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Late Cretaceous brachiopods of the Perth and Carnarvon Basins, Western Australia

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Abstract – Late Cretaceous deposits outcrop in the Perth and Carnarvon Basins in Western Australia. Brachiopods occur in the Gingin Chalk in the Perth Basin and in the Toolonga Calcilutite, Korojon Calcarenite and Miria Formation in the Carnarvon Basin. Fifteen species of brachiopods are described or revised from the Santonian to Campanian Gingin Chalk, seven species from the Santonian to Campanian Toolonga Calcilutite, two species from the Campanian to Maastrichtian Korojon Calcarenite and five species from the Late Maastrichtian Miria Formation.

Ten new species are described: *Eohemithyris miriaensis* sp. nov., *E. wildei* sp. nov., *Proteguforhynchia bevanorum* sp. nov., *Tegulorhynchia hrodelberti* sp. nov., *Terebratulina kendricki* sp. nov., *Liothyrella brimmellae* sp. nov., *L. archboldi* sp. nov. *Gemmarcula doddsae* sp. nov., *Zenobiathyris mutabilis* sp. nov. and *Z. plicatilis* sp. nov. This is the earliest record of *Liothyrella*, and the first record from Australia. A new family, Zenobiathyridae, is proposed.

The presence of a number of genera common to Late Cretaceous and "early Tertiary" of the deposits Antarctic Peninsula suggests that there was a continuous shelf between Western Australia and Antarctica during this period. It is proposed that these brachiopods form part of a high latitude southern circum-Indo-Atlantic faunal province which existed during the Late Cretaceous to the early Cenozoic.

INTRODUCTION

The brachiopod fauna described in this paper was collected from deposits in the Perth Basin and the Carnarvon Basin. Four terebratulids were previously described by Etheridge (1913) as *Terebratulina ovata, Magas mesembrinus, Trigonosemus acanthodes* and *Magasella cretacea*. Three of these were redescribed by Elliot (1952) as *Inopinatarcula acanthodes, Kingena mesembrina* and *Bouchardiella cretacea*. Feldtmann (1963) mentioned *I. acanthodes, B. cretacea, K. mesembrina,* two rhynchonellids and two *Terebratulina* species. McNamara *et al.* (1993) also referred to the rhynchonellid and reassigned *Terebratulina ovata* as *Gisilina.*

Four Late Cretaceous sequences have yielded brachiopods. These are the Gingin Chalk from the Perth Basin and the Toolonga Calcilutite, Korojon Calcarenite and Miria Formation, all from the Carnarvon Basin.

The Gingin Chalk of the Perth Basin (Figure 1), was described as a unit which consists of white chalky limestone with glauconite and beds of greensand in some areas (Glauert 1910). It rests disconformably on the Dandaragan Sandstone or conformably on the Molecap Greensand. The Poison Hill Greensand conformably overlies the Gingin Chalk. The chalk is exposed between Badgingarra in the north and Gingin in the south. It is richly fossiliferous containing regular echinoids, bivalves, gastropods, serpulid worms, ammonites, crinoids, ostracods, foraminifers and coccoliths. These fossils suggest a Santonian to Campanian age (Playford *et al.* 1975). Feldtmann (1963) described the type section of the chalk at McIntyre's Gully in detail.

The Toolonga Chalk from the Carnarvon Basin (Figure 2) was described as " a yellow-white, massive, usually rather coherent rock" which contains a base of phosphatic nodules and chert nodules present in the upper half (Clarke and Teichert 1948). It was named after Toolonga Hill, the highest part of the scarp north-west of the Murchison River. The chalk is widely distributed throughout the lower Murchison River area. Renamed the Toolonga Calcilutite, it was described as "a unit of pale-grey to light-green calcilutite with some chalk in the lower part" (Johnston *et al.* 1958). It is overlain conformably by the Korojon Calcarenite or disconformably by Tertiary deposits. In turn, it overlies disconformably the Alinga Formation. Fossils determined by Clarke and Teichert (1948) include echinoid spines, crinoids, serpulid worms, belemnite fragments, numerous bivalves, brachiopods and abundant foraminifers.

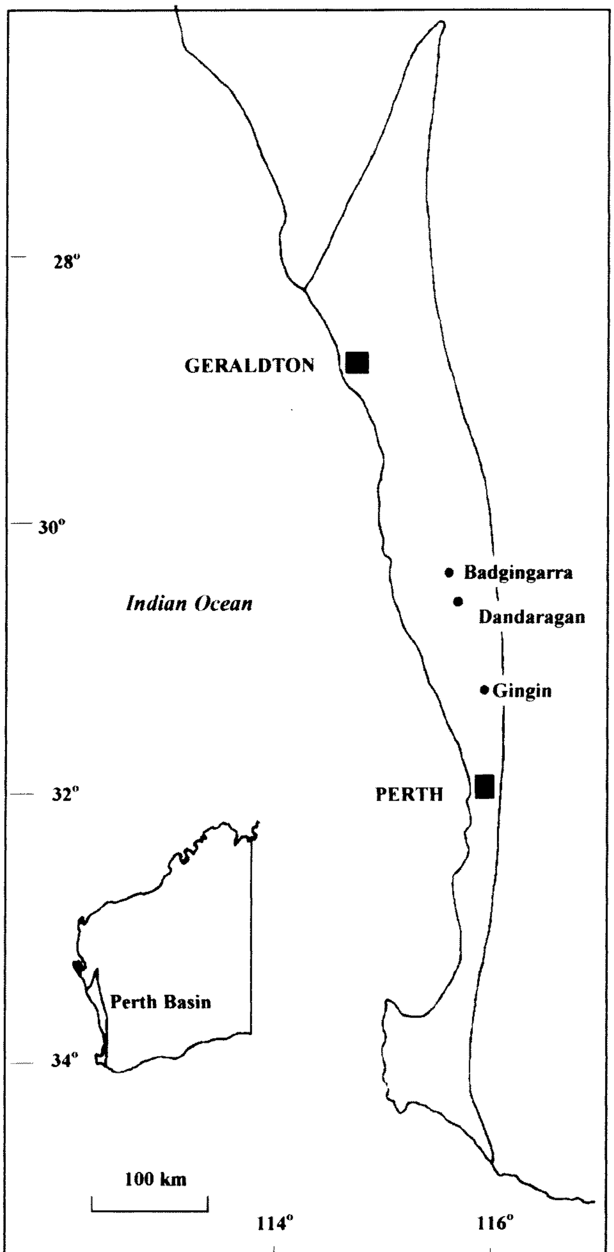


Figure 1 Late Cretaceous Gingin Chalk deposits in the Perth Basin,.

The presence of particular crinoids and foraminifers establishes it as Late Cretaceous (Santonian) in age (Shafik 1990).

The Korojon Calcarenite was described as "a white to yellow calcarenite, calcirudite and calcilutite which conformably overlies the Toolonga Calcilutite and is overlain disconformably by the Miria" Formation (Playford *et al.* 1975). The type section is found in the Giralia anticline. The fossil content includes, bivalves, ostracods, ammonites, and one brachiopod described herein. Shafik (1990) suggests that from the foraminiferal evidence that the main sequence is Campanian and extends to the Maastrichtian.

The Late Maastrichtian Miria Formation (Figure 3) of the Carnarvon Basin, Western Australia contains a rich fauna of invertebrates. This includes ammonoids described by Henderson and McNamara (1985) and Henderson *et al.* (1992). Bivalves, gastropods and scaphopods have also been described (Darragh and Kendrick 1991, Darragh and Kendrick 1994). McNamara (1987) described a holasteriod echinoid from the same formation. The Miria Formation also contains nannofossils described by Shafik (1990). A possible therapod humerus (Long 1992) and an incomplete ulna from a large pterodactyloid pterosaur (Bennett and Long 1991) have also been described. Corals and bryozoans remain undescribed. This paper describes the brachiopod fauna and discusses its palaeogeographical significance.

The Miria Formation consists of cream coloured calcarenite 0.6–2.1 m thick extending some 80 km in the Giralia Range, south of Exmouth Gulf. It overlies disconformably the Campanian-Early Maastrichtian Korojon Calcarenite (Darragh and Kendrick 1991) and is in turn succeeded disconformably by the Paleocene Boongerooda Greensand, of the Cardabia Formation (Henderson and McNamara 1985). The formation has been exposed by extensive gully erosion (Henderson *et al.* 1992).

According to Darragh and Kendrick (1994), the Miria assemblage is consistent with both Tethyan and Temperate affinities.

MATERIAL AND METHODS

The specimens examined have been collected over the past century by a number of geologists and palaeontologists affiliated with the Geological Survey of Western Australia, the University of Western Australia and the Western Australian Museum. Principal collectors include Brian McGowan, Bob Henderson, Ken McNamara, John Long, Tom Darragh and George Kendrick.

Measurement of specimens was undertaken with digital callipers to an accuracy of 0.1 mm. Length, width and depth measurements of all specimens were recorded. Camera lucida diagrams were then prepared after each grinding. Photographs were taken with a Nikon F 90 X camera with a macro lens and each specimen was prepared with a coating of ammonium chloride for photography.

SYSTEMATIC PALAEONTOLOGY

Phylum Brachiopoda Dumeril, 1806

Subphylum Rhynchonelliformea Popov, Bassett, Holmer & Laurie, 1993

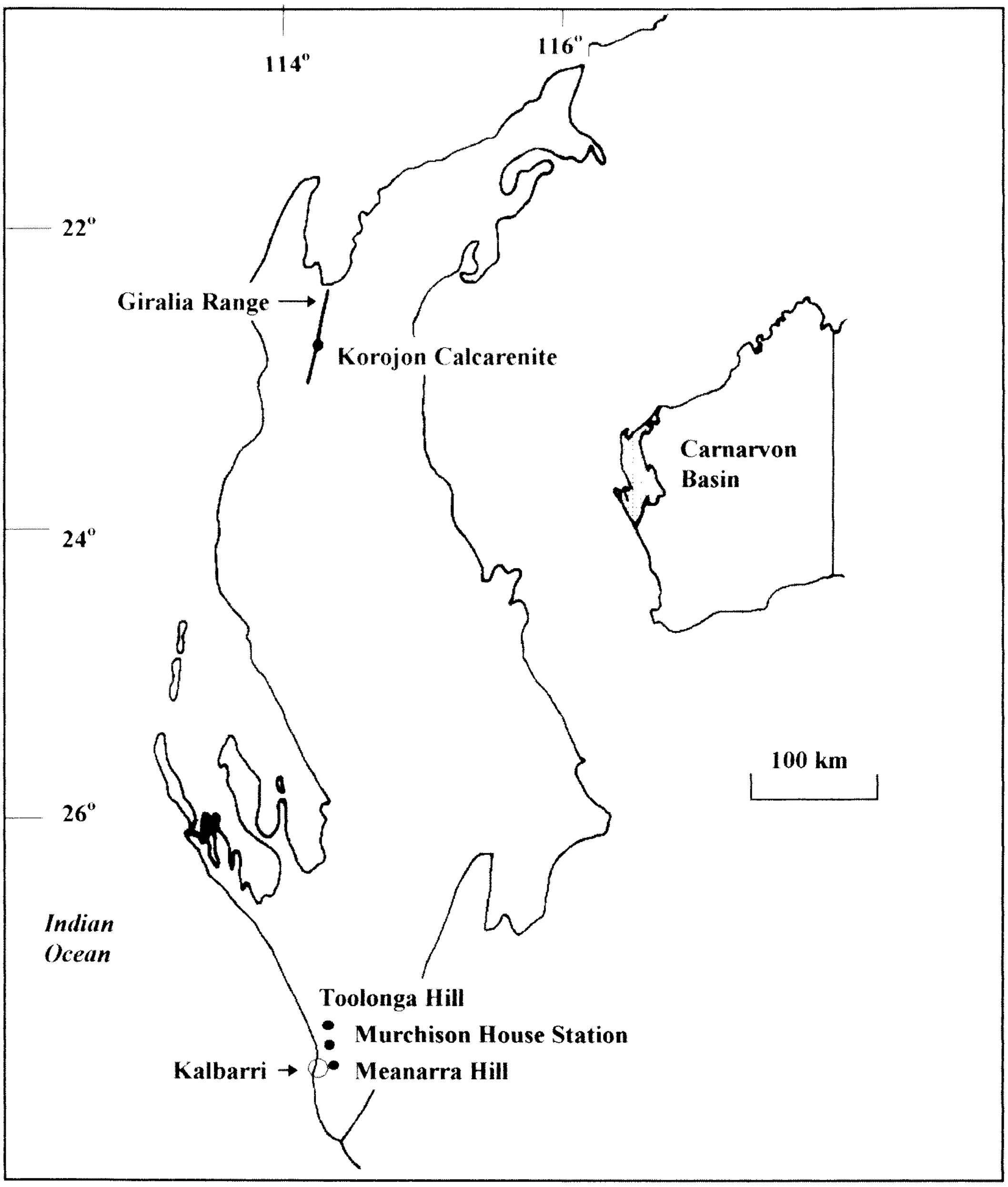


Figure 2 Late Cretaceous Toolonga Calcilutite (Toolonga Hill, Meanarra Hill and Murchison House Station) and Korojon Calcarenite (Giralia Range) in the Carnarvon Basin.

Order Rhynchonellida Kuhn, 1949

Superfamily Rhynchonelloidea Gray, 1848

Family Basiliolidae Cooper, 1959

Subfamily Basiliolinae Cooper, 1959

Genus *Eohemithyris* Hertlein and Grant, 1944

Type Species

Eohemithyris alexi Hertlein and Grant, 1944.

Eohemithyris miriaensis sp. nov.

Figure 4 A–F

Material Examined

Holotype

WAM 96.818, Gully 500 m northwest of West Tank, Giralia Station, Giralia Range, Carnarvon Basin, Miria Formation, Maastrichtian.

Paratype

WAM 96.804, Gully 1 km northwest of West Tank, Giralia Station, Giralia Range, Carnarvon Basin, Miria Formation, Maastrichtian.

Diagnosis

Two valves equally biconvex; shell smooth; foramen submesothyridid; deltidal plates conjunct.

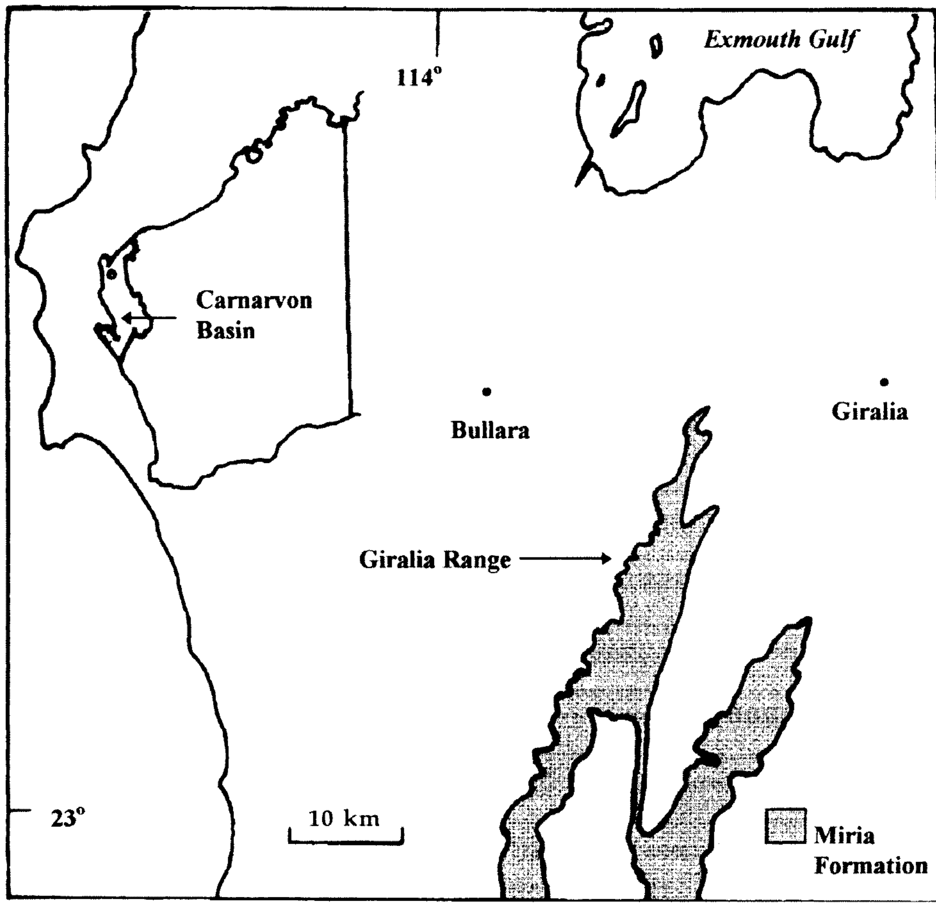


Figure 3 Late Cretaceous Miria Formation in the central Carnarvon Basin.

Description

Exterior. Small triangular shell up to 11.7 mm long. Biconvex, depth to 59% shell length. Width greatest anterior to mid-length, to 97% shell length. Lateral margin of ventral valve curved in posterior two thirds, dips to form a deep sulcus anteriorly, dorsal valve curved posteriorly, flattens towards anterior commissure like the keel of a boat, widest point one third distance to cardinal margin. Shell smooth; no punctation; not costate; growth lines distinct. Cardinal margin gently curved; lateral margin curves gently towards ventral valve; anterior commissure bisulcate. Umbo short, pointed; beak erect; foramen small (4% shell length), submesothyridid; deltidal plates conjunct.

Internal structures unknown.

Remarks

This species is referred to *Eohemithyris* as the two valves are equally convex and it lacks costation. *Rhytirhynchia* Cooper, 1957 and *Probalarina* Cooper, 1959 are clearly costate. The genus *Basiliola* Dall, 1908 has an inconspicuous fold while that of *Eohemithyris* is quite distinct. *Neorhynchia* Thomson, 1915 has a unisulcate anterior commissure and *Streptaria* Cooper, 1959 is sharply uniplicate while this species of *Eohemithyris* is bisulcate.

Eohemithyris miriaensis has an bisulcate anterior commissure. *E. colurnus* (Hedley), a Recent species from Gabo Island of the Coast of Victoria, Australia, is uniplicate and costate, the costae creating a crenulate margin, a feature absent in *E. miriaensis*. *E. alexi* Hertlein and Grant, 1944, an Eocene species from California U.S.A., although smooth shelled, has a uniplicate anterior commissure. *E. grayi* (Woodward, 1855), a Recent species from Fiji Islands, is costate and uniplicate, the costae once again creating crenulate margins. *E. gettysburgensis* Cooper, 1959, a Miocene species from Gettysburg, Washington, U.S.A., is smooth shelled but has a uniplicate anterior commissure while *E. miriaensis* is bisulcate.

Etymology

The name is derived from the Miria Formation.

Eohemithyris wildei sp. nov.
Figure 4 G–K

Material Examined

Holotype

WAM 6705, Hosking' Chalk, Gingin Chalk, Perth Basin, Santonian-Campanian.

Paratypes

WAM 70.1833, Gingin; WAM 97.700, McIntyre's Gully; WAM 78.4356, "Kayanaba", Dandaragan; Gingin Chalk, Perth Basin, Santonian-Campanian;

Other Material

Gingin Chalk: WAM 3850, WAM 6254, 76.2246 Gingin; WAM 6188, 6444/5, 74.1261, McIntyre's Gully, Gingin; WAM 6427, 7460/1, Molecap Hill, Gingin; WAM 63.129,132; 80.743, Yatheroo, Dandaragan; Gingin Chalk, Perth Basin, Santonian-Campanian.

Toolonga Calcilutite: WAM 88.884, Meanarra Hill, Toolonga Calcilutite, Carnarvon Basin, Santonian-Campanian.

Diagnosis

Finely costellate to anterior, deeply costellate at commissure, variable, thin outer socket ridge.

Description

Exterior. Small to medium subcircular shell to 11 mm in length. Biconvex, ventral valve less convex, depth 60% shell length. Width greater than length in some specimens, widest at or anterior to mid-length. Growth lines distinct, fine shallow costellation, plications developing anteriorly, especially in larger specimens. Cardinal margin wide to margin, rounded; lateral valve edge bevelled, lateral margin straight, rises to dorsal valve at anterior; anterior commissure uniplicate to sulciplicate to multiplicate. Umbo short, sharp, erect to slightly incurved; beak ridges sharp. Foramen small, 1-2% shell length, oval, submesothyridid; deltidal plates disjunct, palintrope, slightly concave.

Interior. Ventral valve. Teeth deltidiodont, curved upwards; small, narrow dental plate. Muscle scars small, round, indistinct.

Dorsal valve. Outer socket ridge thin; socket small, curved floor. Inner socket ridge curved partially over socket; groove between crural base and inner socket ridge. Loop incomplete. Cardinal process narrow cup above concave small septalium.

Remarks

Eohemithyris miriaensis (Craig, herein), a Maastrichtian species described from the Miria Formation, Carnarvon Basin, Western Australia differs from *E. wildei* in that the shell is smooth. This is also the case for *E. alexi* Hertlein and Grant, 1944, an Eocene species from California U.S.A. and *E. gettysburgensis* Cooper, 1959, a Miocene species from Gettysburg, Washington, U.S.A. Recent species are described as costellate and uniplicate but differ in having a thicker outer socket ridge and the costae being consistently pronounced. This is the earliest known occurrence of the genus.

Etymology

The species is named after Dr S. A. Wilde, Associate Professor of Geology, School of Applied Geology, Curtin University of Technology.

Family Hemithyrididae Rzhonsnitskaya, 1956

Genus *Proteguloryhnchia* Owen, 1980

Type Species

Protegulorhynchia meridionalis Owen, 1980.

Revised Diagnosis

Rounded straight costae, not spinose; beak erect to incurved; foramen small hypothyridid; socket floor corrugated; crura short, divergent, radulifer; short median septum; cardinal process indistinct, triangular.

Protegulorhynchia meridionalis Owen, 1980

Figure 4 M–Q

1980 *Protegulorhynchia meridionalis* Owen: 129, figs 15 a–c, 16.

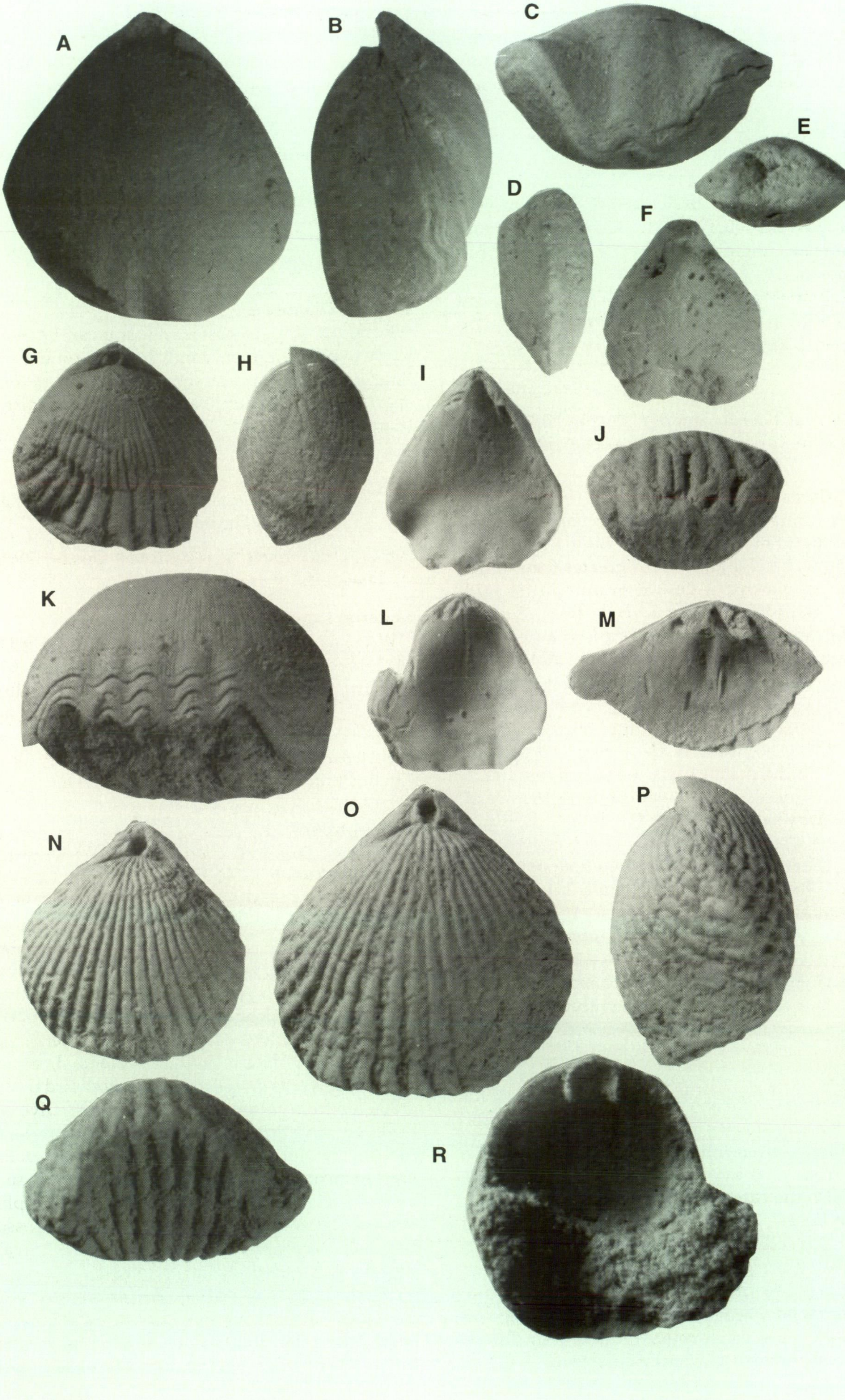
Material Examined

WAM 82.1937 Gingin; WAM WAM 6186, 68.670, McIntyre's Gully, Gingin; WAM 4527, 6253, Hosking's Chalk, Gingin; WAM 5937-9, 44; Musk's Chalk, Gingin; WAM 74.1142, Molecap Hill, Gingin; WAM 63.131, 77.3548/3550, Yatheroo, Dandaragan; WAM 4242, "Kayanaba", Dandaragan,; Gingin Chalk, Perth Basin, Santonian-Campanian.

Description

Exterior. Small to medium sized triangularly pentagonal shell to 11.1 mm in length. Biconvex, ventral valve slightly flatter, depth 61% shell length. Width greatest just anterior to mid-length, 95% shell length. Growth lines distinct to prominent, costellate, ribs as wide as troughs, rounded, 3 ribs per mm at mid length, deep sulcus anterior third of ventral valve. Cardinal margin curved, narrow (60% shell width) to lateral margin; lateral valve edge bevelled, lateral margin sigmoidal, dipping strongly towards dorsal valve anterior third of shell, crenulate from cardinal margin; anterior valve edge bevelled, anterior commissure uniplicate, sulcus 64% shell width, crenulate. Umbo sharp, short. Beak erect to incurved; beak ridges sharp. Foramen small, oval, 4% shell length, hypothyridid; deltidal plates obscured as foramen meets dorsal umbo, possibly conjunct. Interarea concave, depressed towards dorsal valve, raised towards foramen.

Interior. Dorsal valve. Outer socket ridge thickened cardinal margin, curves inwards. Socket short, triangular, round floor, striated horizontally. Inner socket ridge curved towards socket, socket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not completely covered. Hinge plate and crural base fused. Crura short, divergent. Short low median septum widening posteriorly, fused to lower cardinal margin, radulifer. Cardinal process triangular posterior apex; slightly swollen umbo. Muscle scars indistinct, short, round.

Remarks

The specimens have been placed in *Protegulorhynchia meridionalis* Owen, 1980 from the Early Campanian of James Ross Island, Antarctic Peninsula, as they fit the general description and do not fit any other taxon yet described.

Protegulorhynchia bevanorum sp. nov.

Figure 4 R, 5 A–C

Material Examined

Holotype

WAM 6706, Molecap Hill, Gingin Chalk, Perth Basin, Santonian-Campanian.

Paratype

WAM 74.1136, Molecap Hill, Gingin; WAM 4795, One Tree Hill, Gingin; Gingin Chalk, Perth Basin, Santonian-Campanian.

Other Material

WAM 3851, Gingin; WAM 3942, 5289, Molecap Hill, Gingin; Gingin Chalk, Perth Basin, Santonian-Campanian.

Diagnosis

Small *Protegulorhynchia* with numerous costae, parasulcate anterior commissure.

Description

Exterior. Small subpentagonal shell to 6.5 mm in length. Biconvex, both valves equally so, depth 65% shell length. Width just anterior to mid-length, 86% shell length. Growth lines distinct, costellate, non-bifurcating, crowded at umbo, spreading anteriorly, 6 per mm at mid-length, ribs rounded, widening anteriorly, trench widening anteriorly, narrower than ribs posteriorly, wider than ribs anteriorly. Cardinal margin wide, strongly curved; lateral valve edge rounded, lateral margin straight, curved towards ventral valve anteriorly; anterior commissure parasulcate, lateral sulci narrow, central plication wide, 50% shell width, flat. Umbo short, curved; beak erect; beak ridges sharp posteriorly. Foramen circular with spout-like overhanging umbo, hypothyridid; deltidal plates disjunct, raised slightly to form rim.

Internal. Dorsal valve. Sockets short, corrugated; outer socket ridge relatively wide. Inner socket ridge overhanging socket slightly, fused to crural base. Hinge plates indistinguishable. Crura, loop incomplete. Median septum short, blade-like, raised posteriorly raduliform. Cardinal process long, triangle within posterior area, raised slightly above cardinal margin.

Remarks

The specimens examined are similar to *Protegulorhynchia meridionalis* Owen, 1980 except for the greater number of costae per mm (6 per mm in *P. bevanorum* and 3 per mm in *P. meridionalis*) and a parasulcate anterior commissure while the commissure of *P. meridionalis* is uniplicate. These features are of specific importance.

Etymology

The name is in honour of Dr A. W. R. Bevan, Curator of minerals and meteorites at the Western Australian Museum, and his wife Ms J. C. Bevan, Curator of the E. de C. Clarke Geological Museum, University of Western Australia.

Genus *Tegulorhynchia* Chapman and Crespin, 1923

Type Species

Rhynchonella squamosa Hutton, 1873.

Tegulorhynchia hrodelberti sp. nov.

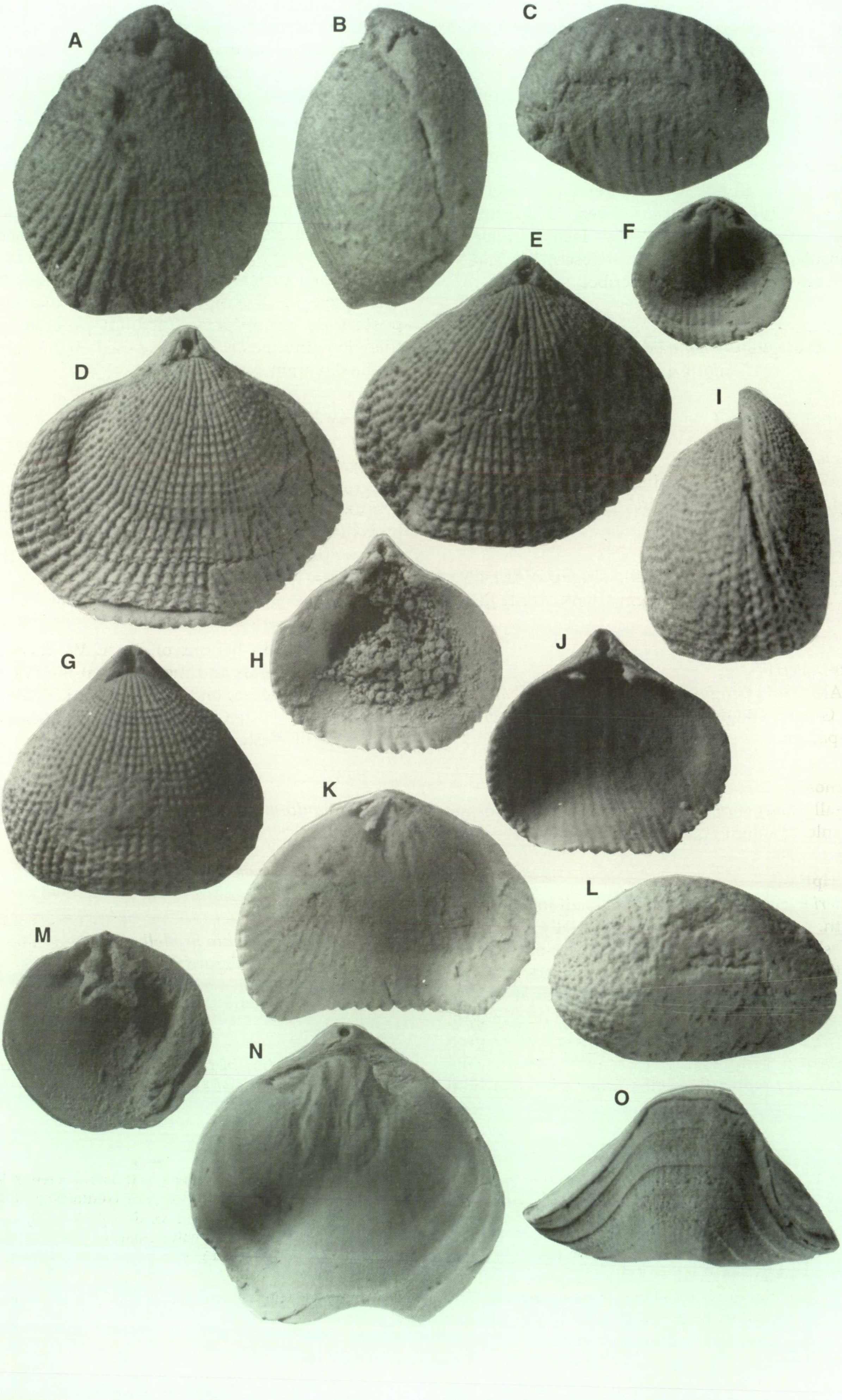
Figure 5 D–L

Material Examined

Holotype

WAM 74.1300a, Spring Gully, Gingin, Gingin Chalk, Perth Basin, Santonian-Campanian.

◀ **Figure 4** A–F, *Eohemithysis miriaensis* sp. nov. **A–C**, WAM 96.818, holotype. **A**, dorsal view x 5; **B**, lateral view x 5; **C**, anterior commissure x 4; **D–F**, WAM 96.804, paratype. **D**, lateral view x 4; **E**, anterior commissure x 4; **F**, dorsal view x 4. **G–N**, *Eohemithyris wildei* sp. nov. **G, H, J**, WAM 6705, holotype. G, dorsal view; **H**, lateral view; **J**, anterior commissure. All x 5; **I, L**, WAM 78.4356, paratype. **I**, ventral valve interior; **L**, Dorsal valve interior. All x 5; **K**, WAM 70.1883, paratype, anterior commissure x 5. **M–Q**, *Protegulorhynchia meridionalis* Owen, 1980. **M**, WAM 63.131, dorsal valve interior; **N**, WAM 6253, dorsal view; **O**, WAM 82.1937, dorsal view; **P**, WAM 82.1937, lateral view; **Q**, WAM 82.1937, anterior commissure. All x 5. **R**, *Protegulorhynchia bevanorum* sp. nov. **R**, WAM 74.1136, paratype, dorsal valve interior x 8.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Paratypes
WAM 74.1300b, c, Spring Gully, Gingin; WAM 70.1836, 76.2221, Gingin; Gingin Chalk, Perth Basin, Santonian-Campanian.

Other Material
Gingin Chalk: WAM 4529, Hosking's Chalk, Gingin, Gingin Chalk, Perth Basin, Santonian-Campanian.
WAM 74.1264, McIntyre's Gully, Gingin; WAM 74.1136, Molecap Hill, Gingin; WAM 77.3529, 78.4197, "Kayanaba", Dandaragan; WAM 74.4396, "Noondel-Wandilla", Dandaragan; WAM 79.2339, "Kyno", Dandaragan; Gingin Chalk, Perth Basin, Santonian-Campanian.
Toolonga Chalk: WAM 74.1175, 75.10, Meanarra Hill; WAM 88.220, Murchison House Station; Toolonga Calcilutite, Carnarvon Basin, Santonian-Campanian.

Diagnosis
Small *Tegulorhynchia*, multicostate, wider than long, short pointed umbo, grooved socket teeth, anterior commissure uniplicate.

Description
Exterior. Small, subpentagonal, subtriangular, to subcircular, shell up to 11.5 mm in length. Biconvex, dorsal valve more convex, depth up to 72% shell length. Width greater than length, widest anterior to mid-length, up to 113% shell length. Costellate, 4 ribs per mm at mid-length, bifurcate posterior to mid-length, growth lines distinct, numerous, form rugose pattern with ribs to spinose. Cardinal margin short, 48% shell length; lateral valve edge rounded, lateral margin straight to gently curved towards ventral valve anteriorly; anterior commissure uniplicate, plication 50% shell width. Umbo strong, pointed; beak erect; beak ridges rounded. Foramen small, up to 6% shell length, round with extension of pedicle collar posteriorly, hypothyridid; deltidal plates small, tips just touching in most specimens to disjunct.

Interior. Ventral valve. Teeth curved towards dorsal valve, corrugated, concave depression posterior connection to cardinal margin. Muscle scars elongate, separated by low wide ridge; pedicle collar sessile, corrugated horizontally.

Dorsal valve. Outer socket ridge indistinct from margin. Socket short, curved floor, slightly buttressed to margin. Inner socket ridge shorter than socket, partially curved over socket. Inner ridge, crural base, hinge plate fused inseparable visually, structure sigmoidally curved to posterior, form acute triangular apex at umbo. Crura short, divergent, radulifer. Short median septum, 43% shell length, follows curve to cardinal margin, blade-like. Muscle scars kidney-shaped either side of median septum. Cardinal process indistinct in triangular posterior apex.

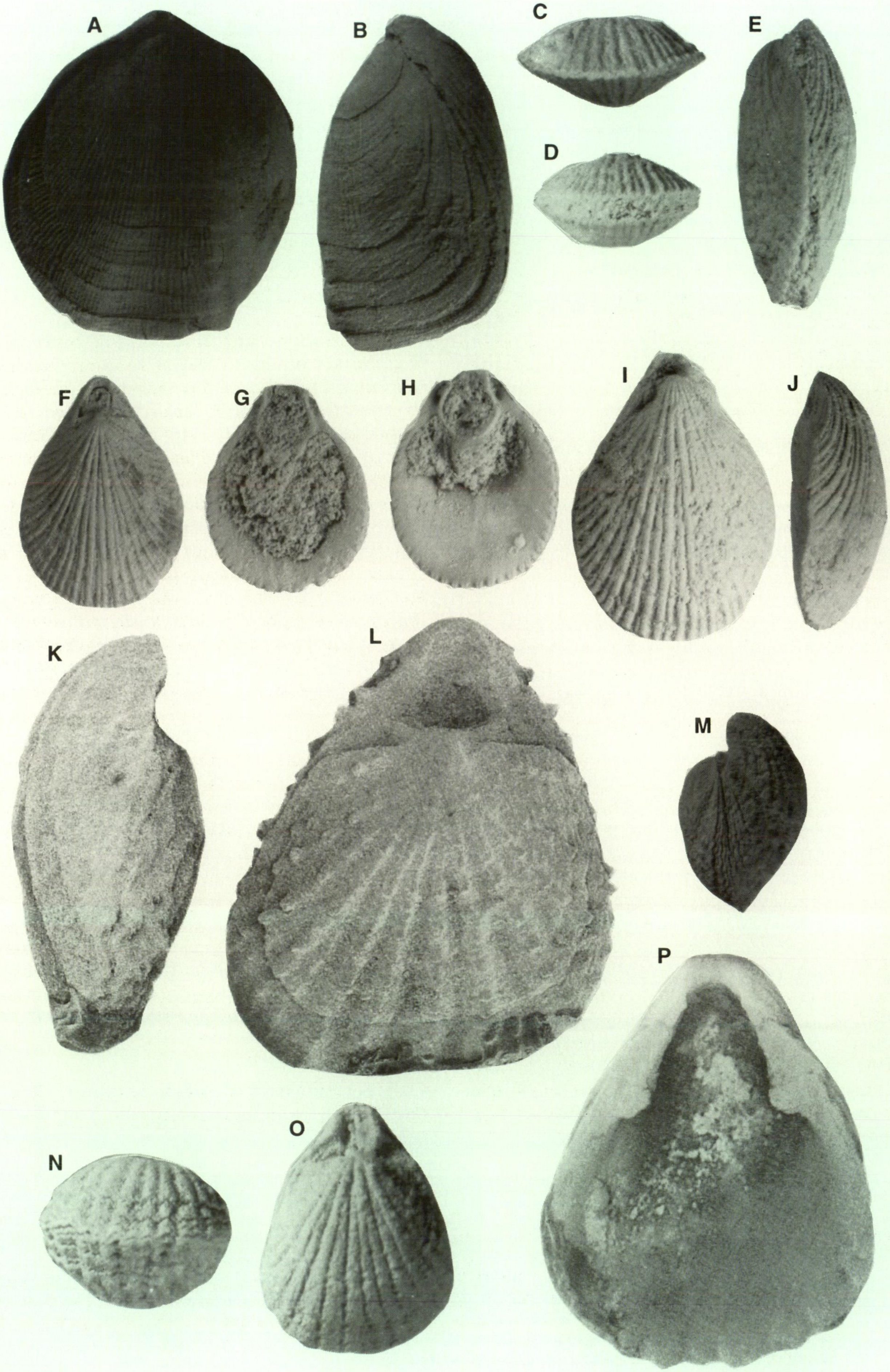
Remarks
The costation rate (number per mm) in *T. hrodelberti* is similar to that of *T. boongeroodaensis*. McNamara (1983) uses this ratio to distinguish *T. boongeroodaensis* from *T. squamosa* (Hutton, 1873), *T. sublaevis* (Thomson, 1918), *T. coelata* (Tenison Woods, 1878) and *T. thomsoni* Chapman and Crespin, 1923. *T. hrodelberti* has more numerous spinose costae than *T. sublaevis* (Thomson, 1918). It differs from *T. boongeroodaensis* in that there is a groove between the inner socket ridge and the crural base, not found in *T. hrodelberti*. *T. boongeroodaensis* also has a deeper socket than *T. hrodelberti*. The plication in *T. hrodelberti* is marked even in the small specimens. McNamara describes the juveniles of *T. boongeroodaensis* as rectimarginate as does Lee (1980) for *T. squamosa* and *T. sublaevis*. *T. hrodelberti* differs from *T. ampullacea* Bitner, 1996 in the deeper ventral valve and less bulbous ventral valve as well as having a higher ratio of costae (4 per mm in *T. hrodelberti* and 2.7 per mm in *T. ampullacea*). *T. imbricata* (Buckman, 1910) is overall flatter and has less costae per mm than *T. hrodelberti*.

Many of the specimens are distorted, becoming asymmetrical. This may be as a result of preservation or substrate conditions.

T. hrodelberti is now the oldest known occurrence of the genus *Tegulorhynchia*. The species is found in greensand deposits which is consistent with McNamara's analysis of their substrate preference.

Etymology
Named in honour of my father, Robert (Hrodelbert), from the Saxon meaning famous and bright.

◀ Figure 5 A–C, *Protegulorhynchia bevanorum* sp. nov. **A**, **B**, **C**, WAM 6706, holotype. **A**, dorsal valve view; **B**, lateral view; **C**, anterior commissure. All x 8. **D–L**, *Tegulorhynchia hrodelberti* sp. nov. **D**, **I**, WAM 74.1300a holotype. **D**, dorsal view x 5; **I**, lateral view x 5; **E**, WAM 70.1836, paratype, dorsal view x 5; **F**, WAM 74.1300c, paratype, dorsal valve interior x 4.5; **G**, WAM 74.1300d, paratype, dorsal valve view x 4.5; **H**, **L**, WAM 74.1300b, paratype. **H**, ventral valve interior x 5; **L**, anterior commissure x 4.5; **J**, WAM 76.2221a, paratype, ventral valve interior x 5; **K**, WAM 76.2221b, paratype, dorsal valve interior x 6. **M–O**, *Inopinatarcula acanthodes* (Etheridge, 1913). **M**, WAM 94.5333, dorsal valve interior x 2.5; **N**, WAM 77.3528, ventral valve interior x 2.5; **O**, WAM 78.4360, anterior commissure x 2.5.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Order Terebratulida Waagen, 1883

Suborder Terebratulidina Waagen, 1883

Superfamily Terebratuloidea Gray, 1840

Family Terebratulidae Gray, 1840

Subfamily Terebratulinae Gray, 1840

Genus *Liothyrella* Thompson, 1916

Type Species

Terebratula uva Broderip, 1883.

Remarks

Cooper (1983) describes the foramen of *Liothyrella* as submesothyridid whilst Thomson (1927) describes it as epithyridid. *Liothyrella archboldi*, a species herein described, is clearly permesothyridid. The overall shape of *L. archboldi* is similar to *Dolichozygus* Cooper, 1983, but the loop appears to be shorter than that indicated by Cooper for *Dolichozygus*.

Liothyrella brimmellae sp. nov.
Figure 8 A–C

Material Examined

Holotype

WAM 92.662, "Kayanaba", Dandaragan, Gingin Chalk, Perth Basin, Santonian-Campanian.

Paratypes

WAM 78.948a and b, 92.663, "Kayanaba", Dandaragan, Gingin Chalk, Perth Basin, Santonian-Campanian.

Diagnosis

Liothyrella with distinct straight radiating ribs, strongly convex valves, relatively long beak.

Description

Exterior. Large ovate shell up to 38 mm in length. Biconvex, depth 57% shell length. Width greatest at mid-length, 74% shell length. Finely densely punctate, growth lines prominent, costellate, 9 ribs per mm at mid-length, distance between ribs variable, bifurcation unclear. Cardinal margin wide, deeply curved, lateral valve edge rounded, lateral margin nearly straight; anterior commissure appears unisulcate to uniplicate. Umbo short, beak suberect, labiate; beak ridges attrite. Foramen large, 6–7% of shell length, mesothyridid, 'V' shaped join to deltidal plates; deltidal plates conjunct. Symphytium with median ridge, small, concave, triangular, distinct horizontal ribbing.

Interior. Ventral Valve. Narrow pedicle collar, sessile. Teeth wide, rectangular, curved, slightly buttressed to lateral margin, no dental plates. Muscle scars indistinct.

Dorsal Valve; Outer socket ridge obscured. Inner socket ridge curved partially over socket, fused to crural base and outer hinge plate, form continuous flat, slightly divergent plate. Crural process flatly curved towards lateral margin. Loop incomplete, short, ascending branch rises, widens anteriorly; transverse band most likely arched, wide. No median septum. Thin ridge separates elongated muscle scars. Cardinal process partially obscured, raised cup, narrow rim.

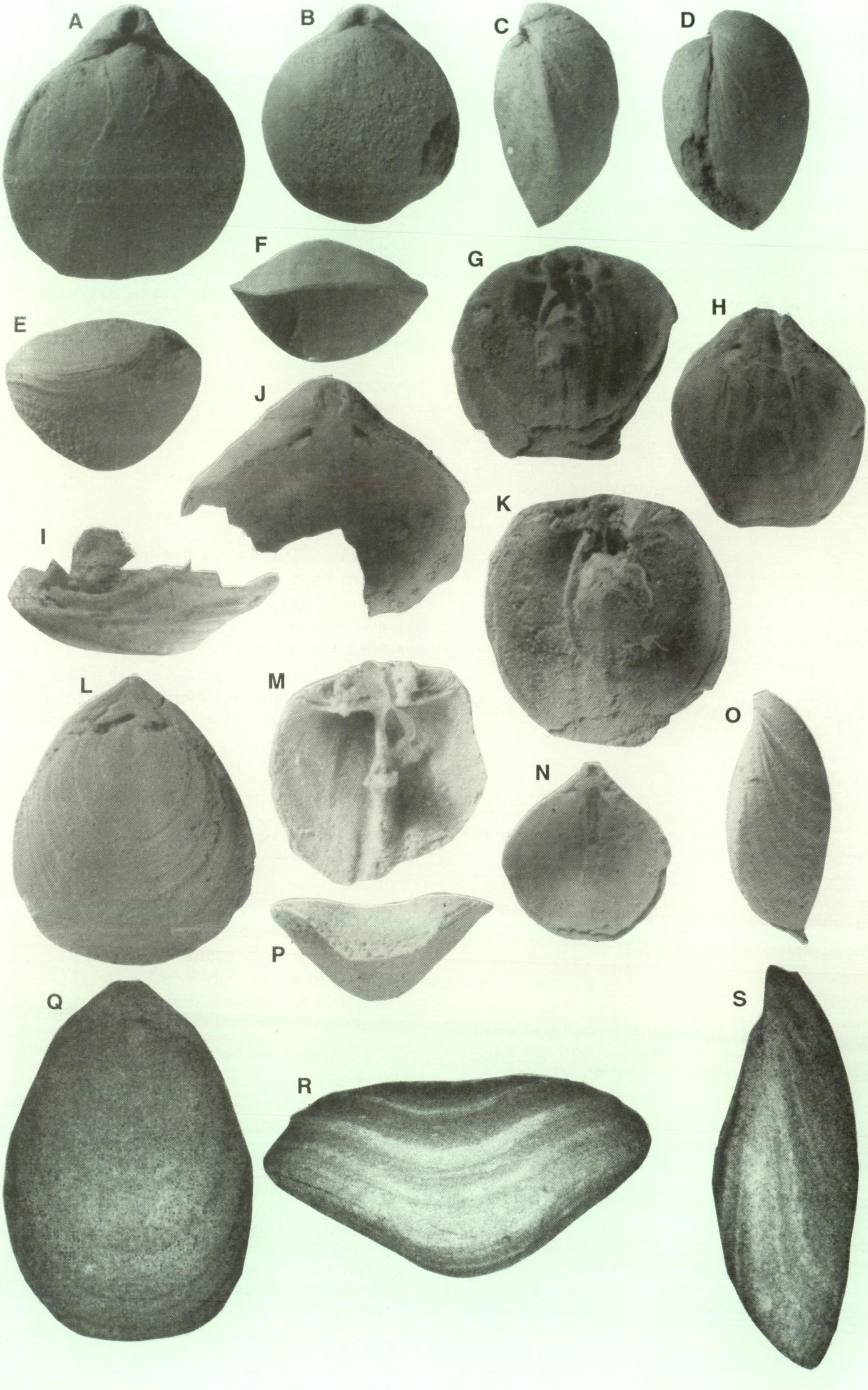
Remarks

There are two specimens, one a mould, the other conjoined. The ribbing is quite distinct. The loop does not appear to be a ring and hence the species is not a *Cancellothyris* or *Terebratulina*. Owen (1980) describes *Liothyrella lecta* from the Campanian of James Ross Island as having "faint radiating ribs". He mentions it having been first described by Guppy (1866) from Trinidad and later by Buckman (1910) from Antarctica. This new species differs in that the radiating ribs are quite strong, the beak more developed and the valves overall more convex and bulbous. *Liaramia* Cooper, 1983, another costae short looped genus, has a much shorter truncated beak, non-divergent crura and thin transverse band. *Arcuatothyris* Popiel-Barczyk, 1972 is also a genus with a short loop and radiating ribs. *Liothyrella brimmellae* differs from *Arcuatothyris* in that the ribs are straight while in *Arcuatothyris* they are curved away from the meridian to the lateral margins.

Etymology

Named after Ms K. Brimmell, Technical Officer at the Western Australian Museum, the collector of both specimens.

◀ **Figure 6** A–B, *Inopinatarcula acanthodes* (Etheridge, 1913). **A**, **B**, WAM 78.4360. **A**, dorsal valve view x 2.5; **B**, lateral view x 2.5. **C–J**, *Terebratulina kendricki* sp. nov. **C**, **F**, **J**, WAM 71.310, holotype. **C**, anterior commissure; **F**, dorsal valve view; **J**, lateral view. All x 4; **D**, **E**, **I**, WAM 96.834, paratype. **D**, anterior commissure x 4; **E**, lateral view x 5; **I**, dorsal valve view x 5. **G**, WAM 96.845a, paratype, dorsal valve interior x 4; **H**, WAM 96.845b, paratype, dorsal valve interior x 4. **K–P**, *Gisilina ovata* (Etheridge, 1913). **K**, lateral view (SEM) x 29; **L**, dorsal valve view (SEM) x 28; **M–O**, WAM 79.2915. **M**, lateral view x 7; **N**, anterior commissure x 8; **O**, dorsal valve view x 7; **P**, ventral valve interior (SEM) x 20.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Liothyrella archboldi sp. nov.
Figure 8 D–I, 9 A–B

Material Examined

Holotype

WAM 89.1278a Gully 500 m northwest of West Tank, Giralia Station, Giralia Range, Carnarvon Basin, Miria Formation, Maastrichtian.

Paratypes

WAM 89.1278 b–g, 96.865 Gully 500 m northwest of West Tank, Giralia Station, Giralia Range, Carnarvon Basin, Miria Formation, Maastrichtian. 74.1267; McIntyre's Gully, Gingin, Gingin Chalk, Perth Basin, Santonian-Campanian.

Other Material

Gingin Chalk: WAM 4597; 7458; 82.2663, Molecap Hill, Gingin; WAM 3852/3, Gingin; WAM 5413, Musk's Chalk, Gingin; WAM 6187; McIntyre's Gully, Gingin; WAM 4576, One Tree Hill, Gingin; WAM 4230/31, Round Hill, "Kayanaba", Dandaragan; WAM 63.153, "Yatheroo", Dandaragan; Gingin Chalk, Perth Basin, Santonian-Campanian.

Toolonga Calcilutite: WAM 88.277, Murchison House Station, Toolonga Calcilutite, Carnarvon Basin, Santonian-Campanian.

Korojon Calcarenite: WAM 84.390, Giralia Range, Korojon Calcarenite, Carnarvon Basin, Campanian-Maastrichtian.

Miria Formation: WAM 60.31, 60.61, 65.555, 71.181, 71.242, 71.288, 80.668, 80.694, 80.870, 80.884, 83.2878, 83.2907, 83.2936, 83.2947, 83.2960, 83.3010, 83.3026, 83.3054, 83.3064, 83.3149, 83.3153, 83.3155, 83.3159, 83.3164, 84.390, 84.426, 84.427, 84.428, 84.432, 84.901, 84.908, 84.922, 84.959, 89.1278, 84.1695, 96.748, 96.802, 96.836, 96.839, 96.842, 96.859, 96.863, 96.865, 96.880, 96.888, 96.894–895, 96.909, 96.917, 96.921 Giralia Range, Carnarvon Basin, Miria Formation, Maastrichtian.

Diagnosis

Shell medium-sized, oval to pear shaped; smooth; not depressed; anterior commissure uniplicate. beak suberect; foramen permesothyridid; symphytium with no median ridge.

Description

External. Oval to pear shaped; medium-sized shell, length from 15.7 to 32.8 mm. Biconvex, greatest depth posterior to mid-length, depth 30% of shell length. Maximum width at mid-length or slightly anterior to it; width 60–65% of shell length. Cardinal process strongly curved; lateral valve edge bevelled to rounded to impressed, lateral margin straight until anterior third where it dips strongly toward dorsal valve; anterior commissure uniplicate (fold 30% of shell length). Shell smooth with distinct growth lines; finely and densely punctate. Umbo stout, beak suberect, labiate, beak ridges rounded, beak margins wide, extend to just posterior to mid-line. Foramen large (8% of shell length), round, permesothyridid. Symphytium concaved, small, no median ridge; pedicle collar sessile.

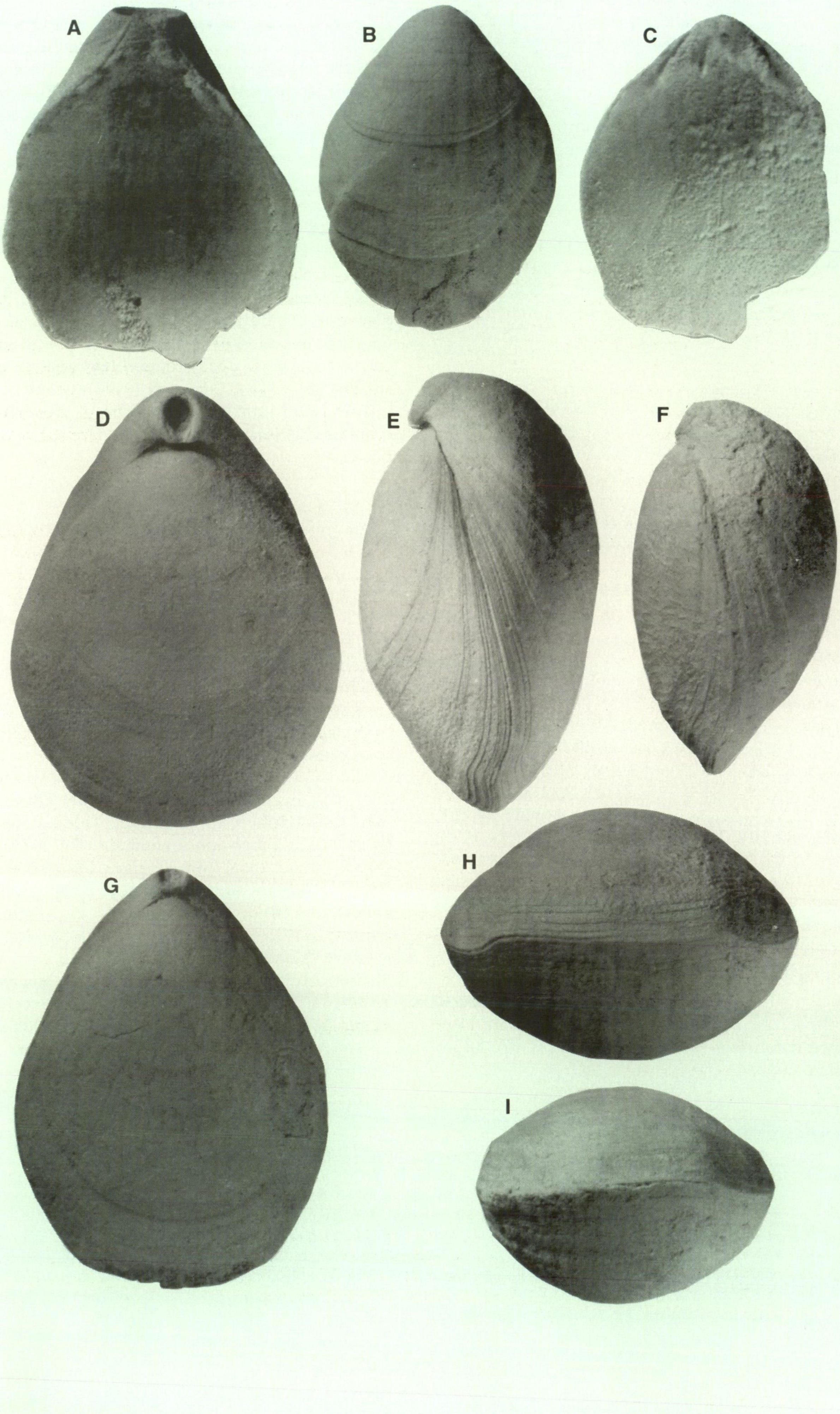
Internal. Loop short, elongate, descending branches wide, transverse band arched towards posterior.

Remarks

Some variation exits where the anterior commissure lacks uniplication, remaining rectimarginate as the lateral margin remains straight. One specimen has markings on the shell similar to those caused by pedicle rootlets (Bromley and Surlyk 1973), and there is a great deal of trace fossil activity on the surface of many of the specimens. The majority of the specimens are casts (or internal moulds). Preservation indicates ridging from near the pedicle. These could be calcite ridges or suggestions of the mantle canals.

Allan (1932) described a number of species of *Liothyrella* from the "Tertiary" of New Zealand. *L. concentrica* (Hutton, 1873) from the Late Eocene-Late Oligocene is much more elongate. The beak of *L. gravida* (Suess, 1864) from the Early Miocene is more strongly labiate and the overall shape is more subcircular than in *L. archboldi*. *L. kakanuensis* (Hutton, 1905) from the Early Oligocene -Miocene is small, inflated, elongate and has an erect beak, distinguishing it from *L. archboldi*. *L. landonensis* Thomson, 1918 from the Middle Oligocene, *L. magna* (Hamilton, 1910) from the Early Oligocene, *L. oamarutica* (Boehm, 1904) from the Late Oligocene-Early Miocene, *L. pulchra* Thomson, 1918

◀ **Figure 7** A–K, *Kingena mesembrina* (Etheridge, 1913). **A**, **C**, **F**, WAM 74.1138a. **A**, dorsal valve view x 3; **C**, lateral view x 2.5; **F**, anterior commissure x 2.5. **B**, **D**, **E**, WAM 74.1138c. **B**, dorsal valve view x 3; **D**, lateral view x 2.5; **E**, anterior commissure x 2.5. **G**, WAM 78.279a, dorsal valve interior x 5; **H**, WAM 78.279b, ventral valve interior x 4.5; **I**, **K**, WAM 3522. **I**, lateral view x 5; **K**, dorsal valve interior x 4.5. **J**, WAM 74.1138b, ventral valve interior x 3. **L–S**, *Bouchardiella cretacea* (Etheridge, 1913). **L**, **O**, **P**, WAM 74.1301. **L**, dorsal valve view x 5; **O**, lateral view x 4.5; **P**, anterior commissure x 4.5. **M**, WAM 63.121, dorsal valve interior x 9; **N**, WAM 74.1301b, ventral valve interior x 5; **Q–S**, WAM 3523 (SEM) holotype. **Q**, dorsal vave exterior x 11.4; **R**, anterior commissure x 20; **S**, lateral margin x 13.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from the Late Eocene-Miocene, *L. circularis* Allan, 1932 from the Early Oligocene-Miocene, *L. pittensis* Allan, 1932 from the Early -Mid Pliocene, *L. skinneri* Allan, 1932 from the Late Miocene-Pliocene, and *L. thomsoni* Allan, 1932 from the Middle-Late Miocene are subcircular while *L. archboldi* is ovate to elongate. *L boehmi* Thomson, 1918, from the Early Miocene is also subcircular, the width 77% of shell length, and longer , up to 45 mm while *L. archboldi* is up to 33 mm. *L. elongata* Allan, 1932 from the Early-Late Miocene and *L. neglecta* (Hutton, 1905) from the Early Miocene are small (7 mm and 11.5 mm respectively) while *L. archboldi* is medium-sized ranging from 15.7 to 32.8 mm in length. *L. neglecta* (Hutton, 1905) has a more depressed shell, a feature not present in *L. archboldi. L. gigantea* (Allan, 1937) from the Middle Oligocene has "wavy radial striae" (Allan, 1937), structures which are not present on *L. archboldi.*

L. vitriodes (Tenison-Woods) from the Late Oligocene-Miocene, Table Cape Tasmania (Tate 1899) is small, smooth, subcircular with a small foramen. Previously the oldest record of *Liothyrella* were the Late Eocene species *L. concentrica* (Hutton, 1873) and *L. pulchra* Thomson, 1918. Cooper (1981,1982 and 1983) has described a number of species of Recent *Liothyrella* from Antarctica, southern South America, the Falkland Islands, the southern Indian Ocean, Australia and New Zealand.

This is the oldest known record of the genus.

Etymology

After Prof. Neil W. Archbold, Professor of Palaeontology, Deakin University, Victoria, Australia, an accomplished Permian brachiopodologist.

Family Zenobiathyridae fam. nov.

Diagnosis

Valves equally biconvex; capillate, rugose; dorsal and ventral folding equal. Anterior commissure rectimarginate to uniplicate; foramen large, round, mesothyridid, deltidal plates conjunct; cardinal process delicate.

Remarks

Although very similar externally to species of *Magellania* and *Dereta* from the suborder Terebratellidina Muir-Wood, 1955, the internal features of *Zenobiathyris*, particularly the short loop and lack of a median septum, places it in the suborder Terebratulidina Waagen, 1883. The other families within the superfamily Terebratuloidea differ in a number of aspects. Terebratulidae is only partially capillate and has a median septum whereas Zenobiathyridae is completely capillate and has no median septum. Members of the Cheniothyrididae are ligate and Tegulithyrididae are ligate to pliciligate, whilst Zenobiathyridae are incipiently to deeply ornithellid. Members of Dictythyrididae have a deep ventral sulcus a feature not common to all species of Zenobiathyridae. The shell is smooth in the Pygopidae and the folding produces an enclosed median perforation. This does not occur in Zenobiathyridae which, as mentioned, are also capillate. Dyscoliid genera develop lateral flanges creating impressed margins. The valve edges in the Zenobiathyridae are bevelled. The loop in the Cancellothyrididae forms a complete ring while in the Zenobiathyridae the loop is merely arched.

Genus *Zenobiathyris* gen. nov

Type Species

Zenobiathyris mutabilis sp. nov.

Diagnosis

Small to medium, biconvex shell, valves equally so. Capillate, rugose. Anterior commissure rectimarginate to uniplicate. Beak stout, suberect. Foramen large, round, mesothyridid, deltidal plates conjunct; cardinal process delicate.

Etymology

From Zenobia, the name of my wife, and the queen of Palmyra in the third century AD, meaning "her father's jewel".

Zenobiathyris mutabilis sp. nov.

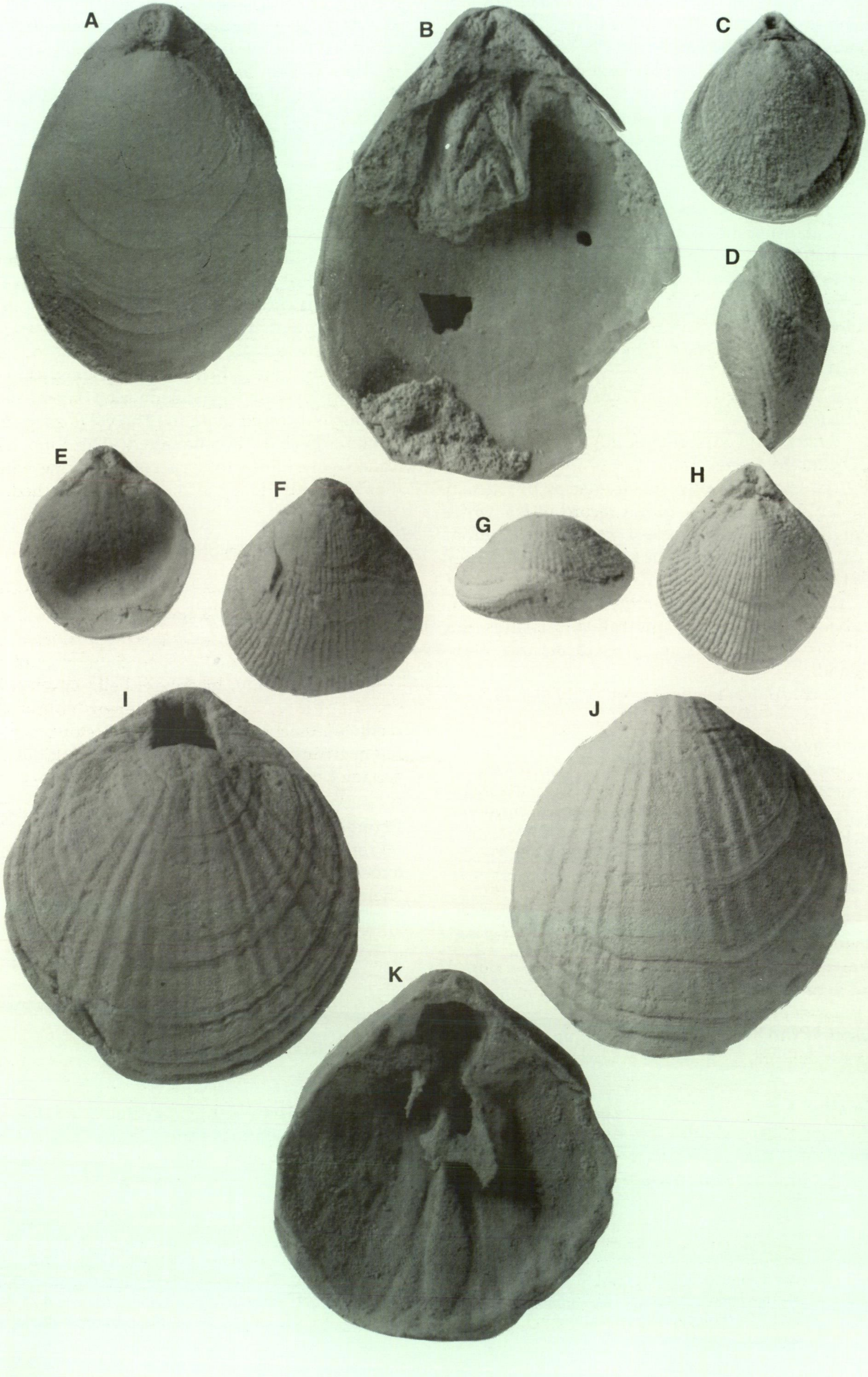
Figures 10 A–O

Material Examined

Holotype

WAM 83.3148, Range paddock, 2.3 km west northwest of Whitlock Dam, Giralia Station, Giralia Range, Carnarvon Basin, Miria Formation, Maastrichtian.

◀ **Figure 8** A–C, *Liothyrella brimmellae* sp. nov. **A**, **C**, WAM 78.948a, paratype. **A**, ventral valve interior x 5; **C**, dorsal valve interior x 4. **B**, WAM 92.662, holotype, ventral valve view x 2. **D–I**, *Liothyrella archboldi* sp. nov. **D**, **E**, **H**, WAM 96.865, paratype. **D**, dorsal valve view; **E**, lateral view; **H**, anterior commissure. All x 3. **F**, **I**, WAM 89.1278a, holotype. **F**, lateral view; **I**, anterior commissure. All x 3.**G**, WAM 89. 1278b, paratype, dorsal valve view x 3.



Paratypes

WAM 83.3011, 83.3115, 83.3148, Gully draining east of Bullara-Giralia Road, Giralia Station, Giralia Range, Carnarvon Basin, Miria Formation, Maastrichtian.

Other Material

Gingin Chalk: WAM 7456, Molecap Hill, Gingin; Gingin Chalk, Perth Basin, Santonian-Campanian.

WAM 78.4420/42, "Noondel-Wandilla", Dandaragan; WAM 63.130, 80.739, "Yatheroo", Dandaragan; Gingin Chalk, Perth Basin, Santonian-Campanian.

Toolonga Calcilutite: WAM 97.708, Ajana; WAM 74.1176, Meanarra Hill; WAM 88.198, Murchison House Station; Toolonga Calcilutite, Carnarvon Basin, Santonian-Campanian.

Korojon Calcarenite: WAM 84.393/7, Giralia Range, Korojon Calcarenite, Carnarvon Basin, Campanian-Maastrichtian.

Miria Formation: WAM 60.109, 60.23, 60.60, 71.152, 71.180, 71.243-245, 71.289, 71.311, 71.477, 74.588, 80.669, 80.695, 80.789, 80.885, 80.948, 80.952, 83.2911, 83.2959, 83.2990, 83.3011, 83.3095, 83.3115, 83.3148, 83.3152, 83.3160, 83.3162, 83.3165-1696, 84.389, 84.391-393, 84.397, 84.429, 84.902, 84.907, 84.921, 84.947, 85.319, 88.126, 88.91-93, 89.1279, 89.1279, 92.702-704, 96.820, 96.821, 96.829, 96.837, 96.843-845, 96.860, 96.861, 96.866, 96.881-882, 96.900, 96.918, 96.923, 96.931-933 Giralia Range, Carnarvon Basin, Miria Formation, Maastrichtian.

Diagnosis

As for genus.

Description

External. Medium-sized subpentagonal shell, length from 5.4 to 25.9 mm. Biconvex, both valves to same degree; bulbous, depth 50-75% of shell length, deepest at or near mid-length. Width 80–85% of shell length, widest anterior to mid-length. Ribbed with 3–5 ribs per mm at mid-length; growth lines prominent, creating rugose appearance at intersection with ribs. Cardinal margin strongly curved; lateral margin straight, crenulate for anterior two thirds; anterior valve edge bevelled, anterior commissure rectimarginate to uniplicate, often squared or curved inwards giving a "bitten off" (strangulate) appearance; many specimens ornithellid, with two sulci, one on each valve, producing a rectimarginate to slightly uniplicate anterior commissure, many have a marked flattening of the anterior composed of several layers or growth lines. Umbo stout, suberect; beak ridges attrite, beak margins extend to lateral margin. Foramen large (9% of shell length), round, mesothyridid. Symphytium acute and small; deltidal plates conjunct.

Internal. Ventral valve. Hinge teeth angled into shell, convex, delicate with no plates and bases not swollen. No muscle scars apparent.

Dorsal valve. Cardinal area small. Sockets shallow, triangular, no roof. Outer socket ridge indistinguishable from edge of lateral margin. Inner socket ridge high curves slightly over socket. Outer hinge plate and crural bases form one thin concaved surface. Median septum absent. No muscle scars apparent. Crural process pointed, descending loop wide, thin; transverse band short, wide, median gentle fold. Cardinal process delicate, protuberant, slightly angled towards ventral valve, surface striated.

Remarks

There is a large degree of variation within the species. At one extreme the depth is 50–60% of shell length, greatest depth being posterior to mid-length. Shell ribbing is less numerous with up to 3 ribs per mm. The ribs are not as raised and thus rugose nature is less pronounced. At the other extreme the depth is 70–75% of shell length, the ribs are more numerous (5 ribs per mm) and the pattern is more rugose. The foramen, beak, margins and general outline are the same over the whole continuum.

There is also a continuum with respect to the number of growth lines. At one end are those which are flatter and have less growth lines. The longest specimens fit this pattern. The shorter specimens which are more bulbous tend to be the ornithellid specimens and have the "bitten off" (strangulate) appearance at the anterior commissure. They also have a greater number of growth lines per mm. This suggests a variance in growth rates between the two forms.

Etymology

From the Latin "mutabilis" meaning changeable or fickle, refering to its variation in shape.

Zenobiathyris plicatilis sp. nov.

Figure 9 C–H

◀ **Figure 9** A, B, *Liothyrella brimmellae* sp. nov. **A**, WAM 89.1278a, holotype, dorsal valve view x 3; **B**, WAM 74.1267, paratype, dorsal valve interior x 4. **C–H**, *Zenobiathyris plicatilis* sp. nov. **C**, **F**, WAM 78.4396, paratype. **C**, dorsal valve view; **F**, ventral valve view. All x 5. **D**, **G**, **H**, WAM 68.135, holotype. **D**, lateral view; **G**, anterior commissure; **H**, lateral view. All x 5. **E**, WAM 76.2245b, ventral valve interior x 10. **I–K**, *Gemmarcula doddsae* sp. nov. **I–K**, WAM 78.4196, holotype. **I**, dorsal valve view x 4.5; **J**, ventral valve view x 4.5; **K**, dorsal interior x 5.

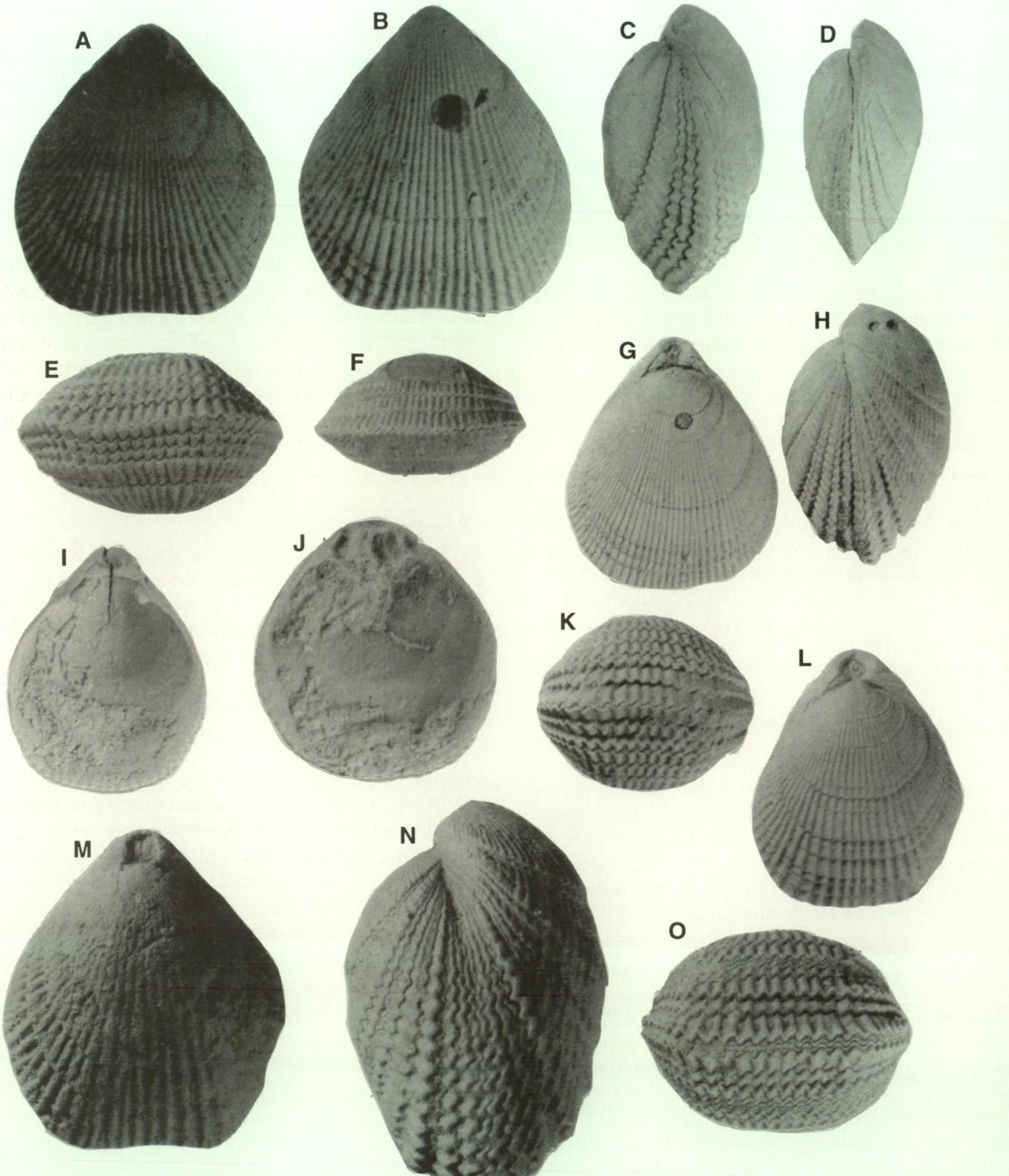


Figure 10 **A–O**, *Zenobiathyris mutabilis* sp. nov. **A–C**, **E**, WAM 83.3011, paratype. **A**, dorsal valve view; **B**, ventral valve view; **C**, lateral view; **E**, anterior commissure. All x 3; **D**, **F**, **G**, WAM 83.3148b, paratype. **D**, lateral view; **F**, anterior commissure; **G**, dorsal valve view. All x 3. **H**, **K**, **L**, WAM 83.3148a, holotype. **H**, lateral view; **K**, anterior commissure; **L**, dorsal valve view. All x 3. **I**, WAM 83.3115a, paratype, ventral valve interior x 3; **J**, WAM 83.3115b, paratype, dorsal valve interior x 3.3; **M**, WAM 80.885a, (larger variant) dorsal valve view x 2; **N**, WAM 97.708, lateral view x 4; **O**, WAM 80.885b, anterior commissure x 2.

Material Examined

Holotype
WAM 68.135, "Yatheroo", Dandaragan, Gingin Chalk, Perth Basin, Santonian-Campanian.

Paratype
WAM 78.4396, "Noondel-Wandilla", Dandaragan, Gingin Chalk, Perth Basin, Santonian-Campanian.

Other material
WAM 74.1263, McIntyres, WAM 76.2245, Hosking's Chalk, Gingin; WAM 4596a, Molecap Hill, Gingin; WAM, 79.2329, WAM 80.402, "Kyno", Dandaragan; WAM 4240-1, 80.737/744, "Kayanaba", Dandaragan; WAM 63.128, "Yatheroo" Dandaragan, Gingin Chalk, Perth Basin, Santonian-Campanian.

Diagnosis

Zenobiathyris with distinct uniplicate anterior commissure; 7 ribs per mm; ribs not producing rugose appearance.

Description

Exterior. Small ovate to pyriform shell to 7.7 mm. Biconvex, depth to 50% shell length. Width greatest anterior to mid-length, to 90% shell length. Growth lines distinct; constellate, 7 ribs per mm, rounded, ribs same width as trenches. Cardinal margin short, curved, to 40% shell length; lateral valve edge bevelled, lateral margin straight posterior two thirds, curves towards dorsal valve anterior third; anterior commissure uniplicate, plication 50% shell width. Umbo stout, curved; beak suberect; beak ridges attrite. Foramen relatively large to 8.5% shell length, submesothyridid; deltidal plates conjunct. Symphytium narrow, flat, corrugated.

Interior. Ventral valve. Pedicle collar narrow, sessile. Socket teeth large cylindrical, curved dorsally, lamella growth, groove between teeth and margin, widens posteriorly, slight buttressing to valve wall. Muscle scars short heart shaped, directly under pedicle opening.

Dorsal valve. Outer socket ridge slight thickening of margin. Sockets large, floor concave, corrugated. Inner socket ridge high, slightly overhangs socket. Crural base fused to inner socket ridge; no hinge plates discernible. Crural process sharp point; loop appears short at end of parallel crura. Cardinal process laterally elongate, thin, striated, fused to inner socket ridge distally; other internal features obscured.

Remarks

This species is similar in many respects to *Zenobiathyris mutabilis.* The anterior plication is much more pronounced and the number of ribs per mm is nearly double (7:4) that of *Z. mutabilis*. The cardinal margin of *Z. plicatilis* is more curved than that of *Z. mutabilis*. The specimens examined are on average smaller than *Z. mutabilis* for the same number of distinct growth lines. The interaction between the growth lines and costae do not produce a rugose appearance in *Z. plicatilis* unlike those of *Z. mutabilis*. These features are considered to be of specific importance.

Etymology

From the well developed fold or anterior plication which is much more pronounced in *Z. plicatilis* unlike that in *Z. mutabilis.*

Superfamily Cancellothyrioidea Thomson, 1926

Family Cancellothyrididae Thomson, 1926

Subfamily Cancellothyridinae Thomson, 1926

Genus *Terebratulina* d'Orbigny, 1847

Type Species

Anomia retusa Linne, 1758.

Terebratulina kendricki sp. nov.

Figure 6 C–J

Material Examined

Holotype
WAM 71.310, Toothawarra Creek, Cardabia Station, Giralia Range, Carnarvon Basin, Miria Formation, Maastrichtian.

Paratypes
WAM 96.834, Toothawarra Creek, Cardabia Station , WAM 96.845, north east side of West Tank, Giralia Station, Giralia Range, Carnarvon Basin, Miria Formation, Maastrichtian.

Other Material
WAM 71.152, 80.670, 96.922, locality as for holotype.

Diagnosis

Small to medium-sized, ovate to pear-shaped shell, biconvex; costate, costae bifurcating anterior to umbo. Anterior commissure uniplicate; beak suberect; foramen large, deltidal plates disjunct. Loop small ring developed from inward curved crural processes.

Description

External. Medium-sized shell, 1.7 mm–11.1 mm long, longest specimen 8.0 mm wide, 3.9 mm deep.

Biconvex, dorsal valve flatter; pear shaped to subpentagonal in shape. Widest at the mid-length. Anterior half rounded, posterior half tapering to umbo, deepest at posterior (a quarter distance from posterior umbo) to mid line. Costate rounded, interstitual spaces wider than ribs, 6 ribs / mm, bifurcating just anterior to umbo. Numerous growth lines, most indistinct; form rugose pattern in contact with costae in posterior 2/3 of shell; finely and densely punctate. Cardinal margin 59% shell width, curved; lateral valve edge bevelled, lateral margin incipiently concave curving towards dorsal valve posteriorly and anteriorly. Slight anterior depression in ventral valve; anterior valve edge bevelled, anterior commissure incipiently uniplicate. Ventral umbo curved, beak suberect, beak ridges rounded. Dorsal umbo protuberant, strongly rounded with "wings" created by inner socket ridges. Foramen large, 10% shell length, round, hypothyridid in juveniles, submesothyridid to mesothyridid in mature specimens; deltidal plates triangular, disjunct, partially obscured by protuberant cardinal area, palintrope slightly concave.

Interior. Dorsal valve. Outer socket ridges narrow, short. Sockets long, shallowing towards anterior forming a platform. Inner socket ridges high, slightly curved over socket, protuberant over cardinal margin. Crura angled towards centre of valve where a ring loop is formed, slightly offset with dorsal section posterior to ventral section. Cardinal process small, slightly depressed anteriorly with two small lobes posteriorly.

Remarks

T. buckmani Owen, 1980 from the "Lower Tertiary" of Cockburn Island, Antarctica, is larger reaching up to 25 mm in length, is oval in shape and possesses an extensive interarea (Owen 1980) in contrast to *T. kendricki* which reaches to 11 mm in length, is pear shaped and has a medium-sized pallintrope.

Australian *Terebratulina* have been generally confused taxonomically. *T. scoulari* (Tate, 1880), and *T. flindersi* Chapman, 1913 are more appropriately placed in *Cancellothyris* on account of their conjunct deltidal plates. *T. lenticularis* Tate, 1880, *T. davidsoni* Etheridge, 1876 (= *T. catinuliformis* Tate, 1899) and *T. triangularis* Tate, 1880 are better regarded as species of *Murravia* Thomson, 1916, as they all have hypothyridid foramen, and hinge plates are also present. *T. ellisoni* Allan, 1932 from the Late Pliocene of Chatham Islands, New Zealand (Allan 1932), has a wide, prominent and pointed beak, a straight cardinal margin and a rectimarginate anterior commissure. *T. kendricki,* on the other hand has a narrow curved beak, curved cardinal margin and uniplicate anterior commissure. *T. kendricki,* in having a uniplicate anterior commissure, differs from a *Terebratulina* species from the Cardabia Formation, Late Paleocene, Carnarvon Basin which is rectimarginate. *T. kendricki* in having 6 ribs per mm differs from another *Terebratulina* from the Late Middle Eocene Nanarup Limestone, Bremer Basin, Western Australia which has 5 ribs per mm and is unisulcate. This is the earliest record of *Terebratulina* in the Southern Hemisphere.

Etymology

After Mr George Kendrick, Research Associate of the Western Australian Museum who has collected numerous specimens of the species.

Family Chlidonophoridae Muir-Wood, 1959

Genus *Gisilina* Steinich, 1963

Type Species

Terebratula gisii Roemer, 1840.

Gisilina ovata (Etheridge, 1913)

Figure 6 K–P

1913 *Terebratulina ovata* Etheridge: 14, pl. II, figs 17, 18.

1993 *Gisilina ovata* McNamara *et al.*: 4, figs 7, 8.

Material Examined

The holotype is missing from the collection. A neotype is not recorded as no taxonomic problem exsits.

Other Material

Gingin Chalk: WAM 76.2224, Gingin; WAM 5934, Musk's Chalk, Gingin; WAM 4573, 5403, One Tree Hill, Gingin; WAM 4528, 5622, Hosking's Chalk, Gingin; WAM 6706, 68.622, 74.1134, Molecap Hill, Gingin; WAM 87.327, McIntyre's Gully, Gingin; WAM 4283/4, Round Hill, "Kayanaba", Dandaragan; WAM 79.2330, "Kyno", Dandaragan; Gingin Chalk, Perth Basin, Santonian-Campanian.

Toolonga Calcilutite: WAM 79.2915, Meanarra Hill; WAM 88.204, Murchison House Station; Toolonga Calcilutite, Carnarvon Basin, Santonian-Campanian.

Description

Exterior. Small pyriform to subpentagonal; shell up to 5 mm in length. Biconvex, bulbous, depth 66% shell length. Widest anterior to mid-length, width 82% shell length. Growth lines distinct, few; costellate, 6 ribs per mm at mid-length, bifurcating, spinose in small specimens. Cardinal margin narrow, nearly straight; lateral valve edge rounded, lateral margin straight, crenulate anterior to mid-length; anterior commissure rectimarginate, crenulate. Umbo relatively large, beak sub erect;

beak ridges indistinct from ribs. Foramen rounded, incomplete, 8% shell length, mesothyridid; deltidal plates disjunct, interarea wide to margin, concaved.

Interior. Ventral valve. Valve deep. Teeth with swollen bases, short deltidiodont; groove between teeth and margin. Muscle scars indistinct.

Dorsal valve. Outer socket ridge narrow. Sockets short, nearly coincident with cardinal margin in some specimens. Inner socket ridge curved over sockets to 50%, fused to crural base; no clear hinge plates. Crura extend inwards from extremities of fused bases. No complete loop. No median septum. Low median ridge separates small round muscle scars; ridge extends to cardinal process. Cardinal process rounded concave knob, swollen anteriorly.

Remarks

This species was first described by Etheridge as a *Terebratulina* (Etheridge 1913). Ms F. S. Dodds, a voluntary worker at the Western Australian Museum, tentatively reclassified it as *Gisilina.* McNamara *et al.* (1993) included it in his description of fossils from the Gingin Chalk. This species fits the generic description of *Gisilina.* This species is distinct from *Gisilina gisii* (Roemer, 1840) in that it is ovate and the umbo is relatively large. Previously it has been recorded from the Late Cretaceous of Europe. No other species of this genus has been recorded from the Southern Hemisphere.

Family Inopinatarculidae Muir-Wood, 1965

Genus *Inopinatarcula* Elliott, 1952

Type Species

Trigonosemus acanthodes Etheridge, 1913.

Inopinatarcula acanthodes (Etheridge, 1913)

Figure 5 M–O, 6 A–B

1913 *Trigonosemus acanthodes* Etheridge: 15, pl. 2, figs. 1–4.

1952 *Inopinatarcula acanthodes* Elliott: 2, pl. 2, figs. 22–27.

1965 *Inopinatarcula acanthodes* Muir-Wood: H800, fig. 670.

1983 *Inopinatarcula acanthodes* Cooper: 224–225, pl. 26, figs. 19–26, pl. 75, figs. 21,22.

1993 *Inopinatarcula acanthodes* McNamara *et al.*: 4, figs. 13–14.

Material Examined

The original described specimen WAM 3521 is missing and hence it is impossible to erect lectotype or paralectotypes. A neotype is not selected as there is no taxonomic problem.

Other Material

Gingin Chalk: WAM 4574; 5117-5126; 68.656-658; 74.1288-89, 75.1200, One Tree Hill, Gingin; WAM 74.1302; 75.5; 76.2245; 82.2660, Spring Gully, Gingin; WAM 6154-55; 77.2758; 82.329; McIntyre's Gully, Gingin; WAM 67.393; 68.110, 578, 588, 619, 621; 74.530, 1133,1135, 1139, 1170; 75.1186, 1189;76.2221; 77.2754; 87.344; 88.903; 91.806, Molecap Hill, Gingin; WAM 4525, Hosking's Chalk, Poison Hill, Gingin; WAM 5414; 5936, Musk's' Chalk, Gingin; WAM 4553-5, Spuff's Chalk, Gingin; WAM 3831; 3851; 63.105-6; 70.1835; 78.280; 87.244; 88.893, Gingin; WAM 63.126, 130; 77.3546; 80.738-39742, "Yatheroo", Dandaragan; WAM 4242, 4249-59, 4261, 4276; 63.120; 77.3528, 3535; 78.949-50, 4217, 4194-5, 4335, 4349, 4357, 4360, 4368, 4407, 80.399, 401, 744, 1310, 1312, 92.661, "Kayanaba", Dandaragan; WAM 79.2329, 2333, 2338, 80.402, "Kyno", Dandaragan; WAM 70.1809, Glenlark Farm, Dandaragan; WAM 79.2346, "Minyulo", Dandaragan; WAM 78.4389, 4395, 4408, 4418, 4441, 4453, 4542; 79. 2267, 2271, 2293, 2303; 80.697, "Noondal-Wandilla", Dandaragan; Gingin Chalk, Perth Basin, Santonian-Campanian.

Toolonga Calcilutite: WAM 74.1176, 1178, 75.11, 79.2913, 80.1017, 84.1749, 88.314, 94.6, Meanarra Hill; WAM 84.1748; 88.197-8, 232, 245, 251-2, 276, 280, 872; 92.737; 94. 303, 316, 533, 546, Murchison House Station; WAM 87.618, Yaringa Station, Shark Bay; Toolonga Calcilutite, Carnarvon Basin, Santonian-Campanian.

Description

External. Circular to sub-circular shell to 30 mm long. Biconvex valves, both to same degree; depth 65% of shell length. Widest at mid length or anterior to it, width 95–100% of shell length. Deep sulcus in ventral valve extending just posterior to cardinal margin, dorsal valve with strong fold, anterior width 43% of shell length. Capillate, up to 7 ribs per mm at mid-length, ribs shallow, bifurcate; very finely densely punctate; growth lines distinct, numerous. Cardinal margin gently curved, lateral valve edges bevelled, lateral margin strongly curved, convex with respect to dorsal valve; anterior commissure strongly uniplicate, plication 33% of shell length, edge bevelled. Umbo short, beak erect, beak ridges rounded. Foramen small, 1–2% of shell length, round, permesothyridid; deltidal plates conjunct; symphytium small, triangular, concave, horizontally striated.

Internal. Ventral valve. Socket teeth cyrtomatodont, long, 9.5% of shell length, width 6.3% of shell length, , thickest (4.3% of shell length) anteriorly, buttressed against thickened lateral margin, series of curved lamella extending from lateral margin anteriorly (corrugated), slight concave depression next to lateral margin.

Diductor muscle scars shaped like tear drops either side of slightly raised platform below umbo, 26% shell length. Lateral diductor scars long and thin; small scars posterior to diductor scars short and raised; median fold begins anterior to muscle scars.

Dorsal valve. Outer socket ridges thin. Socket in thickened buttressed area of lateral margin, socket triangular, 12% of shell length. Inner socket ridge wide, curves partially over socket. Inner hinge plate concaved, joins crural base area strongly laminated. Crural process short, rounded; crura triangular, apex posteriorly, widening greatly to loop. Loop short, width 30% shell length, arched towards ventral valve; muscle scars round with thickened valve floor creating a heart shape posteriolaterally. Median septum low, flattened, short (33% shell length), widening posteriorly forming low trough, extends to base of cardinal process. Cardinal process thin vertically striated concave band 4.5% shell length.

Remarks

The above description accords well with those provided by Elliott (1952) and Cooper (1983). The specimens from Dandaragan are larger than those from Gingin and have a correspondingly deeper anterior sulcus.

Suborder Terebratulidina Waagen, 1883

Superfamily Terebratelloidea King, 1850

Family Dallinidae Beecher, 1893

Subfamily Gemmarculinae Elliott, 1947

Genus *Gemmarcula* Elliott, 1947

Type Species

Terebratula truncate Sowerby, 1826.

***Gemmarcula doddsae* sp. nov.**
Figure 9 I–K

Material Examined

Holotype

WAM 78.4196, "Kayanaba", Dandaragan, Gingin Chalk, Perth Basin, Santonian-Campanian.

Diagnosis

Cardinal process fused to cardinal margin, foramen trapezoid, hypothyridid, anterior commissure unisulcate.

Description

Exterior. Small to medium subcircular shell to 14.4 mm in length. Biconvex, depth 52% shell length. Width greatest at mid-length, 90% shell length. Finely and densely punctate, costellate, growth lines numerous distinct, sulcus extends from cardinal to anterior margins. Cardinal margin wide, nearly straight; lateral valve edge bevelled, lateral margin gently curved to dorsal valve; anterior commissure unisulcate, finely crenulate. Umbo short, wide, erect; beak ridges sharp. Foramen trapezoid, large, 14% shell length, hypothyridid; interarea concave, striated.

Interior. Ventral valve. Teeth unclear, no dental plates. Muscle scars wide, short, pyriform, indented anteriorly, separated by ridge widening into a platform.

Dorsal valve. Socket and outer socket ridges obscured. Inner socket ridge, crural bases and outer hinge plates fused. Inner hinge plate extends across median area in narrow shallow septalium fused to cardinal process and cardinal margin. Median septum short, 31% shell length, rises to the loop projecting above lower transverse band, descends to form broadening ridge consistent with sulcus. Crural process short, triangular with rounded apex; descending branches join median septum widely rising to narrow slightly; loop incomplete. Cardinal process hemispherical, horizontally striated, fused to cardinal margin. Muscle scars indistinct, elongate, lie within shallow ridges either side of median septum.

Remarks

This species differs from others referred to *Gemmarcula* in that it has a trapezoid hypothyridid foramen and the anterior commissure is distinctly unisulcate.

Etymology

After Mrs Frances S. Dodds who spent much time as a voluntary worker at the Western Australian Museum, collecting and sorting specimens, especially those from the Gingin Chalk.

Family Kingenidae Elliott, 1948

Subfamily Kingeninae Elliott, 1948

Genus *Kingena* Davidson, 1852

Type Species

Terebratula lima Defrance, 1828.

***Kingena mesembrina* (Etheridge, 1913)**
Figure 7 A–K

1913 *Magas mesembrinus* Etheridge: 15, pl. 2, figs 5–8, 8a

1952 *Kingena mesembrina* Elliott: 4, pl. 1, figs 1–13.

1965 *Kingena mesembrina* Muir-Wood: H839, figs 725, 1a–h.

1970 *Kingena mesembrina* Owen: 69, pl. 6, figs 9a–c.

1991 *Kingena mesembrina* Sandy: 403.

1993 *Kingena mesembrina* McNamara *et al.*: 4, figs 11, 12.

Material Examined

Holotype

WAM 3522, McIntyre's Gully, Gingin, Gingin Chalk, Perth Basin, Santonian-Campanian.

Other material

Gingin Chalk: WAM 5209,10; 5288; 5291; 6429; 68.618, 624; 74.1141; 75.1190; 84.310; Molecap Hill, Gingin; WAM 89; 74.1138, 1265, 1273; McIntyre's Gully, Gingin; WAM 5127, One Tree Hill, Gingin; WAM 5985-90; 63.107; 70.1832; 76.2223; 82.1938, 2660, Gingin; WAM 4526; 5625, Hosking's Chalk, Gingin; WAM 5675, Southern's Chalk, Gingin; WAM 5940,43,45, Musk's Chalk, Gingin; WAM 4552, Spuff's Chalk, Gingin; WAM 74.1301; 82.2665, Spring Gully, Gingin; WAM 63.127, "Yatheroo", Dandaragan; WAM 4277; 4281; 4234; 4245-6; 78.4358; 79.1032; 80.400, 1311, "Kayanaba", Dandaragan; WAM 80.698, "Kyno", Dandaragan; WAM 79.2347/49, "Minyulo", Dandaragan; WAM 78.4440; 79.1033-4, 2270; 80.1303, "Noondal-Wandilla", Dandaragan; Gingin Chalk, Perth Basin, Santonian-Campanian.

Toolonga Calcilutite: WAM 74.1177, 1179, 1180; 75.9; 78.932; 79.2914; 88.315, 316, 885; 94.5, Meanarra Hill; WAM 94.315, 534, Murchison House Station; Toolonga Calcilutite, Carnarvon Basin, Santonian-Campanian.

Description

External. Medium sized ovate to subpentagonal shell up to 22 mm in length. Biconvex, the dorsal valve variable (depth 45%–69% shell length) to almost flat. Widest at mid-length, width 87% shell length. Punctae dense, elongate; growth lines numerous and distinct. Cardinal margin gently curved to almost straight, lateral valve edge bevelled, lateral margin straight to sigmoidal; anterior commissure variable from incipiently unisulcate to rectimarginate to uniplicate; umbo narrow, overlapping dorsal valve in some specimens. Umbo truncated, beak suberect to erect. Foramen round medium sized, 8.3% of shell length; mesothyridid to permesothyridid. Deltidal plates conjunct in larger specimens, disjunct in smaller specimens, symphytium small almost hidden by overlapping umbo, thin, concave.

Internal. Ventral valve. Hinge teeth developed from deltidal plates or appear so, teeth flat, curved towards posterior, curved groove on anterior side, protuberant towards dorsal valve at angle less than 45°, cyrtomatodont. Dental plates present forming triangular cavity under teeth, strongly ribbed horizontally. Pedicle collar striated horizontally reaches to base of dental plates. Muscle scars tear drop-shaped just beside dental plates. May or may not have median ridge; ridges may be present at anterior of muscle scars which bifurcate anteriorly.

Dorsal valve. Outer socket ridges wide, extend anteriorly. Socket shallow depression extending inwards to form shallow reception area. Inner ridges narrow, fused to outer hinge plates; crural base extends from fused inner socket ridges and outer hinge plates horizontally and anteriorly. Inner hinge plates form septalium with short thin median septum. Loop consists of narrow descending bands extending anteriorly, spines present anterio-laterally, secondary bands extend from initial bands posteriorly, incurved, meet at anterior of median septum. Vertical extension of median septum bifurcates thickly forming two bands which reunite, form circular hole posteriorly, raised curved plate or anteriorly facing hood. Brachidium and incipient muscle scars housed in shallow depressed hollow within valve. Anteriorly a wide low ridge separates depression from rest of valve. Valve turns outwards anterior to dividing ridge. Cardinal process wide laterally, narrow longitudinally, consists a central small shallow depression with two larger depressions either side, connected laterally to valve margin or slightly raised and narrowly bulbous.

Remarks

The above description is consistent with that provided by Etheridge (1913) and Elliott (1952). Elliott's specimens are unnumbered and therefore difficult to trace in the University of Western Australias geological collection. It is difficult to identify true transverse connecting bands in some specimens as these are incurved posterior extensions of the descending bands. The hood is variably developed in juvenile (small) and adult (large) specimens, being short to long in extension anteriorly.

Family Terebratellidae King, 1850

Subfamily Bouchardiinae Allan, 1940

Genus *Bouchardiella* Doello-Jurado, 1922

Type Species

Bouchardia patagonia Ihering, 1903.

Bouchardiella cretacea (Etheridge, 1913)

Figure 7 L–S

1913 *Magasella cretacea* Etheridge: 16, pl. 2, figs 9–12.

1915 *Magadina cretacea* Thomson: 399.

1952 *Bouchardiella cretacea* Elliott: 9, pl. 2, figs 14–21.

1965 *Bouchardiella cretacea* Muir-Wood: H849, fig. 734.

1993 *Bouchardiella cretacea* McNamara *et al.*: 4, figs. 5, 6.

Material

Lectotype
WAM 3523, Molecap Hill, Gingin, Gingin Chalk, Perth Basin, Santonian-Campanian.

Paralectotypes
WAM 99.434, as for lectotype.

Other material
Gingin Chalk: WAM 3829, 3937, 3968, 63.104; 76.2222, 2233, 78.279, Gingin; WAM 4524, 5624, 76.2244, Hosking's Chalk, Gingin; WAM 74.1299, 75.4, 76.2233, Spring Gully, Gingin; WAM 4551, Spiff's Chalk, Gingin; WAM 5673-4, Southern's Chalk, Gingin; WAM 5415, 5914, 5933, Musk's Chalk, Gingin; WAM 5362, 5381, Compton's Chalk, Gingin; WAM 76.2254, Dodd's Chalk, Gingin; WAM 5179, 5208, 5227, 5286, 6433, 6442; 68.594, 618, 620, 623; 74.1137, 1140; 75.1187, 87.343; 91.278, 894, 92.668, Molecap Hill, Gingin; WAM 74.1266, 87.330, McIntyre's Gully, Gingin; WAM 5341, 5350, 68.599, 659, 71.493, 74.1287, 75.1201, 82.2666, 86.1416, One Tree Hill, Gingin; WAM 63.121; 77.3530, 3534; 78.4198, 4367, 79.1029-31, 92.660, 664, "Kayanaba", Dandaragan; WAM 78.4419; 79.2288, 2295, "Noondal-Wandilla", Dandaragan; WAM 79.2232, "Kyno", Dandaragan; WAM 63.134, 139; 77.3541,3547, "Yatheroo", Dandaragan; Gingin Chalk, Perth Basin, Santonian-Campanian.
Toolonga Calcilutite: WAM 74.1174, 79.2916, 88.813, 883, Meanarra Hill; WAM 88.196,219,250; 94.314, Murchison House Station; Toolonga Calcilutite, Carnarvon Basin, Santonian-Campanian.
Miria Formation: WAM 80.671, 88.52, CY Creek, Cardabia Station, Giralia Range, Carnarvon Basin, Miria Formation, Maastrichtian.

Description

Exterior. Small subcircular shell, subtriangular in larger specimens 2–10 mm long. Biconvex, dorsal valve almost flat. Widest slightly anterior to mid-length, width 90% shell length in small specimens, 82% in large. Finely and densely punctate, punctae oval; growth lines numerous anterior to mid-length, prominent. Cardinal margin short, nearly straight, lateral and anterior valve edges bevelled, lateral margin sigmoidal, anterior commissure deeply unisulcate, sulcus greater than 50% shell width. Umbo truncated; beak straight to slightly suberect; beak ridges sharp. Foramen small, 3% shell length, permesothyridid; deltidal plates conjunct. Symphytium triangular, striated, striations form obtuse angle and middle of symphytium.

Interior. Ventral valve. Teeth cyrtomatodont, groove near lateral margin, slightly buttressed to margin. Pedicle collar sessile. Muscle scars elongate either side long low median ridge, rounded anteriorly.

Dorsal valve. Cardinal area contained in platform extending between lateral margins. Outer socket ridge indistinct from margin. Socket wide gently concave, extends laterally into valve space. Inner socket ridge overhangs socket slightly. Crural base, outer hinge plates fused; crura extends anteriorly from fused plates. Inner hinge plates striated, fused to median septum constructing short septalium. Median septum thin, extends beyond mid-length, anteriorly bifurcates to produce anterior section of loop. Loop incomplete. Pyriform muscle scars either side median septum. Narrow low ribs extend beyond median septum to anterior margin from muscle scar anterior. Cardinal process slight thickening of cardinal margin, raised slightly laterally.

Remarks

The description is consistent with that provided by Etheridge (1913) and Elliott (1952). Elliott's description was based on 62 unnumbered specimens in the collection of the Geological Department of the University of Western Australia. A larger specimen (10 mm) was available giving some differences in general shape, a product of ontogeny.

Indeterminate terebratulid genus 1
Figure 11 A–C

Material

WAM 88.873, Murchison House Station, Toolonga Calcilutite, Carnarvon Basin, Santonian-Campanian.

Description

External: Small to medium, ovate to subpentagonal shell up to 14 mm in length. Biconvex, depth 80% shell length. Width 71% shell length, widest at mid-length. Finely and densely punctate, growth lines distinct; multiplicate anterior, 25% of shell width, 7 ribs per mm at anterior commissure. Cardinal margin wide to lateral margin, strongly curved; lateral valve edge steeply rounded, lateral margin straight to anterior boundary, rises sharply; anterior valve edge rounded to squared, anterior commissure unisulcate, sulcus taking up whole margin,

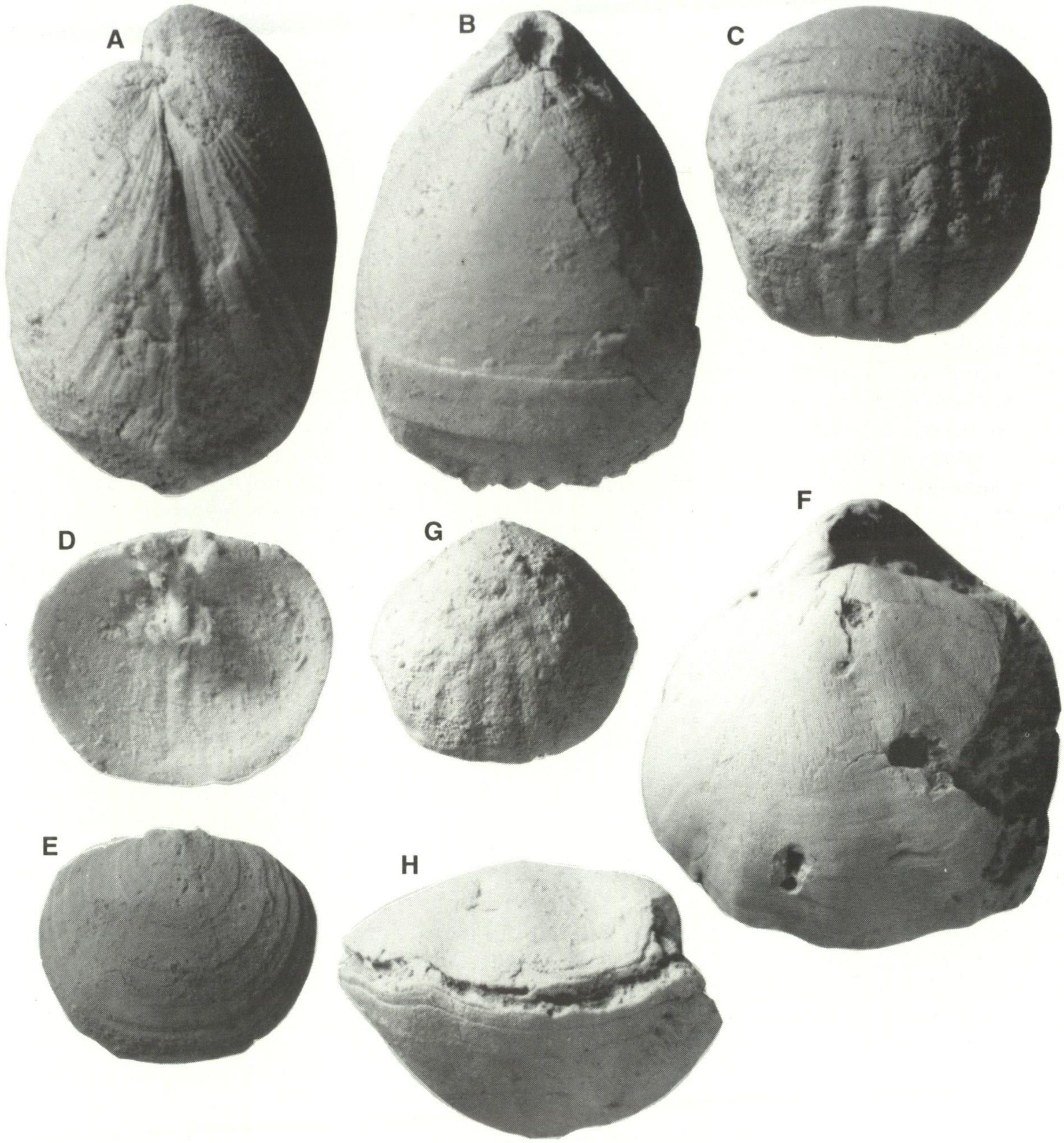


Figure 11 A–C, Indeterminate Terebratulid genus 1. **A–C**, WAM 88.873. **A**, lateral view; **B**, dorsal valve view; **C**, anterior commissure. All x 5. **D**, **E**, Indeterminate Terebratulid genus 2, WAM 74.1262. **D**, dorsal valve interior; **E**, dorsal valve exterior. Both x 4. **F–H**, Indeterminate Terebratulid genus 3, WAM 79.2331. **F**, ventral valve view x 3; **G**, dorsal valve view x 3; **H**, anterior commissure x 3.

crenulate. Umbo stout, short. Beak erect; beak ridges attrite. Foramen medium to large, 6% shell length, mesothyridid; deltidal plates disjunct. Symphytium narrow, concave.

Remarks

Only one specimen of this species has been recovered to date. No internal structure is available. The disjunct nature deltidal plates may be a product of weathering.

Indeterminate terebratulid genus 2

Figure 11 D–E

Material

WAM 74.1262, McIntyre's Gully, Gingin, Gingin Chalk, Perth Basin, Santonian-Campanian.

Description

Exterior. Dorsal valve only. Sub-circular shell to 8.1 mm in length. Convex. Wider than long, width greatest at mid-length, 9.7 mm. Finely and densely punctate, growth lines distinct. Cardinal margin gently curved, wide, inner socket ridges overhang margin; lateral margin straight; anterior commissure rectimarginate.

Interior. Pustulose throughout. Outer socket ridge thin. Socket very short, floor extends into valve, not buttressed. Inner socket ridge fused to crural base and overhangs socket slightly. Crural base swollen. Outer hinge plate united with inner hinge plate to form septalium, concaved; median ridge in centre of trough extends from cardinal process to median septum. Median septum short to posterior of mid-length, anteriorly bifurcating; centrally raised triangular platform, apex posteriorly located. Crura parallel, transverse band wide, attached solidly to median septum. Cardinal process semicircular, striated laterally, ribbed vertically, attached to septalium.

Indeterminate terebratulid genus 3

Figure 11 F–H

Material

WAM 76.2329, Molecap Hill, Gingin; WAM 79.2331, "Kyno", Dandaragan, Gingin Chalk, Perth Basin, Santonian-Campanian.

Description

Exterior. Sub-circular medium-sized shell to 19.8 mm in length. Biconvex, depth 66% shell length. Width greatest anterior to mid-length, 93% shell length (or greater). Finely punctate, growth lines distinct, multiplicate, 6 folds on each valve. Cardinal margin gently curved, wide; lateral valve edge gently bevelled, lateral margin straight, crenulate anteriorly; anterior commissure incipiently unisulcate, crenulate. Umbo stout, curved; beak erect; beak ridges attrite. Foramen large, incomplete in specimen, mesothyridid; deltidal plates probably conjunct. Symphytium concave.

Interior. No interiors available.

CONCLUSIONS

The brachiopod faunas of the Late Cretaceous of Antarctica and the Late Cretaceous of Western Australia show a number of similarities (Table 1) supporting the suggestion that the western coast of Australia was part of a continuous shelf extending all the way to the Antarctic Peninsula. The shelf with the associated brachiopod fauna formed the southern circum Indo-Atlantic province during the Late Cretaceous to Paleogene.

Protegulorhynchia meridionalis Owen, 1980 is common to both the lower Campanian of James Ross Island, Antarctic Peninsula and the Santonian-Campanian of Western Australia. *Tegulorhynchia* is recorded from the Santonian-Campanian deposits of Western Australia. It is recorded in the "Lower Tertiary" of Cockburn Island, Antarctic Peninsula (Owen 1980) and the Late Paleocene of the Cardabia Formation, Carnarvon Basin Western Australia (McNamara 1983). This genus had a long history in the southern circum Indo-Atlantic province.

The presence of *Liothyrella lecta* (Guppy, 1866) and *L. anderssoni* Owen, 1980 from "Early Tertiary" deposits of Cockburn Island and Seymour Island, Antarctic Peninsula respectively (Owen 1980) and *L. archboldi* and *L. brimmellae* from the Late Cretaceous of Western Australia (the first known occurrence of the genus) indicates that this genus may have first evolved in the higher latitudes during the Cretaceous. That *Liothyrella* is known from the Paleogene and Recent of Antarctica, the subantarctic waters, south-eastern Australia and New Zealand may best be explained by the genus persisting on the Antarctic shelf during the Paleogene and migrating west to east whilst the gap between Australia and Antarctica opened in the Late Eocene.

Terebratulina is a cosmopolitan genus, and its presence in the Miria Formation during the Late Cretaceous is not unexpected. It may have migrated into the region, possibly through the Tethyan realm.

Bouchardiella cretacea occurred on the western coast of Australia. This genus is also known from the Cretaceous of South America (Doello-Jurado 1922). A related genus, *Bouchardia* (*B. antarctica* Buckman, 1910) is recorded from the "early Tertiary" of Seymour Island, Antarctic Peninsula (Buckman 1910, Owen 1980, Bitner 1996).

Owen (1980) described a "*Terebratula*" species which is externally similar to *Zenobiathyris*. If a species of *Zenobiathyris*, it shows a wide distribution of the family from the Antarctic Peninsula to Western Australia in the Late Cretaceous. *Zenobiathyris* is not known from any Paleogene deposits.

Sampson *et al.* (1998) have recently proposed a palaeogeographical construction that enables marine faunal migration between India, Madagascar and South America via Antarctica during the Cretaceous. Sandy (1991) suggests a distinct austral brachiopod fauna existed from the Aptian onwards, at least between the Antarctic Peninsula and Western Australia. The presence of *Cretirhynchia* and *Rectithyris* common to both the Gustav Group and Marambio Group, Aptian to Coniacian, James Ross Island, Antarctica (Sandy 1991) and the Kallankurichi Formation, Early Maastrichtian, India (Radulovic and Ramamoorthy 1992) support the hypothesis of Sampson *et al.* (1998). *Kingena* is common to the Gustav Group and Marambio Group, Aptian to Coniacian, James Ross Island, Antarctica (Sandy 1991) and the Santonian

Table 1 Distribution of species described in Western Australia and Antarctica.

Species	Gingin Chalk	Toolonga Calcilutite	Korojon Calcarenite	Miria Form.	Antarctic Peninsula
Bouchardiella cretacea (Etheridge, 1913)	x	x		x	
Eohemithyris miriaensis sp. nov.				x	
Eohemithyris wildei sp. nov.	x	x			
Gemmarcula doddsae sp. nov.	x				
Gisilina ovata (Etheridge, 1913)	x	x			*T.* sp. present
Indeterminate Terebratulid genus 1		x			
Indeterminate terebratulid genus 2	x				
Indeterminate terebratulid genus 3	x				
Inopinatarcula acanthodes (Etheridge, 1913)	x	x			
Kingena mesembrina (Etheridge, 1913)					*K.* sp. present
Liothyrella archboldi sp. nov.	x	x	x	x	
Liothyrella brimmellae sp. nov.	x				"Tertiary"
Protegulorhynchia bevanorum sp. nov.	x				?
Protegulorhynchia meridionalis Owen, 1980	x				Recent
Tegulorhynchia hrodelberti sp. nov.	x				"Tertiary"
Terebratulina kendricki sp. nov.				x	
Zenobiathyris mutabilis sp. nov.	x	x	x	x	?
Zenobiathyris plicatilis sp. nov.	x				?

to Campanian Gingin Chalk, Western Australia (Etheridge 1913). The presence of *Cretirhynchia* and *Rectithyris* in both India and Antarctica may be explained by the existence of a shallow water corridor between these land masses as proposed by Sampson *et. al* (1998). The corridor may have lasted for a period between the Aptian and Santonian following which the gap between India and Antarctica became firmly established. This then allowed the migration of *Kingena,* and possibly other genera, between the Antarctic Peninsula and southwestern Australia.

Liothyrella may have evolved from *Rectithyris*. Both *Liothyrella* and *Rectithyris* are described as being ovate and biconvex with a short broadly triangular loop that is 0.3 times the shell length. Both also have a low laterally extended cardinal process. The difference exists in the foramen which is epithyridid in *Liothyrella* and mesothyridid in *Rectithyris*. Cooper (1983) described the foramen of *Liothyrella* as submesothyridid whilst Thomson (1927) describes it as epithyridid. In *Liothyrella archboldi* the foramen is permesothyridid, half way between the extremes of those described for *Liothyrella* and *Rectithyris*. If *Liothyrella* did indeed evolve from *Rectithyris* it would be expected to be found in the southern Indo-Atlantic province. This would account for its presence in the younger Maastrichtian deposit of the Miria Formation.

Buckman (1910) described species of *Magellania* from the Tertiary of the Antarctic Peninsula. This genus also occurs in Australia. *Terebratulina lenticularis, Hemithyris squamosa,* and *Terebratula bulbosa* described by Buckman (1910) from the Seymour Island and Cockburn Island deposits also occur in the Australian "Tertiary" (Tate 1880).

In the Paleogene to Neogene deposits in the Cardabia Formation, Giralia Range, Carnarvon Basin, Western Australia, a number of brachiopods occur (Craig in press) which are also common to the brachiopod fauna of the La Meseta Formation, Antarctic Peninsula of Late Eocene age. These include the genera *Basiliola, Tegulorhynchia, Liothyrella* and *Terebratulina*. The genus *Cancellothyris*, which is found in the Cardabia Formation, is still living in Antarctica (Foster 1989).

In summary, brachiopod faunal evidence from both the Late Cretaceous and Paleogene of Western Australia and Antarctica, supports the hypothesis of a southern Indo-Atlantic faunal province with a common shelf existing from the Antarctic peninsula to the western coast of Australia.

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