this association. Rozefelds (1988) also recorded insect leaf mines in Anglesea leaf lamina.

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[1]This fossil taxon was originally attributed to the undescribed '*Orites* sp. nov.' from Noah Creek in northeast Queensland. (Christophel 1994: 266), which has subsequently been described as *Megahertzia amplexicaulis* A. S. George & B. Hyland (George & Hyland 1995). The morphology of the leaf fossil is indistinguishable from the extant material.

Bacchus Marsh/Maddingley and Werribee Gorge

McCoy (1876) described leaf fossils in ironstone from Werribee Creek, and Douglas (1983) listed a macroflora at Parwan Creek (Late Paleocene to Early Miocene according to Abele et al. 1988), a tributary of the Werribee River. Both Werribee Creek and Parwan Creek macrofloras are in Werribee Gorge (in the vicinity of Bacchus Marsh); they are preserved in ferruginised sandstone (ironstone), and are likely the same sediments. The majority of collections attributed to Bacchus Marsh/Maddingley appear to be from the same stratigraphic unit as the Werribee Creek and Parwan Creek floras (Werribee Formation) and in the same locale. More recent collections have come from the remaining overburden of the Maddingley Open Cut No. 2 brown coal mine. Large tree trunks have been recovered from the Bacchus Marsh coalfield (Gloe et al. 1988). The Maddingley Coal seam is probably Early Miocene in age (Fig. 2), based on correlation of the associated microflora with the Upper *Proteacidites tuberculatus* Zone of the Gippsland Basin (Stover & Partridge 1974).

Early reports of Paleogene and Neogene plant fossils from Bacchus Marsh refer to the site as Maddingley (or Maddingly), and noted leaf impressions in ironstone (McCoy 1876; Chapman 1921), including Lauraceae (eg. *Cinnamomum polymorphoides* McCoy). Fossil plant material in ironstone was also reported from Parwan. A more recent report (Christophel 1985) is based on collections from a very different lithology, with mummified leaves and fruit compression fossils in unconsolidated mudstones.

Christophel (1985) and Greenwood (1994) reported leaves and cupules of *Nothofagus* subgenus *Lophozonia* (Fig. 3A) with leaves of Myrtaceae (non-*Eucalyptus*), conifer shoots (*Araucaria* Section Eutacta and *Dacrycarpus*), and fruits of Elaeocarpaceae from Bacchus Marsh. Unpublished research on possibly Pliocene–Pleistocene material from fire-holes at the top of the Bacchus Marsh coal has detected abundant charcoalified fruits, flowers and rarely foliage of *Eucalyptus* with *Casuarina* and *Acacia* foliage (Blazey 1994).

Pitfield and Sentinel Rock

Miocene macrofloras at Pitfield (38 km south-west of Ballarat) and Sentinel Rock (2 km west of the mouth of the Aire River) were first described by Deane (1902) and subsequently by Paterson (1935), who listed the following taxa for Pitfield: Lauraceae (as *Cinnamomum*), Sterculiaceae (as *Sterculia*), *Eucalyptus*, Monimiaceae (as *Mollinedia*), Sapind-aceae (as *Nephelites* and *Carpolithes*), *Eucryphia*, *Drimys* (Winteraceae), *Pittosporum* and Araliaceae (as *Panacites*). The Sentinel Rock macroflora consists of leaf compressions in grey mudstone. Taxa include possible *Casuarina*, Myrsinaceae (as *Myrsine*), Proteaceae (as *Persoonia* and *Phyllites*), Rubiaceae (as *Coprosmaephyllum*), *Pultenaea* (Fabaceae) and *Phyllocladus* (Deane 1902; Patterson 1935). Cookson (1954) reported pollen and phyllodes of *Acacia* from the locality. Sentinel Rock deserves recollection and analysis, however the outcrop is part of an intertidal rock platform and is often partly obscured by fallen aeolianite from adjacent coastal cliffs (Douglas 1983). An associated macrofossil locality 500 m east of the mouth of the Aire River (J. G. Douglas, unpub. data) may expand this list of taxa considerably.

Grange Burn and Hamilton

Gill (1952) described Grange Burn as one of the 'oldest known and most prolific sources of Tertiary fossils' in Victoria, due to the wealth of vertebrate remains collected from the site (including whale and marsupial remains), and the presence of a fossil soil horizon with tree stumps preserved in growth position. Douglas (1993) suggested an Early Pliocene age (approximately 5 million years [m.y.]; Fig. 2), and the associated mammalian fauna is Early Pliocene, based on a corrected radiometric date for the overlying basalt of 4.46 ± 0.1 m.y. (Rich et al. 1991). Cookson (1954) reported *Acacia* phyllodes from the locality and some wood from the locality has been identified as *Phyllocladus*. Gill (1952) noted leaf fossils in a grey to black carbonaceous clay below basalt at Wannon Falls, upstream from Grange Burn, and Douglas (1983) reported large fragments of conifer wood and leaves from that locality. Chapman (1910, 1921, 1926b) reported fossil leaves of *Banksia* and leaves 'provisionally' assigned to *Eucalyptus amygdalina* Labill. by Maiden (1922) from ironstone collected below Wannon Falls at Redruth (now Wannon) near Casterton, although the exact source of the latter material is unknown (Spencer-Jones 1971).

Otway Basin bore cores

Plant remains have been recorded from bore cores intersecting Paleogene and Neogene sediments in many parts of the Otway Basin, but records are almost entirely confined to reports commissioned by or written by private companies. Douglas (1960) recorded fungal hyphae from 1423 m depth in Portland Bore 2 and an abundance of cuticular fragments from 1416 m depth in Portland Bore 3.
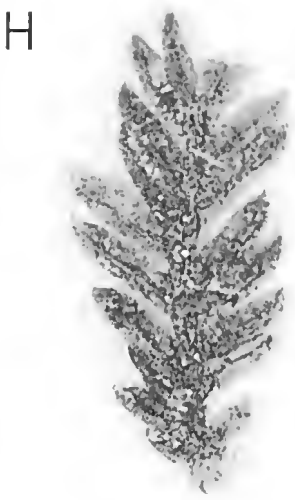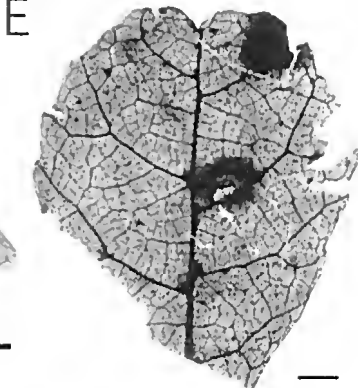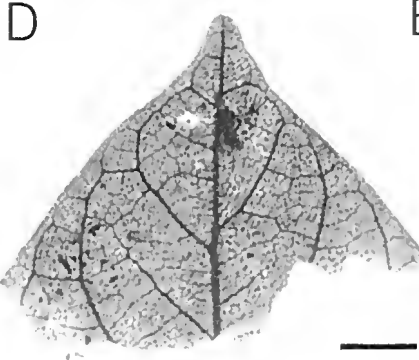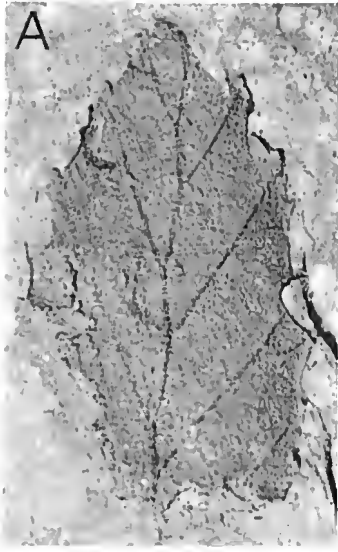
MACROFLORAS OF THE GIPPSLAND BASIN

Brown coal and interseam macrofloras of the LaTrobe Valley, and particularly those from the Yallourn and Morwell open-cut coal mines, have been the most extensively researched of Victorian Cenozoic macrofloras. Leaf impressions were reported from Darlimurla coal mine and at Narracan, in addition to a seed flora from Foster (Deane 1923; Chapman 1926; Paterson 1935; Thomas & Baragwanath 1951; Abele et al. 1988). Duigan (1951) listed Paleogene and Neogene macrofloras at Budgeree, Hazelwood, Korumburra and Tanjil River. Chapman (1918, 1921, 1926b) reported Miocene–Pliocene silicified wood of *Eucalyptus melliodora* from Bruthen near Bairnsdale and of *E. piperita* Sm. from Mallacoota Inlet. Leisman (1986) described silicified lauraceous wood (*Cryptocaryoxylon gippslandicum*) from Jungle Creek approximately 75 km north-east of Bairnsdale, proposing an Eocene age for these fossils based on nearby basalts.

Darlimurla, Narracan and other South Gippsland floras

The thin coal seam at Darlimurla was described by Thomas & Baragwanath (1951) as containing strata of dark, carbonaceous clays bearing leaf impressions and estimated as post-Older Volcanics in age (Fig. 2). Paterson (1935) recorded Sterculiaceae (as *Sterculia*), *Nothofagus*, Lauraceae (as *Cryptocarya*), and Myrtaceae (*Eucalyptus*) from these clays. The nearby locality at Narracan is overlain by Late Oligocene basalts dated at 26 ± 0.5 m.y. (McKenzie et al. 1984) and is particularly diverse. Chapman (1926) and Paterson (1935) described Sterculiaceae (as both *Sterculia* and *Brachychiton*), *Nothofagus*, Cunoniaceae[2] (possibly as *Weinmannia*, but more probably *Geissois* as Chapman referred to a close similarity to *W. biagiana* syn. *Geissois biagiana*), Lauraceae (as *Cinnamomum* and *Cryptocarya*), Moraceae (as *Ficonium*), Proteaceae (as *Lomatia* and *Persoonia*),

Myrtaceae (including both *Eucalyptus* and *Tristanites* or *Tristania* s.l.), Monimiaceae (as *Hedycarya* and *Mollinedia*), Loganiaceae (as *Strychnos*), cf. *Casuarina* (Casuarinaceae), and *Dacrycarpus* (Podocarpaceae, as *Podocarpus praecupressiformis* Ett.) from Narracan. More recent undescribed collections from Narracan include lauraceous leaf impressions and other dicot taxa (A. J. Vadala & J. G. Douglas, unpub. data). These more recent collections are from cemented sandstone of the Childers Formation (LaTrobe Group) and likely represent the same sediments as material described by Paterson (1935). Thomas & Baragwanath (1951) quoted Wright (1894) as suggesting the leaf-bearing clays at Narracan were typical of sediments usually associated with brown coals in the area.

Macrofloras of the brown coals

Highly fossiliferous sediments of the LaTrobe Group are intersected in the open-cut brown coal mines at Yallourn, Morwell and Traralgon in the LaTrobe Valley. Interseam sediments associated with the brown coal seams contain well-preserved fossil leaves, fruits and seeds, wood, and *in situ* tree stumps (Chapman 1922, 1925a, 1925b; Cookson 1947, 1953; Cookson & Duigan 1950, 1951; Cookson & Pike 1953a, 1953b, 1954; Pike 1952; Patton 1958; Duigan 1965). Several specimens of amber from the Morwell open-cut are curated in the NMV. Recent publications provide substantial detail on the coal floras (eg. Blackburn 1981b, 1985; Blackburn & Sluiter 1994; Kershaw et al. 1994; Balme et al. 1995; Barton et al. 1995). Sediments range in age from late Middle Eocene (Traralgon seam, accessible in the Loy Yang open-cut), to Oligocene and Early to Middle Miocene (exposed in the Loy Yang, Morwell and Yallourn open-cut mines). Individual coal seams may attain thicknesses greater than 100 m. Holdgate et al. (1995) indicated the time of accumulation for each coal seam was likely to have been in the range 0.5 to 2 m.y., with substantial time gaps within each seam.

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[2] *Weinmannia* and other genera now placed in the Cunoniaceae were originally placed in the Saxifrageae or Saxifragaceae.

Fig. 3. Leaf fossils from Victorian Neogene macrofloras. A, *Nothofagus tasmanica* (Nothofagaceae) leaf impression from Baechus Marsh (Maddingley). B–I, Leaf and stem fossils from the Yallourn Clays (LaTrobe Valley); scale bars = 5 mm: B, *Nothofagus tasmanica* cuticle; C, *Myrtaciphyllum* sp. (Myrtaceae); D, apical fragment of leaf of indeterminate affinity, showing drip tip; E, cf. *Sloanea* (Elaeocarpaceae); F, *Laurophyllum* sp. (cf. *Beilschmiedia*; Lauraceae); G, H, foliage types of *Dacrycarpus latrobensis* (Podocarpaceae); I, stem fragment of *Gymnostoma* sp.

Macrofossils described from these coals include taxa typical of modern temperate (eg. *Nothofagus*) to subtropical–tropical rainforest (eg. *Agathis, Diospyros* and *Gymnostoma*), in addition to sclerophyllous taxa (eg. *Casuarina* and Banksiinae). Interseam parting clays commonly contain leaf remains. An unpublished report on the interseam unit of the late Early Micoene Yallourn Clay (Greenwood 1981) lists the following taxa: *Pterostoma* (Zamiaceae), *Podocarpus* or *Prumnopitys, Dacrycarpus latrobensis, Phyllocladus, Agathis, Araucaria, Gymnostoma, Diospyros* (Ebenaceae), *Ceratopetalum* (Cunoniaceae), and taxa of Lauraceae and Myrtaceae. Rozefelds & Christophel (1995) described seeds of *Wilkinsonia* (Hicksbeachiinae, Proteaceae) from the Yallourn Formation. These *Wilkinsonia* seeds are most closely similar to extant monotypic *Athertonia*, endemic to rainforests of northeastern Queensland.

The palaeobotanical and palaeoecological potential of the LaTrobe Valley coals are yet to be fully realised. The complete coal and interseam sequence spans the late Middle Eocene to late Middle Miocene (Holdgate et al. 1995: Fig. 2), an interval of substantial climatic change and vegetative evolution. Macrofloras of the Yallourn and Morwell seams are the most studied (Blackburn & Sluiter 1994). A near-complete sequence is available in the Loy Yang open-cut mine, near Traralgon: Traralgon seam (Late Eocene), Morwell 2c aquifer, Morwell 2c seam (Early to Late Oligocene), Morwell 2b aquifer, Morwell 2b seam (Late Oligocene), clays (?), Morwell 2a seam (Late Oligocene–Early Miocene), two parting clays (late Early Miocene), and the Yallourn seam (Middle Miocene). Current mining operations do not intersect the lowest seams. Interseam clays are better exposed in the Yallourn and Morwell open-cuts, as these sediments are much thinner in the Traralgon area (Abele et al. 1988) and individual clays may be absent on exposed benches at any particular time in the Loy Yang open-cut mine. A probable Pliocene macroflora containing *Eucalyptus* fruits has been collected from the top of the overburden, overlying the Haunted Hills Gravel, near the Morwell pumping station.

Thorpdale

Low-grade coals in Thorpdale contain abundant carbonised fruits and seeds. The seeds are not found in attachment with the fruits, and may be isolated by gentle disaggregation of the coal by hand. The coals are overlain by basalts, probably belonging to the LaTrobe Valley Group (Douglas 1984), which have often produced anomalous K/Ar dates

(Bowen 1975; McKenzie et al. 1984). However, the radiometric age range for the Thorpdale Volcanics is 19–24 m.y. (Wellman & McDougall 1974), and Thorpdale Volcanics at nearby Jeffrey's Quarry have been K/Ar dated at 22.4 ± 0.3 m.y. (McKenzie et al. 1984), providing a Late Oligocene–Early Miocene age for the Thorpdale fossils.

Thorpdale fruits represent *Spondylostrobus*, and are comparable to *S. smythii* F. Muell. described from 'auriferous drifts' at Nintingbool and Haddon, near Ballarat in central-western Victoria (Mueller 1874). Fruits recovered from Thorpdale are approximately the same size and shape and overall state of preservation as those described by Mueller (1874) from Haddon and are likely to be conspecific with them (A. J. Vadala, unpub. data). Much of the material referred to by Mueller (1874, 1883) has not been found in the collections of the National Museum of Victoria, and many of the generic affinites are not strongly based.

Gippsland Basin offshore

Macrofloral remains have been recovered from bore cores taken in the offshore Gippsland oil and gas fields. These fossils have been described in company reports, but are otherwise undocumented. The Esso Barracouta 2 bore core from the Gippsland Shelf contains abundant fragmentary leaf impressions and several resin blobs in a highly-compacted siltstone matrix (J. G. Douglas, unpub. data).

MACROFLORAS OF THE EASTERN HIGHLANDS

Paleogene leaf-beds and fossil woods have been reported from the Eastern Highlands (Victorian High Plains), particularly from sediments beneath volcanics near Mt Hotham, the Bogong High Plains and the Dargo High Plains in the Alpine National Park (Hunter 1909; Singleton 1935, 1941; Paterson 1935; Douglas 1983). Plant remains were deposited extensively within gravels, conglomerates, clays, sands and occasionally lignites over the pre-Older Volcanics topography of the Victorian High Plains (Eastern Highlands). The fossil-bearing sediments were subsequently overlain by basalts during the Oligocene; these basalts filled palaeovalleys incised into the eastern section of the Central Uplands. Paleogene macrofossil-bearing sediments are currently only exposed in the banks of creeks and rivers that have subsequently eroded through the basalt cap-rocks (Jenkin 1988). Beavis

(1962) reported *Agathis, Araucaria, Phyllocladus* and fern foliage (*Dryopteris dargoensis* and *Taeniopteris tenuissime striata*) from fossiliferous clays near Mt Jim at a locality called 'The Lake' on the Bogong High Plains. Fossils referred to the Mesozoic pteridosperm *Taeniopteris tenuissime striata* from the Bogong and Dargo High Plains were listed by both Duigan (1951) and Douglas (1983) as misidentifications of dicots.

The systematic composition of Paleogene macrofloras from the High Plains remains under-researched. However, the floras featured prominently in early reports as sites (deep leads) worthy of prospecting for alluvial gold (see references to Brandy Creek and the Cobungra River, Bogong High Plains and the Bundara River in Murray et al. (1878). Paterson (1935) suggested the Dargo macroflora was of Late Oligocene age, whilst Douglas (1983) indicated an Eocene age. Wellman (1974) suggested an age range of Late Eocene to Late Oligocene for basalts in the Eastern Highlands.

Dargo/Brandy Creek

The Dargo macroflora is exposed by the diggings of the abandoned Brandy Creek gold mine, approximately 5 km west of Hotham Heights near Dinner Plain. Fossils occur in two beds at this locality (Douglas 1983). Upper beds contain leaf mummifications in compressed carbonaceous mudstones laminated alternately with siltstones and fine sandstones, immediately overlain by basalt. These basalts are likely to be Early–Mid Oligocene Older Volcanics (Bolger & King 1976; Bolger 1984). Recent palynological analysis of the Dargo (Brandy Creek mine) sediments indicates an Early Eocene age for the macrofloras beneath the basalts (Scriven & Hill 1995; Fig. 2). The other fossil-bearing beds at the Brandy Creek mine site are lower in the section and consist of heavily compacted, iron-stained fine siltstones with impression fossils (A. J. Vadala & D. R. Greenwood, unpub. data). Specimens from Brandy Creek mine held by the National Museum of Victoria are from the lower beds. Infructescences of *Gymnostoma* (Casuarinaceae) have also been reported from this locality, which was described as 'Mt Hotham' by Christophel (1980) and Scriven & Hill (1995).

Paterson (1935) listed the following taxa from Dargo/Brandy Creek mine: *Laurus, Eucalyptus, Ginkgo, Ficus* and *Lastraea* (Filicales; which Gill & McWhae (1959) described as *Cyclosorus dargoensis*). The material described as *Ginkgo* is more likely to be a fern (J. G. Douglas, unpub. data). Although Douglas (1993) stated no post-Cretaceous records of *Ginkgo* exist for Australia, Carpenter et al. (1994) have since reported *Ginkgo* from the Middle–Late Eocene Richmond macroflora in Tasmania.

A leaf flora in the collections of the National Museum of Victoria and labelled as being from Omeo may correspond to the Cobungra River locality (Duigan 1951). Similarities between the matrix and the component taxa of these 'Omeo' fossils and the Brandy Creek macroflora strongly suggest that the material from Omeo is in fact from Brandy Creek (a tributary of the Cobungra River).

Bundara River

The presence of fossils at Bundara River has been comparatively well documented (Table 1) owing to extensive collections over a number of years, described in the National Museum of Victoria collection as 'Head of the Bundarah River, Bogong High Plains,' which was indicated in a map accompanying specimen NMV P166994 and the associated reference (Murray et al. 1878).

The locality re-examined as part of this survey is approximately 0.9 km and 116° SE of Mt Jim on the banks of the Bundara River (36°56.08'S, 147°14.08'E, 1647 m a.s.l.). Another nearby locality, at the branch of the Cope West Aqueduct off the High Plains Creek (36°54.96'S, 147°93.17'E, 1594 m a.s.l.), was not collected but contained many, poorly preserved, leaf remains.

Leaf beds at Bundara River crop out in narrow bands of non-marine sediments otherwise covered by or intercalated with the same Early–mid Oligocene Older Volcanics that cover most of the Bogong High Plains (Bolger & King 1976; Bolger 1984). These Older Volcanics have been K/Ar dated at 36.3 ± 0.6 m.y. to 33.1 ± 0.8 m.y. near Mt Hotham (Wellman 1974). Finely laminated, hard siltstones with carbonaceous streaks contain dark leaf impressions and directly overlie pyroclastics and red-brown clays that are exposed for approximately 10 m above the bed of Bundara River. These sediments are overlain by darker, softer and finely laminated claystones/siltstones containing dark leaf impressions and compressions. Above this layer and overlain by more sediment is an approximately 600 mm wide band of dark brown-black coals with soft organic remains.

Fossil-bearing sediments at Bundara River were first described by Murray et al. (1878) as 'yellowish-brown laminar clay' on the southwest margin of overlying basalts at the head of the Bundara River. These authors described *Taeniopteris tenuissime striata* and *Laestrea dargoensis* as elements

of the flora. Fossils recorded previously from Bundara River include *Dryopteris dargoensis*, *Taeniopteris tenuuissime striata* (likely to be a mis-identification of a dicot: see above), *Phyllocladus* sp., *Agathis* sp. and *Araucaria* sp. (Bolger 1984). Duigan (1951) considered *L. dargoensis* 'incertae sedis', however this taxon was redetermined as *Cyclosorus dargoensis* by Gill & McWhae (1959). A leaf impression from Bundara River in the National Museum of Victoria collection labelled as *Ginkgo murrayi* (Table 1) is more likely to be a dicot. The two extant Victorian taxa of *Cyclosorus* (*C. parasiticus* and *C. pennigerus*) have since been revised (Entwisle 1994) into *Christella dentata* (whose distribution in Victoria is isolated to moist shaded sites around Buchan) and *Pneumatopteris pennigera* (confined to the lower tracts of the Glenelg River, and to stream banks near Port Campbell), respectively. *C. dargoensis* has similar frond morphology to some extant Victorian taxa of *Lastreopsis*, especially *L. hispida*, which currently occurs in the Otway Ranges and the southern part of the Eastern Highlands (Entwisle 1994).

Hotham Heights and other High Plains localities

The Hotham Heights locality is 1 km ESE from Mt Hotham resort along the Great Alpine Road (36°59.65'S,147°09.32'E, 1733 m a.s.l.). Basement marine sedimentary rocks in the area have been assigned to the upper Middle–Upper Ordovician (Bolger & King 1976; Bolger 1984). Basalts near Mt Hotham are Upper Eocene to mid Oligocene Older Volcanics (Wellman 1974; Bolger & King 1976).

Outcrop comprises heavily weathered, steeply-inclined Palaeozoic strata unconformably overlain by fluvio-lacustrine Paleogene sand/siltstones capped by basalts, and Kenny (1937) reported plant remains in sediments below these Older Volcanics. The Mt Hotham macroflora was described as Paleocene by Christophel (1980, 1989), although Scriven & Hill (1995) were critical of this estimate. The palynoflora of the sediments correlates with the uppermost part of the Upper *Malvacipollis diversus* Zone from the Gippsland Basin, indicating a lower Early Eocene age (Partridge 1998; Fig. 2). Recent sampling of basalts associated with the macro-floras should provide a radiometric chronologic framework for them (M. Banks, D. Greenwood, A. Vadala & J. Webb, work in progress).

The Paleogene sediments contain abundant leaf impressions and mummified leaves. This material has significant potential for further collecting and analysis. Lauraceae, Proteaceae (including *Banksi-*

eaephyllum and rainforest taxa) and Elaeocarpaceae are abundant (Greenwood et al. 1999), and leaves of *Spiraeopsis* (Cunoniaceae) have been identified (R. Barnes, pers. comm.). Fern and conifer foliage are also present, including *Agathis*, *Dacrycarpus* and *Libocedrus* (Greenwood et al. 1999; R. S. Hill, pers. comm.). Collections are stored at Victoria University of Technology, The University of Melbourne and The University of Tasmania. Hotham Heights is the highest elevation Paleogene macroflora in Australia (1723 m a.s.l.), but is likely to have been at a substantially lower elevation during the Eocene (Ollier 1986).

Other Paleogene macrofloras occur outside the regions discussed above. For example, Douglas (1983) listed an ironstone leaf flora from Lake Mokoan near Glenrowan. Recent collections of leaf impressions from Glenrowan are likely from the same site as the Lake Mokoan flora listed by Douglas, and include lauraceous leaves and silicified wood. The Glenrowan macroflora is probably of Paleogene age, occurring below Older Volcanics. Fruits and stems have been reported from the Murray Basin Pliocene Calivil Sands (Calivil Formation; Macumber 1972) that crop out between Horsham and Echuca (Abele et al. 1988).

Deep lead floras

'Deep leads' are buried Cenozoic placer deposits formed along rivers that drained inland from the main divide (Hunter 1909; Whiting & Bowen in Abele et al. 1988). These deposits were intensively mined for gold during the mid to late 19th Century, and less intensively up to the 1950s. Several deep leads yielded charcoalified seeds and fruits. Similar deposits containing Paleogene- and Neogene-age fruit and seed floras were reported from southern New South Wales (Mueller 1873, 1874; Kirchheimer 1935; Rozefelds & Christophel 1996b). The most prominent Victorian deep lead floras were Eldorado, Foster and Haddon, although collections have been described from many other sites. Douglas (1976) illustrated and briefly described a mummified leaf from a depth of 70 m recovered from a bore core taken from Woodstock, west of Bendigo. Grey silts at this depth may be associated with the Haddon deep lead (see also Partridge & Wilkinson 1982). Mueller (1873) originally described seeds and fruits from Eldorado, Foster and Haddon, although later researchers (eg. Kirchheimer 1935; Selling 1950; Pike 1952; Rozefelds & Christophel 1996b) have provided most of the detailed systematic analyses of the taxa. *Banksia* cones and *Elaeocarpus clarkei* (F. Muell.) Selling endocarps were described from

Eldorado (Pike 1952; Rozefelds & Christophel 1996b). *Elaeocarpus clarkei* most closely matches *E. bancroftii* F. Muell. & F. M. Bailey and *E. liusmithii* G. P. Guymer, both today restricted to rainforests of northeastern Queensland. Apart from Victorian localities, *Elaeocarpus* fossils are also known from deep leads at Orange, Bathurst and Gulgong in New South Wales (Rozefelds & Christophel 1996b).

Most Victorian deep leads are considered to be Neogene in age (Mueller 1874; Walcott 1920; Macumber 1978), although an Oligocene age has been indicated for deep leads in the Loddon and Murray valleys (Martin 1977; Partridge & Wilkinson 1982; Archer 1984; Fig. 2). Rozefelds & Christophel (1996b) summarised arguments over the age of the Victorian deep lead floras. Deep leads at Orange in New South Wales can be constrained to a minimum mid-Miocene (possibly Early Miocene) age based on a radiometric date of 10.9–12.7 Ma for the overlying basalts (Wellman & McDougall 1974). Rozefelds & Christophel (1996b) argued that the presence of several fruit taxa common to both the Orange and Haddon deep lead macrofloras (Mueller 1874) indicated these floras were broadly contemporaneous, and that Foster and Eldorado may also be of Middle to Early Miocene age.

Abundant and diverse seed and fruit floras at Haddon, Foster and Thorpdale (see below) warrant further systematic analysis. However, the existing collections are in need of careful curatorial attention as much material has been lost through oxidation of pyritic minerals in the fruits.

Daylesford and area

Poorly known macrofloras have been reported from Daylesford and area. McCoy (1876) described leaves of *Eucalyptus pluti* from deep leads at Daylesford. Another (Middle Pliocene) macrofossil locality has been reported at Stony Creek or Stony Creek basin (Orr 1927; Patton 1928; Ewart 1933), and fossil leaves of *E. obliqua* L'Herit from Malmsbury (Chapman 1926b). Leaf morphology of the specimens from Daylesford corresponds to 'typical' non-bloodwood eucalypts, and McCoy (1876) suggested that these specimens represent extant *E. globulus*. Patton (1928) indicated more than one taxon of *Eucalyptus* was present at the Stony Creek basin site and noted the close resemblance of leaves from that locality to extant *E. amygdalina* (syn. *E. regnans*) and *E. viminalis*. Maiden (1922) and Hill (1994) accepted the generic identification of *E. pluti* by McCoy (1876).

Acceptance of the determination of the Daylesford fossils as *Eucalyptus* partly depends on the Pliocene (or rarely Miocene) age given the host sediments. The fossil-leaf bearing sediments reported by Patton (1928) and McCoy (1876) are likely to correspond respectively to the reported 40 m of possibly Pliocene ligneous and diatomaceous clay and sandy clay in the Stony Creek basin. Fossil wood in these sediments was asssigned to *Phyllocladus* (Podocarpaceae; Patton 1928). *Acacia* phyllodes and pollen have also been reported from Stony Creek basin sediments (Ewart 1933; Cookson 1954). Sediments of similar age to those in the Stony Creek basin underlie basalt at Daylesford (Abele et al. 1988), which has been radiometrically dated as Late Miocene to Pliocene (Wellman 1974).

Several other plant macrofossil localities have been reported from near Daylesford–Ballarat and Bendigo (Duigan 1951; Pike 1954; Douglas 1983), including: Ballan (Paleogene, ferns and dicot leaves), Spargo Creek (Paleogene, dicot leaves), Lal Lal (possibly Oligocene, leaves in lignite), Creswick Creek, Toolleen (Pike 1954; Wilkinson 1971) and Smeaton (Hills 1956). Wilkinson (1971) cited an unpublished report by Pike (1954) that leaves of Lauraceae and *Acacia* had been collected from Upper Paleogene and Neogene (possibly Pliocene) fluvial sediments at Toolleen, east of Bendigo. The Pliocene to Pleistocene Smeaton locality (also referred to as 'Allendale': Hills 1956), included a large fragment of fossilised tree resin (amber). The amber apparently included a green leaf of *Agathis* and that of an unnamed dicotyledon. In addition, millipede (*Spirobolus* sp.), acarinid mite (*Acronothrus* sp.), spider (*Ariadna* sp.), beetle (representing the families Pselaphidae, Tenebrionidae and Seymaenidae), and ant bodies (*Ponera* and *Iridomyrmex* spp.) were identified (Hickman 1957; Oke 1957; Womersley 1957). Poinar & Poinar (1995) indicated there were no records of Australian amber containing animal remains, implying the Allendale specimen may be the sole record for Australia. A recent search failed to locate this material in the collections of the National Museum of Victoria, although several specimens of amber are listed in their catalogue.

DISCUSSION

A narrowing of focus has occurred in the study of Paleogene and Neogene macrofloras in Victoria since the early surveys of the 19th Century. Researchers have necessarily focused on large and taxonomically diverse localities such as Anglesea

and the LaTrobe Valley coals. This has led to emphasis on the mid-Paleogene to mid-Neogene (Eocene to Early Miocene). Some recent reviews of the Australian Paleogene and Neogene macrofloral record (Christophel & Greenwood 1989; Truswell 1993; Carpenter et al. 1994; Christophel 1994; Greenwood 1994) have emphasised these Eocene and Miocene floras, noting the comparative paucity of knowledge regarding Paleocene and Pliocene floras. This imbalance may be partly due to local geology (there are no surface sediments of some ages). There are numerous largely unstudied Victorian macrofloras, including a significant number of Oligocene and Pliocene localities that are available for further analysis. Early reports and anecdotal accounts suggest some of these floras (eg. Narracan, Grange Burn and Stony Creek basin) and others of Eocene (eg. Hotham Heights), Miocene (eg. Haddon, Sentinel Rock) and Paleocene age contain material of important plant community types or of key Australian taxa (Table 1; Fig. 2).

This macrofossil record affords a geological long-term view of environmental change, including ecosystem and phylogenetic evolution in response to climatic changes during the Paleogene and Neogene. This record could also provide a basis for debate regarding future environmental and climatic change. Extensive and largely unexplored Victorian Paleogene and Neogene macrofloras potentially offer insights into the evolutionary history of key Australian plant genera and regarding the role of climate change in shaping the taxa and communities that characterise the modern flora of Australia. *Acacia, Agathis, Araucaria, Banksia, Casuarina, Eucalyptus* and *Phyllocladus* are known from a number of Victorian macrofloras, only some of which have been systematically described. Extant *Agathis, Araucaria* and *Phyllocladus* are absent from Victoria, but may have formed a significant part of Victorian forests until the Pleistocene. Several species of *Araucaria* and *Agathis* thrive in cultivation in many parts of Victoria, suggesting that extant climates in Victoria could support natural populations of these taxa.

Eucalyptus is a dominant element in the modern flora of Australia. However, Lange (1980) failed to find conclusive evidence for *Eucalyptus* in a survey of leaf cuticles from Australian Paleogene macrofloras. Hill (1994) noted the Paleogene and Neogene record of *Eucalyptus* is more extensive than commonly recognised, and much of the fossil record of *Eucalyptus* is from Victorian localities (Table 1). Indeed, Duigan (1951) listed 31 records of named Paleogene and Neogene taxa of *Eucalyptus* and three unnamed taxa from 19

localities throughout Australia, of which 14 taxa were from 10 Victorian localities, spanning the Eocene to Pliocene. However, Hill (1994) also noted the relative paucity of taxonomically reliable fossil records of *Eucalyptus*, citing records of wood from New South Wales (Bishop & Bamba 1985), leaves (*E. kitsoni*) from Berwick in Victoria (Deane 1902; Pole et al. 1993), fruit and two distinct leaf forms (*E. bugaldiensis*) from the Warrumbungle Ranges in New South Wales (Holmes et al. 1982), and records of fruit from central Australia (Lange 1978; Ambrose et al. 1979; Greenwood et al. 1990; Greenwood 1991) in addition to leaves (*E. pluti*) from Daylesford. Chapman (1926b) cited only two Pliocene records of *Eucalyptus* leaves, namely *E. pluti* McCoy from Daylesford and *E. milligani* Johnston from Macquarie Harbour in Tasmania. However, Chapman (1926b) also listed several fossil leaves of 'provisional' *Eucalyptus* recorded by Maiden (1922): *E. obliqua* from Malmsbury (likely Pleistocene) and *E. amygdalina* from Redruth/ Wannon (Miocene or Pliocene). Chapman (1926b) additionally listed Miocene–Pliocene silicified wood of *E. melliodora* from Bruthen and of *E. piperita* Sm. from Mallacoota Inlet. White (1994) illustrated fruits and leaves of *Eucalyptus* from Pliocene mudstone from Inverell in New South Wales. Leaves of *Eucalyptus* have also been reliably reported from several Victorian Pliocene sites including Grange Burn, Wannon Falls and Keilor/Bulla (Fig. 2; Patton 1919; Douglas 1983). Examination of literature and the collections of the National Museum of Victoria suggests that Bundara River, Narracan, Dargo, Pascoe Vale, Flemington and Darlimurla should also be re-examined for the presence of *Eucalyptus*.

Abundant seed floras at Haddon and the LaTrobe Valley offer potential for comparisons of seed size and morphological variation within taxa with nearest living relatives in north Queensland rain-forests. Such analyses offer insight into the evolution of lineages as much as on evolution of reproductive strategies (eg. Wing & Tiffney 1987).

Several Victorian Paleogene macrofloras are now at high elevation, including Bundara River, Dargo, Hotham Heights, Bogong and Brandy Creek mine. Contemporaneous floras are also preserved at low elevations. Such pairs of high and low elevation coeval floras potentially offer insight into the timing and rate of uplift of the Victorian Alpine zone. There are three models of the evolution of the high country (Ollier 1986). The first model proposes a late Mesozoic uplift followed by Paleogene and Neogene erosion to the present landforms. The second model proposes a middle

Paleogene and Neogene uplift with initial rapid erosion; and the third proposes several phases of uplift including some degree of middle to late Paleogene and Neogene vertical movement. Several studies on the rate and timing of uplift of mountains or elevated plateaux in North America have used estimates of mean annual temperature from coeval pairs of macrofloras at low and high elevation to estimate palaeoelevation of high elevation floras, and thus in part the elevation of the upland at a point in time. There appears to be scope for a similar analysis in the Victorian high country.

We can only speculate on the Paleogene and Neogene history of many plant groups, especially within the cryptogams, which are poorly represented in fossil records for the Cenozoic. Cryptogams figure prominently in many Victorian Early Cretaceous localities, and seem to have survived and in some cases even diversified during the Paleogene and Neogene, though in environments not represented in either coal measures or sub-basaltic regimes. Consequently, current knowledge of Early Cretaceous bryophytes, for example, is more extensive than that of Paleogene and Neogene bryophytes. Some groups such as the non-calcareous algae are poorly represented throughout the Phanerozoic, whilst others such as the fungi have not been thoroughly researched. Similarly, the Pterophyta have an extensive Early Cretaceous record, with more than thirty taxa described and at least a dozen more awaiting examination and description. Although extant taxa of this group, along with the Lycophytes, Sphenophytes and Psilophytes, dominate many ecological niches in Victoria, their Paleogene and Neogene record is scant.

The Paleogene probably saw the expansion and diversification of the angiosperms first manifest in the Cretaceous, when conifer forests were the dominant elements of the flora. Silicified logs as large as a metre in diameter indicate that dicotyledonous flowering plants were prominent components of the flora of Victoria as early as the mid-Paleogene (Leisman 1986). However, diversification and expansion of the monocots is still largely a matter of mystery.

Examples given in this review illustrate the value of contemporary summaries of stratigraphic, palaeobotanical and bibliographic information for macrofloras. With greater stratigraphic precision, re-examination of the 'revealed' Victorian fossil record of *Eucalyptus* and possibly *Acacia, Agathis, Araucaria, Casuarina* and *Banksia*, may provide insights into the phylogeny and history of these important Australian genera, and the development of the modern flora of Victoria.

SUMMARY

Despite 150 years of palaeobotanical research, the widespread and temporally comprehensive Paleogene and Neogene plant macrofloras of Victoria are a largely untapped resource. Analysis of these macrofloras is urgently required, but should be directed to answer critical questions of interest to a wider scientific and lay audience, or such research will face another period of decline. The macrofloras from the localities and drill cores discussed above, and future new discoveries, furnish an enormous amount of information on the vegetation of the past. This in turn fuels speculation on palaeoenvironment and palaeoclimate, which in turn is a key to providing a forecast for the future management and preservation of our very finite resources.

Key questions include, but are not limited to:

- the character and nature of vegetative responses to climate changes during the Cenozoic;
- the evolutionary history of genera significant in the modern flora of Australia, such as *Acacia, Agathis, Araucaria, Banksia, Casuarina* s.l. and *Eucalyptus* s.l.;
- the nature and character of early Australian rainforest communities, which were the antecedents of extant tropical rainforests of north Queensland; and
- the rate and timing of the uplift of the Victorian high country.

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SUBSURFACE BRACHIOPODA FROM BOREHOLE CORES THROUGH THE EARLY PERMIAN SEQUENCE OF THE CARNARVON BASIN, WESTERN AUSTRALIA: CORRELATIONS WITH PALYNOLOGICAL BIOSTRATIGRAPHY

N. W. Archbold & T. Hogeboom

School of Ecology and Environment, Deakin University, Rusden Campus,
662 Blackburn Road, Clayton, Victoria 3168, Australia

Archbold, N. W. & Hogeboom, T., 2000:06:30. Subsurface Brachiopoda from borehole cores through the Early Permian sequence of the Carnarvon Basin, Western Australia: correlations with palynological biostratigraphy. *Proceedings of the Royal Society of Victoria* 112(1): 93–109 ISSN 0035-9211.

Early Permian Brachiopods from five wells in the Carnarvon Basin, Western Australia (Bidgemia 1, Glenburgh 8, Burna 1, Gascoyne 1 and Ballythanna 1) are identified and illustrated. Macro faunal levels are assigned to the four earliest Permian Brachiopod zones of the Western Australian Permian (the *Lyonia lyoni*, *Trigonotreta occidentalis*, *Strophalosia irwinensis* and *Strophalosia jimbaensis* zones in ascending order) with the most complete sequence of faunas being found in Glenburgh 8. Correlation with the palynological zones (*Granulatisporites confluens*, *Pseudoreticulatispora pseudoreticulata*, *Striatopodocarpites fusus*, *Didecitriletes byroensis* and *Microbaculispora trisina* zones in ascending order) is shown to be consistent with previous outcrop–subsurface correlations.

The new genus *Cimmeriella* (Productida, Brachiopoda) is diagnosed and species from Western Australia and the Cimmerian continental fragments assigned to the genus.

Key words: Permian, Western Australia, Brachiopoda, palynology, Carnarvon Basin, new taxa.

Fig. 1. Map of areas of outcrop of Permian strata in Western Australia.
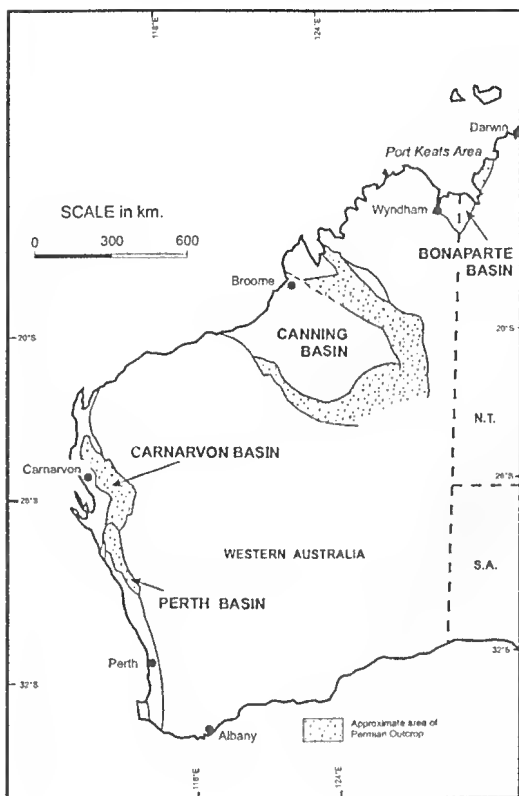
EARLY PERMIAN marine strata and faunas are extensively developed in the marine basins of Western Australia. The most complete sequence of Early Permian marine faunas is to be found in the Carnarvon Basin (Fig. 1) which includes the tectonic units of the Peedamullah Shelf and Merlinleigh and Byro Sub-basins to which Permian sedimentary rocks are now largely confined (Fig. 2). Traditional correlations within the Carnarvon Basin have been based on lithostratigraphical units (Condon 1967; Hocking et al. 1987) or on faunas largely constrained by lithostratigraphy (eg. Dickins 1963; Archbold 1993). More recent work has strongly enhanced the palynological control over the sequences (Backhouse 1991, 1993, 1996, 1998; Mory & Backhouse 1997) and has integrated data from marine faunas and palynology (Archbold 1998a, 1998b, 1999) for purposes of interbasinal, transcontinental and global correlations.

The present study documents Brachiopoda from five boreholes from the onshore Carnarvon Basin (Fig. 3) and demonstrates that information from macrofossils can supplement that provided by

traditional palynological investigations. Macrofossil data may, in some circumstances, provide the only data for biostratigraphy (Archbold 1988).

STRATIGRAPHICAL BACKGROUND

This study follows the interpretation of the Early Permian stratigraphy of the Carnarvon Basin, outlined by Mory & Backhouse (1997). Their study considerably altered previous interpretations of the nature and scope of the Callytharra Formation and its contact relationships with the overlying, essentially clastic sequence, known as the Wooramel Group. Units of quartz rich sandstone, previously included within the Wooramel Group, were regarded by Mory & Backhouse (1997) as being sandstone members within an enlarged definition of the Callytharra Formation.

Complexity of outcrop patterns, problems of onlap and differing interpretations of fault patterns and other geological structures have resulted in various published interpretations of the stratigraphical relationships, sequences and nomenclature of the Callytharra and Wooramel Group. These interpretations have all been based on careful field mapping and measured stratigraphical sections. Skwarko (1993) provided a tabular summary of interpretations of the Permian stratigraphy of the Carnarvon Basin but a few remarks are made herein.

Raggatt (1936), working north of the Gascoyne River, noted the sharp contact (said to be conformable) of the Wooramel Sandstone on the ferruginous upper surface of the Callytharra Formation. The well defined boundary was also noted by Teichert (1952). Condon (1954, 1955, 1967) and Konecki et al. (1958) added substantial data concerning clastic units of the Wooramel Group resting disconformably and unconformably on a transgressive surface developed on the leached and ferruginised upper beds of the Callytharra Formation. Condon (1967) described pinnacles and rock stacks developed on the Callytharra Formation by marine erosion. These were sub-
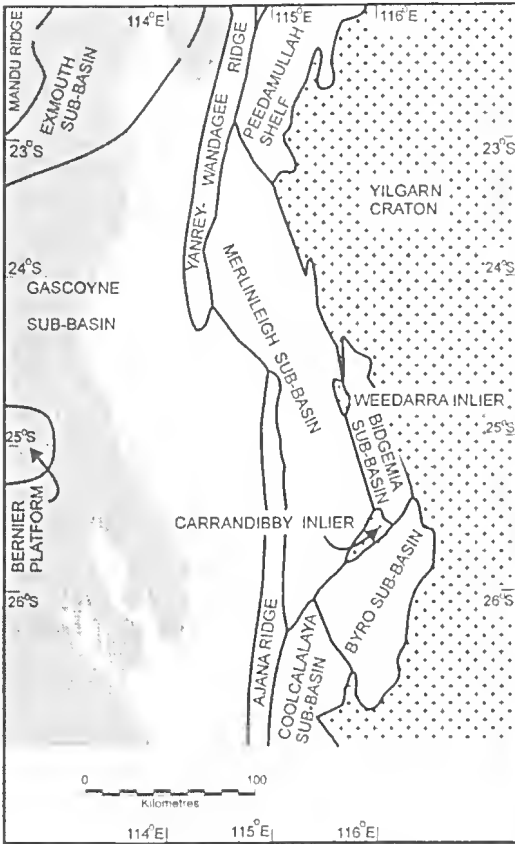
Fig. 2. Structural subdivisions of the Carnarvon Basin, Western Australia.
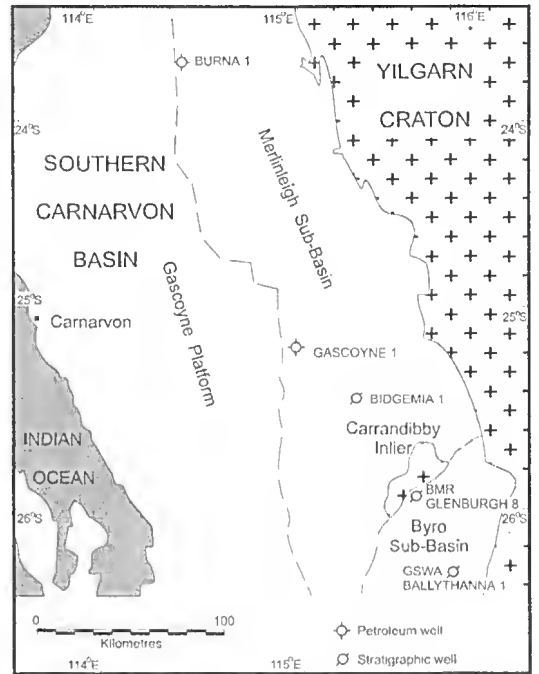
Fig. 3. Location of wells in the Merlinleigh and Byro Sub-basins.

sequently to be interpreted as tower karst features (van de Graaff et al. 1977; Hocking et al. 1987) developed during a period of subaerial leaching and erosion prior to the deposition of the Wooramel Group clastics, although Hocking (1990: 32) subsequently questioned whether much of the solution may have occurred after the deposition of the sandstone. Crostella (1995) has also questioned the evidence for the karst hiatus.

Van de Graaff et al. (1977) accepted the time break (disconformity–unconformity) at the base of the Wooramel Group but considered that sandstone and clastic units proposed southeast of the Carrandibby Inlier (Nunnery Sandstone and One Gum Formation) were variants of the Moogooloo Sandstone. Hocking et al. (1980) commented on additional 'Callytharra-type' limestone lenses, apparently equivalent in position to the Jimba Jimba Calcarenite (ie. stratigraphically above a sandstone unit and below a clastic unit) as part of the Wooramel Group. It is these 'limestone' lenses and units that Mory & Backhouse (1997), within the Byro Sub-basin and the region of the Jimba Jimba Syncline, refer to as their 'Upper Callytharra' units stratigraphically above sandstone bodies (such as the Ballythanna, Winnemia, Nunnery, One Gum, Monument and possibly Curbur Members and Formations). Hence clastic units, traditionally regarded as units of the Wooramel Group are now included within Mory & Backhouse's (1997) concept of the Callytharra Formation.

Biostratigraphically, using brachiopods but not conodonts, within Mory & Backhouse's (1997) definition of the Callytharra Formation, two fossil zones can be recognised. These are a lower 'traditional' Callytharra, *Strophalosia irwinensis* Zone (see Archbold 1993) and a higher 'traditional' Wooramel *Strophalosia jimbaensis* Zone (see Archbold 1991 and Archbold & Shi 1993). The two zones share many species and key species are required in order to recognise the younger of the two zones. The period of time between the two zones is considered by us to be a very short duration.

PREVIOUS SUBSURFACE PERMIAN BRACHIOPOD INVESTIGATIONS

Relatively few published, comprehensive, illustrated accounts of subsurface Permian brachiopod faunas are known to the present authors. Stainbrook & Madera (1941) described a well preserved fauna from Texas (USA), recovered from the Sid Richardson Coe No. 1 well, in the middle of the
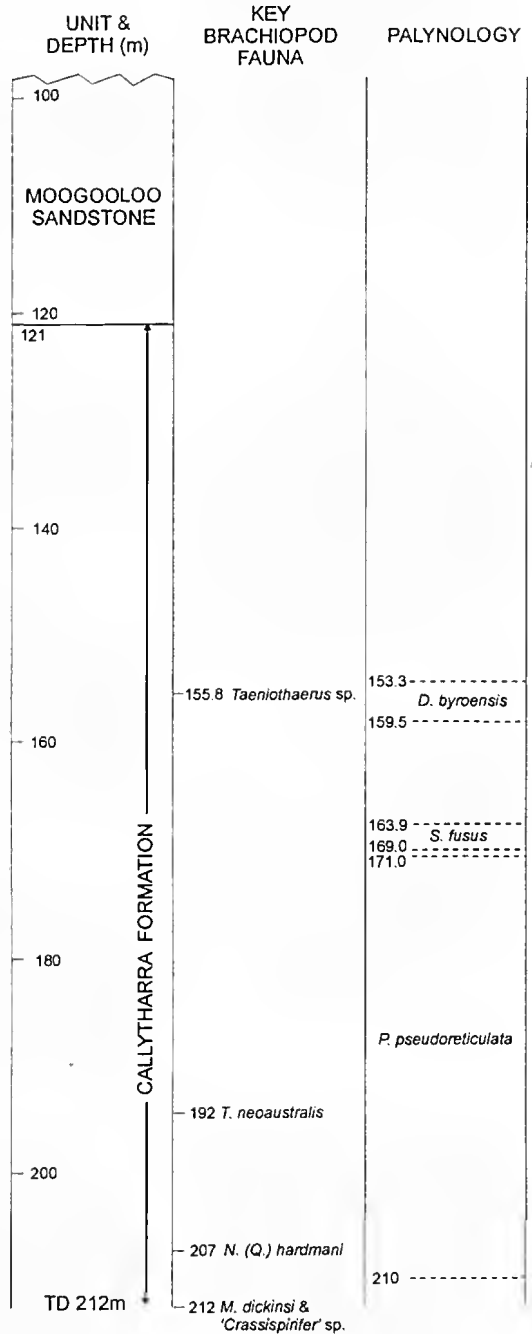
Fig. 4. Simplified well log of Bidgemia 1.

Permian Basin. The fauna was dated as 'probably low in the Word or high in the Leonard' as then understood.

The faunas from boreholes in the German part of the Zechstein Basin have been investigated and illustrated in terms of their Brachiopoda, Decapoda, conodonts, scolecodonts and species of *Estheria* (see Malzahn 1957). Those of the Polish Zechstein have been documented in a particularly well illustrated study of the Brachiopoda, Bryozoa and Bivalvia by Klapcinski (1971).

From the former Soviet Union, more numerous investigations have been published. The eastern (Baltic) end of the Zechstein Basin has received considerable attention with major studies on Lithuanian subsurface brachiopods being undertaken by Stepanov (1959) and Glushenko & Suveizdis (in Suveizdis 1975). The subsurface fauna described by those authors is fully representative of the classic outcrop fauna from comparable stratigraphical successions in England (King 1850) and Germany (Geinitz 1848). Suveizdis (1975) also included investigations on Foraminifera, Bryozoa, Bivalvia, Gastropoda, Ostracoda and palynology. A study on subsurface samples from the Arctic region of the Russian Platform that included Foraminifera, Bryozoa and Brachiopoda was published by Kalashnikov, Mikhailova & Morozova (1972). The sequence, of early Tatarian age, yielded several diagnostic, though variably preserved, genera of Brachiopoda.

A comprehensive study on the Late Carboniferous and Early Permian (Asselian) fusulinid Foraminifera, conodonts, ostracods, brachiopods and palynology from the Skosyskaya Borehole No. 4199, Tatsin Area, Rostov Region, Ukraine, was edited by Stepanov (1983). Brachiopods, were described by N. V. Glushenko, and are numerous, well preserved and age diagnostic. They are typical of those from outcrop sections of the Donets Basin (Glushenko 1975) and permit ready correlation with classic outcrop faunas of the Urals (Chernyshev 1902) and northern European Russia (Kalashnikov 1980, 1998).

Previous Australian studies

Reports, usually consisting of lists of identifications without illustrations, of subsurface occurrences of brachiopods are relatively numerous for the Permian of Australia (eg. Dickins et al. 1961; Dickins 1965; McClung 1978). However, with the continued refinement of taxonomic precision, such lists lose their value rapidly and serve little more than to indicate which genera or families may be present in the fauna.

The comprehensive, multifaceted series of studies on the core of GSQ Eddystone 1, located in the northwestern Surat Basin near the western margin of the underlying southern Denison Trough of the Bowen Basin, Queensland, have continued to yield valuable biostratigraphical and palaeoenvironmental results (Heywood 1978; McClung 1978, 1983; McKellar 1978; Draper & McClung 1983; Palmieri 1998). This series of investigations is a good example of achieving maximum 'value for money' from a drilling programme of stratigraphic holes. The study of the brachiopods (McClung 1978, 1983) demonstrates the value of the group for subsurface biostratigraphical purposes and for providing correlation to schemes based on outcrop occurrences of macrofauna (Briggs 1998).

Apart from the classic study by Etheridge (1907) on the faunas of the Port Keats Boreholes, illustrated accounts of subsurface brachiopods from the Western Australian Permian basins are restricted to those by Foster & Waterhouse (1988) and Archbold (1988, 1995a, 1995b). Those studies enabled the recognition of the Late Permian (Dzhulfian, then called Chhidruan) from the Ashmore Block; the recognition of a new macro-

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Fig. 5. Brachiopods from well cores, Ballythanna 1, Gaseoyne 1, Burna 1 and Bidgemia 1. A, GSWA 00001, *Permorthotetes lindneri* Thomas, Ballythanna 1, 59.3 m, × 1. B, GSWA 00002, *Neochonetes (Sommeriella)* sp., ventral valve, Ballythanna 1, 60.3 m, × 2. C, GSWA 00003, *Neochonetes (Sommeriella)* sp., ventral valve, Ballythanna 1, 60.3 m, × 2. D, E, GSWA 00004, *Neochonetes (Sommeriella) pratii* (Davidson), ventral valve and external mould, Gascoyne 1, 476.8 m, × 1.8. F, GSWA 00005, *Neochonetes (Sommeriella)* sp., ventral valve interior, Ballythanna 1, 60.3 m, × 4. G, GSWA 00006, *Cimmeriella flexuosa* (Waterhouse), ventral valve, Burna 1, 522.45 m, × 1. H, GSWA 00007, *Taeniothaerus?* sp., ventral valve, Bidgemia 1, 155.8 m, × 2.5. I, GSWA 00008, *Cimmeriella foordi* (Etheridge), juvenile ventral valve, Ballythanna 1, 373 m, × 3. J, K, GSWA 00009, *Cimmeriella foordi* (Etheridge), ventral valve external mould and ventral valve, Gascoyne 1, 482.75 m, × 2.2. L, GSWA 00010, *Cimmeriella flexuosa* (Waterhouse), ventral valve, Gascoyne 1, 367.5 m, × 1.5. M, N, GSWA 00011, *Cimmeriella foordi* (Etheridge), ventral valve and external mould, Ballythanna 1, 357 m, × 2. O, GSWA 00012, *Cimmeriella foordi* (Etheridge), ventral valve, Gaseoyne 1, 482.5 m, × 2.

GLENBURGH 8

UNIT & DEPTH (m)	KEY BRACHIOPOD FAUNA	PALYNOLOGY
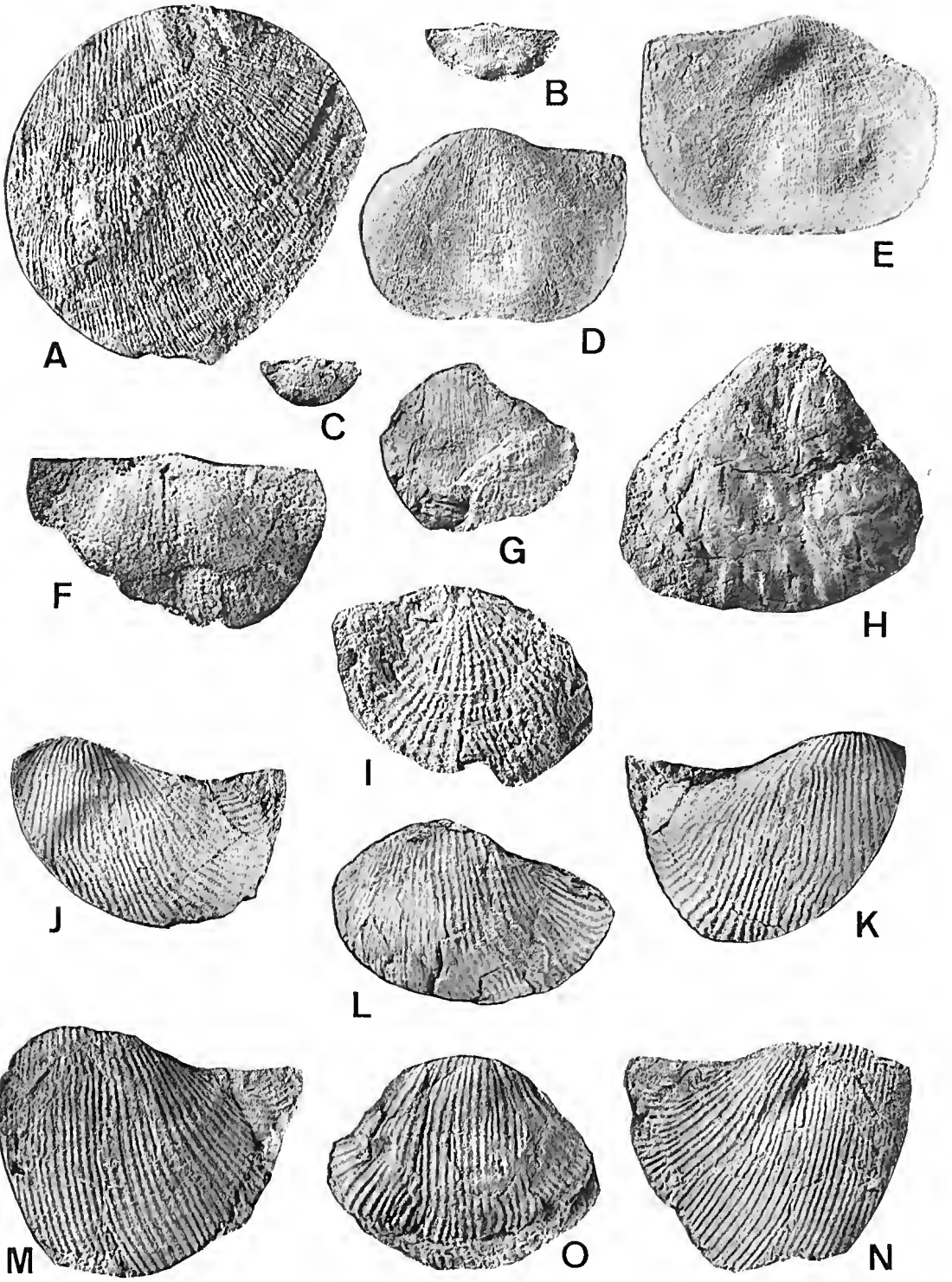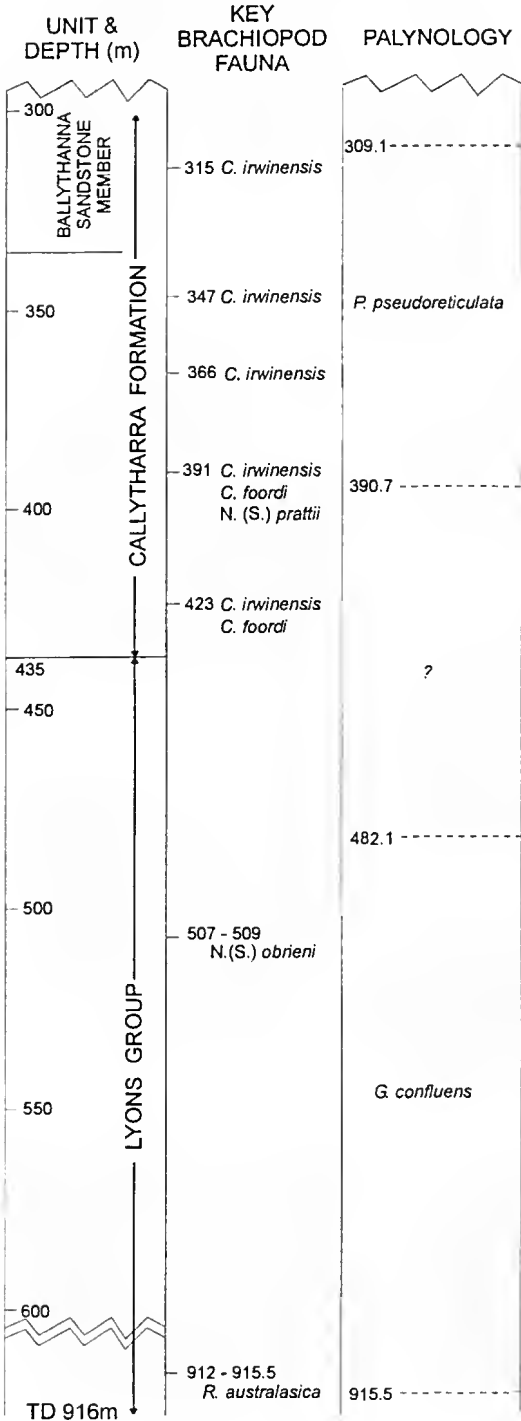
faunal zone of Early Kazanian age, from the Perth Basin and refinement of the international correlation of the *Granulatisporites confluens* palynological Zone.

THE PRESENT STUDY

The palynology of the Western Australian Permian basins has been systematically documented in modern terms in a series of studies by Backhouse (1991, 1993, 1996, 1998 and in Mory & Backhouse 1997). As an adjunct to the study by Mory & Backhouse (1997) on the stratigraphy and palynology of the Carnarvon Basin, one of us (NWA) examined cores from several wells for macrofauna. This report illustrates and summarises the macrofauna data from those wells (Ballythanna 1, Bidgemia 1, Burna 1 and Gascoyne 1) and Glenburgh 8 (formerly known as BMR 8, Mt Madeline) which was investigated by NWA with C. B. Foster in 1991. The stratigraphy in the wells, as currently interpreted, is described in detail by Mory & Backhouse (1997) and the simplified well logs provided herein (with the palynological data) is taken from the detailed logs provided in that study. The brachiopod macrofauna is discussed briefly for each individual well.

Fauna from individual wells

Bidgemia 1 (Fig. 4). In an interval of the Callytharra Formation, from 192 to 212 metres, several brachiopods including *Myodelthyrium dickinsi* (Thomas), '*Crassispirifer*' sp., *Neospirifer (Quadrospira) harduani* (Foord) and *Trigonotreta neoaustralis* (Archbold & Thomas) occur in an interval with the *Pseudoreticulatispora pseudo-reticulata* palynological Zone (see Figs 5 and 12 for illustrations of species present). They indicate that the Lower part of the Callytharra Formation, as defined by Mory & Backhouse (1997), and the *Strophalosia irwinensis* brachiopod Zone as defined by Archbold (1998b), is present at these levels.

From higher (155.8 m) in the Callytharra Formation, at the level of the *Didecitriletes byroensis* palynological subzone, a small specimen, with coarse ventral spine bases, of *Taeniothaerus* sp.

Fig. 6. Simplified well log of Glenburgh 8. Palynological data from Mory & Backhouse (1997) and supplemented by that of C. B. Foster (pers. comm. 24.viii.1992).

that recalls *Reedoconcha*? sp. (Archbold & Shi 1993: fig. 3A) from the Jimba Jimba Calcarenite, was noted. This level in Bidgemia 1 may represent the Upper Callytharra Formation as defined by Mory & Backhouse (1997) and hence the *Strophalosia jimbaensis* brachiopod Zone.

Glenburgh 8 (Fig. 6). Brachiopods from this well were listed by Dickins (1967) and, in part, reported on by Archbold (1995) who noted the occurrence of equivalents of the *Lyonia lyoni* and *Trigonotreta occidentalis* brachiopod zones as represented by *Rhynchopora australasica* Archbold
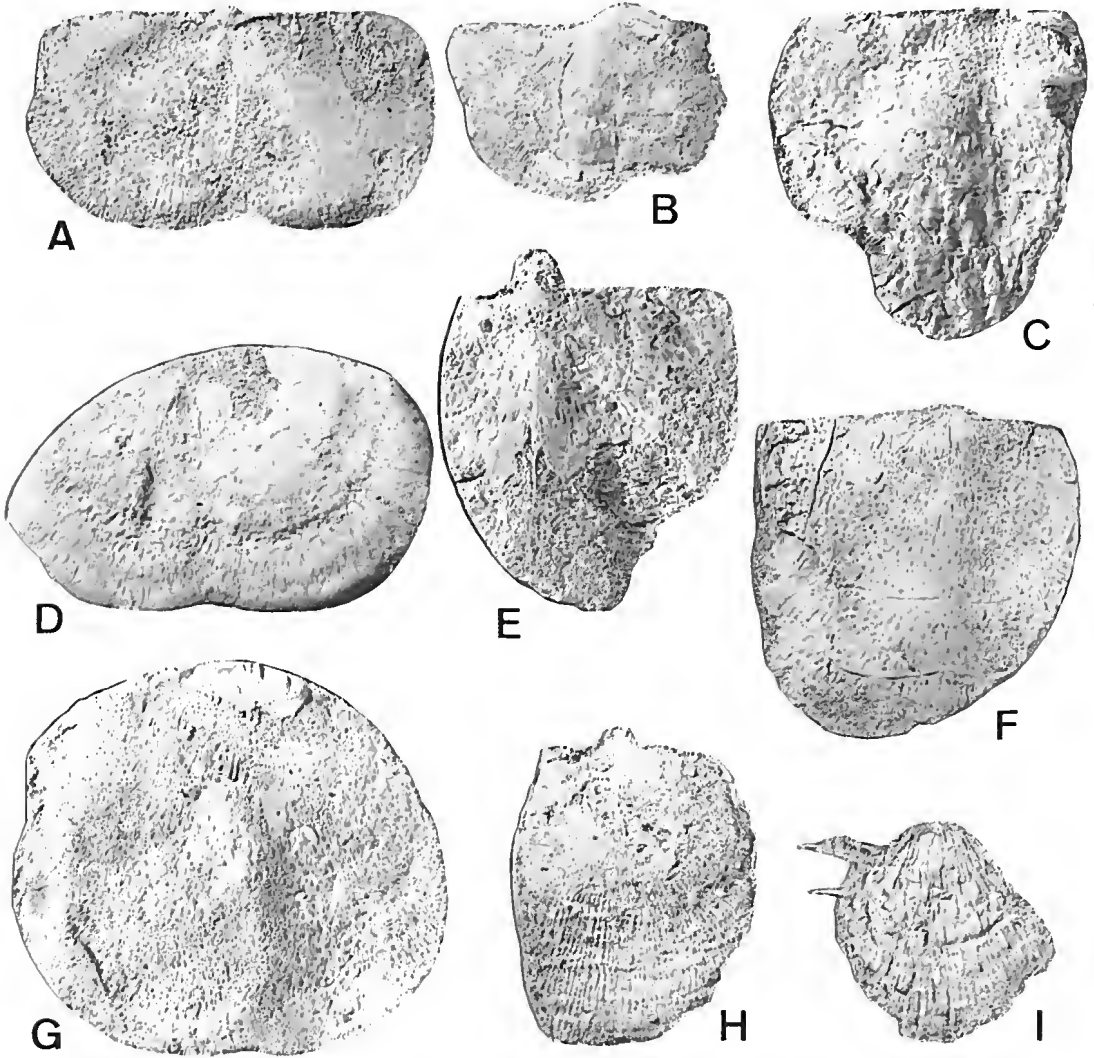
Fig. 7. Brachiopods from Glenburgh 8. A, *Neochonetes (Sommeriella)* cf. *cockbaini* Archbold, dorsal valve interior, 162 m, × 1.8. B, *Neochonetes (Sommeriella)* sp., ventral valve, 161.54 m, × 2. C, E, *Taeniothaerus*? sp., dorsal valve external mould and dorsal valve exterior, 162 m, × 1. D, *Neochonetes (Sommeriella)* cf. *cockbaini* Archbold, dorsal valve interior, 162 m, × 1.5. F, *Taeniothaerus* sp., dorsal valve exterior, 163 m, × 1. G, *Taeniothaerus* sp., 163.5 m, × 1. H, *Costatumulus irwinensis* (Archbold), dorsal valve interior, 310 m, × 2. I, *Costatumulus irwinensis* (Archbold), ventral valve exterior, 338 m, × 2.

and *Neochonetes (Sommeriella) obrieni* Archbold respectively (Archbold 1998b). The present report provides identification of typical brachiopods from the Lower Callytharra Formation *Strophalosia irwinensis* brachiopod Zone which coincides in large part with the *Pseudoreticulatisporites pseudoreticulata* palynological Zone. From 315 m to 423 m brachiopods include *Costatumulus irwinensis* (Archbold), *Cimmeriella foordi* (Etheridge) and *Neochonetes (Sommeriella) prattii* (Davidson) as indicated in Fig. 6 and illustrated in Fig 7.

Glenburgh 8 is of considerable interest because of a brachiopod fauna from Core 6 (160.6–163.7 m depth; see Fig. 7 for illustrations) which includes *Neochonetes (Sommeriella)* cf. *cockbaini* Archbold and *Aulosteges* sp. (cf. *Aulosteges* sp. Archbold 1991: fig. 1E from the basal One Gum Formation = Ballythanna Sandstone). As interpreted by Mory & Backhouse (1997), Core 6 of Glenburgh 8 represents the uppermost Callytharra Formation and is likely to be a correlative with the Jimba Jimba Calcarenite. No palynological data is available from Core 6 but the depth of the core is likely to correlate with the top of the *Striatopodocarpites fusus* Zone or the base of the *Microbaculispora trisina* Zone.

Foraminifera from Glenburgh 8 were described and illustrated by Belford (1968). Palynological data from Mory & Backhouse (1997) were supplemented for this study by determinations by C. B. Foster (pers. comm. 24.viii.1992) for the depths of 482.1 m and 915.5 m.

Burna 1 (Fig. 8). Brachiopods are not common in the well. Two occurrences from the Cordalia Formation, *Cimmeriella flexuosa* (Waterhouse) and *Neospirifer (Quadrospira) hardmani* (Foord), are consistent with a correlation with the Jimba Jimba fauna (the *Strophalosia jimbaensis* Zone). The record of *Cimmeriella flexuosa* at 522.45 m comes from the *M. trisina* Zone whereas the *N. (Q.) hardmani*, at 574.9 m, is probably from the *S. fusus* Zone. Specimens are illustrated in Figs 5 and 12.

Gascoyne 1 (Fig. 9). This well includes a complete section through the Callytharra Formation, including the Winnemia Sandstone Member. From below the Winnemia Sandstone, *Neochonetes (Sommerilla) prattii* (Davidson) and *Cimmeriella foordi* (Etheridge), both typical of the *Strophalosia irwinensis* Zone, are known. Immediately above the Sandstone, at 345.4 m and 401.1 m, respectively, *Costatumulus irwinensis* (Archbold) and *Elivina hoskingae* Archbold & Thomas occur and also probably represent the *Strophalosia irwinensis* Zone (*E. hoskingae* is unknown from the Jimba Jimba

fauna). At 367.5 m, the occurrence of *C. flexuosa* (Waterhouse), from high in the *S. fusus* Zone, indicates the *Strophalosia jimbaensis* Zone. Specimens are illustrated in Figs 5, 10 and 12.

Ballythanna 1 (Fig. 11). This well also intersected a complete section of the Callytharra Formation including the Ballythanna Sandstone Member

BURNA 1
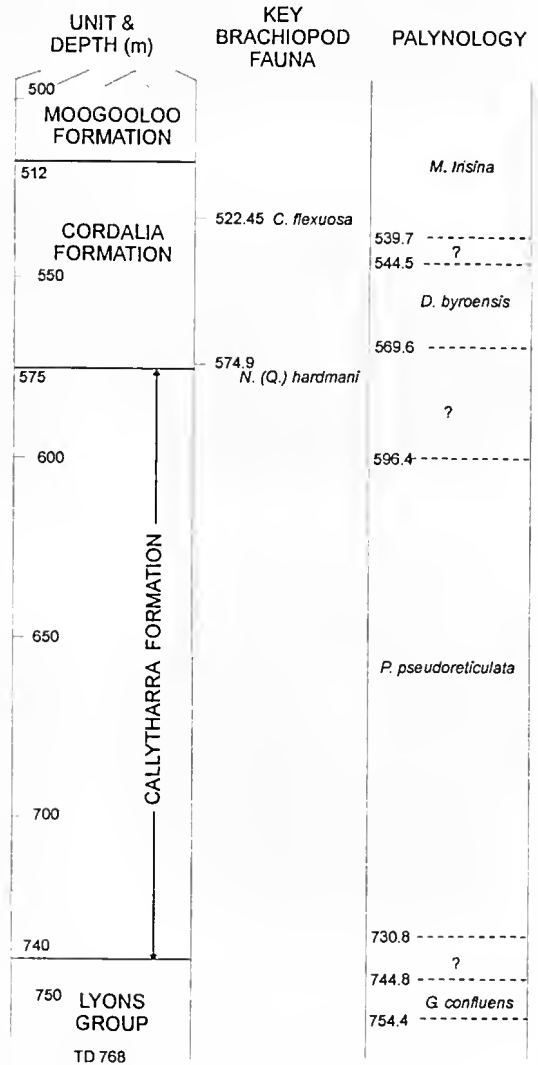
Fig. 8. Simplified well log of Burna 1.

(Mory 1996). From below the sandstone typical brachiopods of the *Strophalosia irwinensis* Zone occur including *Cimmeriella foordi* (Etheridge), *Costatumulus irwinensis* (Archbold), *Cyrtella* sp., *Trigonotreta neoaustralis* Archbold & Thomas and *Spirelytha fredericksi* Archbold & Thomas. These occur with the *P. pseudoreticulata* palynozone and are illustrated in Figs 5, 10 and 12.

From above the Ballythanna Sandstone, associated with the top of the *S. fusus* palynozone, brachiopods including *Permorthotetes lindneri* Thomas may indicate the Jimba Jimba fauna, but preservation is variable and the key species of *Strophalosia* and *Cimmeriella* are absent.

GASCOYNE 1

Fig. 9. Simplified well log of Gascoyne 1.
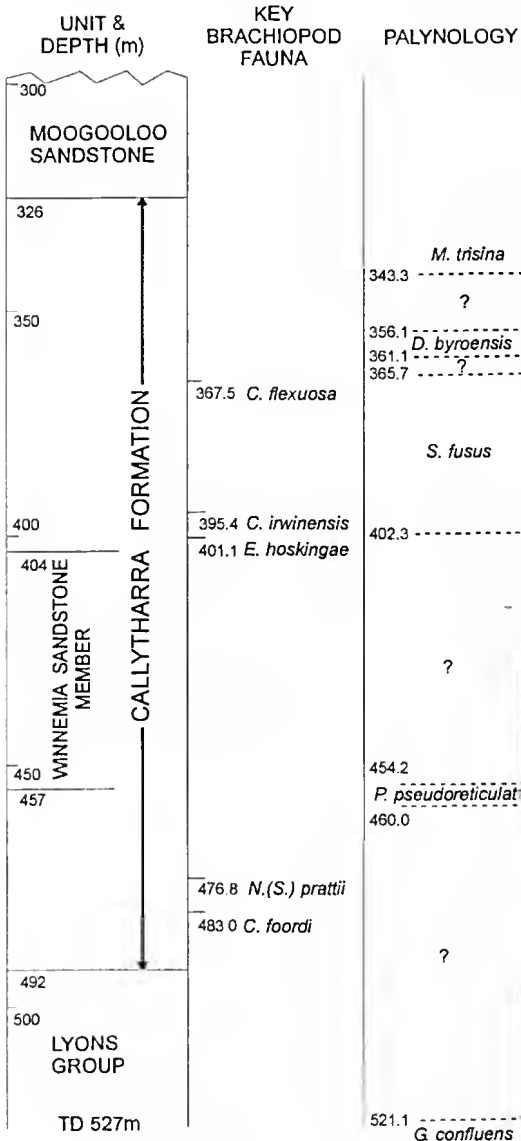
SUMMARY AND CONCLUSIONS

Macrofaunal levels from five wells (Bidgemia 1, Glenburgh 8, Burna 1, Gascoyne 1 and Ballythanna 1) in the Merlinleigh and Byro Sub-basins of the Carnarvon Basin are summarised in Fig. 13. While the quality and abundance of macrofaunal data varies from well to well (as with palynological data), the macrofaunas can be assigned to macro-faunal brachiopod zones developed in outcrop sequences and can be directly matched to the sub-surface palynological zones discussed and refined in Mory & Backhouse (1997). The results of this study indicate that the investigation of cores through marine Permian sequences for macrofossil data provides useful information for biostrati-graphical purposes. Hence such studies should be a normal part of stratigraphical drilling programmes in order to maximise the benefits of such programmes.

SYSTEMATIC PALAEONTOLOGY

Order PRODUCTIDA
Sarycheva & Sokolskaya 1959

Suborder PRODUCTIDINA Waagen 1883

Superfamily LINOPRODUCTOIDEA Stehli 1954

Family LINOPRODUCTIDAE Stehli 1954

Subfamily LINOPRODUCTINAE Stehli 1954

Genus **Cimmeriella** gen. nov.

Type species. Productus tenuistriatus De Verneuil (?) var. *foordi* Etheridge (1903), from the Sterlitamakian (Late Sakmarian) Lower Callytharra Formation, Carnarvon Basin, Western Australia; revised and illustrated by Archbold (1983).

Etymology. Named from the Cimmerian marine province of the Permian from which many of the species of the genus are to be found.

BALLYTHANNA 1

Fig. 11. Simplified well log of Ballythanna 1.

Diagnosis. Small to medium sized, globose Lino-productinae with relatively coarse costellae and wide intercostal valleys. Ventral posterior adductor scars deeply impressed; anterior diductor scars weakly striate. Dorsal median septum arises close to cardinal process. Rugae weak or absent, spines restricted to hinge region of ventral valve.

Discussion. Species of *Cimmeriella* gen. nov. have traditionally been assigned to *Stepanoviella* Zavodovskiy (1960) or to *Globiella* Muir-Wood & Cooper (1960). *Stepanoviella*, type species *S. paracurvata* Zavodovsky (1960), is characterised by extremely fine costellae, as illustrated in the accounts by Zavodovskiy (1960: pl. 81, figs 1–7), Zavodovskiy & Stepanov (1970: pl. 89, figs 1–8; pl. 90, figs 1–3) and Grigoryeva et al. (1977: pl. 27, figs 5–8) and possesses ventral spines of two types, fine dorsal spines and is restricted to species from the Kazanian–Tatarian of northeastern Siberia (Grigoryeva et al. 1977).

Globiella Muir-Wood & Cooper (1960), type species *Productus hemisphaerium* Kutorga (1844: 99, pl. 10, figs 2a–c), includes a group of globose species from the Kazanian of European Russia that have been long studied. Classic accounts of the type species, or closely related species, include those of Keyserling (1854: 102, pl. 2, figs 16, 17), Golovkinskiy (1868: 361, pl. 3, figs 1–3), Geinitz (1861: 102, pl. 18, figs 28, 29), Nechaev (1894: 145+, pl. 4, figs 1a–c, 2a–c), Frech (1901: pl. 63, fig. 7; pl. 64, fig. 13) and Nechaev (1911: 26+, pl. 1, figs 1a–9b; pl. 2, figs 1–16; pl. 3, fig. 1). Modern accounts are those of Muir-Wood & Cooper (1960), Grigoryeva (1962), Grigoryeva et al. (1977) and Gubareva (1998). Reports of this species group, herein treated as true *Globiella*, described from the Late Permian of the Trans-Caucasas (Armenia) by various authors, were shown to be erroneous by Stoyanov (1916). Through the courtesy of N. L. Fomicheva, the Director of the Geological and

Fig. 10. Brachiopods from Ballythanna 1 and Gascoyne 1. A. GSWA 00013, *Cimmeriella foordi* (Etheridge), ventral valve, Ballythanna 1, 373 m, × 2.8. B, GSWA 00014, *Cimmeriella foordi* (Etheridge), ventral valve, Ballythanna 1, 357 m, × 2.4. C, GSWA 00015, *Cimmeriella foordi* (Etheridge), ventral valve, Ballythanna 1, 373 m, × 2.8. D, GSWA 00016, *Cimmeriella foordi* (Etheridge), ventral valve, Gascoyne 1, 482.5 m, × 1.6. E, G. GSWA 00017, *Costatumulus irwinensis* (Archbold), ventral valve internal mould and ventral external mould, Gascoyne 1, 395.4 m, × 1.6. F, GSWA 00018, *Callytharrella callytharrensis* (Prendergast), ventral? valve, Ballythanna 1, 60.2 m, × 4. H, GSWA 00019, *Costatumulus irwinensis* (Archbold), dorsal external mould, Ballythanna 1, 321.2 m, × 1.6. I, GSWA 00020, *Spirelytha fredericksi* Archbold & Thomas, ventral valve, Ballythanna 1, 303.65 m, × 1.8. J, GSWA 00021, *Costatumulus irwinensis* (Archbold), ventral valve internal mould, Ballythanna 1, 303.65 m, × 1.5. K, L, GSWA 00022, *Spirelytha fredericksi* Archbold & Thomas, ventral valve external mould and counterpart, Ballythanna 1, 303.65 m, × 2.
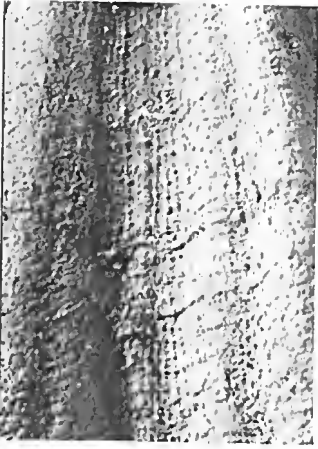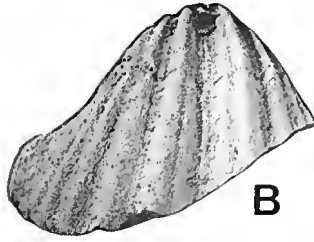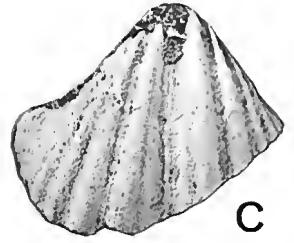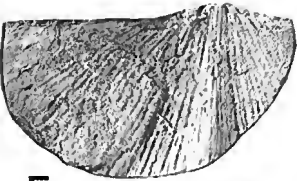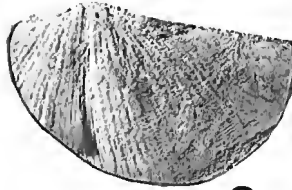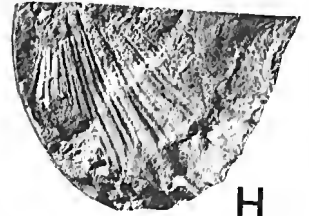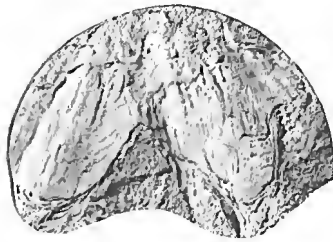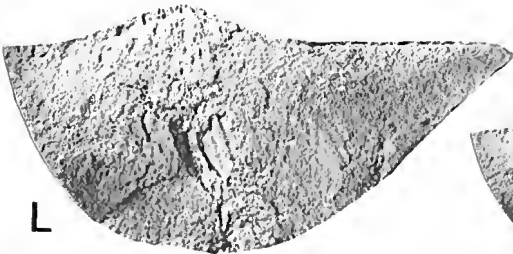
SUBSURFACE CORRELATIONS - CARNARVON BASIN

	STAGE Subslage/Horizon	BRACHIOPOD ZONES (W.A.)	AUSTRALIAN PALYNOLOGY	CARNARVON BASIN (WA)	CARNARVON BASIN CORES

Fig. 13. Correlation of cores with palaeontological and lithological schemes. Recovered macrofauna indicated by thickening of lines. Interpretation of stratigraphy from Mory & Backhouse (1997).

Mineralogical Museum, Kazan University, one of us (NWA) in 1998, was able to examine Nechaev's 1894 specimens (see Fomicheva et al. 1998 for details of Nechaev's collection) and large collections from the Kazanian of the Russian Platform. Examination of large suites of specimens of the Russian species indicated that species from the early Permian of the Gondwanan margin were close to, but distinct from, *Globiella*.

Species and reports assigned to *Cimmeriella* (see below) indicate a group of species with relatively coarse costellae and distinct intercostal valleys unlike those of *Globiella*. Mature *Globiella* is characterised by deeply impressed anterior diductor scars that are markedly striate unlike those of *Cimmeriella* which at maturity are only feebly striate. Other differences between the genera include the nature of the posterior adductor scars which are divided in *Cimmeriella* and the morphology of the dorsal medium septum which extends further posteriorly in *Cimmeriella* than in *Globiella*.

Globiella possesses a thicker dorsal valve than *Cimmeriella*, the dorsal valve of which is very delicate and liable to fragment, no doubt accounting for the rarity of preserved dorsal valves of the latter genus.

Species and reports assigned to Cimmeriella

1. *Productus tenuistriatus* De Verneuil (?) var. *foordi* Etheridge (1903: 19, pl. 1, figs 3, 4; pl. 3, fig. 22). Sterlitamakian, Western Australia.
2. *Stepanoviella flexuosa* Waterhouse (1970: 45, pl. 14, figs 1–8, 15–16). Aktastinian, Western Australia.
3. *Productus cora*: Broili (1915: pl. 21, figs 4a–b). Letti (Leti) Island, Indonesia. Aktastinian?
4. *Productus cora*: Broili (1916: pl. 1, figs 14, 15; pl. 2, figs 1–3). Bitauni, Indonesian Timor, Artinskian.

Fig. 12. Brachiopods from Gascoyne 1, Bidgemia 1, Burna 1 and Ballythanna 1. A, B, C, GSWA 00023, *Elivina hoskingae* Archbold & Thomas, ventral micro-ornament × 8, ventral valve anterior and ventral views, Gascoyne 1, 401.1 m, × 2. D, E, GSWA 00024, *Trigonotreta neoaustralis* Archbold & Thomas, ventral valve and external ventral mould, Bidgemia 1, 192 m, × 1. F, G, GSWA 00025, *Neospirifer (Quadrospira) hardmani* (Foord), ventral external mould and ventral valve, Bidgemia 1, 207 m, × 1. H, I, GSWA 00026, *Trigonotreta neoaustralis* Archbold & Thomas, ventral external mould and ventral valve, Ballythanna 1, 325.55 m, × 1.2. J, GSWA 00027, *Myodelthyrium dickinsi* (Thomas), ventral interarea, Bidgemia 1, 212 m, × 1. K, GSWA 00028, *Neospirifer (Quadrospira) hardmani* (Foord), ventral valve, Burna 1, 574.9 m, × 1. L, M, GSWA 00029, '*Crassispirifer*' sp., ventral valve, Bidgemia 1, 212 m, × 2 and × 1. N, GSWA 00030, *Cyrtella* sp., dorsal valve internal mould, Ballythanna 1, 302.1 m, × 1.2.

5. *Linoproductus cora*: Shimizu (1966: 407, pl. 2, figs 16–23). Several localities, East Timor, Artinskian.

6. *Globiella* sp. Shi & Waterhouse (1991: 33, fig. 2[23–25]). Perak, west Malaysia, Sterlitamakian–Aktastinian.

7. *Stepanoviella hemisphaerium*: Nie et al. (1993: pl. 1, figs 5–8). Western Yunnan, Sterlitamakian.

8. *Stepanoviella mucronata* Fang (1994: 268, pl. 1, figs 10–13). Baoshan Region, Western Yunnan, Sterlitamakian.

9. *Globiella youwangensis* Shi et al. (1996: 92, fig. 4F). Baoshan Region, Western Yunnan, Sterlitamakian.

10. *Stepanoviella gracilis* Ching (in Ching et al. 1977: 244, pl. 1, figs 10–12). Jilong Formation, Tibet, Sterlitamakian.

11. *Stepanoviella flexuosa*: Jing & Sun (1981: 140, pl. 5, figs 7, 8). Poindo Series, Tibet, Sakmarian.

12. *Globiella qiangduoensis* Sun (1991: 234, pl. 3, figs 28–32). Northwestern Tibet, Sakmarian.

13. *Globiella* cf. *rossiae*: Angiolini (1995: 174, pl. 1, figs 14–19). Karakorum, Sterlitamakian–Aktastinian

14. *Productus* cf. *waageuianus*: Merla (1934: 226, pl. 20, figs 45–47). Rimu, North Karakorum, Artinskian?

Reports of '*Stepanoviella*' from Afghanistan (eg. Termier & Termier 1971) cannot be confirmed as the material has not been fully described or illustrated. *Stepanoviella rossiae* Fantini Sestini (1966: 28, pl. 4, figs 1a–b) from North Iran is excluded from *Cimmeriella* in view of the low convexity of the Iranian species and very fine costellae. The *Globiella*? *rossiae* of Grunt & Dmitriev (1973: 107, pl. 7, figs 6–8) from the Early Artinskian of the Pamirs, is characterised by distinct, numerous, fine rugae on the ventral valve that are unlike those of true *Cimmeriella* and hence the report is excluded from the new genus. Peninsula Indian species, referred to *Globiella* by Archbold (1983), are now transferred to *Baudoproductus* Jing & Sun (1981) due to the presence of ventral spines (Archbold et al. 1996).

Globiella costellata Shi & Waterhouse (1996: 98, pl. 15, figs 9–24), from the Sakmarian of the Yukon Territory, Canada, appears to be a true *Cimmeriella* on the basis of its costellae and shell outline and hence indicates the bipolar distribution of the genus during the Early Permian.

Productus ufensis Fredericks (1915: 51, pl. 2, fig. 13; pl. 4, figs 3–6), from the Sakmarian of the Sarva River and other localities in the Ural

Mountains, approaches *Cimmeriella* in terms of its costal characteristics but possesses a narrower, higher ventral umbo.

Productus lutkewitschi Stepanov (1936: 121, pl. 1, figs 5a–c; 1937: 135, figs 1a–c) from the Ufimian of Spitzbergen possesses strongly developed rugae on the posterior of the ventral valve and hence is excluded from the genus *Cimmeriella*.

ACKNOWLEDGEMENTS

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TRANSACTIONS

OF THE

ROYAL SOCIETY OF VICTORIA

THE EFFECT OF THE Y2K BUG ON AUTOMOTIVE INDUSTRY IT

Summary of a presentation to the Royal Society of Victoria

9 December 1999

By Dr Paul Axon CEng

E-mail address: paxon@ford.com

Industry and commerce which use computer systems or processor-controlled equipment has been especially concerned that during and after the transition of the internal clocks of computers through significant dates those systems should maintain planned operation. The representation by computers of several dates, of which the 1 January 2000 was the most publicised, could lead to misoperation of processor-controlled systems. This concern is referred to as the 'Year2000, y2k or Millennium "bug"'.

SUMMARY

The Millennium 'bug' can be traced to the early days of computing, when memory and data storage were very expensive. To conserve these limited resources, computer programmers used just two digits in date fields to identify calendar years. In the year 2000 many computer programs will recognise the year '00' as 1900, causing systems to process incorrect data or simply shut down. The presentation illustrated the mechanism by which the y2k problem stems from the increasing complexity of computers. Although the immediate cause for concern is well understood as the historical use of 2-digit dates, the remedy was to find the occurrence of the bug in ever-more complex software programs which may or may not have reused older flawed program code. Particular generic issues which were highlighted include the observation that:

- Computer software has been more durable than was ever imagined.
- Some software which was first designed and written in the 1960s is still in use and is reused in newer softer which has become ever more complex.
- The cost of computer memory has reduced inexorably as demonstrated by graphs of the price of leading semiconductors.
- Moore's Law which relates the reducing cost and increasing complexity of semiconductor devices appears to have been confirmed.

The automotive industry is particularly dependent on computer-controlled automation and business systems and was chosen to illustrate the possible impact and the planning process used to mitigate the effects.

INTRODUCTION

The Millennium 'bug' and its effect in Information Technology (IT) systems had the potential to significantly affect production and business systems in the automotive industry. From a discussion of the cause of the Millennium 'bug' problem and a review of its impact on computer systems, the key issues facing IT were illustrated. The scale and complexity of the the Australian Automotive Industry were reviewed and the impact on the Global Automotive Industry with specific areas which could be affected; its affect on business systems and the wider implications of the problem and conclusions about the increasing complexity of business and manufacturing automation.

The presentation focused on the automotive IT and described the generic delivery processes in use and the high dependence on computers for the correct flow of information to enable the production process to operate normally. A key issue was to evaluate the level of risk of malfunction to each system. Industry testing and remediation actions were summarised in an endeavour to bring computer systems to a level of conformance at which the impact of the y2k 'bug' will be minimised within acceptable criteria of risk. To fulfil the assessment of risk even after corrective actions were in place, there was ongoing concern to develop Business Contingency Plans such that the effects could be detected as soon as possible after the transition through vulnerable date changes. Realisation of Year2000 compliant systems required management commitment, dedicated resources (personnel and hardware), strategic planning, rapid development, acceptance testing, a well-planned migration, and an adequate budget.

History

When computers were first deployed widely for commercial applications there were good reasons for the two-digit year practice, which stemmed from the comparatively limited capacities of those systems. The limited capacity of early micro-computers and controllers which were introduced in the early 1970s created a need for systems which were as economical as possible in their use of computer resources. The century element in dates was in those circumstances an unnecessary overhead of processor time and space (computer memory and storage) and some software companies treated this overhead as a severe offence.

Several technological and commercial developments have led to a radical shift of the cost and power of the available computer resources.

- Firstly, during the last two decades the cost of each byte of dynamic RAM has fallen by almost seven orders of magnitude. The rationale for economising the use of program memory is no longer valid and standard desktop programs now use enormous amounts of memory.
- Secondly, an observation known as **Moore's Law**[1] notes that each new integrated circuit has contained roughly twice as much **capacity** as its predecessor, and each new version is released approximately 18–24 months later. This is a continuing trend which has increased computing power exponentially over relatively brief periods of time. In 26 years the number of transistors on an integrated circuit has increased almost four orders of magnitude, from 2300 on the 4004 in 1971 to 7.5 million on the Pentium® II processor.
- Thirdly, increased substrate sizes, reduced sizes of devices and tracks and increased automation has proliferated the **availability** and use of programmable semiconductor devices and this effect has led to an exponential proliferation of semiconductor devices which are now widely used in domestic and commercial goods; often with communication networking capability. During the last two decades the use of integrated devices has increased by five orders of magnitude and the total number of devices in use doubles annually.

Legal implications

The House of Congress of the USA has defined failures due to the Millennium 'bug' in the Y2K Act H.R.775 9.12.1999 as:

'2) Y2K FAILURE—The term "Y2K failure" means failure by any device or system (including any computer system and any microchip or integrated circuit embedded in another device or product), or any software, firmware, or other set or collection of processing instructions to process, to calculate, to compare, to sequence, to display, to store, to transmit, or to receive year-2000 date-related data, including failures—
(A) to deal with or account for transitions or comparisons from, into, and between the years 1999 and 2000 accurately;
(B) to recognise or accurately to process any specific date in 1999, 2000, or 2001;'

There is a recognition of the potential for significant litigation and this has prompted both producers and users of IT systems worldwide to analyse their level of compliance and likely risks which they face and to seek advice as appropriate.

Program and software considerations

Computers execute a sequence of instructions known as program code and store data with coding information as directed by the program code. Each sequence of instructions can either be loaded into the computer's processor for execution as needed, eg. when commercial programs are run by a home PC; or it can be stored permanently in the fixed memory of the computer, eg. in the ROM of the processor device.

The program is then replicated across all the devices which need to execute that sequence of instructions and may be included in more-recently developed segments of code. In this way, a logical fault such as the processing of incorrect dates has been propagated to many computers and programmable logic devices throughout the world.

Two factors have exacerbated the situation.

- Firstly, software has been more durable than was ever imagined. Some software first written in the 1960s is still in use; and
- If older software has been replaced by newer, the new software is often built to the same specification or copies the algorithms of the original; including the use of two digits to represent years which had become general practice.

Globally, there has been an enormous growth in the number of software and firmware programmable devices; using programs which, if older, use the 2-digit dates and if newer may use 4-digit dates.

[1] 1965, Gordon Moore: http://www.intel.com/intel/intelis/museum; http://www.intel.com/intel/intelis/moore.htm.

Because of the cheaper devices, programs have become more complex and larger; making identification of those segments of code which are likely to be problematical more difficult.

This is where the real y2k problem stems from because although the immediate cause for concern is well understood; ie. the use of 2-digit dates; the remedy has to be to find the occurrence of the logical bug in ever-more complex software programs which may or may not have reused older code which is affected. Fig. 1 represents the way in which the use of non-compliant computer programs can affect the operation of new 'correct' code and the uncertainty which was faced by the testers. Although this is a complex and far-reaching problem, it is not a technically difficult problem to resolve when viewed on a module-by-module or routine-by-routine basis. The degree of complexity is directly related to the interrelationships between routines and programs and the data passed between them. This is not a trivial programming exercise. Realisation of a Year2000 compliant system required immediate management commitment, dedicated resources (personnel and hardware), strategic planning, rapid development, acceptance testing, a well-planned migration, and an adequate budget.
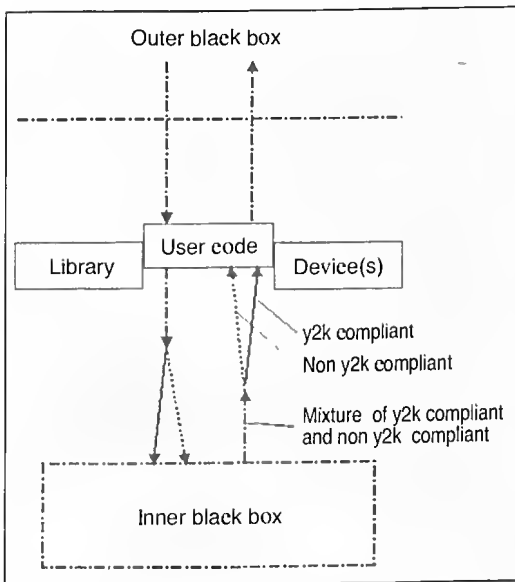
Fig. 1. The effect of code reuse. © The Institution of Electrical Engineers.

The possible effects of the problem

The Year2000 computer problem concerns the manner in which date data is stored and manipulated within computer programs. For the last thirty years, it was common to store a date value as a six-digit numeric field, with two digits representing the year, two digits representing the month and two digits representing the day of the month. For example, the value 970723 would represent the year 1997, the month of July, and the 23rd day. Storing date data in this manner has several inherent advantages. It conserves memory, a computer resource considered scarce until recently and this form of abbreviated representation facilitates both logical and numeric processing of date data. However, this data format implies the assumed century value to be '19'. Hence, when the year changes from '99' (1999) to '00' (2000), many computer programs would process date data values as if they were occurring in the 1900s. Unless remediated, the Year2000 computer problem could have affected the processing of programs in three areas.

1. First, in programs that sort date applications (ie. reports and displays), data that represents values in the 21st Century would always be improperly sorted. For example, assume that the following represents year values (and 00 represents 2000): 89, 67, 97, 00, 92. If the data is sorted from the oldest to the most recent (ie. smallest number to largest) then the resulting sequence would be: 00, 67, 89, 92, 97. Rather than assigning 00 as the year 2000, the program interprets 00 as the significantly smaller 1900. A similar problem occurs if the data is sorted from the most recent to the oldest.
2. Second, when used in calculations, date data can produce spurious results. For example, assume that the number of years is to be determined between 00 and 63 (ie. the years 2000 and 1963). The resulting value would be 63, rather than the correct value of 37. Mistakes like these could be significant when the results are used to determine the age of individuals for certain types of insurance eligibility or coverage.
3. Third, if dates are used in logical processing, (eg. determining if a date has exceeded an expiration), the wrong conclusions can be reached. For example, the value '000421' (21 April 2000) could conceivably be considered less than '970723' (23 July 1997), and the time limit already expired. Mistakes like this could delay the delivery of components to automotive assembly lines or cause records of vehicle movements to be misinterpreted and lost.

In each of the foregoing examples the processing is not interrupted, but the results are wrong. Detecting and correcting these types of errors are what make the Year2000 problem so complex.

Impact on computer database systems

Databases are key structures for the storage and retrieval of information by computers. Examples from databases were used to discuss the effect by which computers can misinterpret the date sequence of data was demonstrated. From effects in which the computer processing may not be interrupted, but the results are wrong, the likely consequences and remediative actions can be categorised and compared across major industry segments. The concern is that if the computer systems do not recognise the historical date at which the data was entered into the database, the data may possibly not be recognised at a future date and in this way data would appear to 'leak away' from the database; although the users would continue to believe erroneously that all the relevant data was still being processed by the database.

Impact on manufacturing and commerce

Miscalculations of dates by computers have the real probability of impacting the delivery of utility and banking services, corporate processing, and government functions, etc. Even if an organisation is able to remediate the Year2000 systems problem, these same systems are still prey to data received through intercomputer commercial communication protocols, eg. Electronic Data Interchange (EDI) or other external systems.

The Year2000 phenomenon potentially has both vertical and horizontal impact on such a computing environment. Vertically, the Year2000 phenomenon can originate from or affect the key components of the computing systems, that is, hardware, software, people, data and procedures. Horizontally, the phenomenon can propagate as the contaminated data flows to other computing systems inside and outside of the organisation to span the entire IT industry.

Embedded systems perform critical industrial automation functions

Embedded processors are contained in, or 'embedded' in, control systems and form an integral part of these systems. Embedded microprocessors

control a wide variety of systems ranging from critical applications in aircraft, medical devices, power plants and complex industrial processes; to relatively mundane applications found in automobiles, VCRs, fax machines and elevators. Embedded systems are everywhere and they are no less vulnerable to the Millennium 'bug' than the traditional IT systems that have received the bulk of management's attention. Embedded systems are far more difficult to fix than IT systems from both a management and a technical perspective, and often must be replaced rather than repaired or upgraded.

As manufacturers have steadily improved the efficiency of plant operations by operating on a just-in-time basis to reduce inventories, communicating with their suppliers through EDI and automating the factory floor using embedded systems, they have concomitantly increased their vulnerability to Year2000-related embedded system failures. Furthermore, lean inventories, EDI and increased use of outsourcing have dramatically increased the dependence of manufacturers upon their outside suppliers and distributors. As a result, the failure of one key member of the production and distribution chain to achieve Year2000 compliance for a mission critical embedded system could cause a domino effect disrupting the entire chain of industrial partners. We now examine the likely impact this disruption could have.

The economic size of the automotive business

The automotive business broadly consists of customers, customer requirements, importers, supplier companies and supply chains, manufacturers, distributors and dealers, and finance companies. In Australia the automotive market provides over 722 000 vehicles per year with a total value of $7.7 billion per annum. New vehicles account for 390 000 vehicles per year of which 325 000 vehicles are manufactured locally by four vehicle assemblers and the balance of vehicles are imported. The industry employs 55 000 people and has a gross turnover of approximately $13.6 billion[2].

The Australian automotive production industry produces 1500 vehicles per day. For this it consumes over 15 million parts and components daily which are provided from 300 supplier companies. A further 50 suppliers of materials provide several thousand tonnes of materials such as steel per day.

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[2] 1997, *The State of the Australian Automotive Industry*, The Minister for Industry, Science & Resources.

Consider from this the complexity of the automotive industry supply chain for which each vehicle consists of an average 1000 subassemblies and 4500 components. One car transporter takes 10 hours to deliver 3 minutes of production to a selection of 5000 dealers. The scheduling and delivery of all these items could not be properly managed by a manual paper system and computers perform an essential function.

Component and subassembly deliveries must be scheduled with the vehicle production scheduling and logistics. For this a component supply chain has developed and in parallel an information flow structure which broadly parallels the physical delivery system. Fig. 2 portrays the supply and distribution chains and the EDI mechanisms which are used for computer-to-computer communications to illustrate the parallel flow of information and components. The information flow is critical to the industry. Without it the components will not be transferred; but this is the crucial area which was at most risk of being affected by the 'bug'.

The first y2k problems in this process were found during mid-1998. Because the logistics and production planning operates 18 months ahead of the build schedule, the applications started to generate expected dates in 2000. These were transferred into the EDI system where it was found that:

- The International Standard for intercomputer commerce (ANSI X12) uses 2-digit dates.
- The software used by many supplier companies had been non-compliant.

Timely diagnosis of these and other issues enabled the software concerned to be replaced as part of the remediation effort prior to the start of the year 2000.

Risk assessment

A particular disaster may not affect the entire company in a similar manner. For instance, a loss of telephone service would have a greater impact on sales and customer service than it might on
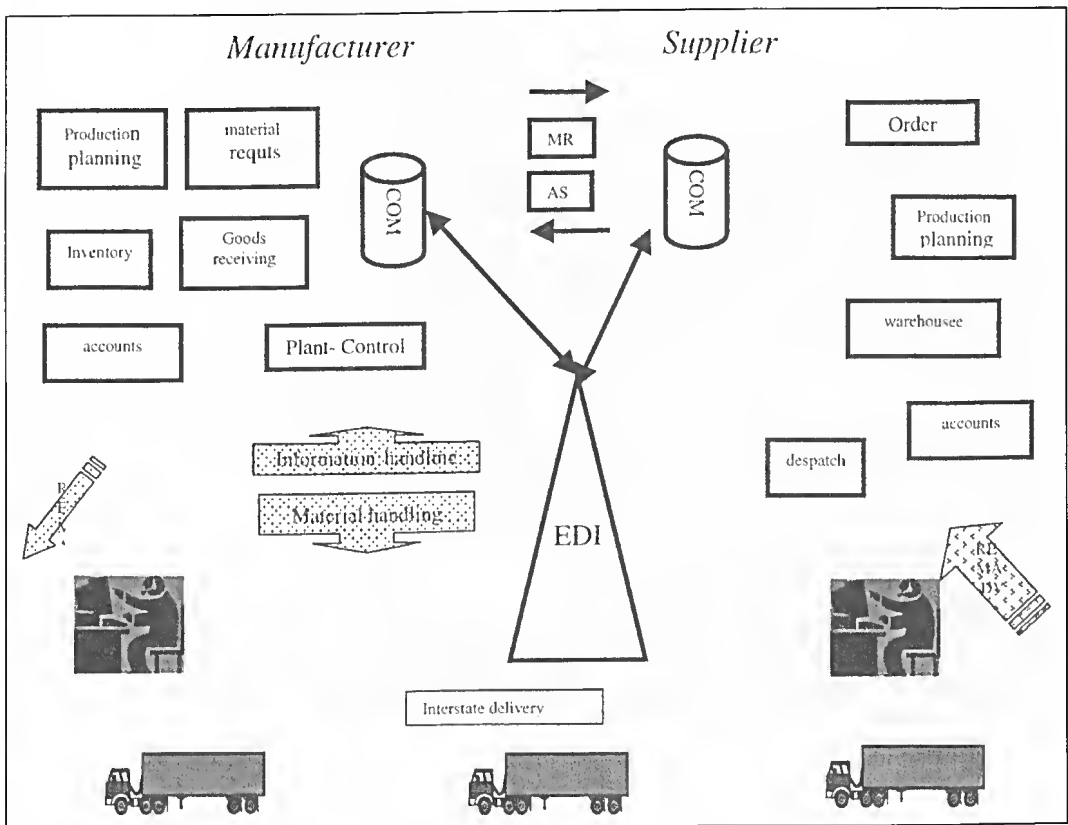
Fig. 2. Information and logistics flow of the automotive industry supply chain.

manufacturing. A gradation process was used to prepare for a potential disaster To rate the likelihood of the disaster occurring the probability of each was rated using the ratings: High, Medium or Low. The Year2000 problem was a certainty, although the severity of its effects on organisations was unknown. Some additional areas were also rated, such as the speed of disaster onset which was used to assess the speed at which the disaster could strike. However, not all y2k disasters can be predicted with such accuracy.

Lastly, the typical duration of the disaster was also rated. To understand the potential risks and to quantify the risks to the industry, Specific contingency plans of action were created for each hazard; including operating instructions, contact lists and flow charts outlining the steps to take in any given circumstance. Categories of RISK were foreseen as:

- business systems;
- technical infrastructure and computer servers;
- end-user computing PC;
- plant floor robots;
- buildings and facilities;
- test facilities;
- suppliers—resulted in extra inventory for non-compliants
- dealers—and exposed dependence on the public data, phone; and
- the EDI network for information transfer.

Compliance and economic impact

Compliance in the business computer systems and technical infrastructure were major items because of the multitude of programs which each computer system runs and because of the complexity of the computer systems. In Australia the industry expended in excess of $80 million to achieve a high confidence in its readiness for y2k, and upgraded mainframe computers, Unix workstations and servers, PCs, PABXs and Call Centres using automated tools to scan files and over-find possible date concerns.

Economic impact is indicated by the industry measures of costs and business impact. Fig. 3 highlights the $80 million costs to the Australian automotive for y2k remediation compared with various other main industry-segment costs for y2k remediation. In the USA the automotive segment of industry spent over $350 million.
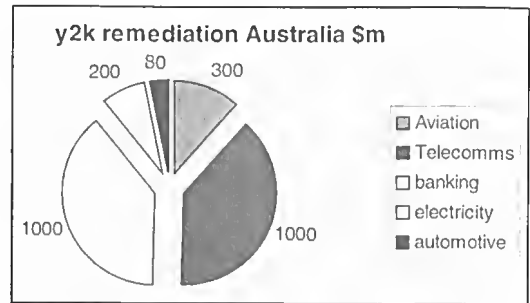
Fig. 3. Cost of remediation of the y2k 'bug' in Australia ($m).

These costs were compared with other industry segments in both continents, as deduced from a survey of 20 000 companies, out of the estimated $488 billion which was spent worldwide between 1995–2001 to remediate the bug.

Outcome of the testing process

The industry was prepared but not overcommitted for the testing exercise at the start of January 2000. By 31.12.99 all computer applications were halted for backup operations. By 01:00 1.1.2000 the operating systems were restarted and by noon all data networks and voice communications services tests were complete. This was then followed by testing of server computers and application programs with a complete system startup by 4.1.2000.

Anecdote

Although vulnerable computer systems had been diagnosed well in advance of the 1 January 2000 the planned remediation and testing processes appear to have performed well. No significant system failures were reported and all IT, production and communication systems continued normal operation.

ACKNOWLEDGEMENT

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INSTRUCTIONS FOR AUTHORS

Papers considered for publication may be: Reviews, Reports of experimental or descriptive research, or Short Communications. Length of papers may vary but Short Communications should not exceed 1500 words.

SUBMISSION

The original and two copies of the typescript and all tables and figures should be submitted to the Executive Officer, Royal Society of Victoria, 9 Victoria Street, Melbourne, Victoria 3000. Use International A4 bond paper for all copies; xerox-style duplicates are preferred to carbon copies. In a letter of transmittal give the names and addresses of three persons not directly associated with the work and outside the author's institution, who could act as referees. Except for short papers (less than 10 manuscript pages) presentation of the final manuscript on word-processor floppy disk is essential. Authors or their institutions may be requested to contribute towards the cost of publication of the paper; in the case of very long papers, such contribution is mandatory.

FORMAT

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:

1. *A brief title*, capitalised and, if possible, beginning with a key word.

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4. *A short abstract* of not more than 200 words describing the results (rather than the contents) of the paper.

5. *The main text*. Capitalise the first word of the introductory paragraph; do not use the heading 'Introduction'. Within the text up to three grades of heading may be used, typed as follows:

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Grade two heading
Grade three heading. Followed by running text on the same line.

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In taxonomic works, synonymies should be of the same format as the following examples, with a dash preceding

authors' names except in the case of reference to the original description.

Endendrium generalis Lendenberg 1885: 351, pl. 6.— Lendenberg 1887: 16.
Endendrium generale.—Hartlaub 1905: 515.—Watson 1985: 196–200, figs 40–52.
non *Endendrium generale*.—Watson 1982: 89, pl. 10, fig. 3.
Endendrium 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.

6. *Acknowledgements*. These should follow the main text and be as brief as possible.

7. *References*. These should conform in arrangement to the examples below, but do not type authors' names in capitals. Journal titles must be cited in full as they appear on the title page.

BIRCH, W. D., 1985. Calc-silicate rocks at Toolangi, Victoria. *Proceedings of the Royal Society of Victoria* 97: 1–18.
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.

8. *Tables and Figures*. Each table with its title should be typed on a separate sheet. A separate sheet should also be used to list captions to figures in numerical order.

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These must be designed for one or two column width (67 mm or 140 mm) and should be submitted at reproduction size; maximum length is 193 mm. Photographs should be supplied as unmounted, glossy prints labelled on the back; a Figure that is a composite of several photographs should be mounted on paper (not card). Line drawings should be made in black ink and supplied as glossy or flat prints; scales must be included and compass directions included where necessary. On composite Figures, items should be labelled A, B, C, etc. (not a, b, c). In the case of tables to be reproduced directly from copy, *italic typeface* not underlining must be used for italicised words. Oversize illustrations, tables or maps may be accepted for publication as foldouts only if the author meets all costs involved in their production. Maximum size for foldouts is 193×285 mm.

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