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Western Australian Late Cretaceous and Cenozoic Brachiopoda

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ABSTRACT

The research reported in this thesis focuses on Late Cretaceous and Cenozoic fossil brachiopods of Western Australia. Although the work is primarily taxonomic, it also includes biodiversity, distribution and some aspects of ecology of the brachiopods described.

The most recent information on the anatomy, physiology and ecology of brachiopods is summarised at the beginning of the thesis.

Identification of brachiopods is determined primarily on internal morphological features as brachiopods tend to be homomorphic, many species looking externally the same. The morphological features used in the identification of the brachiopods described within the thesis are defined.

The fossil material studied has come from four sedimentary basins in Western Australia. The Carnarvon Basin contains Late Cretaceous and Cenozoic fossil material. The Perth Basin also has Late Cretaceous and late Cenozoic brachiopods. The Bremer and Eucla Basin have Cenozoic deposits. The stratigraphy of the deposits containing the brachiopods is described.

Until this study commenced, eight species had been described from Western Australia. This thesis describes fifty eight species including thirty new species, one new family and two new genera.

In preparing descriptions of the new species it become evident that many of the species from the Southern Hemisphere were quite different to those found in the Northern Hemisphere. Their closest affiliation was with genera and species described from the Antarctic Peninsula. Four genera and one species from the Late Cretaceous deposits of Western Australia are common to the Late Cretaceous deposits of the Antarctic Peninsula. In the examination of the Tertiary material from the Carnarvon Basin, it also became clear that there was a strong correlation with

Tertiary material from the Antarctic Peninsula. At least four genera are common to both deposits. Six brachiopod genera from the Middle Miocene deposits of the South Shetland Islands Antarctica are common to New Zealand. Nine genera, identified from the La Meseta Formation, Seymour Island, Antarctic Peninsula, are also common to New Zealand. These genera are also found in Australia. This evidence has led to the proposal that in the Late Cretaceous there was a common shelf environment from the Antarctic Peninsula to the north-west coast of Western Australia. In this area, which formed the high latitude southern circum-Indo-Atlantic faunal province, brachiopods evolved different genera and species than those in the northern hemisphere. Many then dispersed into northern areas of the Indian, Atlantic and finally Pacific Oceans.

When the material from the Middle to Late Eocene of the Bremer and Eucla Basin was examined, five genera were found to be common to the Early Tertiary of the Carnarvon Basin. When comparing the species from the south-western basins and those from the south-east it was evident that similar species occur in the Middle to Late Eocene of the Bremer, Eucla, St Vincent and Murray Basins. There are some fifteen species in common. Many of these species then occur in the Late Oligocene south-eastern basins near Victoria and Tasmania as the gap between the Australia mainland and Tasmania began to open. One species that occurs in the Late Eocene of Western Australia is also described from the Late Oligocene of New Zealand.

In considering the distribution of the Cenozoic brachiopods, genera first appear in the north-west of Western Australia and they then appear in chronological order in the south-western basins and south-eastern basins of South Australia, then the south-eastern basins of Victoria and Tasmania and then New Zealand. By the Late Eocene, there was a shallow marine connection between the Bight and the Tasman Sea. By the Late Oligocene this had widened and Australia was finally totally separated from Antarctica

The Proto-Leeuwin Current was responsible for the distribution of the brachiopods from the north-west of Western Australia to the southern coast. Possible

mechanisms for the distribution of genera to New Zealand include rafting and an extended larval stage.

It has been suggested that brachiopods in Australia are distributed according to the substrate on which they settle rather than any other factor. Using the information on the distribution of brachiopods in Western Australia throughout the Cenozoic this hypothesis is examined. It is suggested that avoidance of light in the photic zone and food availability with competition with bivalves are more important factors than substrate conditions.

MATERIAL AND METHODS

Most of the brachiopod material examined in the thesis has been collected over the past century and stored in the Invertebrate Palaeontological Collection of the Western Australian Museum (WAM numbers). New material was collected from the Giralia Range and Shothole Canyon, Cape Range in the Carnarvon Basin; from Molecap Hill and One Tree Hill, Gingin in the Perth Basin and from the Nanarup Lime Quarry and Manypeaks Lime Quarry in the Bremer Basin during the period of research. A large number of specimens on loan from the Geological Survey of Western Australia (F numbers) were also studied. These were collected by D. C. Lowry from the Eucla Basin of Western Australia. Brachiopod material from the Late Cretaceous and Cenozoic collected and held at the University of Western Australia was also examined.

In order to compare material collected from the south-east of Australia, a visit was made to the Museum of South Australia and the Museum of Victoria. The material in the collections was examined, photographed and briefly described. This was then used in assisting with specimens from Western Australia. Whilst in South Australia, a short field excursion was undertaken to collect material from the Murray River Cliffs at Blanchetown. This material is now part of the Western Australian Museum Collection.

Each specimen was cleaned thoroughly using hot water and brushing. Delicate specimens were brushed with a sable artist brush. More vigorous brushing on harder matrix material on the brachiopod shells was undertaken using a "toothbrush" and a dental wire brush. On occasions, specimens were treated with dilute (10 per cent) ethanoic (acetic) or methanoic (formic) acid. The methanoic acid was found to be the most effective on matrix. A ultra-sound bath was also used on some specimens. Where possible, interiors were cleaned of matrix using various dental tools, needles and fine brushes. Because of the delicate nature of the interior of the brachiopod shell, it was necessary to leave some matrix to support the structures.

Where the interiors of specimens could not be cleaned, and where it was necessary to obtain interior information for identification, serial grinding techniques were employed. A well-preserved shell was taken and cemented in a block of Plaster of Paris. The anterior and posterior ends were marked and levelled on the block. This made measurements of each section removed easier to record. Initially, grinding was undertaken on a large wheel grinder. This was found to be difficult to control, as there were no facilities available to grind off specific measured increments. Although a longer procedure, it was found that more control was available by placing the carborundum of various grades on a sheet of glass, wetting the powder and grinding slowly on the surface. Measurements were made after the ground surface was cleaned. The specimen was then placed under a "camera lucida" microscope and the pattern of the interior drawn onto paper. This was later reduced to appropriate size using a photocopier and the images traced. Even though the exteriors of the shells may have been in good condition, the interiors were often totally destroyed by the post-mortem invasion of matrix material. In some specimens, calcite crystals formed in spaces within the shell and grinding caused the whole structure to collapse. Due to the rarity of some species, serial grinding was undertaken on only a few specimens and if unsuccessful, abandoned before destroying the collection.

Measurements of valves, foramen, internal features and serial sections were made where appropriate (or possible) using either digital or "dial" callipers.

All species were photographed with some examples of variations included. Three views were essential. These included the dorsal valve exterior showing the foramen morphology and cardinal margin, the lateral margin with the beak pointing towards the "west" and the anterior commissure with the dorsal valve uppermost. Where a margin was totally destroyed, no photograph was taken but if the recommended lateral margin was unavailable the "east" view was photographed. To prepare a specimen for photograph, it was placed on a block of black foam plastic to be held into position. The foam allowed for indentations to be made to hold the specimen on its margin or beak. Ammonium chloride powder was then heated in a pipette-like tube and blown gently onto the specimen using a blower bulb used for

airbrushes. A Nikon F 90 X camera with a macro lens was held in position on a bar-type stand. Lighting was always from the "north-west". Back-lighting was provided by either a low wattage light or a semi-circular reflector (made from cutting a round biscuit tin) to enhance the other margins.

Because of the problem of depth-of-field with very small specimens normal photography was unsuccessful. For specimens less than 6 mm in length a scanning Electron Microscope was employed. For non-type specimens the brachiopods were prepared using gold-spatter techniques. For type material an environmental Scanning Electron Microscope was used. The greatest difficulty was attaching specimens in such a way as to prevent charging without interfering with the profiles.

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Chapter 1

THE BRACHIOPODA: Anatomy and Physiology

The following summary of brachiopod anatomy and physiology is based upon James *et al.* (1992) and the relevant sections of the revised Treatise on Invertebrate Paleontology, Part H, Brachiopoda, Volume 1 including Peck *et al.* (1997), Cohen and Gawthorp (1997) and Williams *et al.* (1997). Other information has been added and the relevant references have been noted. Some of the features of the shell are described more fully in chapter 2.

1.1 General Characteristics

The Brachiopoda is a phylum of marine organisms that cover their soft bodies with shells made up of two parts or valves. The valves are bilaterally symmetrical and quite different to each other, one on top, the other below it, unlike bivalves where the valves are asymmetrical and similar, side by side. Brachiopods are lophophorates. This means they have an internal organ called a lophophore that is used for food gathering and respiration. Brachiopods are solitary and do not form colonies, although they may be found in clusters, clinging to one another.

They inhabit continental shelves and the upper part of the continental slope. The majority appear to be fixosessile, that is, fixed to the substrate (sediment, rock or rock wall). Plenipedunculate species have an unbranched stalk, known as a pedicle that attaches to the sea floor or some object upon it. Rhizopendunculate species have a pedicle that is divided into rootlets or papillae and attaches to material in the sediment, like algal holdfasts. Other species may encrust or cement themselves to some object via the umbral region of the shell. The liberosessile species are ambitopic or free lying. They may use spines, the pedicle or their flattened shape to help prevent them from being disturbed by currents. The infaunal lingulids are burrowing brachiopods. The extinct productids were quasi-infaunal (half in and half out of the sediment), using spines to assist in their support.

The name of the phylum was devised by Georges Cuvier (1769-1832), at a time when the lophophore was regarded as a molluscan foot (pod), which evolved

into an arm (brachia), hence, Brachiopoda. The common name lamp-shell was derived from the appearance of the shell of terebratulids when laid on their dorsal (back) valve. They resemble an old fashioned oil lamp.

1.2 General Morphology

For simplicity, brachiopods can be divided into two main groups, the articulates which have teeth and muscles to assist in opening the shell and the non-articulates that use only muscles. The classification of brachiopods is outlined later.

1.2.1 External features of articulated brachiopods

In articulated brachiopods, the shell is composed of calcite. The umbo (pointed end) or beak is posterior and the commissure (margin) with the widest gape is anterior. The valves pivot posteriorly. In articulate strophic shells the pivot is a straight hinge line created by the union of the dorsal (brachial) and ventral (pedicle) valves. At the point of union there may be one or two interareas (the dorsal interarea and the ventral interarea) between the valves. The dorsal interarea may contain a triangular notch known as a notothyrium. The ventral interarea may have a similar triangular gap known as a delthyrium. It is through the gap between the two valves that the pedicle emerges, when present. In some species the gap completely closes during ontogeny (growth). Non-strophic shells have a curved cardinal margin and the hinge line is tangential to this. The delthyrium may develop two lateral deltidial plates that grow inwards to produce a hole, the foramen, through which the pedicle emerges. The pattern produced by the deltidial plates and the degree of posterior movement of the foramen during ontogeny has a series of descriptive terms, useful in classification and outlined in chapter 2.

The umbo of the ventral valve is usually protuberant and may be straight or curved towards the dorsal valve. Beak ridges are often present and these may be sharp or rounded.

The two valves may be both convex (biconvex condition) or one convex (usually the ventral valve), the other concave (concavo-convex condition). The surface may be smooth or ribbed. The ribs may begin at the umbo or anterior to it. Sometimes the ribs bifurcate (split in two) as they are produced during ontogeny. Growth lines may be indistinct, distinct or prominent. Where they meet ribs a rugose (rough) pattern is produced. Strong ribbing often leads to crenulations (zigzag pattern) on the anterior commissure and may extend to the lateral margins.

Spines are also present on the valves of some species. They may be solid or hollow, cylindrical or elongated triangular projections.

Punctae or elongated cavities in the shell created during ontogeny may be observed as a series of "holes", although they do not penetrate to the surface. The density and shape of these punctae can be used in classification as many orders do not develop the cavities.

A sulcus or depression may develop in either one or both valves. Sometimes there is an alternate keel or fold to the sulcus. This causes various alterations to the shape of the anterior commissure. Each of these shapes is given a descriptive name described in chapter 2.

1.2.2 Internal features of articulated brachiopods (including soft parts)

Living species have a series of muscles that are used to open and close the valves and adjust the valves about the pedicle. These leave scars in the valves that may be seen in fossil specimens. The adductor muscles close the valves and are attached to each valve anterior to the hinge line. Two scars are found on each valve. The diductor muscles open the shell. They extend from the cardinal process, near the umbo of the dorsal valve, to the floor of the ventral valve, again leaving scars. Adjustor muscles for the pedicle (when present) are attached to the ventral valve and the cardinal process and also leave one or more scars. There is usually a pair of hinge teeth in the ventral valve that articulate with sockets in the dorsal valve. Some strophomenids lost these teeth and instead had a series of small projections or

denticles along the hinge line. The shape, position, size and development of ancillary structures such as dental plates, which extend to the valve floor, are important morphological features used in classification. Similarly, in the dorsal valve, the features associated with the sockets are used in classification. At the posterior of the dorsal valve the cardinal process, used for muscle attachment, may have a variety of structural features, again used in classification.

All the major organs are contained in the posterior section of the shell, known as the body cavity. A mantle of epithelial tissue exists along the floor of the anterior section of the valves. This separates from the floor and forms the anterior body cavity enclosing the muscles, reproductive, excretory and digestive organs of the living individual. Fossil specimens may show signs of mantle canals that are projections along the valve floors, sometimes called pallial markings.

The lophophore is found in the mantle cavity anterior to the body wall. This is the "arm-foot" from which the brachiopod acquired its name. The lophophore is used for respiration and filter feeding. It may be supported by calcite extensions from the valve floor (strophomenides), extensions from the cardinal area (rhynchonellids) or complex combination, a brachidium. This may be spirally arranged as in atrypids and spiriferids or as a short or long loop as in terebratulids. These structures are important in classification.

Within the shell, on the body wall, mantle and the lophophore, irregular bodies of calcite called spicules can sometimes be found.

1.2.3 External features of non-articulated brachiopods

The Lingulata consist of shells composed of chitino-phosphate. The lingulates have elongated oval shells with growth lines. Obolids are suboval to round shells with the interarea separated into two propareas by a triangular pedicle groove. Acrotretides may be circular with conical ventral valves while dicinids have flat round or oval shells. Some non-articulates are composed of calcium carbonate. Cranids (or "face shells", so called because of the face-like markings produced by

the internal features) have a flat ventral valve and a conical dorsal valve. They contain punctae but no pedicle and the shell is cemented to the substrate. Craniopsids are impunctate (no punctae). Trimerellacids are large thick biconvex shells. The ventral valve has a large pseudointerarea.

1.2.4 Internal features of non-articulated brachiopods

Because there are no teeth or a hinge line, the non-articulates rely entirely on their diductor and adductor musculature to open and close the valves. Oblique muscles enable the valves to move from side to side. Muscle scars may be found in fossil specimens. Muscle platforms or depressions may exist in some species.

The lophophore is not supported. A median septum can be located on the dorsal valve of some species.

1.3 PHYSIOLOGY OF BRACHIOPODS

1.3.1 The Mantle

The mantle is divided into three distinct membranes. The inner mantle lines the mantle cavity. It consists of ciliated epithelium, encloses the brachial cavity and may integrate with the lophophore to provide a suitable environment for feeding and ventilation by secreting mucus that discourages microbenthic settlement and assists water circulation. Within the layers of the inner mantle, the inner and outer membranes unite to form columns and pillars that are associated with the genitalia and assist in pressure control. They may contain spicules to give greater rigidity.

The outer mantle is responsible for the growth of the valves. It consists of an extension of the outer epithelium controlling the expansion of the mantle lining in both valves and the radial growth of the valves through secreting the organo-mineral matrix. The membrane also forms the outer covering for the mantle canals and may form tissue invaginations that penetrate the shell and function as storage tissue. These invaginations are known as caeca. They consist of a brush of numerous tubes joined to the periostracum, elongated core cells, flattened peripheral cells

surrounding the core cells and an encircling membrane made up of a single layer of compressed cells. The morphology of the caeca varies slightly between species. The function of the caeca is debatable, but its morphology implies an interaction with the external environment. Suggestions for its function include assisting with water circulation within the mantle, excretion, calcification, repelling predators, peristocal repair, storage, respiration, secretion and sensation. Peck (1992) suggests that the caeca evolved to reduce pressure on space requirements within the shell of brachiopods.

In the generative region a mucopolysaccaride film is initially secreted. The periostracum is secreted beneath the film. Once the periostracum is sealed, the cells become calcite depositors. The calcite is in the form of isolated rhombs that amalgamate to form the primary layer. After migrating posteriorly, the secreting cells produce additional cells at the margins. Finally they revert to organic exudation and calcite secretion of secondary fibres.

The third membrane consists of the pedicle cuticle and secreting epithelium.

1.3.2 The Pedicle

As mentioned, the majority of brachiopods have a pedicle to attach themselves to the substratum.

The pedicle in non-articulates arises as an outgrowth of the inner epithelium of the ventral mantle and is attached to the ventral mantle. It is continuous with the ventral wall and is covered by a thick layer of chitinous cuticle. There are three pairs of muscles in the pedicle column. *Lingulid* pedicles have the capacity to regenerate after damage.

Articulate pedicles are a solid cylinder with a core of connective tissue enveloped in epithelium. This has an outer chitinous cuticle covering similar to that of the non-articulates. The proximal end is covered in cuticle and a capsule of

epithelium. It develops from the larval segment that attaches to the substratum. It is a relatively rigid structure, acting as a pivot around which the shell moves by contraction and relaxation of muscles. Alternatively, the fibres may be continuous with the ventral adjustor muscles, giving the pedicle some degree of mobility, adjusting the shell position with respect to the substrate by pushing against the sediment.

There appears to be no correlation between pedicle size and attachment strength but there may be some correlation between attachment strength and the micro-environment, particularly the strength of current activity. The distal end may be able to secrete chemicals capable of breaking down organic matter and boring into calcite and aragonite.

Articulate pedicles are classified by Bromley and Surluk (1973) according to size and branching pattern.

size	**branching**
1. medium and massive	short hold fast papillae
2. long and massive	long hold fast papillae
3. very long and massive	long and even splitting
4. short and massive	short hold fast papillae
5. short and massive	distally divided
6. very long	irregular lateral branching
7.	immediately divides into rootlets

Richardson (1979) related pedicle type to muscle size. The muscle attachments may have some importance in classification.

type	**muscle scars**	
1. inert pedicle	large adjustor muscles	reduced ventral muscles
2. muscular pedicle	reduced or absent adjustor muscles	large ventral muscle

1.3.3 The Lophophore

The lophophore is suspended from the anterior body wall and may be supported by a short or long calcareous loop. It extends into the mantle cavity and consists of a pair of symmetrically but variable coiled arms. These are displaced laterally on either side of the slit-like mouth. The brachia are fringed with one or two rows of alternating ciliated tentacles (filaments). A flap of tissue known as the brachial lip runs perpendicular to each row of tentacles. A food groove (brachial groove) runs along the entire length of the brachia, terminating at the mouth.

The brachia are tubular, being constructed of two fluid filled canals with connective tissue that may contain spicules. Each is covered externally by epidermis and internally by coelomic epithelium. Each tentacle contains blood vessels with blind ends and nerve fibres, possibly to detect heavy waste particles. Mucus-secreting cells are found throughout the structure.

The lophophore collects and transfers food particles to the mouth. It is also considered the primary site for gas exchange and possibly the uptake of calcium for shell formation. Long microvilli may have a chemo-sensory function.

1.3.4 Muscles in Brachiopods

There are two main types of muscle in brachiopods. The first type of muscle is made up of myoepithelial cells that are found in the coelom, mantle lobes and lophophore. The other type consists of discrete bundles that control the opening and closing of the valves as well as pedicle movement, allowing orientation.

1.3.5 Feeding in Brachiopods

Brachiopods are ciliary suspension feeders. The lophophore is the main collecting organ. Mucus, secreted by epithelial cells, is used to transport particles of food to the mouth and produce pseudofaeces from the wastes. The mantle assists feeding by producing complimentary currents and accumulates undesirable particles in vortices for rejection. There are three processes in feeding: creating water

Selection of food may be determined by size, specific gravity, charge, shape, other surface features and by chemosensory stimuli. Food type may be species specific.

Food is moved through the digestive system by peristalsis. There are three different structural arrangements. The infaunal non-articulates have a long intestine with an anal opening. Epifaunal non-articulates have a pouch-like intestine opening into an anus. Epifaunal articulates have a blind intestine. All digestive systems consist of a pharynx, an oesophagus, a stomach digestive diverticular (liver), a pylorus, intestines and, as mentioned, an anus in non-articulates.

The alimentary canal fluid is slightly acidic and may contain protease and lipase as well as a variety of carbohydrases in most species. The enzymes seem to be species specific with variations in protease content. Carbohydrase is common to most species examined.

Data on oxygen to nitrogen ratios shows that one Antarctic species, *Liothyrella uva,* utilises protein exclusively as a metabolic substrate. Temperate latitude species from New Zealand, in *Notosaria* and *Terebratella*, use protein mainly in winter, but lipids and carbohydrates during summer months (Curry *et al.* 1989).

1.3.6 Excretion in Brachiopods

Excretion is accomplished via a trumpet-like tube called the metanephridium. In rhynchonellids two such organs exist while all other orders possess only one. Articulate brachiopods do not posses an anus. The solid waste, enmeshed in mucus, is voided by anti-peristalsis into the mantle cavity. The main excretory product is ammonia which, with carbon dioxide, is removed by diffusion from the lophophore. Non-articulates eject faeces through an anus into the mantle cavity. Water currents remove wastes from the shell.

1.3.7 Circulation in Brachiopods

Brachiopods, like many other invertebrates, have an open circulatory system. A contractile sack or heart helps pump the circulatory fluid that bathes all the organs. Nutrients and oxygen are exchanged for wastes, which are voided. Vessels branch through the lophophore, the digestive tract, tentacular canal and posteriorly through the mantle canals. Sporadic muscular contractions assist the heart to circulate the fluids.

Blood cells are often coloured. *Lingula* have cells ranging from pale pink to violet. Erythrocytes found in the blood contain haemerythrins that take up oxygen and discharge wastes. The blood also carries amoeboid cells. These include phagocytes that ingest bacteria as an immune response. Trophocytes, nucleated cells containing lipids, are found in males and are common during gonad maturation. Blood may be involved in the breakdown, recycling and transport of useful compounds. It is also possibly involved in shell and mantle repair.

1.3.8 Respiration in Brachiopods

Brachiopods exchange gases by way of the lophophore and the mantle canals. The gases are carried in the circulatory fluid. Water flow rate over the respiratory organs is similar to bivalves although it is laminar and not turbulent. Oxygen consumption is lower than for bivalves and is affected by starvation and possibly temperature. Because of the low metabolic rate, oxygen requirements can be met by passive diffusion.

1.3.9 Sensory System in Brachiopods

Nerves, with a series of ganglia (nerve bundles) to assist transfer of messages, run from the edge of the valve to a central ganglion around the mouth and to the muscles. This is called a circumesophagneal ring. It controls muscle activity and feeding. Brachiopods also receive information about their surroundings via setae (bristles), spines at the shell's edge, the lophophore and mantle canals. There does appear to be some chemosensitivity, possibly via the lophophore and setae. It is believed that external anterior spines may extend the area of sensitivity and thus be

an early warning device. Brachiopods respond to light (shadow response), touch, chemical stimuli and brackish, turbid and poorly oxygenated water. A dramatic response to unfavourable conditions is rapid tight closure accompanied by movement of the whole shell on the pedicle, drawing the shell nearer the substrate.

The lophophore appears capable of particle selection.

1.3.10 Reproduction in Brachiopods

The reproductive system is made up of a pair of gonads that are little more than aggregates of germ cells. These are often brightly coloured (yellow, orange or red). They have developed ventrally (large) and dorsally (small) from cells lining the body (coelom). They may be tied to the body wall. In some species there are brood pouches which allow some development of the larvae within the mantle cavity. Sexes are separate in the majority of species. Three species are known to be hermaphroditic.

The female lays upwards of 180,000 eggs. After release of eggs and sperm via the gonoducts and metanephrida, fertilisation may occur either in the water or in the mantle cavity. The latter is certainly true for those species that have brood pouches found among the tentacles of the lophophore. Fertilisation is enhanced by synchronised spawning, the proximity of conspecifics, the large number of gametes and, in some cases, the retention of the oocytes within the mantle cavity.

Development occurs within the egg. After hatching, the larvae are free swimming. Non-articulates such as lingulids and discinids are planktotrophic. Planktotrophic larvae are self feeding and may drift in the ocean currents for a number of days or a few weeks. Articulate brachiopod larvae are lecithrotropic. These settle within a few hours. However, Pennington *et al.* (1999) have conducted experiments on the larvae of *Laqueus californianus*. They found that the larvae remain viable from three to seventy one days in water temperatures between 10° to 15° C. This has implications for the migration of brachiopods over large distances in the Southern Ocean. In articulate brachiopods, the larvae may glide or creep over the

substratum, with frequent contacts of the anterior lobe or ventral surface. This appears to be an exploratory attempt to assess the suitability of the surface for settlement (Chuang 1996). The larvae use a sticky secretion to attach tentatively. The primary attachment is not cemented and it can be removed by currents without damage to the pedicle bud. Final attachment is decided once the cuticle is deposited (Chuang 1996). Firm attachment occurs within a short period. Survival of the larva is enhanced once it attaches. The larvae select gravel over sand. Pebbles, boulders and shells are most commonly used and often they become secure in depressions or in gaps in rock walls.

1.4 ECOLOGY OF BRACHIOPODS

1.4.1 Brachiopod Adaptations

Special features on the exterior of brachiopods probably had specific functions. The function is an "educated guess" using similar structures in living species as a guide. Spines were (and still are) most likely used for (i) protection against predators, (ii) anchorage in mud and shifting sediments (eg: productides), and /or extending the sensitivity range of the setae. The "zigzag" commissure would be useful to (i) sieve food particles from sediment, (ii) increase the surface area of sensitivity and/ or (iii) assist in the prevention of predation and parasitism, especially where spines are attached to the edges. The sulcus on the anterior commissure probably helps to separate the inhalant and exhalant currents so that food and wastes do not mix.

1.4.2 Brachiopod Habitats

All Phanerozoic seas appear to have had populations of brachiopods. These include epicontinental seas as well as the major oceans that existed at various times. In the Southern Hemisphere extant species exist in waters around southern Australia, both north and south islands of New Zealand, south-eastern and south-western Africa, the west and east coasts of South America and around Antarctica. Northern Hemisphere brachiopods occur on both sides of the North Atlantic, the Artic, the

Caribbean and West Indies, western coasts of the United States, the Mediterranean Sea and the waters around Japan.

Calcareous valved species occur predominantly in the temperate latitudes while chitino-phosphate valved species mainly inhabiting tropical and sub-tropical waters.

1.4.3 Brachiopod Environmental Tolerances

Brachiopods are sessile (stationary) and may be free lying on, burrowing within or attached to the substrate. Lingula are capable of burrowing into the substrate and leave part of their shell at the burrow mouth to extract food. Attached brachiopods may use the pedicle as a holdfast or be cemented by their shell to the substrate. The craniforms are particularly adept at cementing themselves to the substrate. Many articulate brachiopods have lost their pedicle during evolution and become free lying. The shell may sit on the surface sediment or use spines to prop it upright in soft sediments. All Cenozoic brachiopods were suggested to have used their pedicle only for attachment. Work by Richardson (1981a) and her co-workers in New Zealand have found pedicles from small foramen species can be used by the brachiopod as a type of "pogo stick". This can be used by the brachiopod to move away from predators or from covering sediments. Richardson (1981b) has suggested that thickening in the posterior section of the shell assists the free lying brachiopod to be self-righting when in strong currents.

Attached brachiopods may use rock walls, the shells of other organisms or isolated rocks. In all of these situations they may live in loose communities with juveniles attached to adults. Where such clumping occurs, it may lead to stunting, malformation and a shorter life span.

Some brachiopods are *rugophylic*, settling in rough substratum, including deeply ribbed shells. Settlement in recesses is advantageous with respect to high current activity and grazing disturbance. It is disadvantageous with respect to water flow.

Brachiopods are marine organisms with only lingulids able to live in transitional marine conditions. This, with their ability to burrow, has provided lingulids with a niche that they have been able to exploit for nearly 500 million years, relatively unchanged.

Brachiopods are able to cope with low concentrations of oxygen because of their lower metabolic rate.

They appear to be relatively tolerant of turbidity and can deal quite well with suspended solids. Fixed species are intolerant of high rates of sedimentation that will suffocate them.

The phylum appears to be reasonably tolerant of depth variations, ranging from 5 m to 2000 m in one species (McCammon 1973). This same species could survive in water temperature of between 8° C and 12° C. Work in New Zealand has found that brachiopods range from 8° C to greater than 21°C, and from less than 10 m to over 1000 m, for 12 of the 30 species recorded. (Lee 1991). Foster (1974) recorded brachiopods surviving winter water temperatures as low as -2° C in Antarctic waters.

The range of substrates on which the brachiopods can be found includes biogenic sediments, terrigenous (material washed out from the land) material, gravels, sand and volcaniclastic deposits, especially volcanic pebbles. Richardson (1997) suggested that the only restrictions to brachiopod distribution are the method of larval development (lecithrotropic or planktotrophic) and adaptation to particular substrates. The distribution of Western Australian brachiopods in the Cenozoic suggests that light and competition may be more important restrictions.

1.4.4 Brachiopod Associations

Brachiopod associations with other species have been poorly studied. They are often found with other filter feeders including bivalves, bryozoans and sessile

worms. Brachiopods are often encrusted by other organisms, including corals, worms, bryozoans and cnidarians. Often marks of these organisms can be found on the valves, especially fossil specimens (trace fossils), including the markings of other brachiopod pedicle attachments. Richardson (1997) suggested that brachiopods are associated with bryozoan sediments. This may be due to the presence of a lophophore and similar feeding habits of the two phyla.

The primary predators of brachiopods appear to be gastropods, and both muriciform and naticiform boreholes have been found in fossil specimens. Birds, fish, parasitic worms and asteroids are also likely predators (as well as humans from Australia, Japan and the northern Pacific islands on lingulids). Brachiopods are poorer prey specimens than bivalves. They yield less energy as their tissue has a lower organic content and is often spiculate. Some species appear to be less palatable than others.

Little is known about brachiopod diseases. They can recover from extensive shell and tissue damage. Various organisms, including sporazoans, trematodes, amphipods and parasitic ciliates, have been found within brachiopod valves. Fungi are known to attach to brachiopods that are under stress.

Commensalism (shared livelihood) has also been detected (Feldmann *et al.* 1996).

The size frequency distribution of brachiopods within a community is dependant on recruitment, growth rate and survivorship. Survivorship may be related to size, which may itself be determined by water temperature, type of substratum and food availability. Predation does not appear to depend on size. Because brachiopod shells are susceptible to maceration by acidic waters, carbonate dissolution and fracture, only the larger specimens tend to remain, creating a size bias when sediments, extant or fossil, are investigated.

1.4.5 Brachiopod Life-span

Precise age is difficult to gauge. Growth lines are laid down according to seasonal and environmental changes and thus are not clear indicators of actual age. Most research has centred on growth rates. This work suggests an average life span of eight years and a maximum of fifteen years (Rowell and Grant 1987), although Ruggiero (1996) suggest some specimens are over forty years old.

Life span appears to be correlated to habitat. Species found in shallow and intertidal zones have a life span of eight to ten years. Those found at higher latitudes and greater depths (to 200 meters) live up to thirty years. This may be due to a slower rate of shell secretion. Generally the growth pattern is an exponentially declining curve, growth being rapid early in the life history and slowing appreciably once maturity is reached. Growth rate appears to be least at depth and have the greatest variability in the shallows.

1.5 The Decline of Brachiopods

According to Walsh (1996), the possible mechanisms for the decline of brachiopods since the Paleozoic include: being driven from their habitats by bivalves that out-competed them, restriction to specific habitats that were reduced in number and area over time; and/or predator radiation. Walsh (1996) saw no one mechanism being the cause but rather a combination of biotic and abiotic factors.

Rhodes and Thompson (1993) suggested that as brachiopods are low energy life forms, they were replaced with higher metabolic rate life forms (eg. bivalves) as the overall energy flux through communities has increased through geological time. Plectolophous brachiopods are unable to feed effectively in high nutrient levels and thus tend to be restricted to areas of lower primary production (Rhodes and Thompson, 1993). Collins *et al.* (1991) supported this, suggesting that brachiopods are more abundant where the rate of renewal of food resources is low; food resources, if abundant, are of low quality; and where low temperatures and oxygen levels limit the effectiveness of higher metabolic rate competitors.

In the examination of the distribution and specimen numbers of Western Australian Cenozoic brachiopods, the competition with bivalves certainly appears to be an important consideration (see chapter 5).

1.6 Brachiopod Classification

The classification of brachiopods is under constant review. Researchers have used a number of parameters to establish a classification system. These include:

a) shell morphology;

b) articulation;

and c) dentition.

Areas presently under investigation include shell structure, amino acid analysis, genetics and immunology.

Using types of shell mineralisation, Borissenko (1996) suggested that non-articulates and articulates can be more easily differentiated. He includes variations in the magnesium content of calcite as well as the inclusion of various impurities such as strontium as a basis for his classification.

Walton *et al.* (1993) have suggested intracrystalline proteins characterised by their amino acid composition may be used as "objective taxonomic discriminators" and has "implications for the use of amino acid analysis in the investigation of fossil species". Although the technique can differentiate to the subordinal and sometimes to the subfamily level in living species, because of the degradation of the amino acids, the data is insufficient for molecular taxonomy in fossils (Walton, 1998).

Wright (1996) has used mantle canal and related vascular markings across the interarea, with dentition and calcareous structures that support the lophophore to re-examine articulate classification.

Genetics has also been used. The earliest work utilised electrophoresis to assess the variability in allozomes (products of nuclear loci) to provide a measure of

genetic variability. This revealed high levels of heterozygosity in *Liothyrella uva*. Another study on an Australian *Lingula* species showed no significant genetic differences between dispersed populations. A similar method was used to study restricted length fragment polymorphism analysis of mitochondrial DNA. Unfortunately, no information is yet available on the rate of mitochondrial DNA mutation in brachiopods. The genetic data acquired in this way from *Terebratulina retusa* and *T. septentrionales* indicated their most common ancestor was some eighteen million years old. It also gave some clues to the dispersal and subsequent distribution of *Terebratulina* in the eastern North Atlantic since the Ice Age.

The use of small subunit rRNA suggested that brachiopods, phoronids and ectoprocts belong to the same clade that contains protostomes rather than deuterostomes. There appears to be no distinction between lingulids, discinids and cranids. Articulate and non-articulate brachiopods form a monophyletic group in which articulates and non-articulates form separate clades. Phoronids are included into the non-articulate linage and are not a separate phylum. Articulate brachiopods are divided into three divisions, rhynchonellids, short looped and long looped. The classification is in conflict with that based on morphology.

Immunological techniques involve the production of antibodies against a molecule or group of molecule from one taxon, and the assessment of taxonomic relatedness by measuring the extent to which these antibodies react with homologous compounds in other taxa. Based on suites of antibodies prepared against bulk molecular extracts from within the shells of different taxa, Curry *et al.* (1991) suggested that the relationships within brachiopods contradict morphological classifications. The significance of the loop as a subordinal taxonomic character was brought into question (Curry *et al.* 1991; Endo *et al.* 1994). Immuno taxonomic proposals are inconsistent with SSU rRNA results.

The following classification is based on Homer *et al.* 1995 and Williams *et al.* (1996) and, although incomplete, gives the major groups of extant and extinct

brachiopods (A more comprehensive classification can be found in Williams *et al.*). 1996).

LINGULIFORMEA: Brachiopods with organophosphatic inarticulate shell.

Lingulida: Early Cambrian to Recent

Small to large gently biconvex shell. Large pedicle.

Acrotretida: Early Cambrian to Recent

Small subcircular shells.

Discinida: Middle Ordovician to Recent

Flat, round or oval shells.

Siphonotredida: Late Cambrian to Middle Ordovician

Similar to Acrotredida, except for shell structure and ontogeny.

Paterinida: Early Cambrian to Middle Ordovician

Small biconvex shells. Pedicle sometimes present.

CRANIIFORMEA: Brachiopods without articulation and calcareous shell.

Craniida: Middle Ordovician to Recent

Small, punctate with flat ventral and conical dorsal shells. Muscle scars and median septum give the impression of a face.

Craniopsida: Middle Ordovician to Middle Carboniferous

Similar to Craniida but with impunctate shells.

Trimerellida: Middle Ordovician to Late Silurian

Large biconvex shells. Muscle platforms with central buttress often creating two paired chambers.

RHYNCHONELLIFORMEA: Brachiopods with calcareous valves hinged by teeth and sockets.

Strophic Brachiopods: These have a straight or nearly straight hinge line or cardinal margin.

Orthida: Early Cambrian to Permian (or Early Triassic)

Small, semi-circular, biconvex, densely ribbed shells. Open delthyrium and lacking calcified brachidium.

Strophomenida: Ordovician to Permian

Large, butterfly shaped, concavo-convex shells. No pedicle opening, resting on ventral valve often with spines (Productids) and lacking calcified brachidium.

Spiriferida: Ordovician to Permian. (Some authors include Thecideina in this order and thus extend its range to Recent times. Others (Cohen and Gawthrop 1996) may place Thecideina with the short looped Terebratulids.)

Small to large, biconvex, strongly ribbed, butterfly shells with hinge or cardinal margin widest part. Open delthyrium and a spiral calcified brachidium.

Astrophic or non strophic brachiopods: They have shells with a curved hinge line or cardinal margin.

Pentamerida: Cambrian to Devonian.

Large, biconvex bulbous shells. No pedicle opening and lophophore supported by projections from cardinal area and valve floor.

Rhynchonellida: Ordovician to Recent.

Small to medium biconvex wrinkled shells with a deep depression or sulcus. A pedicle foramen is present and there is a simple crural support for lophophore.

Terebratulida: Silurian to Recent.

Small to large biconvex, smooth or ribbed lamp-shells. Pedicle foramen with deltidal plates and a short or long looped brachidium.

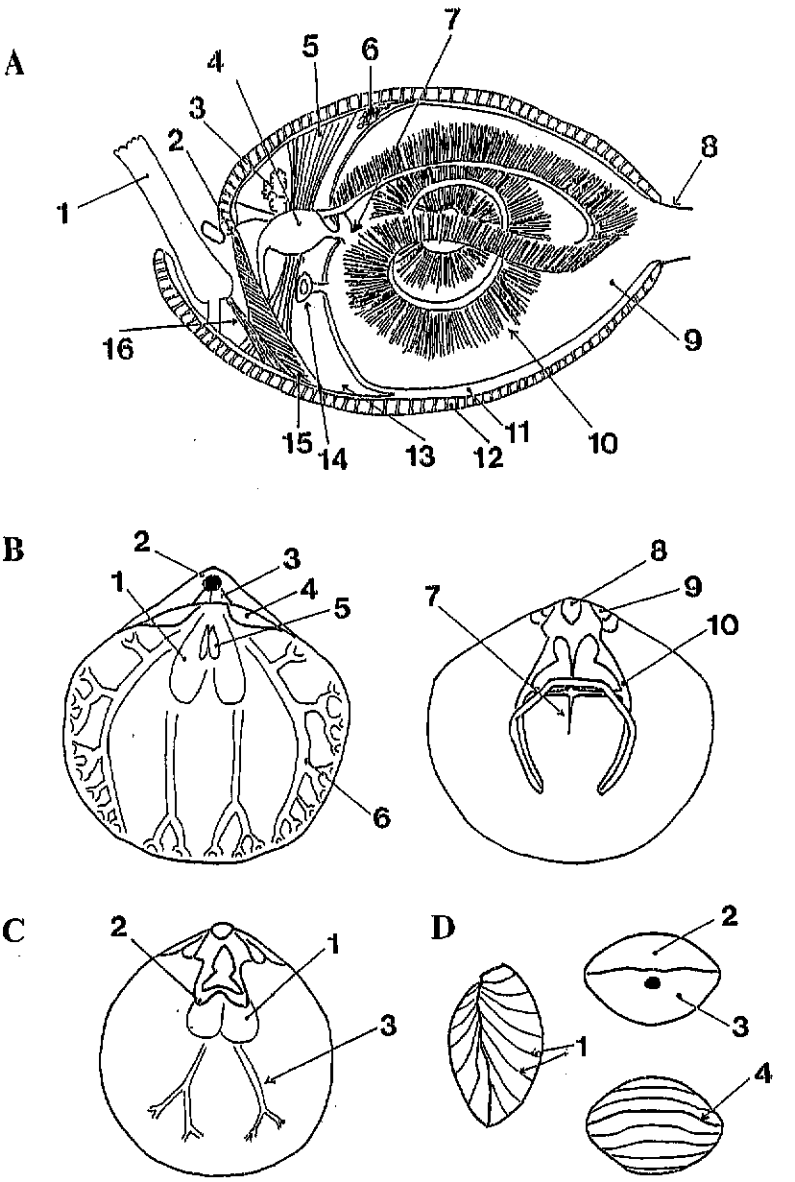


Figure 1.1: Internal and external features of the Brachiopoda.

A: 1, Pedicle; **2**, cardinal process; **3**,diverticula; **4**, stomach; **5**, Adductor muscles; **6**, gonads; **7**, mouth; **8**, setae; **9**, mantle cavity; **10,** ciliated lophophore; **11**, mantle epithelium; **12**, shell with punctae; **13**, body cavity; **14**, nephridium; **15**, diductor muscle; **16**, pedicle adjustor muscle.

B: 1, diductor muscle scars; **2**, foramen; **3**, delthyrium with deltidal plates; **4**, hinge teeth; **5**, adductor muscle scars; **6**, pallial markings or mantle canals; **7**, median septum; **8**, cardinal process; **9**, sockets; **10**, long brachidium.

C: 1, muscle scars; **2**, short brachidium; **3**, mantle canals.

D: 1, growth lines; **2**, brachial or dorsal valve; **3**, pedicle or ventral valve; **4**, anterior commissure or margin.

Chapter 2

BRACHIOPODA: MORPHOLOGICAL FEATURES

Some of the following features have already been discussed in chapter 1. They are redescribed here as they form the basis for the descriptions of the species found in chapter 4 on systematics. The terms are based on Thomson (1927), Williams and Rowell (1965), Brunton *et al.* (1996) and Williams *et al.* (1997).

Brachiopod valves are usually quite different to each other (figure 2.1). There is the **ventral** (pedicle) valve containing the **pedicle**. The pedicle passes through a "hole" in the pedicle shell known as the **foramen** that is found at the posterior umbo of the ventral valve. The other valve is the **dorsal** (brachial) valve that contains a calcareous structure called a **brachidium** used to support the breathing and feeding organ, the **lophophore**.

Muscle scars may be seen in the interior of the shell. Those muscles that open the shell (**diductor**) are attached to cardinal process and the ventral valve floor. Those that close the shell (**adductor**) run from the ventral to the dorsal valve.

Brachiopods tend to be externally **homeomorphic**. This means that many different species have very similar external features. To identify and classify brachiopods a combination of external and internal features is required. When there are no internal features available, classification becomes difficult. Variation in size ratios of external features in the same species is common (Aldridge 1981; Foster 1989; Aldridge 1991). Internal variation within a species is also possible. These factors also make identification difficult.

When describing brachiopods, there are number of conventions related to terms that name the morphological features. These can be quite confusing. What follows is a brief description, with the aid of diagrams, of the terminology used herein.

2.1 BRACHIOPOD DESCRIPTIONS USING MORPHOLOGICAL FEATURES:

2.1.1 External Features

The following check list of external features was used;

Shape

Margins

Surface features

Umbo and Beak

Foramen and symphytium

Shape:

The outline may be ovate, trigonal, pentagonal or a variation of these (eg subpentagonal). The lateral profile of the valves may be biconvex (lenticular), concavo-convex or convexo-concave.

Margins:

There are three margins to be considered. These are the lateral valve margin and edge, the anterior margin or commissure and edge and the posterior or cardinal margin.

[1] The lateral valve margin is usually straight (or plane) or can be concaved in the direction of one valve or another. Specialist terms are sometimes used. **Sigmoidal** is used to represent a curvature that consists of a convex curve towards the dorsal valve posteriorly, convex curve towards the ventral valve medially with a curve towards the dorsal valve anteriorly in the shape of an "S".

The edge may be bevelled, rounded or impressed (figure 2.5).

[2] The anterior commissure can be straight or rectimarginate (or plane) when the shell is regularly biconvex. Departures from this involve an increase in convexity producing a raised section of the valve called a **fold** or **plica** (that are round in cross section) or a **carina** or **keel** (that is angled in cross section). A

decrease in convexity or a depression in the valve is termed a **sulcus**. The opposite stage is when a fold opposes a fold or a sulcus opposes a sulcus and the margin is straight. Various terms are used and are illustrated in figure 2.7.

The anterior valve edge may be rounded, bevelled or impressed (figure 2.5).

[3] The cardinal margin terminology is outlined in figure 2.5 and depends on the curvature and width of the "hinge line".

***Surface Features*:**

[1] Terebratulid shells are punctate. That means they contain small "pores" over the shell. It is important to measure the density of these where possible.

[2] Growth lines are concentric and radiate from the umbo of the shell. There may also be lamellar outgrowths or concentric waving of the shell.

[3] Shells may also be ribbed in some way. This radial ornamentation is perpendicular to the growth lines. They may consist of fine lines or **striae**. Williams and Rowell (1965) suggested that, rather than using descriptive terms to indicate density of ribs, the number of ribs per centimetre should be counted. Where they arise at the umbo (or protegulal node) the ribs are called **costa** (costae). **Costellae** are the result of branching or intercalation between costae.

[4] Combinations of growth lines and radial ornamentation may lead to lines of points or **tubercules**. When the growth lines are raised at the intersections the ribs may produce irregular to ragged margins of the shell lamellae. This is termed **squamose**. If the ribs overlap the growth lines it is termed **imbricate** and may lead to the formation of spines.

[5] Bore holes in the exterior of the shell may be noted when present.

Umbo and Beak:

The **umbo** is the posterior region of either valve.

The ventral valve curves around at the posterior end, or umbo, to produce the **beak**. The beak is the pointed extremity of the umbo of the ventral valve. It may be termed short or long, stout or not stout. The beak may vary from pointing perpendicular to the lateral margin (straight) to curving back towards the dorsal valve (strongly incurved), sometimes covering the cardinal area. The terminology for these positions is illustrated in figure 2.4. When the apex is retained the beak is said to be **aplicate** but **truncate** when the apex is destroyed. When the beak incurves the apex so that contact is made with the dorsal umbo the pedicle is atrophied.

Beak ridges (lines at the edge of the ventral valve) separate the **palintrope** (or interarea) from the rest of the ventral valve and run from the apex or sides of the foramen to the ends of the posterior margin.

Foramen:

The foramen is the hole through which the pedicle passes. A triangular gap, the **delthyrium** remains. This gap may be partially filled by the growth of **deltidal plates**. These may not completely join (**disjunct**) or if joined (**conjunct**) may form a median ridge. The area is called a **symphytium**. The area may be curved (convex or concave) or flat. The size needs to be designated. The positioning of the foramen between the deltidal plates and the beak ridges is given a variety of names (figure 2.2).

(a) Hypothyrid: The foramen is in the centre of the interarea.
(b) Submesothyrid: The beak ridges are tangential to the foramen, which is in the interarea.
(c) Mesothyrid: The beak ridges meet at the side of the foramen. The foramen is equally in the interarea and the ventral valve.
(d) Permesothyrid: The beak ridges are tangential to the foramen, which is outside the interarea.

(e) Epithyrid: The foramen is on the ventral valve side of the beak ridges.

The **ariculate** condition occurs when extensions of the deltidal plates form a flaring rim around the foramen. The **telate** condition is when the beak ridges form little darts on either side of the foramen. If the darts wear off it is said to be **attrite**. When a lip develops over the dorsal umbo it is said to be **labiate**.

2.1.2 Internal Features

The internal features of the valves are described in two sections.

[A] Ventral Valve: (figure 2.1D)

The following check list is used:

Pedicle collar

Hinge Teeth

Muscle scars

Myophragm

Pedicle Collar:

If the deltidal plates grow around the pedicle almost completely enclosing it, a ring-like thickening of the inner surface of the foramen opening is formed.

***Hinge Teeth*:**

The hinge teeth are projections from the hinge line of the ventral valve. They may be various shapes. Cyrtomatodont describes hook-shaped hinge teeth while deltidiodont describe delta shaped hinge teeth. They may or may not be thickened and buttressed at their bases. They may contain grooves where they articulate with socket ridges.

The hinge teeth are generally elongated and pointed. Occasionally they are denticulate (very finely toothed) or striated in a direction transverse to their elongation. There are 3 types of support for hinge teeth;

- Supported solidly by a lateral connection with the palintrope, and the teeth overhang the hollow of the valve. These teeth are not usually large or strong.
- Besides the lateral connection (above) a solid base extending more or less vertically with the valve floor and everywhere united to the sides of the valve may exist. These **dental plates** are dental lamellae that may extend obliquely or vertically from the floor of the ventral valve to the base of the delthyrium supporting the hinge teeth. When present, they produce a delthyrial cavity in the central area. The inner and outer valve surfaces are no longer parallel. The interior of the beak is constricted and the teeth are usually large and strong. No socket grooves exist.

Inner and outer surfaces are parallel and there is a more or less vertical support separated by cavities from the sides of the valves.

***Muscle Scars*:**

These are impressions or elevated areas on the floor of the valve that are the site for the attachment of muscles. They are often hard to distinguish from other markings.

Myophragm:

This is a medium ridge that may be present between the muscle scars in either valve.

[B] Dorsal Valve: (Figure 2.1E and 2.1F).

The cardinalia includes the points of articulation, muscle attachments and attachments for the brachial supports. These sometimes fuse together (strong) or are discrete (weak) The weak condition is regarded as more advanced.

The following check list was used;

Socket ridges

Socket shape

Hinge plates

Septalium (or similar structure)

Crus (crura)

Crural bases

Medium septum

Brachidium

Cardinal process

Socket Ridges:

These are ridges making a slight angle with the cardinal margin and bounding the socket. They may incline outwards to overhang the sockets and may project beyond the cardinal margin.

Socket Shape:

The dental sockets are excavated spaces in the margin of the valve and may have a variety of shapes. They are for the reception of the hinge teeth.

Hinge Plates:

These are divided plates or a platform in the beak region to which the pedicle muscles attach. The are usually joined to the inner socket ridges and the crural bases (figure 2.1F).

Septalium:

This is produced by the bifurcation of the posterior section of the medium septum providing a site for the attachment of pedicle muscles. No excavated hinge plates exist. The forks join the anterior corners of the combined socket ridges and crural bases. The bases descend to meet the middle of the valve floor enclosing a trough terminated anteriorly by the septal forks.

Crura (Singular Crus):

They are processes that extend from the cardinal region or septum to provide support for the posterior end of the lophophore (feeding organ).

Crural Bases:

These are joined to the hinge plates and may separate inner and outer hinge plates if present. They may extend to the valve floor.

***Crural Process*:**

This is a spine-like projection into the valve and is directed upward towards the opposite valve.

Crural Plates or Lamella:

Short septa extending to the valve floor and supporting the crura.

Median Septum:

This is a wall of shell material running down the centre of the valve from the posterior or cardinal region. It may be thick or thin (blade-like), short or long, high or low and may or may not be joined to any brachidium present.

Cardinal Process:

This is a process at the posterior beak region for the attachment of diductor and pedicle muscles. It may be small or large and shaped in various ways. When observed it is fully described.

Brachidium* or *Loop: (Figure 2.1E and 2.3)

This is the shell material that supports the lophophore. It is an extremely delicate structure and may have a simple or complex shape. Where present in the specimens the brachidium is described, and if possible, photographed.

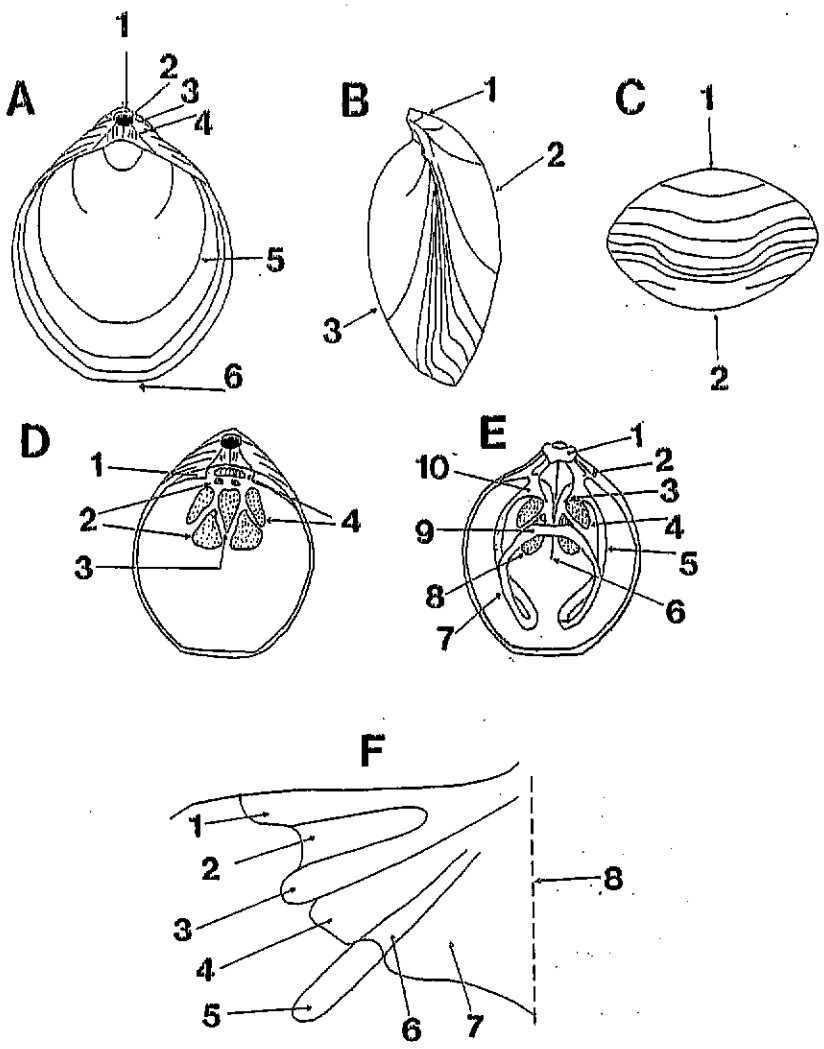


Figure 2.1:

External and internal morphological terms.

A: **1**, Posterior umbo; **2**, Foramen; **3**, Beak ridge; **4**, Deltidal plates (Symphytium); **5**, Growth or disturbance lines; **6**, Anterior.

B (Lateral view): **1**, Umbo or Beak; **2**, Ventral (pedicle) valve; **3**, Dorsal (brachial) valve.

C (Anterior view): **1**, Dorsal valve; **2**, Ventral valve.

D (Ventral valve interior): **1**, Hinge teeth; **2**, Diductor muscle scars; **3**, Adductor muscle scars; **4**, Pedicle adjustor muscle scars.

E (Dorsal valve interior): **1**, Cardinal process; **2**, Socket; **3**, Crural process; **4**, **8**, Adductor muscle scar; **5**, Descending loop; **6**, Median septum; **7**, Ascending loop; **9**, Transverse band; **10**, Crura.

F (Cardinalia) **1**, Outer hinge plate; **2**, Socket; **3**, Inner socket ridge; **4**, Outer hinge plate; **5**, Crus; **6**, Crural plate; **7**, Inner hinge plate; **8**, Median septum.

(A-E modified from Thomson (1927) and F from Brunton *et al.* (1996)).

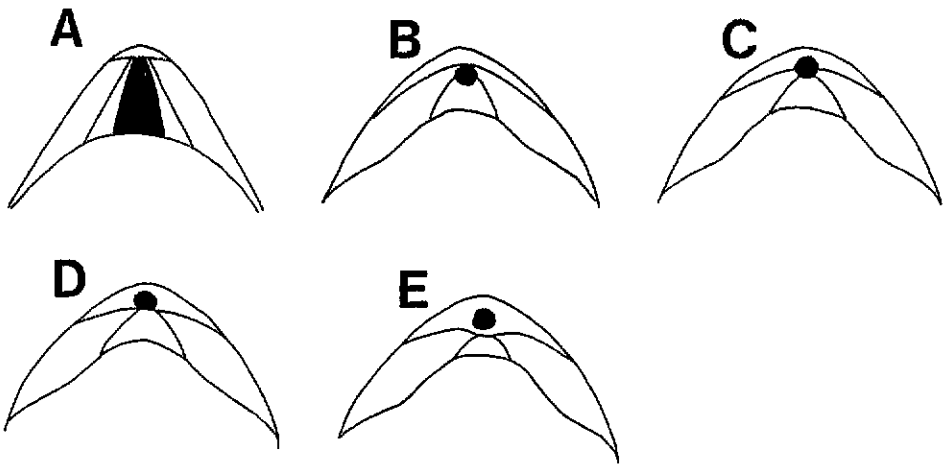


Figure 2.2:

Foramen Descriptive terms.

A, Hypothyridid; **B**, Submesothyridid; **C**, Mesothyridid; **D**, Permesothyridid; **E**, Epithyridid.

(Modified from Williams and Rowell 1965).

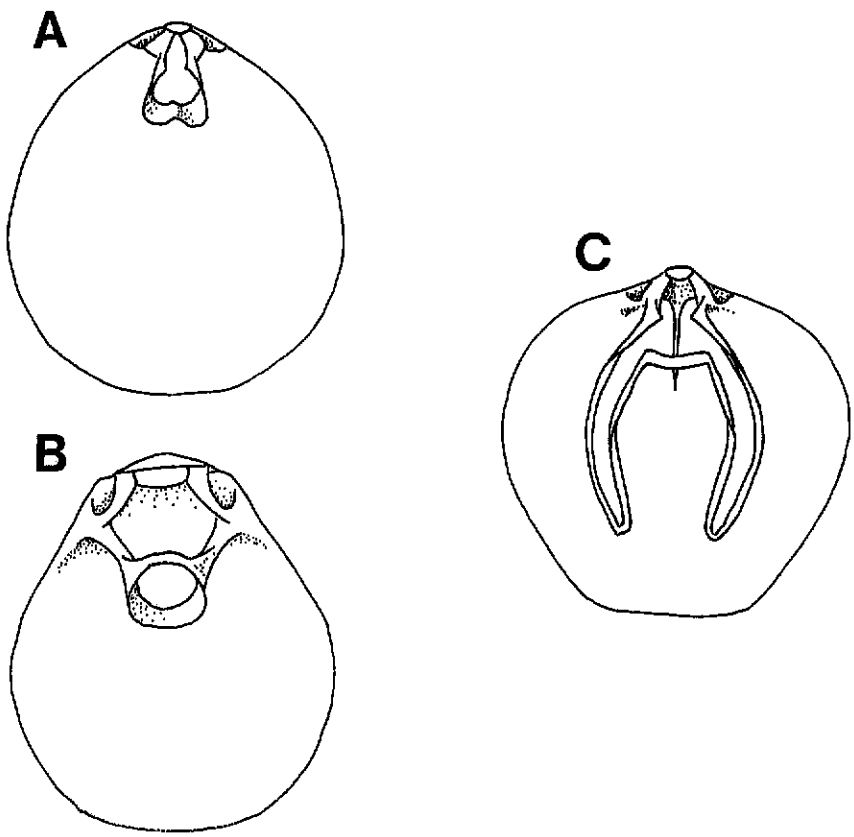


Figure 2.3:

Loop arrangements.

A, Short loop with arched transverse band; **B**, Short loop with complete ring; **C**, Teleform loop (Magellaniform). (Modified from Williams and Rowell 1965).

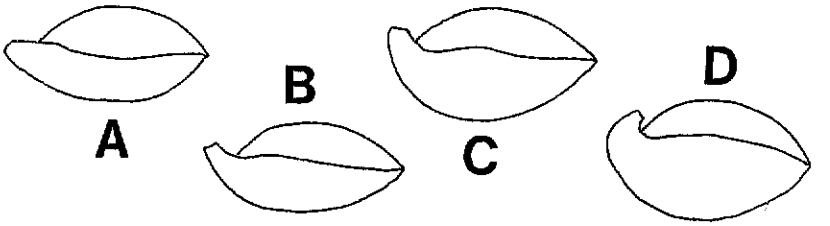


Figure 2.4:

Beak terminology.

A, Straight; **B**, Suberect; **C**, Erect; **D**, Incurved. (Modified from Thomson 1927).

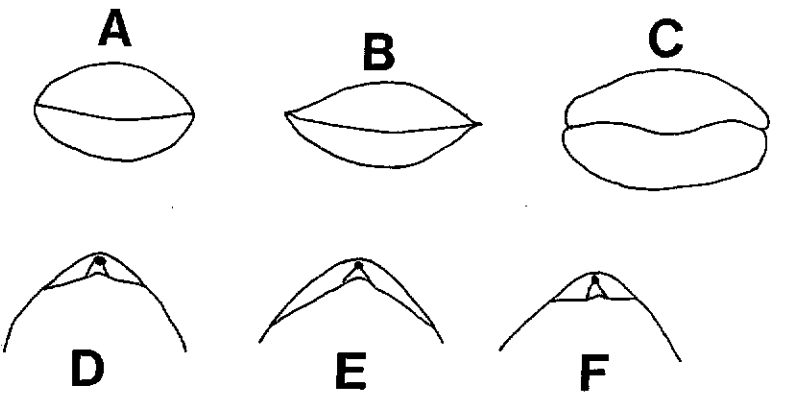


Figure 2.5:

Valve edge and Cardinal margin terminology.

A-C, Valve edge. **A**, Rounded; **B**, Bevelled; **C**, Impressed. **D-F**, Cardinal margin. **D**, Narrow, gently curved; **E**, Wide, strongly curved; **F**, Narrow, straight. (Modified from Thomson 1927).

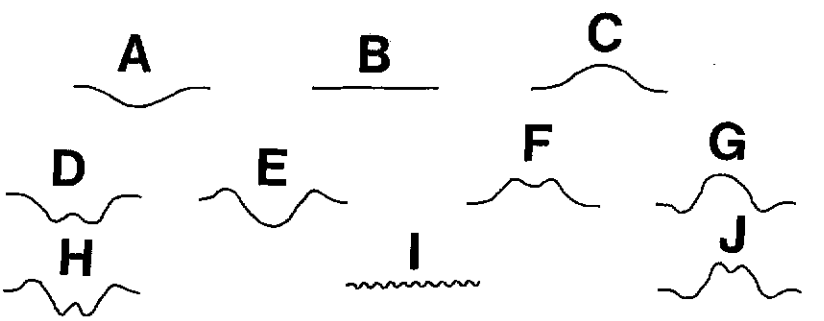


Figure 2.7:

Anterior Commissure terminology.

A, Uniulcate; **B**, Rectimarginate (or straight); **C**, Uniplicate; **D**, Plicosulcate; **E**, Paraplicate; **F**, Sucilplicate; **G**, Parasulcate; **H**, Biplicate; **I**, Rectimarginate-crenulate; **J**, Bisulcate. (Modified from Thomson 1927).

Chapter 3

STRATIGRAPHY: Descriptions of the Late Cretaceous and Cenozoic deposits of Western Australia containing brachiopod fauna.

3.1 STRATIGRAPHY OF THE LATE CRETACEOUS FORMATIONS OF WESTERN AUSTRALIA.

3.1.1 The Perth Basin.

The Gingin Chalk of the Perth Basin (figure 3.1, 3.10, 3.16), is a unit 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. It is exposed between Badgingarra in the north and Gingin in the south. It is richly fossiliferous containing regular echinoids, bivalves, gastropods, serpuild 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 at McIntyres Gully in detail.

3.1.2 The Carnarvon Basin.

The Toolonga Chalk from the Carnarvon Basin (figure 3.2, 3.16) has been 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, beleminite fragments, numerous bivalves, brachiopods and abundant foraminifers. The presence of particular crinoids and foraminifers establishes it as Late Cretaceous (Santonian) age (Shafik 1990).

The Korojon Calcarenite from the Carnarvon Basin (figure 3.2, 3.16) is 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 herein described. Shafik (1990) suggested that from the foraminiferal evidence that the main sequence is Campanian and extends to Maastrichtian.

The rich fauna of the Late Maastrichtian Miria Formation of the Carnarvon Basin, Western Australia (figure 3.3, 3.16) has been previously described by Henderson and McNamara (1985), McNamara (1987), McNamara *et al.* (1988), Shafik (1990), Henderson *et al.* (1992) and Darragh and Kendrick (1991; 1994). It has yielded gastropods, scaphopods, ammonoids, nautiloids, bivalves and nannofossils. A possible therapod humerus (Long 1992) and an incomplete ulna from a large pterodactyloid pterosaur (Bennett and Long 1991) have also been described from the formation. It also contains a brachiopod fauna that has hitherto not been described.

The Miria Formation consists of cream calcarenite 0.6-2.1 m thick extending some 80 km nor-north-west 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 Member, of the Cardabia Formation (Henderson and McNamara 1985). The formation has been degraded by gully erosion, weathering and incipient soil formation (Henderson *et al.* 1992). According to Darragh and Kendrick (1994), the Miria molluscan assemblage has affinities with both the Tethyan and Temperate Realms of the Late Cretaceous.

3.2 STRATIGRAPHY OF THE CENOZIC OF WESTERN AUSTRALIA.

3.2.1 The Carnarvon Basin.

The Paleocene-Miocene deposits (figure 3.4, 3.16) in the Carnarvon Basin are exposed in the Giralia Range (figure 3.11, 12) and Cape Range. Cenozoic sediments in the Giralia Range consist of the Cardabia Formation and the Giralia Calcarenite. The Cardabia Formation consists of five members. The Late Paleocene Boongerooda Greensand Member is the oldest (Hocking *et al.* 1987) and lies disconformably above the Cretaceous Miria Formation. It is believed to have formed in quiet, uniform shelf conditions over a long period of time with water depths of no less than 30 m. The waters were cool, hence the presence of phosphate nodules (Hocking *et al.* 1987). From foraminifer evidence, it has been determined as Zone P3 to P4 (Milner 1987). Above the greensand is the Late Paleocene Wadera Calcarenite Member. This formed in warmer water of an open shelf outer neritic zone between 50 to 100 m with fairly high energy conditions (Hocking *et al.* 1987). It is regarded as Zone P4 (Milner 1987). Overlying this is the Pirie Calcarenite Member, also of Late Paleocene age, Zone P4 to lower P5 (Milner 1987). This member formed in similar but less energetic conditions to the Wadera, probably outer neritic and upper most bathyal zones in water depths from 20 to 50 m (Hocking *et al.* 1987). The Cashin Calcarenite Member (Late Paleocene to Early Eocene) determined as Zone P4 to P5 (Milner 1987), formed in inner neritic zone in depths of less than 50 m (Hocking *et al.* 1987). The youngest member of the Cardabia Formation is the Jubilee Calcarenite Member (Early Eocene), Zone P6 (Milner 1987) formed in an open shelf environment with migrating shoals of calcarenite (Hocking *et al.* 1987).

The Giralia Calcarenite is Zone P12 in age (Middle Eocene). The deposit was formed in a shallow sea with "initial retrogradation of the shore line" reaching a maximum depth of 50 m (Haig *et al.* 1997). The Giralia Calcarenite overlies disconformably the Jubilee Calcarenite and correlates with the late Middle Eocene Kirthar Transgression of the Perth, Eucla, Great Australian Bight and Otway basins (McGowran *et al.* 1997).

A single species of brachiopod occurs in younger deposits in the Cape Range. The oldest deposit is the Late Oligocene Mandu Calcarenite, reported as having been deposited in quiet open shelf conditions at a depth ranging from 12 to 120 m (Hocking *et al.* 1987). This is conformably overlain by the Early Miocene Tulki Limestone, formed in shallower waters (from 12 m) than that of the Mandu Calcarenite (Hocking *et al.* 1987).

3.2.2: The Bremer Basin.

The Plantagenet Group in the southwest Bremer Basin (figure 3.5, 3.16) of Western Australia extends from North Walpole to east of Esperance, from the south coast to north of the Stirling Ranges and Norseman. Cockbain (1968c) formalised the Group as consisting of the Pallinup Siltstone and the Werillup Formation.

The Plantagenet Beds were 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 Pre-Cambrian surface of sands and granite. The non-marine material was most likely produced in peat swamps formed in hollows which 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 deposited during this latter transgression, is described as a Member of the Werillup Formation and is a yellow-white friable bryozoal limestone. It is best exposed at the Nanarup Lime Quarry (Figure 3.14, 15). 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 Member 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 depth of deposition of a maximum of 35 m.

The Pallinup Siltstone overlies the Werillup Formation. It extends to the Pre-cambrian 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 depth of deposition 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) describe 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 imply a depth of deposition of 76 m but Pickett (1982) suggested this estimate might be too great.

Churchill (1973) and Clarke (1994) suggested a present depth of approximately 300 m for the "top" of the formation at Norseman. Churchill quotes an uplift of some 110 to 150 m for the area. If this is consistent for the whole region of deposition, the estimates of depth of deposition by Darragh and Kendrick (1980) are conservative, as the present depth of the north Walpole deposit is 124 m above Australian Depth Datum, some 176 m below the Norseman level.

Age

The Werillup Formation is regarded as late Middle Eocene. This is supported by the presence of the dasycladacian algae, *Larvaria* and *Neomeris* (Cockbain 1969) and the foraminifera *Asterocylinia* (Cockbain 1967b) and *Cyclammina* (Cockbain 1974). The Nanarup Limestone Member has been also determined as Late Eocene from the presence of the nautiloids *Aturia clarkei, Teichertia prora* and *Cimonia felix* (Glenister and Glover 1958; 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 foraminifers 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 which is estimated at 37 Ma (McGowran 1989).

Palaeoclimate

Due to the presence of about 95% dextrally coiled foraminifers 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 (Kendrick personal communication) suggested 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 that there were two marine transgressions during the Late Eocene, the first (Tortachilla Transgression) producing the swamps, depositing silts, clays and the Nanarup Limestone, 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 south-west such as Mt Frankland, Granite Peak (Darragh and Kendrick 1980) and the Porongurup Range which would then have appeared as islands. The Aldinga Transgression would have reached the base of the Pre-Cambrian uplifted deposits of the now Stirling Range, possibly producing an island or headland.

3.2.3: The Eucla Basin.

The Wilson Bluff Limestone (figure 3.6, 3.16) consists of four main units. The lowest is a thick calcarenite made up of bryozoal fragments in a microcrystalline calcite matrix. Within this section is found echinoid tests, brachiopods, bivalves, sponges and foraminifers. Next is a thin layer, similar to that described above, but containing oysters as well as the other fauna. Second from the top is another similar layer, without oysters and less fossiliferous. The top layer is a hard white limestone containing bryozoal fragments and abundant brachiopods (Lowry 1970).

The Wilson Bluff Limestone is believed to extend several metres below sea level. It is overlain discomformably 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 bryozoal 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 which 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. Foraminifers 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 might have been due to baffle 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 an echinoid *Australanthus longianus*, (Lowry 1970). Foraminiferal assemblages suggest that the uppermost part is Late Eocene whilst the base is Middle Eocene (Li *et al.* 1996).

The Abrakurrie Limestone (figure 3.6, 3.16) consists of two parts, the lower friable bryozoal calcarenite and the upper indurate bryozoal calcarenite, both moderately well sorted. Echinoid tests, fragments and spines, brachiopods and bivalves are common throughout, the former 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 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 lays discomformably on the Wilson Bluff Limestone and the Toolinna Limestone. It is overlain by the Nullarbor Limestone. The echinoid fauna is typical of the Longfordian-Janjukian (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, approximating with foraminiferal zones P22 to N4. They suggested that it was deposited during the second-order supercyle TB1, which correlates broadly to the Janjukian Stage of southern Australia N4 (Li *et al.* 1996).

The Toolinna Limestone (figure 3.6, 3.16) consists of "medium to very coarse grained well sorted current bedded, bryozoal calcarenite" (Playford *et al.* 1975). The type section is 55 m high and found on the cliffs at Toolinna Cove in the south-west corner of the Eucla Basin. The fauna is similar to that found in the Wilson Bluff Limestone and therefore the age is 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 which differs to the Wilson Bluff Limestone. The brachiopod fauna suggest a closer relationship with the Wilson Bluff Limestone.

The Roe Calcarenite (figure 3.7, 3.16) is a thin, sandy limestone that forms the surface of the Roe Plains in the southern Eucla Basin. It comprises poorly bedded, medium to coarse grained porous shelly calcarenite (Lowry 1970:121-124). It has a very rich fauna dominated by calcareous algae, foraminifers, molluscs (Ludbrook 1978; Kendrick *et al.* 1991) and, to a lesser extent, echinoids (Foster and Philip 1980; McNamara 1996). The Roe Calcarenite covers most of the Roe Plains in the western Eucla Basin to a thickness of about 1.5 m. It is rarely exposed and is usually obscured under soil or sand. Natural sections are uncommon, but numerous "borrow" pits adjacent to the Eyre Highway have provided stratigraphical information not otherwise available. The type section is the entrance doline of Nurina Cave 10 km south of Madura Roadhouse. The thickest section appears to be at Eucla N°1 well where it is up to 7.5 m thick (Lowry 1970).

The terebratulid brachiopod, *Neothyris rylandae* sp. nov. described in this study represents the only brachiopod known from the deposit and was collected from borrow pits in the Hampton Repeater Tower area. The first 0.2 m of the pit consists of a brown clayey soil that overlies a 0.3 m section of brown, dense, hard blocky calcarenite, with scattered shells throughout. This overlies 0.95 m of brown, clayey

to rubbly, shell calcarenite. A 0.15 m thick layer of yellowish-grey calcarenite with weak horizontal bedding with scattered shells is then observable. This overlies a 1.15 m section of pale grey rubbly calcarenite that is unevenly cemented with pink clayey sand and a few scattered shells, mostly towards the top. Below this is to be found 0.4 m of pale, fine, silty carbonate sand that is very fossiliferous. It is in this section that the brachiopods described were found. Below this, at 3.15 m, is an erosional unconformity above the Abrakurrie Limestone (figure 3.17).

The Roe Calcarenite unconformably overlies a wave-abraded surface of Abrakurrie Limestone in central and western sections of the plain. To the east it unconformably overlies the Wilson Bluff Limestone. In the western and coastal areas it is overlain by coastal dunes. At the foot of the Hampton Escarpment, the northern boundary, it is overlain by colluvium whilst elsewhere it is covered by clay soil with kankar nodules (Lowry 1970).

Ludbrook (1978) suggested an Early Pleistocene age for the unit. The presence in the Roe Calcarenite of a species of arcoid bivalve genus *Cucullaea,* which is not known from post-Pliocene sediments elsewhere in southern Australia casts doubt on Ludbrook's age estimate (Darragh 1985, Table 2). The most important correlative fossil in the Roe Calcarenite is the presence of species of a gastropod genus *Hartungia* which in New Zealand is essentially confined to the Pliocene (Beu and Maxwell 1990). This suggests a Pliocene age for the deposit (Kendrick *et al.* 1991).

3.2.4: The Perth Basin.

The brachiopods investigated were collected by G. W. Kendrick from numerous bores of less than 50 m depth in the Ascot Formation (figure 3.8, 3.9, 3.16) along the coastal plain west of the Darling Scarp in the Perth Basin, Western Australia. The Ascot Formation consists of "fine to very coarse, grey to yellow-brown quartz sands with subordinate carbonate and less frequently quartzose calcarenites" (Kendrick *et al.* 1991). These generally fine upwards and contain well preserved aragonite mollusc shells as well as the brachiopods described below. Some

bones, teeth and phosphatic nodules have been reworked from the underlying Osborne Formation (Kendrick *et al.* 1991).

Kendrick *et al.* (1991) interpreted the formation as "representing a sequence of depositional events along the neritic inner shelf, associated with a progressively prograding shoreline." The age of the formation decreases from east (Late Pliocene) to the west (Early Pleistocene). The Ascot Formation overlies the Albian-Cenomanian Osborne Formation unconformably and is separated by minor transitional units (Balme 1980) from the overlying Bassendean Sands and Guildford Formation (Low 1971; Playford and Low 1972). There was a major regression at the end of the Ascot Formation deposition (Kendrick *et al.* 1991).

The two unnamed members of the Ascot Formation can be separated biostratigraphically by the molluscs present. The older eastwards Ascot assemblage contains the arcoid bivalve *Cucullaea* and the janthinid gastropod *Hartungia* confirming the age as Pliocene (Kendrick *et al.* 1991). Neither of these two genera are found in the younger westwards member of the formation and it is regarded as Early Pleistocene (Kendrick *et al.* 1991). Planktonic foraminifers from the older member are regarded as Pliocene in age (Mallett 1982). Mallett (1982) also suggested that the temperature during deposition was similar ("neither significantly colder, at least as warm") to that presently experienced along the south western margin of Australia. The presence of phosphatic nodules, quartz sand and the lack of carbonate deposits suggests that the temperature was actually much cooler than at present (McNamara, personal communication).

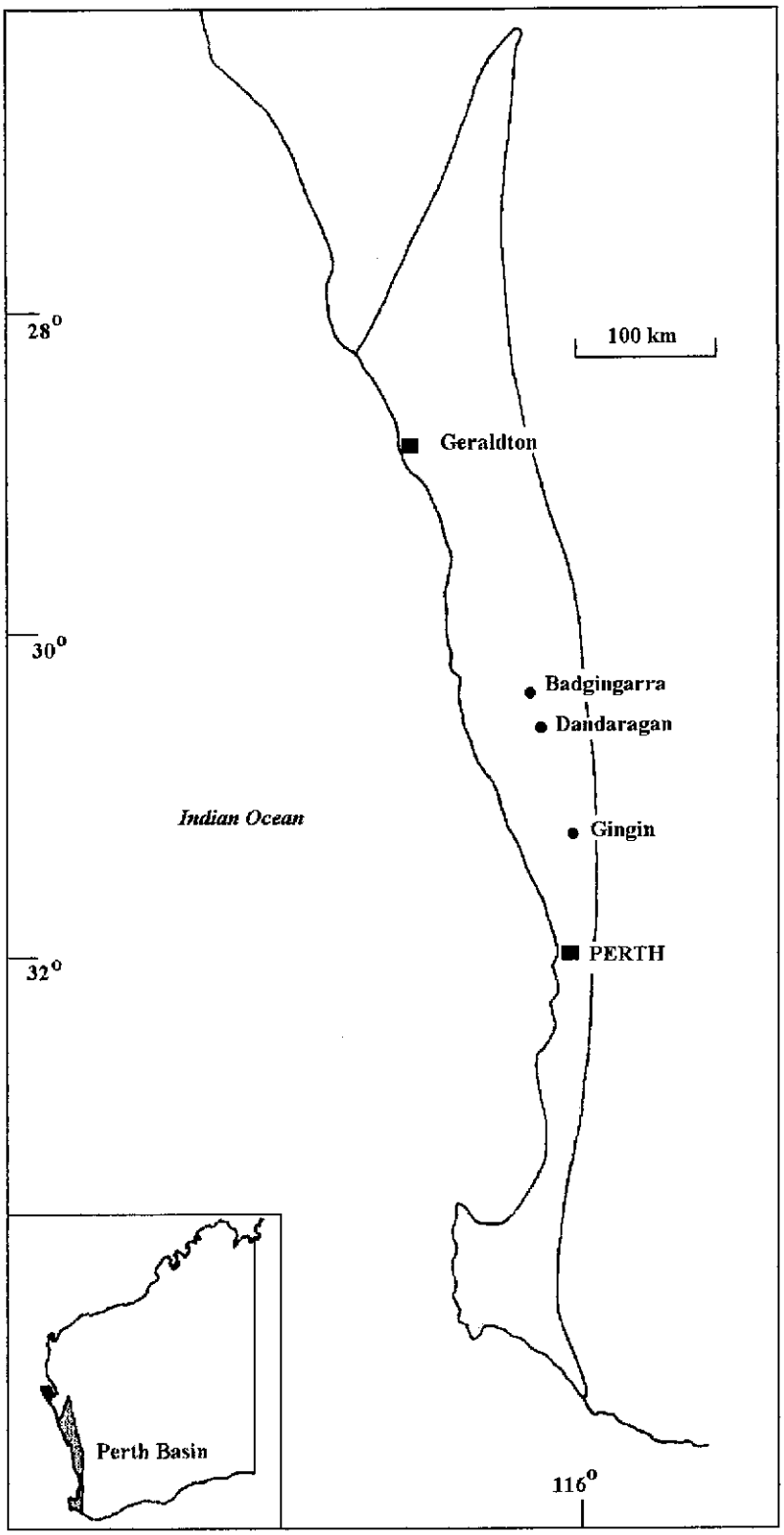


Figure 3.1: Late Cretaceous Gingin Chalk deposits in the Perth Basin.

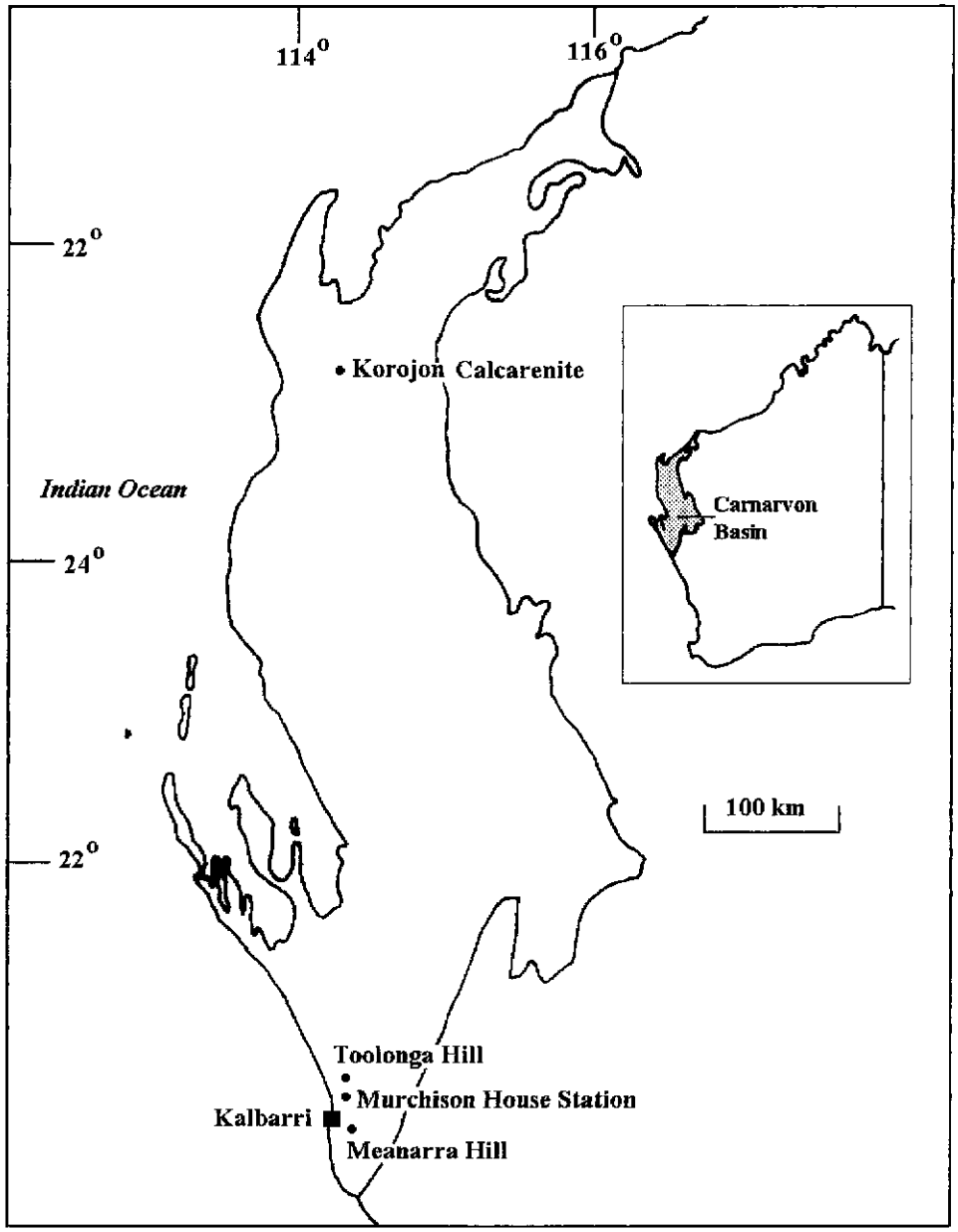


Figure 3.2: Late Cretaceous Carnarvon Basin indicating the Toolonga Calcilutite and Korojon Calcarenite.

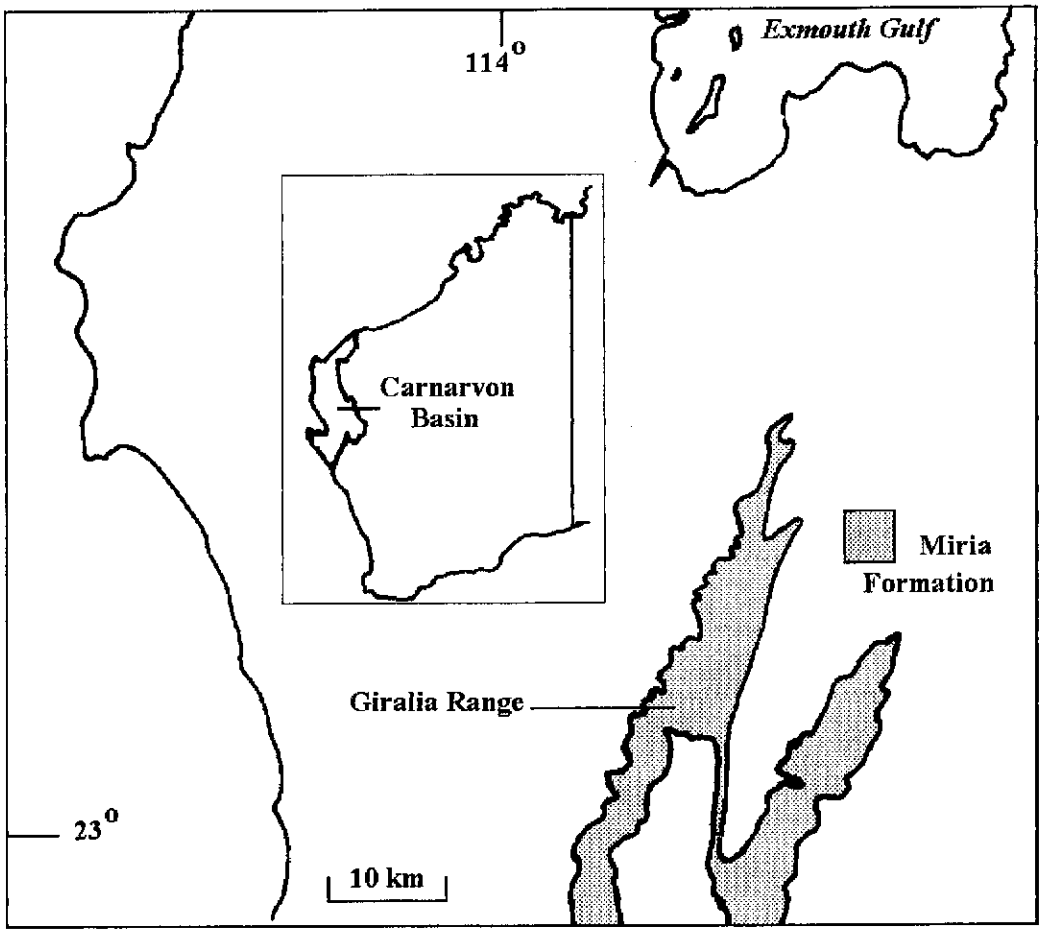


Figure 3.3: Late Cretaceous Miria Formation in the central Carnarvon Basin.

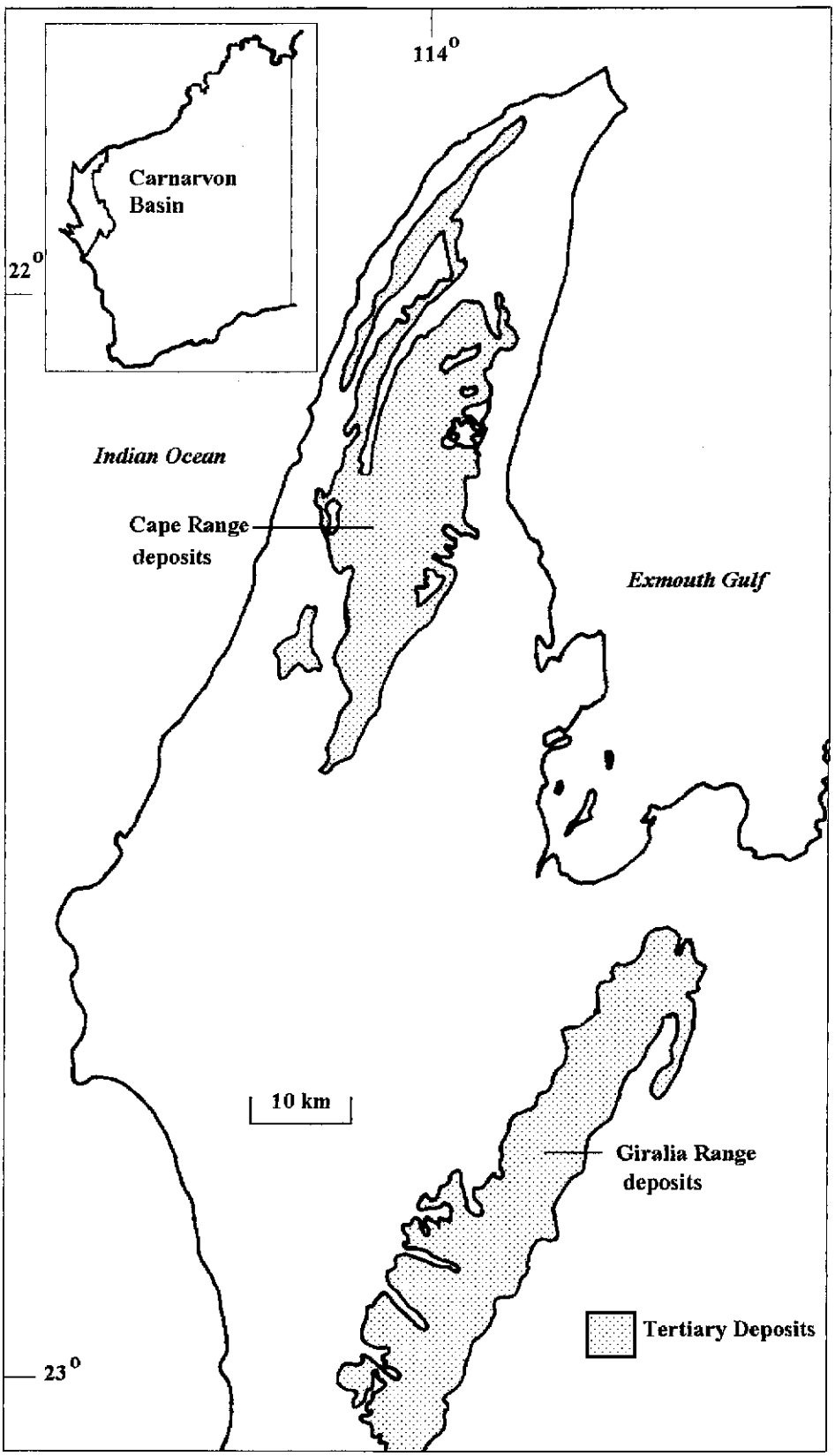


Figure 3.4: The Cenozoic (Tertiary) deposits within the Carnarvon Basin.

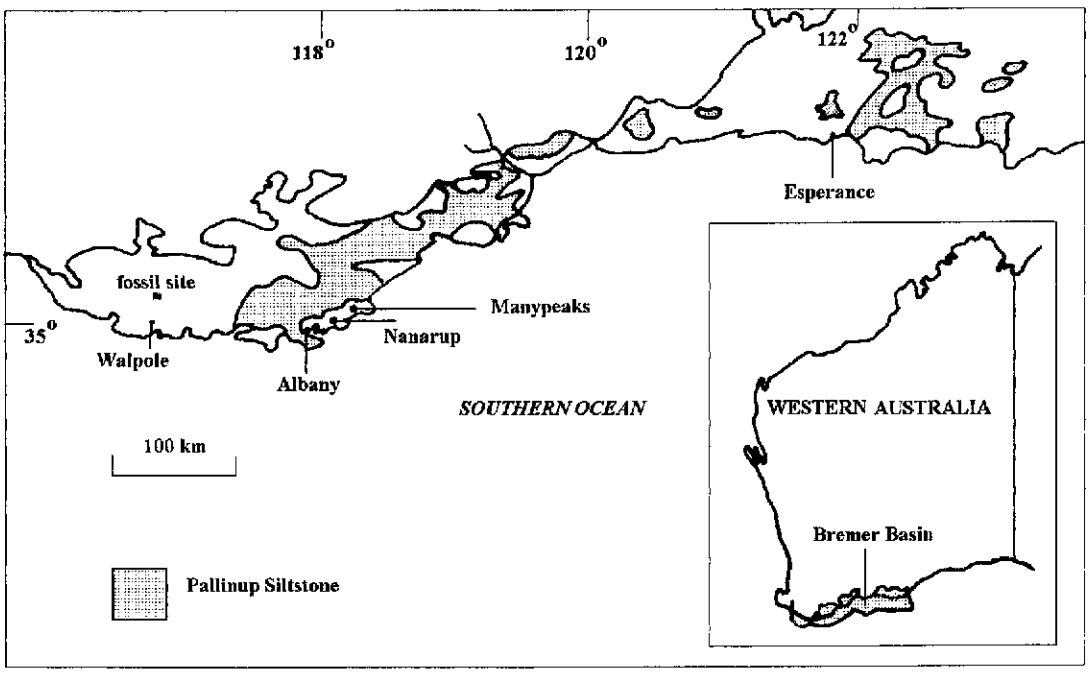


Figure 3.5: The Late Middle Eocene Nanarup Limestone and Pallinup Siltstone Werrilup Formation, Bremer Basin, Western Australia (adapted from Cockbain 1968c).

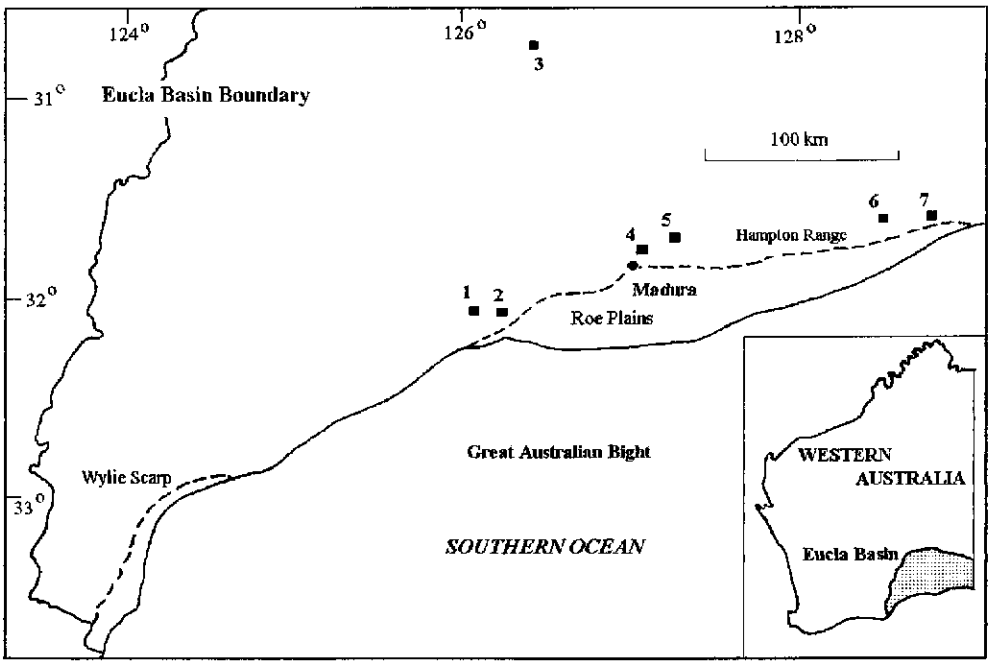


Figure 3.6: Map of the Eucla Basin indicating the fossil sites in the various deposits. 1 = Murra-el-elevyn Cave, 2 = Tommy Graham Cave, 3 = Haig Cave, 4 = Firestick Cave, 5 = Mullamullang Cave, 6 = Abrakurrie Cave, 7 = Weebubbie Cave (derived from Lowry 1970).

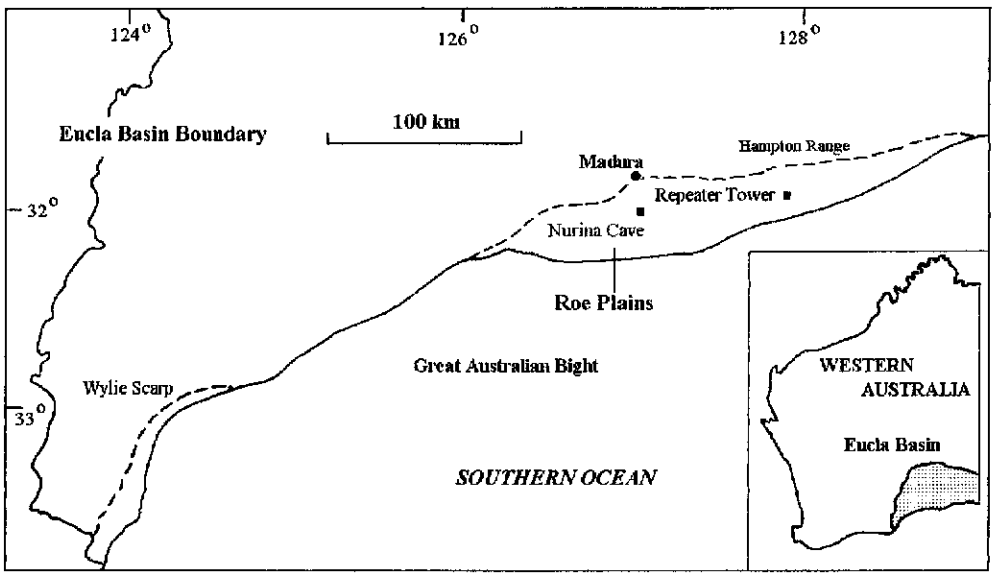


Figure 3.7: Map of the Eucla Basin showing the Roe Plains and the Hampton Range Repeater Tower, the principle fossil site for the Roe Calcarenite.

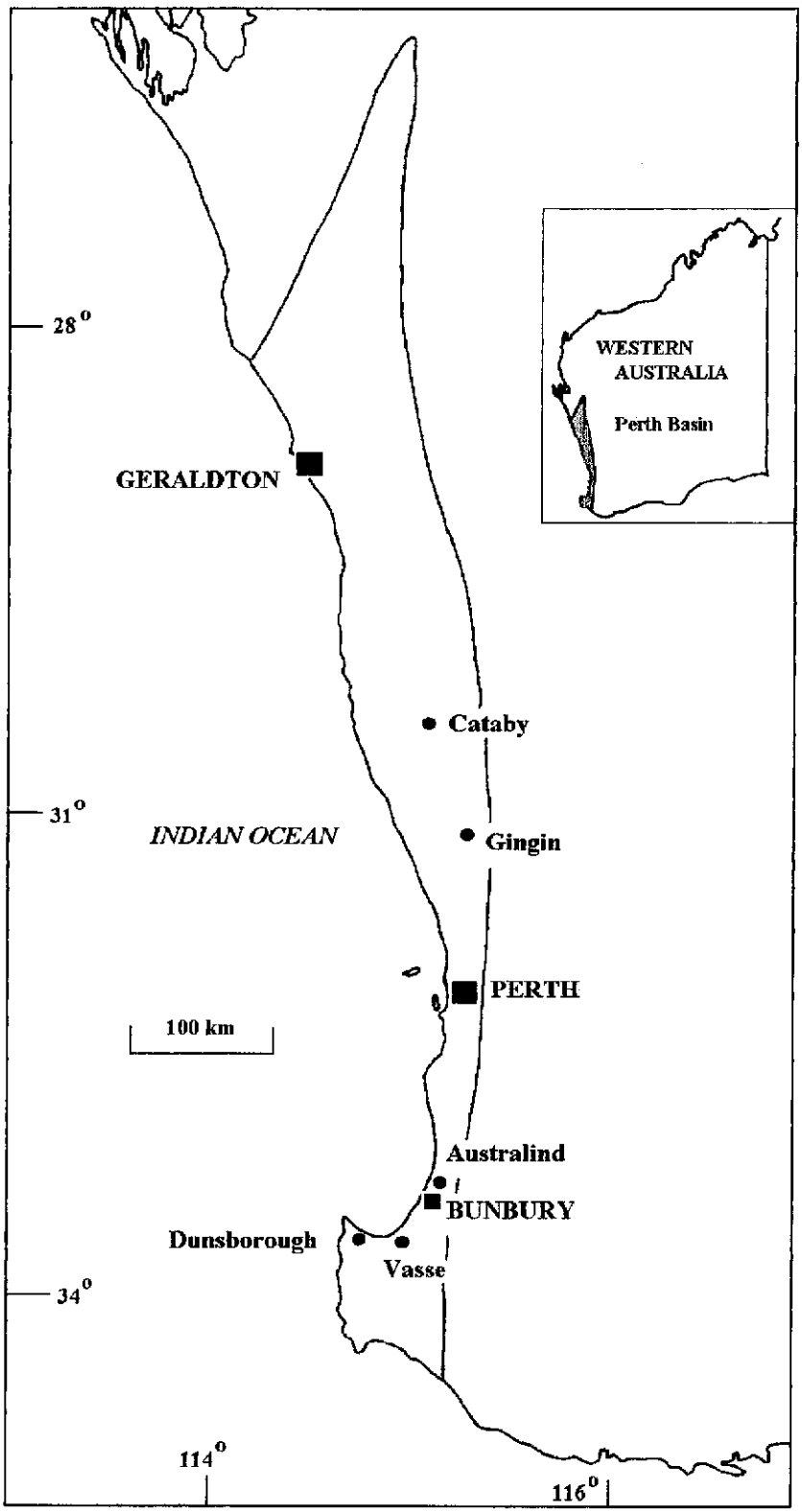


Figure 3.8: The distribution of the Ascot Formation in the Perth Basin

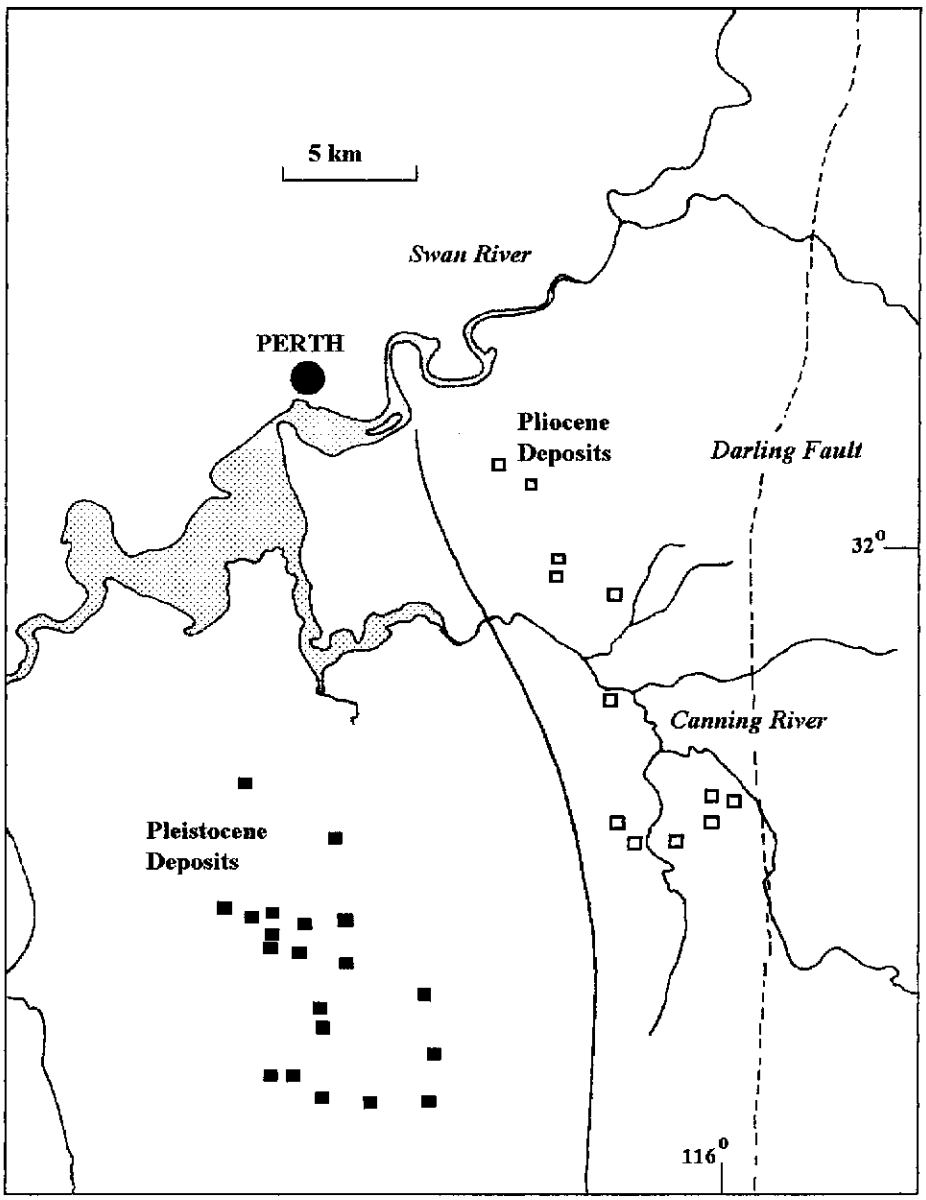


Figure 3.9: Ascot Formation bore holes in the Perth metropolitan area indicating Pliocene and Pleistocene deposits (Adapted from Kendrick *et al.* 1991).

Figure 3.10: Molecap Hill, Gingin Chalk, Perth Basin.

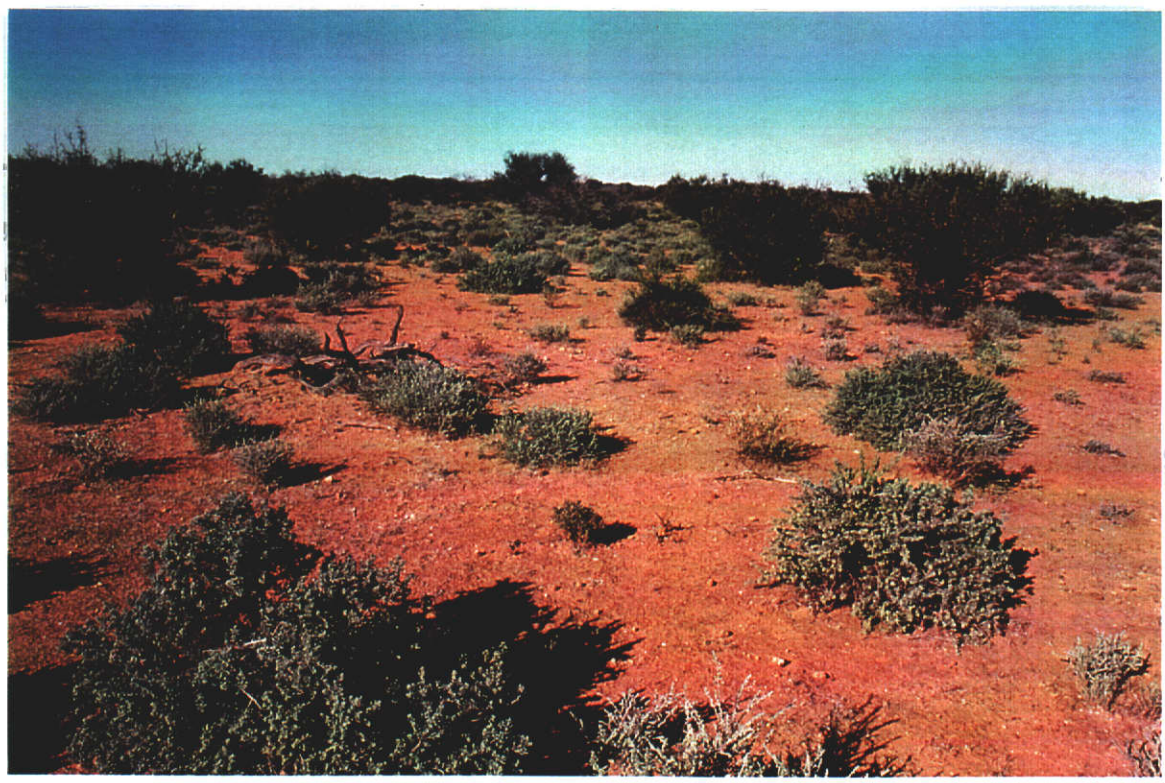


Figure 3.11: Cardabia Formation, Giralia Range, Carnarvon Basin.

Figure 3.12: Brachiopod exposed in the Cardabia Formation, Giralia Range, Carnarvon Basin.

Figure 3.13: Mt Manypeaks Lime Quarry, Nanarup Limestone, Bremer Basin.

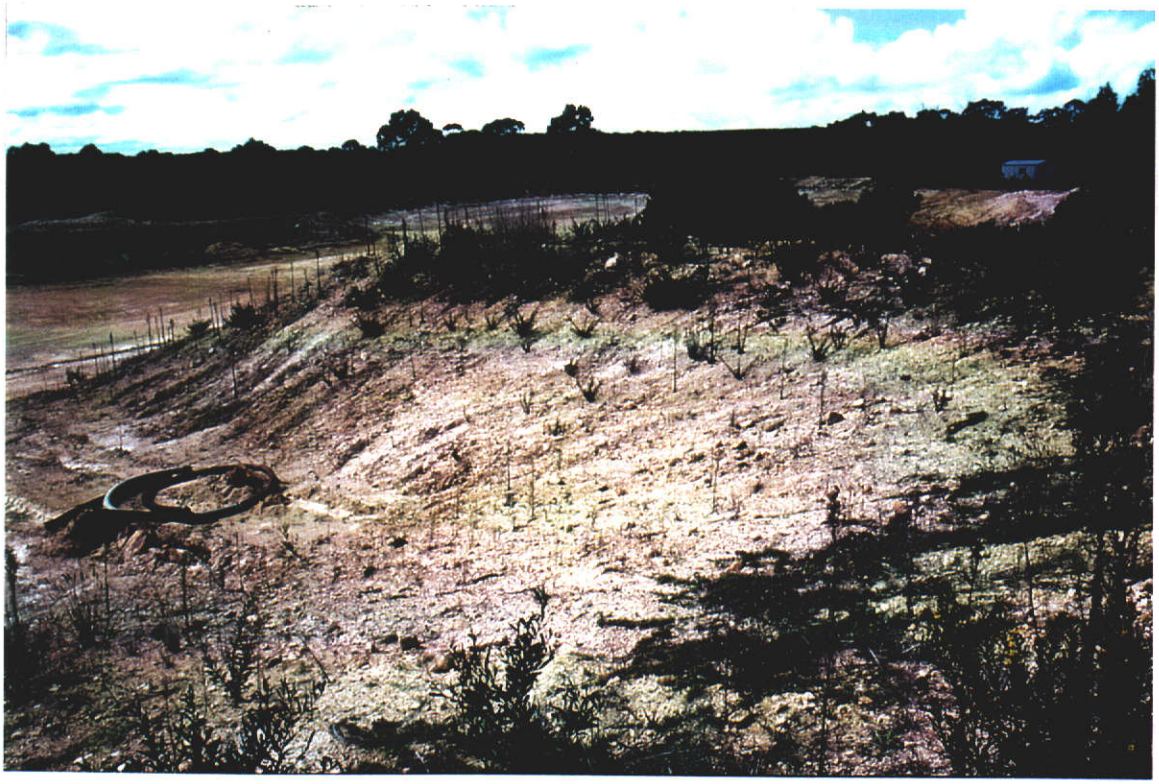
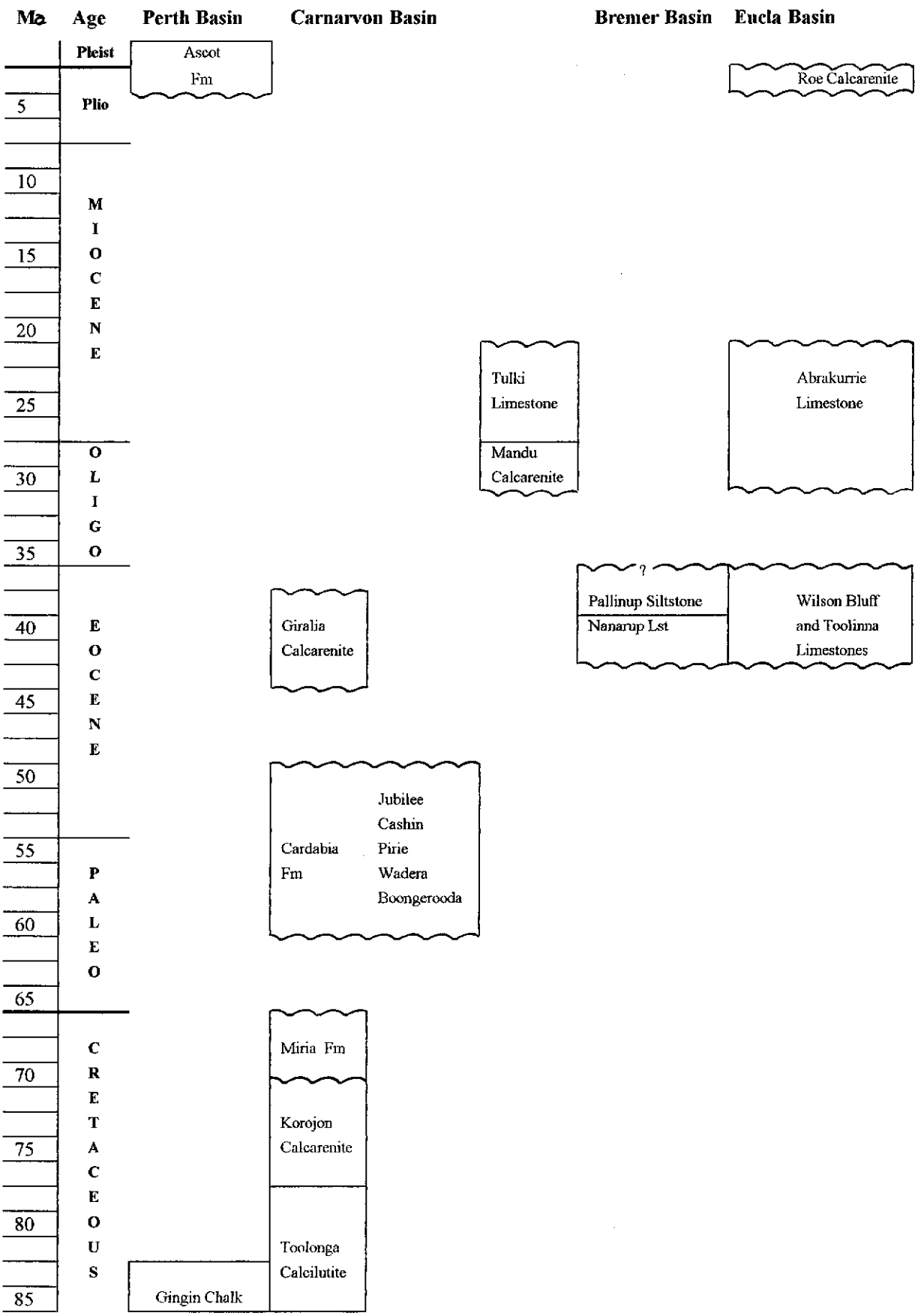


Figure 3.14: Nanarup Lime Quarry, Nanarup Limestone, Bremer Basin.

Figure 3.15: Fossils in the Nanarup Lime Quarry, Nanarup Limestone, Bremer Basin.

Figure 3.16: Stratigraphy of the Western Australian deposits containing Late Cretaceous to Cenozoic brachiopods.



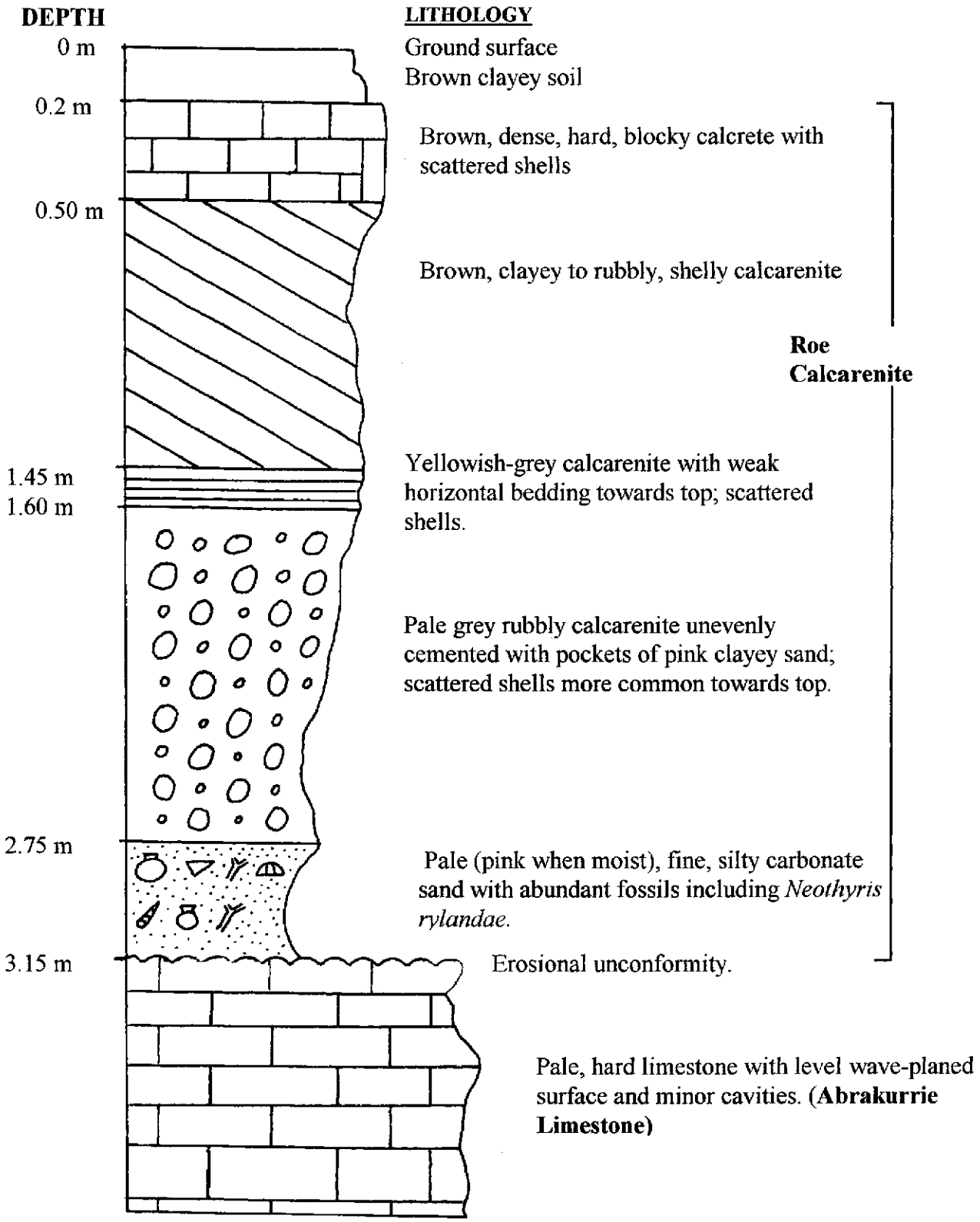


Figure 3.17: Section of the Roe Calcarenite at the type locality in pit 1.5 km north of Hampton Microwave Repeater Tower. (Latitude 31°57'36" South, Longitude 127°34'45" East) Courtesy G. W. Kendrick (personal communication).

Chapter 4

SYSTEMATIC PALAEONTOLOGY

Phylum BRACHIOPODA Dumeril, 1806

Subphylum CRANIIFORMEA Popov, Bassett, Holmer and Laurie, 1993

Class CRANIATA Williams, Carlson, Brunton, Holmer and Popov 1996

Order CRANIIDA Waagen, 1885

Superfamily CRANIACOIDEA Menke, 1828

Family CRANIIDAE Menke, 1828

Genus WESTRALICRANIA Cockbain, 1967

Type species

Westralicrania allani Cockbain, 1967

***Westralicrania allani* Cockbain, 1967**

Figure 4.10 A, B

Table 4.1

1967 *Westralicrania allani*; Cockbain, p. 75, pl. 35.

1986 *Danocrania allani*; Lee and Brunton, p. 148.

1997 *Westralicrania allani*; Craig, p. 311.

Material Examined

WAM 92.714, 96.720 from the Wadera Member and WAM, 84.579-84.583, from the Cashin Member.

Description

Ventral valve. Pseudointerarea short, extending 70 per cent. of valve width, apsacline. Numerous growth lines. Spinose with spines pointing posterior to anterior. Not in regular lines.

Posterior muscle scars on platforms, slightly raised from valve floor, anterior muscle scars in shallow pits; depression between scars; medium septum short, extending anteriorly into "butterfly" shaped muscle attachments; margins appear ridged due to endopunctae being in distinct concentric lines radiating from umbo; exterior irregularly spinose.

Dorsal valve. Cone shaped with apex to posterior end of valve, numerous growth lines, irregularly spinose; internal muscle scars on raised platform on posterior valve floor, below these a shallow depression separated by sharp ridges; medium ridge to anterior.

Table 4.1 : Measurements of *Westralicrania allani* Cockbain, 1967 (in mm).

SPECIMEN	LENGTH	WIDTH	SPECIMEN	LENGTH	WIDTH
84.579a	8.6	8.7	84.581	6.5	6.9
84.579b	6.4	6.0	84.582	6.3	6.9
84.579c	7.0	6.9	84.583	8.8	9.0
84.579d (dorsal)	6.9	7.4	92.714	6.4	6.5
84.580	6.9	6.9	96.720	7.0	6.9

Remarks

These specimens from the Giralia Range are consistent with the type material from the Cardabia Formation, Shark Bay. *W. allani* is generally smaller and has a shorter pseudointerarea than in *W. zenobiae*, the other species of *Westralicrania* from the Late Middle Eocene Nanarup Limestone Member of the Werrilup Formation of the Bremer Basin, Western Australia (Craig 1997). The pseudointerarea of *W. allani* is apsacline whereas in *W. zenobiae* it is anacline. The spines in *W. zenobiae* radiate regularly in lines from the umbo whereas in *W. allani* they are irregular in their radiation.

***Westralicrania zenobiae* Craig, 1997**

Figure 4.10 C-F

Table 4.2, 4.3

Diagnosis

Relatively larger species of *Westralicrania.* Exterior valve with radiating comparatively shorter spines arranged in lines. Interior posterior muscle scars relatively large; median septum comparatively short; pseudointerarea relatively large and anacline.

Material Examined

Holotype

WAM 94.29, ventral valve from the Nanarup Limestone Member (Late Middle Eocene), Nanarup Lime Quarry.

Paratypes

WAM 94.30 to 94.40, ventral valves from the same horizon and locality as the holotype.

Other material. WAM 94.41, a ventral valve from the Nanarup Limestone Member, near Manypeaks Homestead. WAM 94.28 and WAM 88.373, dorsal valves from the Toolinna Limestone (Middle Eocene), Israelite Bay.

Description

Ventral valve. Shell reaches a maximum known length of 11.7 mm; triangular to pear shaped, width 80 per cent. of shell length (SL); dorso-ventrally flattened. Growth lines on exterior indicate mixoperipheral growth, pronounced growth lines on the pseudointerarea. Exterior has elongated pustules to spines which radiate in lines from the posterior attachment area behind the pseudointerarea with some intercalation (3 per mm). The spines point from posterior to anterior. Attachment area is a distinct elliptical region of flattening (16 per cent. SL, 22 per cent. shell width [SW]). Because pseudointerarea is slightly anacline, shell is raised from attachment area. The triangular pseudointerarea (31 per cent. SL) bears stepped growth lines, 3 in the smallest to 11 in the largest. A flat limbus entirely surrounds concave depression of shell interior. Posteromedian extension of limbus impinges slightly on depression before it drops to a shallow depression between large paired, raised muscle scars (20 per cent. SL). Traced anteriorly, this depression leads to a small median septum or ridge (13 per cent. SL) with raised anterior muscle scars on each side with single depression in each. Interior of shell is endopunctate, which in the smallest specimen, leads to shell appearing as if it is tuberculate. Endopunctae radiate from posterior margin in front of pseudointerarea. Limbus and posterior margin similarly endopunctate, some of the punctae forming linear depressions perpendicular to shell edge.

Dorsal valve. Dorsal valve subcircular. Exterior surface has a number of growth lines with radiating spines (3 per mm). Valve slightly conical in shape, top of cone 0.25 to 0.3 distance from posterior margin. Interior has pronounced limbus slightly angled to interior curvature, beginning at posterior-lateral margin; extends around the shell. Towards anterior of shell it widens, being widest at anterior margin. Shell concave, greatest depth at cone top near posterior. Posterior muscle scars are slightly raised from the wall and parallel to it. Anterior muscle scars on the base of shell, triangular in shape. Anterior to these scars is a median ridge which extends 0.3 diameter of the valve with two large depressions either side. Shell endopunctate throughout, endopunctae radiating in a linear fashion.

Intraspecific variation

The larger the specimen, the greater the number of growth lines in the pseudointerarea, each line becoming more densely spaced as the shell gets larger. Furthermore, the greater the shell size the greater the number of radiating lines of spines on the exterior surface of the shell. WAM 94.34 has interior ridge anterior to the median septum from the anterior muscle scars to the margin in an anterior lateral direction. The shell is slightly convex. Other specimens do not show these features. WAM 94.36 and WAM 94.37 are markedly depressed anterior to the median septum and anterior muscle scars. There is a ridge present, dividing area into two equal sized pits. This is not observable in WAM 94.29 and WAM 94.34 nor, due to wear, is it apparent in WAM 94.30-33. WAM 94.35, WAM 94.38 and WAM 94.40,41 have a wider ridge or "bridge" between the anterior muscle scars and limbus than other specimens. WAM 94.37 shows clearly the endopunctae in lines radiating from the pseudointerarea margin. These lines change direction on the limbus to become perpendicular with the shell edge. In WAM 94.38 the pseudointerarea is less pronounced than in other specimens. Around the endopunctate limbus an anterior margin, stemming from the first growth line of the pseudointerarea, surrounds the shell. This is also present in WAM 94.40 and WAM 94.41. The margin is smooth, flat and not punctate. It is possible that such a margin was present on the other specimens but was worn away. WAM 94.39 is appreciably smaller than the other specimens. It is flatter internally, lacking distinctive muscle scars. The endopunctae

produce numerous raised areas which appear as tubercles. The middle of the three growth lines in the pseudointerarea has two flat spines pointing posteriorly. The "roughness" of the edges of growth lines in other specimens may indicate that they too possessed such spines at some stage.

Table 4.2: Measurements of *Westralicrania zenobiae* Craig, 1997 ventral valve (in mm).

SPECIMEN	LENGTH	WIDTH	SPECIMEN	LENGTH	WIDTH
94.29	8.6	7.0	94.36	9.1	8.0
94.30	7.9	7.0	94.37	9.5	7.4
94.31	10.3	8.6	94.38	8.7	7.7
94.32	11.7	8.5	94.39	4.8	3.8
94.33	7.7	6.7	94.40	8.5	6.6
94.34	9.1	7.9	94.41	9.6	7.3
94.35	7.8	6.8			

Table 4.3: Dorsal valve measurements of *Westralicrania zenobiae* Craig, 1997 (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH
94.28	7.3	7.8	2.1
88.373	7.0	7.8	2.1

Remarks

In overall size *Westralicrania zenobiae* Craig, 1997 is generally larger than *Westralicrania allani* Cockbain, 1967 (4.8-11.7 mm for *W. zenobiae* compared with 2.2-6.8 mm for *W. allani*). The posterior muscle scars are comparatively larger (20 per cent. :12.5 per cent. of total valve width) whereas the median septum is comparatively shorter in *W. zenobiae* than *W. allani* (11.1 per cent. : 28.6 per cent. of total valve length). There are significantly more growth lines in the pseudointerarea of *W. zenobiae* than in *W. allani* as it is comparatively longer. The spines on the exterior surface of *W. zenobiae* are relatively shorter on *W. zenobiae,* but they radiate in lines whilst those on *W. allani* have no apparent regularity. The pseudointerarea is anacline in *W. zenobiae* and apsacline in *W. allani.*

Etymology

The species was named in honour of my wife, Zenobia. In Greek, Zenobia means "her father's jewel".

Subphylum RHYNCHONELLIFORMEA Popov, Bassett, Holmer and Laurie, 1993

Order RHYNCHONELLIDA Kuhn, 1949

Superfamily RHYNCHONELLOIDEA Gray, 1848

Family BASILOLIDAE Cooper, 1959

Subfamily BASILOLINAE Cooper, 1959

Genus BASILIOLA Dall, 1908

Type species

Hemithyris beecheri Dall, 1895

***Basiliola* sp.**

Figure 4.10 G-K

Table 4.4

1956 *Zeilleria* Condon *et al.*, p.40.

Diagnosis

Smooth shelled; folded, anterior commissure uniplicate; conjunct deltidial plates; mesothyridid to submesothyridid foramen.

Material Examined

WAM 84.584, 585, 588 Giralia Range, Carnarvon Basin, Cashin Member, Cardabia Formation. Late Paleocene.

Description

Exterior. Small shell to 9.4 mm long, pyriform with sharp beak, biconvex, bulbous, depth to 62 per cent. shell length; deep sulcus in ventral valve, widest at mid-length or anterior to it, width to 94 per cent. shell length; cardinal margin strongly curved; lateral valve edges sharply bevelled, margin curves upward towards ventral valve then dips with sulcus to produce a strongly convex curve with respect to dorsal valve; anterior commissure strongly uniplicate; surface smooth; beak pointed, narrow, erect; beak ridges sharp, extend to end of cardinal margin; foramen

round to "spout-like", small, mesothyridid to submesothyridid; deltidial plates conjunct, symphytium narrow with median ridge.

Interior. Only part of a ventral valve. Semicircular hinge teeth protrude inwards towards shell centre. No dental plates.

Table 4.4: Measurements of *Basiliola* sp. (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
84.588	7.8	6.4	4.6	84.584	8.0	7.0	4.3
84.585	9.4	7.8	5.7	84.584	7.5	7.0	4.2
84.585	7.7	6.6	4.8	84.584	6.7	5.8	3.4
84.585	7.4	6.1	4.4	83.902	6.0	5.6	2.6
84.586	6.5	5.9	3.5	83.902	3.6	2.7	
84.584	7.1	6.7	4.1	83.902	5.4	4.6	2.6
84.584	7.7	6.8	4.7	96.818	11.9	11.3	6.9
84.584	6.8	6.7	4.4				

Remarks

The species description agrees well with the generic description outlined in Ager (1965). *Basiliola* has been recorded from Eocene to Recent deposits. It has been described from Japan (Hatai 1940) and the Indo-Pacific (Cooper 1959) as well as the Eocene La Meseta Formation on Seymour Island, Antarctic Peninsula by Bitner (1996). This is the first record of *Basiliola* from the Upper Paleocene, and thus the earliest known record of the genus, and the first record of the genus from Australia. This species is similar in size and general description to *B. minuta* Bitner, 1996. The inability to fully observe the interior makes it impossible to describe this species as a new or previously described taxon.

Genus EOHEMITHYRIS Hertlein and Grant, 1944

Type species

Eohemithyris alexi Hertlein and Grant, 1944.

***Eohemithyris miriaensis* sp. nov.**

Figure 4.10 L-P, S

Table 4.5

Material Examined

Holotype

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

Paratype

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

Diagnosis

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

Description

Exterior. Small triangular shell up to 11.7 mm long. Biconvex, depth to 59 per cent. shell length. Width greatest anterior to mid-length, to 97 per cent. 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 per cent. shell length), submesothyridid; deltidal plates conjunct.

Internal structures unknown.

Table 4.5: Measurements of *Eohemithyris miriaensis* sp. nov. (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH
96.804	7.7	6.2	3.6
96.818	11.6	11.3	6.8

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 sp. nov. has a bisulcate anterior commissure. *E. colurnus* (Hedley, 1902), 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, Carnarvon Basin.

***Eohemithyris wildei* sp. nov.**

Figure 4.10 Q, R, T-V

Table 4.6

Diagnosis

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

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.

Description

Exterior. Small to medium subcircular shell to 11 mm in length. Biconvex, ventral valve less convex, depth 60 per cent. 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 per cent. shell length, oval, submesothyridid; deltidial 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.

Table 4.6: Measurements of *Eohemithyris wildei* sp. nov. (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
3850	9.0	9.7	-	6705	7.7	7.4	5.3
3850	8.3	8.2	5.1	70.1833	10.9	10.7	8.5
3850a	8.3	8.2	5.1	74.1261	6.4	7.0	3.4
6188	6.4	6.6	4.4	74.1261	6.7	7.0	4.1
6188	6.4	6.5	4.4	74.1261	7.1	7.4	3.3
6254	7.0	6.7	4.7	74.1261	7.0	7.5	3.6
6254	7.0	6.6	4.6	74.1261	6.7	7.1	4.1
63.129	5.9	6.8	3.8	74.1261	6.4	6.4	3.4
63.129	9.2	10.7	4.5	7460	9.6	10.2	5.7
63.129	8.5	8.5	6.1	7460/1	10.0	10.1	5.5
63.132	7.0	7.0	4.4	76.2246	5.6	6.6	2.7
63.132	8.6	8.4	4.6	80.743	8.3	7.0	5.1

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
63.132	7.0	6.9	4.5	80.743	8.2	7.0	5.1
63.132	8.6	8.4	4.9	88.884	5.9	5.7	2.8
6427	8.2	8.1	6.0	88.884	6.2	5.8	3.0
6427	9.2	10.7	4.5	97.700	9.0	7.5	4.6
6444	8.0	7.8	5.0	97.700	8.0	7.6	4.5
6444/5	8.2	7.7	4.8	97.700	8.0	7.6	5.5
6444/5	5.7	6.7	3.5	97.700	9.0	7.5	4.7
6445	5.5	6.5	3.6				

Remarks

Eohemithyris miriaensis sp. nov., a smooth Maastrichtian species described herein from the Miria Formation, Carnarvon Basin, Western Australia differs from *E. wildei* which has fine costation. 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 in honour of Dr S. A. Wilde, Associate Professor of Geology, School of Applied Geology, Curtin University of Technology.

Family HEMITHYRIDIDAE Rzhonsnitskaya, 1956.

Genus PROTEGULORHYNCHIA 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 4.11 A-E

Table 4.7

1980 *Protegulorhynchia meridionalis* Owen, p.129, figs. 15 a-c, 16.

Material Examined

WAM 82.1937 Gingin; 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 per cent. shell length. Width greatest just anterior to mid-length, 95 per cent. shell length. Growth lines distinct to prominent, costellate, ribs as wide as interstitual spaces, rounded, 3 ribs per mm at mid length, deep sulcus anterior third of ventral valve. Cardinal margin curved, narrow (60 per cent. 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 per cent. shell width, crenulate. Umbo sharp, short, erect to incurve; beak ridges sharp. Foramen small, oval to 4 per cent. 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, concave floor, striated horizontally. Inner socket ridge curved towards socket, socket not completely covered. Hinge plate and crural base fused. Crura short, divergent, raduliform. Short low median septum widening posteriorly, fused to lower cardinal margin. Cardinal process triangular in posterior apex of slightly swollen umbo. Muscle scars indistinct, short, round.

Table 4.7: Measurements of *Protegulorhynchia meridionalis* Owen, 1980 (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
68.670	8.2	8.0	5.8	4527	7.3	6.2	3.4
74.1142	10.1	11.7	5.3	4527	7.4	6.3	3.5
77.3548	10.0	9.4	6.4	5944	12.6	12.8	6.1
77.3550	7.2	7.6	4.9	5944	12.4	12.4	6.2
82.1937	11.0	10.5	6.7	6186	7.4	6.9	3.8
4242	7.6	7.6	2.7	6186	7.4	7.0	3.8
4242	7.5	7.5	2.6	6253	9.0	8.4	5.9

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 4.11 F-I

Table 4.8

Diagnosis

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

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.

Description

Exterior. Small subpentagonal shell to 6.5 mm in length. Biconvex, both valves equally so, depth 65 per cent. shell length. Width greatest just anterior to mid-length, 86 per cent. shell length. Growth lines distinct, costellate, non-bifurcating, crowded at umbo, spreading anteriorly, 6 per mm at mid-length, ribs rounded, widening anteriorly, interstitual space between ribs 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 sulcus narrow, central plication wide, 50 per cent. 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.

Table 4.8: Measurements of *Protegulorhynchia bevanorum* sp. nov. (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH
4795	5.6	5.0	2.9
5289	7.5	7.5	4.3
6706b	6.4	5.6	4.3

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* sp. nov. and 3 per mm in *P. meridionalis*) and a parasulcate anterior commissure in *P. bevanorum*, 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 boongeroodaensis McNamara, 1983

Figure 4.11 J-N

1956 *Cyclothyris* spp. nov. Condon *et al.* p. 30.

1983 *Tegulorhynchia boongeroodaensis*; McNamara, p. 461, text fig. 1a-y.

Material Examined

WAM 60.21, 60.22, 71.148, 71.161, 71.172, 80.1490, 80.1491, 80.1494, 80.1495, 80.1498, 80.1503, 80.1505, 80.1511, 81.2255, 81.2256, 81.2257, 84.471, 88.52, 88.70, 88.76, 88.107, 96.815, 96.829, 96.830 Boongerooda Greensand Member, Cardabia Formation, Giralia Range Carnarvon Basin, Late Paleocene

WAM 80.1509, 80.1510, 83.903, 83.992 Pirie Member, Cardabia Formation, Giralia Range Carnarvon Basin, Late Paleocene.

WAM 80.1506, 80.1507, 84.525, 88.31, 88.42, 88.46 Wadera Member, Cardabia Formation, Giralia Range Carnarvon Basin, Late Paleocene.

Description

Exterior. Small to medium shell, 1.5 to 21 mm in length, sub-circular; wider than long, width to 110 per cent. shell length; biconvex, dorsal valve deep, ventral valve nearly flat, depth to 64 per cent. shell length; deep sulcus in ventral valve commencing just posterior to mid-length; costellate, four to six ribs per mm at mid-length, ribs rounded, same width as rounded interstitual spaces; growth lines numerous, meeting ribs to produce rugose pattern; cardinal margin wide, curved; lateral valve edge variable, rounded to bevelled, margin slightly convex with respect

to dorsal valve posteriorly, vertical fall with respect to dorsal valve due to plication at anterior commissure; anterior commissure edge bevelled to flat, commissure uniplicate, fold 75 per cent. shell width; beak short, sharp, erect; beak ridges sharp; foramen small to 2.3 per cent. shell length, submesothyridid; deltidial plates conjunct in most specimens; symphytium narrow, low, concaved.

Interior. Ventral valve. Hinge teeth raised vertically, cylindrical, deep curved groove towards cardinal margin, swollen bases extending towards but not touching valve floor, three horizontal grooves in swollen bases; shallow trough below foramen on raised narrow platform; shallow trough below platform at posterior of valve; muscle scars ovate, extend either side of trough extending anteriorly to mid valve; mantle scars anterior third of valve clearly visible.

Dorsal valve. Outer socket ridges slightly curved over sockets; sockets deep, triangular, horizontally striate; inner socket ridges and crura bases swollen; short, radulifer; median septum low, short to mid-length, bifurcates posteriorly, fused to cardinal margin; cardinal process narrow, triangular near vertical, joins median septum posteriorly; muscle scars pyriform, short, either side of median septum.

Remarks

McNamara (1983) suggested that the anterior commissure is rectimarginate in juveniles and the foramen is hypothyridid. Examination of small specimens indicates that most of them are *Terebratulina* species, probably *Terebratulina lindsayi* described herein, hence the anterior commissure description for juvenile *T. boongeroodaensis* is suspect. This is the earliest Cenozoic record of the genus *Tegulorhynchia.*

***Tegulorhynchia hrodelberti* sp. nov.**

Figure 4.11 O-S

Table 4.9

Diagnosis

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

Material

Holotype

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

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.

Description

Exterior. Small, subpentagonal, subtriangular, to subcircular, shell up to 11.5 mm in length. Biconvex, dorsal valve deeper, depth up to 72 per cent. shell length. Width greater than length, widest anterior to mid-length, up to 113 per cent. 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 per cent. shell length; lateral valve edge rounded, lateral margin straight to gently curved towards ventral valve anteriorly; anterior commissure uniplicate, plication 50 per cent. shell width. Umbo strong, pointed; beak erect; beak ridges rounded. Foramen small, up to 6 per cent. shell length, round with extension of pedicle collar posteriorly, hypothyridid; deltidal plates small, tips just touching in most specimens to disjunct.

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 per cent. shell length, follows curve to cardinal margin, blade-like. Muscle scars kidney-shaped on either side of median septum. Cardinal process indistinct in triangular posterior apex.

Table 4.9: Measurements of *Tegulorhynchia hrodelberti* sp. nov. (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
4529 vv	6.0	5.3	-	74.1300	7.3	7.4	2.6
4596	4.8	4.9	2.1	74.1300	6.3	6.1	2.1
70.1836	10.3	11.3	5.3	74.1300	7.5	8.6	3.7
74.1264	8.0	8.9	-	74.1300	6.0	7.2	3.1
74.1264	5.0	4.9	2.1	74.1300	6.0	6.1	3.1
74.1264	7.9	7.8	4.0	74.1300	8.1	8.1	2.5
74.1264	9.2	10.5	-	74.1300	7.3	6.5	3.2
74.1264	9.0	9.1	3.4	74.1300	7.5	8.5	3.9
74.1264	7.7	8.3	4.0	74.1300	8.8	8.2	3.9
74.1264	6.5	7.1	-	74.1300	8.0	8.9	3.1
74.1264	6.7	6.4	-	74.1300	4.9	5.4	1.9
74.1264	5.1	4.9	1.9	74.1300a	11.0	12.4	3.6
74.1264	8.0	8.1	4.1	74.1300b	10.2	10.7	6.7
74.1264	8.3	7.7	4.0	75.10	9.4	9.6	
74.1264	9.1	9.1	3.3	75.10 vv	9.4	9.5	-
74.1264	9.1	10.6	2.6	77.3529	4.0	3.9	-
74.1264	6.7	6.4	2.2	77.3529	4.0	4.0	1.5
74.1264	6.5	7.3	2.4	77.3529 vv	2.4	2.5	-
74.1300	7.6	9.2	3.5	78.4197	6.4	6.5	3.0
74.1300	8.4	8.6	3.5	88.220	6.3	5.0	3.1

Remarks

The costation rate (number per mm) in *T. hrodelberti* sp. nov. is similar to that of *T. boongeroodaensis*. McNamara (1983) used 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 due to the sulcus is relatively small (50 per cent. shell width) in *T. hrodelberti* while it is large (75 per cent. shell width) in *T. boongeroodaensis.* The plication in *T. hrodelberti* is marked, even the small specimens. McNamara described the juveniles of *T. boongeroodaensis* as rectimarginate as did 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.

Order TEREBRATULIDA Waagen 1883

Suborder TEREBRATULIDINA Waagen, 1883

Superfamily TEREBRATULOIDEA Gray, 1840

Family TEREBRATULIDAE Gray, 1840

Subfamily TEREBRATULINAE Gray, 1840

Genus GIRALIATHYRIS gen. nov.

Type species

Giraliathyris mcnamarai gen. et sp. nov.

Type Locality

Giralia Range, Carnarvon Basin, Wadera Member, Cardabia Formation. Late Paleocene.

Etymology

From the locality, Giralia Range.

Diagnosis

Medium sized shell; equally biconvex; anterior margin rectimarginate to gently unisulcate; surface smooth, finely and densely punctate; foramen mesothyridid to permesothyridid; no inner hinge plates; cardinal process protuberant cup; loop terebratulid to 0.35 shell length.

Remarks

Giraliathyris gen. nov. is similar to *Liothyrella* Thomson, 1916 and *Gryphus* Mergerle von Muhlfeld, 1811. The position of the foramen in *Giraliathyris* is mesothyridid to permesothyridid, whereas *Liothyrella* and *Gryphus* have an epithyridid foramen. In both *Liothyrella* and *Gryphus* the cardinal process is described as a flat laterally extended or small transverse plate respectively, whereas *Giraliathyris* has a protuberant cup. The new genus contains species which are equally convex with rectimarginate to very incipiently unisulcate anterior commissures. The surface is smooth and finely densely punctate in *Giraliathyris*. This may be the species nominated as *Liothyrina* in Condon *et al.* 1956.

***Giraliathyris mcnamarai* gen. et sp. nov.**

Figure 4.1, 4.12 A-F

Table 4.10

Material Examined

Holotype

WAM 96.826 Giralia Range, Carnarvon Basin, Wadera Member, Cardabia Formation. Late Paleocene.

Paratypes

WAM 83.3039b, 84.493 and 96.750 Giralia Range, Carnarvon Basin, Wadera Member, Cardabia Formation. Late Paleocene.

Other Material

WAM 71.149, 71.162, 83.3039, 84.493, 84.1688, 88.77, 88.86, 88.111, 96.816 Giralia Range, Carnarvon Basin, Boongerooda Greensand, Cardabia Formation. Late Paleocene.

WAM 84.548 and 84.550 Giralia Range, Carnarvon Basin, Pirie Member, Cardabia Formation. Late Paleocene.

WAM 72.390, 72.384, 83.3141, 84.518, 84.520, 84.533, 84.538, 88.25, 96.496, 96.502-504, 96.506-529, 96.537, 96.548-554, 96.557-558, 96.612-625, 96.627, 96.639, 96.644, 96.732, 96.751, 96.758, 96.762, 96.779, 96.784, 96.799-800, 96.805, 96.822-824, 96.826 Giralia Range, Carnarvon Basin, Wadera Member, Cardabia Formation. Late Paleocene.

Diagnosis

Medium sized shell; valves equally biconvex; greatest width at or posterior to mid-length; anterior margin rectimarginate to gently unisulcate; surface smooth, finely and densely punctate; beak short; foramen small, mesothyridid; symphytium with median ridge; no inner hinge plates; cardinal process protuberant cup; loop terebratulid.

Description

External. Medium sized shell, maximum length 36.3 mm, sub-circular to sub-pentagonal, equally biconvex, depth to 57 per cent. shell length; width to 98 per cent. shell length, greatest width at, or posterior to, mid-length; cardinal margin gently to strongly curved; lateral valve edges bevelled to round to impressed, margin straight to slightly convex with respect to dorsal valve; anterior commissure gently unisulcate, larger specimens slightly undulating; surface smooth, finely and densely punctate, punctae circular; beak erect to suberect, short, slightly labiate; beak ridges rounded, extend 50 per cent. of shell width and tend to flatten and widen from beak to lateral margin, sometimes becoming part of ventral growth lines; foramen small, to 2 per cent. shell length, mesothyridid; symphytium narrow, concave, nearly obscured and practically vertical, deltidal plates conjunct with median ridge.

Interior. Ventral valve. Hinge teeth cyrtomatodont, swollen bases sigmoidal to shell floor; adductor muscle scars centrally placed with small circular depression at posterior near pedicle trough, length 6.5 per cent. of the shell length; pedicle access area contains four ridges on a raised platform, pedicle collar sessile.

Dorsal valve. Outer socket ridge slightly incurved, prominent inner socket ridge fused to outer hinge plate; socket is triangular, apex posteriorly located, with small socket roof, fulcral plate thick and concave, area below plate thickened; no inner hinge plates, crural bases swollen, fusion with outer hinge plate creating a narrow trough between bases and crural plate, crural process small triangular, thick and divergent; two triangular adductor muscle scars either side of a wide median posterior platform, platform thins dramatically to form a low extension to the mid-length; cardinal process a protuberant cup widening vertically, thin high incurved rim extends either side, central myophore decreasing in height posteriorly.
Serial grinding indicated that the species has a short loop to 0.35 shell length of the terebratulid type (figure 4.1).

Table 4.10: Measurements of *Giraliathyris mcnamarai* gen. et sp. nov. (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
83.3039	36.3	33.3	17.8	96.824	27.0	23.8	13.0
83.3141	20.9	17.5	9.6	96.824	25.1	23.2	12.0
83.3141	23.9	22.1	11.9	96.824	29.5	27.0	14.8
83.3141	25.3	23.8	11.7	96.824	25.1	22.6	10.8
83.3141	26.3	22.9	13.1	96.824	19.1	17.0	8.0
83.3141	26.4	23.3	11.4	96.824	23.0	22.3	10.3
83.3141	28.6	26.8	12.5	96.499	28.9	25.9	15.8
83.3141	30.4	27.6	15.1	96.500	24.2	20.8	9.2
83.3141	31.0	27.0	11.0	96.501	24.3	21.2	11.3
84.518	28.8	25.7	11.6	96.502	24.6	22.4	10.9
84.533	17.4	16.3	7.4	96.504	24.5	21.5	8.7
84.591a	25.0	23.5	10.4	96.505	27.5	24.3	13.2
96.822	26.0	22.5	11.3	96.506	24.5	22.2	9.8
96.822	21.2	20.0	8.7	96.507	24.7	22.4	10.6
96.822	19.6	18.4	7.5	96.508	31.2	30.8	15.5
96.822	20.6	19.3	9.0	96.509	27.2	24.6	13.1
96.822	18.0	17.0	7.4	96.510	28.3	25.1	12.0
96.824	20.3	19.8	7.8	96.511	25.6	23.9	12.6
96.824	26.2	22.6	11.4	96.513	24.5	23.6	12.4
96.824	27.5	23.8	12.2	96.515	29.1	27.8	13.6
96.824	28.6	26.7	13.0	96.516	25.0	23.5	11.0
96.824	20.4	20.2	7.7	96.517	24.6	23.2	10.9
96.824	17.8	16.8	7.1	96.518	26.6	23.9	10.8
96.824	24.8	25.3	12.5	96.519	25.0	23.6	10.6
96.824	27.9	25.6	10.9	96.521	24.3	22.2	10.8
96.824	23.5	21.8	11.5	96.522	25.9	25.2	11.9
96.824	25.1	22.3	12.3	96.558	17.2	16.6	6.9
96.824	22.6	19.9	10.0	96.612	24.2	21.1	9.4
96.824	22.2	20.6	9.0	96.615	19.0	17.4	7.9
96.824	18.5	18.1	7.4	96.617	16.9	15.2	8.6
96.472	18.7	17.5	7.2	96.619	18.9	17.2	8.7
96.474	16.4	15.5	6.3	96.620	21.2	21.8	9.8

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
96.475	13.0	12.6	5.4	96.623	24.6	22.1	14.2
96.476	15.2	14.1	6.4	96.627	33.8	28.8	19.3
96.478	15.4	14.1	5.8	96.639	28.8	26.0	13.0
96.479	14.4	13.4	5.9	96.644	29.1	25.3	15.3
96.480	13.7	14.0	6.0	96.779	26.9	23.4	13.1
96.482	13.1	13.0	5.5	96.799	15.1	15.0	6.7
96.483	20.4	19.2	9.0	96.800	20.1	18.8	9.1
96.484	22.4	20.1	10.6	96.805	19.1	17.1	7.3
96.486	18.9	17.4	8.2				

Etymology

In honour of Dr K. J. McNamara, Senior Curator of Invertebrate Palaeontology, Western Australian Museum. He was also a principle collector of specimens from the Giralia Range.

***Giraliathyris kaitrinae* gen. et sp. nov.**

Figure 4.2, 4.12 G-L

Table 4.11

Material Examined

Holotype

WAM 96.666 Giralia Range, Carnarvon Basin, Wadera Member, Cardabia Formation. Late Paleocene.

Paratype

WAM 84.537, Giralia Range, Carnarvon Basin, Wadera Member, Cardabia Formation. Late Paleocene, WAM 84.547 Giralia Range, Carnarvon Basin, Pirie Member, Cardabia Formation. Late Paleocene.

Other Material

WAM 88.71, 96.817 Giralia Range, Carnarvon Basin, Boongerooda Greensand, Cardabia Formation. Late Paleocene. WAM 96.808 Giralia Range, Carnarvon Basin, Cashin Member, Cardabia Formation. Late Paleocene-Early Eocene. WAM 74.579, 84.527, 84.531, 84.540-541, 84.542, 96.501, 96.530, 96.532-536, 96.538-547, 96.650-664, 96.667, 96.668-676, 96.721-725, 96.727-731, 96.774-778, 96.783, 96.785-790, 96.796-797 Giralia Range, Carnarvon Basin, Wadera Member, Cardabia Formation. Late Paleocene.

Diagnosis

Medium sized shell; equally biconvex; anterior margin rectimarginate to gently unisulcate; surface smooth, finely and densely punctate; beak stout, slightly overhangs dorsal umbo; foramen medium to large, mesothyridid to permesothyridid; symphytium smooth; loop terebratulid.

Description

External. Medium sized shell, maximum length 34.5 mm, ovate to sub-pentagonal to sub-heptagonal in larger specimens, width to 85 per cent. shell length, widest at mid-length, equally biconvex, depth to 56 per cent. shell length; shell smooth with prominent growth lines in larger specimens; finely, densely punctate, punctae circular; cardinal margin curved, to 63 per cent. shell width; lateral valve edges bevelled, posteror-lateral edge slightly impressed in larger specimens, margin straight to slightly curved towards dorsal valve; anterior commissure rectimarginate to insipiently unisulcate; beak stout, sub-erect to erect, labiate; beak ridges rounded, palintrope narrow and concaved, extend from beak to lateral margin, disappear into ventral valve growth lines in larger specimens; foramen medium to large sized, to 5 per cent. shell length, mesothyridid to permesothyridid to nearly epithyridid in larger specimens; deltidial plates conjunct, symphytium concave, smooth.

Serial grinding indicates that the species has a short loop of the terebratulid type (figure 4.2)

Variations

Some specimens have more rounded margins and the growth lines on these are far more distinct. There is some variation in shape, but this is asymmetrical and most likely due to growth in a cramped space (Brunton and Hiller 1990).

Table 4.11: Measurements of *Giraliathyris kaitrinae* gen. et sp. nov. (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
84.531	26.6	22.2	13.1	96.658	23.8	20.0	10.8
84.537	19.6	16.1	8.8	96.662	24.4	20.9	10.9
84.537	25.9	21.5	12.8	96.664	24.5	21.7	11.2
84.537	26.7	21.8	13.1	96.666	28.0	24.2	12.9
84.537	28.7	24.3	15.6	96.667	26.3	22.3	11.5
84.540	23.0	20.9	11.1	96.668	23.9	19.9	9.2
84.540	21.2	18.9	9.5	96.670	25.2	20.9	11.1
84.541	25.6	20.8	12.1	96.673	26.7	22.5	11.9

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
84.541	18.7	15.4	9.5	96.675	23.8	19.6	10.3
84.541	19.9	16.4	8.8	96.676	24.7	20.7	10.2
84.541	22.1	17.9	9.8	96.721	34.4	26.6	17.2
84.541	25.2	20.8	11.5	96.722	26.9	23.6	11.9
84.541	20.6	17.5	10.2	96.725	32.6	28.2	15.3
84.541	24.6	20.9	12.1	96.727	25.6	21.6	13.1
84.547	28.7	24.0	16.1	96.729	19.0	16.4	10.0
88.71	14.1	12.1	5.8	96.730	20.0	17.3	8.7
88.71	14.6	12.6	5.4	96.775	27.6	22.1	13.7
96.532	29.6	25.9	11.3	96.776	31.8	27.3	15.8
96.540	20.7	18.7	9.8	96.777	27.0	21.7	13.1
96.541	19.5	18.4	8.5	96.778	19.5	15.7	9.2
96.546	19.4	17.6	8.1	96.782	25.2	21.9	12.8
96.547	15.6	14.5	6.5	96.785	23.0	20.6	11.3
96.650	25.5	23.1	13.2	96.786	22.7	19.9	10.2
96.654	22.6	19.3	10.6	96.787	27.8	25.4	13.9
96.655	19.3	17.3	9.0	96.796	24.5	20.2	11.7
96.656	25.8	21.1	-	96.808	24.5	23.2	10.5
96.657	25.5	21.7	12.4	96.809	34.5	32.5	19.4

Remarks

Giraliathyris kaitrinae gen. et sp. nov. differs from *Giraliathyris mcnamarai* gen. et sp. nov in that the foramen is much larger (up to 5 per cent. of shell length compared with up to 2 per cent. of shell length) and the beak is less incurved. *G. kaitrinae* has a less sulcate anterior commissure and the symphytium is smooth while *G. mcnamarai* has a median ridge.

Etymology

Named after Kaitrin McNamara, one of the principal collectors of the species.

***Giraliathyris jubileensis* gen. et sp. nov.**

Figure 4.3, 4.12 M-O, 4.13 A

Table 4.12

Material Examined

Holotype

WAM 84.604e Giralia Range, Carnarvon Basin, Jubilee Calcarenite, Cardabia Formation, Middle Eocene.

Paratypes

WAM 84.604i and 84.603e Giralia Range, Carnarvon Basin, Jubilee Calcarenite, Cardabia Formation, Middle Eocene.

Other Material

WAM 75.958, 84.603-.604, 96.809, Giralia Range, Carnarvon Basin, Jubilee Calcarenite, Cardabia Formation, Middle Eocene.

Diagnosis

Medium sized shell, greatest width posterior to mid-length, sub-circular; equally biconvex; anterior margin rectimarginate to incipiently unisulcate; surface smooth, finely densely punctate; beak short, suberect; medium sized foramen, mesothyridid to permesothyridid; loop terebratulid.

Description

Exterior. The majority of specimens are badly weathered; shell large, 38 mm long, equally biconvex, depth to 61 per cent. shell length; sub-circular, widest near mid-length, width 90 per cent. to 110 per cent. shell length; cardinal margin gently curved to nearly straight with "hump" at umbo; lateral valve edges bevelled , margin straight to slightly curved upwards towards dorsal valve anteriorly; anterior commissure incipiently unisulcate in juveniles to rectimarginate in adults; shell surface smooth, finely and densely punctate; beak suberect, beak short; narrow beak ridges extend to lateral margins; foramen medium sized, to 5 per cent. shell length, mesothyridid to permesothyridid; symphytium nearly obscured, concave, deltidal plates conjunct.

Interior. No interiors available. Serial grinding indicates terebratulid type loop (figure 4.3).

Table 4.12: Measurements of *Giraliathyris jubileensis* gen. et sp. nov. (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
84.531	26.6	22.2	13.1	96.658	23.8	20.0	10.8
84.537	19.6	16.1	8.8	96.662	24.4	20.9	10.9
84.537	25.9	21.5	12.8	96.664	24.5	21.7	11.2
84.537	26.7	21.8	13.1	96.666	28.0	24.2	12.9
84.537	28.7	24.3	15.6	96.667	26.3	22.3	11.5
84.540	23.0	20.9	11.1	96.668	23.9	19.9	9.2
84.540	21.2	18.9	9.5	96.670	25.2	20.9	11.1
84.541	25.6	20.8	12.1	96.673	26.7	22.5	11.9

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
84.541	18.7	15.4	9.5	96.675	23.8	19.6	10.3
84.541	19.9	16.4	8.8	96.676	24.7	20.7	10.2
84.541	22.1	17.9	9.8	96.721	34.4	26.6	17.2
84.541	25.2	20.8	11.5	96.722	26.9	23.6	11.9
84.541	20.6	17.5	10.2	96.725	32.6	28.2	15.3
84.541	24.6	20.9	12.1	96.727	25.6	21.6	13.1
84.547	28.7	24.0	16.1	96.729	19.0	16.4	10.0
88.71	14.1	12.1	5.8	96.730	20.0	17.3	8.7
88.71	14.6	12.6	5.4	96.775	27.6	22.1	13.7
96.532	29.6	25.9	11.3	96.776	31.8	27.3	15.8
96.540	20.7	18.7	9.8	96.777	27.0	21.7	13.1
96.541	19.5	18.4	8.5	96.778	19.5	15.7	9.2
96.546	19.4	17.6	8.1	96.782	25.2	21.9	12.8
96.547	15.6	14.5	6.5	96.785	23.0	20.6	11.3
96.650	25.5	23.1	13.2	96.786	22.7	19.9	10.2
96.654	22.6	19.3	10.6	96.787	27.8	25.4	13.9
96.655	19.3	17.3	9.0	96.796	24.5	20.2	11.7
96.656	25.8	21.1	-	96.808	24.5	23.2	10.5
96.657	25.5	21.7	12.4	96.809	34.5	32.5	19.4

Remarks

This species, *Giraliathyris jubileensis* gen. et sp. nov. is wider relative to length than *G. mcnamarai* and *G. kaitrinae* and the beak is shorter. The foramen is more erect than in *G. kaitrinae* and larger than in *G. mcnamarai.*

Etymology

The name is derived from the Jubilee Calcarenite

Genus LIOTHYRELLA Thomson, 1916

Type species

Terebratula uva Broderip, 1883

Liothyrella archboldi sp. nov.

Figure 4.13 B-E

Table 4.13

Material Examined

Holotype

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

Paratypes

WAM 89.1278 b-g, 96.865 Gully 500 m north-west 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, 84.426-428, 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 per cent. of shell length. Maximum width at mid-length or slightly anterior to it; width 60-65 per cent. 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 per cent. of shell length). Shell smooth with distinct growth lines; finely and densely punctate. Umbo stout, suberect, labiate, beak ridges rounded, beak margins wide, extend to just posterior to mid-line. Foramen large (8 per cent. 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.

Table 4.13: Measurements of *Liothyrella archboldi* sp. nov. (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
60.31	21.7	16.4	11.4	83.3026	25.8	18.7	13.5
60.61	24.0	16.9	11.6	83.3054	24.1	17.4	13.0
60.61	24.9	19.5	14.4	83.3054	24.1	18.0	13.2
60.61	28.0	21.3	14.6	83.3064	28.6	19.9	15.7
71.181	23.2	16.5	12.6	83.3149	15.7	12.7	8.2
71.181	23.4	17.3	13.2	83.3149	19.8	14.1	9.0
71.181	24.0	17.7	13.3	83.3149	21.0	15.5	10.2
71.181	24.0	18.3	13.2	83.3149	23.6	17.5	13.3
71.181	25.3	18.9	14.1	83.3153	21.9	15.5	12.5
71.181	25.8	18.8	15.4	83.3153	22.3	16.8	12.1
71.181	26.2	19.3	14.9	83.3153	22.3	17.1	12.7
71.181	27.7	19.9	14.3	83.3155	19.3	14.8	9.6
71.181	27.8	20.7	14.4	83.3155	23.8	19.1	13.1
71.181	28.3	19.5	15.4	83.3155	24.5	18.4	13.7
71.181	29.3	21.2	15.6	83.3155	26.5	19.4	14.4
71.242	16.1	12.8	8.8	83.3155	29.0	21.0	15.0
71.242	18.4	13.1	8.7	83.3159	21.6	16.2	10.2
71.242	20.2	15.9	10.9	83.3159	23.3	17.8	13.8
71.242	20.9	16.0	10.3	83.3159	25.0	19.2	13.1
71.242	21.0	17.4	12.9	83.3159	27.3	19.4	14.8
71.242	22.4	17.2	13.8	83.3164	22.2	17.7	13.2
71.242	24.15	17.7	14.0	83.3164	23.1	17.3	11.0
71.242	24.9	18.6	13.3	83.3164	23.5	17.8	12.2
71.242	31.3	22.4	16.2	83.3164	23.6	17.1	13.2
71.288	22.4	16.8	11.8	83.3164	24.5	20.0	13.8
71.288	24.5	17.8	13.7	83.3164	28.8	21.0	15.0
71.288	26.0	18.0	13.6	84.1695	23.9	18.1	12.7
80.668	20.7	17.2	11.1	84.1695	25.1	19.8	13.8
80.668	23.0	18.1	13.2	84.1695	25.6	18.8	13.6
80.668	24.4	17.8	12.1	84.1695	27.3	20.2	14.5
80.694	18.4	14.1	10.3	84.1695	27.8	20.9	16.2
80.694	21.0	17.2	12.0	84.390	25.5	20.3	11.9
80.694	21.1	15.9	12.3	84.390	25.6	20.3	12.0
80.694	22.1	17.9	12.1	84.426	24.4	17.4	12.8
80.694	24.8	20.7	13.8	84.427	17.3	11.8	8.9
80.694	25.0	19.2	13.9	84.427	22.2	16.9	12.1
80.694	25.9	19.8	13.3	84.427	24.6	19.1	12.6
80.694	26.0	18.1	14.7	84.428	24.0	17.1	13.4
80.694	26.4	20.1	14.3	84.432	25.4	18.4	14.2
80.694	29.3	20.2	16.8	84.901	16.9	14.3	9.7
80.694	30.1	20..3	17.0	84.901	22.5	18.1	13.4
80.870	22.5	16.8	13.0	84.901	24.2	17.8	13.2
80.870	24.1	18.4	13.7	84.901	24.3	17.4	12.2
80.870	25.5	18.3	14.5	84.901	25.4	18.6	14.7
80.870	27.5	19.5	15.7	84.901	26.0	18.5	14.6

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
80.884	19.6	15.2	10.0	84.901	26.9	20.8	14.3
80.884	21.4	15.0	11.1	84.901	27.6	20.0	15.1
80.884	23.4	17.4	12.7	84.922	22.3	16.4	10.4
80.884	23.6	17.9	13.4	88.277	21.6	14.8	10.8
80.884	24.6	18.9	13.4	88.277	21.7	14.8	10.3
80.884	26.1	17.7	13.3	89.1278	16.7	13.7	9.2
80.884	26.8	19.3	14.1	89.1278	19.12	16.3	11.3
80.884	26.8	19.4	14.9	89.1278	19.3	14.9	9.9
80.884	27.0	21.7	16.0	89.1278	19.5	16.1	10.7
80.884	27.2	20.0	15.7	89.1278	21.0	15	11.5
80.884	27.7	20.1	15.8	89.1278	21.7	15.7	11.9
80.884	28.5	18.7	14.5	89.1278	23.3	16.6	14.6
82.2657	16.2	12.2	8.2	89.1278	23.3	15.8	12.5
82.2657	16.3	12.2	8.3	89.1278	25.2	18.5	14.5
82.2960	18.8	14.9	9.8	89.1278	25.3	20.0	13.9
82.2960	19.4	15.0	10.2	89.1278	26.2	19.1	14.5
82.2960	19.5	15.0	10.4	89.1278	26.3	19.8	14.4
82.2960	19.6	15.5	12.0	89.1278	27.4	20.3	13.9
82.2960	20.1	16.1	10.8	89.1278	28.8	20.3	15.1
82.2960	21.7	16.6	10.4	89.1278	30.8	21.7	17.8
82.2960	21.8	16.8	11.6	96.836	23.5	17.4	13.3
82.2960	22.5	16.2	11.6	96.836	26.2	19.5	13.8
82.2960	22.8	18.7	12.6	96.839	31.6	24.2	17.4
82.2960	22.9	17.1	13.1	96.842	19.9	14.9	10.1
82.2960	23.5	16.4	13.4	96.842	22.2	16.0	12.4
82.2960	23.6	17.8	11.8	96.842	23.8	17.5	10.7
82.2960	23.7	18.3	12.4	96.842	24.8	21.0	12.7
82.2960	25.1	17.2	14.0	96.842	28.2	23.7	15.2
82.2960	25.4	18.3	12.2	96.859	24.2	20.0	13.6
82.2960	25.4	18.1	14.5	96.859	27.0	21.5	15.6
82.2960	25.5	17.3	14.0	96.863	27.6	19.3	13.7
82.2960	25.6	19.9	14.4	96.863	30.9	21.1	16.4
82.2960	26.0	18.9	13.0	96.865	28.4	21.1	15.3
82.2960	26.7	19.7	14.5	96.880	18.3	14.1	10.0
82.2960	30.5	21.6	16.5	96.880	20.5	16.0	9.8
83.2878	22.8	16.9	12.7	96.880	22.9	16.8	12.2
83.2907	20.3	16.4	11.0	96.880	24.3	18.9	13.3
83.2907	26.9	19.6	14.6	96.880	24.5	17.9	13.0
83.2907	27.4	17.1	13.5	96.880	25.3	19.0	12.7
83..2936	20.5	15.9	11.0	96.880	27.6	20.4	15.6
83..2936	21.1	16.3	11.0	96.880	28.9	20.0	14.9
83..2936	21.8	16.3	11.7	96.888	18.6	13.5	9.4
83..2936	21.9	16.5	12.1	96.888	21.9	16.4	12.0
83..2936	22.9	17.4	11.6	96.888	22.1	16.0	10.5
83..2936	23.1	18.0	12.1	96.888	23.8	17.2	12.8
83..2936	23.2	18.2	13.5	96.888	23.9	17.5	13.3
83..2936	24.9	19.0	13.0	96.888	24.0	19.1	13.3
83..2936	25.0	18.1	13.2	96.888	27.4	19.3	16.8
83..2936	26.9	19.9	16.1	96.895	24.4	19.4	11.2
83..2936	28.5	18.4	15.7	96.909	20.3	15.9	11.8
83.2947	24.1	16.7	12.8	96.909	24.8	17.7	13.0
83.3010	20.6	15.9	11.2	96.909	25.6	16.5	12.8
83.3010	22.6	17.4	13.1	96.909	25.9	18.8	14.0
83.3010	24.7	19.0	13.3	96.909	28.7	20.4	14.6
83.3026	19.2	15.0	10.2	96.909	32.3	23.6	17.9
83.3026	22.0	16.9	12.2	96.909	32.8	23.5	18.0
83.3026	23.4	17.6	11.6	96.917	23.3	16.3	13.5
83.3026	23.5	18.7	12.6	96.917	27.7	20.5	14.7
83.3026	23.9	17.9	13.4	96.917	28.2	21.7	14.7
83.3026	24.3	17.9	13.2	96.921	19.2	16.1	11.1
83.3026	24.5	18.7	14.3	4230/31	16.5	13.2	8.6
83.3026	25.1	17.8	13.6	4230	16.5	13.1	8.8
83.3026	25.2	18.0	14.0	4597	16.4	12.2	9.3

Remarks

Cooper (1983) describes the foramen of *Liothyrella* as submesothyridid whilst Thomson (1927) describes it as epithyridid. *Liothyrella archboldi* sp. nov. 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*. Some variation exits within this species 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 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 per cent. 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, 1877) 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, 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

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

***Liothyrella brimmellae* sp. nov.**

Figure 4.13 F-H

Table 4.14

Diagnosis

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

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.

Description

Exterior. Large ovate shell up to 38 mm in length. Biconvex, depth 57 per cent. shell length. Width greatest at mid-length, 74 per cent. 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, suberect, labiate; beak ridges attrite. Foramen large, 6-7 per cent. of shell length, mesothyridid, 'V' shaped join to deltidial plates; deltidial 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 adductor muscle scars. Cardinal process partially obscured, raised cup, narrow rim.

Table 4.14: Measurements of *Liothyrella brimmellae* sp. nov. (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH
92.662	31.8	21.4	-
92.663	38.5	25.9	11.5

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) described *Liothyrella lecta* (Guppy, 1866) 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* sp. nov. 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.

***Liothyrella bulbosa* (Tate, 1880)**

Figure 4.4, 4.14, A, B, D, E

Table 4.15

1880 *Terebratula bulbosa*; Tate, p. 145-146. pl. 7, figs 5a-b.

1910 *Terebratula bulbosa*; Buckman, p. 25,26. pl. 3, fig. 7.

1970 *Terebratula bulbosa*; Lowry, p. 67.

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, Middle Eocene.

Description

Exterior. Shell medium to large from 27 to 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 to 75 per cent. shell length. Width greatest at mid-length, width 86 to 93 per cent. shell length. Shell smooth; growth lines distinct; punctae very fine and dense. Cardinal margin gently curved, to 54 per cent. shell width; lateral valve 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 responding keel in ventral valve of strongly pronounced specimens. Umbo short, beak truncated, erect; beak ridges sharp. Foramen permesothyridid, round, small with respect to shell length (to 3 per cent.) but fairly large when compared to other species. Symphytium concaved, obscured by foramen; palintrope wide, low and concaved.

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. Serial grinding indicates a short arched loop with a medium groove (figure 4.4).

Table 4.15: Measurements of *Liothyrella bulbosa* (Tate, 1880) (in mm).

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

Remarks

This species was originally placed in the genus *Terebratula* Müller, 1776 by Tate (1880). This genus was assigned to numerous species in the southern hemisphere until more detailed examination of the specimens led to the erection of numerous genera with similar loop characteristics and cardinalia. It is rejected here as it is a northern hemisphere genus and the morphology of the species under examination is more similar to *Liothyrella* than *Terebratula*. Richardson (1959) placed this species into the genus *Gryphus* which is rejected here for the same reasons. The loop, foramen and cardinalia fit the general description for the genus

Liothyrella and this is a known southern hemisphere species. *L. bulbosa* differs from all prior described specimens because of its large size extending to over 48 mm in length, and 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 to which Buckman (1910) assigned a Miocene age.

***Liothyrella labiata* sp. nov.**

Figure 4.5, 4.14 C, F, G

Table 4.16

Material Examined

Holotype

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

Paratypes

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

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

Diagnosis

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

Description

Exterior. Shell ovate to subpentagonal, medium-sized, 9.7 to 35.5 mm long. Biconvex, ventral valve deeper than dorsal valve, depth to 53 per cent. shell length. Widest anterior to mid-length, to 73 per cent. 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 per cent. 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 per cent. shell length, permesothyridid. Symphytium narrow, thin concaved.

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

Dorsal valve. Serial grinding indicates a short loop. It is ventrally arched anteriorly, diverging little being central within each valve (figure 4.5).

Table 4.16: Measurements of *Liothyrella labiata* sp. nov. (in mm) of complete or nearly complete specimens

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

Remarks

Numerous species of *Liothyrella* 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, 1980 and *L. lecta* (Guppy, 1866) (Owen 1980), *L. kakanuiensis* (Hutton, 1905), *L. circularis* Allan, 1932 *L. londonensis* Thomson, 1918 *L. neglecta* (Hutton, 1905), *L.*

concentrica (Hutton, 1905), *L. oamarutica* (Boehm, 1904), *L. thomsonii* Allan, 1932, *L. skinneri* Allan, 1932, *L. magna* (Hamilton, 1910) and *L. gravida* (Suess, 1864) (Allan 1932), *L. gigantea* Allan, 1937 and a new species *L. longorum* sp. nov. from the Cardabia Formation of the Carnarvon Basin, herein described. *L. labiata* differs from all of these species in that it has a distinctive sulciplicate anterior commissure. *L. archboldi,* herein described from the Late Cretaceous of both the Carnarvon and Perth Basins has a uniplicate anterior commissure. *L. pulchra* Thomson from the Late Eocene has a sulciplicate anterior commissure. It is overall rounder (88 per cent. of shell length) and the foramen is larger (9 per cent. of shell length) compared to *L. labiata* (6.6 per cent.). These features suggest a new taxon is in order. Richardson (1959) described the species as *Gryphus labiatus*. Her specimens included p 17320-22 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 and differs morphologically.

Etymology

Richardson (1959) called the species *labiatus*. In honour of her work I maintain the name in part, due to the large lip on the beak.

***Liothyrella longorum* sp. nov.**

Figure 4.6, 4.14 H-K, 4.15 A, B

Table 4.17

Material Examined

Holotype

WAM 97.795 Giralia Range, Carnarvon Basin, Wadera Member, Cardabia Formation, Late Paleocene.

Paratype

WAM 84.589 Giralia Range, Carnarvon Basin, Cashin Member, Cardabia Formation, Late Paleocene to Early Eocene.

Other Material

WAM 84.549, 84.557, 84.590, 591, 84.593, 84.596 Giralia Range, Carnarvon Basin, Cashin Member, Cardabia Formation, Late Paleocene to Early Eocene. WAM 84.526, 84.528-.530, 96.733, 96.747, 96.768, 96.795, 96.802 Giralia Range, Carnarvon Basin, Wadera Member, Cardabia Formation, Late Paleocene.

Diagnosis

Ovate to sub-pentagonal, biconvex, smooth, medium sized shell; lateral valve edge impressed, margin curved upwards to dorsal valve posteriorly, down towards ventral valve centrally and up towards dorsal valve anteriorly (sigmoidal); anterior commissure rectimarginate to uniplicate; beak suberect, labiate; foramen large, permesothyridid; symphytium partially to totally obscured, concave; loop terebratulid.

Description

Exterior. Shell ovate to sub-pentagonal, medium size to 32 mm, widest at or anterior to mid-length, width to 80 per cent. length, shell biconvex, depth to 61 per cent. shell length, dorsal valve less deep; surface smooth except for prominent growth lines on lateral margin of valves, especially towards anterior; finely and densely punctate; cardinal margin strongly curved to pointed posteriorly; lateral valve edges rounded, each valve curving in towards the other (impressed) in largest specimens, margin sigmoidal; anterior commissure rectimarginate to uniplicate, antero-lateral section of the ventral valve deeply angled towards anterior commissure due to plication; beak stout, suberect, labiate; beak ridges, rounded, curving towards ventral valve then back, meeting lateral margin slightly posterior or anterior to the mid-length; foramen large, 6 per cent. of the shell length, permesothyridid; symphytium small, narrow, obscured, concave; deltidal plates conjunct.

Interior. No interiors available. Serial grinding indicates a short arched loop (figure 4.6).

Table 4.17: Measurements of *Liothyrella longorum* sp. nov. (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
84.549	22.0	20.3	12.3	84.591f	12.6	10.8	5.6
84.589a	30.1	23.8	16.9	84.593	29.2	24.5	14.4
84.589b	29.0	24.0	15.6	84.596a	27.7	22.6	12.1
84.589c	22.4	18.5	11.5	84.891e	14.4	13.1	6.5
84.590a	31.5	27.6	16.4	96.733	25.9	21.8	15.6
84.591b	21.4	20.0		96.795	28.8	23.7	15.1
84.591c	22.5	21.3	10.1				

Remarks

Liothyrella longorum sp. nov. is distinguished from other species of the genus by external features.

Two *Liothyrella* species have been described from the lower Tertiary of the Antarctic Peninsula and associated islands (Owen 1980; Bitner 1996). *L. anderssoni* Owen has a rectimarginate anterior commissure, erect beak and mesothyridid foramen. *L. longorum* is uniplicate with a suberect beak and a permesothyridid foramen. *L. lecta* (Guppy, 1866) is of similar length to *L. longorum* (33mm:32mm) but is more circular with a width:length (W:L) ratio of 86 per cent. (Owen 1980) compared to 80 per cent. for *L. longorum*. *L. lecta* also has numerous fine concentric growth lines extending from the beak with numerous radiating grooves, features absent from *L. longorum*.

Allan has described and redescribed a number of species from the Tertiary of New Zealand. *Liothyrella longorum* is up to 32 mm long and differs from *L. kakanuiensis* (Hutton, 1905) Lower - Middle Miocene (Allan 1932) which is short (11 mm) and narrower W:L 70 per cent.. *L. elongata* Allan, 1932 from the Early Miocene (Allan 1932) is also shorter and narrower (W:L is 65 per cent.). *L. circularis* Allan, 1932 from the Early-Middle Oligocene (11 mm) and *L. londonensis* Thomson, 1918 of the Late Oligocene (16 mm) are smaller and more circular in shape than *L. longorum*. *L. neglecta* (Hutton, 1905) from the Early Miocene (Allan 1932) is smaller (11.5 mm) and is widest posterior to the mid-length whilst *L. longorum* is wider anterior to the mid-length. Although *L. concentrica* (Hutton, 1905) from the Late Eocene-Late Oligocene (Allan 1932) is of similar size to *L. longorum* (37 mm:32 mm) but narrower (W:L 64 per cent.). *L. oamarutica* (Boehm) from the Early-Middle Oligocene (Allan 1932) is also of similar length but more

circular (W:L 90 per cent.) than *L. longorum*. *L. thomsonii* Allan, 1932 from the Middle Miocene (Allan 1932) similarly is slightly larger (38 mm:32 mm) and is also more circular (W:L 84 per cent.) with the greatest width on the mid-length whereas *L. longorum* is widest anterior to the mid-length. *L. boehmi* Thomson, 1918 from the Early to Late Miocene is longer (52 mm:32 mm), relatively deeper and incipiently labiate while *L. longorum* is clearly labiate. *L. magna* (Hamilton, 1910) from the Early-Middle Oligocene (Allan 1932) is broader than long (W:L 113 per cent.) compared with *L. longorum*. *L. pulchra* Thomson, 1918 from the Late Eocene has a sulciplicate anterior commissure while the commissure of *L. longorum* is uniplicate. *L. skinneri* Allan, 1932 of Early Pliocene age (Allan 1932) is larger (40 mm:32 mm) narrower (W:L 75 per cent.) and more strongly labiate than *L. longorum*. *L. gigantea* Allan, 1937 of the Late Oligocene (Allan 1960) is a large (85 mm) species with an epithyridid foramen and wavy radial striae. *L. longorum* is smooth with a permesothyridid foramen. *L. gravida* (Suess, 1864) of unknown age (Allan 1932) is larger than *L. longorum* (45 mm:32 mm) and more circular (W:L 91 per cent.). *L. archboldi*, herein described from the Miria Formation, Maastrichtian, is of similar length (32 mm:32 mm) but is narrower (W:L 65 per cent.) and has wide beak ridges and a larger foramen (8 per cent. S.L.: 6 per cent. S.L.) compared with *L. longorum*. It differs from *L. labiata*, herein described from the Late Middle Eocene Nanarup Limestone, in that *L. longorum* is uniplicate whilst *L. labiata* is sulciplicate.

Etymology

After Dr J. A. Long and his children who were the principle collectors of specimens.

***Liothyrella subcarnea* (Tate, 1880)**

Figure 4.7, 4.15 C-E

Table 4.18

1880 *Terebratula subcarnea* Tate, p. 145, pl. 9, figs 1a-b.

1899 *Terebratula subcarnea*; Tate, p. 251.

1927 *Terebratula subcarnea*; Crespin and Chapman in Thomson, p. 299.

1970 *Terebratula subcarnea*; Lowry, p. 67.

Material Examined

Eucla Basin: F5541, Twilight 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, Middle 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 to 68 mm in length. Biconvex with dorsal valve less curved to nearly flat, greatest depth posterior to mid-length, depth to 56 per cent. shell length. Width greatest at mid-length, width from 84 per cent. to 102 per cent. 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 per cent. shell width; lateral valve 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 permesothyridid to epithyridid, small with respect to shell length (4.4 per cent.) but relatively large compared to other species. Symphytium low, wide, concave, deltidal plates joined without midrib, slight "notch opposite dorsal umbo. 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 observed.

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 a protuberant, hemispherical, flat top with swollen base, surface irregularly rough.

Muscle scars in large triangular troughs either side median wide median ridge. Serial grinding indicates a short loop (figure 4.7).

Table 4.18: Measurements of *Liothyrella subcarnea* (Tate, 1880) (in mm).

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

Remarks

For similar reasons as for *Liothyrella bulbosa* (Tate, 1880), the genera *Gryphus* and *Terebratula* are rejected. The large size of *Liothyrella subcarnea,* up to 60 mm in length, its flatter dorsal valve and the high ratio of width to length substantiate this species as different to all other recorded *Liothyrella.*

Family ZENOBIATHYRIDAE fam. nov.

Diagnosis

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

Remarks

Although very similar externally to species of *Magellania* Bayle, 1880 and *Dereta* Elliott, 1959 from the suborder Terebratellidina Muir-Wood, 1955, the internal features of Zenobiathyridae fam. nov., particularly the short loop and lack of a median septum, places it in the suborder Terebratulidina Waagen, 1883. The other families within the superfamily Terebratuloidae Gray, 1840 differ in a number of aspects. Terebratuloidae are described as only partially capillate with a median septum whereas Zenobiathyridae is completely capillate and has no median septum.

Members of the Cheniothyrididae Muir-Wood, 1965 are ligate and Tegulithyrididae Muir-Wood, 1965 are ligate to pliciligate, whilst Zenobiathyridae are incipiently to deeply ornithellid. Members of Dictythyrididae Muir-Wood, 1965 have a deep ventral sulcus a feature not common to all species of Zenobiathyridae. The shell is smooth in the Pygopidae Muir-Wood, 1965 and the folding produces an enclosed median perforation. This does not occur in Zenobiathyridae which, as mentioned, are also capillate. Dyscoliidae Fisher and Oehlert, 1891 genera develop lateral flanges creating impressed margins. The valve edges in the Zenobiathyridae are bevelled. The loop in the Cancellothyrididae Thomson, 1926 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, deltidial plates conjunct; cardinal process delicate.

Zenobiathyris mutabilis gen et sp. nov.

Figures 4.15 F-M

Table 4.19

Diagnosis

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

Material Examined

Holotype

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

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.

Description

External. Medium-sized subpentagonal shell, length from 5.4 to 25.9 mm. Biconvex, both valves to same degree; bulbous, depth 50 to 75 per cent. of shell length, deepest at or near mid-length. Width 80 to 85 per cent. of shell length, widest anterior to mid-length. Ribbed with 3 to 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, extend to lateral margin. Foramen large (9 per cent. 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 observed.

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 observed. 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.

Table 4.19: Measurements of *Zenobiathyris mutabilis* gen. et sp. nov. (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
60.23	17.5	14.2	12.1	84.902	17.5	15.7	10.3
60.60	22.5	17.7	14.9	84.907	14.3	10.3	8.5
63.130	5.7	5.4	2.2	84.921	13.8	11.7	8.0
63.130 vv	6.0	5.7	-	84.947	12.9	11.3	6.9
63.130	7.0	5.6	2.9	84.947	13.1	11.1	7.9
71.180	11.0	9.6	5.7	84.947	15.0	12.9	9.6
71.180	14.0	12.9	7.9	85.319	10.2	9.4	
71.180	17.5	15.5	9.3	88.92	5.4	3.9	2.4
71.180	18.4	16.1	11.4	88.92	7.6	6.9	3.5
71.243	10.3	9.3	6.4	89.1279	9.5	8.2	4.6
71.243	10.9	9.6	6.4	89.1279	9.7	8.8	5.3
71.243	12.3	10.8	7.3	89.1279	9.7	7.9	5.0
71.243	12.9	10.5	8.8	89.1279	10.9	9.9	7.5
71.243	13.4	10.8	7.7	89.1279	11.0	9.4	4.5
71.243	13.7	12.3	8.8	89.1279	11.6	10.4	5.1
71.243	14.5	12.3	8.8	89.1279	11.7	10.1	6.7
71.244	13.7	11.3	7.8	89.1279	11.9	10.5	6.0
71.289	7.7	6.4	3.7	89.1279	12.0	11.1	5.8
71.289	9.2	8.0	4.7	89.1279	12.2	11.3	7.9
71.289	10.1	9.3	5.3	89.1279	12.3	10.7	6.3
71.289	10.6	8.8	6.0	89.1279	12.4	10.8	7.6
71.289	13.0	10.4	8.3	89.1279	12.5	10.7	7.5
71.289	16.5	13.5	12.3	89.1279	12.7	12.1	6.9
71.289	16.9	13.9	10.2	89.1279	12.8	10.3	7.1
71.311	11.8	9.3	7.6	89.1279	12.9	12.0	6.9
71.311	12.1	9.7	7.2	89.1279	13.1	9.2	8.1
71.311	12.4	9.5	8.2	89.1279	13.2	10.4	7.9
71.477	12.3	11.1	7.8	89.1279	13.3	10.9	6.2
74.1176	6.0	5.9	2.0	89.1279	13.5	11.5	6.8
74.1176	6.2	5.5	-	89.1279	13.9	12.0	7.6
74.588	14.3	13.3	9.0	89.1279	14.1	11.0	8.1
74.588	15.5	12.6	10.6	89.1279	14.5	12.4	8.7
78.4420 vv	8.0	7.1	-	89.1279	14.6	12.0	8.1
78.4442 vv	7.0	5.7	-	89.1279	14.6	13.0	6.9

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
80.669	10.2	8.5	5.3	89.1279	14.7	12.3	8.0
80.669	10.9	10.1	6.5	89.1279	14.7	12.9	8.7
80.669	13.6	12.3	7.5	89.1279	14.7	12.6	8.8
80.669	13.9	11.9	7.7	89.1279	14.9	13.1	9.2
80.669	14.2	12.6	8.4	89.1279	15.2	12.8	8.6
80.695	12.71	11.4	7.2	89.1279	15.5	13.9	8.9
80.695	15.6	13.0	11.2	89.1279	15.5	13.6	9.4
80.789	15.4	11.9	9.1	89.1279	15.6	13.7	9.2
80.885	14.5	13.7	8.2	89.1279	15.8	12.4	9.7
80.885	15.4	13.4	8.8	89.1279	15.9	14.4	8.9
80.885	16.2	14.2	10.8	89.1279	16.2	13.2	8.8
80.885	25.9	22.8	15.6	89.1279	16.4	14.1	9.0
80.948	13.3	11.8	8.3	89.1279	16.6	15.5	10.4
80.952	14.2	13.3	9.4	89.1279	16.7	15.2	9.4
80.952	15.0	13.1	8.6	89.1279	16.9	13.4	9.7
80.952	15.1	11.7	9.6	89.1279	16.9	13.6	9.6
80.952	15.7	13.6	9.6	89.1279	17.3	14.8	9.0
83.2959	12.7	12.4	7.9	92.702	12.5	10.6	6.9
83.2959	13.5	11.2	7.1	92.703	12.9	10.8	6.5
83.2990	15.6	13.9	8.6	92.704	15.6	13.4	10.8
83.2990	17.3	15.8	9.9	96.837	11.7	8.6	5.4
83.3011	13.4	11.6	7.7	96.837	15.8	11.7	8.8
83.3011	17.3	15.4	9.8	96.843	8.8	7.8	4.3
83.3095	12.4	10.7	6.4	96.843	9.9	8.2	5.4
83.3115	14.4	11.8	8.2	96.843	11.4	10.2	6.2
83.3148	14.8	12.5	7.4	96.843	12.7	11.2	5.8
83.3148	15.3	12.5	10.0	96.843	12.8	10.8	7.2
83.3152	14.4	12.1	8.0	96.843	13.5	10.7	7.0
83.3160	11.6	10.6	8.2	96.844	10.4	9.1	5.1
83.3162	12.8	11.6	7.2	96.844	11.4	10.4	5.9
83.3165	11.9	10.3	6.9	96.844	11.8	9.5	6.9
83.3165	12.8	11.9	7.9	96.844	12.1	10.7	6.9
84.1696	11.5	10.9	8.0	96.844	12.4	10.9	8.0
84.1696	13.1	11.9	7.2	96.844	13.0	12.5	7.2
84.1696	13.8	11.6	7.1	96.844	13.9	12.0	8.8
84.1696	18.3	16.4	11.4	96.844	14.3	13.0	10.1
84.389	9.7	8.6	5.5	96.844	14.4	11.9	7.8
84.391	17.1	15.9	9.5	96.844	14.7	12.1	8.1
84.391	20.8	17.4	10.9	96.860	12.5	11.4	7.5
84.397	17.2	14.9	9.7	96.860	14.3	12.2	7.8
84.397	17.2	14.8	9.8	96.861	10.7	9.0	5.0
84.397	17.27	14.8	9.7	96.861	12.7	11.0	7.1
84.429	12.5	7.8	10.8	96.866	12.8	10.6	7.4
84.902	7.4	6.4	3.2	96.866	15.1	13.5	9.3
84.902	8.8	7.9	4.5	96.881	10.1	8.4	5.2
84.902	9.1	8.0	4.8	96.882	18.6	16.4	12.0
84.902	9.5	7.7	4.7	96.894	14.6	10.8	8.6
84.902	9.6	8.0	4.8	96.900	17.8	14.6	10.2
84.902	9.7	9.0	6.0	96.918	13.6	12.0	9.0
84.902	10.8	9.6	4.8	96.918	14.9	13.2	8.2
84.902	11.1	9.7	5.0	96.931	13.3	11.0	7.2
84.902	11.3	9.4	7.0	96.931	14.5	12.2	7.8
84.902	11.5	9.9	5.8	96.931	15.2	12.9	10.6
84.902	12.1	10.7	7.9	96.931	15.5	14.1	9.2
84.902	12.5	11.0	6.8	96.931	16.14	14.1	9.0
84.902	15.2	12.6	7.9	96.933	14.6	12.9	8.2
84.902	15.6	14.3	8.9	97.708	16.6	13.7	10.9

Remarks

There is a large degree of variation within the species. At one extreme the depth is 50 to 60 per cent. 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 to 75 per cent. 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 Zenobia, the name of my wife, and the queen of Palmyra in the third century AD, meaning "her father's jewel". Mutabilus meaning variable, refers to the degree of variation within the species.

***Zenobiathyris plicatilis* gen. et sp. nov.**

Figure 4.16 A-F

Table 4.20

Diagnosis

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

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 76.2245, Hosking's Chalk, Gingin; WAM 4596a, Molecap Hill, Gingin; WAM 79.2329, "Kyno", Dandaragan; WAM 4240, 80.737/744, "Kayanaba", Dandaragan; Gingin Chalk, Perth Basin, Santonian-Campanian.

Description

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

Interior. Ventral valve. Pedicle collar narrow, sessile. Socket teeth large cylindrical, curved dorsally, groove between teeth and margin, widen posteriorly, slight buttressing to valve wall. Diductor 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.

Table 4.20: Measurements *Zenobiathyris plicatilis* gen. et sp. nov. (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
63.128	6.9	6.8	3.2	4240	9.0	8.0	4.4
68.135	7.1	6.1	3.7	4240	9.0	8.0	4.4
74.1263k	7.3	6.5	4.3	4241	5.6	5.3	2.6
78.4217	10.5	10.3	4.5	4276	8.5	8.4	-
78.4396	7.7	6.9	3.6	4276	8.5	7.6	3.9
79.2913	19.3	19.4	4.4	4276	5.5	5.2	2.1
80.402	6.2	5.8	-	4555	6.7	6.3	3.6
80.737 vv	6.3	6.1	-	4596a	8.3	7.2	3.6
80.737 vv	6.5	6.1	-	4596a vv	5.7	5.3	-
80.744	6.4	5.8	3.2	4596	8.3	7.2	3.5

This species is similar in many respects to *Zenobiathyris mutabilis* gen. et sp. nov. 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* gen. et sp. nov 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 that is much more pronounced in *Z. plicatilis* unlike that in *Z. mutabilis*.

Superfamily CANCELLOTHYRIDOIDEA Thomson, 1926

Family CANCELLOTHYRIDIDAE Thomson, 1926

Subfamily CANCELLOTHYRIDINAE Thomson, 1926

Genus CANCELLOTHYRIS Thomson, 1926

Type species

Terebratula cancellata Koch, 1843

***Cancellothyris ascotensis* sp. nov.**

Figure 4.16 G-K

Diagnosis

Non bifurcating costae; incipient folding; narrow symphytium; rectangular socket teeth.

Material Examined

Holotype

WAM 86.1606 Jupp's Bore, West Gingin, Ascot Formation, Perth Basin, Late Pliocene.

Paratypes

WAM 78. 172, 590,1147, 3117 Paulik's Bore, Jandakot, Ascot Formation, Perth Basin, Early Pleistocene.

Description

External. Shell small to medium-sized, 2.2 mm to 15.3 mm long. Pyriform. Biconvex. Width greatest anterior to mid-length, 75 per cent. of shell length. Surface capillate (6 ribs per mm at mid-length), not bifurcating. Costae increasing in number after each major growth line. Ridges wider than troughs. Finely and densely punctate Cardinal margin curved; lateral margin convex with respect to ventral valve; anterior commissure incipiently paraplicate (shell distorted). Umbo short, beak suberect, slightly labiate. Foramen mesothyridid, large (13 per cent. of shell length). Palintrope and symphytium very narrow. Deltidial plates conjunct, triangular, meeting at apex.

Internal. Ventral Valve: Hinge teeth rectangular, slightly convex towards dorsal valve, slightly swollen bases. Pedicle collar narrow, complete.

Dorsal Valve: Outer socket ridge thin. Sockets a narrow trench. Inner socket ridge thin and joins upward curved outer hinge plate. These are fused with crural base. Cardinal area very delicate, wide, with little thickening towards lateral margin. Cardinal process small, subcircular striated cup, 7 per cent. shell length.

Remarks

The lack of bifurcation of the ribs is significant in *Cancellothyris ascotensis* sp. nov.. There is an increase in number of ribs and these appear after each of the major distinct growth lines.

Richardson (1959) placed *Terebratulina flindersi* Chapman, 1913 and *Terebratulina scoulari* Tate, 1880 in the genus *Cancellothyris*. This is accepted here as the deltidial plates on these species are conjunct whereas in *Terebratulina* they are disjunct. The new species differs from *C. flindersi* described from Mallee Bore of Late Eocene age in South Australia, in that it is longer, lacks bifurcation of the ribbing and lacks spines at the lateral margins (Chapman 1913).

C. scoulari described from the Late Oligocene to Early Miocene of South Australia (Tate 1880) differs in that the socket teeth are tapered in contrast to the

rectangular teeth in *C. ascotensis*. However, it has a clear deep sulcus lacking in *C. ascotensis* and the ribs repeatedly bifurcate which does not occur in *C. ascotensis*.

C. hedleyi (Finlay, 1927) is a recent species described from southern Australian and South Pacific waters (Foster 1989). It has a wide symphytium, unlike the narrow symphytium of *C. ascotensis*. It also has bifurcating costae and a clear sulcus in the dorsal valve, features not found in *C. ascotensis*.

C. platys Brunton and Hiller, 1990 is a Recent species described from the western coast of South Africa. It is very similar to *C. ascotensis* but is larger and has a well-developed pedicle collar which is free anteriorly. *C. ascotensis* has a narrow sessile pedicle collar.

Etymology

This species is named after the Ascot Formation.

***Cancellothyris cashinensis* sp. nov.**

Figure 4.16 L-N

Diagnosis

Medium sized, ovate to subpentagonal, valves biconvex; surface finely capillate; umbo short, suberect.

Remarks

The generic diagnosis (Muir-Wood 1965) suggests the foramen is epithyridid. However, all species observed suggest that it is mesothyridid to submesothyridid. The genus is also described as labiate (Thomson 1926). The new species is not labiate (which may be due to weathering) and the anterior commissure is rectimarginate being ornithellid to ligate.

Material Examined

Holotype

WAM 84.592 Giralia Range, Carnarvon Basin, Cashin Member, Cardabia Formation, Late Paleocene to Early Eocene.

Description

Exterior. Medium sized shell, 29.5 mm x 19.4 mm x 14.6 mm, elongate oval to sub-pentagonal; shell biconvex, the dorsal valve being swollen posteriorly, tapering to the anterior commissure, finely ribbed, with approximately five ribs per mm at tip of ventral valve beak; cardinal margin is sharply curved; lateral valve edge gently bevelled, lateral margin slightly sigmoidal; two folds extend for the anterior two thirds of both valves, create a sulcus on the longitudinal mid-length; anterior commissure carinate to lobate; beak is short, protuberant and sub erect; beak ridges attrite; foramen large to 6.2 per cent. shell length, mesothyridid; deltidial plates appear disjunct.

No internal structures available.

Remarks

Although only one very weathered specimen has been collected, *Cancellothyris cashinensis* sp. nov. is significant in being the earliest record of the genus. Four *Cancellothyris* species have been described from Australia. *C. flindersi*, (Chapman, 1913) Mallee Bore, South Australia is a small (4.8 mm) specimen with a tapering beak. *C. cashinensis* is larger (29.5 mm) and the beak does not taper posteriorly. *C. hedleyi*, (Finlay, 1927) is a Recent species from Western Australia that has a strongly labiate foramen absent in *C. cashinensis*. *C. australis* (Thomson, 1927) from the Miocene of New Zealand and Recent of south-east Australia (Thomson 1927) is a large species, with a uniplicate to sulciplicate anterior commissure and a labiate beak. *C. cashinensis* is medium sized, has a ornithellid to ligate anterior commissure and the beak is not labiate. This is taxonomically significant.

Etymology

Named from the Cashin Member of the Cardabia Formation.

Genus MURRAVIA Thomson, 1916

Type species

Terebratulina davidsoni Etheridge, 1876 = *Terebratulina catinuliformis* Tate, 1899

Murravia triangularis (Tate, 1880)

Figure 4.16 O-S

Table 4.21

1880 *Terebratulina triangularis* Tate, p. 160, pl. 7, figs. 7a-7d.

1899 *Terebratulina triangularis* Tate, p. 254.

1927 *Terebratulina triangularis* Thomson, p. 299.

1970 *Murravia triangularis*; Lowry, p. 67

Diagnosis

Dorsal valve nearly flat, internal crenation of both valves, hypothyridid 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, Middle Eocene.

Description

Exterior. Small shell, 6.6 to 8.1 mm in length, triangular to subcircular. Biconvex, dorsal valve nearly flat, depth to 32 per cent. shell length. Width at or near mid-length, 94 to 101 per cent. 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 per cent. shell length; valves lateral edge bevelled, lateral margin nearly straight; valves anterior edge bevelled, anterior commissure unisulcate, sulcus nearly taking up entire width. Beak short, triangular, suberect; beak ridges sharp. Foramen medium sized to 4 per cent. shell length,

trapezoid to round; hypothyridid; deltidial plates disjunct, short; palintrope narrow, concaved.

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 4.21: Measurements of *Murravia triangularis* (Tate, 1880) (in mm).

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* (Tate, 1880). The flat to concave dorsal valve, internal crenulations at the valve margins, hypothyridid foramen and strong cardinal process place it in *Murravia* Thomson, 1916. It is described from Blanche Point, Aldinga Cliffs, Late Eocene and in the Bunda Cliffs, Middle Eocene, Great Australian Bight (Tate 1880) and Castle Cove, Aire River district, Castle Cove Limestone, Early Oligocene, and Point Flinders, Browns Creek Clays, Eocene, Victoria (Richardson 1959)

Genus TEREBRATULINA d'Orbigny, 1847

Type species

Anomia retusa Linnaeus, 1758

Terebratulina christopheri sp. nov.

Figure 4.17 A-F, H

Table 4.22

Diagnosis

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

Material Examined

Holotype

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

Paratypes

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

UWA 23724, Plantagenet Beds, Brick pit near Albany.

UWA 7826, Warrinup Block 1874. Road east of Albany, Nanarup Limestone, Werillup Formation, Late Middle Eocene, Bremer Basin.

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

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, Middle Eocene.

Description

Exterior. Shell pyriform to subpentagonal, small to medium, 3.6 to 24 mm long. Biconvex, both valves equally so, depth to 50 per cent. shell length. Width to 81 per cent. shell length, widest anterior to mid-length. Finely and densely punctate. Costellate, 5 ribs per mm, ribs same width as interstitial spaces, rounded, bifurcate over entire length; numerous growth lines. Cardinal margin strongly curved to triangular, acute, to 64 per cent. shell width; lateral valve edge bevelled, lateral margin straight to sigmoidal; anterior commissure uniplicate, plication to 65 per cent. shell width. Umbo truncated; beak sub erect; beak ridges attrite. Foramen medium to large, to 7.5 per cent. shell length, round, mesothyridid. Deltidal plates small, disjunct, symphytium with lateral ridges.

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

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

Table 4.22: Measurements of *Terebratulina christopheri* sp. nov. (in mm) of complete or nearly complete specimens.

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
70.176a	25.5	16.9	10.7	94.77	-	-	6.8
70.176b	22.7	15.1	8.4	94.78	-	14.6	7.4
70.176c	14.1	9.2	4.8	94.79	19.2	14.1	-
72.327	11.5	9.7	-	94.80	14.7	11.8	-
75.38	22.8	16.3	-	94.82	21.9	17.8	10.2

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
75.40	10.1	6.7	3.9	94.83	15.8	10.6	5.7
76.81	8.6	-	2.7	94.84	24.1	16.8	9.2
78.4099a	11.5	8.5	3.6	94.85	22.7	15.8	8.7
78.4099b	4.9	4	1.6	94.86	21	14.5	7.0
78.4099c	8.9	6.2	3.1	94.87	17.9	11.9	5.7
78.4099d	5.8	3.9	1.9	94.89	14.8	11	5.7
78.4099e	15.4	-	4.7	94.94	16.9	14.5	-
82.3059	6.2	3.7	2.2	94.95	14.3	9.6	4
82.3062	3.8	2.7	-	94.97	11.9	8.8	3.7
82.3063	3.9	-	1.5	94.99	13.0	9.9	3.8
82.3064	3.6	-	-	94.101	14.2	10.4	-
83.2652	-	9.9	5.7	94.109	17.2	13.0	5.5
88.852	21.2	16.6	8.2	F6831	3.6	2.4	-
94.71	23.3	16.1	8.5	F6831	3.9	3.6	-
94.72	20.7	14.7	8.2	F6832	5.8	3.8	2.2
94.74		17.2	7.3	F6850	6.8	5.4	3.2
94.75	22.9	-	10.2	F6831	3.6	2.4	-
94.76	16.3	-	5.7	F6831	3.9	3.6	-

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

Remarks

Small (less than 5 mm in length) specimens from the Pallinup Siltstone have relatively larger foramen (to 40 per cent. shell length) compared with small specimens (less than 5 mm) from the Nanarup Limestone (to 10 per cent. 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. davidsoni* Etheridge, 1876 (= *T. catimuliformis* Tate, 1899), *T. lenticularis* Tate, 1880 and *T. triangularis* Tate, 1880 are species of *Murravia* as they have a hypothyridid foramen, and hinge plates are present. When collections of these species were studied during my research, they contained some examples of *Terebratulina* found in similar Late Eocene to Miocene deposits. These *Terebratulina* are very similar to that described above. *T. suessi* Allan, 1932 and *T. ellisoni* Allan, 1932 are both described as having large submesothyridid foramen. The foramen of *T. christopheri* sp. nov., although large, is mesothyridid. *T. kendricki* sp. nov, herein described from the Late Cretaceous of the Carnarvon Basin has only 6 ribs per mm, bifurcation occurs anterior to the umbo and the foramen is submesothyridid . In *T. christopheri* there are 5 ribs per mm, bifurcation begins on the umbo and the foramen is mesothyridid. *T. christopheri* differs from, *T. lindsay* sp. nov., herein described from the Wadera

Calcarenite (Late Paleocene), Cardabia Formation, Carnarvon Basin, which bifurcates anterior to the mid-length and has only 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.

***Terebratulina kendricki* sp. nov.**

Figure G, I-K, M

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-length.

Costate rounded, interstitial 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 per cent. 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 per cent. 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* sp. nov. which reaches to 11 mm in length, is pear shaped and has a medium-sized pallintrope. *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 *T. lindsayi* sp. nov., herein described from the Cardabia Formation, Late Paleocene, Carnarvon Basin which is rectimarginate. *T. kendricki* in having 6 ribs per mm differs from *T. christopheri* sp. nov., herein described from the Late Middle Eocene Nanarup

Limestone Member, Bremer Basin, Western Australia that 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.

***Terebratulina lindsayi* sp. nov.**

Figure 4.17 L, N, O

Diagnosis

Triangular to subpentagonal, bifurcating ribs; foramen triangular to trapezoid; deltidial plates disjunct; hinge teeth short, no dental plates; cardinal area poorly developed.

Material Examined

Holotype

WAM 88.126 Giralia Range, Carnarvon Basin, Pirie Member, Cardabia Formation, Late Paleocene.

Other Material

WAM 83.904 , 83.991, 83.993, as for holotype.

Description

Exterior. Small, 1 to 6.4 mm, triangular to sub-pentagonal; shallowly biconvex, depth to 33 per cent. shell length; width greatest at mid-length, 78 per cent. of shell length; shell costellate, four ribs per mm, bifurcating after mid-length, nodules on ribs of small specimens; growth lines indistinct; cardinal margin strongly curved, lateral margin straight, anterior commissure rectimarginate; beak suberect, short; foramen triangular to trapezoid, submesothyridid to hypothyridid; deltidial plates not developed on smallest specimens, disjunct on larger.

Interior. Ventral valve. Hinge teeth short, cyrtomatodont, derived from lateral margin, no dental plates.

Dorsal valve. Cardinal area poorly developed, sockets indentations in lateral margin, crural process extending from anterior edge of inner socket ridge, slightly thickened; cardinal process small, in gentle cup with two rims distally extending from inner socket ridge, slightly protuberant over cardinal margin.

Remarks

The specimens appear to be those of juveniles and sub-adults.

T. ellisoni Allan, 1932 from the Late Pliocene of Chatham Islands, New Zealand (Allan 1932), has a wide, prominent and pointed beak and a straight cardinal margin. *T. lindsayi* has a strongly curved cardinal margin. *T. lindsayi* sp. nov. differs from *T. christopheri* sp. nov., herein described from the Late Middle Eocene Nanarup Limestone Member, Bremer Basin, Western Australia. The ribs in *T. lindsayi* bifurcate below the beak and *T. lindsayi* has only four ribs per mm. In *T. christopheri* the ribs in the bifurcate for the entire length and *T. christopheri* has up to five ribs per mm. These differences justify the new taxon. Besides a brief reference to *Terebratulina* cf. *dutempleans* d'Orbigny, 1847 being present in the Cardabia Formation, with no description provided (Condon *et al.*, 1956), this is the first record of *Terebratulina* from the Paleocene in Australia.

Etymology

After Dr Lindsay Collins, Associate Professor of Sedimentology at Curtin University of Technology.

Family CHLIDONOPHORINAE Muir-Wood, 1959.

Genus GISILINA Steinich, 1963.

Type species

Terebratula gisii Roemer, 1840.

Gisilina ovata (Etheridge, 1913)

Figure 4.17 P-S

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

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

Material Examined

The holotype is missing from the collection. A neotype is not selected as no taxonomic problem exists.

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 per cent. shell length. Widest anterior to mid-length, width 82 per cent. 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 per

cent. shell length, mesothyridid; deltidial 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 per cent., 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 adductor 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 their description of fossils from the Gingin Chalk. This species fits the generic description of *Gisilina*. *G. ovata* is distinct from *Gisilina gisii* (Roemer, 1840) in that *G. ovata* 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. There are numerous specimens all under 6 mm in total length.

Family INOPINATARCULIDAE Muir-Wood, 1965

Genus INOPINATARCULA Elliott, 1952

Type species

Trigonosemus acanthodes Etheridge, 1913.

Inopinatarcula acanthodes (Etheridge, 1913)

Figure 4.18 A, B, D, E, I

Table 4.23

1913 *Trigonosemus acanthodes* Etheridge, p. 15, pl. 2, figs 1-4.

1952 *Inopinatarcula acanthodes* Elliott, p. 2, pl. 2, figs 22-27.

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

1983 *Inopinatarcula acanthodes*; Cooper, p. 224-225, pl. 26, figs 19-26, pl. 75, figs 21,22.

1993 *Inopinatarcula acanthodes*; McNamara *et al.* p. 4, figs. 13-14.

Material Examined

The original specimen WAM 3521 is missing and it is impossible to erect a 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; 74.1263; 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; 88903; 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, 128, 130; 77.3546; 80.738-39742, "Yatheroo", Dandaragan; WAM 4241-2, 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, both valves to same degree; depth 65 per cent. of shell length. Widest at mid-length or anterior to it, width 95 to 100 per cent. of shell length. Deep sulcus in ventral valve extending just posterior to cardinal margin, dorsal valve with strong fold, anterior width 43 per cent. 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 valve edge bevelled, anterior commissure strongly uniplicate, plication 33 per cent. of shell length. Umbo short, erect, beak ridges rounded. Foramen small, 1 to 2 per cent. of shell length, round, permesothyridid; deltidial plates conjunct; symphytium small, triangular, concave, horizontally striated.

Internal. Ventral valve. Socket teeth cyrtomatodont, long, 9.5 per cent. of shell length, width 6.3 per cent. of shell length, thickest (4.3 per cent. 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 per cent. shell length. Lateral adjustor scars long and thin; small adductor 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 per cent. 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 per cent. shell length, arched towards ventral valve; adductor muscle scars round with thickened valve floor creating a heart-shape posteriolaterally. Median septum low, flattened, short (33 per cent. shell length), widening posteriorly forming low trough, extends to base of cardinal process. Cardinal process thin vertically striated concave band 4.5 per cent. shell length.

Table 4.23: Measurements of *Inopinatarcula acanthodes* (Etheridge, 1913) (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
63.105	16.4	16.0	8.2	78.949	16.5	16.7	7.3
63.120	17.2	16.5	8.8	78.949	7.4	7.2	4.1
63.120	12.7	12.9	4.7	79.2267	16.7	16.5	8.2
63.120	9.1	8.9	3.8	79.2293	15.7	14.6	6.8
67.393	12.7	11.9	4.5	79.2293	12.9	12.8	4.9
68.110	15.6	16.4	5.9	79.2293	10.3	9.7	5.5
68.578	16.3	16.1	6.6	79.2333	23.3	24.3	12.7
68.588	14.5	13.6	6.7	79.2333	26.4	24.2	13.5
68.588	13.4	12.9	4.2	79.303	16.7	15.6	6.8
68.619	16.0	15.1	6.0	79.303	14.4	14.3	6.1
68.619	14.5	14.1	5.2	79.303	12.4	12.5	4.4
68.619	6.3	5.4	2.0	79.303	15.0	14.5	9.8
68.658	14.0	13.9	6.1	80.1017	6.9	6.9	2.8
70.1809	25.8	26.5	12.6	80.1310	22.3	22.9	17.3
70.1835	10.0	9.0	3.2	80.1310	20.6	19.7	9.5
74.1133	18.1	17.1	7.0	82.2660	15.2	15.3	7.3
74.1178	15.1	15.1	6.5	84.1748	21.0	24.4	11.9
74.1263	16.2	14.3	6.8	84.1748	18.4	17.8	8.6
74.1263	13.4	13.5	4.9	84.1749	23.6	25.8	10.8
74.1263	15.7	15.5	9.2	84.1749	16.8	16.2	6.7
74.1263	14.4	15.4	6.1	87.244	16.0	15.3	6.7
74.1288	16.2	15.4	7.9	87.244	15.7	15.3	4.2
74.1288	11.5	12.0	4.2	87.244	14.4	12.9	6.7
74.1289	20.8	18.3	11.9	87.244	14.1	13.9	6.5
74.1302	1.0	11.6	4.5	87.244	15.0	13.3	4.9
74.530	10.5	10.8	3.6	87.244	13.9	12.3	6.8
75.11	20.9	21.3	8.9	87.244	13.5	12.6	7.4
75.1188	16.2	14.8	9.0	87.244	15.6	14.2	6.8
75.1188	15.1	14.8	5.9	87.244	15.9	14.6	7.2
75.1188	13.9	14.6	6.6	87.244	16.0	15.7	6.3
75.1188	16.9	15.8	5.2	87.329	13.8	12.9	7.8
75.1188	14.5	13.1	3.7	87.329	15.8	15.7	7.8
75.1188	16.2	18.3	5.9	87.329	13.3	13.1	4.4
75.1200	16.0	15.5	7.3	87.329	11.6	10.5	4.3
75.1200	15.9	14.0	7.9	87.329	6.8	6.5	2.1
76.2245	10.2	10.4	3.4	87.344	14.9	15.6	5.1
76.2253	16.0	15.3	8.7	87.344	17.0	13.8	7.9
77.2754	16.4	16.0	5.0	88.232	9.7	10.0	3.9
77.2758	6.8	6.8	2.8	88.232	10.7	9.8	4.8
77.2758	17.3	16.6	7.4	88.245	17.2	18.3	5.5
77.2758	16.3	15.9	5.5	88.251	6.7	5.7	2.3
77.3528	19.8	19.6	10.6	88.252	5.8	6.1	1.7
77.3528	24.0	23.8	15.6	88.252	6.8	7.1	2.6
77.3528	21.3	21.6	10.7	88.252	5.8	5.8	2.2
77.3528	16.8	17.0	7.8	88.280	18.6	17.7	6.4
77.3528	21.2	19.6	11.3	88.314	14.1	14.2	4.4
77.3528	28.5	26.8	14.5	88.314	14.6	14.2	4.2
77.3535	16.3	15.4	8.1	88.314	18.3	18.1	7.9
77.3535	18.7	19.2	9.1	88.314	15.0	15.0	4.6
77.3546	15.5	14.2	7.2	88.314	10.6	9.6	5.0
77.3546	16.0	15.7	7.0	88.872	16.7	16.4	8.1
77.3546	12.5	12.1	6.1	88.872	17.1	16.7	3.9
77.3546	12.2	11.4	5.5	88.872	14.3	13.8	5.4
77.3546	12.9	12.0	6.2	88.872	6.3	6.2	2.4
77.3546	12.0	12.6	4.4	88.903	28.2	28.6	15.7
77.3546	14.4	12.4	7.0	88.903	27.5	26.5	11.1
77.4418	19.3	19.3	6.7	88.903	14.1	13.2	6.3
77.4418	13.7	13.5	5.5	92.661	20.8	23.3	10.9
77.4418	13.8	12.2	5.4	92.661	19.5	17.0	10.2
77.4418	7.9	8.4	3.2	92.661	14.8	15.0	7.0
77.5328	22.5	20.5	11.1	92.669	13.7	14.2	5.0
77.5328	24.9	23.8	11.8	92.669	10.2	10.5	4.0
78.280	16.2	15.2	6.5	92.737	21.2	22.8	11.3
78.280	17.3	17.7	6.3	94.303	18.0	17.9	6.4
78.280	14.4	13.8	6.2	94.316	14.7	14.1	5.2
78.280	14.4	14.5	5.7	94.533	16.6	16.1	7.4
78.280	15.5	14.1	5.8	94.546	12.3	11.8	5.2
78.280	9.5	9.7	3.7	94.546	13.3	13.8	4.7

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
78.280	13.6	12.4	15.5	94.6	16.2	16.1	6.3
78.280	12.6	11.5	5.2	94.6	15.8	15.1	6.8
78.280	15.2	15.1	6.3	3831	7.1	7.0	2.3
78.280	11.3	11.5	4.1	3851a	5.9	6.1	2.7
78.4195	5.8	5.1	1.9	4242	5.5	6.2	2.0
78.4349	25.1	19.7	12.2	4250	7.9	7.2	4.2
78.4355	6.6	5.7	1.7	4251	5.9	5.7	2.6
78.4360	21.3	25.3	9.8	4252	5.0	5.0	2.5
78.4360	15.0	15.2	4.6	4261	11.7	10.8	6.4
78.4360	9.8	10.4	4.1	4261	12.5	10.9	5.1
78.4368	14.9	15.0	7.6	4261	13.7	13.7	6.4
78.4368	23.4	22.9	11.8	4261	13.3	13.6	6.3
78.4368	23.3	21.5	8.8	4261	10.0	10.0	3.4
78.4395	17.0	15.6	6.0	4525	16.2	14.2	7.2
78.4395	13.3	13.0	5.7	4553	28.1	27.9	11.9
78.4395	14.9	14.8	5.4	4574	13.0	12.9	4.9
78.4395	15.1	13.9	6.3	4574	10.7	11.5	13.7
78.4395	13.8	13.9	4.6	5117	16.2	15.9	5.8
78.4395	11.6	11.3	5.4	5117	11.0	10.6	3.9
78.4395	13.4	13.5	3.7	5118	15.8	15.5	7.8
78.4395	6.4	6.8	1.8	5118	13.5	12.5	6.5
78.4395	7.6	8.1	3.0	5119	16.1	15.5	6.3
78.4407	14.2	13.3	7.0	5119	14.5	13.6	4.5
78.4407	9.4	8.9	4.3	5120	14.4	14.0	6.4
78.4408	10.4	11.2	4.3	5120	15.0	12.7	5.1
78.4408	12.8	12.2	6.5	5121	14.3	12.8	3.8
78.4453	16.1	14.4	7.7	5121	12.6	12.6	3.9
78.4453	10.7	10.7	4.9	5122	13.4	14.2	6.4
78.4453	9.0	10.0	4.0	5122	13.8	14.9	7.2
78.4542	15.8	18.5	8.0	5123	16.1	16.4	5.1
78.4542	18.9	20.5	9.7	5124	12.1	10.9	5.5
78.949	17.3	18.3	7.5	5125	14.3	13.2	5.9
78.949	22.3	23.1	11.6	5126	14.2	13.5	5.8

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 TEREBRATULININA Waagen, 1883

Superfamily TEREBRATELLOIDEA King, 1850

Family KRAUSSINIDAE Dall, 1870

Genus MEGERLINA Deslongchamps, 1884

Type species: *Kraussia lamarckiana* Davidson, 1852.

***Megerlina irenae* sp. nov.**

Figure 4.18 A, B, D, E, I

Material Examined

Holotype

WAM 86.1604a, Jupp's Bore, West Gingin, Ascot Formation, Perth Basin, Late Pliocene.

Paratypes

WAM 86.1604b, as for holotype. WAM 70.1629a and b, 70.1409, 78.2683, 4062, 79.507 Paulik's Bore, Jandakot, Ascot Formation, Perth Basin, Early Pleistocene.

Other Material

Ascot Formation, Perth Basin.

Late Pliocene. WAM 71.1597 Bushell's Bore, Kewdale.

Early Pleistocene. WAM 76.1478, 78.2774, 3469, 4063, 79.263, 378, 1081 Paulik's Bore, Jandakot.

Diagnosis

Shell wider than long; costae not bifurcating; dorsal valve with wide sulcus; ventral valve with medial ridge;

Description

Exterior. Shell small to 4 mm long by 4.5 mm wide by 2 mm deep. Sub-rectangular. Widest at mid-length; Shell costate, ribs same width as interstitial spaces, 5 ribs per mm. Growth lines distinct, densely punctate. Cardinal margin straight to nearly so (megathyrid); lateral margin straight; anterior commissure crenulate, unisulcate to paraplicate, sulcus 30 per cent. shell length. Umbo short, wide; beak suberect; beak ridges sharp. Foramen large, 21 per cent. shell length, mesothyridid. Deltidial plates present, disjunct. symphytium concaved.

Interior. Ventral valve: Hinge teeth rectangular, converging towards dorsal valve, sharp on upper margin with swollen bases. Pedicle collar extends width of umbo, striated vertically. Median rise extending from posterior to mid-length. Shell thin, translucent and punctae clear.

Dorsal valve. Hemispherical and very deep. Outer socket ridge indistinct from lateral margin. Inner socket ridges up-curved forming the roof of socket. Socket

cylindrical and slight with some swelling at base of sockets. Cardinal process indistinct from posterior margin. Socket ridges and cardinal process curve towards valve floor meeting at bifurcating median septum to form thin shallow septalium. Median septum extends two thirds of shell length from the posterior margin then rises up anteriorly to bifurcate into two diverging processes.

Remarks

Megerlina irenae sp. nov. differs from *M. pisum* (Lamarck, 1819) found off the eastern coast of South Africa in possessing a median ridge in the ventral valve, a feature lacking in *M. pisum* (Hiller 1986). *M. levis* Hiller, 1979, described from the Late Pleistocene deposits on the Zululand coast, lacks any radial ornamentation (Hiller 1979).

M. davidsoni (Velain, 1876) described from shallow water at St Paul Island in the Southern Ocean, differs from *M. irenae* in having a longer beak, a narrower sulcus (Cooper 1981) and lacking the median ventral ridge found in *M. irenae*.

Cooper (1973) described an extant species of *Megerlina* from the Southern Ocean. This species has outer hinge plates that are concave, thick and unite with the median septum (Cooper 1973), unlike *M. irenae*. Moreover it does not have the median ridge present in the ventral valve found in *M. irenae*.

M. striata Jackson, 1952, an extant species from the Cape of Good Hope, is large, attaining 14.1 mm in length. The ribs are bifurcate and the socket ridges are stout (Jackson 1952). This differs from *M. irenae* which is small (up to 4 mm), with ribs that do not bifurcate and slender socket ridges, the outer ridge indistinguishable from the lateral margin.

M. capensis (Adams and Reeve, 1850), an extant species also from the Cape of Good Hope, is twice the size of the largest *M. irenae*, is longer than wide and has bifurcating costae (Jackson 1952). *M. lamarckiana* (Davidson, 1886-88), an extant species described from Port Jackson, New South Wales, has a wide hinge plate lacking in *M. irenae*.

Etymology

The species is named after my wife and is derived from Irena.

***Megerlina dorothyae* sp. nov.**

Figure 4.18 L, M

Diagnosis

Small thick shell; surface smooth; swollen sockets.

Material Examined

Holotype

WAM 71.1536 Bushell's Bore, Kewdale, Ascot Formation, Perth Basin, Late Pliocene.

Description

Exterior. Dorsal valve only. Shell small to 2 mm long by 2.5 mm wide. Convex with medial sulcus. Finely punctate; growth lines distinct with no costation. Cardinal margin nearly straight. Shell relatively thick.

Interior:

Outer socket ridges thick. Inner socket ridges curved upwards to form incomplete socket roof. Shell thickened laterally along socket area. Median septum bifurcates posteriorly forming a narrow septalium. Septum rises anteriorly and bifurcates. Laminar on either side of septum. Interior margin of shell slopes away from septum. Two large (50 per cent. shell length) adductor muscle scars either side of septum posteriorly. Median septum and muscle scars in a thick deep depression, 70 per cent. shell length. Cardinal process insignificant.

Remarks

This single specimen of *Megerlina dorothyae* sp. nov. is similar to *M. irenae* sp. nov. in general shape. However, it lacks costation, as does *M. levis* Hiller, 1979, but the sockets are comparatively thicker and the overall thickened shell and depression housing the septum and muscle scars is distinctive. This is taxonomically significant.

Etymology

Named in honour of my mother, Mrs Dorothy Gertrude Craig.

Family DALLINIDAE Beecher, 1893.

Subfamily GEMMARCULINAE Elliott, 1947.

Genus GEMMARCULA Elliott, 1947.

Type species

Terebratula truncate Sowerby, 1826.

***Gemmarcula doddsae* sp. nov.**

Figure 4.18 N, 4.19 A, B

Diagnosis

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

Material Examined

Holotype

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

Description

Exterior. Small to medium subcircular shell to 14.4 mm in length. Biconvex, depth 52 per cent. shell length. Width greatest at mid-length, 90 per cent. 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. Beak erect; beak ridges sharp. Foramen trapezoid, large, 14 per cent. shell length, hypothyridid; interarea concave, striated.

Interior. Ventral valve. Teeth unclear, no dental plates. Adductor 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 per cent. 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 and narrowing slightly; loop incomplete. Cardinal process hemispherical, horizontally striated, fused to cardinal margin. Adductor 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 Ms Francis 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 LAQUEIDAE Thomson, 1927

Remarks

Richardson (1973) placed the following genera in the family Laqueidea based on the development of loop characteristics.

Subfamily KINGENINAE Elliott, 1948

Remarks

Richardson (1975) erected the subfamily Kingeninae in which she placed a number of genera including *Aldinga, Paraldingia* and *Kingena*. The basis for this is the loop development and the morphological characteristics of the cardinal area.

Genus ALDINGIA Thomson, 1916

Type species

Terebratella furculifera Tate, 1880.

Aldingia furculifera (Tate, 1880)

Figure 4.19 C-G

Table 4.24

1880 *Terebratella furculifera* Tate, p. 161, pl. 11 figs 7a-c.

1880 *Waldheimia* (?) *insolita*; Tate, p. 151-152.

1899 *Terebratella furculifera*; Tate, p. 254-255.

1916 *Aldingia furculifera*; Thomson, p. 501.

1927 *Aldingia furculifera*; Thomson, p. 230-231, fig. 71a.

1970 *Aldingia furculifera*; Lowry, p. 67.

1973 *Aldingia furculifera*; Richardson, p. 121-122, pl. 5, fig. 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, WAM 82.3050, 51, Walpole North, Pallinup Siltstone, Werillup Formation, Late Middle Eocene, 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, Middle 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 per cent. shell length. Width greatest at mid-length to 100 per cent. shell length. Smooth, growth lines fine, very fine and dense punctae. Cardinal margin to 50 per cent. shell width, strongly curved; lateral valve 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 per cent. shell length, round, submesothyridid; deltidal 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 adductor muscle scars either side of ridge.

Dorsal valve. Outer socket ridge narrow. Socket triangular with roof posteriorly, floor swollen to lateral margin. Inner socket ridge curved over socket, base slightly swollen. Crura divergent, bases fused to inner socket ridge, slightly swollen. Septalium formed from union of inner hinge plates, 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 septalium. Serial grinding indicates teloform (magellaniform) type loop, extends to mid-length.

Table 4.24: Measurements of *Aldingia furculifera* (Tate, 1880) (in mm) of complete or nearly complete specimens.

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
F 6108/1	17.4	16.4	-	F 6114/1	23.0	17.0	11.2
F 6112/1	25.5	22.9	13.5	F 6114/1	24.2	18.4	11.8
F 6112/1	25.8	23.0	12.0	F 6114/2	29.8	25.8	-
F 6112/1	26.1	23.4	12.0	F 6114/3	19.8	17.9	10.0
F 6112/1	26.2	21.7	12.9	F 6818/1-2	20.3	18.1	9.3
F 6112/1	28.5	23.4	16.8	F 6818/1-2	26.3	22.6	11.5
F 6112/1	28.7	26.0	14.7	F 6822/1-3	15.1	13.6	6.6
F 6112/1	29.0	27.6	14.7	F 6824/1-4	17.5	17.1	6.4

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
F 6112/1	29.5	25.3	13.9	F 6826/1-2	22.9	22.5	10.6
F 6112/1	30.1	28.3	-	F 6826/1-2	26.7	24.6	13.8
F 6112/1	33.6	28.7	16.4	F 6828	6.6	6.6	2.5
F 6112/10	19.9	16.8	8.7	F 6828	8.4	8.3	3.2
F 6112/10	20.1	18.1	9.6	F 6840	21.8	17.6	10.8
F 6112/10	21.0	18.1	9.9	F 6843	25.0	22.4	-
F 6112/11	23.7	19.2	13.1	F 6845/1-5	18.4	15.3	9.2
F 6112/2	18.6	19.0	9.1	F 6845/1-5	20.2	16.7	10.1
F 6112/2	21.7	19.4	-	F 6845/1-5	21.2	17.8	-
F 6112/2	21.8	17.9	10.9	F 6845/1-5	24.5	20.3	-
F 6112/2	22.1	18.3	11.4	F 6851/1-7	12.2	10.7	4.7
F 6112/2	23.0	19.2	10.3	F 6851/1-7	12.4	10.6	5.5
F 6112/2	24.6	21.0	12.5	F 6851/1-7	14.5	12.7	6.3
F 6112/2	26.5	22.3	14.7	F 6851/1-7	16.5	14.6	-
F 6112/6	28.5	25.1	12.2	94.147	23.0	21.0	11.1
F 6112/6	33.1	28.4	15.0	94.148	21.5	17.0	8.5
F 6112/7	22.8	17.8	11.8	94.149	17.7	16.0	7.0
F 6113/3	15.3	13.4	6.6	94.150	16.9	15.2	7.1
F 6113/3	20.6	17.9	-	94.151	22.1	18.1	9.2
F 6113/3	22.4	19.0	11.6	94.152	22.5	21.5	10.0
F 6114/1	19.1	15.1	10.2				

Remarks

Aldingia furculifera (Tate, 1880) 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 (Middle 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 1973). *Waldhemia*(?) *insolita was assigned to Aldingia furculifera* by Richardson (1973).

Chapman and Crespin (1934) described *Terebratula aldingae* from the Plantagenet Beds, Norseman, Western Australia. It is most likely to be *Aldingia furculifera*, although the description is very brief.

Genus PARALDINGIA Richardson, 1973

Type species

Terebratella woodsii Tate, 1880

***Paraldingia timi* sp. nov.**

Figure 4.19 H-K

Table 4.25

Material Examined

Holotype.

WAM 96.756 Giralia Range, Carnarvon Basin, Wadera Calcarenite, Cardabia Formation, Late Paleocene.

Paratype

WAM 96.755, as for the holotype.

Diagnosis

Small, sub-circular biconvex shell; widest posterior to mid-length; foramen submesothyridid, oval; palintrope not wide; no carina.

Description

External. Small shell to 16 mm in length, sub-circular, biconvex, depth to 47 per cent. shell length, greatest convexity posteriorly, tapering anteriorly; width to 99 per cent. shell length, widest at the mid-length; cardinal margin gently curved, lateral valve edges bevelled, margin straight; anterior commissure straight to incipiently unisulcate; surface smooth, growth lines indistinct, finely and densely punctate; beak short, weak, rounded, erect to suberect; beak ridges attrite; foramen oval, widest laterally, submesothyridid; deltidal plates disjunct (or missing); palintrope narrow, extend halfway along cardinal margin.

Table 4.25: Measurements of *Paraldingia timi* sp. nov. (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH
96.755	11.3	10.8	5.3
96.756	15.9	15.8	6.6

Remarks

Paraldingia woodsii (Tate, 1880) has been described from the Freestone Cove Sandstone, Early Miocene, of Table Cape, Tasmania, *P. tepperi* (Tate, 1880) from the Late Eocene Muloowurtie Clays and *P. pentagonalis* (Tate, 1880) from the Late Eocene Tortachilla Limestone of South Australia (Richardson 1973a). This is the first record of the genus from the Late Paleocene and the earliest overall.

Although no interiors are available, *P. timi* sp. nov. closely matches the generic diagnosis in the external features. However, *P. timi* can be distinguished from *P. woodsii* (Tate, 1880) and *P. pentagonalis* (Tate, 1880) by its subcircular shape (Richardson 1973a). The greatest depth of the *P. timi* is posterior to the mid-length, similar to *P. tepperi* (Tate, 1880), The palintrope, however, is not wide and the lateral margin is straight and not sigmoidal and there is no indication of a carina on the dorsal valve, as has been described in *P. tepperi* (Tate, 1880) (Richardson 1973a).

Etymology

After Timothy McNamara, one of the principal collectors.

Genus KINGENA Davidson, 1852

Type species

Terebratula lima Defrance, 1828

Kingena mesembrina (Etheridge, 1913)

Figure 4.19 L-N, 4.20 A-G

Table 4.26

1913 *Magas mesembrinus* Etheridge, p. 15, pl. 2, figs 5-8, 8a

1952 *Kingena mesembrina*; Elliott, p. 4, pl. 1 figs 1-13.

1965 *Kingena mesembrina*; Muir-Wood, p. H839, figs 725, 1a-h.

1970 *Kingena mesembrina*; Owen, p. 69, pl. 6, figs 9a-c.

1991 *Kingena mesembrina*; Sandy, p. 403.

1993 *Kingena mesembrina*; McNamara *et al.* p. 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 to 69 per cent. shell length) to almost flat. Widest at mid-length, width 87 per cent. 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 per cent. 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. Socket 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. Diductor 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 adductor 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.

Table 4.26: Measurement of *Kingena mesembrina* (Etheridge, 1913) (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
63.127	11.6	11.3	5.8	88.885	12.1	10.8	5.2
68.618	10.3	10.1	5.0	94.5	14.2	12.5	5.3
70.1832	9.7	8.5	5.1	94.534	6.9	6.9	2.2
74.1138	15.3	13.7	8.5	4235/39	12.3	10.0	7.0
74.1138	14.6	13.1	9.8	4235/39	15.8	15.0	8.7
74.1138	13.4	11.0	6.4	4235/39	11.4	8.8	5.5
74.1177	9.1	8.7	4.5	4234	12.4	11.6	16.7
74.1301	7.0	6.6	3.7	4552	8.1	7.4	3.9
74.1301	7.5	7.2	3.2	5209	9.0	8.5	4.5
75.1190	13.4	12.2	7.9	5291	13.2	11.5	7.4
78.279	8.7	9.1	4.7	5626	8.1	7.3	4.1
78.279	12.2	11.3	5.1	5626	7.5	7.1	3.5
78.279	17.8	16.8	7.3	5627	9.2	8.6	5.0
78.279	9.2	7.9	4.3	5627	7.5	7.4	3.3
78.4358	9.2	8.5	4.6	5628	10.0	9.1	4.6
78.4358	13.4	12.1	7.1	5628	7.7	7.1	4.0
78.4440	19.0	18.1	11.9	5629	7.9	7.5	3.4
78.4440	13.7	12.9	8.0	5630	9.2	7.6	5.1
78.4440	16.7	14.5	10.4	5631	9.2	8.8	4.8
78.932	9.3	8.3	3.9	5632	8.3	8.2	3.9
79.1032	17.4	16.3	9.4	5633	7.5	7.2	4.1
79.1033	21.6	19.8	13.9	5634	7.9	7.7	3.4
79.1034	19.1	18.4	12.5	5635	7.7	6.3	3.9
79.2347	18.8	15.6	9.8	5636	8.2	7.3	3.7
79.2349	14.7	13.0	7.1	5637	8.7	7.5	3.1
79.2914	6.3	6.2	3.9	5638	6.9	6.5	3.2
80.1303	13.6	11.2	7.2	5639	6.5	6.2	2.7
80.400	6.2	5.4	2.4	5640	8.2	7.3	3.9
82.2660	8.9	8.3	4.6	5641	7.7	6.8	3.7
82.2665	6.1	5.3	2.3	5642	7.3	6.9	3.2
82.2665	9.5	7.5	3.6	5985	8.8	7.8	3.8

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
84.310	10.0	10.2	4.8	5986	9.5	8.2	4.7
84.310	10.8	9.4	4.4	5987	8.3	7.5	4.2
87.328	8.1	7.5	4.3	5988	9.1	7.9	3.7
87.328	6.8	6.3	2.8				

Remarks

The above description is consistent with that provided by Elliott (1952) although 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.

Suborder TEREBRATELLIDINA Muir-Wood, 1955

Superfamily TEREBRATELLACEA King, 1850

Family TEREBRATELLIDAE King, 1850

Subfamily TEREBRATELLINAE King, 1850

Genus DIEDROTHYRIS Richardson, 1980

Type Species

Waldheimia (?) johnstoniana Tate, 1880

***Diedrothyris johnstoniana* (Tate, 1880)**

Figure 4.20 H-L

Table 4.27

1880 *Waldheimia (?) johnstoniana* Tate, p. 151, pl. 8, fig. 9a-b.

1880 *Waldheimia (?) fimbriata*; Tate, p. 150-151, pl. 8, fig. 2a-b.

1899 *Magellania johnstoniana*; Tate, p. 253.

1899 *Magellania (?) fimbriata*; Tate, p.252.

1927 *Magellania (?) fimbriata*; Thomson, p. 295.

1980 *Diedrothyris johnstoniana*; Richardson, p. 49, pl. 11, fig. 9-16.

Material

Bremer Basin: WAM 74.42, 94.142-145, Nanarup Lime Quarry; WAM 95. 438, Mount Richard Road, Paul Terry Land, Lot 3195; Nanarup; WAM 94.161, Manypeaks Lime Quarry; Nanarup Limestone, Bremer Basin, Late Middle Eocene.

Description

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

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

Table 4.27: Measurements of *Diedrothyris johnstoniana* (Tate, 1880) (in mm) of complete or nearly complete specimens.

SPECIMEN	LENGTH	WIDTH	DEPTH
74.42	23.5	17.1	11.9
94.142	22.9	16.3	12.4
94.143	23.4	19.2	11.4
94.144	23.0	20.5	13.9
94.145	24.2	17.4	12.8
95.438	21.8	18.0	9.5

Remarks

Richardson (1980) describes the species from the Late Eocene Tortachilla Limestone south eastern Australia. The specimens described above are consistent with her description.

Diedrothyris cf *johnstoniana* (Tate, 1880).

Figure 4.20 K-N

Table 4.28

Material Examined

WAM 84.614 and 84.615Giralia Range, Carnarvon Basin, Giralia Calcarenite, Middle Eocene.

Description

External. Medium sized to a maximum length of 27.5 mm, ovate shell, equally biconvex, depth to 60 per cent. shell length; shell width to 83 per cent. of length, widest about the mid-length; cardinal margin strongly curved; lateral valve edges gently bevelled to slightly impressed, especially on the postero-lateral margin, margin slightly convex with respect to dorsal valve, antero-laterally margin and anterior commissure undulate to crenulate, anterior commissure slightly unisulcate; shell smooth except for series of flattened plications extending from beak to the antero-lateral margin and anterior commissure (these are much clearer under low frequency UV light), very fine growth lines; shell densely and finely punctate; beak suberect and protuberant; beak ridges attrite, extending to lateral margin; foramen large, 7 per cent. of shell length, mesothyridid; dental plates conjunct; symphytium slightly concave with a raised median ridge.

Table 4.28: Measurements of *Diedrothyris* cf *johnstoniana* (Tate, 1880). (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH
84.614	26.9	22.2	14.9
84.615	27.5	22.4	16.5

Remarks

Only two specimens of this species have been collected to date. The external features compare closely with those used to describe *Diedrothyris johnstoniana*

(Tate, 1880), a species known from the Late Eocene Tortachilla Limestone, in South Australia (Richardson 1980) and the Nanarup Limestone, Late Middle Eocene, Bremer Basin, Western Australia. Without internal structure, assignment of this species is tentative.

***Diedrothyris plicata* Richardson, 1980**

Figure 4. 21 A-C

1910 *Magellania garibaldiana* Pritchard, p. 90. fig. 20

1955 *Magellania garibaldiana* Gill and Baker, pp. 39-43, pl. 1, fig. 1.

1980 *Diedrothyris plicata* Richardson, pp. 50-51, pl. 11, figs. 20-25.

Material Examined

Eucla Basin: 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, Middle Eocene.

Description

Exterior. Medium sized shell to 25.7 mm long. Oval to subcircular, widest at mid-length, width to 77 per cent. shell length. Biconvex, both valves nearly equal, depth greatest at mid-length, depth to 53 per cent. shell length. Shell plicate, plica 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 per cent. shell width; lateral valve 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 per cent. of shell length, mesothyridid. Deltidal plates conjunct, symphytium medium width and depth, slightly convex with wide ribs.

No internal parts accessible.

Remarks

Richardson (1980) described 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 MAGELLANIA Bayle, 1880

Type Species

Terebratula flavescens Lamarck, 1819.

Magellania flavescens (Lamarck, 1819)

Figure 4.21 D-I

1819 *Terebratula flavescens* Lamarck, p. 246.

1819 *Terebratula dentata*; Lamarck, p. 246.

1835 *Terebratula australis*; Quoy and Gaimard, p. 551, pl. 85 figs 1-5.

1835 *Terebratula recurva*; Quoy and Gaimard, p. 554, pl. 85, figs 10-11.

1847 *Terebratula spadae*; Aradas p. 237.

1850 *Waldheimia australis*; King, p. 145, pl. 20, figs 10-12.

1852 *Waldheimia flavescens*; Davidson, p. 64, figs 6-7.

1859 *Waldheimia australis*; Hancock, pp. 791-869, pl. 52-59, 62, 63.

1860 *Terebratula* (*Waldheimia*) *flavescens*; Reeve, pl. 1.

1877 *Waldheimia flavescens*; Tenison-Woods, p. 57.

1880 *Waldheimia flavescens*; Davidson, p. 41, pl. 3, figs 10-12.

1880 *Magellania flavescens*; Bayle, p. 240.

1886 *Waldheimia flavescens*; Davidson, pp. 41-49, pl. 7, figs 6-19. text figs 3-8.

1902 *Waldheimia flavescens*; Hedley, p. 289.

1910 *Magellania flavescens*; Verco, p. 96.

1927 *Magellania flavescens*; Thomson, pp. 294-295, figs 5, 8, 9, 19c, 102.

1939 *Magellania australis*; Allan, pp. 234-235, pl. 30, fig 6.

1939 *Magellania flavescens*; Allan, pp. 235-236, pl. 30, fig 7.

1939 *Magellania iredalei*; Allan, pp. 236-237. pl. 30, fig. 5.

1974 *Magellania flavescens*; Foster, pp. 123-125, pl. 11, fig. 8, pl. 19, figs 15-16, pl. 23. figs 5-5. text fig. 3 part 25, text fig. 31. C-D

Material Examined

WAM 71.1537 Bushell's Bore, Kewdale, Ascot Formation, Late Pliocene.

WAM 70.1738 Poletti's Bore; 73.325, 510 Cement Works Bore; 74.817, 75.1267, 76.257, 473, 1039, 1960, 77.4233, 78.591, 1146, 1479, 2199, 3116, 79.845, 1080, 1980 Paulik's Bore, Jandakot; 77.2675 Murdoch, Ascot Formation, Perth Basin, Early Pleistocene.

WAM 86.277 Buayanyup drain, Vasse, Perth Basin, Middle Holocene.

Description

Exterior. Shell small to medium-sized, 3 mm to 12 mm long (largest specimens incomplete). Subtriangular to ovate. Biconvex, dorsal valve flatter than ventral valve Widest anterior to mid-length. Finely and densely punctate, punctae oval. Shell ribbed, extending from posterior margin; ribs wide, 6 per cent. of shell length, interstitual spaces as wide as ribs, some ribs bifurcate anterior to mid-length. Dorsal valve sulcus anterior to mid-length. Cardinal margin strongly curved; lateral margin convex towards ventral valve, crenulate anterior to mid-length; anterior commissure unisulcate, crenulate (2 crests per mm). Umbo truncated; beak suberect, beak ridges rounded. Foramen large, 14 per cent. of shell length, mesothyridid. Deltidial plates triangular and disjunct. Lip over dorsal valve.

Interior. Ventral valve. Pedicle collar narrow, sessile. Hinge teeth unclear, wide, no dental plates.

Dorsal valve. Outer socket ridge thin. Inner socket ridge, slightly curved over socket. Socket triangular with no roof. Outer hinge plate, crural base and inner hinge plate fused. Vertical ribbing exists along union of inner socket ridge with outer hinge plate. Crural base extends posteriorly as slight rise. Crura divergent. Inner hinge plates join bifurcating median septum in cardinal third of posterior section. Median septum extends just beyond mid-length; crest to base thin, not swollen. septalium, sockets and cardinal process form a platform over posterior section of valve. Cardinal process with protuberant lip, projects towards ventral valve, trilobed, lamella parallel to trilobed edge producing folded pattern. Loop incomplete.

Remarks

The disjunct deltidial plates are not characteristic of the genus. Richardson (1994) said the deltidial plates are "invariably conjunct". However, Bitner (1996) illustrated a disjunct specimen of *M. antarctica*. The fusion of the plates may well be a feature of later ontogeny. Unfortunately no specimens of large ventral valves or conjoined valves are available. The species is known from the present day of south eastern and south western Australia. This is the earliest record of the species.

Genus VICTORITHYRIS Allan, 1940

Type species

Victorithyris peterboroughensis Allan, 1940

Victorithyris blakeorum sp. nov.

Figure 4.8, 4.21 J-N

Table 4.29

Material Examined

Holotype

WAM 96.697 Giralia Range, Carnarvon Basin, Wadera Member, Cardabia Formation, Late Paleocene.

Paratypes

WAM 88.50c, 88.111 Giralia Range, Carnarvon Basin, Boongerooda Greensand, Cardabia Formation, Late Paleocene, 96.706, 96.711 and 96.713 a and b, as for holotype.

Other Material

WAM, 60.110, 71.149, 71.162, 88.50-51, 88.77 c,d, 88.110, 95.242, 96.810-813, 96.832, 96.930, Giralia Range, Carnarvon Basin, Boongerooda Greensand, Cardabia Formation, Late Paleocene. WAM 84.532, 88.25 de, 88.127, 96.497, 96.578, 96.649, 96.657, 96.677-678, 96.680-696, 96.698-705, 96.707-710, 96.712, 96.752-754, 96.759, 96.764-765, 96.798, 96.825, as for holotype.

Diagnosis

Small to medium shell, foramen medium size, anterior commissure rectimarginate to incipiently unisulcate, sulcus when present shallow, lacking dorsal plication.

Description

External. Shell medium, to 24 mm long, ovate to sub-circular. Width to 78 per cent. shell length, widest at the mid-length or just posterior to it. Equally biconvex, depth to 48 per cent. shell length. Cardinal margin curved; lateral valve edges bevelled, margin straight to slightly convex with respect to dorsal valve; anterior commissure rectimarginate to incipiently unisulcate. Surface smooth, growth lines prominent over whole shell, punctae very fine, circular and dense. Beak sub erect to erect, slightly labiate in some specimens; beak ridges extend to lateral margins, attrite. Foramen mesothyridid, medium sized, to 5.5 per cent. shell length. Symphytium narrow, slightly concave with a median swollen ridge.

Interior. Ventral valve. Hinge teeth stout and large, deltidiodont, bases swollen to valve floor. Pedicle collar complete, sessile. Hinge teeth and dental plates form narrow pedicle trough. Adductor muscle scars in triangular "basin" anterior to pedicle trough.

Dorsal valve. Outer socket ridge thin, narrow; inner socket ridge fused with outer hinge plate. Socket triangular, weak and without roof or fulcral plate. Hinge plate joins with crural bases. Area dorsal to socket and crural bases heavily thickened. Crural process thin , diverging either side of septalium. Median septum low, short, not extending beyond mid-length of the valve, distinctive dip towards its anterior end. Cardinal process small, protuberant, with narrow rim, slightly swollen posterior section, overhangs septalium.

Loop incomplete in specimens observed. Serial grinding indicates a teloform-like (magellaniform) loop with two loop elements, ascending and descending lamella indicated (figure 4.8).

Table 4.29: Measurements of *Victorithyris blakeorum* sp. nov. (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
84.532	21.6	16.7	9.0	96.689	18.8	13.8	8.3
88.111a,c	23.0	18.1	10.0	96.690	20.7	16.0	9.2
96.825	13.8	13.1	6.3	96.691	18.8	13.6	8.3

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
96.825	18.3	15.6	8.4	96.693	16.5	13.3	6.6
96.825	16.1	12.9	7.6	96.695	18.7	15.2	9.7
96.825	17.4	14.4	6.8	96.696	17.5	13.8	7.9
96.825	15.2	14.0	6.7	96.697	20.8	16.0	9.4
96.497	12.8	11.0	5.1	96.698	17.6	13.9	7.2
96.578	20.2	16.6	8.1	96.700	18.1	14.3	8.7
96.649	19.6	16.5	8.8	96.701	18.2	14.2	8.1
96.677	19.3	15.0	7.4	96.702	19.4	16.0	8.4
96.679	19.8	15.5	9.5	96.703	18.4	16.5	8.0
96.680	18.5	15.0	8.2	96.704	17.9	14.7	8.0
96.681	18.1	14.6	7.9	96.705	17.2	14.0	6.9
96.682	19.9	14.7	8.3	96.706	19.7	15.2	9.4
96.683	16.3	13.4	6.8	96.708	11.5	9.8	4.9
96.684	19.4	15.3	7.8	96.709	11.1	8.7	4.5
96.685	17.0	12.2	7.5	96.710	16.7	13.5	7.2
96.686	17.5	14.5	7.9	96.798	23.5	18.1	10.1
96.688	19.7	15.2	9.0				

Remarks

Victorithyris blakeorum sp. nov. is slightly smaller than *V. cardabiaensis* sp. nov. and *V. decapello* sp. nov., herein described. The cardinalia is less thickened, the beak is not incurved, the foramen larger and the palintrope is not as wide. It differs from *V. peterboroughensis* Allan, 1940 in lacking a sulcus in the dorsal valve. It can be distinguished from *V. tateana* (Tate, 1880), *V. divaricata* (Tate, 1880) and *V. garibaldianai* (Davidson, 1862) in which there is no plication (Richardson 1980)

Etymology

After the Blake family of the Giralia Station, on which the species was found.

***Victorithyris cardabiaensis* sp. nov.**

Figure 4.9, 4.22 A-D

Table 4.30

Material Examined

Holotype.

WAM 96.735 Giralia Range, Carnarvon Basin, Wadera Member, Cardabia Formation, Late Paleocene

Paratype

WAM 96.738, as for holotype.

Other Material

WAM 96.734-736, 96.738-743, 96.745, 96.828. as for holotype.

Diagnosis

Incurved beak, wide palintrope, greatest width posterior to mid-length, near cardinal margin.

Description

External. Shell medium sized, 27 mm long. Sub-equally biconvex, depth to 54 per cent. shell length. Dorsal valve subtriangular, widest posterior to mid-length, width to 90 per cent. shell length. Cardinal margin gently curved to nearly straight; lateral edges sharply bevelled, margin slightly convex with respect to dorsal valve; anterior commissure gently unisulcate. Shell smooth; finely densely punctate. Beak "hooked", sharp, erect; beak ridges sharp, extend to lateral margins. Foramen small, to 1.5 per cent. shell length, mesothyridid; pedicle collar a thin rim not united anteriorly. Deltidal plates conjunct, thin median ridge. Symphytium is slightly concaved, low wide. Palintrope narrow, concaved.

No interiors were available. Serial grinding indicates a teloform-like (magellaniform) loop (figure 4.9).

Table 4.30: Measurement of *Victorithyris cardabiaensis* sp. nov. (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH
96.827	21.1	19.6	7.9
96.829	19.5	19.1	8.5
96.531	24.9	24.2	13.4
96.735	22.2	20.2	10.2
96.738	25.1	22.7	11.1
96.740	27.0	26.9	12.9

Remarks

Victorithyris cardabiaensis sp. nov , like *V. decapello* sp. nov., herein described, is distinguished from all other species by the incurved, cobra head-like appearance, wide palintrope and small foramen. The wide anterior and tapering width from the cardinal margin distinguishes it from *V. decapello.*

Etymology

From the Cardabia Formation.

***Victorithyris decapello* sp. nov.**

Figure 4.22 E-I

Table 4.31

Material Examined

Holotype

WAM 96.645 Giralia Range, Carnarvon Basin, Wadera Member, Cardabia Formation, Late Paleocene. from the type locality.

Paratypes

WAM 96.607 and 609, as for holotype.

Other Material

WAM 74.578, 84.539, 96.559-577, 96.579-606, 96.608, 96.610-611, 96.625, 96.628, 96.629, 96.630-633, 96.635-638, 96.640-643, 96.646-648, 96.737, 96.744, 96.746, 96.760-761, 96.763, 96.766, 96.780-781, 96.791-794, 96.803, 96.806-807, 96.863, as for holotype.

Diagnosis

Biconvex; smooth. Finely and densely punctate. Anterior commissure rectimarginate to weakly unisulcate. Beak suberect to erect, incurved. Foramen small, mesothyridid to permesothyridid. Wide palintrope. Socket ridges prominent, inner ridges swollen; inner hinge plates meeting on septum; median septum short. Narrow septalium. Cardinal process swollen plate with bilobed rim.

Description

Exterior. Shell medium sized, maximum length 35 mm, round to ovate to sub-pentagonal to sub-heptagonal in largest specimens. Width to 85 per cent. shell length, widest at mid-length or slightly anterior to it. Equally biconvex, depth to 55 per cent. shell length. Cardinal margin gently curved; lateral valve margin edges rounded, impressed in larger specimens, margin straight; anterior edge bevelled, commissure rectimarginate to weakly unisulcate. Surface smooth, growth lines prominent at lateral margin; finely and densely punctate, punctae circular. Beak "cobra head" shaped, suberect to erect, beak overhangs dorsal valve; beak ridges

wide and extend from beak to beyond the cardinal margin to meet on lateral margins. Foramen small, to 1.5 per cent. shell length, mesothyridid to permesothyridid. Symphytium concave, nearly obscure in some specimens; deltidal plates conjunct with median ridge clearly present in specimens with flatter symphytium.

Internal. Ventral valve. Hinge teeth stout, deltidiodont, grooved for reception of socket ridges, swollen bases, attached obliquely to valve lateral margin. Pedicle collar unclear due to small size of foramen. Adductor muscle scars in long, slightly depressed trough,.

Dorsal valve. Outer socket ridges prominent, fairly wide, extend length of cardinal margin. Fulcral plate curved, sockets deep. Inner socket ridges swollen. Outer hinge plates connected to crural bases with a slight depression between these in some specimens. Inner hinge plates joined to form a narrow septalium. Crura although incomplete in all specimens examined, curve outwards towards lateral margin (forked), bases joined to posterior of median septum. Median septum short, top parallel to lateral margin, hence low at anterior and higher at posterior where it rises above the trough, thickened posteriorly at the base. Cardinal process with socket ridges extend slightly beyond margin. Cardinal process consists of a swollen plate with a cup-like protuberant structure posterior to it, the rim of which is not conjunct dorsally. Adductor muscle scars in deep troughs either side of median septum, separated by slight curved ridge. No loop available.

Table 4.31: Measurements of *Victorithyris decapello* sp. nov. (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
84.518	29.1	25.7	13.2	96.601	25.3	21.3	11.8
84.539	26.2	23.9	14.4	96.605	26.8	21.7	12.9
84.540c	26.3	23.7	11.8	96.623	24.6	22.1	14.2
96.500	23.8	21.7	11.0	96.625	25.3	21.8	11.6
96.505	27.4	24.2	13.2	96.626	25.3	21.7	11.7
96.559	30.9	26.6	16.6	96.628	26.8	23.6	12.4
96.561	24.6	22.1	12.0	96.629	29.5	25.7	13.4
96.562	28.7	25.4	12.7	96.630	28.0	23.5	11.4
96.564	24.8	22.4	10.9	96.631	23.4	19.2	9.9
96.566	21.4	19.0	9.8	96.633	26.3	24.2	11.3
96.569	19.4	17.9	9.3	96.634	29.1	25.8	11.2
96.571	23.1	21.3	9.9	96.635	24.9	24.0	11.8
96.573	24.5	22.7	11.5	96.638	27.1	22.9	12.2
96.575	25.2	23.5	11.0	96.639	28.8	26.0	13.0
96.576	27.3	22.7	13.1	96.641	19.9	18.4	7.2
96.579	22.6	20.2	9.7	96.642	22.7	19.6	9.2
96.580	23.0	21.0	8.1	96.643	23.6	21.3	9.5
96.582	18.1	16.7	7.0	96.644	29.1	25.3	15.3
96.585	29.2	23.8	12.9	96.645	31.2	27.0	15.3
96.586	23.5	21.1	10.9	96.646	25.1	21.8	10.7
96.588	30.2	24.1	15.7	96.647	27.3	22.6	11.6

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
96.593	16.3	14.5	7.0	96.648	28.9	24.7	11.1
96.594	35.1	29.5	12.4	96.737	26.3	23.8	13.5
96.595	27.6	24.1	14.9	96.780	27.3	21.3	12.4
96.596	30.3	26.5	14.9	96.802	31.4	26.9	12.9
96.597	33.2	26.9	14.3	96.806	23.4	20.2	10.5
96.598	26.3	23.1	13.7	96.807	26.3	23.5	11.8

Remarks

The external features of this species are similar to those of *Rhizothyris* Thomson, 1915, but internally it is quite different. The presence of a cup-shaped cardinal process and the highly swollen crural bases with the inner hinge plates joining the median septum to create a short septalium place the species in the genus *Victorithyris*. This is the earliest record of this genus. Allan (1940) assigned the genus for *Victorithyris peterboroughensis* Allan, 1940 that he described from the Middle Miocene, Port Campbell Limestone of Victoria. Species of the genus described from South Australia include *V. garibaldiana* (Davidson, 1862) from the Early to Late Miocene of the Mount Gambier Limestone, *V. divaricata* (Tate, 1880) from the Early Miocene Mannum Limestone, and *V. tateana* (Tate, 1880) of the Late Eocene Tortachilla Limestone (Richardson 1980). There are no described species of this genus that have the overhanging umbo, wide palintrope or extremely small foramen possessed by *V. decapello*. The posterior thickening, including the cardinalia, as well as the small foramen of this species suggests it may have had a free-lying life style as described by Richardson (1981).

Etymology

From *cobra de capello* meaning "snake with a hood".

***Victorithyris divaricata* (Tate, 1880)**

Figure 4.22 J-M

Table 4.32

1880 *Waldheimia* (?) *divaricata* Tate, p.149, pl. 8, figs 8a-b.

1980 *Victorithyris divaricata* Richardson, pp. 47-48, pl. 10, fig. 16.

Material Examined

Eucla Basin: F5542/1, Twilight Cove; F6111/2, Murra-el-elevyn Cave; Wilson Bluff Limestone, Middle 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 per cent. shell length. Width greatest at mid-length, width to 87 per cent. 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 per cent. shell width; lateral valve 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 per cent. shell length, mesothyridid. Deltidial plates conjunct, symphytium wide, concaved with swollen mid-section.

Table 4.32: Measurements of *Victorithyris divaricata* (Tate, 1880) (in mm).

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 (Tate, 1880) is described from the Mannum Formation of Early Miocene age in South Australia (Richardson 1980). This is the earliest record of the species.

***Victorithyris garibaldiana* (Davidson, 1862)**

Figure 4.22 N-P, 4.23 A-D

Table 4.33

1833 *Terebratula* sp. Sturt, p. 254, pl. 3, fig. 15

1862 *Terebratula compta*; Tenison-Woods, p. 74.

1862 *Waldheimia garibaldiana*; Davidson, p. 446, pl. 24, fig. 9.

1865 *Waldheimia imbricata*; Tenison-Woods, p. 2, figs 3a-b.

1876 *Waldheimia garibaldiana*; Etheridge, pp. 17,18, pl. 1, figs 2a-b.

1877 *Waldheimia macropora*; McCoy, pl. 43, figs 4, 6.

1880 *Waldheimia garibaldiana*; Tate, pp. 146-148, pl. 11, figs 1a-c.

1899 *Magellania garibaldiana*; Tate, pl. 252.

1927 *Magellania garibaldiana*; Thomson, p. 295.

1970 *Magellania garibaldiana*; Lowry, p.67.

1980 *Victorithyris garibaldiana*; Richardson, pp. 45-47, pl. 10, figs 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, Middle Eocene.

Description

External. Small to medium-sized shell from 7.9 to 25 mm long; ovate to subcircular. Biconvex, dorsal valve flatter than ventral valve; depth greatest at mid-length, depth to 66 per cent. shell length. Widest slightly posterior to mid-length; width to 89 per cent. shell length. Shell mutiplicate, plica arising shallowly posterior to umbo, deepening anteriorly and antero-laterally; width of interstitial spaces variable; plica rounded; shallow sulcus in dorsal valve in 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 per cent. shell width; lateral valve edge rounded, lateral margin straight to anterior then curved towards ventral valve, crenulate anterior to mid-length; anterior valve edge rounded, anterior commissure unisulcate, sulcus shallow to deep, narrow (33 per cent. shell width) to wide (62 per cent. shell width); crenulate. Umbo stout, truncate, beak suberect with slight lip; beak ridges rounded. Foramen medium-sized to 5 per cent. shell length, mesothyridid. Deltidial plates

conjunct, symphytium medium width and depth, divided by grooves, convex within grooved 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 plate small, united to form shallow septalium. Median septum blade-like, extends to anterior to mid-length, base thickens posteriorly and again anteriorly, to widens anteriorly then reduces to valve floor. Cardinal process small protuberant striated depressed "dish" within swollen bases of cardinalia, swollen boss under process. Loop incomplete, transverse bands appear to connect to medium septum anteriorly. Adductor muscle scars in sunken floor anterior to cardinal area, sharp posteriorly widening into ovate depressions.

Table 4.33: Measurements of *Victorithyris garibaldiana* (Davidson, 1862) (in mm).

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

Remarks

Richardson (1980) described *Victorithyris garibaldiana* (Davidson, 1862) 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 4.23 E-J, N

Table 4.34

1880 *Waldheimia tateana* Tate, p. 150, pl. 7, fig. 6a-b, pl. 8, fig. 6 a-c, pl. 9, fig. 2.

1899 *Magellania tateana*; Tate, p.233.

1970 *Terebratula tateana*; Lowry, p. 67.

1980 *Victorithyris tateana* Richardson, p. 48, pl. 11, figs 1-8.

Material Examined

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

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 top of formation; F6814, Abrakurrie Cave, 23-26 m below top of formation; F6849, Wilson Bluff; WAM 66.1418, Madura, 13 km North Cave; Wilson Bluff Limestone, MiddleEocene.

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 per cent. shell length. Greatest width near mid-length, width to 80 per cent. shell length. Shell smooth, growth lines distinct, finely and densely punctate. Cardinal margin strongly curved; lateral valve edge rounded, lateral margin nearly straight to slightly curved to ventral valve posteriorly; anterior valve edge gently rounded, anterior commissure rectimarginate. Umbo strong, beak erect; beak ridges rounded. Foramen round, 4 to 6 per cent. shell length, mesothyridid; 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. Adductor 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

septalium widening posteriorly, plates wider than join with bifurcated septum, cut off extension either side of septum. Median septum extends beyond mid-length, bifurcates posteriorly to join septalium. Cardinal process overhangs trough, slightly depressed thin round transverse plate. Muscle scars obscured.

Table 4.34: Measurements of *Victorithyris tateana* (Tate, 1880) (in mm) of complete or nearly complete specimens.

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

Remarks

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

***Victorithyris tulkiensis* sp. nov.**

Figure 4.23 K-M, O, P

Material Examined

Holotype

WAM 82.1711 Tulki Limestone, Cape Range, Carnarvon Basin, Western Australia, Middle Miocene.

Paratypes

WAM 82.1717 and 82.1714 as for holotype.

Other Material

WAM 84.617, 95.546, 95.574 Mandu Calcarenite, Cape Range, Carnarvon Basin, Western Australia, Early to Late Oligocene, WAM 82.1710, 1712, 1713, 1715, 1716, 1718 and 1719 as for holotype.

Diagnosis

Small subcircular *Victorithyris*, plicate anteriorly, anterior commissure rectimarginate

Description

External. Small to a maximum length of 14.5 mm, sub-circular, width to 88 per cent. shell length, widest at mid-length. Biconvex, dorsal valve slightly flatter, depth to 53 per cent. shell length shell. Cardinal margin gently curved; lateral valve edge bevelled, lateral margin straight; anterior commissure rectimarginate. Shell smooth except for the antero-lateral and anterior margins which show weak plication on the dorsal valve and create a crenulated edge. Finely and densely punctate. Beak suberect, short; beak ridges sharp. Foramen round, small, 2 per cent. shell length, mesothyridid to permesothyridid. Symphytium wide and triangular, deltidial plates conjunct, median ridge present. Palintrope narrow.

Internal. Dorsal valve. Socket with wide, triangular roof extending from inner socket ridge the roof slightly curved upwards. Sockets shallow. Inner socket ridge, outer hinge plates and crural bases fused to cardinal margin. Crura project from united hinge plate and crural base. Median septum is incomplete, blade-like, thickened posteriorly at it's base, rising to form vase shaped septalium. Shallow depression exists between septalium and cardinal process. Cardinal process extending anteriorly over depression, gently cup-shaped, short protrusion posteriorly, narrow short rims laterally. Whole cardinal area thickened, Adductor muscle scars form deep triangular depressions either side of median septum.

Remarks

V. tulkiensis sp. nov. differs from *V. garibaldiana* (Davidson, 1862), as it is smaller, lacks the coarse plication and a sulcus *V. divaricata* (Tate, 1880) is narrower, more oval and more inflated than *V. tulkiensis* (Richardson 1980). *V. tateana* (Tate, 1880) is narrow, oval with a truncated beak and a smooth surface (Tate 1880). *V. tulkiensis* is subcircular, the beak not truncated and plicate anteriorly. *V. peterboroughensis* (Allan, 1940) is large with a high median septum and striated cardinal process (Richardson 1980). *V. tulkiensis* is small with a low median septum and a smooth cup shaped cardinal process. The presence of marginal dorsal plication and crenulation distinguishes the species from others found in the Carnarvon Basin.

Etymology

The name is derived from the type locality.

Genus NEOTHYRIS Douville, 1879

Type species

Terebratula lenticularis Deshayes, 1839 WAM

Neothyris rylandae Craig, 1999

Figure 4.23 Q, 4.24 A-F, H, I

Table 4.35

Diagnosis

A large *Neothyris*, high degree of convexity, cardinal margin strongly curved, anterior commissure unisulcate to incipiently intraplicate, foramen size large relative to shell length, swollen cardinal process, labiate beak.

Material Examined

Holotype

WAM 82.2368; Roe Plains, Madura district, W. A. Pit 0.5 km N of Hampton Microwave Repeater Tower. Basal 0.6 m carbonate sand.

Paratypes

WAM 82.2367, 76.2480 as for holotype.

WAM 82.2378, 82.2379 Roe Plains, Madura district, W. A., Pit 1.5 km N of Hampton Microwave Repeater Tower. Basal 0.4 m of carbonate sands.

Other Material

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

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

WAM, 82.2369, 82.2370, 82.2372, 82.2373, 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, 82.2380 - 82.2388; Roe Plains, Madura district, W. A., Pit 1.5 km N of Hampton Microwave Repeater Tower: spoil heaps near base of tower.

Description

External. Shell large (up to 65 mm in length), ovate to subpentagonal, Biconvex, both valves approximately equal. Greatest width just anterior to mid-length, width 80 per cent. of length. Cardinal margin strongly curved, 60 per cent. of shell width; lateral valve edge rounded, lateral margin convex towards ventral valve, crenulate anterior to mid-length; anterior valve edge bevelled, anterior commissure unisulcate to incipiently intraplicate. Ventral valve with keel developing posteriorly and widening until anterior commissure where it generates a fold. Surface smooth. Growth lines towards anterior commissure very prominent. Punctae fine and regularly dense. Beak suberect to erect, truncated, labiate; beak ridges wide, rounded meeting dorsal valve indistinctly anterior to cardinal margin. Foramen round, large, 6 per cent. of shell length, mesothyridid. Symphytium narrow, deeply concave, deltidal plates conjunct, without obvious median ridge.

Internal. Ventral valve. Pedicle collar short and thin; trench leading into pedicle area created by thickened posterior sides of valve. Adductor muscle scars a pair of furrows either side of pedicle neck, diverging and extending to mid-length.

Hinge teeth strong, facing inward at a slight angle; grooved for reception of socket ridges. Teeth wider than thick with swollen bases. No dental plates.

Dorsal valve. Sockets wide and deep; triangular with small roof posteriorly at apex; base anteriorly located. Fulcral plate relatively thin. Outer socket ridges sharp and slightly raised, extend slightly above hinge line, 12.5 per cent. shell length. Inner socket ridges slightly raised. Outer hinge plate joins inner socket ridge and crural bases to make V-shaped trough. Inner hinge plates extend from crural bases to median septum, meeting medianly to create a septalium. Crural bases thin, extending from posterior of shell to crura. Crural process dart to talon shaped, vertical with slight anterio-medial curve producing a sharp point. Median septum extends posterior of mid-length; raised posteriorly, appearing to bifurcate where septalium meets it; base thickened posteriorly (crural bases and median septum swelling more pronounced with increase in size of valve). Loop teleform (magellaniiform), extending greater than 75 per cent. shell length; descending band thin and wide; ascending loop very wide near transverse band which is wide, incurved and arched towards ventral valve. Cardinal process protuberant, round with raised margins laterally and anteriorly, anterior extends vertically to cardinal margin, swollen and extending into shell overseptalium, raising the cardinal process well above the cardinalia.

Table 4.35: Measurements of *Neothyris rylandae* Craig, 1999 (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
69.382	65.0	43.8	37.9	82.2379	42.9	33.4	28.3
76.2480	40.1	37.1	-	82.2380	44.6	40.4	32.6
82.2367	65.1	48.8	46.3	82.2381	39.2	30.2	20.4
82.2367	65.3	50.1	46.6	82.2382	29.7	24.5	15.1
82.2368	63.8	50.9	42.5	82.2383	10.6	9.6	5.2
82.2369	51.0	40.8	32.4	82.2384	8.3	6.3	4.5
82.2370	52.2	39.8	33.3	82.2385	5.8	4.0	2.9
82.2371	55.3	39.2	37.5	82.2386a	5.0	3.9	2.2
82.2372	51.5	35.3	35.0	82.2386b	4.6	3.2	1.9
82.2373	21.6	16.6	10.6	82.2387	4.1	3.3	1.6
82.2374	43.1	35.9	25.9	82.2388	6.0	5.0	-
82.2375	56.6	43.3	35.3	85.2026 a	60.1	41.1	36.8
82.2376	37.7	34.1	21.6	85.2026 b	57.4	42.8	39.6
82.2377	31.4	27.0	18.1	85.2026 c	51.9	38.2	32.8
82.2378	55.3	36.9	36.1	85.2026 d	51.3	39.7	-

Remarks

Neothyris rylandae Craig, 1999 has similarities to *Cudmorella* Allan, 1939, especially in the interior of the dorsal valve. Allan (1939) suggested that there is an affinity between *Cudmorella* and *Neothyris* but differentiated them on the basis of *Cudmorella* having a permesothyridid foramen and a primitive cardinal process whilst *Neothyris* has a mesothyridid foramen and is less folded. *Neothyris rylandae* has a mesothyridid foramen and the folding is incipient.

The primary areas of morphological difference between *Neothyris* species are in the overall size, degree of convexity, cardinal margin, anterior commissure, foramen size relative to shell length, socket teeth and cardinal process. *Neothyris rylandae* is the only species with a labiate beak.

N. anceps Thomson, 1920 (Miocene) is a large shell (53 mm long) with a large foramen and a convex lateral margin similar to *N. rylandae,* which has a maximum length of 65 mm. The cardinal process is described as being "confined to the posterior part of the hinge trough (septalium)" (Thomson, 1920) whereas in *N. rylandae* the cardinal process is very large and takes up the majority of the septalium. Few details are available for *N. novara* Ihering, 1903 (Miocene), although Thomson (1920) described it as being more than half as deep as long, having a straighter hinge line and a less convex lateral margin than *N. lenticularis* (Deshayes, 1839). *N. rylandae* is as bulbous as, but has a more strongly curved hinge line and lateral margin than, *N. lenticularis.*

N. iheringi Thomson, 1920 (Miocene) is medium sized (based on an illustration in Thomson (1920)), with a long beak and a small foramen. None of these features is comparable to those of *N. rylandae*, which is larger and has a larger foramen. The Pliocene *N. thomsoni* Allan, 1932 is similar to *N. rylandae* in that it is of similar size, strongly biconvex, having deep sockets, a septalium and a large crural process (Allan 1932). It differs from *N. rylandae* in having a smaller foramen and a rectimarginate anterior commissure.

The Pliocene *N. campbellica ovalis* (Hutton, 1886) differs from *N. rylandae* in that it has a rounded commissure, smaller sockets and a thin cardinal process. The size is moderate to large, as is the size of the foramen (Neall 1972). *N.c. campbellica* (Filhol, 1885) from the Pliocene was described by Neall (1972) as moderate to large in size, narrow and having a small foramen, all these features differing from *N.*

rylandae. *N. c. elongata* Neall, 1972 (Pleistocene) is a flattened shell of medium size and with a medium-sized foramen (Neall 1972).

The living *N. lenticularis* (Deshayes, 1839) is large, but in comparison to *N. rylandae* it would better be described as medium sized. The cardinal process has a small median boss whilst in *N. rylandae* it is very swollen.

The living *N. compressa* Neall, 1972 is medium-sized with a maximum length of 50 mm, having a compressed biconvex appearance (Chapman and Richardson 1981). *N. rylandae* is bulbous and much larger. *N. dawsoni* Neall, 1972 (Recent) is small with a tiny foramen (Chapman and Richardson 1981). According to Neall (1972) *N. obtusa* ranges from the Pliocene to the Recent. The species is described as having a small septalium, small hinge teeth and a small to medium-sized cardinal process, making it quite different from *N. rylandae* with a swollen "hinge trough", large cardinal process and large hinge teeth.

N. rylandae has a large foramen and a suberect to erect beak. The cardinalia and posterior sections of the shell are much thickened (see above description). According to Richardson and Watson (1975) and Richardson (1981,1984) this would suggest that the species is capable of, and adapted to, a free lying habit. The presence of the labiate suberect to erect beak, concave symphytium and mesothyrid foramen would indicate an inert pedicle (Richardson 1981). *N. rylandae* is found in sandy calcarenite and this is consistent with the life habit as described above.

Etymology

The species is named after Ms Valerie Anne Ryland, who was technical officer at the Western Australian Museum and undertook the preliminary work on all the specimens from the Roe Calcarenite.

Subfamily STETHOTHYRIDINAE MacKinnon, Beus and Lee, 1993.

Genus ALIQUANTULA Richardson, 1991

Type species

Waldheimia(?) insolita Tate, 1880.

Remarks

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

***Aliquantula insolita* (Tate, 1880)**

Figure 4.24 G, J, K-M

Table 4.36

1880 *Waldheimia(?) insolita* Tate, p. 151-152, pl. 9, fig. 6b.

1899 *Magellania insolita*; Tate, p. 282.

1927 *Stethothyris (?) insolita*; Thomson, p. 282.

1991 *Aliquantula insolita*; Richardson, p. 44, fig. 6G-L.

Material Examined

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

F6837, Tommy Grahams Cave, Abrakurrie Limestone, Early Miocene.

Description

Exterior. Shell ovate to subcircular; medium-sized, 14 to 21.7 mm long. Biconvex, dorsal valve almost flat, depth 40 per cent. in small to 50 per cent. shell length in larger specimens. Widest anterior to mid-length, width to 80 per cent. in small to 67 per cent. shell length in larger specimens. Valves smooth, growth lines distinct. Cardinal margin wide, curved; lateral valve 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 per cent. shell length, mesothyridid to submesothyridid; deltidial plates conjunct. Symphytium relatively wide, low and narrow in small to high in larger specimens, smooth.

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

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. Septalium 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.

Table 4.36: Measurements of *Aliquantula insolita* (Tate, 1880) (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
69.264a	14.0	10.7	6.3	94.168	-	5.2	2.6
69.264b	21.5	19.1	8.7	F6817	19+	16.3	7.1
75.39	15.7	10.7	7.4	F6819/1-4	13.8	12.3	5.5
75.41	-	7.2	3.7	F6819/1-4		17.2	8.2
76.15a	21.7	18.3	9.9	F6819/1-4	14.4	12.9	5.2
76.15b	16.6	-	6.4	F6834	6.6	5.8	2.7
94.146	18.9	12.8	9.6				

Remarks

Aliquantula insolita (Tate, 1880) has been 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) described a specimen of this species from the Plantagenet Beds, Norseman, Western Australia.

Aliquantula tapirina (Hutton, 1873)

Figure 4.24 N, 4.25 A-F

Table 4.37

1873 *Waldheimia tapirina* Hutton, p. 36.

1905 *Bouchardia tapirina*; Hutton, p. 480, pl. XLVI, fig. 6.

1960 *Stethothyris tapirina*; Allan, p. 239, 266.

1993 *Stethothyris tapirina*; MacKinnon *et al.* p. 343, fig 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* based on the revised generic characteristics of *Aliquantula* (page 163).

Material Examined

Bremer Basin: WAM 94.155, 95.602, 99.313-316, Manypeaks Quarry, Nanarup Limestone, Werillup Formation, Late Middle Eocene, Bremer Basin.

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

Description

Exterior. Shell subcircular; small to large, 14 to 42.5 mm long. Biconvex, ventral valve with slight keel; depth to 52 per cent. shell length. Width to 101 per cent. 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; beak ridges sharp, extend to lateral margin. Foramen small, 1 per cent. shell length in large specimens, mesothyridid; deltidial plates conjunct. Symphytium wide, high, concaved.

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 separated by short thin median ridge 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. Adductor muscle scars elongated troughs.

Table 4.37: Measurements of *Aliquantula tapirina* (Hutton, 1873) (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH
94.155	18.3	18.0	7.6
99.313a	36.7	37.0	18.0
99.313b	14.1	12.7	5.6
99.314	42.5	-	-
99.315	44.0	42.3	23.0

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.

Aliquantula 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 this species. This is the earliest record of the species and the first record from Australia.

Genus AUSTROTHYRIS Allan, 1939

Type Species

Waldheimia gambierensis Thomson, 1918

Remarks

Hiller and MacKinnon (in press) placed *Austrothyris* in the subfamily Stethothyridinae due to thickenening of shell in the posterior cardinal area.

Austrothyris grandis (Tate, 1880)

Figure 4.25 G-I, 4.26 A-E

Table 4.38

1865 *Waldeimia grandis* Tenison-Woods p. 2, pl. I, fig A-B.

1876 *Waldeimia gambierensis*; R. Etheridge junior. p.19, pl. II, figs 4 a-d.

1880 *Waldheimia grandis*; Tate, pp. 152-153, pl. XI, figs 3-4.

1927 *Magellania grandis*; Thomson, p. 301.

1939 *Austrothyris grandis*; Allan, pp. 239-240, pl. XXIX, fig 1-3, XXX, fig 4.

Material Examined

Eucla Basin: F6109/4, Madura - 12.8 Km North Cave; WAM 62.158, Swallow Cave, Cockelbiddy Station; Wilson Bluff Limestone, Middle Eocene.

Ascot Formation: WAM 86.1605 Jupp's Bore, West Gingin; 73.179 Kowalski's Bore, Gosnells, Ascot Formation, Perth Basin, Late Pliocene.

WAM 71.887 Thompson Lake; 73.220 Australind; 76.256, 948, 949, 1038, 1040, 77.3798, 78.2775 Paulik's Bore, Jandakot; 72.1388, 1728, 2054, 2056, 2267 Cement Works Bore, Jandakot, Ascot Formation, Perth Basin, Early Pleistocene.

Description

Exterior. Incomplete specimens, shell medium-sized (greatest part 22 mm long). Biconvex. Smooth, growth lines distinct, finely and densely punctate. Cardinal margin curved with deeper curve under umbo. Umbo stout, beak straight to slightly suberect; beak ridges rounded. Foramen large (18 per cent. of greatest length available), mesothyridid, circular, bevelled. Deltidial plates conjunct. Palintrope narrow, convex; symphytium striated horizontally, ridges on either edge.

Dorsal valve. Convex, ovate, 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. Ventral valve: Pedicle collar sessile, complete, does not extend into valve. Hinge teeth roundly rhombic, pointing posteriorly, leading edge slightly concave, flush with lateral margin, no dental plates and bases not swollen. Diductor muscle scars kidney-shaped depressions either side of a low ridge.

Dorsal valve: Outer socket ridges thin and curve inwards to form dart with inner socket ridges over socket. Socket narrow, triangular. Shell thickened under

socket. Inner socket ridge and hinge plate fused, curve slightly towards socket. Join between outer hinge plate and crural base "V" shaped, fused to hinge plates and traceable to posterior of shell. Crural process triangular shape, crest inner most. Median septum thick at base posteriorly, thins anteriorly, blade-like. Posteriorly bifurcates, joining inner hinge plates to form septalium. Cardinal process a flattened cup, protuberant and angled towards ventral valve. Swollen rounded base of cardinal process extending into septalium. Adductor muscle scars triangular, sharp apex posteriorly, curved base anteriorly. No complete loop observed.

Table 4.38: Measurement of *Austrothyris grandis* (Tate, 1880) (in mm).

SPECIMEN	LENGTH	WIDTH
F6109/4	50.2	38.6
62.158	52.7	37.7

Remarks

Although the median septum does not appear to run fully into the septalium, there is a small ridge half way into the trough in some specimens. This may be consistent with either the median septum or the cardinal process support. The specimens are consistent with the descriptions of *Austrothyris grandis* (Tate, 1880) in all other respects. *A. grandis* was described from the Early Miocene of South Australia (Allan 1939). A small specimen (3.3 mm long) has a clear septalium and the septum rises at the anterior end which is just anterior to the midline. The deltidal plates are disjunct at this stage.

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 EPACROTHYRIS Hiller and MacKinnon (in press)

Type species

Waldhemia pectoralis Tate, 1880

Remarks

Allan (1940) suggested that for Australian species, *Stethothyris* was actually *Victorithyris*. Richardson (1980) reinstated *Stethothyris* based on the studies of the growth stages. MacKinnon *et al.* (1993) considered the name acceptable. In the latest examination of the genus, 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 their new genus *Epacrothyris*.

***Epacrothyris pectoralis* (Tate, 1880)**

Figure 4.26 F-I, 4.27 A-D

Table 4.39

1880 *Waldheimia pectoralis* Tate, p. 157, pl. VII, figs 1a-d.

1899 *Magellania pectoralis*; Tate, p. 253.

1918 *Stethothyris pectoralis*; Thomson, p. 25, pl. XVII, fig. 60.

1927 *Stethothyris pectoralis*; Thomson, p. 282.

1940 *Victorithyris pectoralis*; Allan, p. 292, pl. XXXV, fig. 3.

1970 *Victorithyris pectoralis*; Lowry, p. 67.

1980 *Stethothyris pectoralis*; Richardson, p. 43.

1996 *Stethothyris pectoralis*; Brunton *et al.*, fig. 16 A and B.

Material Examined

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, Late Middle Eocene, 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, Middle Eocene

Description

Exterior. Shell subcircular; medium to large to 62.9 mm long. Biconvex, ventral valvedeeper, depth to 79 per cent. shell length. Width to 87 per cent. 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 per cent. shell width; lateral valve edge bevelled, lateral margin convex with respect to dorsal valve; anterior commissure unisulcate, sulcus to 60 per cent. shell width. Umbo stout. Beak suberect to erect; beak ridges attrite. Foramen small, 2 per cent. shell length, round, permesothyridid; deltidal plates conjunct. Symphytium, striated longitudinally, raised under beak, concaved either side of raised area, takes up majority of interarea.

Interior. Ventral valve. Pedicle collar short, sessile, pedicle opening a narrow trough, 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 with swollen base posteriorly, fused to hinge platform. Adductor muscle scars shallow elongate trenches either side of septum. Cardinal process small deep rimmed trilobed cup.

Table 4.39: Measurements of *Epacrothyris pectoralis* (Tate, 1880) (in mm) of complete or nearly complete specimens.

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
67.201	-	37.9	28.3	94.138	43.1	32	26.6
69.231a	35.8	31	18.4	99.312	44.4	38.3	19.7
69.231b	-	32.2	19.7	UWA 16660	38.2	34.4	-
70.175	-	38.6	27.3	F68811/1-2	25.8 (part only)	36.0	-
94.128	44.9	33.3	-	F6814/1-10	31.0	-	-

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
94.129	-	39.9	28.0	F6113/1	62.9	49.0	36.1
94.133	-	34.5	-	F6816	44.4	30.9	27.5

Remarks

Epacrothyris pectoralis (Tate, 1880) has been described from Eocene Tortachilla Limestone, Blanche Point Cliff, Aldinga and Happy 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) described a specimen of this species from the Plantagenet Beds, Cape Riche, Western Australia.

***Epacrothyris sufflata* (Tate, 1880)**

Figure 4.27 E-G

Table 4.40

1880 *Waldheimia sufflata* Tate, pp. 157-8, pl. vii, fig. 3, pl. viii, fig. 4.

1899 *Magellania sufflata*; Tate, p. 253.

1927 *Stethothyris sufflata*; Thomson, pp. 73, 88, 282.

1940 *Victorithyris sufflata*; Allan, pp. 292-203, pl. XXXV, fig. 4.

1970 *Victorithyris sufflata*; Lowry, p. 67.

1980 *Stethothyris sufflata*; Richardson, p. 43.

Material Examined

Eucla Basin: F6829, Weebubbie Cave, , F6831, Wilson Bluff, 15.3 m below top of formation; F6830, Abrakurrie Cave; Wilson Bluff Limestone, Middle Eocene.

Remarks

Epacrothyris sufflata differs externally from *E. pectoralis* as 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.* No internal features were available for description.

Table 4.40: Measurements of *Epacrothyris sufflata* (Tate, 1880) (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH
F6829	47.1	38.9	31.0

Remarks

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

Family TEREBRATELLIDAE King, 1850

Subfamily BOUCHARDIINAE Allan, 1940

Genus BOUCHARDIELLA Doello-Jurado, 1922

Type species

Bouchardia patagonia Ihering, 1903.

***Bouchardiella cretacea* (Etheridge, 1913)**

Figure 4.27 H-L, 4.30 D-F

1913 *Magasella cretacea*; Etheridge, p. 16, pl. 2, figs 9-12.

1915 *Magadina cretacea*; Thomson, p. 399.

1952 *Bouchardiella cretacea*; Elliott, p. 9, pl. 2, figs 14-21.

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

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

Material Examined

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 3523, 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 to10 mm long. Biconvex, dorsal valve almost flat. Widest slightly anterior to mid-length, width 90 per cent. shell length in small specimens, 82 per cent. 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 per cent. shell width. Umbo truncated. Beak straight to slightly suberect; beak ridges sharp. Foramen small, 3 per cent. shell length, permesothyridid; deltidal plates conjunct. Symphytium triangular, striated, striations form obtuse angle in middle of symphytium.

Interior. Ventral valve. Teeth cyrtomatodont, groove near lateral margin, slightly buttressed to margin. Pedicle collar sessile. Diductor 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 adductor 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, slightly raised laterally.

Remarks

The description is consistent with that provided by Elliott (1952). A larger specimen (10 mm) was available giving some differences in general shape, a product of ontogeny. The majority of the numerous specimens are less than 5 mm in length.

Subfamily ANAKINETICINAE Richardson, 1991

Genus ANAKINETICA Richardson, 1987

Type Species

Terebratella cumingii Davidson, 1852

***Anakinetica breva* Richardson, 1991**

Figure 4.28 A-F

Table 4.41

1880 *Magasella compta* Tate, p. 162-163, pl. 10, fig 6a-e.

1991 *Anakinetica breva* Richardson, p. 35-36, fig. 2G-L.

Material Examined

Eucla Basin: 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 to17.4 mmin length. Ovate, greatest width at or near mid-length, width to 88 per cent. shell length. Biconvex, dorsal valve flatter, ventral valve carinate, dorsal valve with shallow sulcus, depth to 62 per cent. shell length. Shell smooth, very finely densely punctate, growth lines distinct, not prominent. Cardinal margin curved, to 75 per cent. shell width; lateral valve edge rounded, lateral margin sigmoidal; anterior valve edge bevelled, anterior commissure unisulcate, sulcus shallow, to 40 per cent. shell width. Umbo truncated. Beak

suberect, labiate; beak ridges rounded anteriorly, sharp posteriorly. Foramen small, 3.5 per cent. shell length, meso to permesothyridid. Palintropes narrow, symphytium with thickened ridge centrally, striated horizontally, low, wide, concaved.

Internal. Ventral valve. Hinge teeth triangular (deltidiodont), thick with slightly swollen bases, pointing anteriorly. Pedicle opening narrow with 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 trabecular, connecting bands widening distally. Cardinal process a cup with straight lateral walls, 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. Adductor muscle scars half moon shaped either side of median septum.

Table 4.41: Measurements of *Anakinetica breva* Richardson, 1991 (in mm).

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

Remarks:

The specimens accord well with Richardson's (1991) description and figures. Richardson described the cardinal margin as straight. Specimens examined herein varied from gently curved to nearly straight. The species has been 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.

Anakinetica recta Richardson, 1991

Figure 4.28 G-J

1991 *Anakinetica recta* Richardson, p. 33, fig 1. G-L.

Material Examined

Holotype

WAM 90.241 Paulik's Bore, Jandakot, Ascot Formation, Perth Basin, Early Pleistocene.

Paratypes

WAM 90.242-246 Paulik's Bore, Jandakot, Ascot Formation, Perth Basin, Early Pleistocene.

Other Material

Ascot Formation, Perth Basin, Late Pliocene. WAM 81.218 Number 1 Bore, Redcliffe State School; 86.965, 974 Iley's Bore Number 1; 86.1260, 1414 Iley's Bore number 2, Banjup; 87.183 Iley's Bore number 4 bore; 80.1092 Western Mining Corporation, Cataby; 64.5 number 5 bore, Gnangara; 66.918 number 8 bore, Gnangara; 77.921,922 Rando's Bore number 1; 77.1425, 1653, 1863, 1864, 2077, 2926, 3210 Rando's Bore number 2, Thornlie; 83.2411 Humfrey's Bore; 85.1009 Cameron's Bore; 94.1280 Larsen's Bore, West Gingin; 74.1008 Gray's Bore, Gosnells.

Ascot Formation, Early Pleistocene. WAM 84.1273 Argentiers Bore, Canning Vale; 86.413 Iley's Bore, Forrestdale; 67.702 Adrian's Nursey Bore; 70.997 Schafer's Bore; 70.1754 Poletti's Bore; 75.1016,1025 Exploratory Bore; 71.141, 74.176, 376, 816, 76.255, 472, 706, 864, 947, 1081, 1123, 1163, 1223, 1252, 1408, 90.241-246 Paulik's Bore, Jandakot; 75.807 West Pinjarra.

Description

Exterior. Shell subcircular to ovate from 1.4 to 12 mm long. Biconvex, depth 35 to 49 per cent. shell length, ventral valve deeper than dorsal valve in majority of specimens. Width greatest at or anterior to mid-length, 66 to 98 per cent. shell length. Growth lines clearly visible, punctae very fine and dense. Cardinal margin gently curved to nearly straight, distinct umbo in dorsal valve; lateral valve edge

bevelled to round, margin concave with respect to ventral valve; anterior valve edge bevelled, anterior commissure unisulcate. Umbo strong truncated. Beak straight to incipiently suberect; beak ridge sharp to gently rounded. Foramen small in large specimens, 3 per cent. shell length, permesothyridid. Palintrope high, wide, concave, symphytium striated longitudinally.

Interior. Ventral valve. Hinge teeth triangular up curved, grooved at union with lateral margin, heavily buttressed to margin; no dental plates. Pedicle trough narrow between thickened ridges lateral margin walls. Muscle scars short, kidney-shaped, separated by low septum.

Dorsal valve. Outer socket ridges insignificant. Sockets triangular, no roof. Inner socket ridge fused to crural base and swollen, buttressed to valve floor. Narrow shallow groove between crural base and swollen united hinge plates which form a raised septalium. Crura thin, convergent. Median septum curved upward anteriorly, low posteriorly uniting at base to septalium, thin. Remnants of loop on anterior of median septum comprised of two connecting bands, one lower than the other. Adductor muscle scars short, elongate kidney shaped, deep. Valve floor thickened. Cardinal process a small deep depression within thin extensions of inner socket ridge.

Remarks

The material studied contained the type specimens and 324 others. The greatest width appears to be at the mid-length in the more elongate specimens but posterior to it in the more sub-circular specimens. The dorsal valves are very convex exteriorly. When standing alone, they are asymmetrically balanced, with the thickened posterior weighed downwards, the thin anterior upwards. Many specimens are broken towards the anterior where there is no lateral thickening. The concentric growth lines are clearly visible and close together. Curvature of the dorsal valve varies from strongly convex to almost flat. This curvature is not size dependent, as both the larger (up to 13 mm) and the smallest (2 mm) can be deeply curved or nearly flat. Those that are flattest are more sub-circular. The foramen is very small and does not change size greatly with ontogeny being 15 per cent. (0.3 mm diameter) of shell length in small specimens and 3 per cent. (0.4 mm in diameter) of shell

length in the largest. The beak ridges are roundly sharp, and the beak gives the appearance of being notched where the foramen cuts the ridge. The specimens range over both the older and younger Ascot Formation and thus range from Late Pliocene to Early Pleistocene in age (Kendrick *et al.* 1991).

Genus ADNATIDA Richardson, 1991

Type species

Magasella deformis Tate, 1880

Adnatida gnangarensis Richardson, 1991

Figure 4.28 K-Q, 4.29 A, B

1991 *Adnatida gnangarensis* Richardson, p. 41, fig. 5A-F

Material Examined

Holotype

WAM 90.247 Mines Department Bore N° 5, Gnangara, , Ascot Formation, Perth Basin, Late Pliocene.

Paratypes

WAM 90.248,249 Mines Department Bore N° 5, Gnangara, , Ascot Formation, Perth Basin, Late Pliocene.

Other Material

WAM 64.5, 90.247 Mines Department Bore N° 5, Gnangara; 73.132 Kowalski's Bore, Gosnells; 77.1425 Rando's Bore, Thornlie, Ascot Formation, Perth Basin, Late Pliocene.

Description

Exterior. Shell 2 mm to 20 mm long. Ovate. Biconvex, dorsal valve flatter than ventral valve, depth to 56 per cent. shell length. Widest at mid-length or anterior to it, width to 71 per cent. shell length. Growth lines numerous, distinct, punctae fine and dense. Cardinal margin relatively narrow to 30 per cent. shell length, strongly curved; lateral valve edge rounded, lateral margin sigmoidal; anterior commissure edge bevelled, margin unisulcate. Beak sharp, incurved; beak ridges rounded.

Foramen small, 2 per cent. shell length, permesothyridid. Symphytium high, triangular, concaved.

Interior. Ventral valve. Hinge teeth deltiodont with posterior vertical groove and swollen bases, strongly buttressed to margin. Semicircular recess between teeth and valve floor. Pedicle trough very narrow. Diductor muscle scars elongated thin kidney-shaped. Thin low median ridge arising at mid-length and extending to anterior margin.

Dorsal valve. Outer socket ridges wide. Socket ovate, floor swollen, strongly thickened to valve base. Inner socket ridges fused to swollen crural base and overhanging socket slightly. Septalium indistinguishable from swollen crural bases. Cardinal area united with thin cleavage to septum. Median septum blade-like, bifurcates narrowly posteriorly. Crural process high, slightly converging, triangular with sharp point. Loop 71 per cent. of shell length, teloform (Magallaniiform) and terminates just anterior of anterior commissure, covered in calcite crystals. Connection with septum obscured. Adductor muscle scars large elongate, either side of median septum.

Remarks

Adnatida has also been described from the Eocene of South Australia (Richardson 1991). All specimens of *Adnatida gnangarensis* Richardson, 1991 came from bores of Late Pliocene age (Kendrick *et al.* 1991). One specimen has a deep cleft anterio-laterally primarily on the ventral valve resulting in a "dimple". This may be the result of differential growth after attack or due to being "squeezed" between substrate elements.

Genus MAGADINELLA Thomson, 1915

Type species

Magadinella woodsiana Tate, 1880.

Magadinella woodsiana (Tate, 1880)

Figure 4.29 C-G

Table 4.42

1880 *Magasella woodsiana* Tate, p. 163-164, pl. 10, fig. 3a-d.

1896 *Magasella compta*; Pritchard, p. 142-143.

1899 *Magasella woodsiana*; Tate, p. 256-257.

1915 *Magadinella woodsiana*; Thomson, p. 400-4002, fig. 13a-c.

1927 *Magadinella woodsiana*; Thomson, p. 277-278, fig. 92a-c.

1970 *Magadinella woodsiana*; Lowry, p. 67.

1991 *Magadinella woodsiana*; Richardson, p. 36, fig. 3A-F.

Material Examined

Bremer Basin: WAM , Nanarup Lime Quarry, Nanarup Limestone, Late Middle Eocene, 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, Middle 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, both valves to much the same degree, depth to 65 per cent. of shell length. Width greatest at mid-length, to 91 per cent. shell length, most to 75 per cent. 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 per cent. shell width; lateral valve edge bevelled to rounded in more elongate specimens, margin straight; anterior valve edge bevelled, anterior commissure gently to strongly unisulcate. Umbo truncated to 25 per cent. shell length. Beak suberect; beak ridges

rounded. Foramen permesothyridid to mesothyridid, round, medium sized to 5 per cent. shell length, slightly labiate, lip divided in some specimens. Symphytium high, wide, thick ridge centrally, concaved 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 and crura bases, plate 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 base with blade-like upper surface. Cardinal process rectangular cup, open posteriorly, broached by swollen socket ridges laterally, shallow triangle interiorly with posterior apex, swollen protuberant "knob" anteriorly. Adductor muscle scars in deep elongated trough either side of septum.

Table 4.42: Measurements of *Magadinella woodsiana* (Tate, 1880) (in mm).

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
68.324	16.6	12.6	-	68.323	15.2	11.7	-
68.323	16.2	13.6	9.8	68.323	13.0	10.2	7.4
68.323	9.3	8.7	4.7	66.1462	9.9	7.7	5.2
66.1462	9.9	8.0	4.7	62.161	16.7	13.9	9.1
62.161	14.2	9.7	-	65.691	20.2	15.5	13.2
65.691	14.0	11.3	7.0	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

SPECIMEN	LENGTH	WIDTH	DEPTH	SPECIMEN	LENGTH	WIDTH	DEPTH
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				

Remarks

Magadinella woodsiana (Tate, 1880) 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 (Late Middle Eocene) specimens are the oldest record of the species in Australia.

Family (indeterminate)

The following specimens have too few morphological features to place in an appropriate family or genus.

Indeterminate terebratulid genus 1

Figure 4.29 H-J

Material Examined

WAM 84.587 Giralia Range, Carnarvon Basin, Cashin Member, Cardabia Formation, Upper Paleocene to Lower Eocene.

Description

Exterior. Small specimen, 9.1 mm long and incomplete. Biconvex. Cardinal margin curved. Beak large, protuberant over dorsal valve, suberect; beak ridges attrite, extend to cardinal margin. Foramen large, mesothyridid. Symphytium semi-vertical; deltidal plates conjunct.

Indeterminate terebratulid genus 2

Figure 4.29 K, L, N, O

Material Examined

WAM 84.519, 534 Giralia Range, Carnarvon Basin, Wadera Member, Cardabia Formation, Upper Paleocene.

Description

Exterior. Shell small to 19 mm long, elongate ovate to sub-pentagonal. Biconvex, deepest posterior to mid-length, widest at anterior to mid-length. Cardinal margin strongly curved; lateral valve edges bevelled, margins straight to slightly convex with respect to dorsal valve; anterior commissure uniplicate. Shell smooth, growth lines indistinct. Beak protuberant, erect and stout; beak ridges slightly concaved, extend to lateral margin. Foramen large, 6.6 per cent. of shell length, submesothyridid; deltidal plates appear disjunct (possibly due to weathering).

Indeterminate terebratulid genus 3

Figure 4.29 M, Q, P

Material Examined

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 per cent. shell length. Width 71 per cent. shell length, widest at mid-length. Finely and densely punctate, growth lines distinct; multiplicate

anterior, 25 per cent. of shell width, 7 ribs per mm at anterior commissure. Cardinal margin wide extending to lateral margin, strongly curved; lateral valve edge steeply rounded, lateral margin straight to anterior boundary where it rises sharply; anterior valve edge rounded to squared, anterior commissure unisulcate, sulcus taking up whole margin, crenulate. Umbo stout, short, erect; beak ridges attrite. Foramen medium to large, 6 per cent. 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 of the deltidal plates may be a product of weathering.

Indeterminate terebratulid genus 4

Figure 4.29 R, S

Material Examined

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 producing a centrally raised triangular platform with the 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 5

Figure 4.30 A-C

Material Examined

WAM 76.2329, Molecap Hill, Gingin; 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 per cent. shell length. Width greatest anterior to mid-length, 93 per cent. 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 possibly conjunct. Symphytium concave.

Interior. No interiors available.

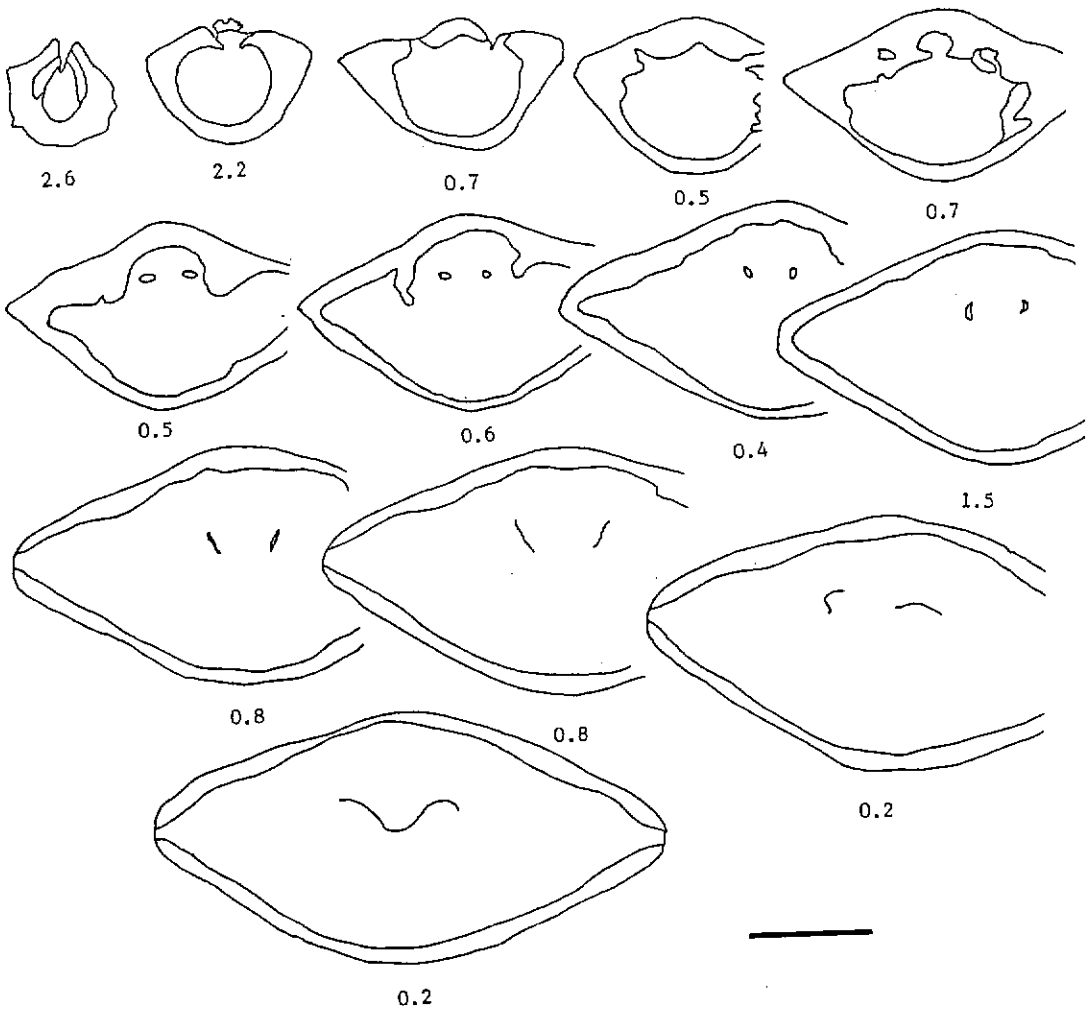


Figure 4.1: Serial grinding of *Giraliathyris mcnamarai* gen. et sp. nov. Measurements indicate distance from last section. Loop short and arched. Scale bar = 1 cm.

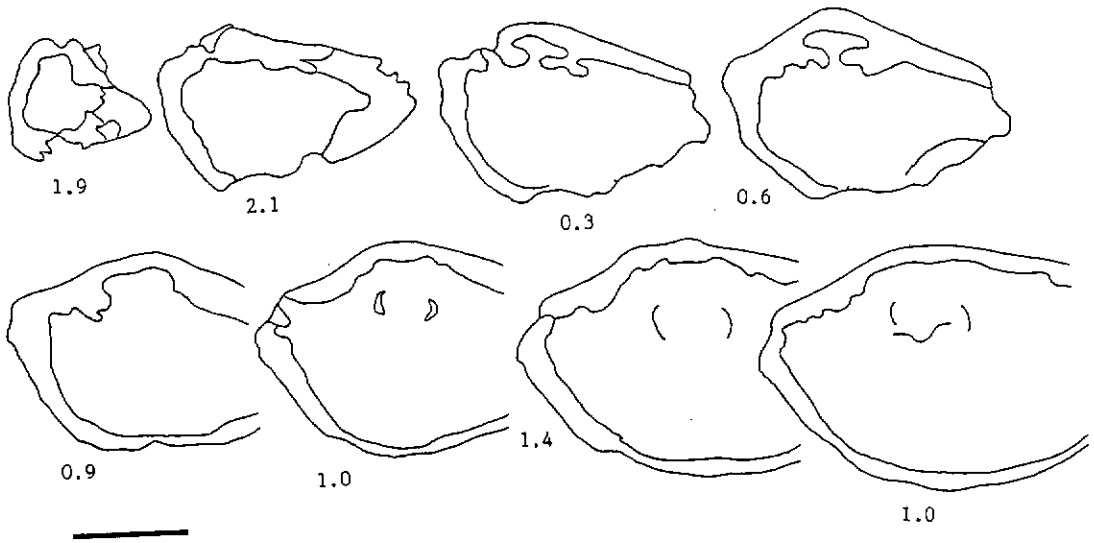


Figure 4.2: Serial grinding of *Giraliathyris kaitrinae* gen. et sp. nov. Measurements indicate distance from last section. Loop short and arched. Scale bar = 1 cm.

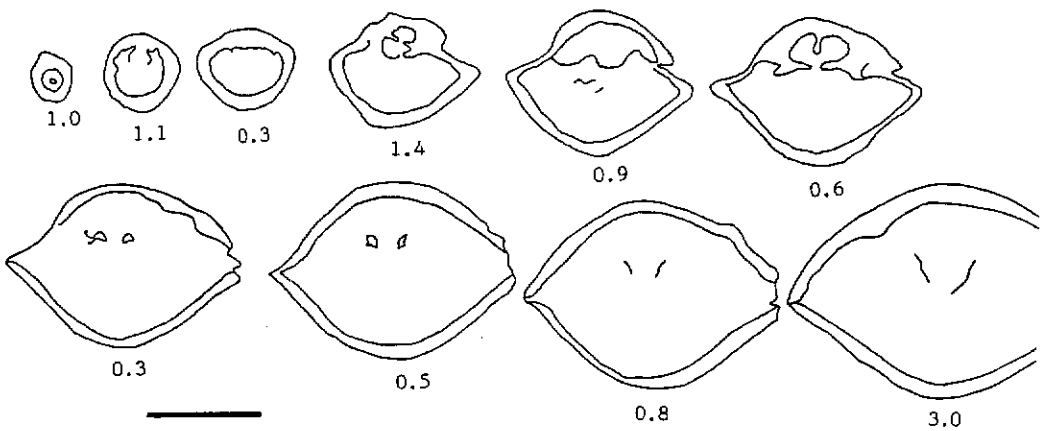


Figure 4.3: Serial grinding of *Giraliathyris jubileensis* gen. et sp. nov. Measurements indicate distance from last section. Loop short. Scale bar = 1 cm.

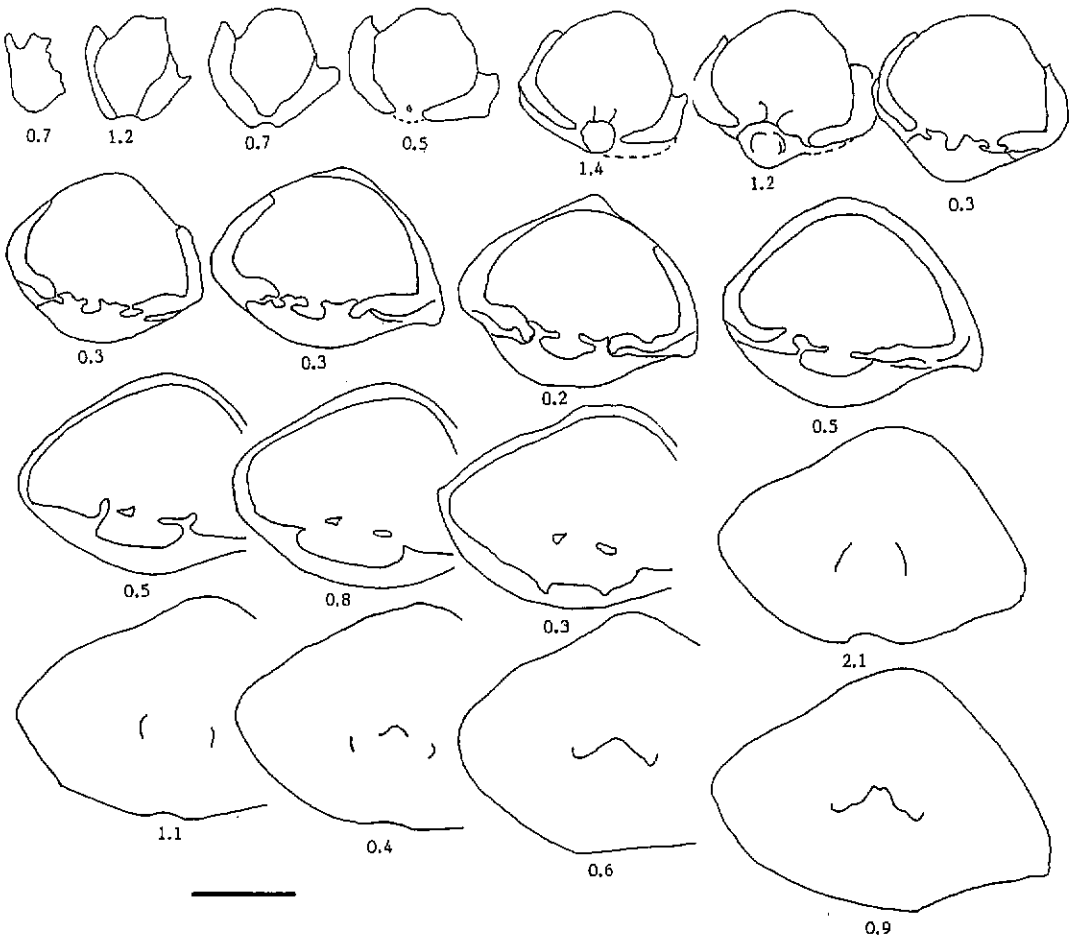


Figure 4.4: Serial grinding of *Liothyrella bulbosa* (Tate,1880). Measurements indicate distance from last section. Loop short and arched with median curvature. Scale bar = 1 cm.

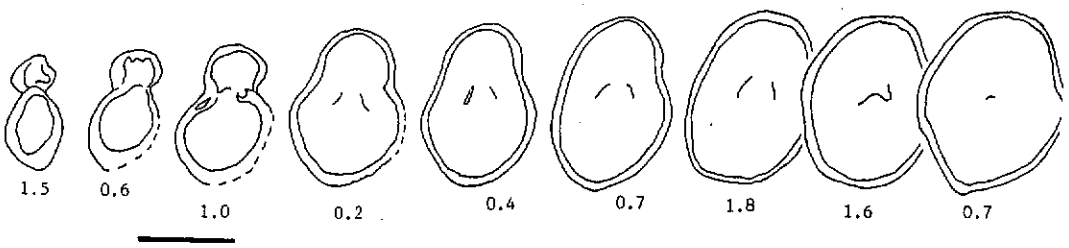


Figure 4.5: Serial grinding of *Liothyrella labiosus* sp. nov. Measurements indicate distance from last section. Loop short and arched. Scale bar = 1 cm.

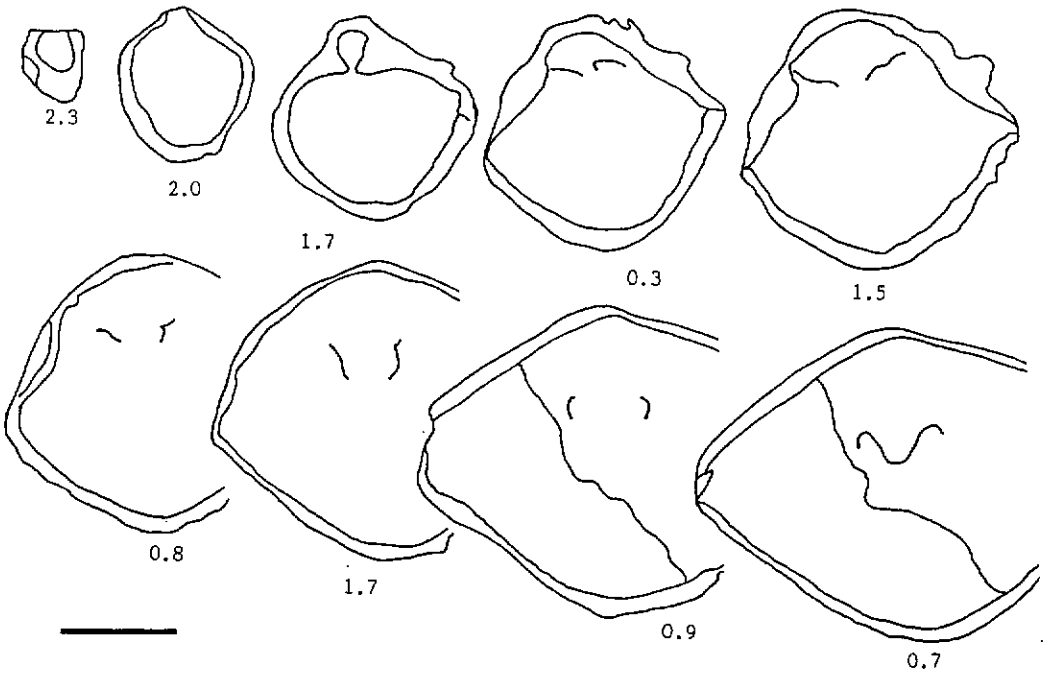


Figure 4.6: Serial grinding of *Liothyrella longorum* sp. nov. Measurements indicate distance from last section. Loop short and arched. Scale bar = 1 cm.

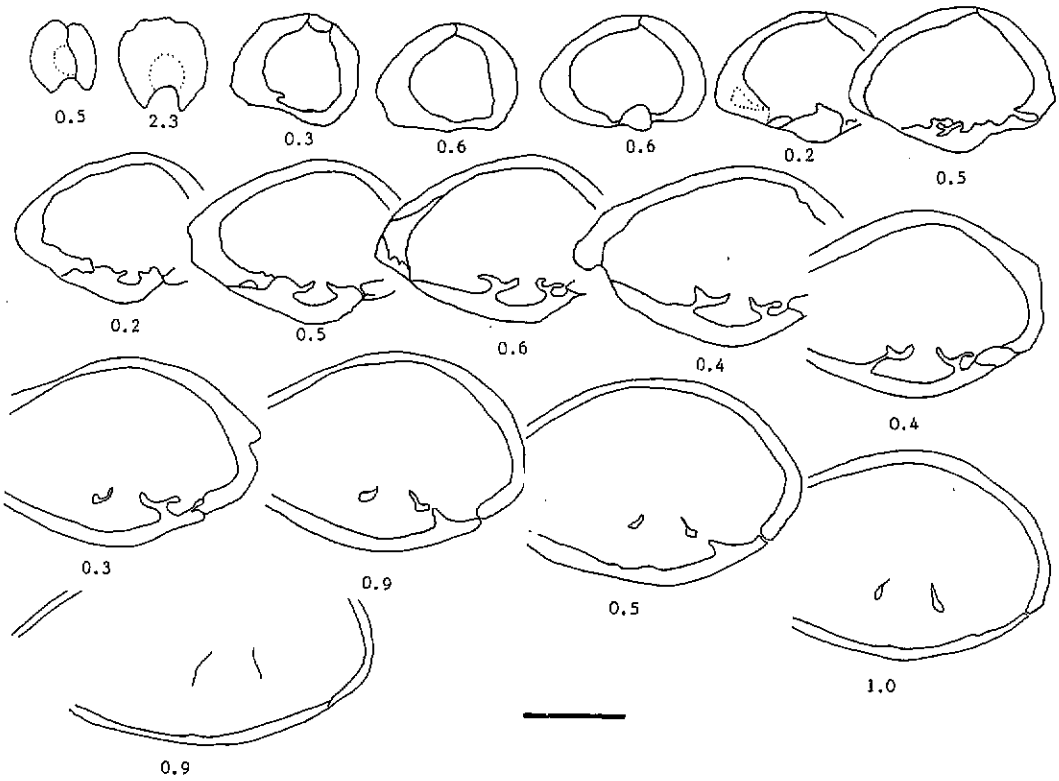


Figure 4.7: Serial grinding of *Liothyrella subcarnea* (Tate,1880). Measurements indicate distance from last section. Loop short. Scale bar = 1 cm.

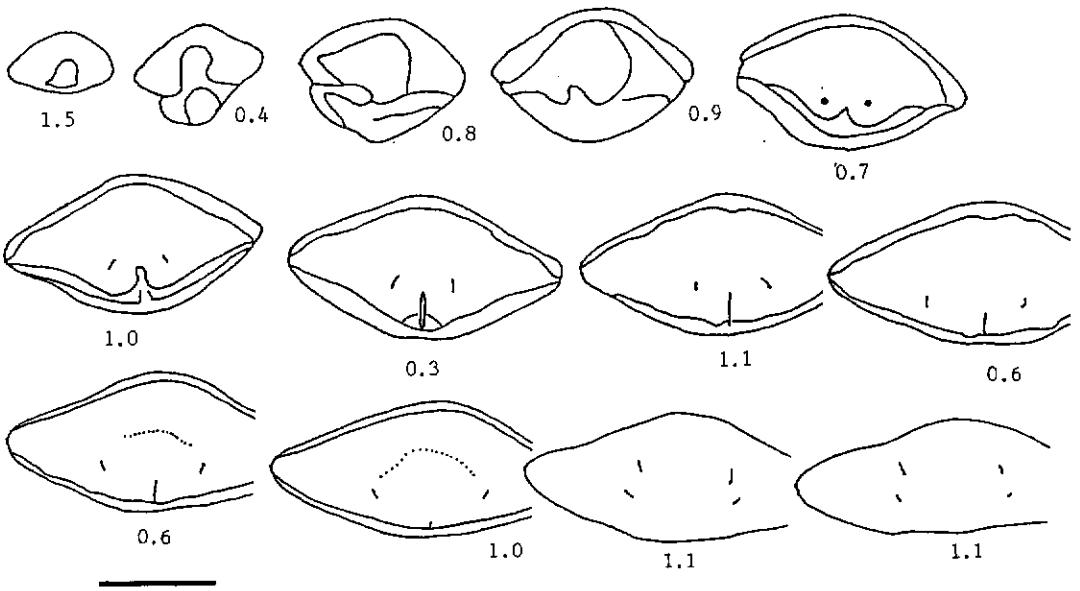


Figure 4.8: Serial grinding of *Victorithyris blakeorum* sp. nov. Measurements indicate distance from last section.. Shows median septum and ascending and descending loop elements. Scale bar = 1 cm.

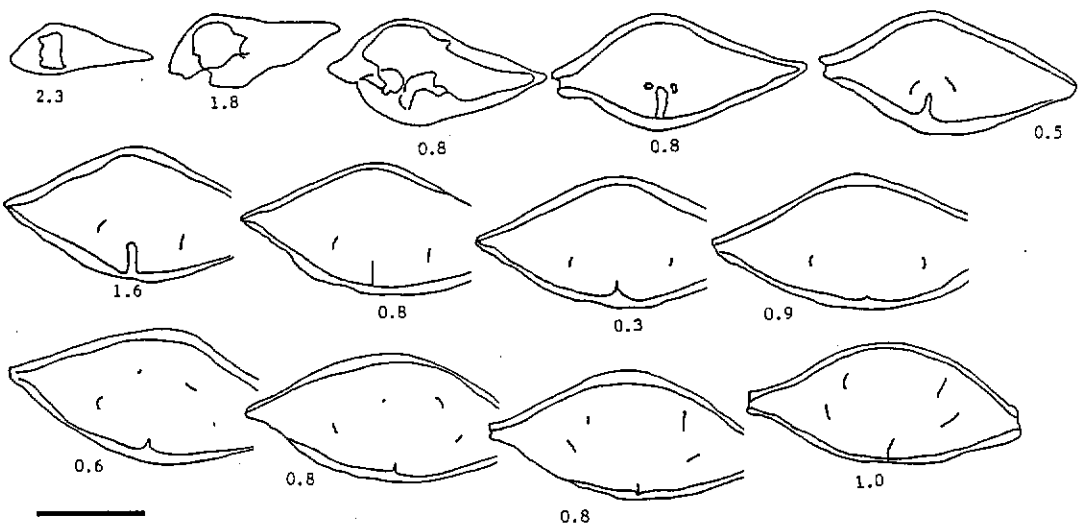


Figure 4.9: Serial grinding of *Victorithyris cardabiaensis* sp. nov. Measurements indicate distance from last section.. Shows median septum and ascending and descending loop elements. Scale bar = 1 cm.

Figure 4.10

A, B, *Westralicrania allani* Cockbain, 1967. **A**, WAM 85.583, ventral valve interior; **B**, WAM 94.714, ventral valve exterior. All x 5.

C-F, *Westralicrania zenobiae* Craig, 1997. **C**, **D**, WAM 94.30, paratype. **C**, ventral valve interior; **D**, ventral valve exterior; **E**, **F**, WAM 88.873. **E**, dorsal valve exterior; **F**, dorsal valve interior. All x 5.

G-K, *Basiliola* sp. **G**, **I**, **K**, WAM 84.584. **G**, dorsal valve exterior; **I**, anterior commissure; **K**, lateral margin; **H**, WAM 84.583, anterior commissure; **J**, WAM 84588, dorsal valve exterior. All x 5.

L-P, **S**, *Eohemithyris miriaensis* sp. nov. **L-N**, WAM 96.818, holotype. **L**, anterior commissure x 5; **M**, dorsal valve exterior x 4; **N**, lateral margin x 4.5; **O**, **P**, **S**, WAM 96.804, paratype. **O**, dorsal valve exterior x 5; **P**, lateral margin x 5; **S**, anterior commissure x 4.

Q, **R**, **T-V**, *Eohemithyris wildei* sp. nov. **Q**, WAM 70.1833, paratype, ventral valve interior; **R**, **T**, **V**, WAM 6705, holotype. **R**, dorsal valve exterior; **T**, anterior commissure; **V**, lateral margin; **U**, WAM 78.4356, paratype, dorsal valve interior. All x 4.5.

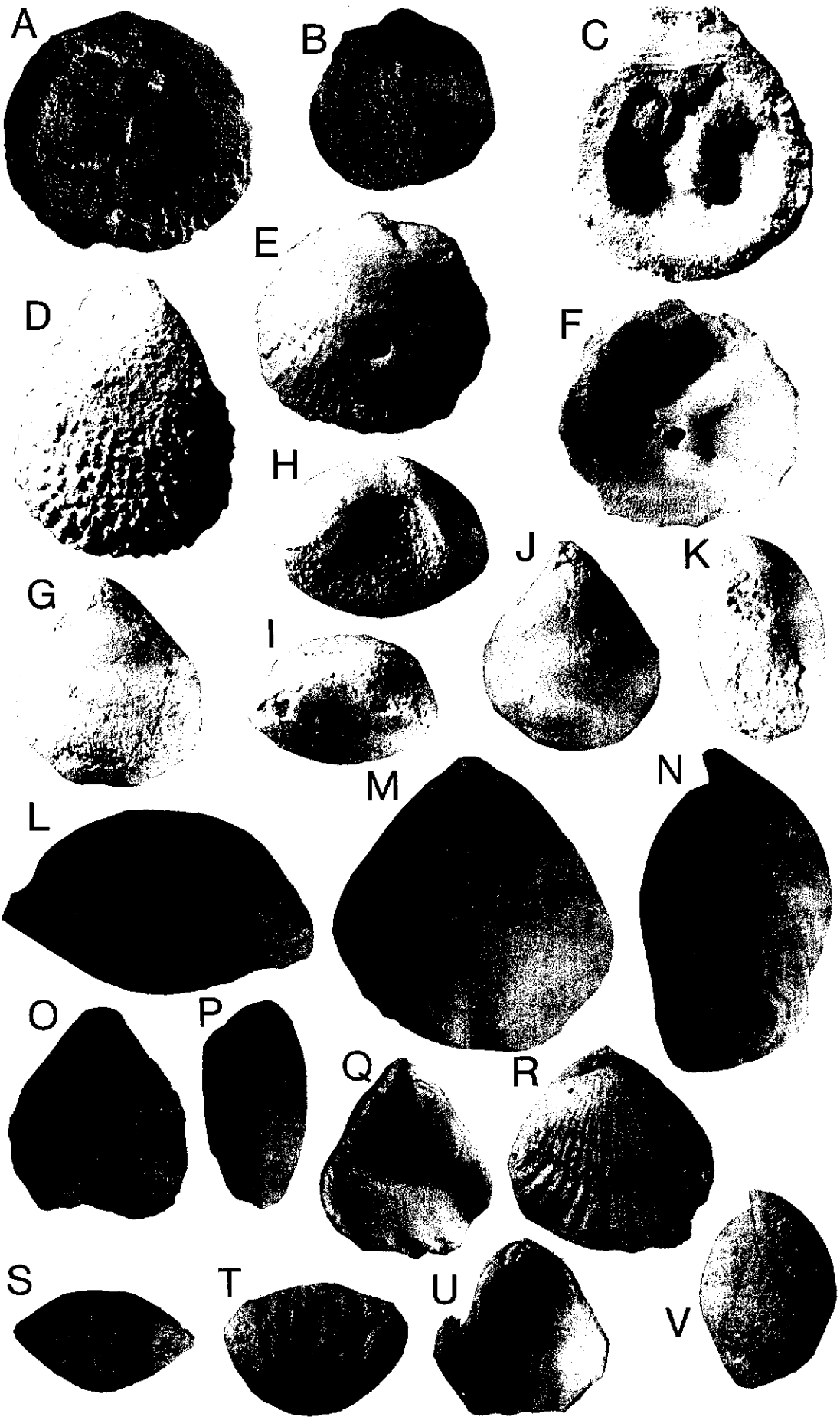

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Figure 4.11

A-E, *Protegulorhynchia meridionalis* Owen, 1980. **A-C**, WAM 82.1937. **A**, lateral margin x 5; **B**, dorsal valve exterior x 4.5; **C**, anterior commissure x 5; **D**, WAM 63.131, dorsal valve interior x 4; **E**, WAM 62.53, dorsal valve exterior x 4.5.

F-I, *Protegulorhynchia bevanorum* sp. nov. **F**, **H**, **I**, WAM 6706, holotype. **F**, lateral margin x 6; **H**, dorsal valve exterior x 4.5; **I**, anterior commissure x 4.5; **G**, WAM 74.1136, paratype, dorsal valve interior x 4.5.

J-N, *Tegulorhynchia boongeroodaensis* McNamara, 1983. **J**, WAM 80.152, dorsal valve interior x 4.5; **K-M**, WAM 80.1523. **K**, dorsal valve exterior; **L**, anterior commissure; **M**, lateral margin. All x 2.5; **N**, WAM 80.1497, ventral valve interior x 2.5.

O-S, *Tegulorhynchia hrodelberti* sp. nov. **O**, WAM 70.1836, paratype, dorsal valve exterior x 4.5; **P**, **R**, WAM 74.1300a, holotype. **P**, anterior commissure x 4.5; **R**, lateral margin x 4.5; **Q**, WAM 76.2271, paratype, ventral valve interior x 4.5; **S**, WAM 74.1300c, paratype, dorsal valve interior x 5.

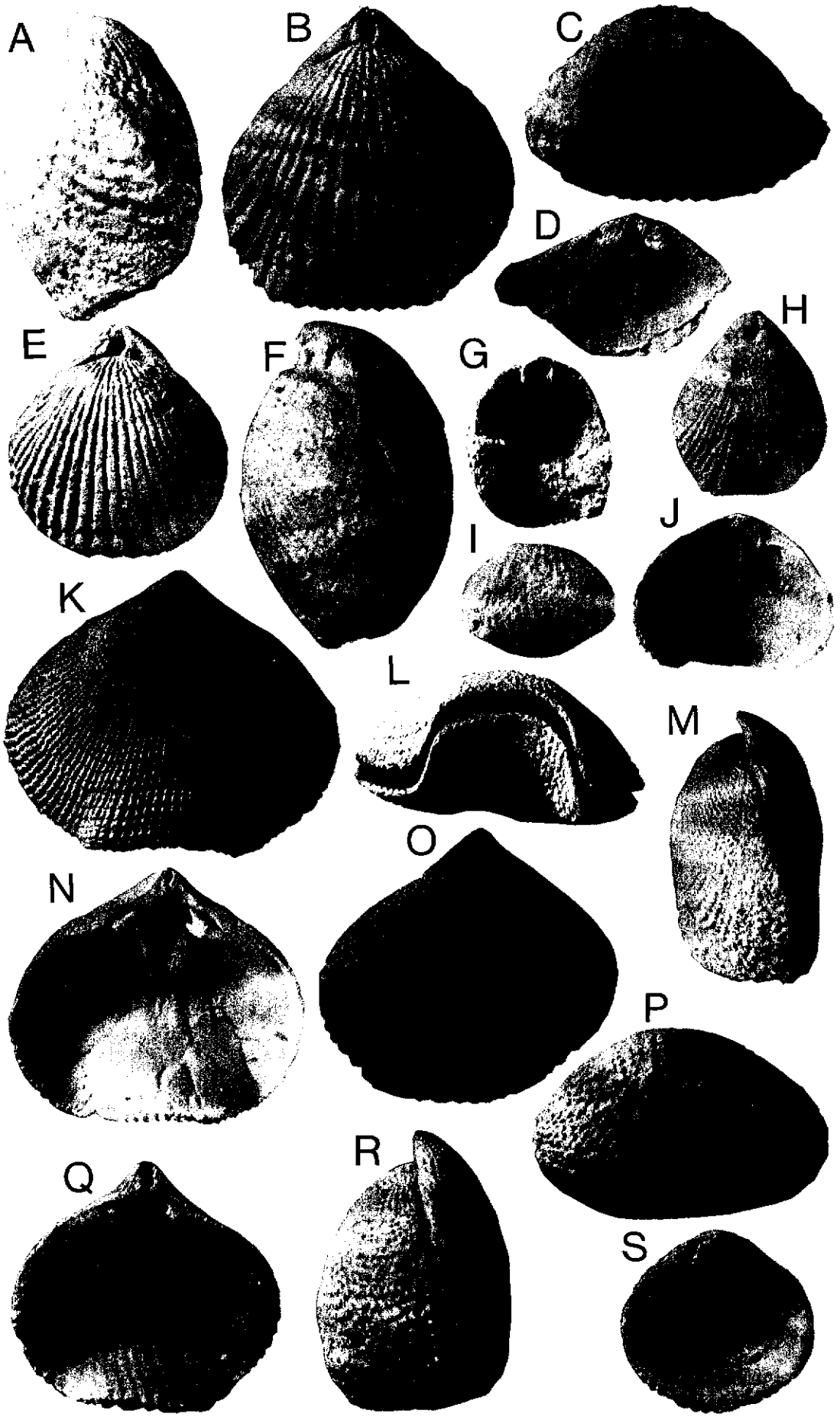
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Figure 4.12

A-F, *Giraliathyris mcnamarai* gen. et sp. nov. **A**, WAM 96.750, paratype, dorsal valve interior x 3; **B**, WAM 83.3039b, paratype, dorsal valve interior x 2; **C**, **E**, **F**, WAM 96.826, holotype. **C**, dorsal valve exterior; **E**, anterior commissure; **F**, lateral margin. All x 1.5; **D**, WAM 84.493, paratype, ventral valve interior x 1.5.

G-L, *Giraliathyris kaitrinae* gen. et sp. nov. **G**, **H**, **J**, WAM 84.547, paratype. **G**, dorsal valve exterior; **H**, lateral margin; **J**, anterior commissure; **I**, **K**, **L**, WAM 96.666, holotype. **I**, lateral margin; **K**, dorsal valve exterior; **L**, anterior commissure. All x 2.

M-O, *Giraliathyris jubileensis* gen. et sp. nov. **M**, WAM 84.603e, paratype, dorsal valve exterior; **N**, **O**, WAM 84.604e, holotype. **N**, anterior commissure; **O**, lateral margin. All x 1.5.

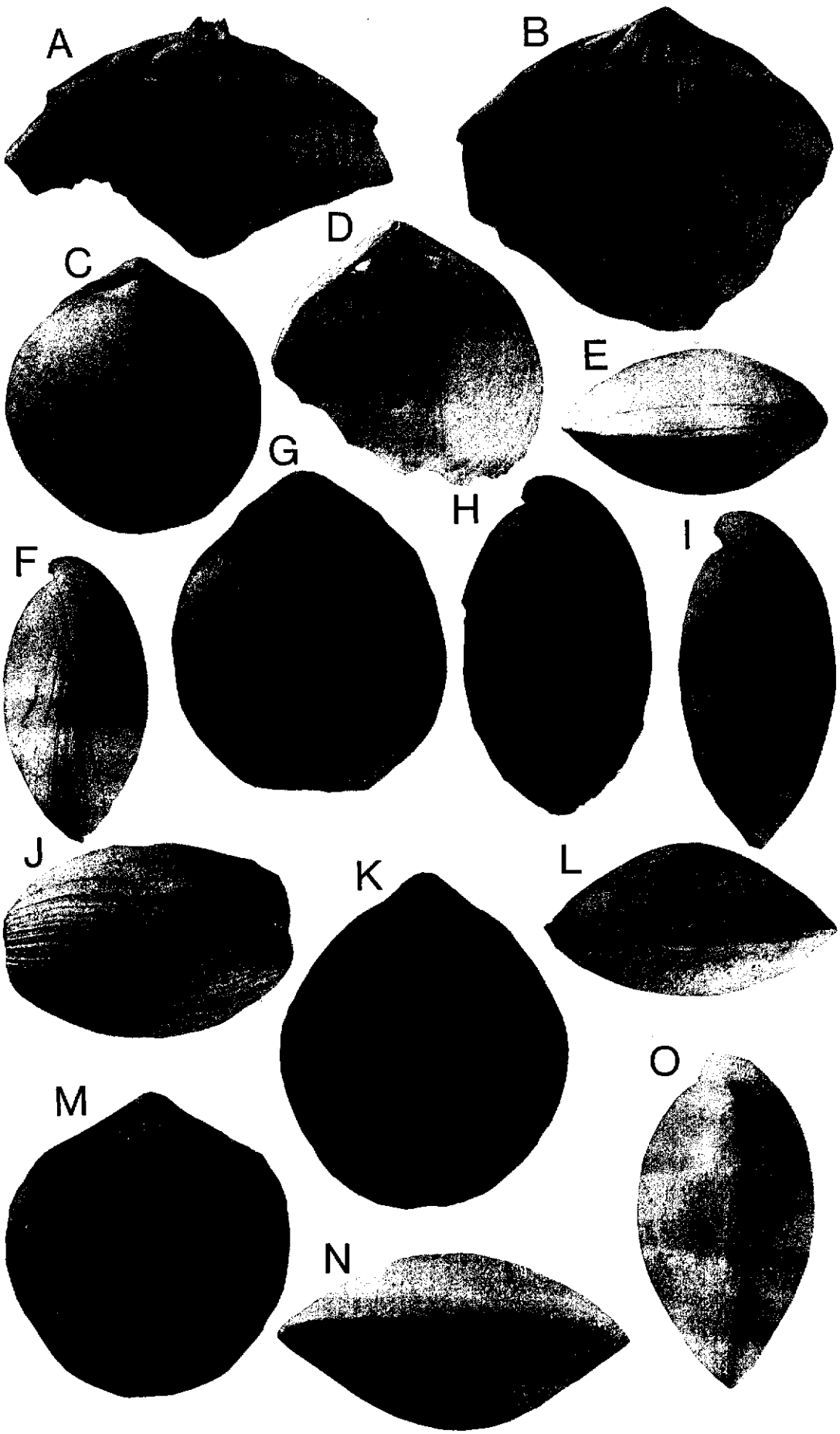
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Figure 4.13

A, *Giraliathyris jubileensis* gen. sp. nov. WAM 84.604e, x 1.4.

B-E, *Liothyrella archboldi* sp. nov. **B**, WAM 74.1267, paratype, dorsal interior x 4; **C-E**, WAM 96.865, paratype. **C**, anterior commissure x 2.5; **D**, lateral margin x 2.5; **E**, dorsal valve exterior x 3.

F-H, *Liothyrella brimmellae* sp. nov. **F**, WAM 78.948b, paratype, dorsal valve interior x 4; **G**, WAM 78.948a, paratype, ventral valve interior x 7; **H**, WAM 92.622, paratype ventral valve exterior x 2.5.

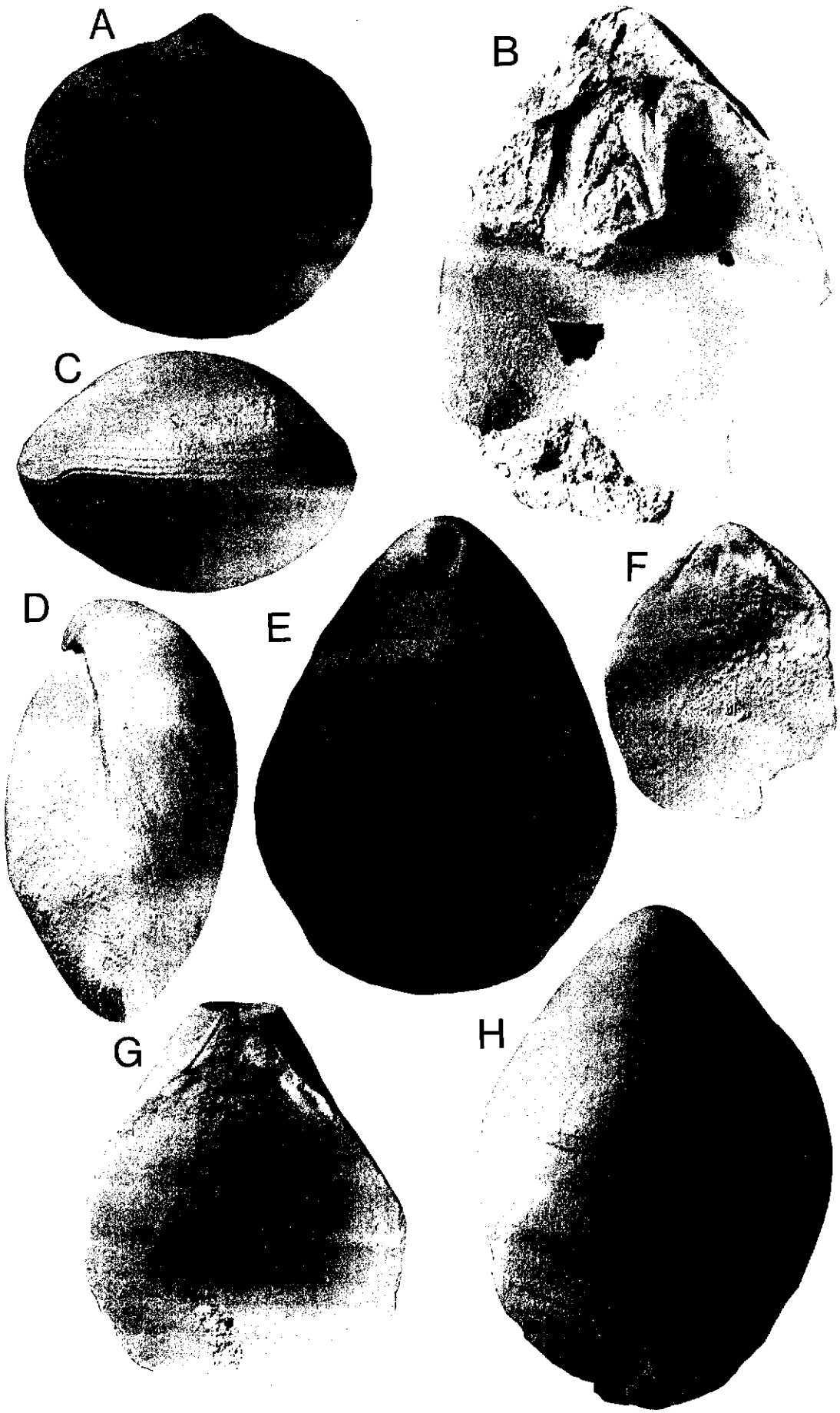
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Figure 4.14

A, **B**, **D**, **E**, *Liothyrella bulbosa* (Tate, 1880). **A**, **B**, F6810, **A**, dorsal valve exterior; **B**, lateral margin. Both x 1; **D**, F6812, dorsal valve interior x 1; **D**, F6830, anterior commissure x 1.

C, **F**, **G**, *Liothyrella labiosus* sp. nov. WAM 94.61, holotype. **C**, lateral margin x 2.5; **F**, anterior commissure; **G**, dorsal valve exterior. Both x 2.

H-K, *Liothyrella longorum* sp. nov. **H**, **J**, **K**, WAM 84.589, paratype. **H**, lateral margin x 2; **J**, anterior commissure x 2.5; **K**, dorsal valve exterior x 2; **I**, WAM 96.795, holotype, lateral margin x 2.

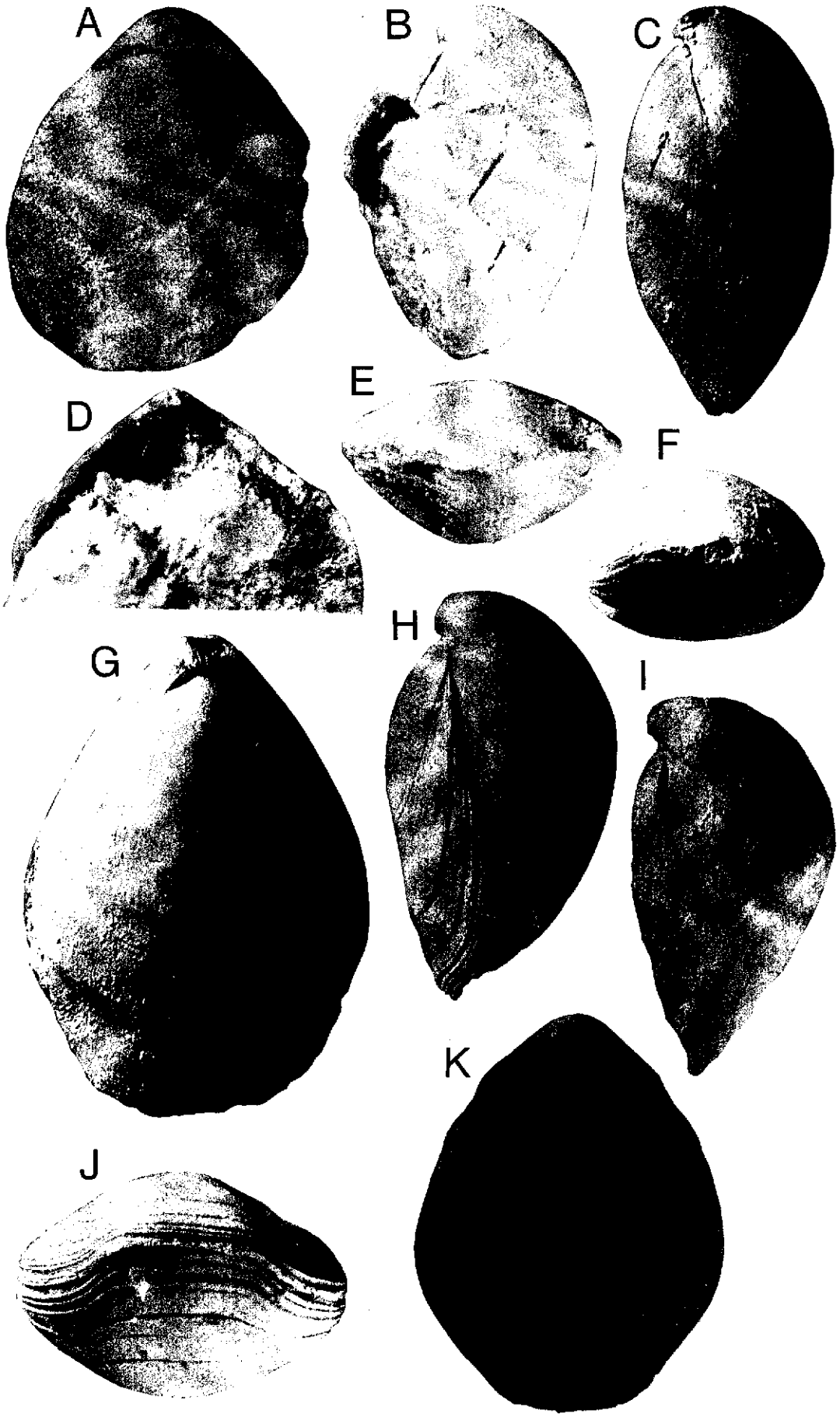
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Figure 4.15

A, **B**, *Liothyrella longorum* sp. nov. WAM 96.795, holotype. **A**, dorsal valve exterior; **B**, anterior commissure. Both x 2.

C-E, *Liothyrella subcarnea* (Tate, 1880). **C**, **D**, F6808/1. **C**, lateral margin; **D**, anterior commissure; **E**, F6807/1, dorsal valve. All x 1.5.

F-M, *Zenobiathyris mutabilis* gen and sp. nov. **F**, WAM 83.3115d, paratype, anterior commissure x 4; **G**, WAM 83.3148, paratype, lateral margin x 3; **H**, WAM 83.3011, paratype, ventral valve x 3; **I**, WAM 83.3115, paratype, dorsal valve interior x 4; **J**, **K**, WAM 80.885. **J**, dorsal valve exterior x 4.5; **K**, anterior commissure x 3.5; **L**, WAM 83.3115a, paratype, ventral valve interior x 3; **M**, WAM 83.311c, paratype, lateral margin x 4.5.

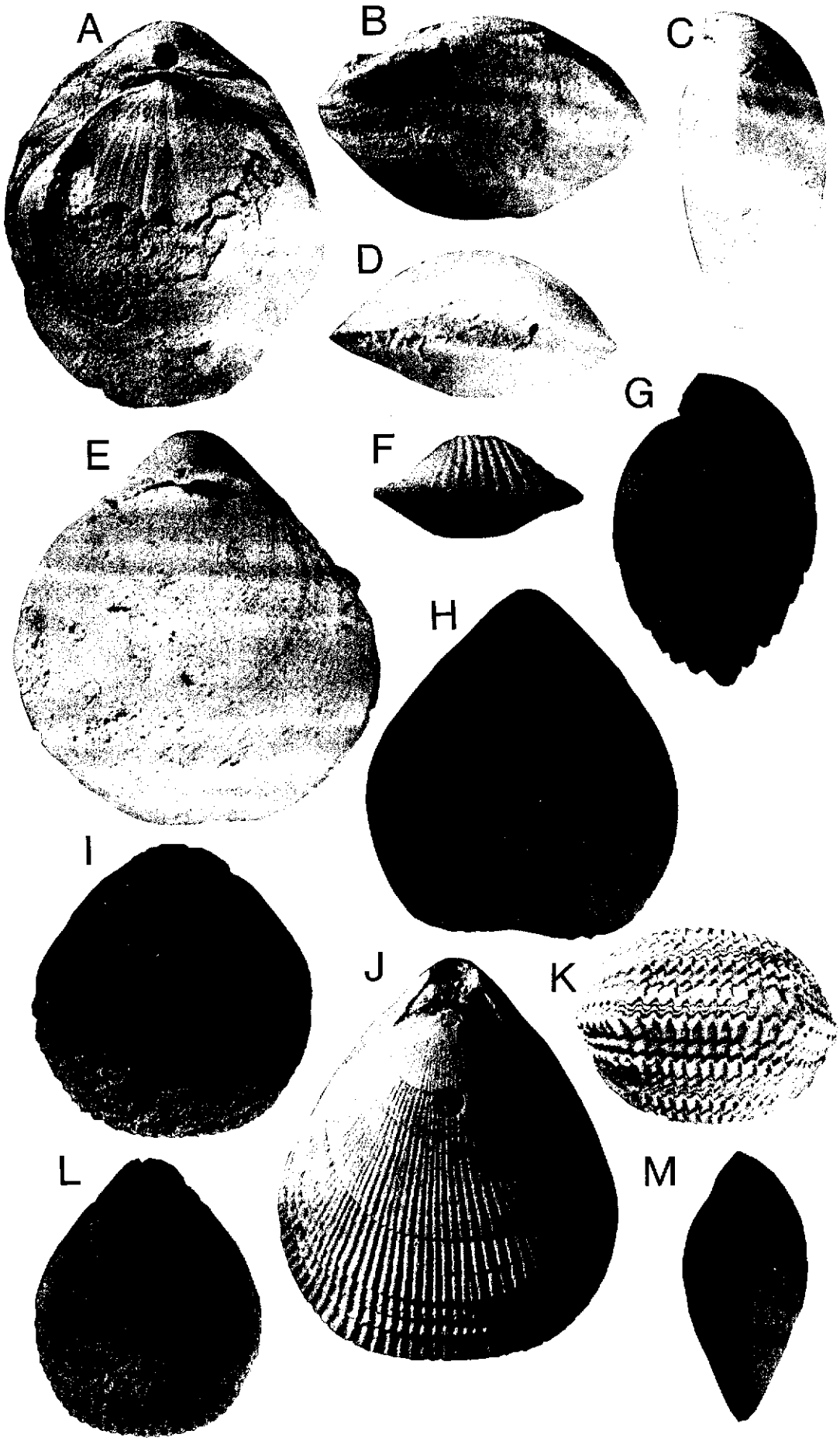
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Figure 4.16

A-F, *Zenobiathyris plicatilis* sp. nov. **A**, **B**, WAM 78.4396, paratype. **A**, dorsal valve exterior; **B**, ventral valve exterior; **C-E**, WAM 68.135, holotype. **C**, dorsal valve exterior; **D**, lateral margin; **E**, anterior commissure; **F**, WAM 76.2245, ventral valve interior. All x 5.

G-K, *Cancellothyris ascotensis* sp. nov. **G**, **I**, **J**, WAM 86.1606b, holotype. **G**, ventral valve exterior; **I**, ventral valve interior; **J**, anterior commissure; **H**, **K**, WAM 86.1606a, holotype. **H**, dorsal valve interior; **K**, dorsal valve exterior. All x 3.

L-N, *Cancellothyris cashinensis* sp. nov. WAM 84.592. **L**, dorsal valve exterior; **M**, anterior commissure; **N**, lateral margin. All x 2.

O-S, *Murravia triangularis* (Tate, 1880), **O**, F6836/3, ventral valve interior x 5; **P**, F68361, ventral valve exterior x 5; **Q**, F6836/2, anterior commissure x 4; **R**, F6836/2, lateral margin x 5; **S**, F6836/1, dorsal valve exterior.

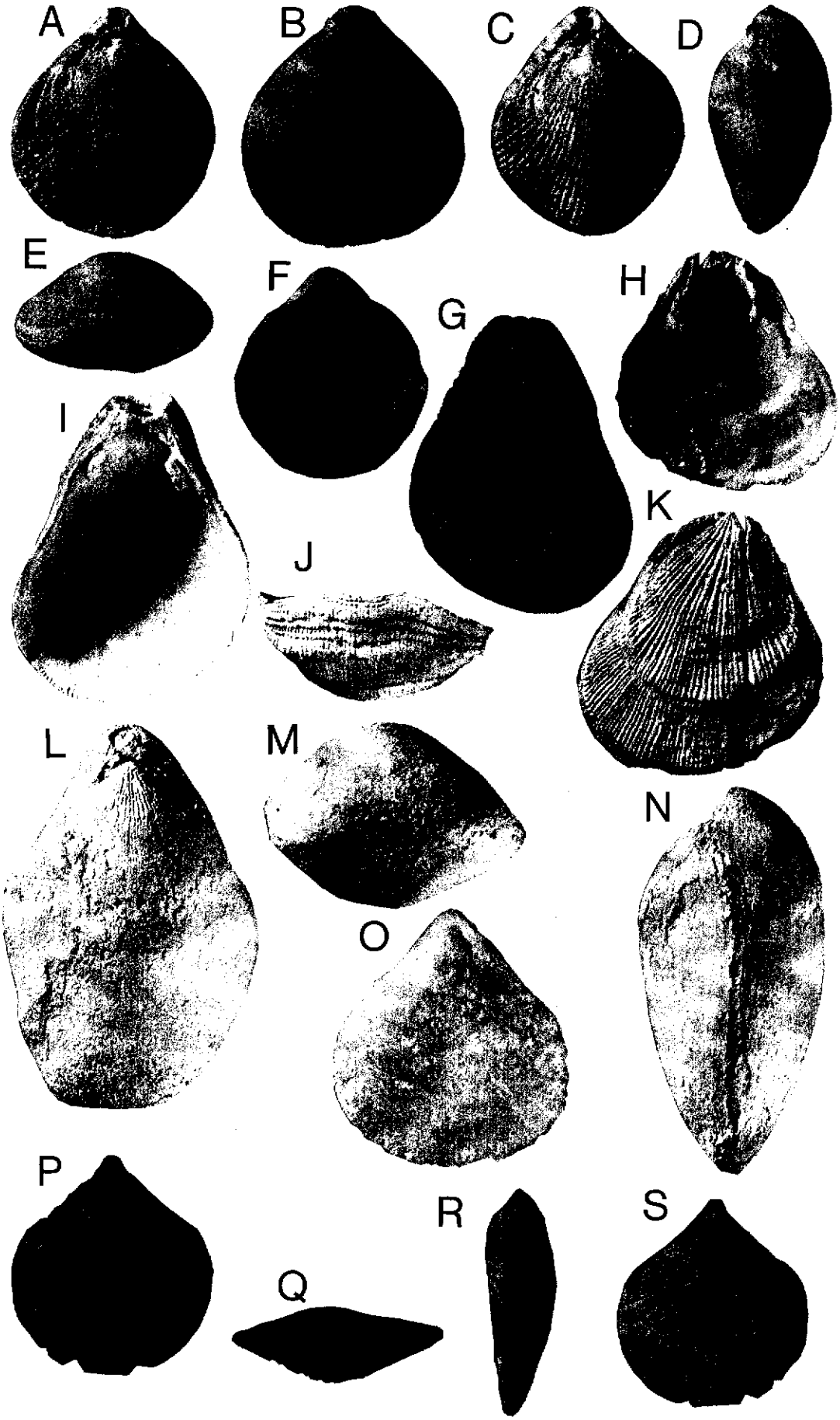
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Figure 4.17

A-F, H, *Terebratulina christopheri* sp. nov. **A, B, F, H**, WAM 88.852, holotype. **A**, ventral valve exterior x 2.5; **B**, dorsal valve exterior x 2.5; **F**, lateral margin x 2; **H**, anterior commissure x 2; **C**, WAM 94.127a, paratype, ventral valve interior x 2.5; **D**, WAM 94.127b, paratype, dorsal valve interior x 3; **E**, WAM 94.92, paratype, dorsal valve interior x 2.5.

G, I, J, K, M, *Terebratulina kendricki* sp. nov. **G, I, K**, WAM 73.310, holotype. **G**, lateral margin x 4.5; **I**, dorsal valve exterior x 4; **K**, anterior commissure x 4.5; **J**, WAM 96.834a, paratype lateral margin x 5; **M**, WAM 96. 834b, dorsal valve interior x 5.

L, N, O, *Terebratulina lindsayi* sp. nov. WAM 88126, holotype. **L**, lateral margin x 7; **N**, dorsal valve exterior x 5.5; **O**, anterior commissure x 5.5.

P-S, *Gisilina ovata* (Etheridge, 1913). **P-R**, WAM 79.2915a. **P**, anterior commissure x 5; **Q**, lateral margin x 5; **R**, dorsal valve x 8; **S**, WAM 79.2915b, ventral valve interior x 7.

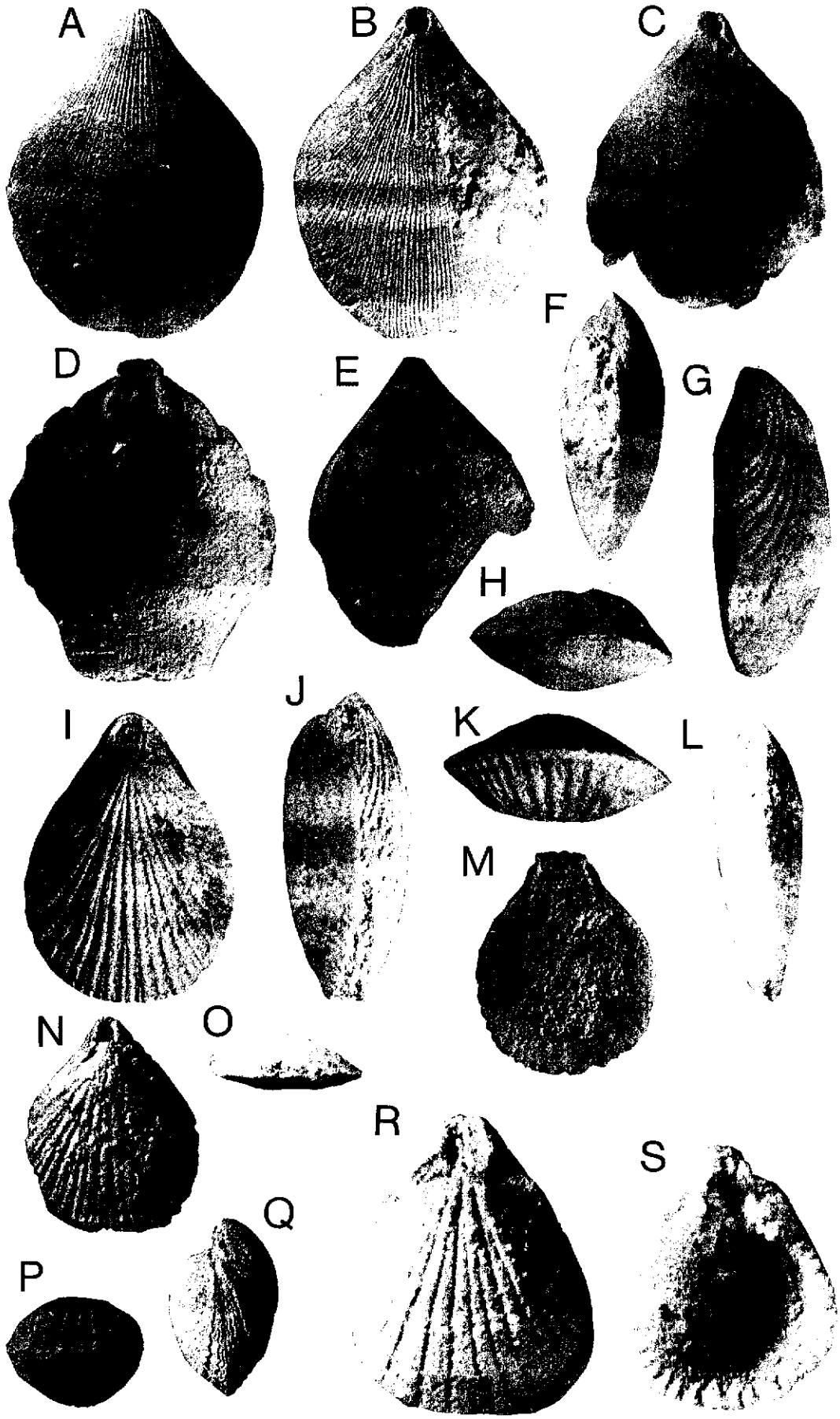
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Figure 4.18

A, **B**, **D**, **E**, **I**, *Inopinatarcula acanthodes* (Etheridge, 1913). **A**, **E**, **I**, WAM 78.4360. **A**, dorsal valve x 2.5; **E**, lateral margin x 2.5; **I**, anterior commissure x 3; **B**, WAM 77.3528, ventral valve interior x 2; **D**, dorsal valve interior x 3.

C, **F-H**, **J**, **K**, *Megerlina irenae* sp. nov. **C**, **F**, **H**, WAM 86.1604, holotype. **C**, lateral margin; **F**, dorsal valve exterior; **H**, anterior commissure; **G**, WAM 70.1629, dorsal valve interior x 8; **J**, WAM 78.4062a, paratype, (SEM) dorsal valve interior x 20; **K**, WAM 78.4062a, paratype, ventral valve x 8.

L, **M**, *Megerlina dorothyae*. WAM 71.1536. **L**, dorsal valve exterior; **M**, dorsal valve interior x 20.

N, *Gemmarcula doddsae* sp. nov. WAM 78.4196, holotype, dorsal valve exterior x 5.

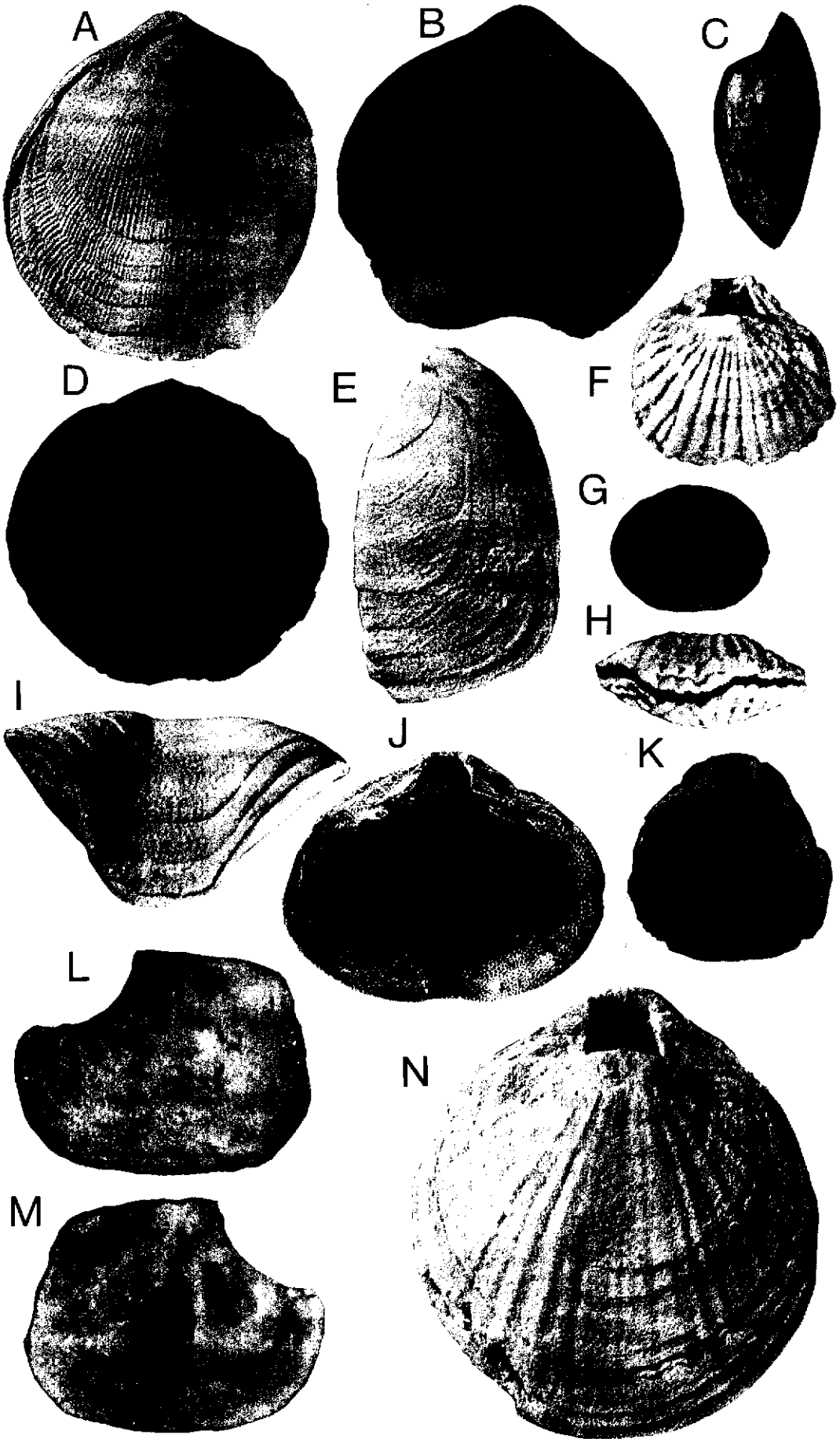
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Figure 4.19

A, **B**, *Gemmarcula doddsae* sp. nov. WAM 78.4196, holotype. **A**, dorsal valve interior; **B**, ventral valve exterior.

C-G, *Aldingia furculifera* (Tate, 1880). **C-E**, F6112/2. **C**, dorsal valve x 2.5; **D**, anterior commissure; **E**, lateral margin. Both x 2; **F**, **G**, F6851/1-7. **F**, dorsal valve interior; **G**, ventral valve interior. Both x 2.5.

H-K, *Paraldingia timi* sp. nov. **H**, WAM 96.755, paratype, dorsal valve exterior x 4.5; **I-K**, WAM 96.756, holotype. **I**, dorsal valve exterior; **J**, lateral margin, **K**, anterior commissure. All x 3.

L-N, *Kingena mesembrina* (Etheridge, 1913). **L**, WAM 74.1138c, anterior commissure. **N-M**, WAM 74.1138a. **M**, anterior commissure; **N**, lateral margin. Both x 3.5.

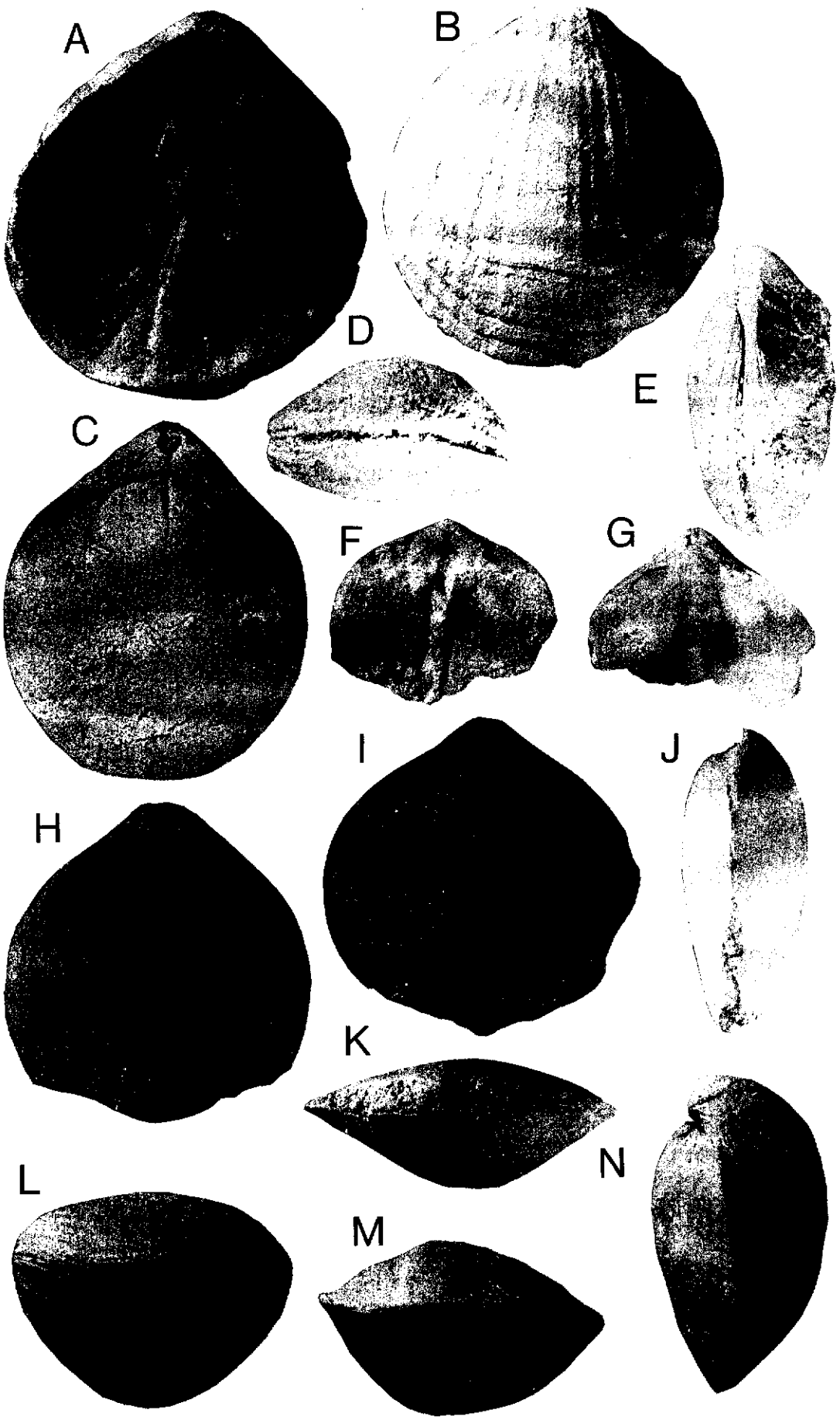
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Figure 4.20

A-G, *Kingena mesembrina* (Etheridge, 1913). **A**, WAM 74.1138d, dorsal valve exterior x 3.5; **B**, WAM 78.279b, ventral valve interior x 4; **C**, WAM 78.279b, dorsal valve interior x 4; **D**, WAM 74.1138c, lateral margin x 3.5; **E**, WAM 74.1138b, ventral valve x 3.5; **F**, WAM 3522, holotype, lateral view of dorsal interior x 5; **G**, WAM 74.1138a, dorsal valve exterior x 3.5.

H-L, *Diedrothyris johnstoniana* (Tate, 1880). WAM 94.142. **H**, dorsal valve exterior; **I**, lateral margin; **J**, anterior commissure. All x 2.

K-N, *Diedrothyris* cf *johnstoniana* (Tate, 1880). WAM 86.614a. **K**, anterior commissure; **L**, dorsal valve exterior; **M**, lateral margin; **N**, WAM 86.614b, anterior commissure. All x 2

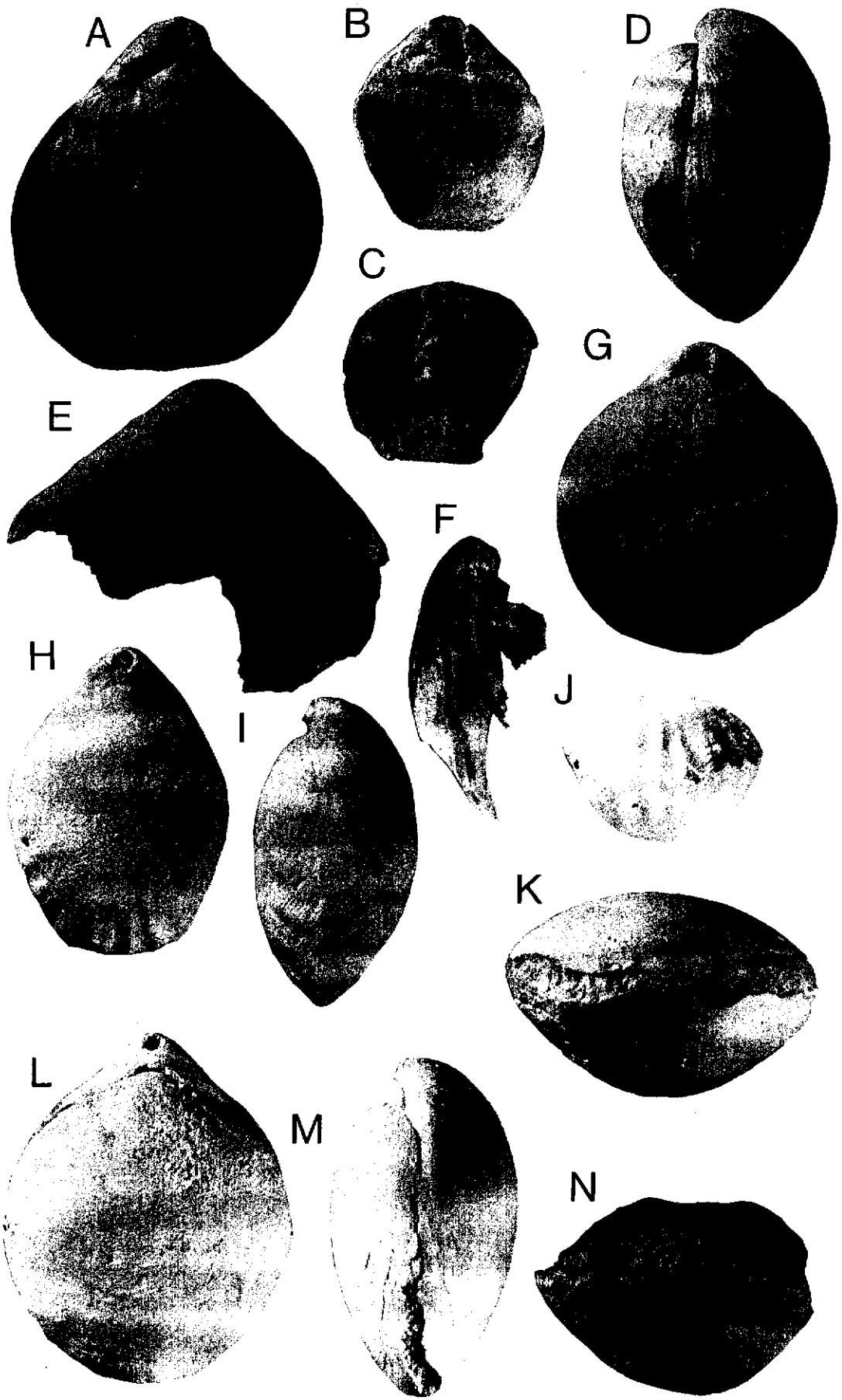
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Figure 4.21

A-C, *Diedrothyris plicata* Richardson, 1980. **A**, F6112/4, ventral valve exterior x 1.5; **B**, WAM 88.185, ventral valve exterior x 2; **C**, F6109/2, lateral margin x 2.

D-I, *Magellania flavescens* (Lamarck, 1819). **D**, **F**, **H**, WAM 78.3116. **D**, lateral margin; **F**, dorsal valve exterior. Both x 5. **E**, WAM 77.2675, dorsal valve interior x 4; **G**, WAM 76.257c, dorsal valve interior x 5; **I**, WAM 76.257b, ventral valve interior x 5.

J-N, *Victorithyris blakeorum* sp. nov. **J**, **N**, **O**, WAM 96.697, holotype. **J**, dorsal valve exterior x **3; N**, lateral margin x 2; ; **O**, interior commissure x 2.5; **K**, WAM 88.111a, paratype, ventral valve interior x 3; **L**, WAM 88.50c, paratype, dorsal valve interior x 3; **M**, WAM 88.111b, paratype, dorsal valve interior x 2.5.

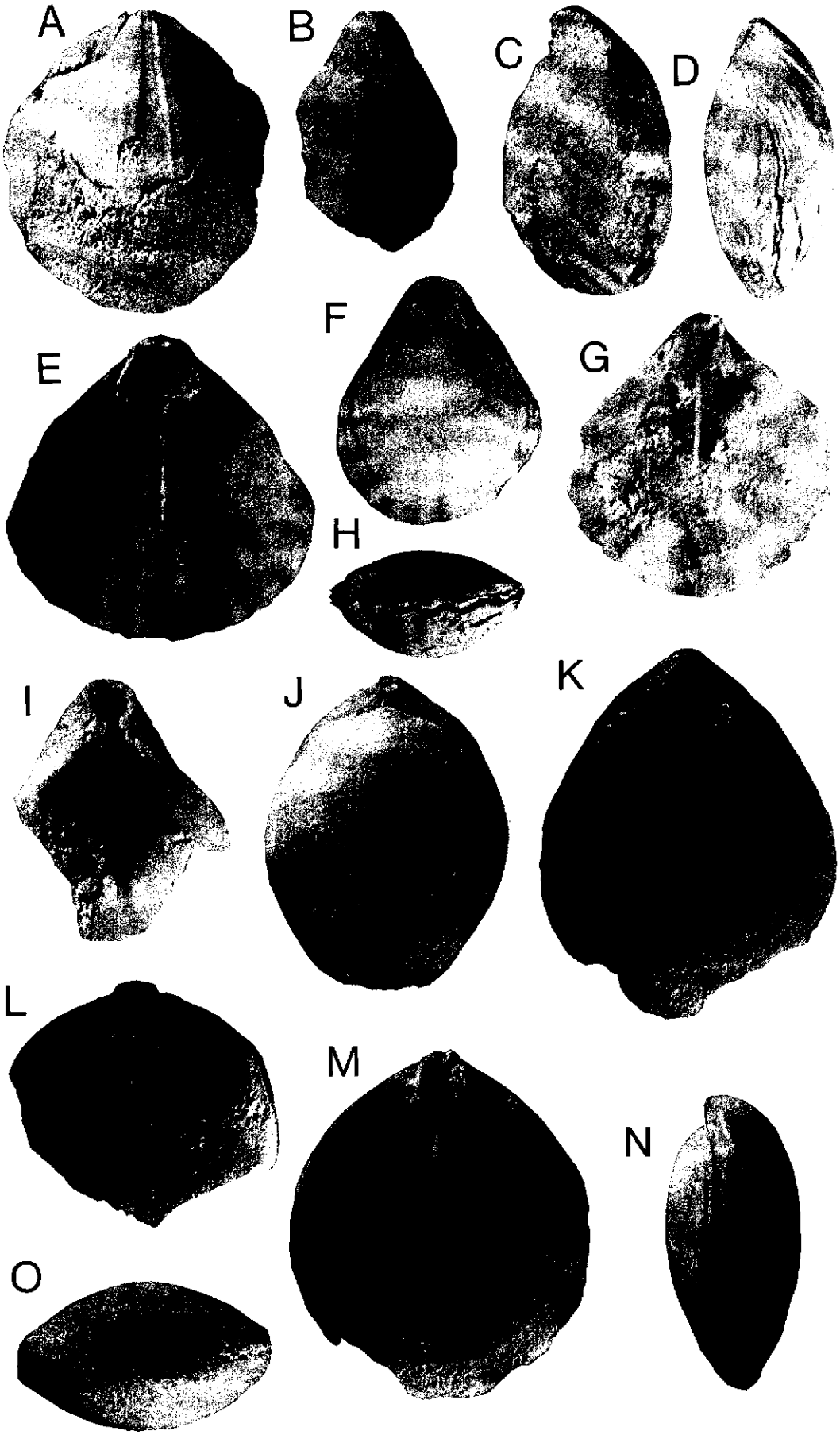
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Figure 4.22

A-D, *Victorithyris cardabiaensis* sp. nov. **A**, WAM 97.738, paratype, dorsal valve exterior; **B-D**, WAM 96.735, holotype. **B**, anterior commissure; **C**, lateral margin; **D**, dorsal valve exterior. All x 2.

E-I, *Victorithyris decapello* sp. nov. **E-G**, WAM 96.645, holotype. **E**, dorsal valve exterior; **F**, anterior commissure; **G**, lateral margin. All x 2; **H**, WAM 96.609, paratype, dorsal valve interior x 2; **I**, WAM 96.607, paratype, interior of cojoined valves x 2.5.

J-M, *Victorithyris divaricata* (Tate, 1880). **J**, F6112/2, dorsal valve exterior x 2.5; **K**, **L**, **M**, F6857. **K**, ventral valve exterior x 2; **L**, lateral margin x 2.5; **M**, anterior commissure x 2.

N-P, *Victorithyris garibaldiana* (Davidson, 1862). **N**, **O**, F6847. **N**, anterior commissure x 2; **O**, ventral valve x 2.5; **P**, F6848, dorsal valve exterior x 2.5.

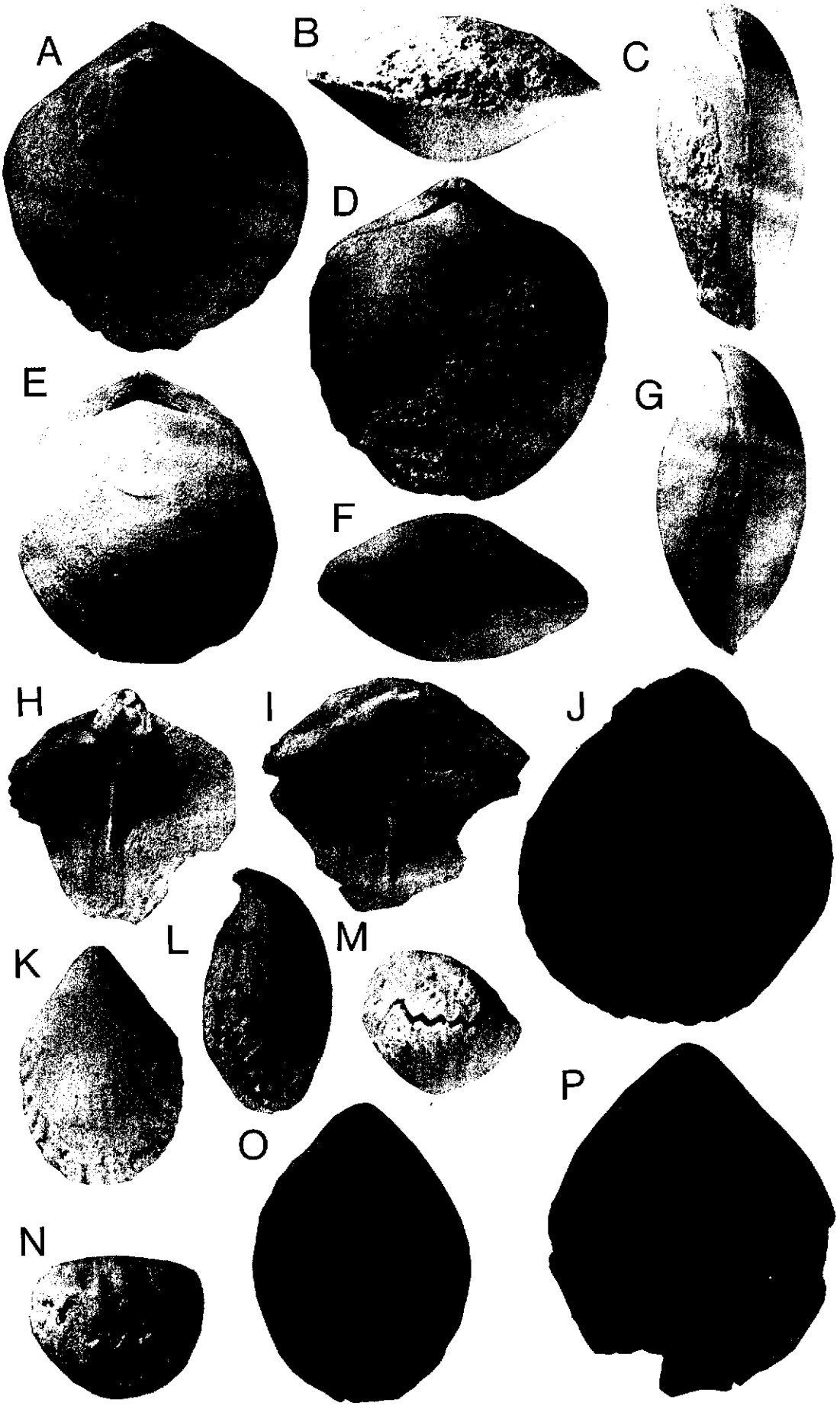
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Figure 4.23

A-D, *Victorithyris garibaldiana* (Davidson, 1862). **A**, F6847, dorsal valve exterior x 3; **B**, F6853, dorsal valve interior x 3; **C**, F6113/2, dorsal valve interior x 3; **D**, F6847, lateral margin x 2.5.

E-J, **N**, *Victorithyris tateana* (Tate, 1880). **E**, **H**, **J**, F6112/12a. **E**, dorsal valve exterior; **H**, anterior commissure; **J**, lateral margin. All x 2.5; **F**, F6814, dorsal valve interior x 4; **G**, F6112/12b, ventral valve interior x 2.5; **J**, WAM 94.164, ventral valve interior x 2.5; **N**, WAM 95.491

K-M, **O**, **P**, *Victorithyris tulkiensis* sp. nov. **K**, WAM 82.1717, paratype, part of dorsal valve exterior x 3; **L**, **M**, **O**, WAM 82.1711, holotype. **L**, dorsal valve; **M**, lateral margin; **O**, anterior commissure. All x 3; **P**, WAM 82.174, paratype, dorsal valve interior x 3.

Q, *Neothyris rylandae* Craig, 1999. WAM 82.2378b, paratype, dorsal valve interior x 1.

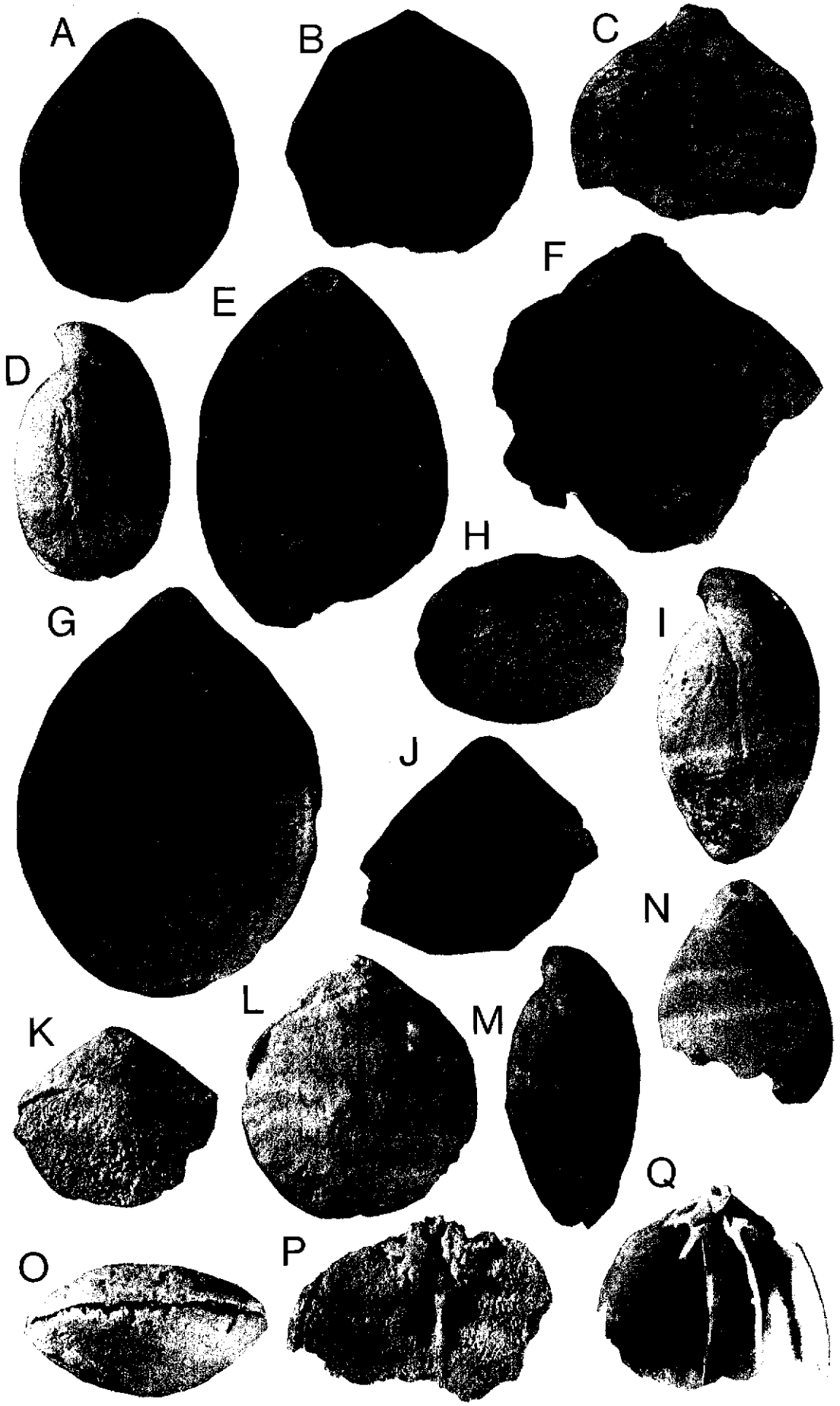
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Figure 4.24

A-F, **H**, **I**, *Neothyris rylandae* Craig, 1999. **A**, **C**, **F**, WAM 82.2368, holotype. **A**, dorsal valve exterior x 1; **C**, anterior commissure x 1; **F**, lateral margin x 1.5; **B**, WAM 82.2378a, paratype, ventral valve interior x 1; **D**, WAM 82.2367b, paratype, ventral valve interior x 1; **E**, WAM 76.2480, paratype, dorsal valve interior x 1.5; **H**, **I**, WAM 82.2367a, paratype. **H**, dorsal valve interior, lateral view; **I**, dorsal valve interior, plan view. Both x 1.

G, **J**, **K-M**, *Aliquantula insolita* (Tate, 1880). **G**, **K-M**, F6819. **G**, lateral margin; **K**, ventral valve exterior; **L**, anterior commissure; **M**, dorsal valve exterior. **J**, F6814/3, dorsal valve interior. All x 2.5.

N, *Aliquantula tapirina* (Hutton, 1873). WAM 99.316b, ventral valve interior x 2.

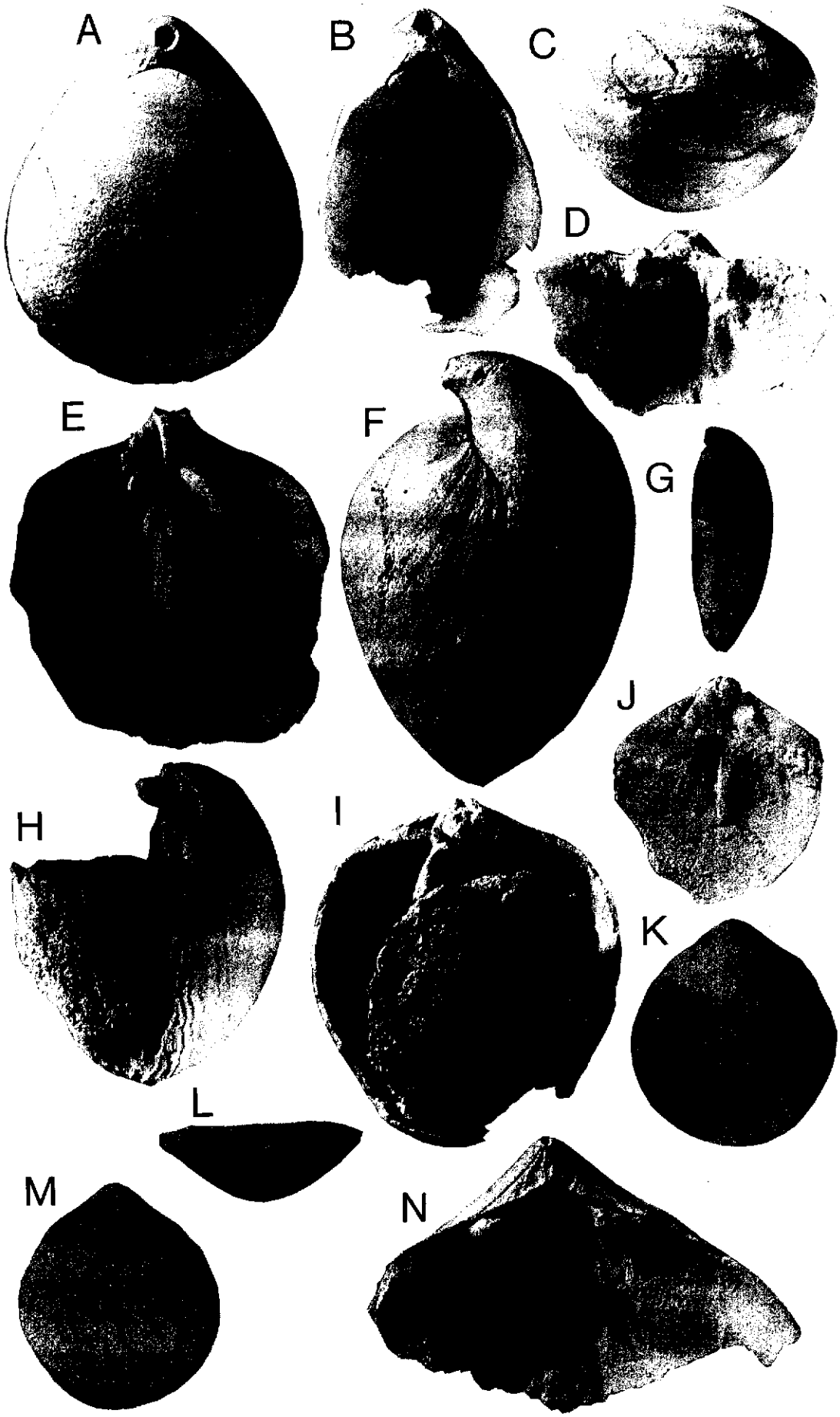
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Figure 4.25

A-F, *Aliquantula tapirina* (Hutton, 1873). **A**, **E**, WAM 99.315. **A**, dorsal valve exterior; **E**, lateral margin. Both x 1.5; **B**, WAM 99.316a, dorsal valve interior x 2; **C**, **D**, **F**, WAM 99.313. **C**, anterior commissure; **D**, dorsal valve exterior; **F**, lateral margin. All x 1.5.

G-I, *Austrothyris grandis* (Tate, 1880). **G**, WAM 76.1038a, ventral valve interior; **H**, WAM 76.1038b, dorsal valve interior. Both x 2; **I**, WAM 71.887a, dorsal valve interior x 2.

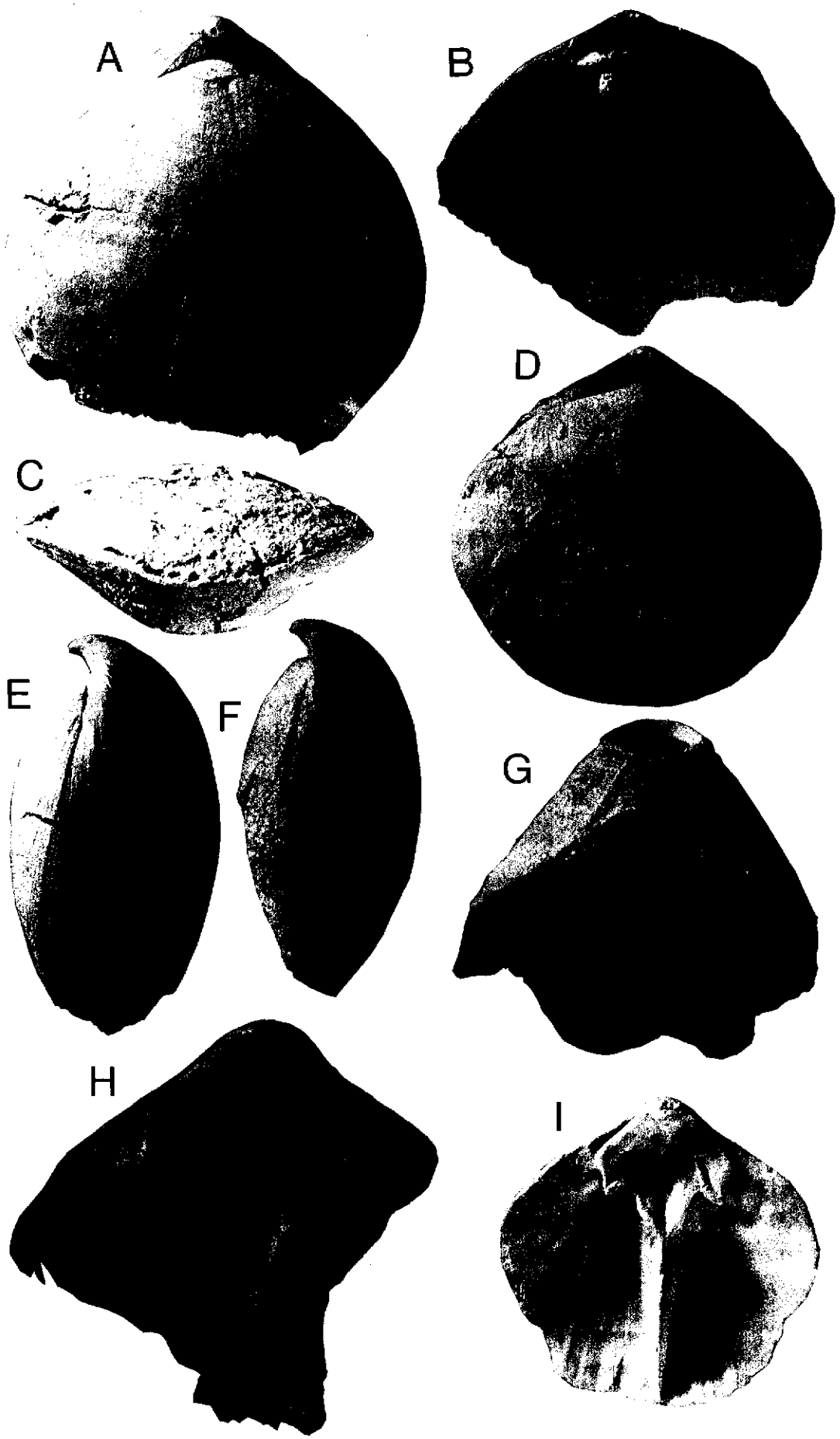
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Figure 4.26

A-E, *Austrothyris grandis* (Tate, 1880). **A**, WAM 62.158, dorsal valve exterior x 1.5; **B**, WAM 76.1038c, dorsal valve interior x 3.5; **C**, WAM 76.1038d, dorsal valve interior x 3.5; **D**, WAM 71.887a, dorsal valve exterior x 2; **E**, F6109/4, dorsal valve exterior x 1.5.

F-I, *Epacrothyris pectoralis* (Tate, 1880). **F-H**, WAM 94.312. **F**, lateral margin; **G**, dorsal valve; **H**, anterior commissure. All x 1.5; **I**, WAM 99.334a, dorsal valve interior.

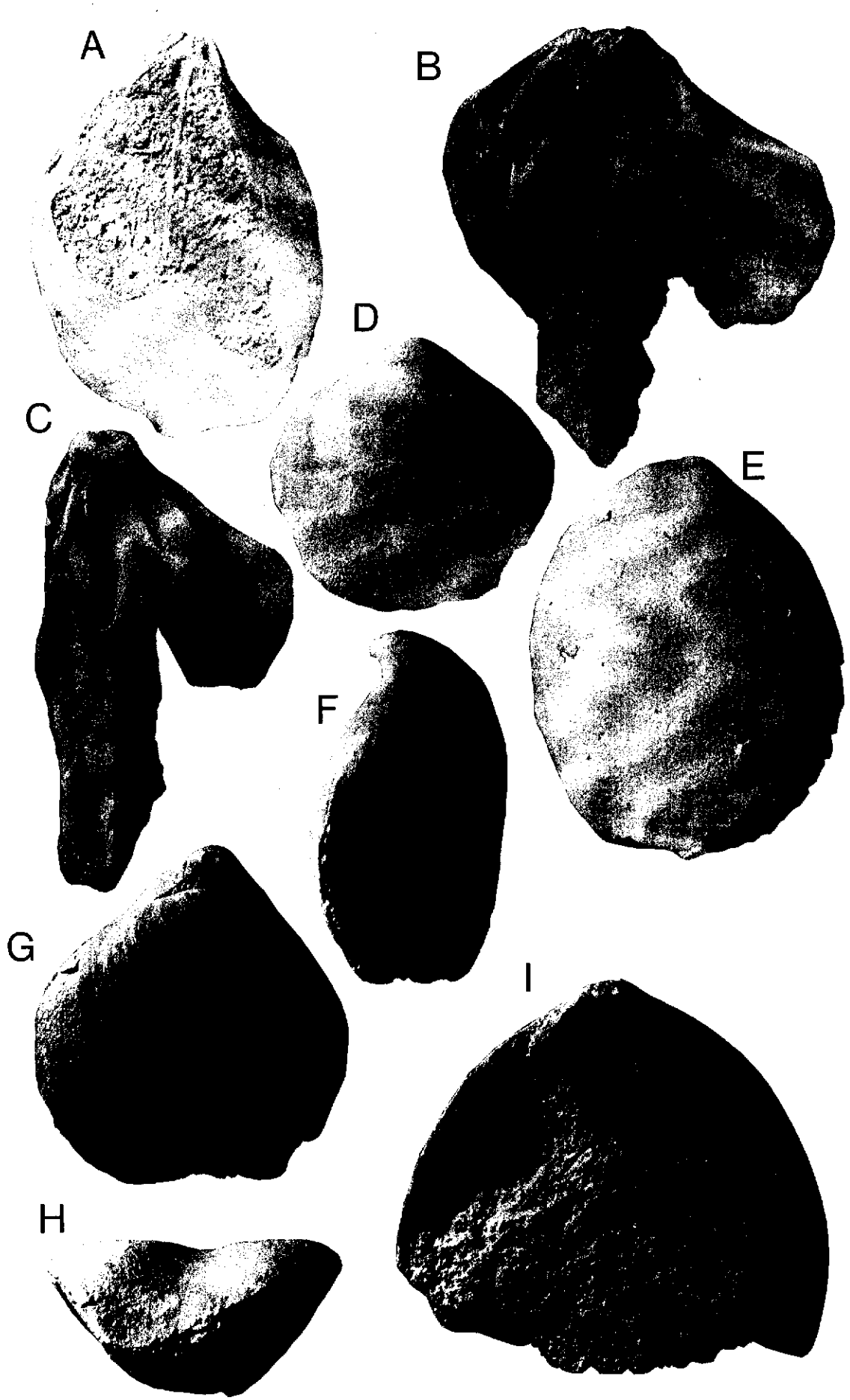
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Figure 4.27

A-D, *Epacrothyris pectoralis* (Tate, 1880). **A-C**, WAM 94.138. **A**, dorsal valve exterior; **B**, lateral margin; **C**, anterior commissure. All x 1.5; **D**, WAM 99.334b, dorsal valve interior x 2.

E-G, *Epacrothyris sufflata* (Tate, 1880). **E**, F6831, dorsal valve interior x 2.5; **F**, **G**, F6829. **F**, lateral margin; **G**, dorsal valve exterior.

H-L, *Bouchardiella cretacea* (Etheridge, 1913). **H**, WAM 79.1029, ventral valve interior x 5; **I**, **J**, **L**, WAM 74.1301. **I**, anterior commissure x 5; **J**, dorsal valve exterior x 4.5; **L**, lateral margin x 5; **K**, WAM 63.121, dorsal valve interior x 7.

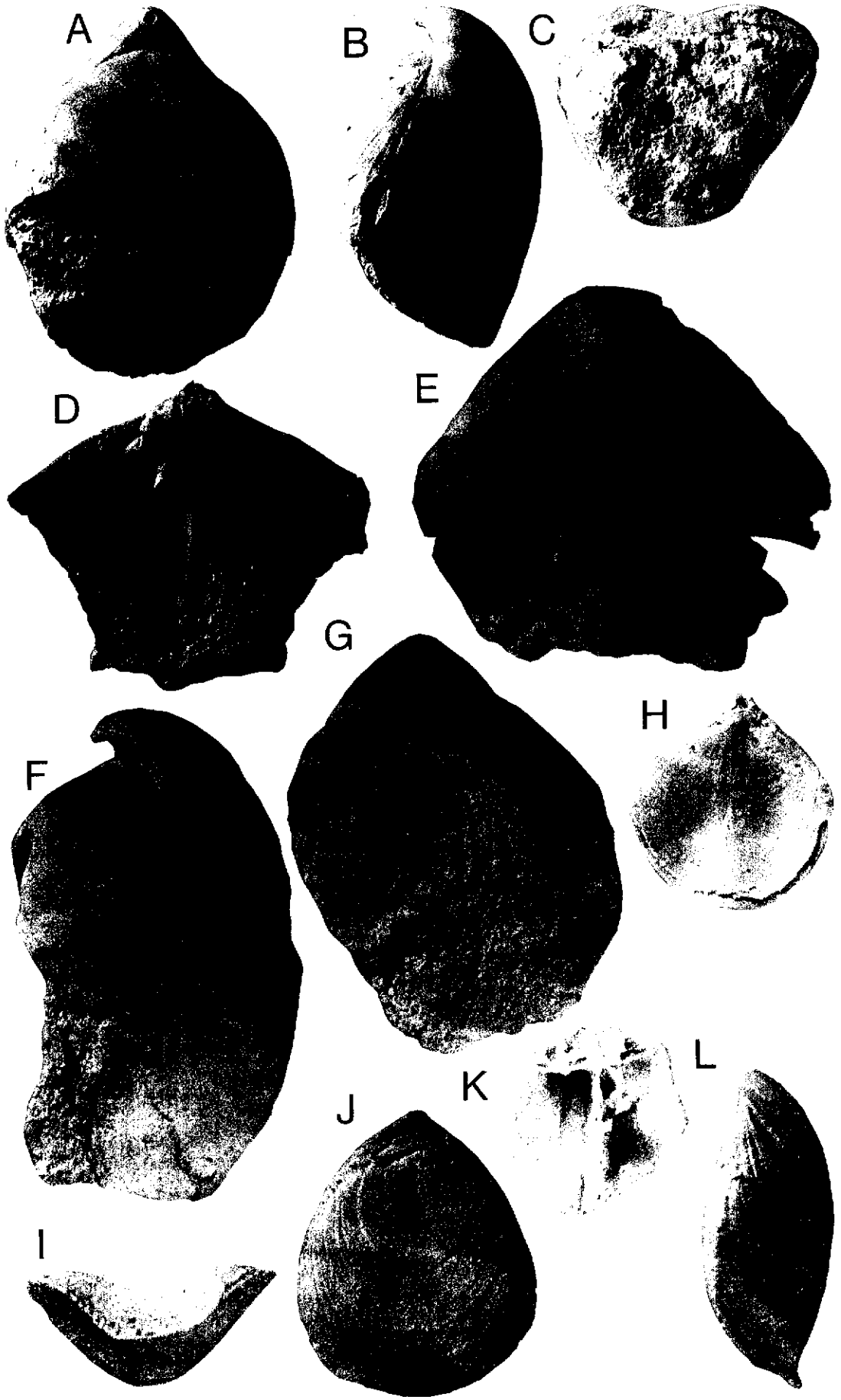
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Figure 4.28

A-F, *Anakinetica breva* Richardson, 1991. **A**, **E**, **F**, F6566/1-2. **A**, dorsal valve exterior; **E**, lateral margin; **F**, anterior commissure; **B**, F6868/1-5a, ventral valve interior; **C**, F6864/1-10, dorsal valve interior with partial brachidium; **D**, F6868/1-5b, dorsal valve interior. All x 2.5.

G-J, *Anakinetica recta* Richardson, 1991.**G**, **I**, WAM 90.241, holotype. **G**, lateral margin; **I**, dorsal valve exterior; **H**, WAM 90.246, paratype, ventral valve interior; **J**, WAM 72.2055, anterior commissure. All x 5.

K-Q, *Adnatida gnangarensis* Richardson, 1991. **K**, **O**, **Q**, WAM 90.247, holotype. **K**, dorsal valve exterior x 3; **O**, lateral margin x 3; **Q**, anterior commissure x 3.5; **L**, WAM 64.5a, ventral valve exterior showing developmental distortion x 4; **M**, WAM 64.5b, lateral margin showing brachidium covered in calcite crystals x 3; **N**, WAM 90.248, paratype, dorsal valve interior; **P**, WAM 64.5c, dorsal valve interior showing partial brachidium.

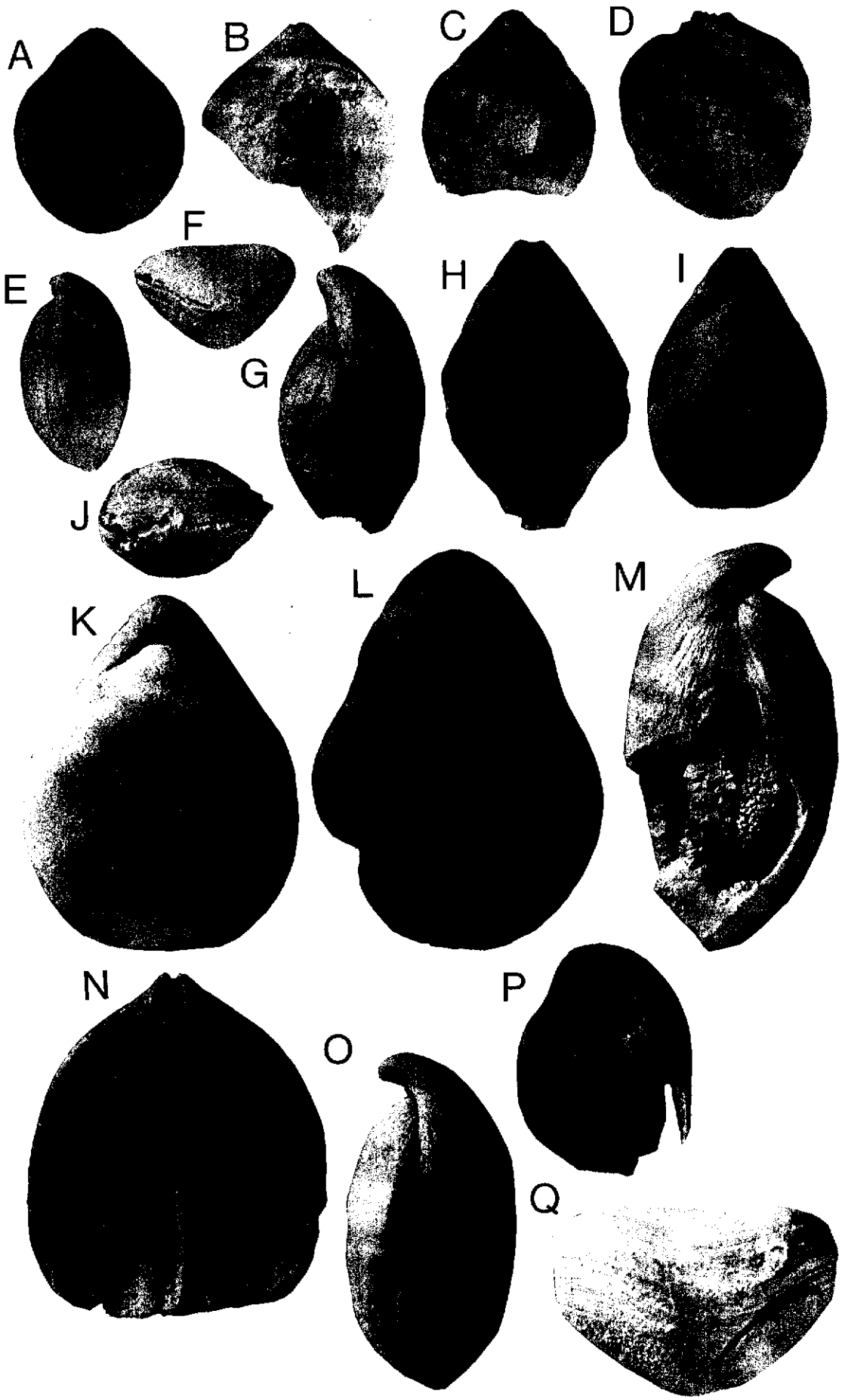
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Figure 4.29

A, **B**, *Adnatida gnangarensis* Richardson, 1991. **A**, WAM 90.249, paratype, ventral valve interior; **B**, 64.5d, dorsal valve interior. Both x 3.5.

C-G, *Magadinella woodsiana* (Tate, 1880). **C**, F6842, ventral valve interior; **D**, **E**, **G**, F6862/1-14. **D**, lateral margin; **C**, dorsal valve exterior; **G**, anterior commissure; **F**, F6861, dorsal valve interior. All x 2.5.

H-J, Indeterminate terebratulid genus 1, WAM 84.587. **H**, anterior commissure x 4; **I**, dorsal valve exterior x 5; **J**, lateral margin x 5.

K, **L**, **N**, **O**, Indeterminate terebratulid genus 2. **K**, **N**, WAM 84.519. **K**, lateral margin; **N**, dorsal valve. Both x 3; **L**, **O**, WAM 84.534. **L**, dorsal valve exterior x 3; **O**, anterior commissure x 3.

M, **Q**, **P**, Indeterminate terebratulid genus 3, WAM 88.873. **M**, lateral margin, **Q**, dorsal valve; **P**, anterior commissure. All x 3.5.

R, **S**, Indeterminate terebratulid genus 4, WAM 74.1262. **R**, dorsal valve exterior; **S**, dorsal valve interior. Both x 3.

T, Indeterminate terebratulid genus 5, WAM 79.2331, dorsal valve exterior x 2.5.

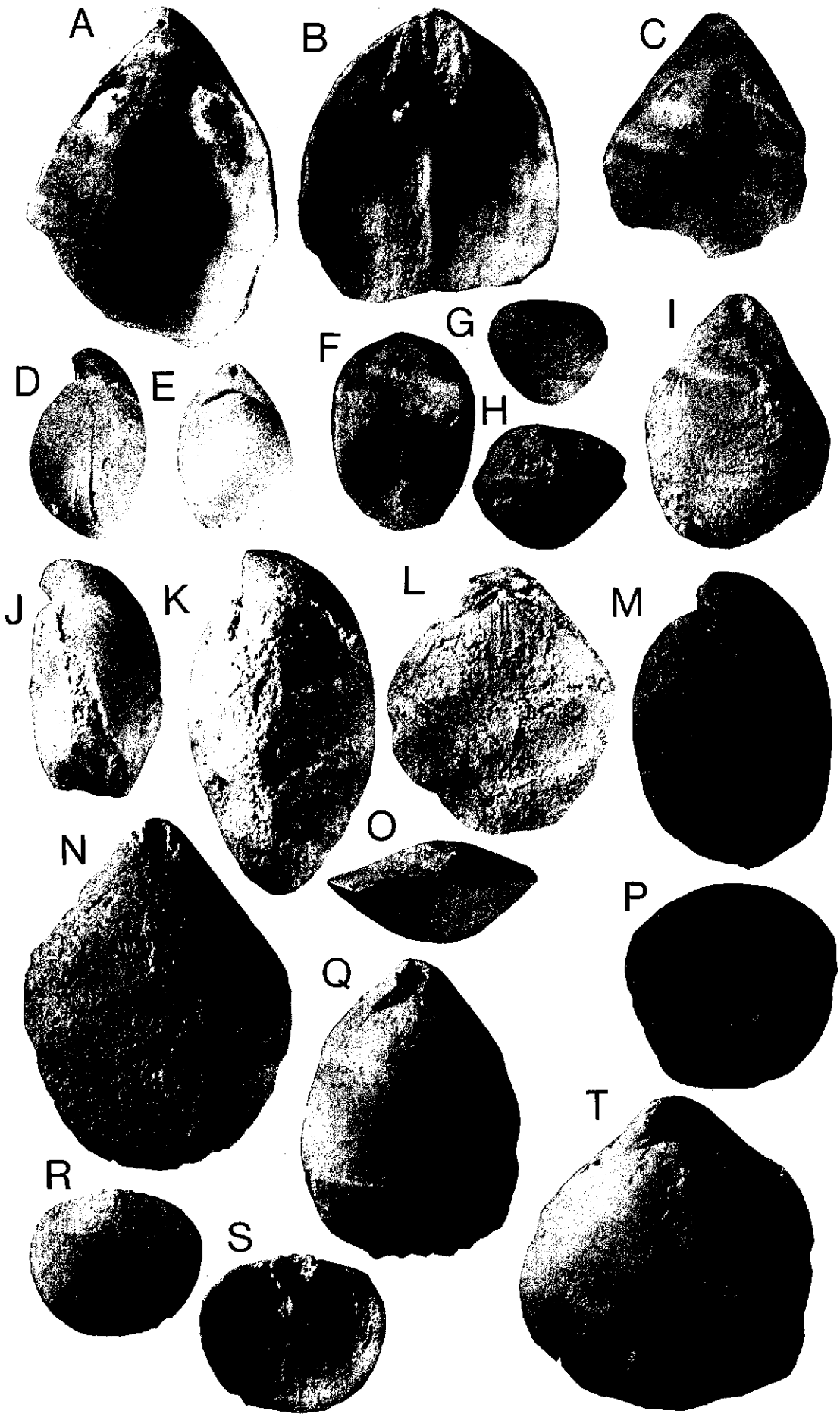
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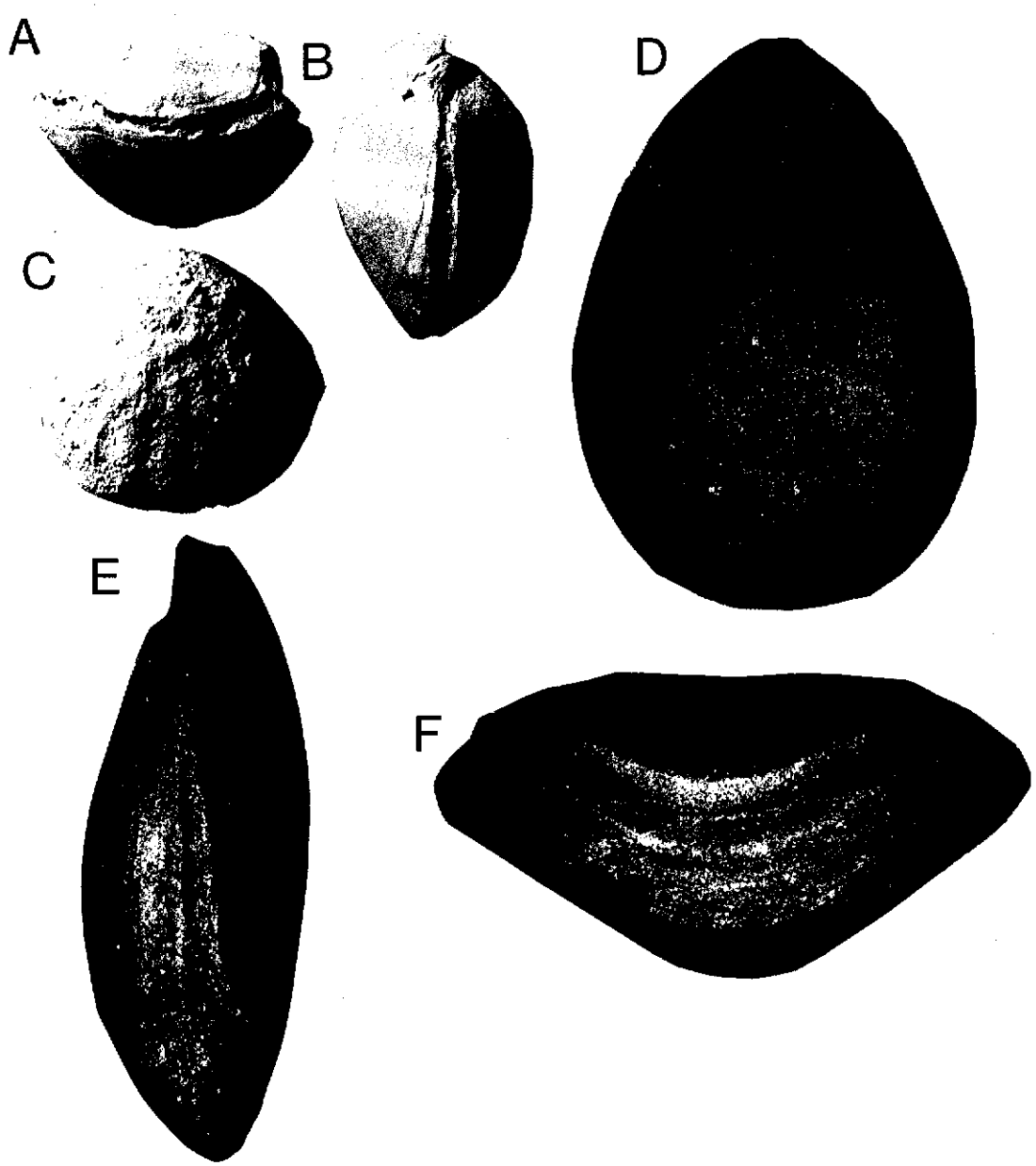
Figure 4.30

A-C, Indeterminate terebratulid genus 5. **A**, **B**, WAM 79.2331. **A**, anterior commissure; **B**, lateral margin (reverse view). Both x 2. **C**, WAM 76.2329, anterior commissure x 5.

D-F, *Bouchardiella cretacea* (Etheridge, 1913). WAM 3523, holotype (SEM). **D**, dorsal valve x 14; **E**, lateral margin x 15; **F**, anterior commissure x 21.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Chapter 5

PALAEOGEOGRAPHY: The palaeogeography and biodiversity of the Western Australian brachiopod fauna.

5.1 LATE CRETACEOUS BRACHIOPODS

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 (Table 5.1, Figure 5.5).

Ten new species are described: *Eohemithyris miriaensis* sp. nov., *E. wildei* sp. nov., *Protegulorhynchia bevanorum* sp. nov., *Tegulorhynchia hrodelberti* sp. nov., *Terebratulina kendricki* sp. nov., *Liothyrella brimmellae* sp. nov., *L. archboldi* sp. nov. and *Gemmarcula doddsae* sp. nov. This is the earliest occurrence of *Liothyrella*, and the first occurrence in Australia. A new family, Zenobiathyridae, and a new genus *Zenobiathyris* are proposed. *Zenobiathyris mutabilis* gen. et sp. nov. and *Z. plicatilis* gen. et sp. nov. are described. Three indeterminate species are also described.

Four terebratulids have previously been described by Etheridge (1913). They are *Terebratulina ovata*, *Magas mesembrinus*, *Trigonosemus acanthodes* and *Magasella cretacea*. Three of these have been redescribed by Elliot (1952). *Trigonosemus acanthodes* became *Inopinatarcula acanthodes*, *Magas mesembrinus* became *Kingena mesembrina* and *Magasella cretacea* became *Bouchardiella cretacea*. Feldtmann mentioned the *I. acanthodes*, *B. cretacea*, *K. mesembrina* two rhynchonellids and two *Terebratulina* species (Feldtmann 1963). McNamara *et al.* 1993 mentioned the rhynchonellid species including a diagram. McNamara *et al.* (1993) also renamed *Terebratulina ovata* as *Gisilina ovata*.

Fourteen species of brachiopod are described from the Santonian to Campanian Gingin Chalk. These include *Eohemithyris wildei* sp. nov., *Protegulorhynchia meridionalis* Owen, 1980, *P. bevanorum* sp. nov., *Tegulorhynchia hrodelberti* sp. nov., *Inopinatarcula acanthodes* (Etheridge, 1913),

Gisilina ovata (Etheridge, 1913), *Bouchardiella cretacea* (Etheridge, 1913), *Liothyrella brimmellae* sp. nov., *L. archboldi* sp. nov., *Zenobiathyris mutabilus* gen. et sp. nov., *Z. plicatilis* sp. nov., *Gemmarcula doddsae* sp. nov. and two indeterminate species. *Protegulorhynchia meridionalis* Owen, 1980, Of these, *P. bevanorum* sp. nov., *Tegulorhynchia hrodelberti* sp. nov., *Liothyrella brimmellae* sp. nov., *Zenobiathyris plicatilis* sp. nov., *Gemmarcula doddsae* sp. nov and the two indeterminate species are not found in any of the other four deposits. There are eight species from the Santonian to Campanian Toolonga Calcilutite. Of these species, *Eohemithyris wildei* sp. nov., *Inopinatarcula acanthodes* (Etheridge, 1913), *Gisilina ovata* (Etheridge, 1913), *Bouchardiella cretacea* (Etheridge, 1913), *Kingena mesembrina* (Etheridge, 1913), *Liothyrella archboldi* sp. nov. and *Zenobiathyris mutabilus* gen. et sp. nov. are common to the Toolonga Calcilutite and the Gingin Chalk. One indeterminate species present in the Toolonga Calcilutite is not found in any of the other deposits. The two species from the Campanian to Maastrichtian Korojon Calcarenite, *Liothyrella archboldi* sp. nov. and *Zenobiathyris mutabilus* gen. et sp. nov., are common to all four deposits (Table 5.1). Five species are recorded from the Miria Formation. *L. archboldi* sp. nov. and *Z. mutabilus* sp. nov. are common to all four deposits. *Bouchardiella cretacea* (Etheridge, 1913) is also found in the Gingin Chalk and Toolonga Calcilutite. *Eohemithyris miriaensis* sp. nov., and *Terebratulina kendricki* sp. nov. are not recorded in any of the other deposits.

Table 5.1: The Late Cretaceous Brachiopoda of Western Australia.

	Perth Basin	Carnarvon Basin		
Species	**Gingin Chalk**	**Toolonga Cal**	**Korojon Cal**	**Miria Fm**
Eohemithyris miriaensis sp. nov.				x
Eohemithyris wildei sp. nov.	x	x		
Protegulorhynchia meridionalis Owen, 1980	x			
Protegulorhynchia bevanorum sp. nov.	x			
Tegulorhynchia hrodelberti sp. nov.	x			
Inopinatarcula acanthodes (Etheridge, 1913)	x	x		
Terebratulina kendricki sp. nov.				x
Gisilina ovata (Etheridge, 1913)	x	x		
Kingena mesembrina (Etheridge, 1913)				
Bouchardiella cretacea (Etheridge, 1913)	x	x		x
Liothyrella brimmellae sp. nov.	x			
Liothyrella archboldi sp. nov.	x	x	x	x
Zenobiathyris mutabilus gen. et sp. nov.	x	x	x	x
Zenobiathyris plicatilis gen. et sp. nov.	x			
Gemmarcula doddsae sp. nov.	x			

Species	Perth Basin	Carnarvon Basin		
	Gingin Chalk	Toolonga Cal	Korojon Cal	Miria Fm
Indeterminate Terebratulid genus 1		x		
Indeterminate Terebratulid genus number 2	x			
Indeterminate Terebratulid genus number 3	x			

5.2 CENOZOIC BRACHIOPODA

5.2.1 Carnarvon Basin

The Cenozoic Paleocene to Miocene deposits of the Carnarvon Basin of Western Australia contain a rich fauna of brachiopods (Table 5.2, Figure 5.6). Only two species, *Tegulorhynchia boongeroodaensis* McNamara, 1983 and *Westralicrania allani* Cockbain, 1967, both from the Paleocene, have previously been described from the basin. One new genus, *Giraliathyris*, and twelve species, eleven of which are new, are herein described. They include *Giraliathyris mcnamarai* gen. et sp. nov., *G. kaitrinae* gen. et sp. nov., *G. jubileensis* gen. et sp. nov., *Terebratulina lindsayi* sp. nov., *Cancellothyris cashinensis* sp. nov., *Liothyrella longorum* sp. nov., *Victorithyris decapello* sp. nov., *V. cardabiaensis* sp. nov., *V. blakeorum* sp. nov., *V. tulkiensis* sp. nov., *Paraldingia timi* sp. nov., and *Diedrothyris* cf. *johnstoniana* (Tate, 1880). A *Basiliola* species and two species of indeterminate genera are also described. *Basiliola*, *Cancellothyris*, *Victorithyris*, *Liothyrella* and *Paraldingia* are recorded for the first time from the Late Paleocene of Australia. It is the earliest record of the genera.

The Cardabia Formation consists of five members (Chapter 3.2.1). The Boongerooda Greensand contains four species, *Giraliathyris mcnamarai* gen. et sp. nov., *Giraliathyris kaitrina* gen. et sp. nov., *Tegulorhynchia boongeroodaensis* McNamara, 1983 and *Victorithyris blakeorum* sp nov., all of which are also found in the Wadera Calcarenite. *G. kaitrina* gen. et sp nov. is also found in the Pirie Calcarenite and the Cashin Calcarenite and is the species with the greatest stratigraphical range. *G. mcnamarai* gen. et sp. nov. and *T. boongeroodaensis* McNamara, 1983 are present in the Wadera and Pirie Calcarenites as well as the Boongerooda Greensand. The Wadera Calcarenite has the most diverse brachiopod fauna with ten species including *Liothyrella longorum* sp. nov., *Paraldingia timi* sp. nov., *Victorithyris cardabiaensis* sp. nov., *V. decapello* sp. nov., *Westralicrania allani* Cockbain, 1967, an indeterminate species as well as *G. mcnamarai* gen. et sp.

nov. and *T. boongeroodaensis* McNamara, 1983 mentioned above. *L. longorum* sp nov. and *W. allani* Cockbain, 1967 are also found in the Cashin Calcarenite. *Terebratulina lindsayi* sp. nov. is the only species found in the Pirie Calcarenite not common to the Wadera. It is, in fact, not found in any other deposit. Six species are described from the Cashin Calcarenite. *Basiliola* sp., *Cancellothyris cashinensis* sp. nov. and an indeterminate species are the only species from the Cashin Calcarenite not found in the Wadera Calcarenite or any other deposit. Only one species, *Giraliathyris jubileensis* gen. et sp. nov., is recorded from the Jubilee Calcarenite.

Diedrothyris cf *johnstoniana* (Tate, 1880) is recorded from the Giralia Calcarenite.

Victorithyris tulkiensis sp. nov. is recorded from both the Mandu Calcarenite and Tulki Limestone in the Cape Range deposits.

Table 5.2: Distribution of Cenozoic Brachiopoda in the Carnarvon Basin, Western Australia.

(BG = Boongerooda Greensand, L. Paleocene; W = Wadera Calcarenite, L. Paleocene, P = Pirie Calcarenite, L. Paleocene; C = Cashin Calcarenite, L. Paleo-E. Eocene; J = Jubilee Calcarenite, M. Eocene; All from the Cardabia Formation.
G = Giralia Calcarenite, M. Eocene.
M = Mandu Limestone, L. Oligocene
T = Tulki Limestone, E. Miocene;

	CARDABIA FORMATION							
Species	**BG**	**W**	**P**	**C**	**J**	**G**	**M**	**T**
Basiliola sp.				X				
Cancellothyris cashinensis sp. nov.				X				
Diedrothyris cf *johnstoniana* (Tate, 1880)						X		
Indeterminate terebratulid genus 1				X				
Indeterminate terebratulid genus 2		X						
Giraliathyris jubileensis gen. et sp. nov.					X			
Giraliathyris kaitrina gen. et sp. nov.	X	X	X	X				
Giraliathyris mcnamarai gen. et sp. nov.	X	X	X					
Liothyrella longorum sp. nov.		X		X				
Paraldingia timi sp. nov.		X						
Tegulorhynchia boongeroodaensis McNamara, 1983	X	X	X					
Terebratulina lindsayi sp. nov.			X					
Victorithyris blakeorum sp. nov.	X	X						
Victorithyris cardabiaensis sp. nov.		X						
Victorithyris decapello sp. nov.		X						
Victorithyris tulkiensis sp. nov.							X	X
Westralicrania allani Cockbain, 1967		X		X				

5.2.2 Bremer and Eucla Basins

In the southwest of Western Australia, two basins, the Bremer Basin and the Eucla Basin, contain a very similar diverse brachiopod fauna. Comparison of

brachiopods from the Nanarup Limestone (Late Middle Eocene, Bremer Basin) and the Wilson Bluff Limestone (Middle to Late Eocene, Eucla Basin) (Table 5.3, Figure 5.7) indicates eight species in common to the two formations. These include *Aldingia furculifera* (Tate, 1880), *Aliquantula insolita* (Tate, 1880), *Liothyrella labiata* sp. nov., *Magadinella woodsiana* (Tate, 1880), *Epacrothyris pectoralis* (Tate, 1880), *Aliquantula 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 be a problem of collection as the specimens are flat and quite small. The Wilson Bluff Limestone is significantly richer in species having seven species that are not found in the Nanarup Limestone. These include *Austrothyris grandis* (Tenison-Woods, 1865), *Diedrothyris plicata* Richardson, 1980, *Liothyrella subcarnea* (Tate, 1880), *Murravia triangularis* (Tate, 1880), *Epacrothyris sufflata* (Tate, 1880), *Victorithyris divaricate* (Tate, 1880) and *Victorithyris garibaldiana* (Davidson, 1862). Overall, there are fifteen species present in the Wilson Bluff Limestone.

The Pallinup Siltstone has only three species of brachiopod recorded. These include *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 be due to a different environment shown by the high level of siliciclastic material within the deposit. This is possibly a product of lower water temperatures (McNamara 1994), restricted water circulation and low oxygen levels (Jones 1990).

The Toolinna Limestone consists of the species *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*) are different to the Abrakurrie Limestone but only one, *W. zenobiae*, is 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).

The Abrakurrie Limestone is less species rich than the Wilson Bluff Limestone, having only seven 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 erosion effects which produced the sequence of hardgrounds (Li *et al.* 1996) and possibly reduced the number of fossilised specimens. It contains two species, *Anakinetica breva* Richardson, 1991 and *Liothyrella bulbosa* (Tate, 1880), not recorded from any of the other deposits.

There is only one brachiopod species so far recorded from the Roe Calcarenite, Roe Plains, Eucla Basin, the new species *Neothyris rylandae* Craig, 1999.

Table 5.3: Brachiopod distribution within the Bremer and Eucla Basins. (NL = Nanarup Limestone, PS = Pallinup Siltstone, WBL = Wilson Bluff Limestone, TL = Toolinna Limestone, AL = Abrakurrie Limestone, RC = Roe Calcarenite)

Species	NL	PS	WBL	TL	AL	RC
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			
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		
Neothyris rylandae Craig, 1999						X
Epacrothyris pectoralis (Tate, 1880)	X		X			
Epacrothyris sufflata (Tate, 1880)			X			
Aliquantula tapirina (Hutton, 1873)	X		X			
Terebratulina christopheri sp. nov.	X	X	X	X		
Victorithyris divaricate (Tate, 1880)			X		X	
Victorithyris garibaldiana (Davidson, 1862)			X			
Victorithyris tateana (Tate, 1880)	X		X	X	X	
Westralicrania zenobiae Craig, 1997	X			X		

5.2.3 Perth Basin

The distribution of the Cenozoic brachiopods in the Perth Basin is summarised in Table 5.4. The most abundant species collected is *Anakinetica recta*

Richardson, 1991, which comprises some 73% of the total number of specimens. *A. recta* Richardson, 1991, *Austrothyris grandis* (Tenison-Woods, 1865), *Cancellothyris ascotensis* sp. nov. and *Megerlina irenae* sp. nov. have been found in both the Late Pliocene and Early Pleistocene sections of the Ascot Formation (Kendrick *et al.* 1991). *Magellania flavescens* (Lamarck, 1819) is also found throughout the Ascot Formation, and also extends into the Holocene. Its distribution pattern indicates a greater frequency in the Early Pleistocene than in the Late Pliocene. This is the only species described from the Ascot Formation that is extant. *Megerlina dorothyae* sp. nov. and *A. gnangarensis* Richardson, 1991 have only been recorded from the Late Pliocene. *A. recta* Richardson, 1991, *A. grandis* (Tenison-Woods, 1865), and *M. irenae* sp. nov. are all more prevalent in the Early Pleistocene than in the Late Pliocene. *C. ascotensis* sp. nov. is more prevalent in the Late Pliocene than in the Early Pleistocene. Larger specimens tend to be very poorly preserved, many being broken, and shell pieces confused with those of bivalves. This may have implications in the diversity percentages. Overall the total number of specimens compared to bivalves is very low (less than 1%).

Table 5.4: Distribution of species in the Cenozoic deposits of the Perth Basin shown as a percentage of all brachiopod specimens found.

SPECIES	Late Pliocene	Early Pleistocene	Holocene
Anakinetica recta Richardson, 1991	24.90 %	48.11 %	
Adnatida gnangarensis Richardson, 1991	7.55 %		
Austrothyris grandis (Tenison-Woods, 1865)	1.32 %	5.28 %	
Magellania flavescens (Lamarck, 1819)	0.38 %	5.66 %	0.18 %
Cancellothyris ascotensis sp. nov.	1.32 %	0.75 %	
Megerlina irenae sp. nov.	0.38 %	3.39 %	
Megerlina dorothyae sp. nov.	0.18 %		

Table 5.5: Distribution of Late Cretaceous and Cenozoic Brachiopods of Western Australian

Species	WA: Age & Formation
Admitida gnangarensis Richardson, 1991	Ascot Fm, Late Plio to E. Pleisto
Aldingia furculifera (Tate, 1880)	Nanarup Lst, Toolinna Lst, Wilson Bluff Lst, M. Eoc. Abrakurrie Lst, E. Mio.
Aliquantula insolita (Tate, 1880)	Nanarup Lst, Toolinna Lst, Wilson Bluff Lst M. Eoc. Abrakurrie Lst. E. Mio
Anakinetica breva Richardson 1991	Abrakurrie Lst, E. Mio
Anakinetica recta Richardson 1991	Ascot Fm, Late Plio to E. Pleisto
Austrothyris grandis (Tenison-Woods, 1865)	Abrakurrie Lst, E. Mio, Ascot Fm, Late Plio to E. Pleisto
Basiliola sp.	Cardabia Fm (Cashin), L. Paleo to E. Eoc
Bouchardiella cretacea (Etheridge, 1913)	Gingin Clk, Toolonga Cal, Sant-Camp. Miria Fm, L. Maastr
Cancellothyris ascotensis sp nov.	Ascot Fm, Late Plio to E. Pleisto
Cancellothyris cashinensis sp. nov.	Cardabia Fm (Cashin), L. Paleo to E. Eoc
Diedrothyris cf *johnstoniana* (Tate, 1880)	Giralia Cal, M. Eoc
Diedrothyris johnstoniana (Tate, 1880)	Nanarup Lst, M. Eoc
Diedrothyris plicata Richardson, 1980	Toolinna Lst, Wilson Bluff Lst, M. Eoc
Eohemithyris miriaensis sp. nov.	Miria Fm, L. Maastr
Eohemithyris wildei sp. nov.	Gingin Clk, Toolonga Cal, Sant-Camp.
Gemmarcula doddsae sp. nov.	Gingin Clk, Sant-Camp.
Indeterminate terebratulid genus 1	Cardabia Fm (Cashin), L. Paleo to E. Eoc
Indeterminate terebratulid genus 2	Cardabia Fm (Wadera), L. Paleo
Giraliathyris jubileensis gen. et sp. nov.	Cardabia Fm (Jubilee), M. Eoc
Giraliathyris kaitrina gen. et sp nov.	Cardabia Fm (Boongerooda/Wadera/ Pirie /Cashin), L. Paleo to E. Eoc
Giraliathyris mcnamarai gen. et sp. nov.	Cardabia Fm (Boongerooda/Wadera/Pirie), L. Paleo
Gisilina ovata (Etheridge, 1913)	Gingin Clk, Toolonga Cal, Sant-Camp.
Indeterminate terebratulid genus 3	Toolonga Cal, Sant-Camp.
Indeterminate terebratulid genus 4	Gingin Clk, Sant-Camp.
Indeterminate terebratulid genus 5	Gingin Clk, Sant-Camp.
Inopinatarcula acanthodes (Etheridge, 1913)	Gingin Clk, Toolonga Cal, Sant-Camp.
Kingena mesembrina (Etheridge, 1913)	Gingin Clk, Toolonga Cal, Sant-Camp.
Liothyrella archboldi sp. nov.	Gingin Clk, Toolonga Cal, Sant-Camp, Miria Fm, L. Maastr.
Liothyrella brimmellae sp. nov.	Gingin Clk, Sant-Camp.
Liothyrella bulbosa (Tate, 1880)	Wilson Bluff Lst, M. Eoc
Liothyrella labiata sp. nov.	Nanarup Lst, Wilson Bluff Lst, M. Eoc
Liothyrella longorum sp. nov.	Cardabia Fm (Wadera/Cashin), L. Paleo to E. Eoc
Liothyrella subcarnea (Tate, 1880)	Wilson Bluff Lst, M. Eoc
Magadinella woodsiana (Tate, 1880)	Nanarup Lst, Wilson Bluff Lst, M. Eoc. Abrakurrie Lst, E. Mio.
Magellania flavescens (Lamarck, 1819)	Ascot Fm, Late Plio to E. Pleisto
Megerlina irenae sp. nov.	Ascot Fm, Late Plio to E. Pleisto
Megerlina dorothyae sp. nov.	Ascot Fm, Late Plio to E. Pleisto
Murravia triangularis (Tate, 1880)	Toolinna Lst, Wilson Bluff Lst, M. Eoc
Neothyris rylandae Craig, 1999	Roe Calcarenite, L. Pliocene
Paraldingia timi sp. nov.	Cardabia Fm (Wadera), L. Paleo
Protegulorhynchia bevanorum sp. nov.	Gingin Clk, Sant-Camp.
Protegulorhynchia meridionalis Owen, 1980	Gingin Clk, Sant-Camp.
Epacrothyris pectoralis (Tate, 1880)	Nanarup Lst, Wilson Bluff Lst, M. Eoc
Epacrothyris sufflata (Tate, 1880)	Wilson Bluff Lst, M. Eoc
Aliquantula tapirina (Hutton, 1873)	Nanarup Lst, M. Eoc
Tegulorhynchia boongerooda ensis McNamara, 1983	Cardabia Fm (Boongerooda/Wadera/Pirie), L. Paleo
Tegulorhynchia brodelberti sp. nov.	Gingin Clk, Toolonga Cal, Sant-Camp.
Terebratulina kendricki sp. nov.	Miria Fm, L. Maastr
Terebratulina christopheri sp. nov.	Nanarup Lst, Toolinna Lst, Wilson Bluff Lst, M. Eoc
Terebratulina lindsayi sp. nov.	Cardabia Fm (Pirie), L. Paleo
Victorithyris blakeorum sp. nov.	Cardabia Fm (Boongerooda/Wadera), L. Paleo
Victorithyris cardabiaensis sp. nov.	Cardabia Fm (Wadera), L. Paleo
Victorithyris decapello sp. nov.	Cardabia Fm (Wadera), L. Paleo
Victorithyris divaricate (Tate, 1880)	Wilson Bluff Lst, M. Eoc, Abrakurrie Lst, E. Mio
Victorithyris garibaldiana (Davidson, 1862)	Wilson Bluff Lst, M. Eoc, Abrakurrie Lst, E. Mio
Victorithyris tateana (Tate, 1880)	Nanarup Lst, Toolinna Lst, Wilson Bluff Lst, M. Eoc,
Victorithyris tulkiensis sp. nov.	Mandu Cal, L. Oligo, Tulki Lst, M. Mio
Westralicrania allani Cockbain, 1967	Cardabia Fm (Wadera/ Cashin), L. Paleo to E. Eoc
Westralicrania zenobiae Craig, 1997	Nanarup Lst, Toolinna Lst, M. Eoc
Zenobiathyris mutabilus gen. et sp. nov.	Gingin Clk, Toolonga Cal, Sant-Camp, Miria Fm, L. Maastr.
Zenobiathyris plicatilis gen. et sp. nov.	Gingin Clk, Sant-Camp.

5.3 PALAEOGEOGRAPHY AND DISTRIBUTION OF WESTERN AUSTRALIAN BRACHIOPODS IN THE SOUTHERN HEMISPHERE.

The brachiopod fauna of the Late Cretaceous and Cenozoic deposits of Western Australia fill an important gap in the understanding of the palaeobiogeographical distribution of southern hemisphere genera during this period. The presence of a number of genera including *Basiliola, Prototegulorhynchia, Tegulorhynchia, Terebratulina, Liothyrella* and *Magellania* in the Late Cretaceous and/or "Early Tertiary" deposits of the Antarctic Peninsula (Buckman 1910; Owen 1980; Bitner 1996) and the Late Cretaceous and/or Cenozoic deposits of the western margin of Australia herein described, suggests that many of these genera may have evolved *in-situ*. It is proposed that a shelf existed between the Antarctic Peninsula and the coast of Western Australia during the Late Cretaceous and it was in this environment that the genera evolved. This region is named the southern circum-Indo-Atlantic faunal province. The evidence supporting this proposal is outlined below.

Sampson *et al.* (1998) proposed a palaeogeographic construction that enables links between India, Madagascar and South America via Antarctica during the Cretaceous. Sandy (1991) suggested a distinct austral brachiopod fauna existed from the Aptian onwards, at least between the Antarctic Peninsula and Western Australia. The presence of *Cretirhynchia* Pettitt, 1950 and *Rectithyris* Sahni, 1929 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) supports the hypothesis of Sampson *et al.* (1998). 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 some time between the Aptian and Santonian following which the gap between India and Antarctica became firmly established. This then allowed the migration of genera, between the Antarctic Peninsula and south-western Australia. This would explain the presence of *Kingena,* common to the Gustav Group and Marambio Group, Aptian to Coniacian, James Ross Island, Antarctica (Sandy 1991) and the Santonian to Campanian Gingin Chalk, Western Australia (Etheridge 1913).

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 earliest occurrence of the genus) indicates that this genus may have first evolved in the higher latitudes during the Cretaceous. *Liothyrella* is known from the Paleogene and Recent of Antarctica, the subantarctic waters, south-eastern Australia and New Zealand. This 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 Middle Eocene.

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 that 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 circum-Indo-Atlantic province. This would also account for its presence in the younger Maastrichtian deposit of the Miria Formation.

Terebratulina is a cosmopolitan genus, and its presence in the Miria Formation during the Late Cretaceous is not unexpected. *Terebratulina* species are described from the "Tertiary" deposits of the Antarctic Peninsula (Buckman 1910; Owen 1980; Bitner 1996). 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, *B. angusta* Buckman, 1910, *B. elliptica* Buckman, 1910, *B. attemuata* Buckman, 1910) is recorded from the

"early Tertiary" of Seymour Island and Cockburn Island, Antarctic Peninsula (Buckman 1910; Owen 1980; Bitner 1996).

Owen (1980) described a "*Terebratula*" species that 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.

This hypothesis is further supported by the presence of *Protegulorhynchia meridionalis* Owen, 1980 common to both the lower Campanian of James Ross Island, Antarctic Peninsula and the Santonian-Campanian of Western Australia. Another new species of *Prototegulorhynchia*, *P. bevanorum* sp. nov., is herein described from 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. Its absence from the Cretaceous of Antarctica does not preclude its presence there, but only proves that it has not yet been found.

Table 5.6: Distribution of species described from Western Australia and Antarctica.

Species	**Antarctic Peninsula**
Eohemithyris miriaensis sp. nov.	no record
Eohemithyris wildei sp. nov.	no record
Protegulorhynchia meridionalis Owen, 1980	Present
Protegulorhynchia bevanorum sp. nov.	Genus present
Tegulorhynchia hrodelberti sp. nov.	Tertiary species present
Inopinatarcula acanthodes (Etheridge, 1913)	no record
Terebratulina kendricki sp. nov.	Tertiary species present
Gisilina ovata (Etheridge, 1913)	no record
Kingena mesembrina (Etheridge, 1913)	*Kingena* species present
Bouchardiella cretacea (Etheridge, 1913)	*Bouchardia* species in Tertiary
Liothyrella brimmellae sp. nov.	Tertiary species present
Liothyrella archboldi sp. nov.	Tertiary species present
Zenobiathyris mutabilus sp. nov.	Possibly present
Zenobiathyris plicatilis sp. nov.	Genus possibly present

As mentioned, many genera from the Late Paleocene to Early Eocene deposits in the Cardabia Formation, Carnarvon Basin, Western Australia also occur in the Early Tertiary of Seymour and Cockburn Islands, Antarctica. These include species of *Tegulorhynchia*, *Terebratulina* and *Liothyrella* (Owen 1980). Buckman (1910) described species of *Magellania* from the Antarctic Peninsula. This genus also occurs in Australia. *Terebratulina lenticularis*, *Hemithyris squamosa*, (now known as *Tegulorhynchia squamosa*) and *Terebratula bulbosa* (herein reassigned to *Liothyrella*) described by Buckman (1910) from the Seymour Island and Cockburn Island deposits also occur in the Australian "Tertiary" (Tate 1880).

Westralicrania, *Liothyrella*, *Victorithyris*, *Paraldingia*, *Diedrothyris*, *Tegulorhynchia* and *Terebratulina* are found in the Early Cenozoic of the Carnarvon Basin, Western Australian whereas *Westralicrania*, *Liothyrella*, *Victorithyris*, *Diedrothyris* and *Terebratulina* are also found in the south-west Bremer Basin and Eucla Basin Late Middle Eocene deposits. This may be explained by a southerly current allowing migration. Their subsequent appearance in the Late Eocene and Oligocene of south-eastern Australia can be explained by an eastwards migration along the opening basin between Australia and Antarctica. McGowran (1991) made it clear that there were marine deposits along the southern region of Australia during the Late Maastrichtian, Paleocene and early Eocene. The gap between Australia and Antarctica was, however, probably more like a rift valley than a substantial ocean way as the deposits are sporadic and are carbonate-poor. It was not until the Wilson Bluff Transgression of the Middle Eocene that significant carbonate deposits were formed (McGowran 1991). This points to distinctive reef formations occurring at this time with the development of a shelf environment. The presence of brachiopods after this time would be due to reef conditions existing off the then coast of southern Australia. This would provide a "source" of fauna for the marine incursions that formed the deposits in the St Vincent and Murray Basins.

The proposed hypothesis that the brachiopods evolved *in situ* implies that the chronological sequence of distribution would be Western Australia, then South Australia, then Victoria and Tasmanian and possibly New Zealand. McNamara

(1983) suggested this for *Tegulorhynchia*. The hypothesis is supported by the distribution pattern indicated in Table 5.7.

Table 5.7: Distribution of brachiopod genera found in the Carnarvon Basin

Genus	Antarctica	Australia					New Zealand
		NW W. A	SW W. A.	S. A.	Vic	Tas	
Westralicrania		L. Paleo	L. Eoc	-	-	-	-
Basiliola	L. Eocene	L. Paleo	-	-	-	-	Recent
Tegulorhynchia	L. Eocene	L. Paleo	-	-	Oligo	Mio	Oligocene
Cancellothyris	Recent	L. Paleo	-	L. Eoc	-	-	Recent
Liothyrella	L. Eocene	L. Cret	M. Eoc	L. Eoc	-	-	L. Eocene
Paraldingia		L. Paleo	-	L. Eoc	-	E. Mio	-
Terebratulina	L. Eocene	L. Cret	L. Eoc	L. Eoc	M. Mio	-	-
Victorithyris		L. Paleo	L. Eoc	L. Eoc	M. Mio	-	-
Diedrothyris		E. Eoc	L. Eoc	L. Eoc	-	L. Oligo	-

The brachiopods *Murravia triangularis* (Tate, 1880), *Victorithyris garibaldiana* (Davidson, 1862), *V. tateana* (Tate, 1880), *V. divaricate* (Tate, 1880) *Diedrothyris johnstoniana* (Tate, 1880), *D. plicata* Richardson, 1980, *Epacrothyris pectoralis* (Tate, 1880), *E. 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 herein from the Late Middle Eocene deposits in the Bremer and Eucla Basins of Western Australia have also been described from Late Eocene to Early Miocene deposits in south-eastern Australia (Table 5.8).

Table 5.8: Table of species found in the Bremer and Eucla Basins and correlation to other southern Australian states.

Species	SA: Age	Vic: Age	Tas: Age
Admitida gnangarensis Richardson, 1991	***Eocene***	***Pliocene***	
Aldingia furculifera (Tate, 1880)	L. Eoc-Oligocene	Oligo	
Aliquantula insolita (Tate, 1880)	L. Eoc-Miocene	Oligo-Mio	
Anakinetica breva Richardson 1991	L. Oligocene	E. Miocene	
Austrothyris grandis (Tenison-Woods, 1865)	E. Miocene	Oligocene	E. Miocene
Diedrothyris johnstoniana (Tate, 1880)	E.-L. Eocene		E. Miocene
Diedrothyris plicata Richardson, 1980		E. Miocene	
Liothyrella bulbosa (Tate, 1880)	Eocene		
Liothyrella labiata sp. nov.	E.-L. Eocene		
Liothyrella subcarnea (Tate, 1880)	M. Eocene		
Magadinella woodsiana (Tate, 1880)	L. Oligocene	L. Oligocene	
Murravia triangularis (Tate, 1880)	L. Eoc-Oligocene		
Epacrothyris pectoralis (Tate, 1880)	L. Eoc-E. Oligo		
Epacrothyris sufflata (Tate, 1880)	E. Oligo-E. Mio		
Terebratulina christopheri sp. nov.	? L. Eocene	? E. Miocene	
Victorithyris divaricate (Tate, 1880)	E. Mio		
Victorithyris garibaldiana (Davidson, 1862)	E. Mio	E. Mio-E. Plio	E. Mio
Victorithyris tateana (Tate, 1880)	E.-L. Eoc	E.-L. Oligo	

During my recent visit to the Museum of South Australia, I discovered that *Terebratulina* species had been included in collections that had been renamed *Murravia* and *Cancellothyris*. Further examination of this material is required to determine if these specimens are consistent with the description for *Terebratulina christopheri* sp. nov.

Specimens very similar to *Liothyrella labiata* were described in Richardson's unpublished thesis (1959) and are recorded from the Tortachilla Limestone, Maslin Bay, South Australia.

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

Neothyris is not known from elsewhere in Australia. This 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).

Aliquantula 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. Whilst visiting the Museum of Victoria, a specimen (P 31765), similar to *A. tapirina*, was observed.

The Cenozoic brachiopod fauna of New Zealand may have evolved from species which first evolved in Western Australia. MacKinnon (1987) suggested that *Stethothyris (Epacrothyris)* evolved from the New Zealand species *"Neothyris" esdailei* Thomson, 1918. Thomson also saw 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. *Victorithyris* has been recorded from the Late Paleocene Cardabia Formation, Carnarvon Basin, Western Australia. 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) suggested that a possible candidate for the ancestral form of *Victorithyris* could be from the Paleocene of Western Australia. Hiller and MacKinnon (in press) also suggested that *"Neothyris" esdailei* Thomson, 1918 may best be assigned to *Diedrothyris*. The presence of *Diedrothyris* cf *johnstoniana* from the Cardabia Formation, Carnarvon Basin, Western Australia and *D. johnstoniana* (Tate, 1880) from the Nanarup Limestone indicates that the genus *Stethothyris* (*Epacrothyris)* 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 *Epacrothyris* in the Nanarup Limestone supports this hypothesis.

There is also a continuous link of genera between Australia, New Zealand (*Terebratulina, Neothyris* and *Stethothyris* (*Epacrothyris)* in common) and Antarctica (*Liothyrella, Terebratulina, Neothyris* and possibly *Epacrothyris* in common) (Table 5.9). Bitner (1996) described a species of *Stethothyris* (*Epacrothyris*) from the Late Eocene La Meseta Formation of Seymour Island. If this identification is correct, then *Epacrothyris* may have a wider range and different history than herein proposed. The genera that 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. The movement of brachiopods 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). 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.

Magellania flavescens (Lamark, 1819) recorded from the Late Pliocene to Pleistocene of the Perth Basin may have evolved on the western coast of Australia. It

Ocean marine fauna evolved largely *in situ* over a long time period, and that evolutionary processes at high latitudes are as every bit as complex as elsewhere. Prior to widespread glaciation there appear to have been large areas of shallow water. In particular, there were a number of embayments situated between eastern and western Antarctica. During the Mesozoic-Cenozoic a vast area of continental shelf was available for marine organisms and this would have included sites of active speciation. Closely related species still exist in the shallow waters of the Antarctic and sub-Antarctic, almost certainly the products of *in situ* adaptive radiations (Clarke and Crame 1989). These examples of brachiopod genera having been present in Antarctica, and the ideas of their distribution, are consistent with my proposal.

My emphasis, however, is that the brachiopods evolved along the southern circum-Indo-Atlantic province. This would explain the early occurrence of the genera on the western coast of Australia and subsequent distribution as outlined in Table 5.9 and Figures 5.1 and 5.2

The occurrence of similar species in the Murray Basin and the Torquay Basin during the Late Oligocene and Early Miocene suggests that the species drifted east and appeared in these areas once the Tasman Rise was inundated and the gap between Australia and Antarctica was in its final formation. Holasteroid echinoids are known to have been distributed from west to east (Foster and Philip 1978). The mechanism for this distribution would most likely be the Proto-Leeuwin Current that is believed to have been influential in the distribution of echinoids (McNamara 1999), large warm water foraminifera (McGowran *et al.* 1997) and the arcoid bivalve *Anadara trapezia* (Deshayes) (Murray-Wallace *et al.* in press). The influence of the Proto-Leeuwin Current in the distribution of brachiopods is also supported by the movement of Late Paleocene to Late Eocene brachiopods from the Carnarvon Basin to southern Australia.

The present Leeuwin Current (Figure 5.3, 5.4) 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, p.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, p. 105).

Austrothyris grandis (Tenison-Wood, 1865) was described from the Early Miocene of South Australia (Allan 1939) and is present in the Early Miocene Abrakurrie Limestone of the Eucla Basin and the Late Pliocene and Early Pleistocene Ascot Formation, Perth Basin Western Australia. *Adnatida* has been described from the Eocene of South Australia (Richardson 1991. It is also present in the Late Pliocene Ascot Formation as is *Anakinetica* that has been described from the Late Oligocene of Victoria, the Early Miocene of Victoria and South Australia (*A. breva*) and the Pliocene of Victoria (*A. tumida*) (Richardson 1991). *A. breva* is also present in the Early Miocene Abrakurrie Limestone of the Eucla Basin, Western Australia. The depositional conditions in the Ascot Formation were cooler than present with the formation of phosphate nodules. This, with the presence of *Austrothyris*, *Adnitida* and *Anakinetica* in the Ascot Formation, Perth Basin can best be explained by a hiatus in the Leeuwin Current. Cooler waters moving south to north with no interruption from the southerly flowing Leeuwin Current could have possibly allowed for the northward migration of the genera.

Two genera, *Gemmarcula* (*G. doddsae* sp. nov.) and *Gisilina* (*G. ovata*), both from the Gingin Chalk of the Perth Basin, Western Australia, are not recorded from any other deposits in the southern hemisphere. *Gisilina* Steinich, 1963 has been recorded from the Upper Cretaceous deposits in Denmark, Germany and Britain. *Gemmarcula* Elliot, 1947 has been recorded from the Lower to Upper Cretaceous of the United States of America and England. Both genera may have may have arrived from a northerly Tethyan migration.

5.4 Migration mechanisms of Cenozoic Brachiopoda.

Richardson (1994; 1997) suggested that the brachiopods common to the Cenozoic of Australia and New Zealand must have evolved along the shelves of Gondwana before the break-up. She could not see how, considering the short larval life-span of brachiopods, that they could migrate to New Zealand from Australia,

even though they appeared in early deposits in Australia. If her hypothesis is considered, the brachiopods would have had to evolve into similar genera on both sides of the South American "wall". There was no avenue for migration between the Indo-Atlantic and the Pacific until after the separation of South America from Antarctica in the Late Oligocene (Foster 1974). Even then, the currents were against an east to west migration. The only other explanations are that the brachiopods co-evolved to similar genera on both sides of the wall or migrated up the South American coast and then through the then open Panama Canal. This hypothesis would also be contrary to the proposed currents (Beu and Kitman 1998).

It is important to consider the migration of other invertebrate phyla. The Trans-Tasman migration of echinoids is well established throughout the late Cenozoic (Foster and Philip 1978). Beu (1985 p.1) concluded that "marine larvae can be transported only eastwards in the Antarctic circum polar current, so the taxon (*Chlamys patagonica delicatula*) apparently did not reach Tasmania from New Zealand". Beu and Kitman (1998) suggested that molluscs migrate from west to east to New Zealand.

MacKinnon (1987) proposed that the Tasman Sea formed in the Late Cretaceous and that by the Middle 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 if they have a short larval life of several hours to a few days (Richardson 1997).

The mechanism for migration of brachiopods across the widening Tasman Sea is therefore uncertain. 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) report the finding of '*Rhynchonella*' *subvariabilis* attached to a piece of fossil drift wood 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 have attached to vagile scallops. A report by Gabbott (1999) suggested that brachiopods in the Ordovician Soom Shale, South Africa have attached to the orthocone of cephalopods and "hitched" a ride. In discussing the distribution of molluscs, Beu (1976) suggested that larval stages might postpone their metamorphosis until a suitable substrate had been located. This may have also occurred in brachiopods. Beu also suggested (1976) that molluscan larva may reduce their metabolic rate in cold sea temperatures, allowing a longer period of drift. Pennington *et al.* (1999) have conducted experiments on the larvae of *Laqueus californianus*. They found that the larvae remain viable from three to seventy one days in water temperatures between 10° to 15° C. This would give more than sufficient time to be transported across the Tasman. These mechanisms might explain the distribution of the brachiopods.

It is also possible that early Cenozoic brachiopods had a longer lecithrotropic life span than current species.

Brachiopods may well have used these mechanisms to move along the coast of Antarctica and Australia. The mechanisms could also explain the movement of brachiopods into the Tasman Sea and hence to New Zealand after the earliest breaching of the gap between Australia and Antarctica. The final separation of Australia from Antarctica occurred in the Oligocene (MacKinnon 1987). There was, however, a shallow marine connection between the Great Australian Bight and the Tasman Sea by the Late Eocene (Kennett 1978; Beu *et al.* 1997).

From the palaeogeographic distribution of the brachiopods in the southern hemisphere it can be concluded that the phylum evolved species along a wide coastal shelf formed along the Antarctic coast and extended to western coast of Australia in the Late Cretaceous. The origin of these brachiopods is uncertain but most likely some migrated from the northern hemisphere along the eastern coast of South America. The terebratellid brachiopod fauna of the southern hemisphere appears to have a high endemic content (Richardson 1997) which suggests that their source of origin was Gondwana. Richardson (1997) suggests that the shorelines and shelf of

Gondwana were occupied by generalists. From her definition, specialist brachiopods contain thickened cardinalia, a small to minute pedicle foramen and evidence of reduction in size of adjustor muscles. Many of the brachiopods from Western Australia, including the Late Cretaceous *Inopinatarcula acanthodes* (Etheridge, 1913) and the Late Paleocene *Giraliathyris mcnamarai* gen. et sp. nov., *Victorithyris blakeorum* sp. nov., *V. decapello* sp. nov. and the Middle to Late Eocene *Epacrothyris pectoralis* (Tate, 1880) appear to be specialist by this definition. Richardson (1997) suggested that the survival of the specialists would have been strongly influenced by the amount of suitable substrate remaining after the break-up of Gondwana. The extinction of many of the Late Eocene species may well have been due to destruction of suitable substrate (Richardson 1997).

Richardson (1997) suggested that generalists are more likely to survive periods of environmental change. Once the gap between Australia began to open and significant shelf environments were formed by the Middle Late Eocene, brachiopods migrated west to east, finally appearing in New Zealand. With the final separation of the continents by the Late Oligocene, and the continual northwards drifting of the Australian landmass, substrate conditions changed. Specialist species were then restricted to environments that showed little change from the past (the anakineticenes). Generalists, such as *Magellania flavescens* (Lamark, 1819), became the most wide spread species in the southern hemisphere (Richardson 1994).

5.5 Substrate Relationships

The presence of so many species common to Western Australia and the southern states of Australia indicates that the abiotic ecological conditions were certainly similar for a long period from the Middle Eocene to at least the Early Miocene. The presence of similar species in Western and South Australia during the Middle 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 support this hypothesis. In the Antarctic Peninsula, the greatest brachiopod diversity also appears to occur in the deposits in which bryozoans are most prolific (Bitner 1996).

Both brachiopods and bryozoans are lophophorates. Bryozoans are, to some degree, temperature restricted in their distribution but there appears to be a great deal of overlap between regions (McKinney and Jackson 1989). Both brachiopods and bryozoans feed on similar foods including phytoplankton and diatoms (Peck *et al.* 1997; McKinney and Jackson 1989). Again, both adhere to similar substrates, restricted only from very fine mud (Rudwick 1970; McKinney and Jackson 1989). It is therefore possible that the main reason that brachiopods are found in sediments containing a high proportion of bryozoans is that both need similar substrate and nutritional requirements.

Bryozoan limestones are the product of cool-water deposits possibly including up-welling (James personal communication). Although the surface temperatures due to the flow of the Leeuwin Current are said to be warm ranging from 17° to 19°, James and Bone (1991) suggest those water temperatures between 14° to 19° are cool enough to allow the deposition of bryozoan limestones. 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.

There are four units in Western Australia where brachiopod populations are low to non existent during the Cenozoic. These include the Mandu Calcarenite and the Tulki Limestone of the Upper Oligocene Carnarvon Basin, the Roe Calcarenite of the Late Pliocene Eucla Basin and the Ascot Formation of the Late Pliocene to Early Pleistocene Perth Basin. Only one species, *Victorithyris tulkiensis* is described from the Mandu Calcarenite and Tulki Limestones. In the Ascot Formation there are a number of species (seven) but the overall percentage of specimens of brachiopods relative to bivalves is very low (less than 1%) (Kendrick, pers. comm). In the Roe Calcarenite, only one brachiopod, *Neothyris rylandae* Craig, 1999, is recorded. Again the number of specimens compared to bivalves is quite low.

The presence of fine deposits and large foraminifera suggest that the Mandu Calcarenite and Tulki Limestones were formed in a warm water inshore environment

possibly supporting a seagrass community. Kendrick *et al.* (1997) concluded from the presence of *Marginopora vertebralis* and the bryozoan *Densipora* (both of which attach to seagrasses in the present day) that the Roe Calcarenite was laid down on a shallow inshore shelf with well-circulated warm water. The deposit was in sandy substrate with a rich growth of seagrasses indicating a well lit area. Kendrick (pers. comm.) suggested that the Ascot Formation is shallow inshore shelf with several regressional episodes indicated. It is believed to have been a high photic zone with seagrasses. This is also supported by the presence of the bryozoan *Densipora.* Large seagrass attaching foraminifers are conspicuously absent, possibly because of the lower temperature suggested by the presence of phosphate nodules.

Brachiopods are avoiders of light tending to attach or lie in shadow or underneath objects in shallow photic zones (Richardson 1997). Light holds no fear for bryozoans although they are less numerous in shallow photic zones due to being out-competed by other photic organisms (McKinney and Jackson 1989). The absence of a numerous and diverse fauna of brachiopods from the Ascot Formation and the Roe Calcarenite may therefore be due to the waters being too shallow and light intensity too great for brachiopods. The bryozoans may be less diverse due to them being ousted by more competitive organisms such as seagrasses and algae.

From discussions with the principle collectors (Kendrick, Darragh, McNamara) and my own observations in the field, where there are numerous brachiopods, the overall number of molluscs is relatively smaller than where brachiopod numbers are reduced. This is apparent in the bryozoan rich limestones of the Carnarvon, Bremer and Eucla Basins compared to the Roe Calcarenite and Ascot Formations. A possible explanation is food availability. Lophophorates are able to take advantage of areas where food supplies are limited and hence can out-compete the molluscs that require a larger food supply. Where food sources are plentiful, molluscs out-compete the brachiopods for available substrate and hence the brachiopod numbers (genera and /or specimens) are reduced.

Much more work on the ecology of living species and the taxonomy and evolution of the Late Cretaceous to Cenozoic brachiopods of the southern hemisphere is required before the complete picture can be determined.

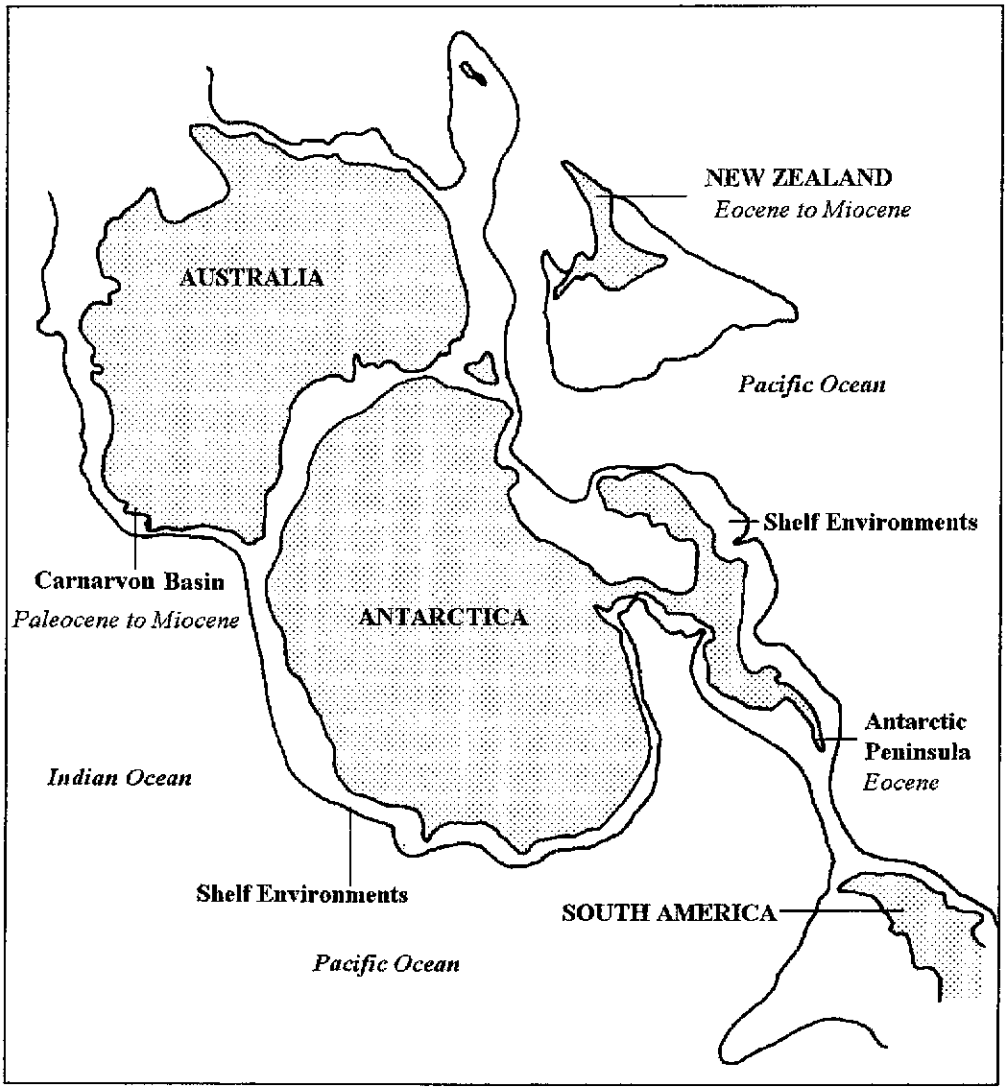

Figure 5.1: Map indicating the possible shelf environments during the Late Cretaceous and Early Cenozoic. Adapted from Lawver *et al.* 1985.

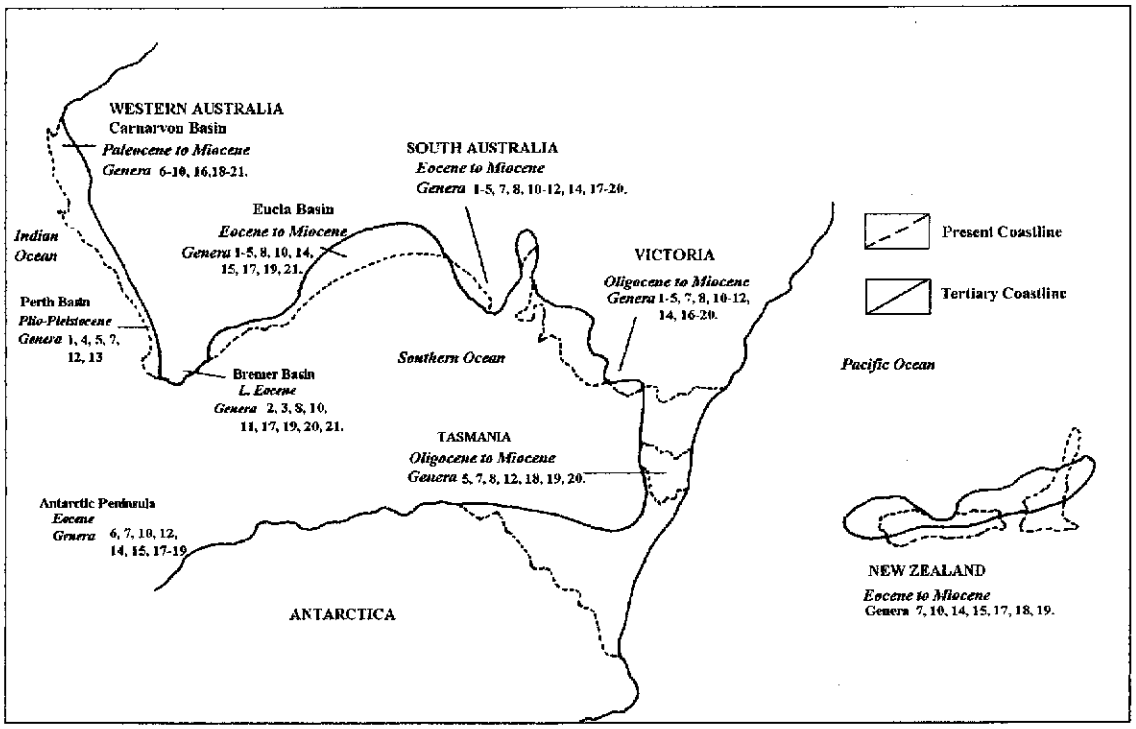

Figure 5.2: The distribution of Cenozoic brachiopod genera in Antartica, Australia and New Zealand. Adapted from Foster and Philip 1978.

1. *Adnitida*
2. *Aldinga*
3. *Aliquantula*
4. *Anakinetica*
5. *Austrothyris*
6. *Basiliola*
7. *Cancellothyris*
8. *Diedrothyris*
9. *Giraliathyris*
10. *Liothyrella*
11. *Magadinella*
12. *Magellania*
13. *Megerlina*
14. *Murravia*
15. *Neothyris*
16. *Paraldingia*
17. *Stethothyris*
18. *Tegulorhynchia*
19. *Terebratulina*
20. *Victorithyris*
21. *Westralicrania*

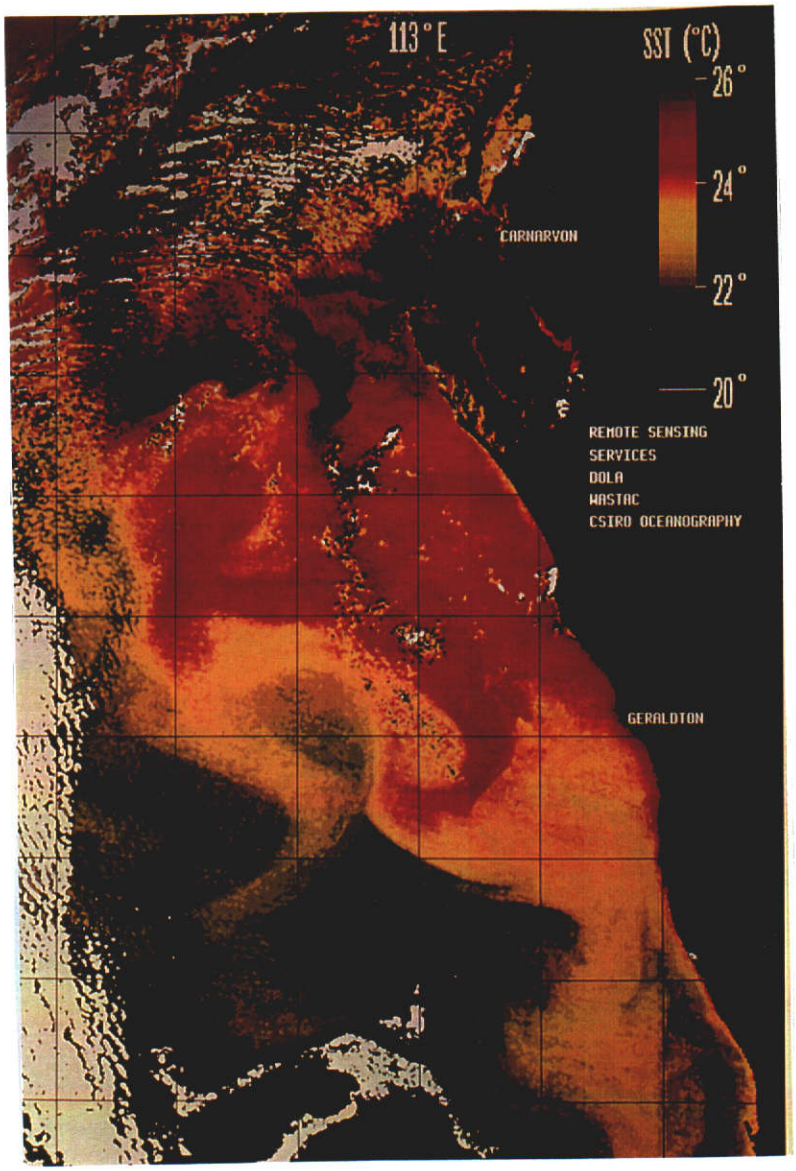

Figure 5.3: Satellite image of the Leeuwin Current (red) taken on the 23rd of February, 1999 indicating the movement south along the Western Australian coast (Courtesy of DOLE, Shenton Park, Western Australia).

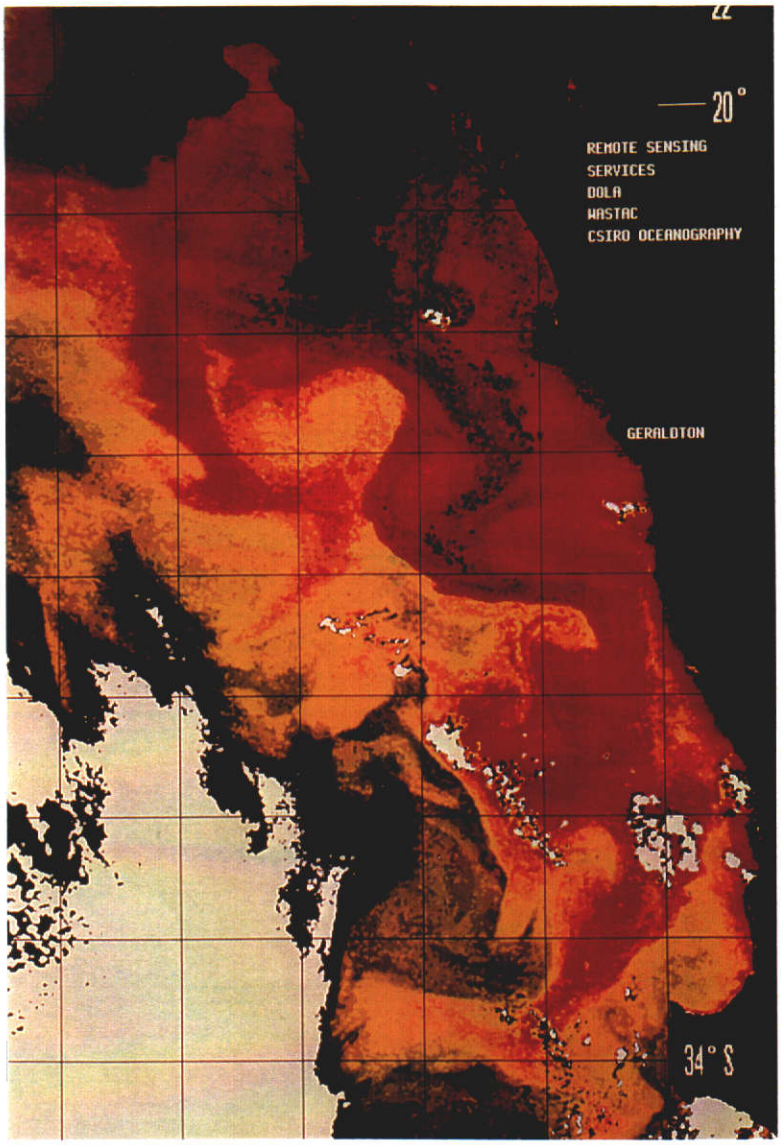

Figure 5.4: Satellite image of the Leeuwin Current (red) taken on the 26th of February, 1999 indicating the movement south along the Western Australian coast. When compared to figure 5.3, it can be seen that the current has moved 600 kilometres in three days (Courtesy of DOLE, Shenton Park, Western Australia).

Figure 5.5 Distribution of brachiopod species in the Late Cretaceous Perth and Carnarvon Basins. Dotted lines indicate species **not** present in that deposit (see figure 3.16 for stratigraphical and age correlation).

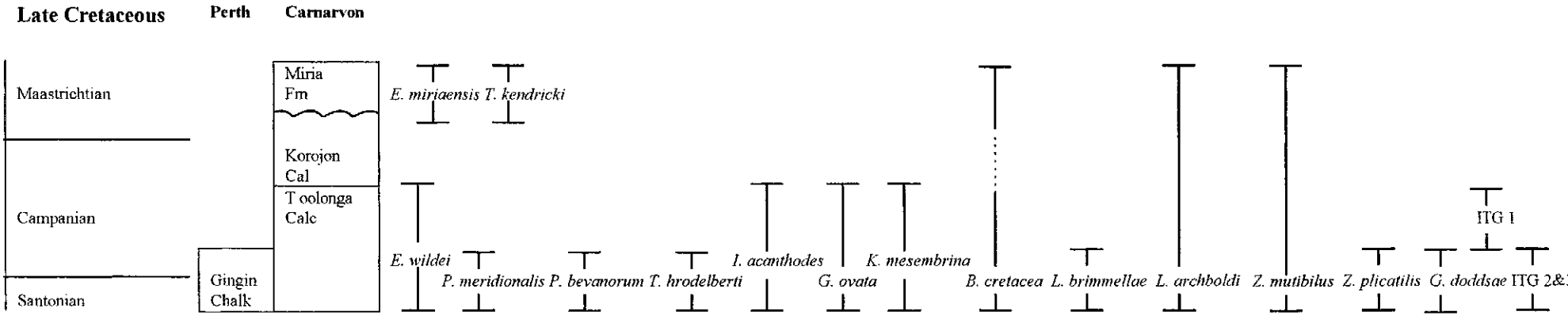

Figure 5.6: Distribution of brachiopods in the Cenozoic deposits of the Carnarvon Basin (Cape Range and Giralia Range). Dotted line indicates that the species is **not** present in this deposit (see figure 3.16 for stratigraphical and age correlation).

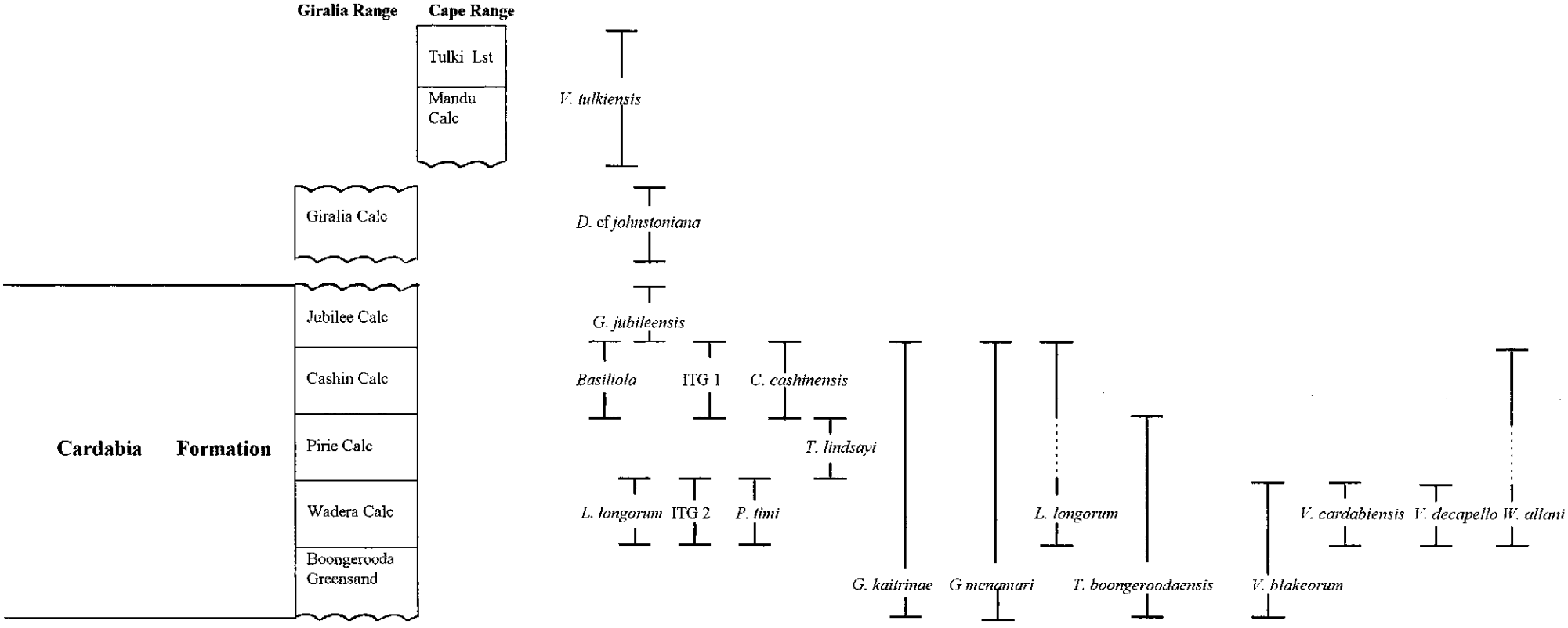

Figure 5.7: Distribution of brachiopods in the deposits of the Bremer and Eucla Basins. Dotted lines indicate species **not** present in that deposit. The asterix (*) indicates species also present in the Pallinup Siltstone (see figure 3.16 for stratigraphical and age correlation).

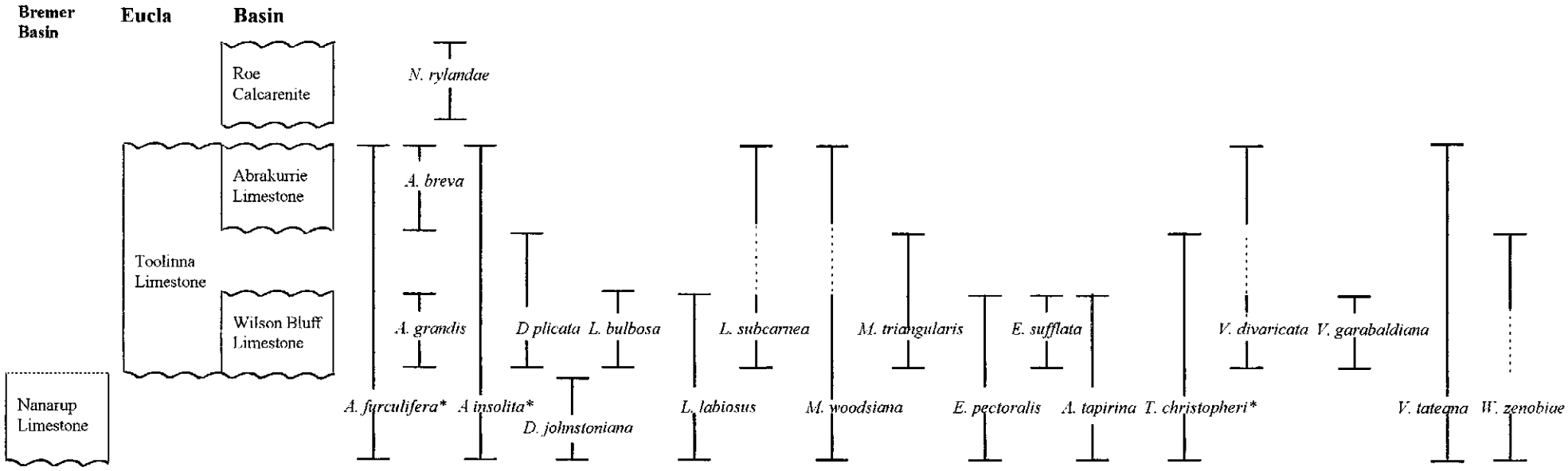

Table 5.9: Western Australian Late Cretaceous and Cenozoic Brachiopods and their correlation with southeastern Australia, New Zealand and Antarctica. *(Ages identified in **bold italics** are for the appearance of the **genus** in these areas).*

Species	WA: Age	SA: Age	Vic: Age	Tas: Age	NZ: Age	Antarctica: Age
Adnitida gnangarensis Richardson, 1991	L. Plio - E. Pleisto	***Eocene***	***Pliocene***			
Aldingia furculifera (Tate, 1880)	M. Eoc - E. Mio	L. Eoc-Oligocene	Oligo			
Aliquantula insolita (Tate, 1880)	M. Eoc - E. Mio	L. Eoc-Miocene	Oligo-Mio			
Anakinetica breva Richardson, 1991	L. Oligo - E. Mio	L. Oligocene	E. Miocene			
Anakinetica recta Richardson, 1991	L. Plio - E. Pleisto	***L. Eocene***	***Pliocene***			
Austrothyris grandis (Tenison-Woods, 1865)	L. Oligo - E. Pleisto	E. Miocene	Oligocene	E. Miocene		
Basiliola sp nov.	L. Paleo - E. Eoc					***L. Eocene***
Bouchardiella cretacea (Etheridge, 1913)	Sant - Maast					
Cancellothyris ascotenisis sp nov.	L. Plio - E. Pleisto	***L. Eocene***	***Recent***	***Recent***	***Recent***	***Recent***
Cancellothyris cashinensis sp. nov.	L. Paleo - E. Eoc					
Diedrothyris cf *johnstoniana* (Tate, 1880)	M. Eoc	E.-L. Eocene		E. Miocene		
Diedrothyris johnstoniana (Tate, 1880)	M. Eoc	E.-L. Eocene		E. Miocene		
Diedrothyris plicata Richardson, 1980	M - L. Eoc		E. Miocene			
Eohemithyris miriaensis sp nov.	Maast					
Eohemithyris wildei sp. nov.	Sant - Camp					
Gemmarcula doddsae sp. nov.	Sant - Camp					
Giraliathyris jubileensis gen. et sp nov.	M. Eoc					
Giraliathyris kaitrina gen. et sp nov.	L. Paleo - E. Eoc					
Giraliathyris mcnamari gen. et sp nov.	L. Paleo - E. Eoc					
Gisilina ovata (Etheridge, 1913)	Sant - Camp					
Indeterminate terebratulid genus 1	L. Paleo - E. Eoc					
Indeterminate terebratulid genus 2	L. Paleo					
Indeterminate terebratulid genus 3	Sant - Camp					
Indeterminate terebratulid genus 4	Sant - Camp					
Indeterminate terebratulid genus 5	Sant - Camp					
Inopinatarcula acanthodes (Etheridge, 1913)	Sant - Camp					
Kingena mesembrina (Etheridge, 1913)	Sant - Camp					
Liothyrella archboldi sp nov.	Sant - Maast				***Oligo-Recent***	***L. Eoc-Recent***
Liothyrella brimmellae sp. nov.	Sant - Camp					
Liothyrella bulbosa (Tate, 1880)	M. Eoc	Eocene				
Liothyrella labiosus sp. nov.	M. Eoc	E.-L. Eocene				
Liothyrella longorum sp nov.	L. Paleo - E. Eoc					
Liothyrella subcarnea (Tate, 1880)	M. Eoc	M. Eocene				
Magadinella woodsiana (Tate, 1880)	M. Eoc - E. Mio	L. Oligocene	L. Oligocene			

Species	WA: Age	SA: Age	Vic: Age	Tas: Age	NZ: Age	Antarctica: Age
Magellania flavescens (Lamarck, 1819)	L. Plio - E. Pleisto	Plio-Recent	Plio-Recent	Recent		***Recent***
Megerlina irenae sp nov.	L. Plio - E. Pleisto	***Recent***				***Recent***
Megerlina dorothyae sp nov.	L. Plio - E. Pleisto					
Murravia triangularis (Tate, 1880)	M. Eoc	L. Eoc-Oligocene			***Miocene***	
Neothyris rylandae Craig, 1999	L. Plio				***Oligo-Mio***	***E. Mio-Rec***
Paraldingia timi sp nov.	L. Paleo	***L. Eocene***	***E. Miocene***			
Protegulorhynchia bevanorum sp. nov.	Sant - Camp					*L. Cretaceous*
Protegulorhynchia meridionalis Owen, 1980	Sant - Camp					L. Cretaceous
Epacrothyris pectoralis (Tate, 1880)	M. Eoc	L. Eoc-E. Oligo			***Oligo-Miocene***	***? L. Eocene***
Epacrothyris sufflata (Tate, 1880)	M. Eoc	E. Oligo-E. Mio				
Aliquantula tapirina (Hutton, 1873)	M. Eoc				Oligocene	
Tegulorhynchia boongeroodaensis McNamara, 1983	L. Paleo	***Eocene***	***Oligo-Miocene***	***Oligocene***	***Oligo-Recent***	***L. Eocene***
Tegulorhynchia hrodelberti sp. nov.	Sant - Camp					
Terebratulina kendricki sp nov.	Maast	***Eocene***	***Oligo-Mio***	***Oligo-Mio***	***Eoc-Pliocene***	***L. Eocene***
Terebratulina christopheri sp. nov.	M. Eoc					
Terebratulina lindsayi sp. nov.	L. Paleo					
Victorithyris blakeorum sp nov.	L. Paleo					
Victorithyris cardabiaensis sp nov.	L. Paleo					
Victorithyris decapello sp nov.	L. Paleo					
Victorithyris divaricate (Tate, 1880)	M. Eoc - E. Mio	E. Mio				
Victorithyris garibaldiana (Davidson, 1862)	M. Eoc - E. Mio	E. Mio	E. Mio-E. Plio	E. Mio		
Victorithyris tateana (Tate, 1880)	M. Eoc	E.-L. Eoc	E.-L. Oligo			
Victorithyris tulkiensis sp nov.	L. Oligo - M. Mio					
Westralicrania allani Cockbain, 1967	L. Paleo - E. Eoc					
Westralicrania zenobiae Craig, 1997	M. Eoc					
Zenobiathyris mutabilis gen. et sp nov.	Sant - Maast					***? L. Cret***
Zenobiathyris plicatilis gen. et sp. nov.	Sant - Camp					***? L. Cret***

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APPENDIX

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3. **Abstracts from Conferences and Seminars** 291

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APPENDIX 1

PERSONAL COMMUNICATIONS CITED IN THE TEXT

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APPENDIX 2

CONFERENCES AND SEMINARS

1997 The Cenozoic brachiopods of Western Australia at the Palaeobiogeography of Australasian Floras and Faunas Conference, Wollongong.

1999 The Late Mesozoic and Cenozoic brachiopods of Western Australia at the Inaugural Postgraduate Symposium Royal Society of Western Australia.

1999 The Late Mesozoic and Cenozoic brachiopods of Western Australia at the Ecosystem Management Seminar Series, Edith Cowan University.

1999 The Late Cretaceous and Cenozoic Brachiopoda of Western Australia. Fourth Australian Marine Geoscience Conference, 26 September - 1 October 1999, Exmouth, Western Australia.

APPENDIX 3

ABSTRACTS

Appendix 3 (a):

Craig, R. S. (1997). The Cenozoic brachiopods of Western Australia. *Geological Society of Australia Abstracts* **48**: 18-19.

Note: For copyright reasons the content of Appendix 3(a) (pp292-293 of the thesis) has not been reproduced.

(Co-ordinator, ADT Project (Retrospective), Curtin University of Technology, 25.11.02)

Appendix 3 (b):

Craig, R. S. (1999). The Brachiopoda of the Late Cretaceous and Cenozoic of Western Australia. *Proceedings of the Royal Society of Western Australia.* May 1999 Supplement.

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Appendix 3 (c):

Craig, R. S. (1999). The Late Cretaceous and Cenozoic Brachiopoda of Western Australia. *In* Collins, L. B. and Zhu, Z. R. (eds) *Abstracts of the Fourth Australian Marine Geoscience Conference, 26 September - 1 October 1999, Exmouth, Western Australia.* Consortium for Ocean Geosciences of Australian Universities and School of Applied Geology Curtin University of Technology. pp 17-18.

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APPENDIX 4

PUBLICATIONS DURING THESIS

Appendix 4 (a):

Craig, R. S. (1997). A new cranioid brachiopod from the Eocene of southwest Australia. *Records of the Western Australian Museum.* **18**: 311-315.

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(Co-ordinator, ADT Project (Retrospective), Curtin University of Technology, 25.11.02)

Appendix 4 (b):

Craig, R. S. (1999). A new Pliocene terebratulid brachiopod from the Roe Calcarenite, Eucla Basin of southern Australia. *Records of the Western Australian Museum* **19**: 267-275.

Note: For copyright reasons the content of Appendix 4(b) (pp306-314 of the thesis) has not been reproduced.

(Co-ordinator, ADT Project (Retrospective), Curtin University of Technology, 25.11.02)

Appendix 4 (c):

Craig, R. S. (1999). Late Cretaceous brachiopods from the deposits of the Perth and Carnarvon Basins, Western Australia. *Records of the Western Australian Museum* **19**: 413-442. **(proof only)**

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Appendix 4 (d):

Craig, R. S. (1999). The Brachiopod fauna of the Plio-Pleistocene Ascot Formation, Perth Basin Western Australia. *Records of the Western Australian Museum* **19**: 451-464. **(proof only)**

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(Co-ordinator, ADT Project (Retrospective), Curtin University of Technology, 25.11.02)

Appendix 4 (e):

Craig, R. S. (2000). The Cenozoic brachiopods of the Carnarvon Basin, Western Australia. *Palaeontology* **43** (1). **(proof only)**

Note: For copyright reasons the content of Appendix 4(e) (pp362-403 of the thesis) has not been reproduced.

(Co-ordinator, ADT Project (Retrospective), Curtin University of Technology, 25.11.02)