Records of the Western Australian Museum 20: 199–236 (2001).

The Cenozoic Brachiopoda of the Bremer and Eucla Basins, southwest Western Australia

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Abstract – The brachiopod fauna from the Late Eocene Bremer Basin and Middle Eocene to Pliocene Eucla Basin are described. Nineteen species have been recorded from the six major deposits in the two basins. Two new species, *Terebratulina christopheri* and *Liothyrella labiata*, are described. Two described species are re assigned from *Terebratula* to *Liothyrella*: *T. bulbosa* (Tate, 1880) and *T. subcarnea* (Tate, 1880). The close relationship between the species found in the basins and those found in Late Eocene to Miocene deposits in south-eastern Australia is examined. The later appearance of species in eastern South Australia, Victoria and Tasmania may well accord with the separation of Australia from Antarctica. The relationship between genera in Australia, New Zealand and Antarctica is also examined with implications for the evolution of Southern Hemisphere Brachiopoda.

INTRODUCTION

The brachiopods described herein from the Bremer Basin and Eucla Basins in the southern margins of Western Australia.

Stratigraphy of Bremer Basin (Figure 1)

The Plantagenet Group of the Bremer Basin in the south-west of Western Australia extends from North Walpole to east of Esperance. Cockbain (1968c) formalised the Group as consisting of the Pallinup Siltstone and the Werillup Formation (Figure 1). Chapman and Crespin (1934) very briefly described four brachiopod species from the Plantagenet Beds, Western Australia.

The Plantagenet Beds are described by Clarke and Phillips (1955) as "a horizontal series of conglomerates, sandstones, and clays overlain by the very characteristic and widely distributed "spongolite" (a sandy or silty rock containing abundant sponge spicules, and occasional entire sponges) in which, here and there, are lenses of limestone."

Cockbain (1968c) described the Werillup Formation as consisting of 'grey and black clay, siltstone, sandstone, lignite and carbonaceous siltstone.' The Werillup Formation contains both marine and non-marine strata overlaying a Precambrian surface of sands and granite. The non-marine material was most likely produced in peat swamps formed in hollows that became land locked after "an initial marine phase". A further shallow marine transgression resulted in deposits of silt, sand, clay and limestone. The Nanarup Limestone, probably due to this latter transgression, is described as a Member of the Werillup Formation and is a yellow-white friable bryozoan limestone. It is best exposed at the Nanarup Lime Quarry. Quilty (1981) suggested that, due to the lack of sorting and presence of complete echinoids and articulated brachiopods, current activity was negligible at the time of deposition. He further suggested that from the spatial distribution of the limestone immediately 'east of present-day granite hills' that it "accumulated in the lee of islands, protected from the easterly-moving currents" and detritus. He proposed a maximum depth of deposition of 35 m.

The Pallinup Siltstone overlies the Werillup Formation. It extends to the Precambrian basement in areas either not covered in the transgression previously mentioned or exposed by erosional effects. Cockbain (1968c) described the Pallinup Siltstone as typically 'white, brown or red siltstone and spongolite.' He concluded that this was laid down in a shallow transgressive sea with negligible input of terrigenous material, allowing sponges to thrive. The actual thickness of the Pallinup Siltstone varies and in the Norseman area there is some dispute over the correlation (Cockbain, 1968a; Backhouse, 1969). Darragh and Kendrick (1980) described the Pallinup Siltstone as resulting from "deposition... accompanied downwarping and transgression along the newly formed continental margin in the aftermath of the geological separation of Australia and Antarctica ... The Pallinup Siltstone formed in a shallow shelf environment with well-circulated water of normal marine salinity". They inferred a depth of deposition of 76 m but Pickett (1982) suggested this estimate might be too great.

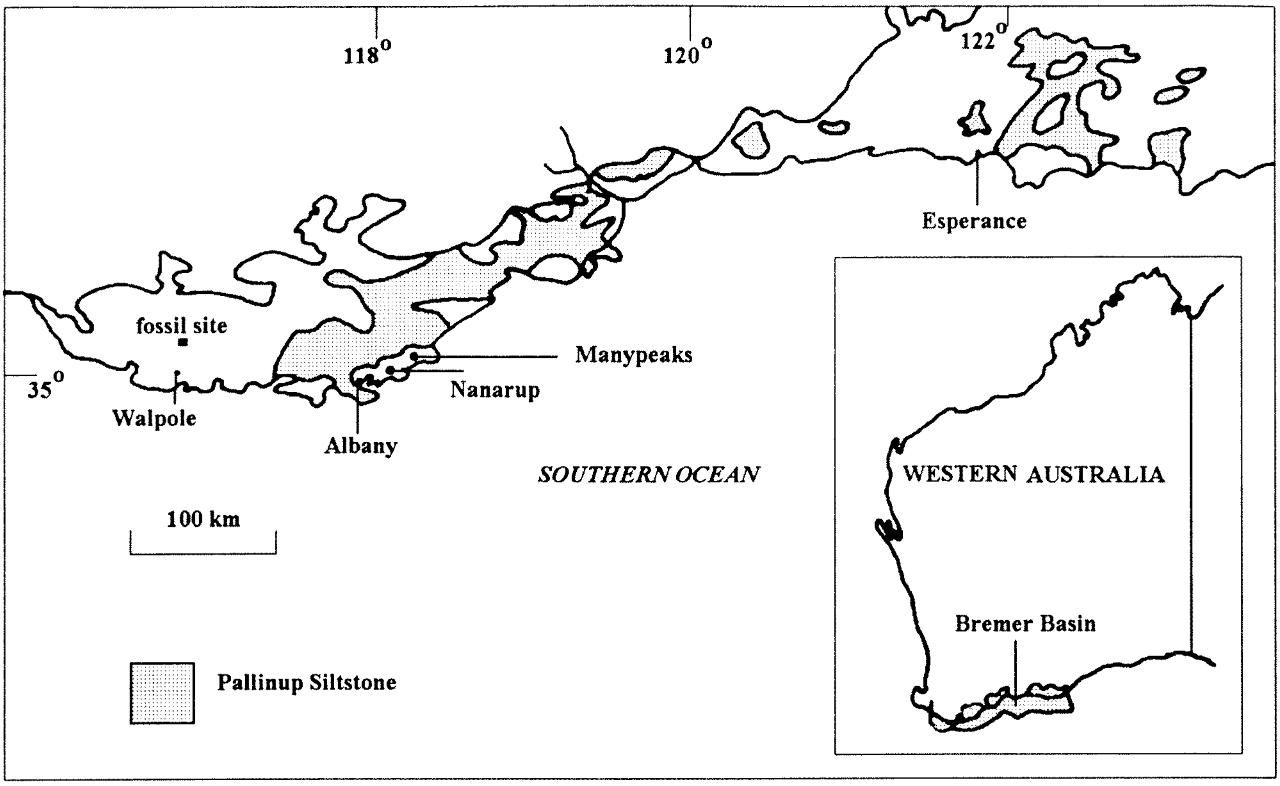


Figure 1 Map indicating the fossil sites from the Nanarup Limestone and Pallinup Siltstone (Adapted from Cockbain, 1968c).

Churchill (1973) and Clarke (1994) inferred a depth of deposition of approximately 150 m. The estimates of depth of deposition by Darragh and Kendrick (1980) are therefore possibly conservative.

Age

The Werillup Formation is regarded as late Middle Eocene. This is supported by the presence of the Dasycladcian algae, *Larvaria* and *Neomeris* (Cockbain 1969) and the foraminifer *Asterocylinia* (Cockbain 1967). The Nanarup Limestone Member has also been also determined as Late Eocene from the presence of the nautiloids *Aturia clarkei*, *Teichertia prora* and *Cimonia felix* (Cockbain 1968 b, c) as well as foraminifers reported by Quilty (1969). The Pallinup Siltstone is of similar age, again from the presence of the nautiloid *Aturia clarkei* and foraminifer reported by Backhouse (1969), Cockbain (1968a) and Quilty (1969). The foraminifers correspond with Ludbrook's "Tortachilla microfauna" (Cockbain 1968c).

The two transgressions discussed above are the Tortachilla Transgression assigned an age of 41 Ma and the Aldinga Transgression that is estimated at 37 Ma (McGowran 1989).

Palaeoclimate

Due to the presence of about 95% dextrally coiled foraminifer Quilty (1969) suggested that these sediments were deposited in a warm environment. Temperatures in the Southern Ocean have been discussed by Kemp (1978) who showed that they were warmer than the present day, probably influenced by Indian Ocean and Proto-Leeuwin currents. The bivalves from the Pallinup Siltstone at Walpole suggest a temperate climate (Darragh and Kendrick, 1980). Recent work on the gastropods (G.W. Kendrick, personal communication) suggests that they are warm water species. These views are supported by the palynological studies of Hos (1975), the presence of the sponge *Vaceletia progenitor* (Pickett, 1982), the echinoid *Echinolampas* and the marsupiate echinoid, *Fossulaster* (McNamara, 1994) as well as the microflora described by Balme and Churchill (1959) and Cookson (1954). McNamara (1994) suggested the Pallinup Siltstone probably was deposited in a cooler sea than that of the first transgression (still warmer than present conditions).

Clarke (1994) and Churchill (1973) described flora, including mangroves from the hinterland of the Late Eocene as being semi-tropical to tropical. The climate of the area was therefore quite different to that found there today.

Overview

In summary, it appears, then, that there were two marine transgressions during the Late Eocene. The first (Tortachilla Transgression) producing swamps, depositing silts, clays and the Nanarup Limestone

Member, while the second (Aldinga Transgression) produced the spongolite and siltstone of the Pallinup Formation. These transgressions would have washed around the granite outcrops of the southwest such as Mt Frankland, Granite Peak (Darragh and Kendrick, 1980) and the Porongurup Range that would then have appeared as islands. The Aldinga Transgression would have reached the base of the Precambrian uplifted deposits of the now Stirling Range, possibly producing an island or headland.

Stratigraphy of the Eucla Basin formations (Figure 2)

The Wilson Bluff Limestone Formation consists of four main subsections. The lowest is a thick calcarenite made up of bryozoan fragments in a microcrystalline calcite matrix. Within this section are found echinoid tests, brachiopods, bivalves, sponges and foraminifers. The overlying subsection is a thin layer, similar to that described above, but containing oysters as well as the other fauna. Overlying this is another similar layer, without oysters and less fossiliferous. The top layer is a hard white limestone containing bryozoan fragments and abundant brachiopods (Lowry 1970).

The Wilson Bluff Limestone is believed to extend several metres below sea level. It is overlain disconformably by the Abrakurrie Limestone and overlies the Hampton Sandstone. The Wilson Bluff Limestone can be best described as a poorly sorted white, compact packestone with bryozoan fragments in lime mud. Chert nodules can be found in all but the lowest 12 m. Some compaction structures are present and current bedding is common. It is found throughout the Eucla Basin but is replaced by the Toolinna Limestone that it abuts in the south-west (Lowry, 1970).

Lowry (1970) suggested that it was deposited in a flooded old river valley system and formed a wide continental shelf of normal marine salinity. Foraminifer suggest the lower section was deposited in water greater than 76 m deep, whilst the upper section was originally shallower. The abundance of lime mud may have been due to baffles formed by sponges, non-calcareous alga or sea grasses.

An Eocene age was originally suggested for the formation. This has been confirmed by the discovery of the Late Eocene bivalve *Notostrea lubra*, and *Australanthus longianus*, an echinoid of the same age. Foraminiferal assemblages suggest that the uppermost part is Late Eocene and the base is Middle Eocene (Li *et al.*, 1996)

Abrakurrie Limestone consists of two parts. These

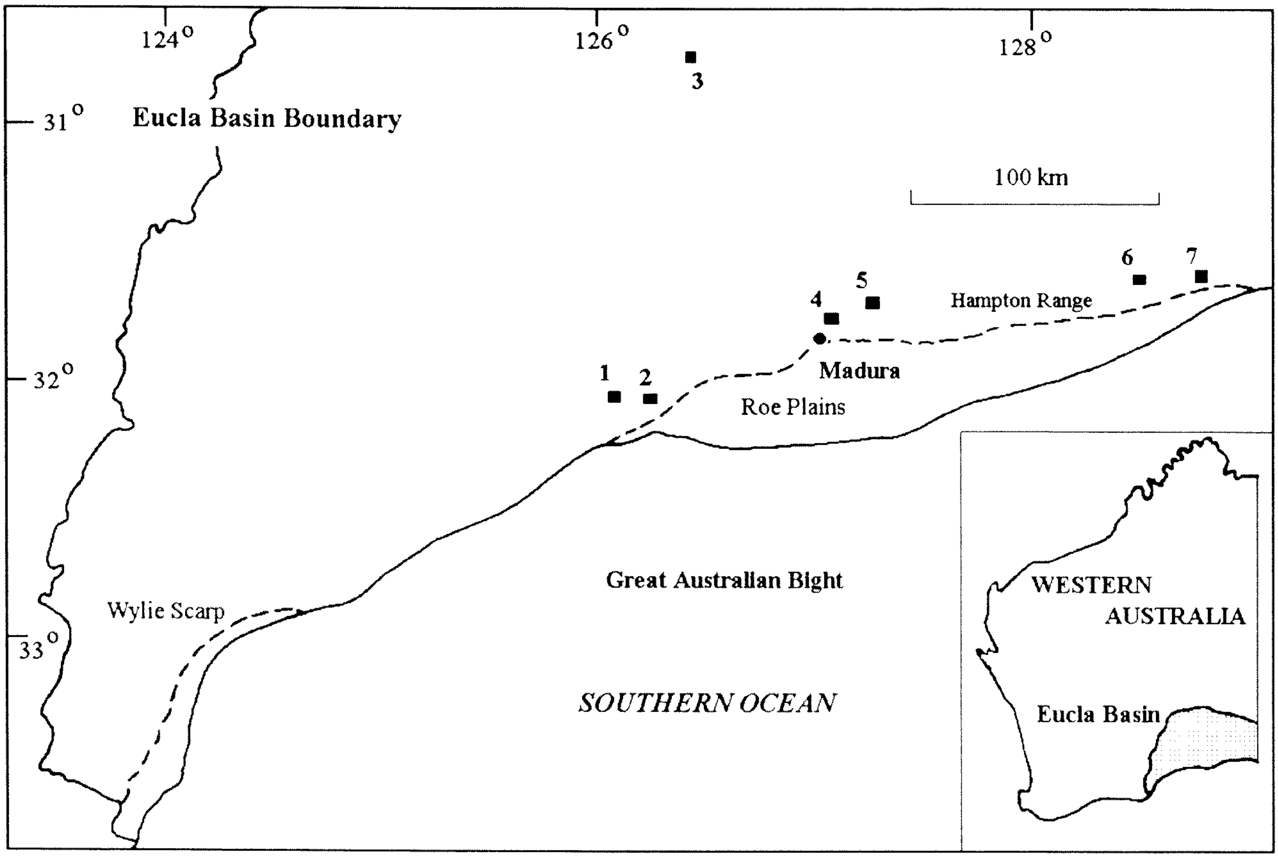


Figure 2 Map of the Eucla Basin indicating the fossil sites in the various deposits. 1 = Murra-el-elevyn Cave, 2 = Tommy Graham Cave, 3 = Haig Cave, 4 = Firestick Cave, 5 = Mullamullang Cave, 6 = Abrakurrie Cave, 7 = Weebubbie Cave (derived from Lowry, 1970).

are the lower friable bryozoan calcarenite and an upper indurate bryozoan calcarenite, both moderately well sorted. Echinoid tests, fragments and spines, brachiopods and bivalves are common throughout. The echinoids are most abundant at the top of the formation. Nodules of coralline algae are also present. The rock is generally coarse grained but ranges from granular to fine grained. Beds are mostly grainstones with some packestones. Large scale cross bedding is prominent (Lowry, 1970).

The Abrakurrie Limestone is developed in the central basin and is thickest at Madura where it is exposed in numerous caves. The thickest known exposure is in Mullamullang Cave where it extends from 17.5 m below the surface to 91 m. This formation lies disconformably on the Wilson Bluff Limestone and the Toolinna Limestone. It is overlain by the Nullarbor Limestone. The echinoid fauna is typical of the Janjukian-Longfordian (Middle Oligocene-Early Miocene) and the foraminifers are mostly long ranging benthic forms (Lowry 1970).

Lowry (1970) suggested that the Abrakurrie Limestone was deposited on a shallow open shelf of normal marine salinity. He suggested sea temperatures were probably warmer than at present. James and Bone (1992) interpreted the limestone as a cool-water deep shelf deposit that accumulated in water depths greater than 70 m on the inner part of the Eucla Platform. They suggested a model of deposition and cementation on a carbonate shelf swept by open ocean swells. Deposition occurred when sea level was high. Hardgrounds formed when sea levels dropped and erosion took place due to wave abrasion. The James and Bone (1991) model is based on modern swell dominated shelves. They suggested sea-level fluctuations were due to storms and periods of glacial activity. The lack of calcareous red alga brings them to the conclusion that the deposition was below the zone of active coralline growth. Li *et al.* (1996) concluded that the Abrakurrie Limestone is late Oligocene to earliest Miocene. It approximates to foraminiferal zones P22 to N4. They suggested that it was deposited during the second-order supercycle TB1, which correlates broadly to the Janjukian Stage of southern Australia N4 (Li *et al.*, 1996).

The Toolinna Limestone consists of "medium to very coarse grained well sorted current bedded, bryozoan calcarenite" (Playford *et al.*, 1975). The type section is 55 m high and found on the cliffs at Toolinna Cove in the southwest corner of the Eucla Basin. The macrofauna is similar to that found in the Wilson Bluff Limestone and therefore the age is determined as Late Eocene (Playford *et al.*, 1975). Li *et al.* (1996) suggested that it is Middle Eocene to Early Miocene and that it could belong to the Abrakurrie Limestone due to the benthic foraminiferal fauna that differs to the Wilson Bluff Limestone.

The Roe Calcarenite is a thin, sandy limestone of Pliocene age that forms the surface of the Roe Plains (Figure 3) in the southern Eucla Basin. Its stratigraphy and age correlation are fully outlined in Craig (1999). One species of brachiopod,

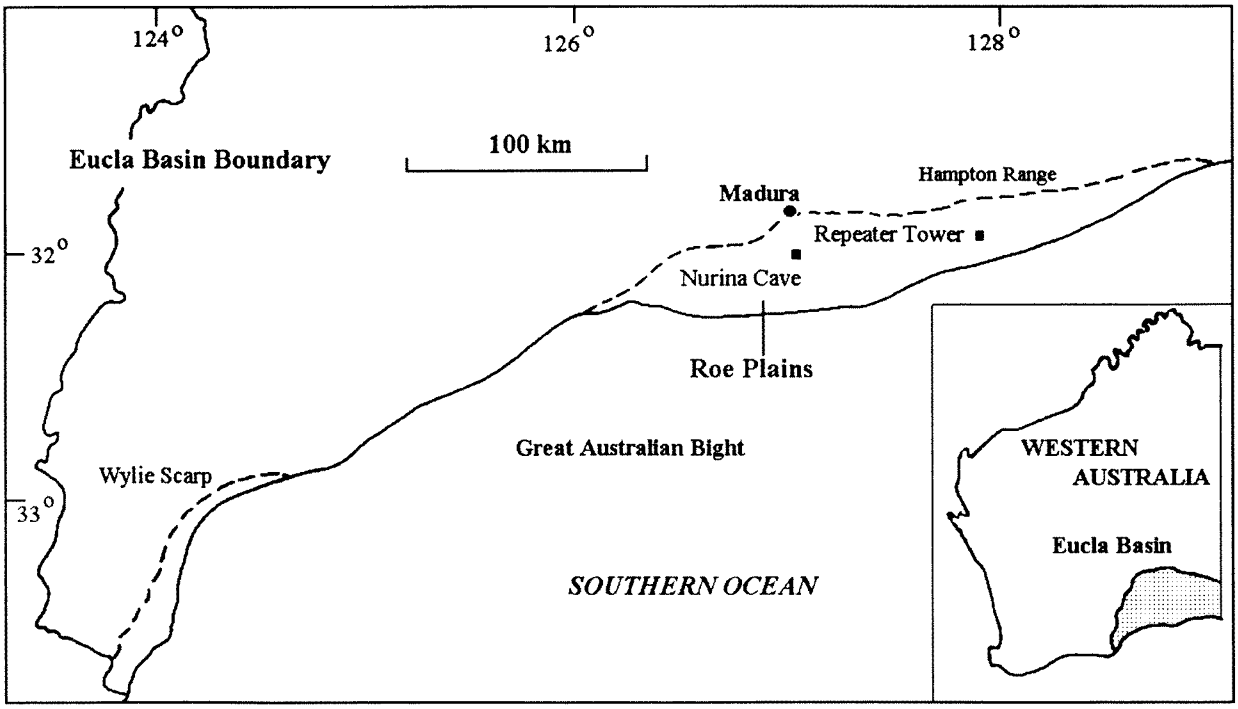


Figure 3 Map of the Eucla Basin showing the Roe Plains and the Hampton Range Repeater Tower, the principle fossil site for the Roe Calcarenite.

Neothyris rylandae, has been described from the deposit (Craig, 1999).

MATERIAL AND METHODS

The brachiopods examined are housed in the Museum of Western Australia (WAM), the Geological Survey of Western Australia (F numbers) and the University of Western Australia (UWA). Specimens from the Museum were principally collected by Dr T. Darragh, Mr G.W. Kendrick, Dr K.J. McNamara and family, Mr R.S. and Mrs Z.I.T. Craig and Mr I. Green.

The specimens were cleaned from the matrix using dental tools. Where possible, the interiors were also cleaned. Serial grinding was conducted on complete specimens using a large wheel grinder and sections were drawn using a camera lucida microscope.

Photographs were taken with a Nikon F 90 X camera with a macro lens and each specimen was prepared for photography with a coating of ammonium chloride.

SYSTEMATIC PALAEONTOLOGY

Phylum Brachiopoda Dumeril, 1806

Subphylum Craniiformea
Popov, Bassett, Holmer & Laurie, 1993

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

Order Craniida Waagen, 1885

Superfamily Craniacea Menke, 1828

Family Craniidae Menke, 1828

Genus *Westralicrania* Cockbain, 1966

Types Species

Westralicrania allani Cockbain, 1966.

***Westralicrania zenobiae* Craig, 1997**
Figure 8 A–G

Westralicrania zenobiae Craig, 1997: 311–315, Figures 1, 2, A–L.

Material Examined

Holotype

WAM 94.29, (Ventral valve) Nanarup Lime Quarry, Nanarup Limestone, Werillup Formation, Bremer Basin.

Paratypes

WAM 94.30-40, (ventral valve) Nanarup Lime Quarry, Nanarup Limestone, Werillup Formation, Bremer Basin.

Other material

Bremer Basin: WAM 94.41, (ventral valve) Manypeaks Lime Quarry, Nanarup Limestone, Werillup Formation, Bremer Basin.

Eucla Basin: WAM 88.371, 373, 873, 94.28, Israelite Bay, Toolinna Limestone, Late Eocene.

Remarks

The original description by the author remains unchanged. This species was described from the Late Eocene, Nanarup Limestone, Bremer Basin, Western Australia (Craig 1997). The material listed above was used in the description of the species by Craig (1997).

Order Terebratulida Waagen 1883

Suborder Terebratulidina Waagen, 1883

Superfamily Terebratuloidea Gray, 1840

Family Terebratulidae Gray, 1840

Subfamily Terebratulinae Gray, 1840

Genus *Liothyrella* Thomson, 1916

Type Species

Terebratula uva Broderip, 1833.

***Liothyrella labiata* sp. nov.**
Figures 4, 9 A–D

Material Examined

Holotype

WAM 94.61 Nanarup Lime Quarry, Nanarup Limestone, Werillup Formation, Bremer Basin.

Paratypes

WAM 94.62-64, Nanarup Lime Quarry, Nanarup Limestone, Werillup Formation, Bremer Basin.

Other Material

Bremer Basin: WAM 94.42 – 70, 94.153, 94.160, 94.169 – 170, Nanarup Lime Quarry; WAM 94.1338, 0.5 km west of Nanarup Lime Quarry; WAM 94.840, 95.444, Manypeaks Quarry, Nanarup Limestone, Werillup Formation, Bremer Basin.

Eucla Basin: F6110/1, Madura south cave; F6111/3, F6111/4, Murra-el-elevyn Cave, Burnabbie, Wilson Bluff Limestone, Late Eocene.

Diagnosis

Liothyrella with sulciplicate anterior commissure; beak suberect, large lip (labiate), foramen large.

Figure 4 *Liothyrella labiata* sp. nov. Serial section. Measurements indicate distance from last section in mm. Scale bar = 1 mm.

Description

Exterior. Shell ovate to subpentagonal, medium-sized, 9.7 to 35.5 mm long. Ventribiconvex, depth to 53% shell length. Widest anterior to mid-length, to 73% shell length. Shell smooth, finely and densely punctate, growth lines prominent anterior to mid-length. Folding on ventral valve incipient, double fold on dorsal valve in anterior third of shell to 60% shell width. Cardinal margin strongly curved; valves lateral edge gently rounded, lateral margin straight to incipiently sigmoidal; anterior commissure sulciplicate. Umbo truncated, beak suberect, labiate; beak ridges attrite. Foramen large, to 6.6% shell length, permesothyrid. Symphytium narrow, thin concave.

Table 1 Measurements (in mm) of complete or nearly complete specimens of *Liothyrella labiata* sp. nov.

Specimen	Length	Width	Depth
WAM 70.117a	21.7	–	11
WAM 70.177b	35.1	22.6	–
WAM 94.42	25.5	19.1	12.2
WAM 94.43	23.0	17.2	10.2
WAM 94.44	30.9	–	–
WAM 94.45	29.7	20.4	–
WAM 94.46	32	–	–
WAM 94.47	26	–	–
WAM 94.48	28.2	18.7	–
WAM 94.49	33.7	–	–
WAM 94.50	–	–	11.3
WAM 94.51	24.6	18.7	12.5
WAM 94.57	21.9	14.2	9.8
WAM 94.61	30.3	22.0	15.8
WAM 94.62	27.6	19.2	13.7
WAM 94.63	34.6	23.9	18.3
WAM 94.64	25.7	18.5	13.9
WAM 94.66	29.1	18.4	13.9
WAM 94.67	–	–	12.1
WAM 94.1338d	17.9	12.1	7.6
WAM 94.1338b	31.6	20.6	16.1
WAM 94.1338f	9.7	7.1	5.7
F6110/1	24.9	19.4	12.6
F6111/3	20.2	15.6	10.8
F6111/4	20.7	14.2	–

Interior. Ventral valve. Pedicle collar narrow, sessile. Socket teeth short, rectangular with deep groove at margin, no dental plates, bases incipiently enlarged.

Dorsal valve. (From serial grinding) Loop short, ventrally arched anteriorly, diverges little, central between each valve.

Remarks

Liothyrella is known from the Oligocene to Recent. Numerous species have been described from Antarctica, southern South America, west coast of Central and South America, New Zealand and Australia (Cooper, 1983). Tertiary *Liothyrella* include *L. anderssoni* Owen and *L. lecta* (Guppy) (Owen 1980), *L. kakanuiensis* (Hutton), *L. circularis* Allan, *L. neglecta* (Hutton), *L. concentrica* (Hutton), *L. oamarutica* (Boehm), *L. thomsonii* Allan, *L. skinneri* Allan and *L. gravida* (Suess) (Allan, 1932), *L. gigantea* Allan (Allan, 1960) and a new species from the Cardabia Formation of the Carnarvon Basin. *L. labiata* differs from all of these species in that it has a distinctive sulciplicate anterior commissure. A new species of *Liothyrella* from the Late Cretaceous of both the Carnarvon and Perth Basins (Craig, 1999b) has a uniplicate anterior commissure. *L. pulchra* Thomson from the Late Eocene has a sulciplicate anterior commissure. It is overall more round (width 88% of shell length) and the foramen is larger (9% of shell length) compared to *L. labiata*. These features suggest a new taxon is in order. Richardson described the species in her unpublished thesis (1971) as *Gryphus labiata*. Her specimens included P17320-22 (Museum of Victoria) from the Tortachilla Limestone (Late Eocene), Maslin Bay, Aldinga in South Australia. The species does not belong to *Gryphus*, which is a Northern Hemisphere genus, due to morphological differences from the genus.

Etymology

Richardson, in her unpublished thesis, called the species *labiatus*. In honour of her work I maintain the name in part, due to the large lip on the beak.

Liothyrella bulbosa (Tate, 1880)

Figures 5, 9 E–H

1880 *Terebratula bulbosa* Tate: 145–146, plate 7, figures 5a–b.

1910 *Terebratula bulbosa:* Buckmann, 25, 26, plate 3, figure 7.

1910 *Terebratula bulbosa:* Lowry, 67, 86.

Material Examined

Eucla Basin: F6806/1, F6806/2–13, F6806/17, F6813/1–7, 2 km east of Wilson Bluff, 0–6 m below top of formation; F6810b and d, Wilson Bluff; F6851/1–7, Abrakurrie Cave; F6817/1–21, Abrakurrie Cave, 0–3.35 m below top of formation; F6830/1–2, Abrakurrie Cave, near top of formation; F6833, Mullamullang Cave; F6875/1–5, Toolinna Cove; F6812, Madura– 13 km north of Firestick Cave; Wilson Bluff Limestone, Late Eocene.

Description

Exterior. Shell medium to large from 27 - 51 mm in length, ovate to subcircular. Biconvex, greatest depth at mid-length, dorsal valve from slightly flatter to as convex as ventral valve, depth 50–75% shell length. Width greatest at mid-length, width 86–93% shell length. Shell smooth; growth lines distinct; punctae very fine and dense. Cardinal margin gently curved, to 54% shell width; valves lateral edge sharply bevelled, lateral margin gently concave with respect to ventral valve except for anterior fifth where it rises strongly towards ventral valve; anterior valve edge sharply bevelled, anterior commissure unisulcate, sulcus gently to strongly pronounced, with corresponding keel in ventral valve of strongly pronounced specimens. Umbo short, beak truncated, erect; beak ridges sharp. Foramen permesothyrid, round, small with respect to shell length (to 3%) but fairly large when compared to other species. Symphytium

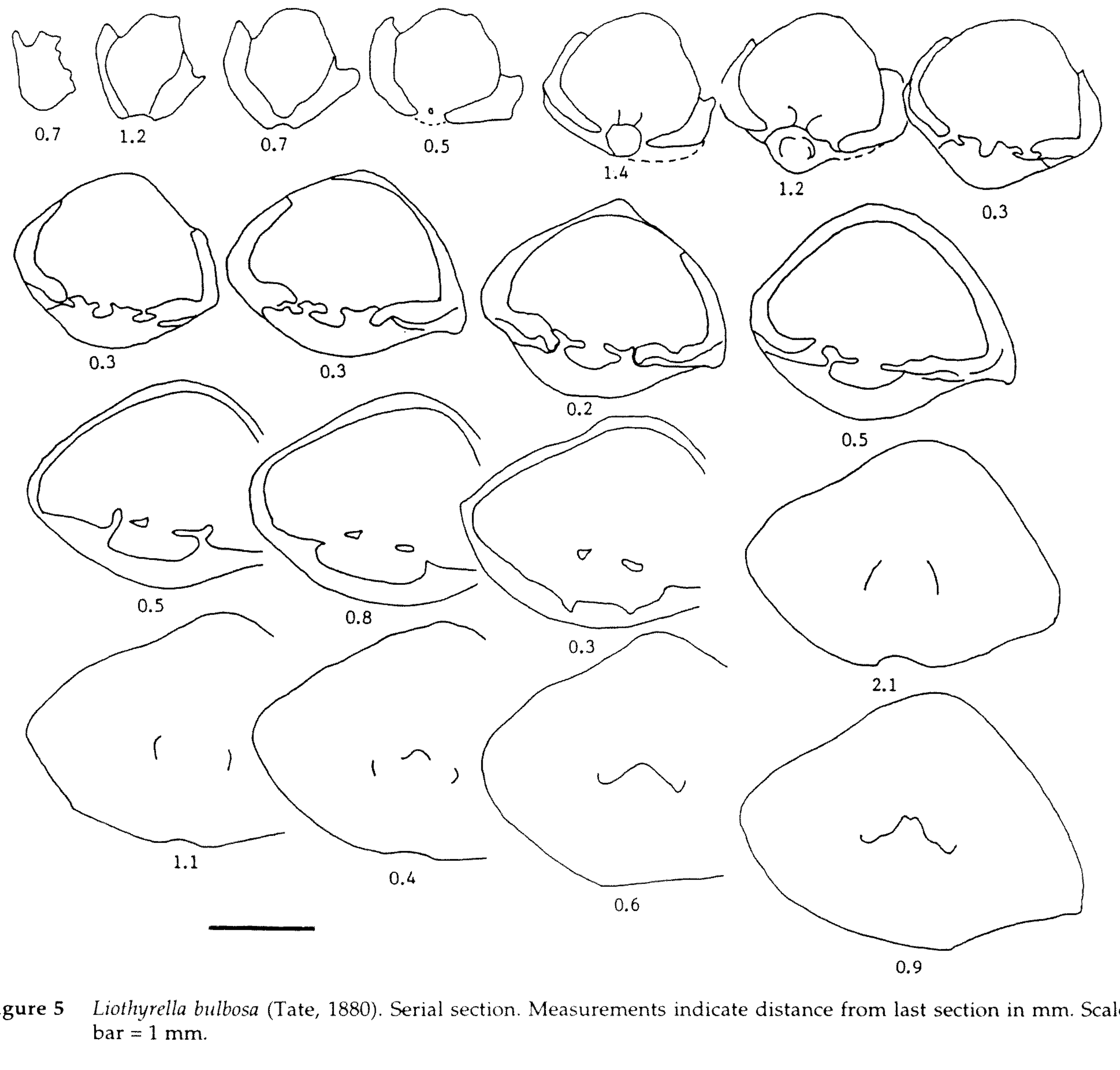


Figure 5 *Liothyrella bulbosa* (Tate, 1880). Serial section. Measurements indicate distance from last section in mm. Scale bar = 1 mm.

Table 2 Measurements (in mm) of *Liothyrella bulbosa* (Tate, 1880).

Specimen	Length	Width	Depth
F6806/1	44.5	38.0	22.4
F6806/2	42.3	36.7	25.2
F6806/5	–	40.1	25.0
F6806/6	27.1	25.2	15.9
F6810	43.1	36.6	21.8
F6812	41.2	38.0	–
F6813/1–7	50.7	45.0	28.3
F6813/1–7	48.1	43.7	30.8
F6813/1–7	41.3	–	26.5
F6813/1–7	–	35.3	19.1
F6817/1–21	24.5	21.6	12.01
F6817/1–21	–	30.7	–
F6817/1–21	–	25.6	–
F6830/1–2	42.9	34.4	30.0

concave, obscured by foramen; palintrope wide, low and concave.

Interior. Ventral valve. Hinge teeth strong, curved, no dental plates but swollen bases. Pedicle trough wide.

Dorsal valve. Sockets triangular; outer socket ridge narrow; inner socket ridge curved over socket, wide, joined to crural base with deep groove between them. No hinge plates observed. Crura divergent, thin, sharp. Cardinal process ranges from protuberant small cup to one with a swollen base. Rim with three vertical extensions, crown-like.

Remarks

This species originally placed in the genus *Terebratula* by Tate is known from the northern hemisphere. The *Terebratula* has numerous species in the southern hemisphere assigned to it until more detailed examination of the specimens led to the formation of numerous genera with similar loop characteristics and cardinalia. It is rejected as it is a northern hemisphere genus and *L. bulbosa* has characteristics more consistent with *Liothyrella* than *Terebratula*. These include the features of the loop, foramen and cardinalia, which best fit the general description for the genus *Liothyrella*. *Liothyrella* is a known southern hemisphere species. *L. bulbosa* differs to all prior described specimens because of its large size extending to over 48 mm in length, its large depth to length ratio, and ovate outline.

L. bulbosa is recorded from Edithburgh, Yorke Peninsula (Tate, 1880) in deposits of Late Oligocene age and a glauconite bank, Cockburn Island, Antarctic Peninsula that Buckmann (1910) concludes as of Miocene age.

Liothyrella subcarnea (Tate, 1880)

Figures 6, 9 I–L

1880 *Terebratula subcarnea* Tate: 145, plate 9, figures 1a–b;

1899 *Terebratula subcarnea:* Tate, 1899: 251;

1927 *Terebratula subcarnea:* Crespin and Chapman in Thomson: 299.

1970 *Terebratula subcarnea*: Lowry 67, 86.

Material Examined

Eucla Basin: F5541, Twilght Cove; F6113/5, Cockelbiddy Cave; F6808/1, F6808/2–3, F6809/1–7, F6809/8–9, F6814/1–10, Abrakurrie Cave; F6817/1–21, Abrakurrie Cave, 0–3.2 m below top of formation; F6811, Abrakurrie Cave, 3.4 – 3.7 m from top of formation; F6803, F6844, Abrakurrie Cave, 6.2–12.1 m below top of formation; F6804, Weebubbie Cave; F6807/1, F6807/2, F6845/1–5, Mullamullang Cave; F6805, F6806, F6823, F6825, 2 km east of Bluff; F6810, Wilson Bluff; F6875, Toolinna Cove; Wilson Bluff Limestone, Late Eocene.

WAM 68.350, Cliff face of Toolinna; F6812, Madura, 12.9 km north of Firestick Cave; Abrakurrie Limestone, Early Miocene.

Description

Exterior. Shell ovate to subcircular from 17–68 mm in length. Ventribiconvex with dorsal valve nearly flat, greatest depth posterior to mid-length, depth to 56% shell length. Width greatest at mid-length, width from 84% to 102% shell length. Shell smooth, growth lines distinct anteriorly, punctae very dense and very fine, oval in shape. Cardinal margin gently curved, dorsal umbo protuberant, margin to 60% shell width; valves lateral edge sharply bevelled, lateral margin straight; anterior valve edge sharply bevelled, anterior commissure rectimarginate. Umbo short; beak erect, labiate extension to foramen; beak ridges quite sharp. Foramen permesothyrid to epithyrid, small with respect to shell length (4.4%) but relatively large compared to other species. Symphytium low, wide, concave, deltidial plates joined without midrib. Palintrope low, very wide, concave.

Interior. Ventral valve. Pedicle collar narrow, sessile, thick. Pedicle trough wide. Teeth rectangular, "rolled" inwards, groove laterally and distally, bases swollen. No muscle scars apparent.

Dorsal valve. Outer socket ridge raised, socket floor swollen to margin, socket short, triangular. Inner socket ridge wide, flat, fused to outer hinge plate and crural base. Crural base perpendicular to outer hinge plate. Crura divergent, thin. No inner hinge plates. Deep depression below cardinal process. Cardinal process protuberant, hemispherical, with a flat top and swollen base, surface irregularly rough. Muscle scars in large triangular troughs either side of wide median ridge.

Remarks

The large size of this species (up to 60 mm in length), the flatness of the dorsal valve and the high

Table 3 Measurements (in mm) of *Liothyrella subcarnea* (Tate, 1880).

Specimen	Length	Width	Depth
F6113/5	32.1	26.8	–
F6802	67.7	59.0	27.8
F6804	58.8	49.6	24.2
F6807/1	47.1	43.0	25.6
F6808/1	35.2	33.3	17.5
F6808/2–3	37.1	34.8	20.6
F6811	33.7	33.1	–
F6817	20.6	19.3	10.6
F6817	24.4	22.3	12.0
F6817	28.4	25.1	13.0
F6817	19.4	19.0	10.3
F6823	40.6	–	17.8
F6825	14.2	14.8	7.2
F6825	12.8	11.6	5.8
F6825	14.7	13.1	6.3
F6844	16.9	15.1	8.6
F6845/1–5	22.1	22.5	11.9

ratio of width to length substantiate this species as different to all other recorded *Liothyrella*.

Superfamily Cancellothyroidea Thomson, 1926

Family Cancellothyrididae Thomson, 1926

Subfamily Cancellothyridinae Thomson, 1926

Genus *Murravia* Thomson, 1916

Type Species

Terebratulina davidsoni Etheridge = *Terebratulina catinuliformis* Tate.

Murravia triangularis (Tate, 1880), comb. nov.

Figure 8 H–L

1880 *Terebratulina triangularis* Tate: 160, plate 7, figures 7a–7d.

1899 *Terebratulina triangularis:* Tate: 254.

1927 *Terebratulina triangularis:* Thomson: 299.

1970 *Murravia triangularis*: Lowry: 67.

Diagnosis

Dorsal valve nearly flat, crenulation within

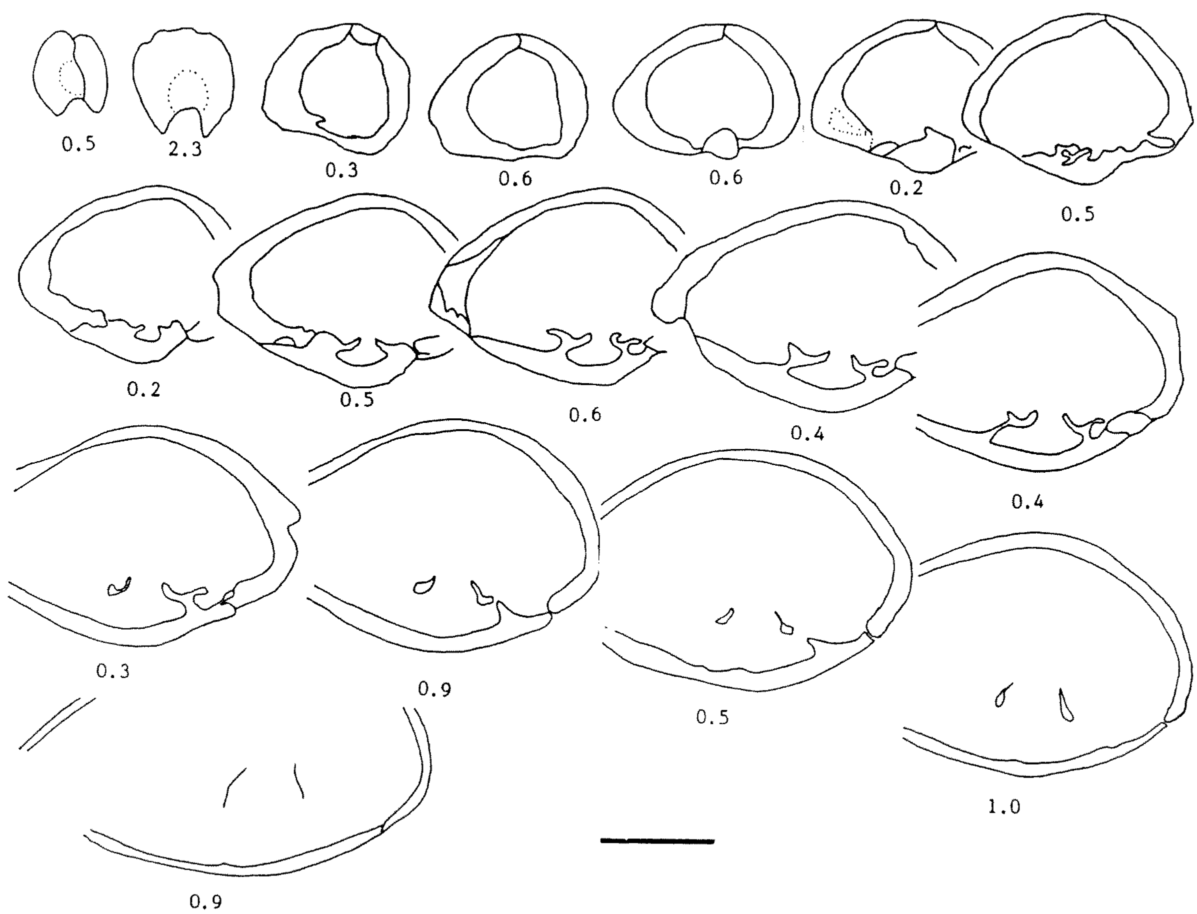


Figure 6 *Liothyrella subcarnea* (Tate, 1880). Serial section. Measurements indicate distance from last section in mm. Scale bar = 1 mm.

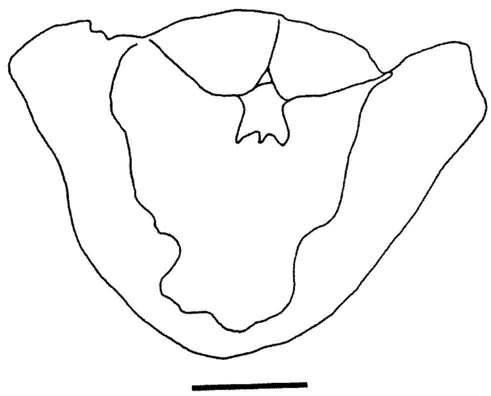


Figure 7 *Stethothyris pectoralis* (Tate, 1880). Serial section indicating shape of cardinal process. Scale bar = 1 mm.

anterior margins of both valves, hypothyrid foramen, cardinal process small, strong.

Material Examined

WAM 88.372, Cliffs at eastern end of Israelite Bay, Toolinna Limestone, Late Eocene. F6836/1–3, Abrakurrie Cave; F6837, Weebubbie Cave, 0–12.2 m below top of formation; F6831, 15.2 m below top of formation; WAM 68.324b, Murra-el-elevan Cave, Wilson Bluff Limestone, Late Eocene.

Description

Exterior. Small shell, 6.6 to 8.1 mm in length, triangular to subcircular. Ventribiconvex, dorsal valve nearly flat, depth to 32% shell length. Width at or near mid-length, 94–101% shell length. Shell costate, 6 ribs per mm at mid-length, ribs rounded, much wider than interstitial spaces, ribs bifurcate at umbo, strongly curved towards lateral margins; growth lines distinct, not prominent. Cardinal margin curved, narrow to 30% shell length; valve lateral edge bevelled, lateral margin nearly straight; valve anterior edge bevelled, anterior commissure unisulcate, sulcus nearly taking up entire width. Beak short to 12% shell length, triangular, suberect; beak ridges sharp. Foramen medium sized to 4% shell length, trapezoid to round; hypothyrid; deltidial plates disjunct, short; palintrope narrow, concave.

Interior. Ventral valve. Hinge teeth rectangular, edge narrowly triangular, cyrtomatodont, no buttressing on valve, no dental plates. Pedicle trough deep, width of valve with no thickening. Muscle scars indistinct. Some crenulations on inner margins.

Dorsal valve. Outer socket ridges wide; socket short, nearly flat. Inner socket ridge overhangs socket slightly, projecting over cardinal margin. Cardinal process slightly depressed, small, subcircular, posterior margin squared. No loop or muscle scars observed.

Table 4 Measurements (in mm) of *Murravia triangularis* (Tate, 1880).

Specimen	Length	Width	Depth
F6836/1-3	7.8	7.3	–
F6836/1-3	6.6	6.2	2.1
F6836/1-3	7.3	7.4	2.3
F6837	7.3	6.4	2.2
F6837	8.1	8.2	–

Remarks

This species was previously known as *Terebratulina triangularis*. The flat to concave dorsal valve, internal crenulations at the valve margins, hypothyrid foramen and strong cardinal process place it in the genus *Murravia* (Thomson, 1916). It is described from Blanche Point, Aldinga Cliffs and in the Bunda Cliffs, Great Australian Bight (Tate, 1880) and Castle Cove, Aire River district, Castle Cove Limestone, and Point Flinders, Browns Creek Clays, Victoria (Richardson, unpublished thesis).

Genus *Terebratulina* d'Orbigny, 1847

Type Species

Anomia retusa Linné, 1758.

Terebratulina christopheri sp. nov.
Figure 8 M–S

Diagnosis

Small to medium sized *Terebratulina*, multicostate to 5 ribs per mm; foramen large, mesothyrid.

Material

Holotype

WAM 88.852 Nanarup Lime Quarry, Nanarup Limestone, Werillup Formation, Bremer Basin.

Paratypes

WAM 94.92 0.5 km west of Nanarup Lime Quarry, WAM 94.127, Nanarup Lime Quarry, Nanarup Limestone, Werillup Formation, Bremer Basin.

Other Material

Bremer Basin: WAM 67.215, 70.176, 75.38, 75.40, 76.81, , 94.71 – 94.91, 94.93 – 94.124, 94.126, 94.170, UWA 37562, Nanarup Lime Quarry; WAM 94.93, 94.1337, 0.5 km west of Nanarup Lime Quarry; WAM 94.125, 94.805, Manypeaks Quarry, Nanarup Limestone, Werillup Formation, Bremer Basin.

WAM 67.72, 67.82, 69.200, 72.327, 78.4099, 82.3049, 82.3052 –3076, 83.2652, North Walpole, 26 km North of Walpole on Thompson Highway, Pallinup Siltstone, Werillup Formation, Bremer Basin.

UWA 23724, Plantagenet Beds, Brick pit near Albany.

UWA 7826, Warrinup Block 1874. Road east of Albany, Nanarup Limestone, Bremer Basin.

Eucla Basin: WAM 93.85, Kullinggobinya Dam, Balladonia, Pallinup Siltstone/Toolinna Limestone transition, Late Eocene.

Table 5 Measurements (in mm) of complete or nearly complete specimens of *Terebratulina christopheri* sp. nov.

Specimen	Length	Width	Depth
WAM 70.176a	25.5	16.9	10.7
WAM 70.176b	22.7	15.1	8.4
WAM 70.176c	14.1	9.2	4.8
WAM 72.327	11.5	9.7	–
WAM 75.38	22.8	16.3	–
WAM 75.40	10.1	6.7	3.9
WAM 76.81	8.6	–	2.7
WAM 78.4099a	11.5	8.5	3.6
WAM 78.4099b	4.9	4	1.6
WAM 78.4099c	8.9	6.2	3.1
WAM 78.4099d	5.8	3.9	1.9
WAM 78.4099e	15.4	–	4.7
WAM 82.3059	6.2	3.7	2.2
WAM 82.3062	3.8	2.7	–
WAM 82.3063	3.9	–	1.5
WAM 82.3064	3.6	–	–
WAM 83.2652	–	9.9	5.7
WAM 88.852	21.2	16.6	8.2
WAM 94.71	23.3	16.1	8.5
WAM 94.72	20.7	14.7	8.2
WAM 94.74		17.2	7.3
WAM 94.75	22.9	–	10.2
WAM 94.76	16.3	–	5.7
WAM 94.77	–	–	6.8
WAM 94.78	–	14.6	7.4
WAM 94.79	19.2	14.1	–
WAM 94.80	14.7	11.8	–
WAM 94.82	21.9	17.8	10.2
WAM 94.83	15.8	10.6	5.7
WAM 94.84	24.1	16.8	9.2
WAM 94.85	22.7	15.8	8.7
WAM 94.86	21	14.5	7.0
WAM 94.87	17.9	11.9	5.7
WAM 94.89	14.8	11	5.7
WAM 94.94	16.9	14.5	–
WAM 94.95	14.3	9.6	4
WAM 94.97	11.9	8.8	3.7
WAM 94.99	13.0	9.9	3.8
WAM 94.101	14.2	10.4	–
WAM 94.109	17.2	13.0	5.5
F6831	3.6	2.4	–
F6831	3.9	3.6	–
F6832	5.8	3.8	2.2
F6850	6.8	5.4	3.2
F6831	3.6	2.4	–
F6831	3.9	3.6	–

WAM 82.3065 –3076, 94.123 – 125, 170,805, 1337 specimens less than 3 mm in length.

WAM 88.183, Booanya Well, Nanambinia Station, Toolinna Limestone, Late Eocene.

F6831, Wilson Bluff, 15.3 m below top of formation; F6850, Abrakurrie Cave, F6832, Wilson Bluff Limestone, Late Eocene.

Description

Exterior. Shell pyriform to subpentagonal, small to medium, 3.6 to 24 mm long. Biconvex, both valves equally so, depth to 50% shell length. Width to 81% shell length, widest anterior to mid-length. Finely and densely punctate. Costellate, 5 ribs per mm, ribs same width as trenches, rounded, bifurcate over entire length; numerous growth lines. Cardinal margin strongly curved to triangular, acute, to 64% shell width; valves lateral edge bevelled, lateral margin straight to sigmoidal (curved upwards to dorsal valve posteriorly, down towards ventral valve centrally and up towards dorsal valve anteriorly); anterior commissure uniplicate, plication to 65% shell width. Umbo truncated; beak sub erect; beak ridges attrite. Foramen medium to large, to 7.5% shell length, round, mesothyrid. Deltidial plates small, disjunct, with lateral ridges.

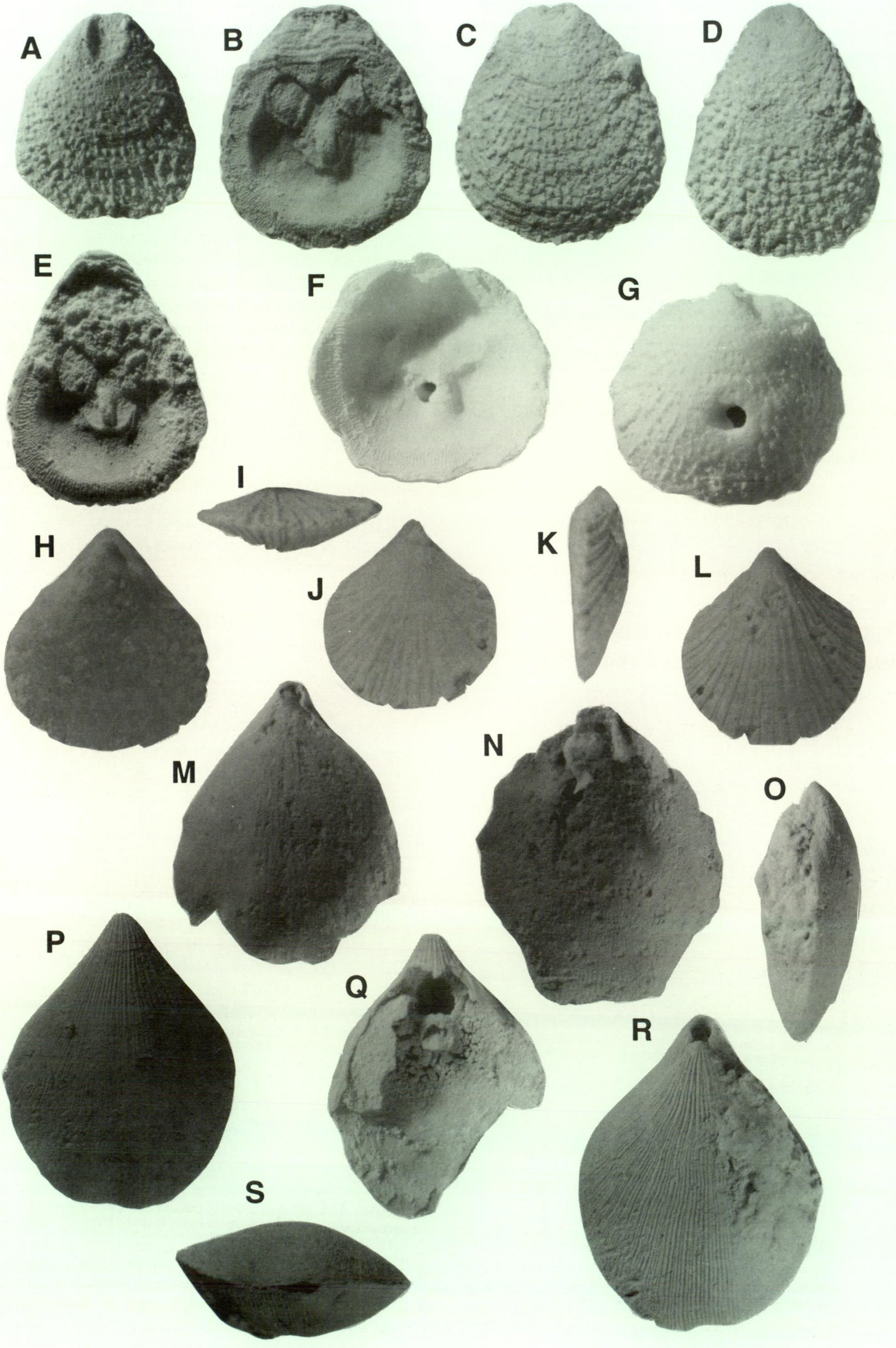
Interior. Ventral valve. Hinge teeth small, rectangular, pointed posteriorly (cyrtomatodont), groove with cardinal margin, no plates, no buttressing. Muscle scar indistinct, elongate.

Dorsal valve. Outer socket ridge thin; socket an elongate groove; inner socket ridge and outer hinge plate both fused to crural base, thin, folding over socket posteriorly producing "wings" which extend beyond cardinal margin. Crura convergent to loop, loop offset ring, transverse band with depressed arch. Cardinal process small striated cup between inner socket ridge wings.

Remarks

Small (less than 5 mm in length) specimens from the Pallinup Siltstone have relatively larger foramen (to 40% shell length) compared with small specimens (less than 5 mm) from the Nanarup Limestone (to 10% shell length).

Australian Tertiary *Terebratulina* have been generally confused taxonomically. *T. scoulari* (Tate, 1880), and *T. flindersi* Chapman, 1913 are *Cancellothyris* species due to their conjunct deltidial plates. *T. lenticularis* Tate, 1880 and *T. triangularis* Tate, 1880 are species of *Murravia* as they have a hypothyrid foramen and hinge plates. *T. suessi* Allan, 1932 and *T. ellisoni* Allan, 1932 are both described as having large submesothyrid foramen. The foramen of *T. christopheri*, although large, is mesothyrid. A new *Terebratulina* species (Craig, 1999b) from the Late Cretaceous of the Carnarvon Basin has 6 ribs per mm, bifurcation occurs anterior to the umbo and the foramen is submesothyrid. In *T. christopheri* there are 5 ribs per mm, bifurcation begins at the umbo and the foramen is mesothyrid.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T. christopheri differs from a new *Terebratulina* species from the Wadera Calcarenite (Late Paleocene), Cardabia Formation, Carnarvon Basin (Craig, 2000), which bifurcates anterior to the mid-length and has 4 ribs per mm.

Etymology

The species is named in honour of Dr Christopher J. S. De Silva, research associate at the University of Western Australia.

Suborder Terebratellidina Muir-Wood, 1955

Superfamily Terebratellioidea King, 1850

Family Laqueidae Thomson, 1927

Genus *Aldingia* Thomson, 1916

Type Species

Terebratella furculifera Tate, 1880.

Aldingia furculifera (Tate, 1880)

Figure 15 A–I

1880 *Terebratella furculifera* Tate: 161, plate 11 figures 7a–c.

1880 *Waldheimia* (?) *insolita:* Tate: 151–152.

1899 *Terebratella furculifera:* Tate: 254–255.

1916 *Aldingia furculifera:* Thomson: 501.

1927 *Aldingia furculifera:* Thomson: 230–231, figure 71a.

1970 *Aldingia furculifera*: Lowry: 67.

1973 *Aldingia furculifera:* Richardson: 121–122, plate 5, figure 9–16.

Material Examined

Bremer Basin: WAM 94.147–152, 95.443, Manypeaks Lime Quarry; WAM 94.165, Nanarup Lime Quarry; WAM 95.63, 437, Nanarup off Mount Richard Road, Paul Terry land Lot 3195; Nanarup Limestone, Bremer Basin.

WAM 82.3050, 51, Walpole North, Pallinup Siltstone, Bremer Basin.

Eucla Basin: WAM 88.370, Start of cliffs at east side of Israelite Bay, Toolinna Limestone, Late Eocene.

F 6108/4 Malcolm Scarp, 9–12.3 m below plain; F 6108/1 Malcolm Scarp, 12.3 – 15.3 m, below plain; F6112/1, 2, 6, 7, 10, 11, Toolinna, 0 – 75.4 m above the sea level; F 6113/3, 4, 5, Cockelbiddy Cave; F6114/1-3, Haig Cave, immediately below top of limestone; F6809, Abrakurrie Cave; F6851/1-7, Abrakurrie Cave, 0- 3.4 m below top of formation; F 6819/1–4, 6821, 6828, 6840, Abrakurrie Cave, 3.4 – 6.5 m Below top of formation; F 6814/1–10, 6815, Abrakurrie Cave, 24.6 – 33.8 m below top of formation; F 6818, Weebubbie Cave, 0 – 12.3 m below top of formation; F 6820/ 1–5, Wilson Bluff; F 6806/9, 6810, 6824/1–4, 6843, 2 km east of Wilson Bluff; F 6826/1–2, Toolinna Cave, 24.6 m above sea level; F 6845/1–5, Mullamullang Cave; WAM 62.70, C. Days property, 425 km east of Kalgoorlie; Wilson Bluff Limestone, Late Eocene.

F 6822/1–3, Madura, 12.9 km north of Firestick Cave; WAM 68.349, Toolinna Cliffs; Abrakurrie Limestone, Early Miocene.

Description

Exterior. Shell ovate to subcircular, medium-sized to 6.6 to 33.6 mm long. Biconvex, dorsal valve flatter in some specimens, depth to 55% shell length. Width greatest at mid-length to 100% shell length. Smooth, growth lines fine, very fine and dense punctae. Cardinal margin to 50% shell width, strongly curved; valves lateral edge bevelled, lateral margin gently sigmoidal; anterior valve edge bevelled, anterior commissure rectimarginate. Umbo strong, beak erect to slightly incurved; beak ridges rounded. Foramen large to 10% shell length, round, submesothyrid; deltidial plates conjunct in most cases. Symphytium low, narrow, slightly convex.

Interior. Ventral valve. Hinge teeth relatively small, triangular (deltidiodont) with curve to the posterior; swollen bases to margin and in some cases to valve floor. Pedicle trough fairly narrow. Median ridge developed from base of trough and extending to mid-length. Elongate muscle scars either side of ridge.

Dorsal valve: Outer socket ridge narrow. Socket triangular with posterior roof, floor swollen to lateral margin. Inner socket ridge curved over socket, base slightly swollen. Crura divergent, bases fused to inner socket ridge, slightly swollen. Hinge trough formed from union of inner hinge plates,

◀ **Figure 8** **A-F**, *Westralicrania zenobiae* Craig, 1997. **A**, WAM 94.33, paratype, ventral valve exterior. **B-C**, WAM 94.36, paratype. **B**, ventral valve interior; C, ventral valve interior. **D-E**, WAM 94.37, paratype. **D**: ventral valve exterior; **E**, ventral valve interior. **F-G**, WAM 88.373. **F**, dorsal valve interior; **G**, dorsal valve exterior. All x 5. **H-L**, *Murravia triangularis* (Tate, 1880) **H**, F6836b, ventral valve interior. **I-L**, F6836a. **I**, anterior commissure; **J**, dorsal valve exterior; **K**, lateral margin; **L**, ventral valve exterior. All x 5. **M-S**, *Terebratulina christopheri* sp. nov. **M**, WAM 94.92, paratype, ventral valve interior x 3; **N**, WAM 94.127b, paratype, dorsal valve interior x 3. **O**, **P**, **R**, **S**, WAM 88.852, holotype. **O**, lateral margin x 2; **P**, ventral valve exterior x 2.5; **R**, dorsal valve exterior x 3; **S**, anterior commissure x 3. **Q**, WAM 94.92b, paratype, dorsal valve interior x 3.

Table 6 Measurements (in mm) of complete or nearly complete specimens of *Aldingia furculifera* (Tate, 1880).

Specimen	Length	Width	Depth
F 6108/1	17.4	16.4	-
F 6112/1	25.5	22.9	13.5
F 6112/1	25.8	23.0	12.0
F 6112/1	26.1	23.4	12.0
F 6112/1	26.2	21.7	12.9
F 6112/1	28.5	23.4	16.8
F 6112/1	28.7	26.0	14.7
F 6112/1	29.0	27.6	14.7
F 6112/1	29.5	25.3	13.9
F 6112/1	30.1	28.3	-
F 6112/1	33.6	28.7	16.4
F 6112/10	19.9	16.8	8.7
F 6112/10	20.1	18.1	9.6
F 6112/10	21.0	18.1	9.9
F 6112/11	23.7	19.2	13.1
F 6112/2	18.6	19.0	9.1
F 6112/2	21.7	19.4	-
F 6112/2	21.8	17.9	10.9
F 6112/2	22.1	18.3	11.4
F 6112/2	23.0	19.2	10.3
F 6112/2	24.6	21.0	12.5
F 6112/2	26.5	22.3	14.7
F 6112/6	28.5	25.1	12.2
F 6112/6	33.1	28.4	15.0
F 6112/7	22.8	17.8	11.8
F 6113/3	15.3	13.4	6.6
F 6113/3	20.6	17.9	-
F 6113/3	22.4	19.0	11.6
F 6114/1	19.1	15.1	10.2
F 6114/1	23.0	17.0	11.2
F 6114/1	24.2	18.4	11.8
F 6114/2	29.8	25.8	-
F 6114/3	19.8	17.9	10.0
F 6818/1–2	20.3	18.1	9.3
F 6818/1–2	26.3	22.6	11.5
F 6822/1–3	15.1	13.6	6.6
F 6824/1–4	17.5	17.1	6.4
F 6826/1–2	22.9	22.5	10.6
F 6826/1–2	26.7	24.6	13.8
F 6828	6.6	6.6	2.5
F 6828	8.4	8.3	3.2
F 6840	21.8	17.6	10.8
F 6843	25.0	22.4	-
F 6845/1–5	18.4	15.3	9.2
F 6845/1–5	20.2	16.7	10.1
F 6845/1–5	21.2	17.8	-
F 6845/1–5	24.5	20.3	-
F 6851/1–7	12.2	10.7	4.7
F 6851/1–7	12.4	10.6	5.5
F 6851/1–7	14.5	12.7	6.3
F 6851/1–7	16.5	14.6	-
WAM 94.147	23.0	21.0	11.1
WAM 94.148	21.5	17.0	8.5
WAM 94.149	17.7	16.0	7.0
WAM 94.150	16.9	15.2	7.1
WAM 94.151	22.1	18.1	9.2
WAM 94.152	22.5	21.5	10.0

connects with bifurcating median septum. Median septum blade-like, higher posteriorly than anteriorly, extends to mid-length or just posterior to it. Cardinal process incipiently raised triangular posteriorly located in hinge trough. Serial grinding indicates teloform (magellaniform) type loop, extends to mid-length.

Remarks

Aldingia furculifera has been described from the Tortachilla Limestone (Eocene) and the Blanche Point Marl (Eocene), Maslin Bay, and Christies Beach, Aldinga, South Australia, the Wilson Bluff Limestone (Late Eocene), Bunda Cliffs, Great Australian Bight, Western Australia, the Browns Clay Limestone (Eocene), Aire, Johanna River, the Castle Cove Limestone (Eocene), Aire, the Aire Clay (Eocene), Aire and the Calder River Limestone Aire coast, Glen Aire in Victoria (Richardson, 1973a). Chapman and Crespin (1934) describe *Terebratula aldingae* from the Plantagenet Beds, Norseman, Western Australia. It is most likely to be this species, although the description is very brief.

Family Terebratellidae King, 1850

Subfamily Terebratellinae King, 1850

Genus *Austrothyris* Allan, 1939

Type Species

Waldheimia gambierensis Thomson, 1918.

Austrothyris grandis (Tate, 1880)

Figure 15 J–K

1865 *Waldheimia grandis* Tenison-Woods: 2, figure 1.

1876 *Waldheimia gambierensis:* Etheridge: 19, plate 2, figures 4a–d.

1880 *Waldheimia grandis:* Tate: 152, plate 11, figures 3 and 4.

1927 *Magellania grandis:* Crespin and Chapman in Thomson: 301

1939 *Austrothyris grandis:* Allan: 239–240, plate 29, figures 1–3, plate 30, figure 4.

1999 *Austrothyris grandis*: Craig: 456–458, figure 4A–F.

Material Examined

F6109/4, Madura – 12.8 km North Cave; WAM 62.158, Swallow Cave, Cocklebiddy Station; Wilson Bluff Limestone, Late Eocene.

Description

Exterior. Dorsal valve only. Convex, ovate,

Table 7 Measurement (in mm) of *Austrothyris grandis* (Tate, 1880).

Specimen	Length	Width
F6109/4	50.2	38.6
WAM 62.158	52.7	37.7

multiplicate anteriorly. Growth lines distinct, ovate punctae fine and dense. Cardinal margin curved; valves lateral edge rounded, lateral margin straight or nearly so, incomplete; anterior edge roundly crenulate, anterior commissure rectimarginate, incomplete.

Interior. Interior unavailable due to matrix. Median septum partially visible on weathered specimen, extends to mid-length, blade-like, no swollen base anteriorly, thickens posteriorly.

Remarks

Although only two partial brachial valves were available for identification, the size, plication and straight lateral and anterior margins are quite distinctive.

The species is recorded from Mount Gambier and the Murray River cliffs of South Australia (Allan, 1939). It is found in deposits of Early Miocene age. This is the earliest record of the species in Australia.

Genus *Diedrothyris* Richardson, 1980

Type Species

Waldheimia (?) johnstoniana Tate, 1880.

Diedrothyris johnstoniana (Tate, 1880)
Figure 11 A–D

1880 *Waldheimia (?) johnstoniana* Tate: 151, plate 8, figure 9a–b.

1880 *Waldheimia (?) fimbriata:* Tate: 150–151, plate 8, figure 2a–b.

1899 *Magellania johnstoniana:* Tate: 253.

1899 *Magellania (?) fimbriata:* Tate: 252.

1927 *Magellania (?) fimbriata:* Thomson: 295.

1970 *Magellania fibriata*: Lowry: 67.

1980 *Diedrothyris johnstoniana:* Richardson: 49, plate 11, figure 9–16.

Material Examined

WAM 74.42, 94.142–145, Nanarup Lime Quarry, Nanarup; WAM 95. 438, Nanarup off Mount Richard Road, Paul Terry Land, Lot 3195; Nanarup; WAM 94.161, Manypeaks Lime Quarry; Nanarup Limestone, Bremer Basin.

Table 8 Measurements (in mm) of complete or nearly complete specimens of *Diedrothyris johnstoniana* (Tate, 1880).

Specimen	Length	Width	Depth
WAM 74.42	23.5	17.1	11.9
WAM 94.142	22.9	16.3	12.4
WAM 94.143	23.4	19.2	11.4
WAM 94.144	23.0	20.5	13.9
WAM 94.145	24.2	17.4	12.8
WAM 95.438	21.8	18.0	9.5

Description

Exterior. Shell ovate to subpentagonal, medium-sized 21.8 to 24.2 mm long. Biconvex, both valves equally so, depth to 57% shell length. Widest at or near mid-length, width to 80% shell length. Finely and densely punctate, growth lines prominent, multiplicate marginally, wide keel in ventral valve. Cardinal margin wide, strongly curved; valves lateral edge bevelled to rounded, lateral margin sigmoidal shaped, crenulate anterior half of valves; anterior valve edge bevelled, anterior commissure rectimarginate to incipiently unisulcate, sulcus angular, crenulate (multiplicate) with 5 plicae per 10 mm. Umbo strong, beak suberect; beak ridges attrite to sharp. Foramen large to 7% shell length, mesothyrid; deltidial plates conjunct. Symphytium narrow.

Interior. (From serial grinding) Median septum extends to mid-length, long. Possibly teloform (magellaniform) loop extending to mid-length.

Remarks

Richardson (1980) describes the species from the Late Eocene Tortachilla Limestone south eastern Australia. The specimens described above are consistent with her description. The species is also possibly present in the Late Paleocene Cardabia Formation of the Carnarvon Basin, north west Western Australia (Craig, 2000).

Diedrothyris plicata Richardson, 1980
Figure 11 E–G

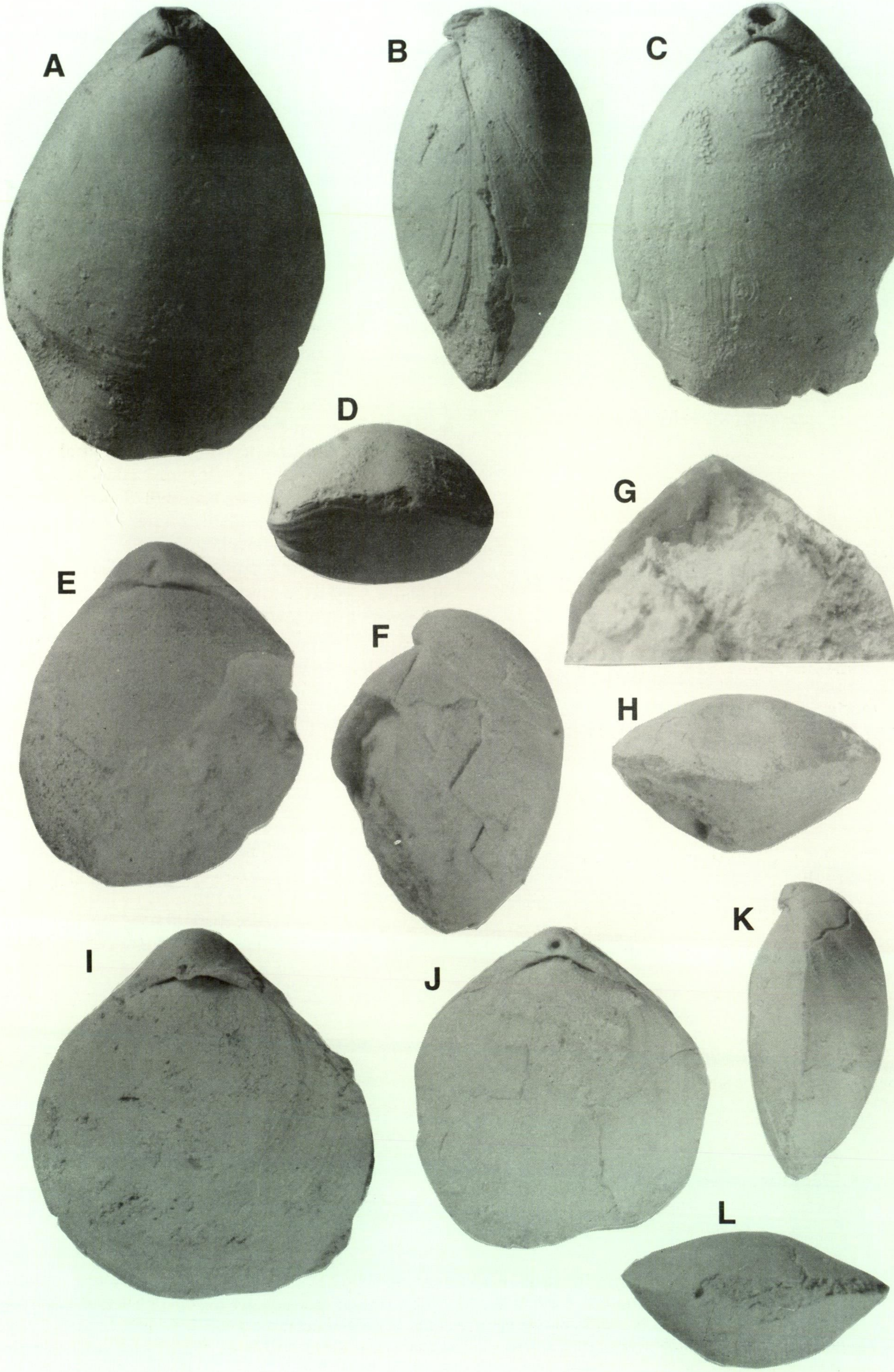
1910 *Magellania garibaldiana:* Pritchard: 90, figure 20

1955 *Magellania garibaldiana:* Gill and Baker: 39–43, plate 1, figure 1.

1980 *Diedrothyris plicata* Richardson: 50–51, plate 11, figures 20–25.

Material Examined

WAM 88.185, Booanya Well, Nanambinia Station, Toolinna Limestone, Late Eocene. F6109/2, Madura, 12.9 km North Cave; F6112/4 Toolinna, 0–75 m above sea level; Wilson Bluff Limestone, Late Eocene.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Description

Exterior. Medium sized shell to 25.7 mm long. Oval to subcircular, widest at mid-length, width to 77% shell length. Biconvex, both valves nearly equal, depth greatest at mid-length, depth to 53% shell length. Shell plicate, plicae extending from umbo, more pronounced centrally, growth lines numerous, distinct, finely and densely punctate, punctae ovate. Strong double fold in centre of keel on ventral valve. Cardinal margin curved, to 60% shell width; valves lateral edge gently bevelled, lateral margin with slight sigmoidal curve, crenulate from just posterior to mid-length; anterior commissure unisulcate, crenulate (multiplicate). Umbo strong, truncate; beak suberect, with slight lip; beak ridges gently rounded. Foramen medium to large to 6.5% of shell length, mesothyrid. Deltidial plates conjunct, symphytium medium width and depth, slightly convex with wide ribs. No internal parts accessible.

Remarks

Richardson (1980) describes the species from Late Oligocene to Middle Miocene deposits in Victoria and Tasmania. This is the earliest record of the species and the first from Western Australia.

Genus *Victorithyris* Allan, 1940

Type Species

Victorithyris peterboroughensis Allan, 1940.

Victorithyris divaricata (Tate, 1880)
Figure 10 A–D

1880 *Waldheimia* (?) *divaricata* Tate: 149, plate 8, figures 8a–b.

1970 *Magellania divaricata*: Lowry: 86.

1980 *Victorithyris divaricata:* Richardson: 47–48, plate 10, figure 16.

Material Examined

F5542/1, Twilight Cove; F6111/2, Murra-el-elevyn Cave; Wilson Bluff Limestone, Late Eocene.

F6857, Tommy Graham's Cave, 30.5–36.6 m below surface, Abrakurrie Limestone, Early Miocene.

Description

External. Medium-sized ovate to sub-circular shell, 15.7 to 23.3 mm long. Biconvex, greatest depth at mid-length, depth to 64% shell length. Width greatest at mid-length, width to 87% shell length. Shell finely and densely punctate, growth lines prominent especially anteriorly; plicate, two ribs per mm at mid-length, plicae triangularly rounded. Cardinal margin curved, to 74% shell width; valves lateral edge rounded to impressed, lateral margin straight, crenulate; anterior valve edge rounded to flat, anterior commissure unisulcate, crenulate. Umbo stout, beak suberect, thin lip present; beak ridges rounded. Foramen medium-sized, 3.7% shell length, mesothyrid. Deltidial plates conjunct, symphytium wide, concave with swollen mid-section.

Table 9 Measurements (in mm) of *Victorithyris divaricata* (Tate, 1880)

Specimen	Length	Width	Depth
F5542/1	15.7	10.4	9.7
F6857	16.6	11.5	8.7
F6111/2	23.3	20.2	14.9

Remarks

Victorithyris divaricata is described from the Mannum Formation of Early Miocene age in South Australia (Richardson, 1980). This is the earliest record of the species and the only record from Western Australia.

Victorithyris garibaldiana (Davidson, 1862)
Figure 10 E–K

1833 *Terebratula* sp. Sturt: 254, plate 3, figure 15

1862 *Terebratula compta:* Tenison-Woods: 74.

1862 *Waldheimia garibaldiana* Davidson: 446, plate 24, figure 9.

1865 *Waldheimia imbricata* Tenison-Woods: 2, figures 3a–b.

1876 *Waldheimia garibaldiana:* Etheridge: 17,18, plate 1, figures 2a–b.

1877 *Waldheimia macropora* McCoy: plate 43, figures 4, 6.

1880 *Waldheimia garibaldiana:* Tate: 146–148, plate 11, figures 1a–c.

1899 *Magellania garibaldiana:* Tate: plate 252.

1927 *Magellania garibaldiana:* Thomson: 295.

◀ **Figure 9** A-D, *Liothyrella labiata* sp. nov. **A, B, D**, WAM 94.61, holotype. **A**, dorsal valve exterior x 2.5; **B**, lateral margin x 2; **D**, anterior commissure x 2. **C**, WAM 94.62, paratype, dorsal valve exterior x 2.5. **E-H**, *Liothyrella bulbosa* (Tate, 1880). **E-F**: F6810. **E**, dorsal valve exterior x 1.5; **F**, lateral margin x 1. **G**, F6812, ventral valve interior x 1. **H**, F6830, anterior commissure x 1. **I-L**, *Liothyrella subcarnea* (Tate, 1880) **I**, F6807/1, dorsal valve exterior x 1.5. **J-L**, F6808/1. **J**, dorsal valve exterior x 1.5; **K**, lateral margin x 1.5; **L**, anterior commissure x 1.5.

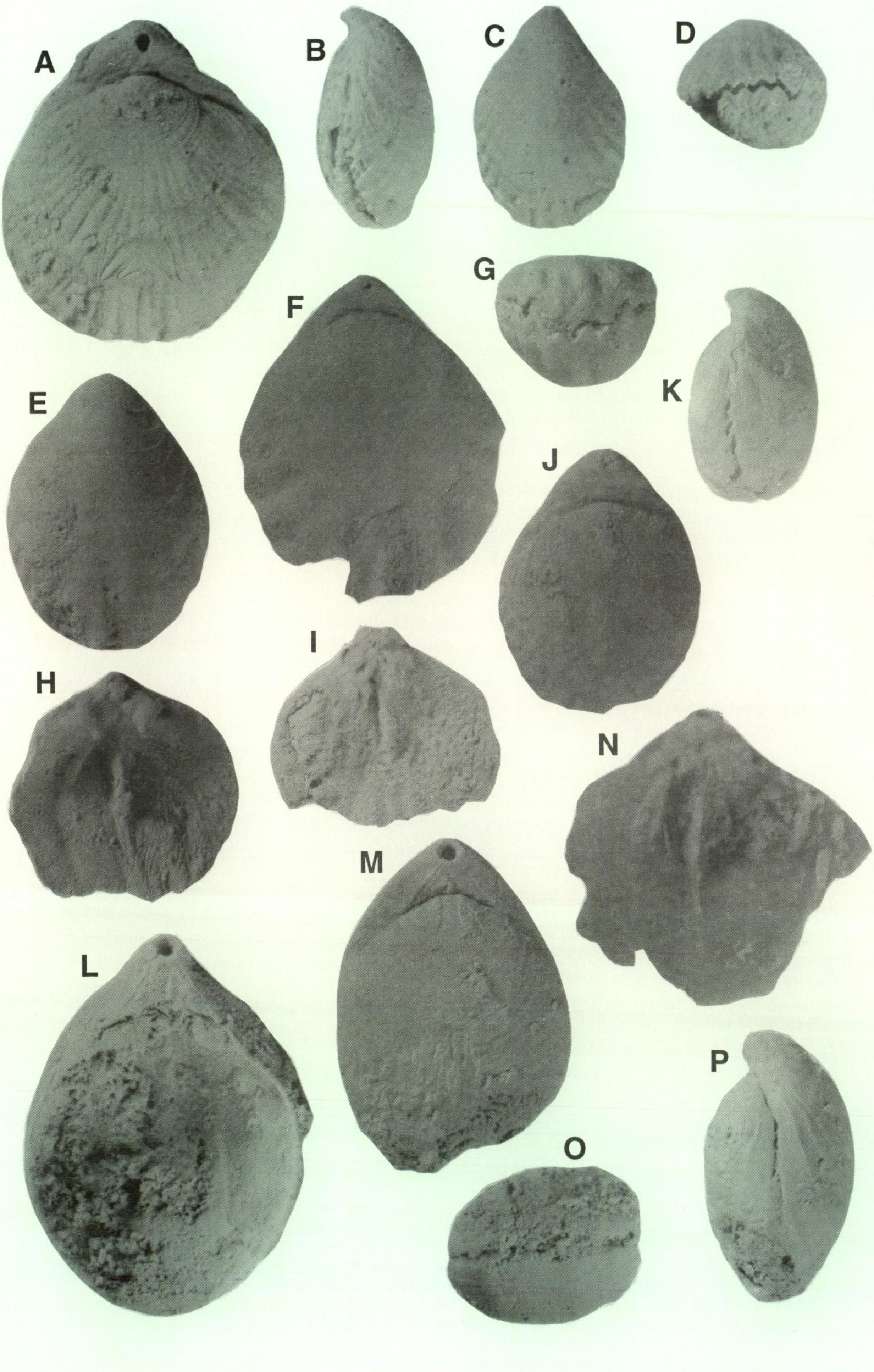
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Table 10 Measurements (in mm) of *Victorithyris garibaldiana* (Davidson, 1862).

Specimen	Length	Width	Depth
WAM 68.1424	23.8	18.5	9.8
F 6108/5	15.8	12.3	8.4
F6109/3	20.3	14.5	13.0
F6109/3	15.7	11.1	9.6
F6109/3	7.9	5.3	5.2
F6110/3	17.9	13.7	12.4
F6110/4	17.6	14.9	8.9
F6111/6	22.0	17.5	13.4
F6111/6	22.0	17.1	13.0
F6846	21.0	16.3	13.1
F6848	25.0	19.7	13.1
F 6852 (BV)	14.3	12.6	–
F6853 (BV)	13.2	13.6	–
F6853 (BV)	16.1	14.3	–
F6854	16.9	14.0	9.4
F6855 (PV)	15.4	13.4	–
F6855	15.3	12.8	7.1
F6856/1–2	16.4	12.9	9.0
F6856/1–2	17.3	13.2	9.5

1970 *Magellania garibaldiana*: Lowry: 67, 86.

1980 *Victorithyris garibaldiana:* Richardson: 45–47, plate 10, figures 1–15.

Material Examined

Eucla Basin: WAM 68.1424, F6856/1–2, Mullamullang Cave; F 6108/5, Malcolm Scarp, 12.3 – 15.4 m below plain; F6109/3, F6846, F6847, F6852–55 Madura, 12.9 km north of Firestick Cave; F6110/3,4, Madura, 9.6 km, South Cave; F6111/1, 6, Murra-el-elevyn Cave; F6113/2 Cocklebiddy Cave; F6848, Abrakurrie Cave; Wilson Bluff Limestone, Late Eocene.

Description

External. Small to medium-sized shell from 7.9 to 25 mm long; ovate to subcircular. Ventribiconvex; depth greatest at mid-length, depth to 66% shell length. Widest slightly posterior to mid-length; width to 89% shell length. Shell multiplicate, plicae arising shallowly posterior to umbo, deepening anteriorly and antero-laterally; width of interstitial spaces variable; plicae rounded; shallow sulcus in dorsal valve of some specimens; finely and densely punctate, punctae egg shaped, widest anteriorly; growth lines numerous and distinct. Cardinal margin gently to strongly curved, ventral umbo prominent in some specimens, width to 90% shell width; valves lateral edge rounded, lateral margin straight to anterior then curved towards ventral valve, crenulate anterior to mid-length; valves anterior edge rounded, anterior commissure unisulcate, sulcus shallow to deep, narrow (33% shell width) to wide (62% shell width); crenulate. Umbo stout, truncate, beak suberect, with slight lip; beak ridges rounded. Foramen medium-sized to 5% shell length, mesothyrid. Deltidial plates conjunct, symphytium medium width and depth, grooved, convex within groove margins; palintrope narrow.

Internal. Outer socket ridges thin marginally, swollen under socket. Socket triangular, floor curved, no roof. Inner socket ridge swollen, fused to outer hinge plate and crural bases in some specimens. Swollen bases protuberant over cardinal margin. Crural bases thickened posteriorly, not swollen. Inner hinge plates small, united to form shallow trough. Median septum blade-like, extends to anterior to mid-length, base thickens posteriorly and again anteriorly. Cardinal process small protuberant striated depressed "dish" within swollen bases of cardinalia, swollen boss under process. Loop incomplete, transverse bands appear to connect to median septum anteriorly. Muscle scars in sunken floor anterior to cardinal area, sharp posteriorly widening into ovate depressions.

Remarks

Richardson (1980) described *Victorithyris garibaldiana* from early to late Miocene deposits in South Australia, Tasmania and Victoria. This is the earliest record of the species and the first from Western Australia.

Victorithyris tateana (Tate, 1880)

Figure 10 L–P

1880 *Waldheimia tateana* Tate: 150, plate 7, figures 6a–b, plate 8, figures 6 a–c, plate 9, figure 2.

1899 *Magellania tateana:* Tate: 233.

1970 *Terebratula tateana*: Lowry: 86.

1980 *Victorithyris tateana:* Richardson: 48, plate 11, figures 1–8.

Material Examined

Bremer Basin: WAM 76.82, 67.214, 94.156, 94.164, 95.441 Nanarup Lime Quarry, Nanarup, Nanarup Limestone, Bremer Basin.

◀ Figure 10 A-D, *Victorithyris divaricata* (Tate, 1880). **A**, F6111/2, dorsal valve exterior. **B-D**, F6857. **B**, lateral margin; **C**, ventral valve exterior; **D**, anterior commissure. All x 2. **E-K**, *Victorithyris garibaldiana* (Davidson, 1862). **E, G, J, K**, F6847. **E**, ventral valve exterior x 2.5; **G**, anterior commissure x 2; **J**, dorsal valve exterior x 3; **K**, lateral margin x 2. **F**, F6848, dorsal valve exterior x 2.5. **H**, F6853, dorsal valve interior x 3. **I**, F6113, dorsal valve interior x 3.**L-P**, *Victorithyris tateana* (Tate, 1880). **L**, F6112/12b, ventral valve interior x 2.5. **M, O, P**, F6112/12a. **M**, dorsal valve exterior x 2.5; **O**, anterior commissure x 2.5; **P**, lateral margin x 2.5. **N**, F6814, dorsal valve interior x 4.

Table 11 Measurements (in mm) of complete or nearly complete specimens of *Victorithyris tateana* (Tate, 1880).

Specimen	Length	Width	Depth
WAM 67.214	13.9	9.3	7.1
WAM 76.82	10.1	6.7	4.8
WAM 94.156	25.0	-	-
WAM 94.164	incomplete 14.5	-	-
WAM 95.441	incomplete 11.4	8.5	6.5
WAM 88.184	14.8	11.5	-
WAM 88.184	15.7	10.5	-
F6108/2	16.1	12.4	8.3
F6108/3	18.2	12.2	9.9
F6110/1	27.1	22.8	12.7
F6110/2	24.3	19.3	12.5
F6112/3	19.6	13.8	11.5
F6112/3	16.0	11.0	7.8
F6112/8	17.1	11.6	9.4
F6112/9	14.9	12.0	7.7
F6112/12	23.0	16.9	12.0
F6112/12	22.2	16.5	-
F6112/12	23.9	16.5	13.5
F6112/12	19.8	13.9	11.3
F6112/12	23.2	17.4	-
F6112/12	17.8	13.7	10.0
F6112/12	17.0	12.2	8.9
F6112/12	19.8	14.0	11.4
F6112/12	19.3	15.1	9.2
F6114/4	17.5	13.5	9.1
F6114/4	18.6	14.9	8.5
F6114/5	14.2	10.4	7.0
F6814/1–10	31.5	25.9	17.0
F6849	27.9	23.0	16.0
F6869/1–8	21.2	15.5	12.0
F6869/1–8	14.0	11.6	7.2

Eucla Basin: WAM 88.184, Booanya Well, Nanambinia Station, Toolinna Limestone, Late Eocene.

F6108/2, F6108/3, Scarp, 9.2–12.2 m below plain; F6110/1,2, WAM 62.51, Cave 10 km south of Madura; F6112/3, F6112/8, F6112/9, Toolinna; F6112/12, Toolinna, 0– 74.7 m above sea level; F6114/4,5, Haig Cave, immediately below formation; F6814, Abrakurrie Cave, 23–26 m below to of formation; F6849, Wilson Bluff; WAM 66.1418, Madura, 13 km North Cave; Wilson Bluff Limestone, Late Eocene.

F6869/1–8, 10 km north of Firestick Cave, 6–9 m below top of formation, Abrakurrie Limestone, Early Miocene.

Description

Exterior. Elongate oval 10 to 25 mm long. Biconvex, depth greatest posterior to mid-length to 59% shell length. Narrow, greatest width near mid-length, width to 80% shell length. Shell smooth, growth lines distinct, finely and densely punctate. Cardinal margin strongly curved; lateral valve edges rounded, lateral margin nearly straight to slightly curved to ventral valve posteriorly; anterior valve edge gently rounded, anterior commissure rectimarginate. Umbo strong, beak suberect; beak ridges rounded. Foramen round 4% to 6% shell length, mesothyrid; deltidial plates conjunct. Symphytium high in small to low in larger specimens, narrow, convex.

Interior. Ventral valve. Pedicle collar narrow, sessile. Hinge teeth thin wide, triangular, gently curved, grooved to fit socket; no dental plates. Muscle scars elongate; series of ribs on valve floor extending anterior to mid-length.

Dorsal valve. Socket unclear; inner socket ridge overhangs socket. Outer hinge plate narrow; crural base not swollen. Inner hinge plates form shallow trough widening posteriorly, plates widen than join with bifurcated septum. Median septum extends beyond mid-length, bifurcates posteriorly to join hinge trough. Cardinal process overhangs trough, slightly depressed thin round transverse plate. Muscle scars obscured.

Remarks

Victorithyris tateana is described from the Tortachilla Limestone (Late Eocene), Maslin Bay, Aldinga, from Port Noarlunga and Stansbury, Yorke Peninsula in South Australia as well as Castle Cove Limestone (Late Eocene – Early Oligocene), Calder River Limestone and the Glen Aire Clays in Victoria (Richardson, 1980). Chapman and Crespin (1934) described a specimen of this species from the Plantagenet Beds, Albany, Western Australia.

Genus *Neothyris* Douville, 1879

Type Species

Terebratula lenticularis Deshayes, 1839.

Neothyris rylandae Craig, 1999

Figures 13 G–J, 14 A–C

1999 *Neothyris rylandae* Craig: 267–275, figures 3 A–F, 4 A–C.

Material Examined

Holotype

WAM 82.2368; Roe Plains, Madura district, Wester Australia, Pit 1.5 km N of Hampton Microwave Repeater Tower. Basal 0.4 m carbonate sand.

Paratypes

WAM 69.382; Roe Plain, 25 miles east of Madura-south side of Eyre Highway. Bulldozed pit approx. 3 m deep.

WAM 75.178, WAM 76.2480; Roe Plain, Eucla Basin, Quarries beside road from Eyre Highway to Hampton Microwave Tower.

WAM 82.2367, 82.2369, 82.2370, 82.2372, 82.2373, 82.2378; Roe Plains, Madura district, W. A. Pit 0.5 km N of Hampton Microwave Repeater Tower. Basal 0.6 m carbonate sand.

WAM 85.2026, 82.2374, 82.2376, 82.2377, 82.2379 – 82.2388; Roe Plains, Madura district, W. A., Pit 1.5 km N of Hampton Microwave Repeater Tower: spoil heaps near base of tower.

Remarks

The material above is fully described in Craig, (1999a). There is no revision to the original descriptions.

Subfamily Stethothyridinae MacKinnon, Beus and Lee, 1993

Genus *Stethothyris* Thompson, 1918

Type Species

Stethothyris uttleyi Thompson, 1918.

Remarks

Allan (1940) suggested that Australian species placed in the genus *Stethothyris* were actually *Victorithyris*. Richardson (1980) reinstated *Stethothyris* based on the studies of the growth stages. MacKinnon *et al.* (1993) considered the name *Stethothyris* acceptable. Hiller and MacKinnon (in press) consider that the "more elaborate cardinal process, more strongly incurved beak, greater overall inflation of the valves and more elaborate commissure folding" place *Stethothyris pectoralis* in the new genus.

Stethothyris pectoralis (Tate, 1880)

Figures 7, 11 H–M, 12 A–C

1880 *Waldheimia pectoralis* Tate: 157, plate VII, figures 1a–d.

1899 *Magellania pectoralis:* Tate: .253.

1918 *Stethothyris pectoralis:* Thomson: 25, plate XVII, figure 60.

1940 *Victorithyris pectoralis:* Allan: 292, plate XXXV, figure 3.

1970 *Victorithyris pectoralis*: Lowry: 67, 86.

1980 *Stethothyris pectoralis:* Richardson: 43.

1996 *Stethothyris pectoralis:* Brunton *et al.*: figure 16 A and B.

Material

Bremer Basin: WAM 67.201, 67.213, 69.231, 70.175, 94.132 – 141, 94.167, 99.312 Nanarup Lime Quarry; WAM 94.128 – 94.131, 95.439 0.5 km west of Nanarup Lime Quarry; WAM 95.602, 95.603 Manypeaks Quarry; Nanarup Limestone, Werillup Formation, Bremer Basin.

UWA 16660 Plantagenet Beds, Cape Riche.

Eucla Basin: F6113/1, Cockelbiddy Cave, 44.2–70.2 m below top of formation, F6809/8–9, F6814/1–10, Abrakurrie Cave; F6817/1–21, Abrakurrie Cave, 0–3.4 m below to of formation; F6811/1–2, Abrakurrie Cave, 3.4–6.4 m below top of formation; F6816, Abrakurrie Cave, 24.4–27.5 m below top of formation; F6810, Wilson Bluff; Wilson Bluff Limestone, Late Eocene

Description

Exterior. Shell subcircular; medium to large to 62.9 mm long. Ventribiconvex, depth to 79% shell length. Width to 87% shell length, widest at mid-length. Finely and densely punctate, growth lines numerous, distinct, sulcus in dorsal valve from dorsal umbo divergent to anterior commissure, keel in ventral valve from ventral umbo. Cardinal margin curved, to 42% shell width; valves lateral edge bevelled, lateral margin convex with respect to dorsal valve; anterior commissure unisulcate, sulcus to 60% shell width. Umbo stout, suberect to erect; beak ridges attrite. Foramen small, 2% shell length, round, permesothyrid; deltidial plates conjunct. Symphytium, striated longitudinally, raised under beak, concave either side of raised area, takes up majority of interarea.

Interior. Ventral valve. Pedicle collar short, sessile, pedicle opening narrow tube, shell thickened either side. Cardinal area thick. Hinge teeth relatively small, triangular, rounded apex, curved posteriorly (deltidiodont), buttressed with swollen bases, deep groove between teeth and cardinal margin. Series of low ridges emanating from pedicle opening, extend to beyond mid-length. Muscle scars indistinct; shell thickened posteriorly thinning anterior to mid-length.

Dorsal valve. Outer socket ridge as thick as margin; socket small, triangular. Inner socket ridge overhangs socket posteriorly, swollen, fused to outer hinge plate and crural base; slight groove between inner socket ridge and outer hinge plate. Crural base swollen posteriorly. Inner hinge plates fused, transect centre of cardinal area, narrow, extend to upper platform on median septum, posterior extension to cardinal process. Median septum short, low, blade-like, rises, base swells posteriorly, fused to hinge platform. Muscle scars shallow elongate trenches either side of septum. Cardinal process small deep rimmed trilobed cup.

Remarks

This species is described from Eocene Tortachilla Limestone, Blanche Point Cliff, Aldinga and Happy

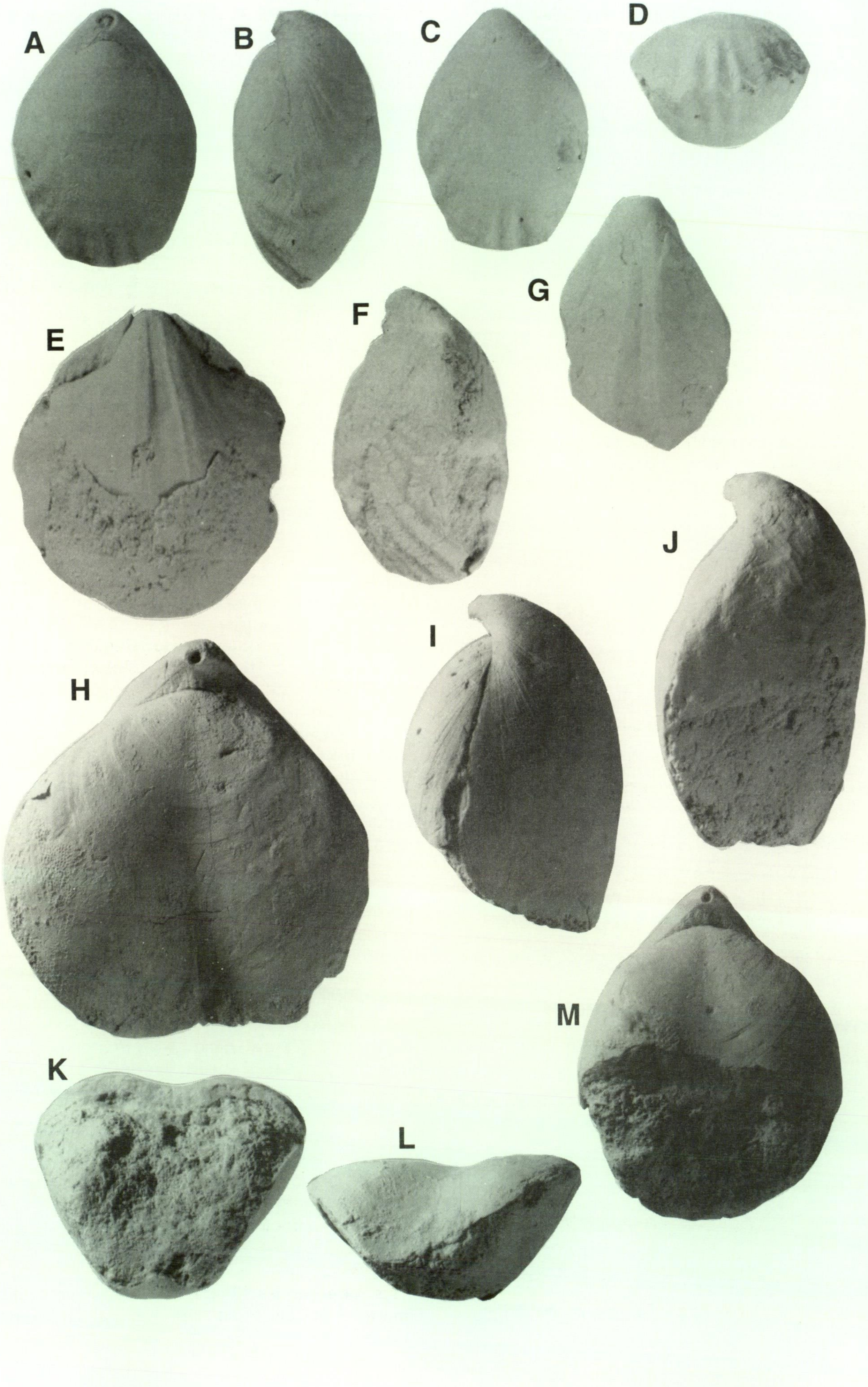
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Table 12 Measurements (in mm) of complete or nearly complete specimens of *Stethothyris pectoralis* (Tate, 1880).

Specimen	Length	Width	Depth
WAM 67.201	–	37.9	28.3
WAM 69.231a	35.8	31	18.4
WAM 69.231b	–	32.2	19.7
WAM 70.175	–	38.6	27.3
WAM 94.128	44.9	33.3	–
WAM 94.129	–	39.9	28.0
WAM 94.133	–	34.5	–
WAM 94.138	43.1	32	26.6
WAM 99.312	44.4	38.3	19.7
UWA 16660	38.2	34.4	–
F68811/1–2	25.8 (part only)	36.0	–
F6814/1–10	31.0	–	–
F6113/1	62.9	49.0	36.1
F6816	44.4	30.9	27.5

Valley, South Australia (Tate, 1880; Allan, 1940) as well as the Tortachilla Limestone, Maslin Bay, Aldinga (Hiller and MacKinnon in press). Chapman and Crespin (1934) describe a specimen of this species from the Plantagenet Beds, Cape Riche, Western Australia.

Stethothyris sufflata (Tate, 1880)
Figure 12 D–F

1880 *Waldheimia sufflata* Tate: 157–8, plate vii, figure 3, plate viii, figure 4.

1899 *Magellania sufflata:* Tate: 253.

1927 *Stethothyris sufflata:* Thomson: 73,88, 282.

1940 *Victorithyris sufflata:* Allan: 292–203, plate XXXV, figure 4.

1970 *Victorithyris sufflata*: Lowry: 67.

1980 *Stethothyris sufflata:* Richardson: 43.

Material Examined

F6829, Weebubbie Cave, Wilson Bluff Limestone, F6831, Wilson Bluff, 15.3 m below top of formation; F6830, Abrakurrie Cave; Late Eocene.

Description

Stethothyris sufflata differs externally to *S. pectoralis* in that it is more bulbous, the dorsal valve being more convex, the dorsal sulcus not being as deep and the beak being incurved rather than suberect to erect as in *S. pectoralis*.

Table 13 Measurements (in mm) of *Stethothyris sufflata* (Tate, 1880).

Specimen	Length	Width	Depth
F6829	47.1	38.9	31.0

Remarks

Stethothyris sufflata is described from the Tertiary deposits of the Yorke Peninsula (Late Eocene – Early Oligocene) (Tate, 1880; Allan, 1940), and Aldinga Bay which is possibly Tortachilla Limestone (Late Eocene) (Tate, 1880), South Australia.

Stethothyris tapirina (Hutton, 1873)
Figure 13 A–F

1873 *Waldheimia tapirina* Hutton: 36.

1905 *Bouchardia tapirina:* Hutton: 480, plate XLVI, figure 6.

1960 *Stethothyris tapirina:* Allan: 239, 266.

1993 *Stethothyris tapirina:* MacKinnon *et al.*: 343, figure 10 [15–21].

Remarks

In their reappraisal of the systematics of the *Stethothyris* group, Hiller and MacKinnon (in press) place *S. tapirina* in the genus *Aliquantula*.

Material Examined

Bremer Basin: WAM 94.155, 95.602, 99.313–316, Manypeaks Quarry, Nanarup Limestone, Werillup Formation, Bremer Basin.

Eucla Basin: F6809/1–7, F6821, Abrakurrie Cave; F6820/1–7, Wilson Bluff; Wilson Bluff Limestone, Late Eocene.

Description

Exterior. Shell subcircular; small to large, 14 to 42.5 mm long. Biconvex, ventral valve with slight keel; depth to 52% shell length. Width to 101% shell length, widest at mid-length. Valves smooth, numerous small growth lines, finely and densely punctate. Cardinal margin wide to lateral margin, curved; lateral margin edge bevelled to slightly impressed posteriorly, margin sigmoidal; anterior valve edge bevelled, anterior commissure unisulcate. Umbo strong, beak erect to incurved;

◀ Figure 11 A-D, *Diedrothyris johnstoniana* (Tate, 1880). **A-D**, WAM 94.142. **A**, dorsal valve exterior; **B**, laterial margin; **C**, ventral valve exterior; **D**, anterior commissure. All x 2. **E-G**, *Diedrothyris plicata* Richardson, 1980. **E**, F6112/4, ventral valve exterior. **F**, F6109/2, lateral margin. **G**, WAM 88.185, ventral vave exterior. All x 2. **H-M**, *Stethothyris pectoralis* (Tate, 1880). **H, J, L**, WAM 99.312. **H**, dorsal valve exterior; **J**, lateral margin; **L**, anterior commissure. **I, K, M**, WAM 94.138. **I**, lateral margin; **K**, anterior commissure; **M**, dorsal valve exterior. All x 1.5.

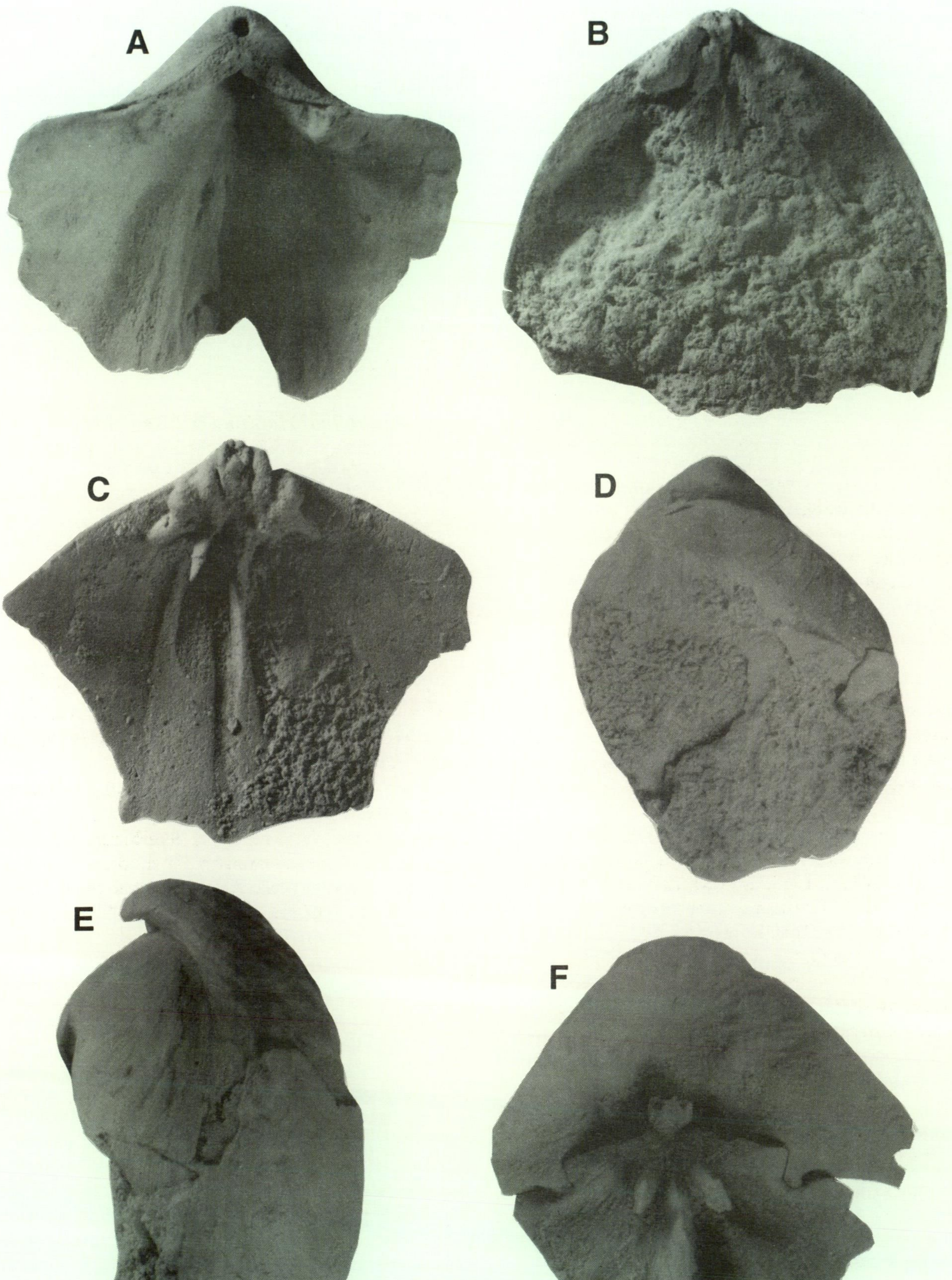


Figure 12 **A-C**, *Stethothyris pectoralis* (Tate, 1880). **A**, WAM 94.140, ventral valve interior x 2. **B**, WAM 99.334, ventral valve interior x 2. **C**, WAM 95.603, dorsal valve interior x 3. **D-F**, *Stethothyris sufflata* (Tate, 1880). **D, E**, F6829. **D**, dorsal valve exterior x 1.5; **E**, lateral margin x 2. **F**, F6831, dorsal valve interior x 2.5.

Table 14 Measurements (in mm) of *Stethothyris tapirina* (Hutton, 1873).

Specimen	Length	Width	Depth
WAM 94.155	18.3	18.0	7.6
WAM 99.313a	36.7	37.0	18.0
WAM 99.313b	14.1	12.7	5.6
WAM 99.314	42.5	–	–
WAM 99.315	44.0	42.3	23.0

beak ridges sharp, extend to lateral margin. Foramen small, 1% shell length in large specimens, mesothyrid; deltidial plates conjunct. Symphytium wide, high, concave.

Interior. Ventral valve. Hinge teeth strong (deltidiodont), bases swollen buttressed to margin, grooved ledge in apex. Pedicle trough narrow; valve posteriorly thickened. Muscle scars elongate in narrow trough, trough divided by short thin median septum posteriorly.

Dorsal valve. Cardinal area thickened, outer socket ridge wide; socket deep, buttressed to margin; crura wide. Median septum short in posterior third of valve, rising blade-like, thickening posteriorly. Muscle scars elongated troughs.

Remarks

The cardinal area was broken in the only specimen with an internal view available. It was observed that the area under the sockets, cardinal process and centre of the thickened section of the median septum was hollow.

Stethothyris tapirina (Hutton, 1873) is described from Oligocene deposits in New Zealand (Hutton, 1873, 1905; Allan, 1960, MacKinnon *et al.*, 1993) including the Cobden Limestone Quarry, Greymouth, Westland and the Kokoamu Greensand, North Otago. Hiller and MacKinnon (in press) redescribe the species as *Aliquantula tapirina*. It is clear that the specimens from the Nanarup Limestone correspond well with the description of the this species. This is the earliest record of the species and the first record from Australia.

Subfamily Anakineticinae Richardson, 1991

Genus *Anakinetica* Richardson, 1987

Type Species

Terebratella cumingii Davidson, 1852.

Anakinetica breva Richardson, 1991

Figure 14 D–I

1880 *Magasella compta* Tate: 162–163, plate 10, figure 6a–e.

1970 *Magadinella compta*: Lowry: 86.

1991 *Anakinetica breva:* Richardson: 35–36, figure 2G–L.

Material Examined

F6862/1–14, F6864/1–10, F6865/1–5, F6866/1–2, F6868/1–5, Firestick Cave, Abrakurrie Limestone, Early Miocene.

Description

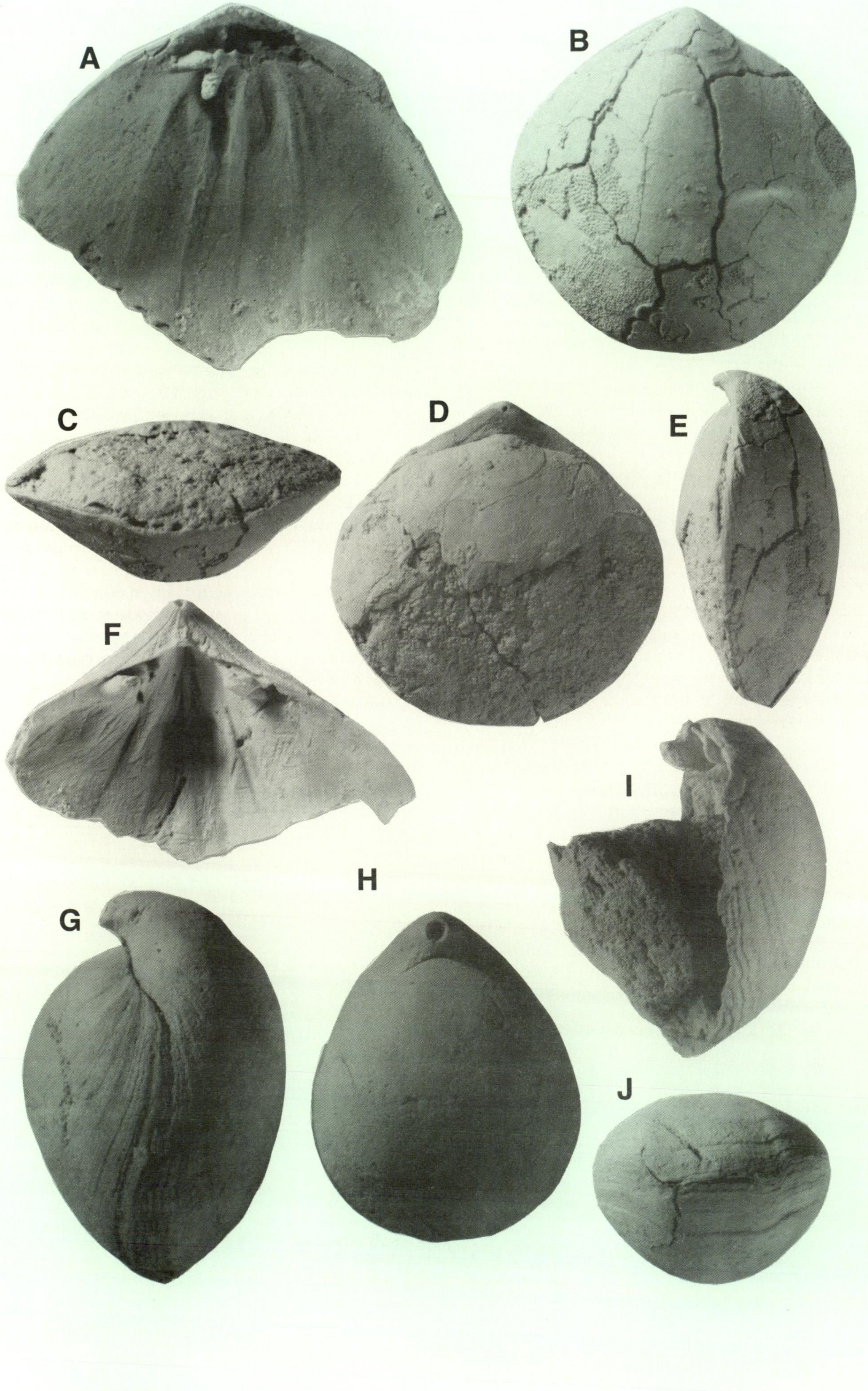
Exterior. Shell small, 8–17.4 mm, ovate, greatest width at or near mid-length, width to 88% shell length. Ventribiconvex, ventral valve carinate, dorsal valve with shallow sulcus, depth to 62% shell length; shell smooth, very finely densely punctate, growth lines distinct, not prominent; cardinal margin curved, to 75% shell width; valves lateral edge rounded, lateral margin sigmoidal from cardinal to anterior margins; anterior valve edge bevelled, anterior commissure unisulcate, sulcus shallow, to 40% shell width; beak truncated, suberect, umbo labiate; beak ridges rounded anteriorly, sharp posteriorly; foramen small, 3.5% shell length, mesothyrid to permesothyrid; symphytium with thickened ridge centrally, striated horizontally, low, wide, concave; palintrope narrow.

Internal. Ventral valve. Hinge teeth triangular (deltidiodont), thick with slightly swollen bases, pointing anteriorly; pedicle opening narrow, narrow trough anteriorly; posterior area thickened; muscle scars unclear.

Dorsal valve. Sockets wide, floor swollen, no roof; inner socket ridges, outer hinge plate and crural base fused, swollen, posterior overhangs cardinal margin; crura short, rounded; median septum relatively thick posteriorly, bifurcates posteriorly under cardinal process, extend to mid-length; loop

Table 15 Measurements (in mm) of *Anakinetica breva* Richardson 1991.

Specimen	Length	Width	Depth
F6862/1–14	13.9	11.7	7.4
F6862/1–14	13.5	11.2	6.4
F6862/1–14	16.5	13.9	8.5
F6864/1–10	15.5	14.8	9.7
F6864/1–10	11.4	9.1	5.5
F6864/1–10	14.4	12.4	8.4
F6864/1–10	14.2	12.2	7.0
F6864/1–10	14.4	12.0	–
F6864/1–10	9.9	8.2	–
F6865/1–5	14.4	12.3	6.2
F6865/1–5	8.5	7.5	4.4
F6866/1–2	14.5	12.2	6.8
F6866/1–2	12.2	11.1	5.0
F6868/1–5	17.4	13.6	8.0
F6868/1–5	13.7	10.0	5.9
F6868/1–5	12.1	9.7	9.2
F6868/1–5	11.1	–	8.3
F6868/1–5	10.8	9.0	8.2


A
B
C
D
E
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I
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J

trabecular, connecting bands widening distally; cardinal process a cup, lateral walls straight, extending inwards in a series of narrowing sections, anterior wall square, short ridge extends anteriorly to end of inner hinge plates, interior of process striated; muscle scars half moon shaped either side of median septum.

Remarks

The specimens accord well with Richardson's (1991) description and figures. Richardson describes the cardinal margin as straight. Specimens examined herein varied from gently curved to nearly straight. The species is recorded (Richardson, 1991) from the Point Addis Limestone (Janjukian, Upper Oligocene), Aireys Inlet, Victoria, Mannum Formation, Fyansford Formation, Puebla Formation and the Scutellina Limestone, all of Early Miocene age from South Australia.

Genus *Aliquantula* Richardson, 1991

Type Species

Waldheimia (?) insolita Tate, 1880.

Remarks

Hiller and MacKinnon (in press) place the genus *Aliquantula* in the subfamily Stethothyridinae because it differs from other Anakineticinae in that the hinge trough is excavated in juveniles, the posterior end of the septum bifurcates and the foramen is permesothyrid.

Aliquantula insolita (Tate, 1880)
Figure 14 J–O

1880 *Waldheimia (?) insolita* Tate: 151–152, plate 9, figure 6b.

1899 *Magellania insolita:* Tate: 282.

1927 *Stethothyris (?) insolita:* Thomson: 282.

1970 *Terebratula insolita*: Lowry: 67.

1991 *Aliquantula insolita:* Richardson: 44, figure 6G–L.

Material Examined

Bremer Basin: WAM 75.39, 41, 94.146, 168, 95.440, Nanarup Lime Quarry, Nanarup, Nanarup Limestone, Bremer Basin.

WAM 69.264, 14.5 km east of Northcliff; WAM 76.15, Green Range; Pallinup Siltstone, Bremer Basin.

Eucla Basin: WAM 88.186, Booanya Well, Nanambinia, Station, Balladonia, Toolinna Limestone, Late Eocene.

F 6114/3, Haig Cave, immediately below top of formation; F6812/1–21, F6817, Abrakurrie Cave, 0 – 3.4 m; F 6819/1–4, Abrakurrie Cave, 3.4 – 6.5 m; Wilson Bluff Limestone, Late Eocene.

F6837 Tommy Grahams Cave, Abrakurrie Limestone, Early Miocene.

Description

Exterior. Shell ovate to subcircular; medium-sized, 14 to 21.7 mm long. Ventribiconvex, dorsal valve almost flat, depth 40% in small to 50% shell length in larger specimens. Widest anterior to mid-length, width to 80% in small to 67% shell length in larger specimens. Valves smooth, growth lines distinct. Cardinal margin wide, curved; valves lateral edge bevelled, lateral margin straight; anterior valve edge bevelled, anterior commissure rectimarginate to unisulcate. Umbo truncated, beak erect to slightly incurved in small to suberect in larger specimens; beak ridges sharp. Foramen pyriform to ovate in small specimens, round in larger specimens, medium sized to 5%, mesothyrid to submesothyrid; deltidial plates conjunct. Symphytium relatively wide and low in small to narrow and high in larger specimens, smooth.

Interior. Ventral Valve. Pedicle trough narrow. Hinge teeth deltidiodont with swollen bases.

Table 16 Measurements (in mm) of *Aliquantula insolita* (Tate, 1880).

Specimen	Length	Width	Depth
WAM 69.264a	14.0	10.7	6.3
WAM 69.264b	21.5	19.1	8.7
WAM 75.39	15.7	10.7	7.4
WAM 75.41	–	7.2	3.7
WAM 76.15a	21.7	18.3	9.9
WAM 76.15b	16.6	–	6.4
WAM 94.146	18.9	12.8	9.6
WAM 94.168	–	5.2	2.6
F6817	19·	16.3	7.1
F6819/1–4	13.8	12.3	5.5
F6819/1–4		17.2	8.2
F6819/1–4	14.4	12.9	5.2
F6834	6.6	5.8	2.7

◀ **Figure 13** A-F, *Stethothyris tapirina* (Hutton, 1873). **A**, **F**, WAM 99.316a. **A**, dorsal valve interior; **F**, ventral valve interior. Both x 2.5. **B-E**, WAM 99.313a. **B**, ventral valve exterior; **C**, anterior commissure; **D**, dorsal valve exterior; **E**, lateral margin. All x 2; **G-J**, *Neothyris rylandae* Craig, 1999. **G**, **H**, **J**, WAM 62.2368, holotype. **G**, lateral margin x 1; **H**, dorsal valve exterior x 1; **J**, anterior commissure x 0.5. **I**, WAM 82.2367, paratype, lateral margin, dorsal valve interior x 1.

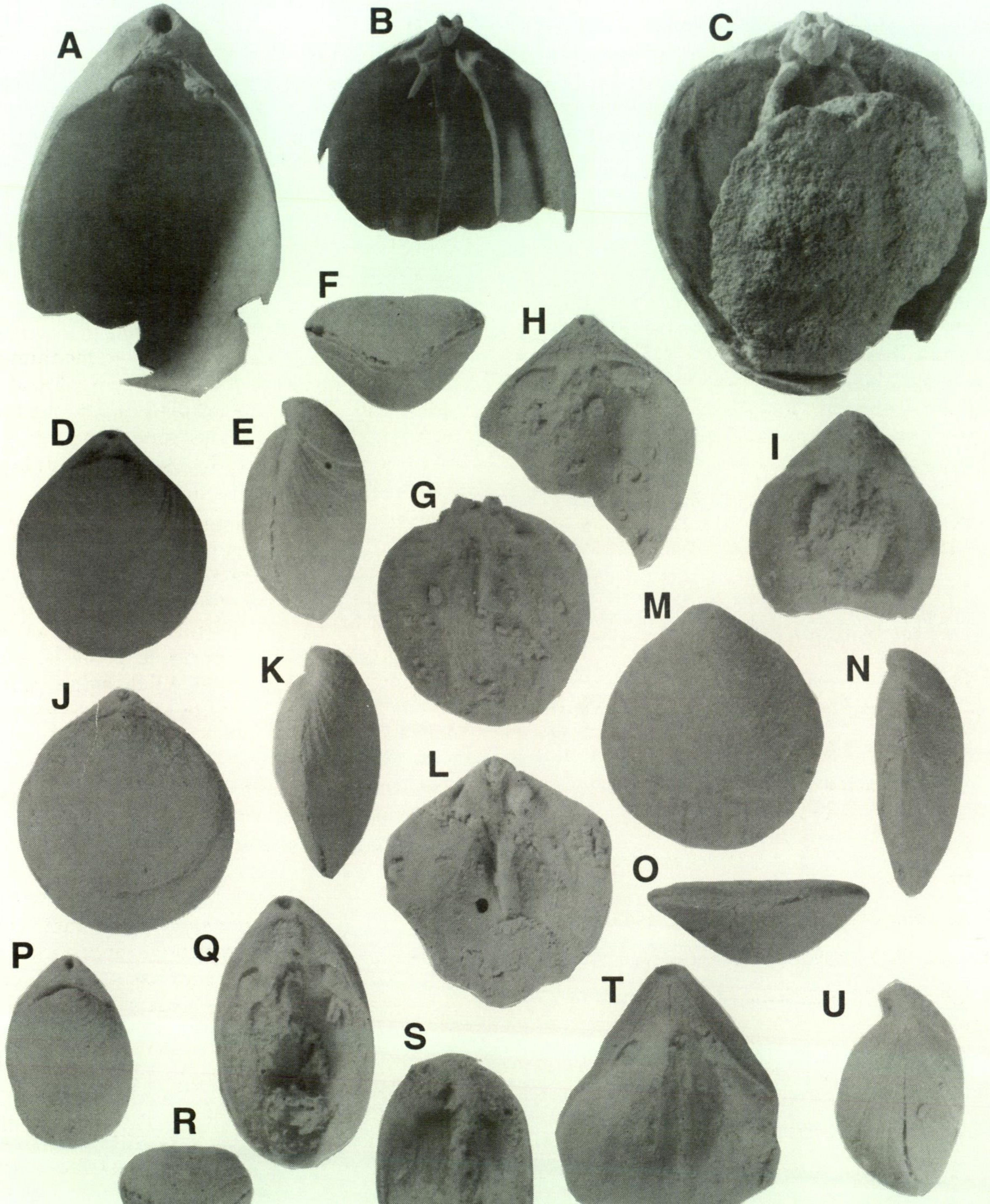

Figure 14 **A-C**, *Neothyris rylandae* Craig, 1999. **A**, WAM 82.2378a, paratype, ventral valve interior. **B**, WAM 82.2378b, paratype, dorsal valve interior. **C**, WAM 82.2367, paratype, dorsal valve interior. All x 1. **D-I**, *Anakinetica breva* Richardson, 1991. **D-F**, F6866/1-2. **D**, dorsal valve exterior; **E**, lateral margin; **F**, anterior commissure. All x 2.5. **G**, F6868/1-5a, dorsal valve interior x 2.5. **H**, F6868/1-5b, ventral valve interior x 2.5. **I**. F6864/1-10, dorsal valve interior x 2.5. **J-O**, *Aliquantula insolita* (Tate, 1880). **J**, **M-O**: F6819. **J**, dorsal valve exterior. **M**, ventral valve exterior; **N**, lateral margin; **O**, anterior commissure. All x 2.5. **K**, WAM 75.39, lateral margin x 2. **L**, F6114/3, dorsal valve interior x 2.5. **P-T**, *Magadinella woodsiana* (Tate, 1880). **P**, **R**, **T**, F6862/1-14. **P**, dorsal valve exterior; **R**, anterior commissure; **T**, lateral margin. All x 2.5. **Q**, F6861a, ventral valve interior x 2.5. **S**, F6842, ventral valve interior x 2.5.

Dorsal valve. Outer socket ridge narrow. Socket wide anteriorly, margin rounded, pointed posteriorly. Inner socket ridge and crural bases fused and swollen, bases separated by a slight depression . Crura slightly divergent. Hinge trough present, narrow bifurcation of posterior median septum. Median septum short, extends to posterior to mid-length; blade-like anteriorly, low. Cardinal process on boss, boss swollen anteriorly, process small rimmed cup.

Remarks

Aliquantula insolita is described from the Tortachilla Limestone (Eocene) and the Blanche Point Marl (Eocene), Maslin Bay, Aldinga South Australia as well as the Browns Creek Clay (Eocene), Aire River District and the Castle Cove Limestone (Early Oligocene), Castle Cove at the mouth of the Johanna River of Victoria (Richardson, 1991). Chapman and Crespin (1934) describe a specimen of this species from the Plantagenet Beds, Norseman, Western Australia.

Genus *Magadinella* Thomson, 1915

Type Species

Magadinella woodsiana Tate, 1880.

Magadinella woodsiana (Tate, 1880)

Figure 14 P–U

1880 *Magasella woodsiana* Tate: 163–164, plate 10, figure 3a–d.

1896 *Magasella compta:* Pritchard: 142–143.

1899 *Magasella woodsiana:* Tate: 256–257.

1915 *Magadinella woodsiana:* Thomson: 400–4002, figure 13a–c.

1927 *Magadinella woodsiana:* Thomson: 277–278, figure 92a–c.

1970 *Magadinella woodsiana*: Lowry: 67, 86.

1991 *Magadinella woodsiana:* Richardson: 36, figure 3A–F.

Material Examined

Bremer Basin: WAM 94.146, Nanarup Lime Quarry, Nanarup Limestone, Bremer Basin.

Eucla Basin: F5542/2, F5543/1–4, Twilight Cove WAM 66.1462, F6109/3, Madura 12.9 km North Cave; WAM 65.691, F6109/5, F6110/1, F6110/2, Madura, 9.7 km South Cave; WAM 68.323,324, F6111/6, Murra-el-elevyn Cave; F6112/7, Toolinna, 30.1–33.6 m above sea level; F6112/10, 11, 12, Toolinna, 0–74.7 m above sea level; F6841, F6842, Toolinna, 24.4 m above sea level; F6861, Abrakurrie Cave; Wilson Bluff Limestone, Late Eocene.

F6858/1–6, F6859/1–5, Tommy Graham's Cave; F6862/1–14, F6863/1–10, F6864/1–10, F6865/1–5, F6867/1–11, F6869/1–8, Madura 12.9 km north of Firestick Cave; F6870/1–4, Thylacine Hole, 0–12.2 m below top of formation; Abrakurrie Limestone, Early Miocene.

F6860/1–9, Mullamullang Cave, alluvium from Abrakurrie Limestone, Early Miocene.

WAM 62.161, Cocklebiddy Station, Nullarbor Plain.

Description

Exterior. Shell ovate, mid-sized, 8.8 to 24.2 mm in length. Biconvex shell, depth to 65% of shell length. Width greatest at mid-length, to 91% shell length, most to 75% shell length. Surface smooth, growth lines distinct, numerous, not prominent, punctae very fine and dense, ventral valve slightly carinate. Cardinal margin gently curved to 50% shell width; valves lateral edge bevelled to rounded in more elongate specimens, margin straight; anterior valve edge bevelled, anterior commissure gently to strongly unisulcate. Umbo truncated, beak suberect; beak ridges rounded. Foramen permesothyrid to mesothyrid, round, medium sized to 5% shell length, slightly labiate, lip divided in some specimens. Symphytium high, wide, thick ridge centrally, concave either side. Palintrope very narrow.

Interior. Ventral valve. Posteriorly thickened. Pedicle trough narrow, deep. Hinge teeth swollen, triangular (deltidiodont), central region projects into valve, posterior with small triangular groove to margin, bases swollen.

Dorsal valve. Cardinal area very swollen, high above septum. Sockets shallow troughs, outer socket ridge wide, inner socket ridge high, swollen overhanging socket posteriorly. Inner socket ridge, outer hinge plates and crura bases, indistinct from each other, swollen; inner hinge plates form narrow trough. Crura straight narrow bands. Medium septum extends beyond mid-length, anterior blade like, shallows to valve floor; posterior swollen, blade-like upper surface. Cardinal process rectangular cup, open posteriorly, encroached by swollen socket ridges laterally, shallow triangle interiorly with posterior apex, swollen protuberant "knob" anteriorly. Muscle scars in deep elongated trough either side of septum.

Remarks

Magadinella woodsiana has been described from the Mount Gambier Limestone (Late Oligocene), Mount Gambier, South Australia and the Calder River Limestone (Late Oligocene), Aire coast, Point Addis Limestone, (Late Oligocene), Kawarren and the Sandford Limestone (Late Oligocene), Sandford in Victoria (Richardson, 1991). The Nanarup Limestone specimens are the oldest record of the species in Australia.

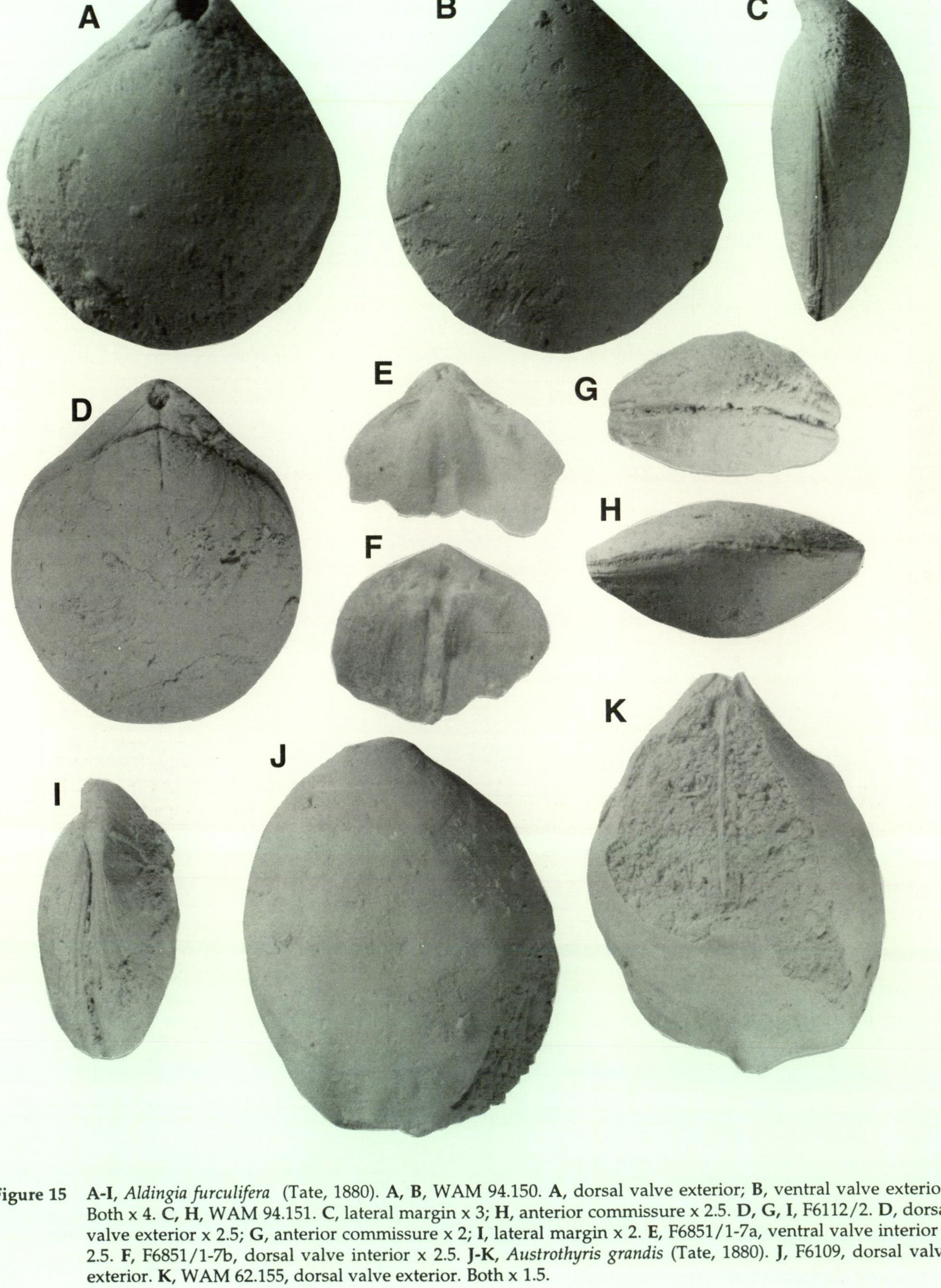

Figure 15 **A-I**, *Aldingia furculifera* (Tate, 1880). **A**, **B**, WAM 94.150. **A**, dorsal valve exterior; **B**, ventral valve exterior. Both x 4. **C**, **H**, WAM 94.151. **C**, lateral margin x 3; **H**, anterior commissure x 2.5. **D**, **G**, **I**, F6112/2. **D**, dorsal valve exterior x 2.5; **G**, anterior commissure x 2; **I**, lateral margin x 2. **E**, F6851/1-7a, ventral valve interior x 2.5. **F**, F6851/1-7b, dorsal valve interior x 2.5. **J-K**, *Austrothyris grandis* (Tate, 1880). **J**, F6109, dorsal valve exterior. **K**, WAM 62.155, dorsal valve exterior. Both x 1.5.

Table 17 Measurements (in mm) of *Magadinella woodsiana* (Tate, 1880).

Specimen	Length	Width	Depth	Specimen	Length	Width	Depth
WAM68.324	16.6	12.6	–	WAM 68.323	15.2	11.7	–
WAM 68.323	16.2	13.6	9.8	WAM 68.323	13.0	10.2	7.4
WAM 68.323	9.3	8.7	4.7	WAM 66.1462	9.9	7.7	5.2
WAM 66.1462	9.9	8.0	4.7	WAM 62.161	16.7	13.9	9.1
WAM 62.161	14.2	9.7	–	WAM 65.691	20.2	15.5	13.2
WAM 65.691	14.0	11.3	7.0	WAM 65.691	18.4	13.4	9.4
F5542/2	13.9	10.3	–	F6859/1–5	7.5	5.9	3.9
F5543/1–4	13.8	10.2	8.2	F6860/1–9	12.3	10.8	6.9
F5543/1–4	14.3	11.0	–	F6860/1–9	12.3	9.0	6.5
F5543/1–4	17.9	13.8	9.9	F6860/1–9	14.4	11.0	9.1
F5543/1–4	14.4	11.6	7.0	F6860/1–9	15.4	11.3	8.3
F6109/3	11.9	8.8	8.0	F6861	16.4	9.3	10.6
F6109/3	13.2	9.7	7.7	F6862/1–14	15.2	12.3	9.0
F6109/3	11.5	9.6	6.9	F6862/1–14	15.8	11.0	8.6
F6109/3	14.6	11.3	7.9	F6862/1–14	16.7	13.5	9.9
F6109/5	17.1	11.4	–	F6862/1–14	12.1	9.2	6.5
F6110/1	23.2	17.0	15.5	F6862/1–14	11.9	7.6	6.8
F6110/1	15.7	12.3	8.6	F6862/1–14	12.2	9.2	5.9
F6110/1	21.9	15.0	14.0	F6862/1–14	16.5	12.8	8.9
F6110/1	21.2	17.1	12.8	F6862/1–14	12.4	9.7	–
F6110/2	21.7	16.8	–	F6862/1–14	16.3	11.5	8.9
F6110/2	(bv) 11.4	11.6	–	F6862/1–14	15.8	13.2	7.9
F6111/6	16.0	12.1	9.8	F6863/1–10	9.3	6.7	4.8
F6111/6	16.0	12.4	8.7	F6863/1–10	14.0	10.5	6.8
F6111/6	16.8	13.0	9.7	F6863/1–10	14.8	11.9	9.0
F6111/6	15.0	11.2	9.6	F6863/1–10	13.6	10.2	9.1
F6111/6	16.8	13.1	9.9	F6863/1–10	10.7	9.0	5.6
F6111/6	12.4	9.9	7.0	F6863/1–10	12.9	9.5	7.8
F6111/6	17.6	12.6	9.0	F6863/1–10	9.8	6.9	–
F6111/6	14.0	10.5	–	F6863/1–10	16.1	11.7	10.5
F6111/6	13.0	11.9	–	F6863/1–10	9.0	6.8	5.0
F6111/6	14.7	10.3	8.4	F6864/1–10	16.9	13.5	9.4
F6111/6	11.9	9.6	5.3	F6864/1–10	15.3	12.5	8.0
F6111/6	13.8	11.3	–	F6864/1–10	9.8	8.2	5.8
F6111/6	12.1	9.9	5.2	F6864/1–10	16.0	11.6	9.5
F6111/6	8.9	7.1	–	F6865/1–5	13.3	9.9	8.2
F6112/7	20.2	15.6	12.1	F6865/1–5	12.2	8.5	–
F6112/10	20.0	15.6	11.5	F6865/1–5	6.7	5.7	–
F6112/10	20.3	16.3	10.7	F6867/1–11	16.3	11.7	–
F6112/10	17.0	13.0	8.8	F6867/1–11	15.8	10.4	9.7
F6112/12	18.4	12.4	11.1	F6867/1–11	13.5	10.6	–
F6112/12	19.5	14.4	11.7	F6867/1–11	13.3	9.9	6.9
F6841	18.0	14.7	10.8	F6867/1–11	12.4	9.3	8.4
F6842	20.4	14.8	13.0	F6867/1–11	12.4	9.7	–
F6842	15.6	12.9	–	F6867/1–11	13.3	9.2	7.6
F6858/1–6	24.2	16.8	–	F6867/1–11	14.6	11.6	9.2
F6858/1–6	14.0	9.5	7.3	F6867/1–11	15.1	11.0	9.2
F6858/1–6	17.1	13.1	9.1	F6869/1–8	14.5	10.4	8.1
F6858/1–6	18.4	14.3	9.4	F6869/1–8	13.3	10.8	8.2
F6858/1–6	14.2	11.2	8.5	F6869/1–8	14.9	10.7	–
F6858/1–6	11.7	8.4	–	F6869/1–8	13.0	9.9	7.6
F6859/1–5	10.8	7.8	5.8	F6870/1–4	13.7	9.7	7.4
F6859/1–5	8.8	6.3	4.2	F6870/1–4	15.1	10.0	9.2
F6859/1–5	10.6	8.6	–	F6870/1–4	14.1	9.6	7.7
F6859/1–5	8.8	6.8	4.5				

CONCLUSION

Comparison of brachiopods (Table 18) from the Nanarup Limestone (Late Eocene) and the Wilson Bluff Limestone (Middle to Late Eocene) indicates 8 species in common between the two formations. These are *Aldingia furculifera* (Tate, 1880), *Aliquantula insolita* (Tate, 1880), *Liothyrella labiata* sp. nov., *Magadinella woodsiana* (Tate, 1880), *Stethothyris pectoralis* (Tate, 1880), *Stethothyris tapirina* (Hutton, 1873), *Terebratulina* *christopheri* sp. nov. and *Victorithyris tateana* (Tate, 1880).

Two brachiopods found in the Nanarup Limestone are not present in the Wilson Bluff Limestone. These are *Diedrothyris johnstoniana* (Tate, 1880) and *Westralicrania zenobiae* Craig, 1997. The absence of *W. zenobiae* may well be a problem of collection as the specimens are flat and quite small. The Wilson Bluff Limestone is significantly richer having 8 species, which are not found in the Nanarup Limestone. These include *Austrothyris grandis* (Tenison-Woods, 1865), *Diedrothyris plicata* Richardson, 1980, *Liothyrella bulbosa* (Tate, 1880), *Liothyrella subcarnea* (Tate 1880), *Murravia triangularis* (Tate, 1880), *Stethothyris sufflata* (Tate, 1880), *Victorithyris divaricata* (Tate, 1880) and *Victorithyris garibaldiana* (Davidson, 1862). Overall, there are 16 species present in the Wilson Bluff Limestone.

The three species recorded from the Pallinup Siltstone are *Aldingia furculifera* (Tate, 1880), *Aliquantula insolita* (Tate, 1880) and *Terebratulina christopheri* sp. nov., *A. furculifera* (Tate, 1880) and *A. insolita* (Tate, 1880) are common to all five deposits, while *T. christopheri* sp. nov. is not recorded from the Abrakurrie Limestone. The lower diversity of brachiopod species may well be due to a different palaeoenvironment as shown by the high level of siliciclastic material within the deposit, which is believed to be a product of lower water temperatures (McNamara, 1994). The Toolinna Limestone contains *Aldingia furculifera* (Tate, 1880), *Aliquantula insolita* (Tate, 1880), *Diedrothyris plicata* Richardson, 1980, *Murravia triangularis* (Tate, 1880), *Terebratulina christopheri* sp. nov., *Victorithyris tateana* (Tate, 1880) and *Westralicrania zenobiae* Craig, 1997. Four species (*D. plicata, M. triangularis, T. christopheri* and *W. zenobiae*) do not occur in the Abrakurrie Limestone but only one, *W. zenobiae*, different to the Wilson Bluff Limestone. This would suggest that the Toolinna Limestone has greater affinities to the Wilson Bluff deposit than that of the Abrakurrie, in contrast to Li *et al.* (1996). All species found in the Abrakurrie Limestone are found in the Wilson Bluff Limestone, but it is less species rich, having only 8 species recorded from the deposit. This may be a result of lower water temperatures during the Late Oligocene to Early Miocene or a result of erosional effects that produced a sequence of hardgrounds (Li *et al.*, 1996).

The brachiopods *Murravia triangularis* (Tate, 1880), *Victorithyris garibaldiana* (Davidson, 1862), *V. tateana* (Tate, 1880), *V. divaricata* (Tate, 1880) *Diedrothyris johnstoniana* (Tate, 1880), *D. plicata* Richardson 1980, *Stethothyris pectoralis* (Tate, 1880), *S. sufflata* (Tate, 1880), *Anakinetica breva* Richardson, 1991, *Magadinella woodsiana* (Tate, 1880), *Aliquantula insolita* (Tate, 1880), *Aldingia furculifera* (Tate, 1880), *Liothyrella bulbosa* (Tate, 1880), *L. subcarnea* (Tate, 1880) and *Austrothyris grandis* (Tenison-Woods, 1865) described above from the Bremer and Eucla Basins of Western Australia have also been described from Late Eocene to Early Miocene deposits in south eastern Australia (Table 19).

Specimens very similar to *Liothyrella labiata* were described in Richardson (1971) and are recorded from the Tortachilla Limestone, Maslin Bay, South Australia.

Westralicrania zenobiae Craig, 1997 is not known from south-eastern Australia.

Table 18 Brachiopod distribution over the deposits in the Bremer and Eucla Basins. (X indicates the presence of the species in the deposit) NL = Nanarup Limestone, PS = Pallinup Siltstone, WBL = Wilson Bluff Limestone, TL = Toolinna Limestone and AL = Abrakurrie Limestone.

Species	NL	PS	WBL	TL	AL
Aldingia furculifera (Tate, 1880)	X	X	X	X	X
Aliquantula insolita (Tate, 1880)	X	X	X	X	X
Anakinetica breva Richardson, 1991					X
Austrothyris grandis (Tenison-Woods, 1865)			X		
Diedrothyris johnstoniana (Tate, 1880)	X				
Diedrothyris plicata Richardson, 1980			X	X	
Liothyrella bulbosa (Tate, 1880)			X	X	X
Liothyrella labiata sp. nov.	X		X		
Liothyrella subcarnea (Tate, 1880)			X		X
Magadinella woodsiana (Tate, 1880)	X		X		X
Murravia triangularis (Tate, 1880)			X	X	
Stethothyris pectoralis (Tate, 1880)	X		X		
Stethothyris sufflata (Tate, 1880)			X		
Stethothyris tapirina (Hutton, 1873)	X		X		
Terebratulina christopheri sp. nov.	X	X	X	X	
Victorithyris divaricata (Tate, 1880)			X		X
Victorithyris garibaldiana (Davidson, 1862)			X		
Victorithyris tateana (Tate, 1880)	X		X	X	X
Westralicrania zenobiae Craig, 1997	X			X	

Table 19 Distribution of Bremer and Eucla Basin species in Australia, New Zealand and Antarctic. Ages identified in ***bold italics*** are for the appearance of the *genus* in these states.

Species	WA: Age & Fm	SA: Age	Vic: Age	Tas: Age	NZ: Age	Antarctica
Aldingia furculifera (Tate, 1880)	Nanarup Lst, Toolinna Lst, Wison Bluff Lst, L. Eoc. Abrakurrie Lst, E. Mio.	L. Eoc-Oligo	Oligo			
Aliquantula insolita (Tate, 1880)	Nanarup Lst, Toolinna Lst, Wilson Bluff Lst L. Eoc. Abrakurrie Lst. E. Mio	L. Eoc-Mio	Oligo-Mio			
Anakinetica breva Richardson, 1991	Abrakurrie Lst, E. Mio	L. Oligo	E. Mio			
Austrothyris grandis (Tate, 1880)	Abrakurrie Lst, E. Mio	E. Mio				
Diedrothyris johnstoniana (Tate, 1880)	Nanarup Lst, L. Eoc	E.-L. Eoc		E. Mio		
Diedrothyris plicata Richardson, 1980	Toolinna Lst, Wilson Bluff Lst, L. Eoc		E. Mio			
Liothyrella bulbosa (Tate, 1880)	Wilson Bluff Lst, L. Eoc Abrakurrie Lst, E. Mio	Eocene				***L. Eoc-Rec***
Liothyrella labiata sp. nov.	Nanarup Lst, Wilson Bluff Lst, L. Eoc	E.-L. Eoc				
Liothyrella subcarnea (Tate, 1880)	Wilson Bluff Lst, L. Eoc	M. Eocene				
Magadinella woodsiana (Tate, 1880)	Nanarup Lst, Wilson Bluff Lst, L. Eoc. Abrakurrie Lst, E. Mio.	L. Oligo	L. Oligo			
Murravia triangularis (Tate, 1880)	Toolinna Lst, Wilson Bluff Lst, L. Eoc	L. Eoc-Oligo				
Neothyris rylandae Craig, 1999	Roe Calcarenite				***Oligo-Mio***	***E. Mio-Rec***
Stethothyris pectoralis (Tate, 1880)	Nanarup Lst, Wilson Bluff Lst, L. Eoc	L. Eoc-E. Oligo			***Oligo-Mio***	***L. Eocene***
Stethothyris sufflata (Tate, 1880)	Wilson Bluff Lst, L. Eoc	E. Oligo-E. Mio				
Stethothyris tapirina (Hutton, 1873)	Nanarup Lst, Wilson Bluff Lst, L. Eoc				Oligo	
Terebratulina christopheri sp. nov.	Nanarup Lst, Toolinna Lst, Wilson Bluff Lst, L. Eoc					***L. Eocene***
Victorithyris divaricata (Tate, 1880)	Wilson Bluff Lst, L. Eoc, Abrakurrie Lst, E. Mio					
Victorithyris garibaldiana (Davidson, 1862)	Wilson Bluff Lst, L. Eoc, Abrakurrie Lst, E. Mio	E. Mio				
Victorithyris tateana (Tate, 1880)	Nanarup Lst, Toolinna Lst, Wilson Bluff Lst, L. Eoc,	E. Mio	E. Mio-E. Plio	E. Mio		
Westralicrania zenobiae Craig, 1997	Nanarup Lst, Toolinna Lst, L. Eoc					

The genus *Neothyris* is not known from elsewhere in Australia and may be the result of separate evolution from Neothyridinae stock or the result of east to west movement of currents during a hiatus in the Proto-Leeuwin Current (Craig, 1999).

Stethothyris tapirina (Hutton, 1873) has not been recorded from elsewhere in Australia but is known from Oligocene deposits in New Zealand. It is likely that this species may be present in south-eastern Australian Late Eocene or Early Oligocene deposits.

The presence of so many species common to Western Australia and the south eastern states of Australia indicates that the abiotic ecological conditions were certainly similar for a long period from the Late Eocene to at least the Early Miocene. The presence of similar species in Western and South Australia during the Late Eocene agrees with the series of transgressions that extended from the Bremer Basin in Western Australia, across the Eucla Basin to the St Vincent Basin in South Australia. Richardson (1997) suggested that brachiopods are more influenced by substrate than by any other environmental condition. The fact that the brachiopod faunas are of greatest diversity in the bryozoan limestone formations of the Bremer and Eucla Basins tends to support this hypothesis.

Bryozoan limestone is the product of cool-water deposits possibly including up-welling (James personal communication). Although the surface temperatures due to the flow of the Proto-Leeuwin Current are said to be warm ranging from 17° to 19°, James and Bone (1991) suggested that water temperatures between 14° to 19° are cool enough to allow the deposition of bryozoan limestone. This does not preclude cool-water up-welling although Li and McGowran (1994) suggested that during cool water up-welling bryozoans are reduced in diversity.

Brachiopods and bryozoans are both lophophorates and sessile benthic filter feeders. It is likely that they occur in close association due to the availability of food or reduced light intensity, rather than for substrate conditions. Bryozoans are found on a variety of substrates, as are brachiopods.

The occurrence of similar species in the Murray Basin and the Torquay Basin during the Late Oligocene and Early Miocene to those in the southwest basins suggests that the species dispersed east and appeared in these areas once transgressions inundated the Tasman Rise. The mechanism for this distribution would most likely be the Proto-Leeuwin Current that is believed to have influenced the distribution of echinoids (McNamara, 1999) and large warm water foraminifers (McGowran *et al.*, 1997). The influence of the Proto-Leeuwin Current on the distribution of brachiopods is also supported by the migration of Late Paleocene to Late Eocene brachiopods from the Carnarvon Basin to southern Australia (Craig, 2000). The present Leeuwin Current is defined as "a stream of warm, low salinity water that flows at the surface from near North West Cape to Cape Leeuwin and thence towards the Great Australian Bight (Cresswell, 1991: 1). There is strong circumstantial evidence for a direct, relatively short-term process of transportation of larvae of extant species of invertebrate and finfish from Western Australian spawning areas to South Australia nursery areas (Lenanton *et al.*, 1991: 105).

The Cenozoic brachiopod fauna of New Zealand may have evolved from species, which first evolved in Western Australia. MacKinnon (1987) suggested that *Stethothyris* evolved from *"Neothyris" esdailei* Thomson, 1918. He also sees a close relationship between *"Neothyris" esdailei* Thomson, 1918 and *Victorithyris tateana* (Tate, 1880), except for the loop, which in *"Neothyris" esdailei* Thomson, 1918 is trabecular while *Victorithyris tateana* (Tate, 1880) is teloform. The genus *Victorithyris* has been recorded from the Late Paleocene Cardabia Formation, Carnarvon Basin, Western Australia (Craig, 2000). Three species of *Victorithyris* are described, the oldest from the Boongerooda Greensand. They differ from *V. tateana* in the lack of plication. Hiller and MacKinnon (in press) suggest that a possible candidate for the ancestral form of *Victorithyris* could be from the Paleocene of Western Australia. Hiller and MacKinnon (in press) suggest that *'Neothyris' esdailei* Thomson 1918 may best be assigned to *Diedrothyris*. *Diedrothyris* cf *johnstoniana* from the Cardabia Formation, Carnarvon Basin, Western Australia (Craig, 2000) and *D. johnstoniana* from the Nanarup Limestone indicates that the genus *Stethothyris* is more likely to have evolved from a species of *Victorithyris* or *Diedrothyris* in Western Australia. It would then have been dispersed due to the presence of the Proto-Leeuwin Current south along the western coastline and, with the Great Australian Bight Current, eastwards along southern coastline of Western Australia (McGowran *et al.*, 1997). The presence of *Stethothyris* in the Nanarup Limestone supports this hypothesis.

Although the Trans-Tasman migration of echinoids is well established throughout the late Cenozoic (Foster and Philip, 1978) and Beu and Kitman (1998) suggested that molluscs migrate from west to east to New Zealand, the mechanism for such a migration of brachiopods across the widening Tasman sea is uncertain. There was a shallow marine connection between the Great Australian Bight and the Tasman Sea by the Late Eocene (Kennett, 1978; Beu *et al.*, 1997). MacKinnon (1987) proposed that the Tasman Sea formed in the Late Cretaceous and that by the mid to Late Oligocene as the gap between Australia and Antarctica widened, the circum Antarctic current became established. He also suggested that strong bottom currents scoured the gap between Australia and New Zealand prior to and after the breaching of the Tasman Rise. This would have made transport across the Tasman Sea by the brachiopods difficult as they have a short larval life of several hours to a few days (Richardson, 1997). One mechanism may have been the attachment of larvae to sea weed or other drifting material such as pumice and wood. Wignall and Simms (1990) reported the finding of *'Rhynchonella' subvariabilis* attached to a piece of fossil driftwood from the lower Mutabilis Zone (Lower Kimmeridge Clay, Upper Jurassic) at Wyke Rigis, Weymouth, Dorset, United Kingdom. McKinney and Jackson (1989) suggested that the only answer for the widespread distribution of bryozoans with a short larval phase would be such methods of rafting. Allan (1937) suggested that brachiopods might attach to vagile scallops. In discussing the distribution of molluscs, Beu (1976) suggested that larval stages might postpone their metamorphosis until a suitable substrate had been located. He also suggested in the same paper that molluscan larva may reduce their metabolic rate in cold sea temperatures, allowing a longer period of drift. These mechanisms might also explain the distribution of the brachiopods. It is also possible that early Cenozoic brachiopods had a longer lecithotropic life span than current species. A report by Gabbott (1999) suggests that brachiopods in the Ordovician Soom Shale, South Africa have attached to the orthocone of cephalopods and "hitched" a ride.

There is also a continuous link of genera between Australia, New Zealand (*Terebratulina, Neothyris* and *Stethothyris* in common) and Antarctica (*Liothyrella, Terebratulina, Neothyris* and possibly *Stethothyris* in common) (Table 19). Bitner (1996) described a species of *Stethothyris* from the Late Eocene La Meseta Formation of Seymour Island. If this identification is correct, then *Stethothyris* may have a wider range and different history than proposed by Hiller and MacKinnon (in press). The genera, which are in common between the three shelves, may have evolved along the Antarctic shelf. Movement to New Zealand might be then explained by drift north from Antarctica. Unfortunately, there are no fossil deposits including brachiopods from this region of Antarctica. Movement westwards from the Antarctic Peninsula could only have occurred after the opening of the seaway between South America and Antarctica in the Late Oligocene (Foster, 1974) and would have been against the recognised current flow patterns (Kennett, 1978). Further examination of south eastern Australian, Antarctic and South American specimens should provide the evidence required to settle the evolutionary history and biogeographical distribution of these (Terebratellinae and Stethothyridinae) subfamilies.

ACKNOWLEDGEMENTS

I would like to take this opportunity to thank Dr Noel James and Dr D. I. MacKinnon, for their input in the preparation of this paper. Ms Kris Brimmell prepared the photographs of *Westralicrania zenobiae*. I would also like to thank Dr K. J. McNamara for his review and comments, the Western Australian Museum for their support during my research and the Geological Society of Western Australia for the loan of the specimens collected by D. C. Lowry.

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Manuscript received 2 August 1999; accepted 14 March 2000.