Ostracode and foraminiferal taxonomy and palaeoecology of the Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia.

by

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Abstract

The Sakmarian (Cisuralian, Permian) Fossil Cliff Member of the Holmwood Shale is situated in the northern Perth Basin, Western Australia, and consists of alternating beds of shale and silty calcarenite forming three parasequences. Within this member a diverse fauna of ostracodes and foraminifera are present. During the Cisuralian the northern Perth Basin formed part of the Gondwanan supercontinent and was linked to Greater India via an epeiric sea that opened to the north.

The ostracode fauna is restricted to the calcareous beds of the member and consists of a diverse benthic fauna comprising 31 new species and 13 previously recorded species. Species from the Healdioidea, Bairdioidea, Youngielloidea, and Thlipsuroidea dominate the assemblage and suggest a normal-marine environment during the period represented by the calcareous beds, with an overall shallowing trend up the sequence. The fauna shows some similarity to faunas from the Tethyan deposits of North America and the Boreal deposits of Russia during the Late Carboniferous and Cisuralian.

Twenty-eight species of foraminifera were recorded from the Fossil Cliff Member and underlying Holmwood Shale and comprise two distinct faunas, an agglutinated benthic foraminiferal fauna found within the shale beds and a calcareous benthic foraminiferal fauna present in the calcarenite units. The agglutinated foraminifera are inferred to represent deposition in dysoxic to suboxic (0.1-1.5 mL/LO_2), poorly circulated bottom waters below wave base. The calcareous foraminifera are inferred to represent deposition in normal-marine conditions. Both foraminiferal assemblages show a shallowing trend in their distribution that matches the trend identified in the ostracode fauna.

Based upon the palaeoecology of the ostracode and foraminiferal faunas, the depositional environment for the Fossil Cliff Member is inferred to have been within shallow water in an epeiric basin during an overall marine regression that is overprinted by eustatic and isostatic oscillations resulting from deglaciation that occurred during the early Sakmarian (Cisuralian). These sea-level oscillations raised and lowered the oxic surface waters of the epeiric sea above and below the substrate resulting in a sparse agglutinated foraminiferal fauna or an abundant and diverse ostracode and calcareous foraminiferal fauna respectively.

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Chapter 1: Introduction

The Fossil Cliff Member of the Holmwood Shale contains one of the most diverse and well-preserved Early Permian (herein referred to as the Cisuralian) fossil assemblages in Western Australia. This study focuses on two groups of microfossils found within the member, the Ostracoda and Foraminiferida, and aims to document the species from these two groups. In conjunction with other palaeontological and lithological data this study also constructs an environmental setting for deposition of the Fossil Cliff Member.

Foraminifera and ostracodes are used in this study as they are ideal for biostratigraphic studies due to their small size, rapid evolution, and abundance within marine sediments. They are commonly used alongside palynomorphs in biostratigraphic work, as substantial assemblages can be recovered from relatively small quantities of rock. Foraminifera are testate protists that exhibit a wide range of test morphology and composition (Culver, 1993), and within the Palaeozoic they were exclusively benthic and inhabited marine environments from tidal flats, estuaries, and lagoons to deep abyssal plains of the open ocean. Benthic foraminifera evolved during the Cambrian, with major taxonomic diversifications in the Devonian and the Triassic to Early Jurassic (Culver, 1993). Ostracodes are benthic marine crustaceans that are characterised by having a bivalved shell hinged along the dorsal margin. Like foraminifera, they inhabit a variety of marine conditions from fresh-water lakes to open ocean abyssal plains (Moore et al., 1961). Ostracodes evolved during the Cambrian and underwent major taxonomic diversifications in the Ordovician to Silurian and Late Triassic (Scott, 1961a).

Significance and aims of this study

This detailed study of the ostracodes and foraminifera of the Fossil Cliff Member has the following aims:

- Present detailed taxonomic lists, stratigraphic distributions, and illustrations of ostracodes and foraminifera from the Fossil Cliff Member of the Holmwood Shale;

- Systematically document ostracode and foraminiferal faunal variations within the Fossil Cliff Member;

- Determine the depositional environment of the Fossil Cliff Member through study of the ostracode and foraminiferal faunas;

- Illustrate links between the cool-water southern hemisphere ostracode and foraminiferal faunas of the Fossil Cliff Member the warm-water equatorial Tethyan faunas and cool-water Boreal faunas of the northern hemisphere;

- Provide basic data on the taxonomy, diversity, and distribution of Cisuralian Fossil Cliff Member ostracode faunas as an initial step in establishing a Cisuralian ostracode biostratigraphy for Western Australia.

The significance of this study is that although the macrofauna of the Fossil Cliff Member of the Holmwood Shale has been well documented, the ostracodes within it have not, with only one significant study on the ostracode fauna undertaken (Fleming in Foster et al., 1985). Apart from the work of Crespin (1958) and Palmieri (in Foster et al., 1985), who had access to a limited number of samples, the foraminifera from the Fossil Cliff Member are also poorly recorded, and no previous detailed studies have been undertaken to document their distribution within the member. In addition, many of the ostracode forms recorded from the Fossil Cliff Member show an affinity at both generic and specific levels with forms from the warm-water Tethyan deposits of North America and Europe, as well as cold-water Boreal deposits of northern Europe. This study investigates this affinity to assess whether ostracodes can be used for palaeoecological comparisons based upon taxonomic similarity. The well-preserved nature of the microfauna present in the Fossil Cliff Member makes it ideal for taxonomic studies, and the distinct lithological and faunal variations within the member permit studies on the palaeoenvironment of the ostracode and foraminifera species present.

Regional setting and study area

Cisuralian sediments are found within all the major Phanerozoic basins in Western Australia, notably the Perth, Carnarvon, Canning, and Officer Basins (Figure 1). The thickest accumulation of Cisuralian sediments tends to be on the eastern-most margins of these basins, with the exception of the Officer Basin, where Cisuralian glacial sediments overlie a series of Palaeo-, Meso-, and Neoproterozoic sub-basins.

The Fossil Cliff Member is situated in the northern Perth Basin on the Irwin Terrace, where a thick sequence of Cisuralian marine and nonmarine sediment is present (Mory and Iasky, 1996) (Figure 2). The Irwin Terrace comprises a northerly elongated fault-bounded platform that is 20 km wide in the vicinity of the type section of the Fossil Cliff Member (Hocking, 1994). The eastern flank is bounded by the Darling Fault, which strikes slightly northwest and dips between 38° and 65° to the west. Displacement on the Darling Fault is at least 1700 m. Le Blanc Smith and Mory (1995) postulated that the moderate westerly dips on the contact between the basement and the Permian strata along the east of the Terrace represent a fjord-like glacial valley wall, and that the Darling Fault extends into the Urella Fault. The Urella Fault, which is the principal fault separating the Irwin Terrace from the Allanooka High to the west, is parallel to the Darling Fault, dips to the west, and has a substantial downthrow of several kilometres (Le Blanc Smith and Mory, 1995).

The Mullingarra Ridge, which extends along the western side of the Terrace, comprises an irregularly exposed and relatively topographically high assemblage of Precambrian sedimentary and crystalline rocks, known as the Mullingarra Complex, over which Permian strata are draped to form a broad anticlinal structure. Due to this, the Mullingarra Ridge is inferred to have been exposed during the Cisuralian (Mory and Iasky, 1996). The Fossil Cliff Member type section is located along the eastern side of the Irwin Terrace in Permian strata that lie in a weakly folded half graben. The strata here dip at a few degrees (8 to 15°) to the east and abut the Darling Fault, where the strata are dragged up at a moderate angle (30 to 55°) against the basement contact and about a fold axis that subparallels the Darling Fault. Most of the intrabasinal faults in the Irwin Terrace are predominantly dip-slip with throws of up to several hundred metres subparallel to the graben axis, trending northwest and transecting low-amplitude folds. Small reverse faults occur but are rare. This combination of structures is broadly indicative of sinistral transtensional extension (Mory and Iasky, 1996). Geological relationships and gravity modelling of the Irwin Terrace suggest an irregular pre-Permian topography that was buried by Permian sediments and later down faulted and preserved (Le Blanc Smith and Mory, 1995). The depositional basin during the Permian was extensive, encompassing all of the onshore Perth Basin as well as the onshore Carnarvon Basin and into the Canning Basin (Le Blanc Smith and Mory, 1995; Mory and Iasky, 1996).

The Permian sedimentary sequence within the Irwin Terrace comprises six formations, which are, from oldest to youngest, the Nangetty Formation, Holmwood Shale, High Cliff Sandstone, Irwin River Coal Measures, Carynginia Formation, and Wagina Sandstone. The Holmwood Shale contains three carbonate-bearing members, the Beckett, Woolaga Limestone, and Fossil Cliff Members. The Late Carboniferous to Asselian Nangetty Formation through to the Artinskian Carynginia Formation form a conformable sequence overlying the Precambrian basement that records the depositional history of the area through the majority of the Cisuralian, and this sequence is unconformably overlain by the Wordian (Guadalupian) Wagina Sandstone.

This study concentrates on the outcrop of the Fossil Cliff Member of the Holmwood Shale at its type section. The type section lies on the north branch of the Irwin River at latitude 28°55'S and longitude 115°33'E, 450 km north of Perth and 32 km north-east of Mingenew on the Yalgoo and Perenjori 1:250 000 standard map sheets (Figure 3). Exposed as a cliff face in the Irwin River valley, the section is approximately 12 m thick and comprises three parasequences consisting of alternating beds of fossiliferous limestone, sandy siltstone, and shale forming a progradational parasequence set. The maximum exposed thickness of the Fossil Cliff Member is at Beckett's Gully, 5 km to the southwest, where Playford et al. (1976) measured a 45 m-thick section.

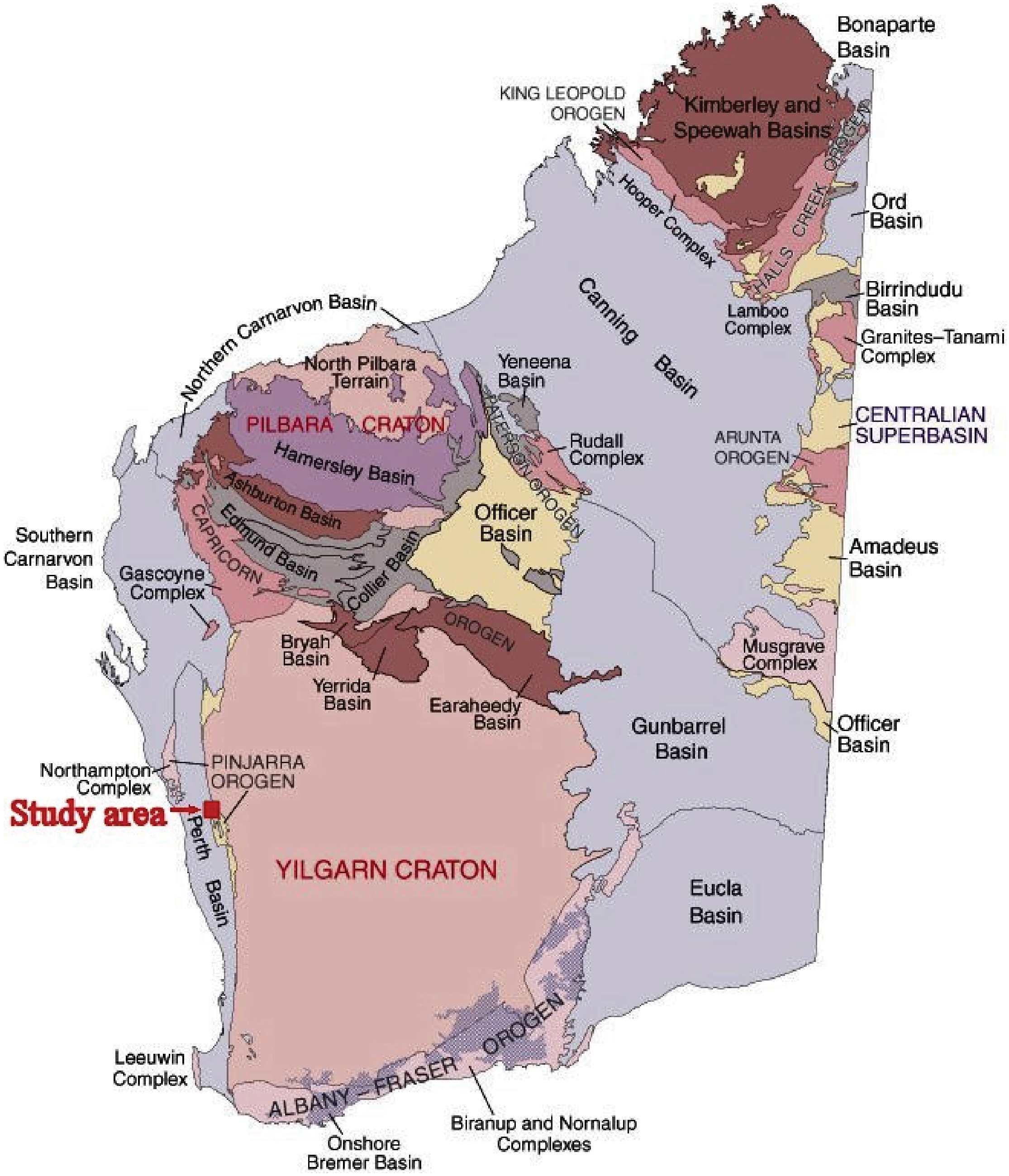


Figure 1. Major tectonic subdivisions of Western Australia, highlighting the location of Phanerozoic sedimentary basins in blue (after Geological Survey of Western Australia, 2001).

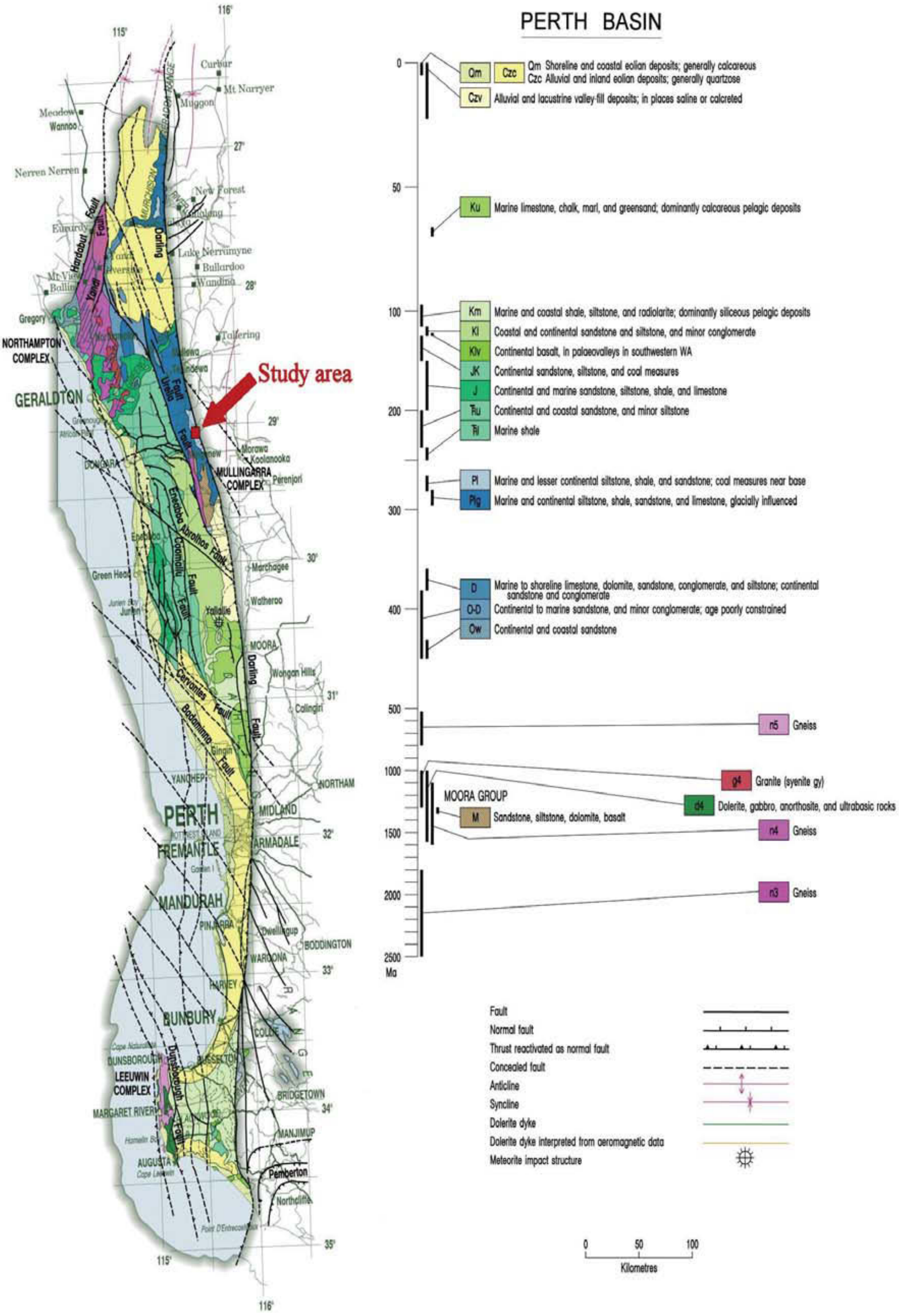


Figure 2. Solid geology map of the Perth Basin showing location of study area (diagram courtesy of P. Taylor, Geological Survey of Western Australia).

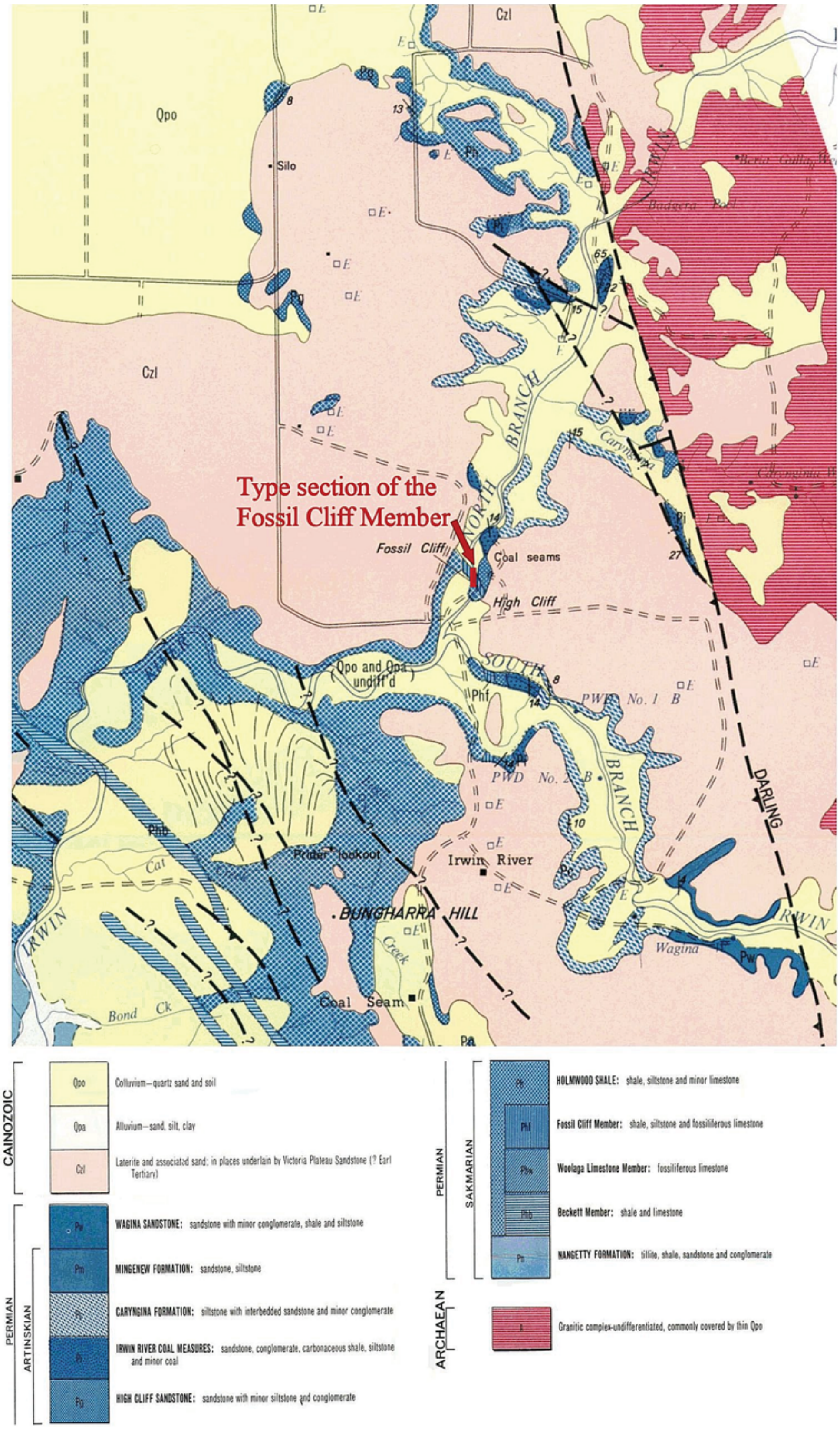


Figure 3. Locality diagram for the type section of the Fossil Cliff Member of the Holmwood Shale (adapted from Playford et al., 1976).

Previous work

The first studies on the Permian of the Perth Basin were based on outcrop areas from the Irwin Terrace, Coolcalaya Sub-basin, and Allanooka High (e.g. Campbell, 1910; Woolnough and Somerville, 1924; Clarke et al., 1951; Johnson et al., 1954). This work established the broad framework of the stratigraphic sequence within the Cisuralian rocks of the northern Perth Basin and has since been modified by Playford et al. (1976) and Mory and Iasky (1996).

The fossil fauna of the Fossil Cliff Member has been described in varying degrees of detail since 1859 when Davidson described the type specimen of *Neochonetes (Sommeria) pratti*, which was the first fossil species to be described from Western Australia (Newton, 1892). Both Playford et al. (1975) and Skwarko (1993) provided a detailed listing of the macrofaunal species found within the Fossil Cliff Member.

Foraminifera were first described from the Fossil Cliff Member by Howchin (1895), in what is the second oldest publication describing Australian foraminiferids. Since the work by Howchin, a number of important studies have been undertaken on Permian foraminifera by Chapman and Howchin (1905), Crespin and Parr (1941), Parr (1942), Crespin (1945b, 1947, 1958), Scheibnerová (1982), Palmieri (1983, 1994), Foster et al. (1985), and Palmieri et al. (1994). Apart from the detailed work by Crespin (1958), which included a broad biostratigraphy of the Permian of Australia, most of these studies have concentrated on the taxonomy of the foraminifera, and the only other work detailing the distribution of the foraminifera in the Fossil Cliff Member is by Ferdinando (2002).

The ostracodes of the Fossil Cliff Member are perhaps one of the least documented fossil groups within the unit, despite their excellent preservation. Only one taxonomic study of the Fossil Cliff Member ostracodes has been undertaken (Fleming in Foster et al., 1985), although Crespin (1945a) recorded an ostracode fauna from eastern Australia that shares some common species with the ostracode assemblage of the Fossil Cliff Member. Other work that has recorded ostracodes from the Fossil Cliff Member includes Clarke et al. (1951), McWhae et al. (1958), and Ferdinando (1990, 1992). In addition Jones (1989) described a Carboniferous ostracode fauna from the Bonaparte Basin that shows similarities to the fauna of the Fossil Cliff Member. Studies of ostracode assemblages from the Carboniferous to Permian Tethyan faunas of North and South America, Europe, Timor, and China indicate a similarity to the ostracode assemblages of the Fossil Cliff Member on a generic and in some cases specific level, e.g. Sohn (1954, 1983), Guseva (1971), Haack and Kaesler (1980), Bless (1987), Dewey (1988), Dewey et al. (1990), Dewey and Coker (1991), Crasquin-Soleau (1997), and Crasquin-Soleau et al. (1999).

Materials and methods

This study is based upon 160 samples taken from 3 m below the type section of the Fossil Cliff Member of the Holmwood Shale to the top of the exposed section. Samples were taken at approximately 10 cm intervals, and from 100 to 200 g of fresh sample was obtained from the outcrop by removing surrounding sediment and digging 5 to 10 cm into the exposure.

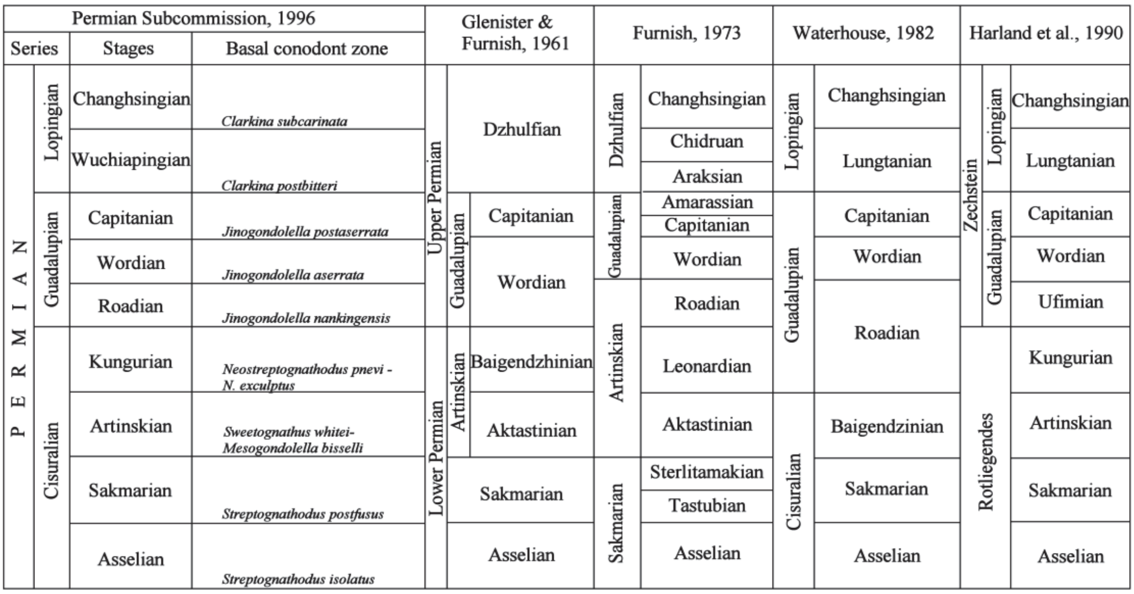
Samples were processed for microfossils using standard preparation techniques (see Glaessner, 1945). These involved boiling and disaggregation of samples in a solution of water, Calgon ™, and detergent, and then passing the resulting slurry through 2 mm, 150µm, and 63µm mesh sieves. The 150µm and 63µm sand fractions were then collected on filter paper in a Buchner funnel, dried, and stored in glass or plastic vials.

All sand fractions were systematically picked for foraminifera, ostracodes, and other bioclastic grains, and the specimens mounted on slides. Because of the difficulty in obtaining a consistent volume of residue from the various lithologies, the samples were examined from a qualitative perspective, although in some instances over one hundred specimens of ostracodes and foraminifera were picked from samples.

The relative abundance of foraminiferal and ostracode species were recorded as abundant (>20 specimens per sample), common (10 to 20 specimens per sample), frequent (5 to 9 specimens per sample), or rare (1 to 4 specimens per sample). Well-preserved foraminiferal and ostracode specimens were digitally imaged with a Phillips 505 Scanning Electron Microscope (SEM), having been sputter coated for 8 minutes with gold and platinum at 20 to 30 mÅ. All images were imported into a digital cataloguing program, Extensis Portfolio, and images were digitally cleaned using a graphics program, Paint Shop Pro.

Permian age correlation

Since the recognition of the Permian System by Murchison (1841), the scope and subdivisions of the Permian have changed substantially. The base of the Permian has recently been formally defined (Bogoslovskaya et al., 1995; Davydov et al., 1998) as the first occurrence of the conodont *Streptognathodus isolatus* in the *S. wabaunsensis* chronocline at Aidaralash Creek, Aktöbe region, northern Kazakhstan, with an age of approximately 291.5 Ma. The Permo-Triassic boundary is based upon the last appearance of the conodont *Clarkina changxingensis* and dated at 251.1 Ma (Yugan et al., 1997). Permian chronostratigraphic subdivisions adopted by the International Union of Geological Sciences (IUGS) divide the Permian into three series based on sequences and faunas from the Russian Platform, North America, and China (Figure 4): the Cisuralian, Guadalupian, and Lopingian respectively. The Cisuralian is divided into four stages, the Asselian, Sakmarian, Artinskian, and Kungurian. The Cisuralian Series is equivalent to the Early Permian chronostratigraphic subdivision used prior to the new division of the Permian by the IUGS. Overlying the Cisuralian is the Guadalupian Series, which is divided into the Roadian, Wordian, and Capitanian Stages. Above the Guadalupian Series is the Lopingian Series, divided into the Wuchiapingian and Changhsingian Stages. The Guadalupian and Lopingian Series combined form the Late Permian chronostratigraphic subdivision of the Permian previously used.



Permian Subcommission, 1996				Glenister & Furnish, 1961			Furnish, 1973		Waterhouse, 1982		Harland et al., 1990		
Series		Stages	Basal conodont zone										
PERMIAN	Lopingian	Changhsingian	*Clarkina subcarinata*	Upper Permian	Dzhulfian		Dzhulfian	Changhsingian	Lopingian	Changhsingian	Zechstein	Lopingian	Changhsingian
		Wuchiapingian	*Clarkina postbitteri*					Chidruan Araksian		Lungtanian			Lungtanian
	Guadalupian	Capitanian	*Jinogondolella postaserrata*		Guadalupian	Capitanian	Guadalupian	Amarassian Capitanian	Guadalupian	Capitanian		Guadalupian	Capitanian
		Wordian	*Jinogondolella aserrata*			Wordian		Wordian		Wordian			Wordian
		Roadian	*Jinogondolella nankingensis*				Artinskian	Roadian		Roadian			Ufimian
	Cisuralian	Kungurian	*Neostreptognathodus pnevi - N. exculptus*	Lower Permian	Artinskian	Baigendzhinian		Leonardian			Rotliegendes		Kungurian
		Artinskian	*Sweetognathus whitei-Mesogondolella bisselli*			Aktastinian		Aktastinian	Cisuralian	Baigendzinian			Artinskian
		Sakmarian	*Streptognathodus postfusus*			Sakmarian	Sakmarian	Sterlitamakian Tastubian		Sakmarian			Sakmarian
		Asselian	*Streptognathodus isolatus*			Asselian		Asselian		Asselian			Asselian

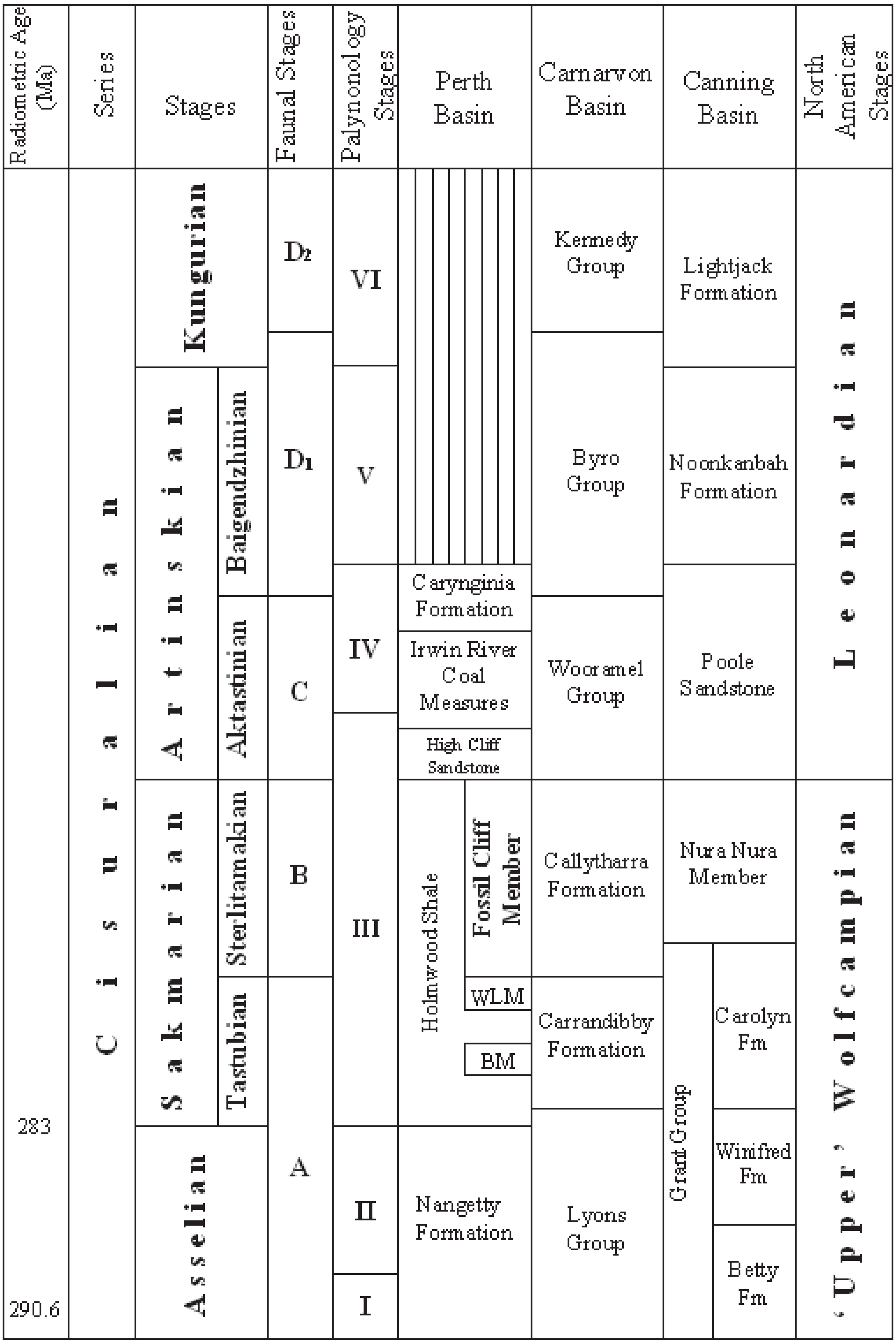
Figure 4. Permian chronostratigraphic scales showing the relationship of various scales that have been used for the Permian (adapted from Yugan et al. 1997).

The Permian in Australia

The Permian System in Australia has been subdivided into a number of Australian Stages on the basis of the bivalve, brachiopod, and gastropod faunas in marine strata (Dickins, 1978; Archbold, 1982; Archbold and Dickins, 1991). The main reason behind this is the paucity of ammonoid, conodont, and fusuline foraminiferal material in Australian Permian deposits, which have been the traditional media for providing correlation with the Permian stratotypes. The major fossil group used to subdivide the nonmarine rocks of the Permian in Australia are palynomorphs.

Dickins (1978), Archbold (1982), Archbold and Dickins (1991), and Archbold et al. (1993) have all proposed a subdivision of the Permian marine faunas of Western Australia into six faunal stages based upon the distribution of bivalves, brachiopods, and gastropods, which are abundant within the Permian of Western Australia and well documented and described. This zonation is tied into a similar zonation established for eastern Australia and, where possible, with international stratotypes. The Permian sequence within the Irwin River area has been correlated to have been deposited during the first four of these six faunal stages (Dickins, 1978; Archbold and Dickins, 1991; Archbold et al., 1993) (Figure 5).

Stage A includes the Asselian (Cisuralian) cold-water faunas of the Nangetty Formation and the Holmwood Shale (excluding the upper part of the Holmwood Shale containing the Fossil Cliff Member). This stage also includes the Lyons Group (Carnarvon Basin) and the Grant Group (Canning Basin). Cold-water bivalves from the genus *Eurydesma* are generally diagnostic of Stage A. Correlation of these faunas to eastern Australia links this fauna with the fauna found in the Lochinvar and Allandale Formations in New South Wales (Dickins, 1978; Archbold et al., 1993).



Note: BM – Beckett Member, WLM – Woolaga Limestone Member

Figure 5. Correlation chart of chronostratigraphy of the Cisuralian, Australian biozonations, and of stratigraphic units in the Perth, Canning, and Carnarvon Basins (modified from Archbold and Dickins, 1991; Brackel and Totterdell, 1995; and Yugan et al. 1997).

Faunal Stage B correlates to the Sakmarian fauna found in the Fossil Cliff Member of the Holmwood Shale. The Callytharra Formation (Carnarvon Basin) and Nura Nura Member of the Poole Sandstone (Canning Basin) also correlate to this stage, and the presence of an ammonoid fauna within both the Callytharra Formation and Nura Nura Member allow this faunal stage to be correlated with the Sterlitamakian (Late Sakmarian) Substage of the international scale. This is based upon the occurrence of the ammonoid *Metalegoceras hudsoni* in Oman, which Glenister et al. (1973) regarded as conspecific with *M. clarki* from the Nura Nura Member. Glenister et al. (1993) did not rule out an Upper Tastubian (Lower Sakmarian) age for this stage on the basis of ammonoids alone; however, other faunal elements of this stage can readily be correlated with international Sterlitamakian faunas (Dickins and Shah, 1980; Archbold, 1982, 2001). Faunal Stage B is less readily correlated with eastern Australian faunas, and Archbold et al. (1993) tentatively correlated this fauna with the Rutherford and Farley Formations of the Sydney Basin, New South Wales. Foster et al. (1985) on the basis of palynological evidence concluded that the Fossil Cliff Member appeared to be older than the Cattle Creek and Tiverton Formations of the Bowen Basin, Queensland. They however also remarked on the discrepancies between the correlations made using palynological, microfaunal, and macrofaunal data. Archbold et al. (1993), however, concluded that there is no discrepancy between these faunal groups with the zonation that they proposed nor with the earlier work on Australian correlation of the Permian done by Dickins (1970, 1977, 1978).

Faunal Stage C includes the fauna of the High Cliff Sandstone and the flora of the Irwin River Coal Measures. The marine fauna of the High Cliff Sandstone is sparse, with only a few brachiopod species (Coleman, 1957; Archbold, 1993), foraminiferal tests (Crespin, 1958), bivalves, and gastropods (Dickins, 1963) described. The flora of the Irwin River Coal Measures is very rich and diverse, consisting of both palynomorphs and plant fossils, dominated by *Glossopteris* and *Gangamopteris* palynomorphs. Faunal Stage C also includes the marine fauna of the lower and middle Wooramel Group (Carnarvon Basin) and the flora of the Poole Sandstone (above the Nura Nura Member) (Canning Basin). Dickins (1963, 1978) suggested that Faunal Stage C is equivalent to Early Artinskian (Aktastinian); however, Cockbain (1980) and Glenister et al. (1993) regarded the fauna as Baigendzhinian (Late Artinskian) on the basis of the presence of the ammonoid genus *Pseudoschistoceras*. Archbold et al. (1993) cited evidence from the bivalve, brachiopod, and gastropod fauna regarding the close relationship between the marine faunas of Faunal Stages B and C, in addition to a lack of independent evidence on the range of *Pseudoschistoceras*, as reasons to include Faunal Stage C in the Aktastinian (Early Artinskian).

Within the Cisuralian sequence of the Irwin River area, Faunal Stage D is represented by the Carynginia Formation. Archbold et al. (1993) divided Faunal Stage D into Faunal Stages D_1 and D_2. The Carynginia Formation lies within Faunal Stage D_1, and Faunal Stage D_2 does not crop out within the Irwin River area. Across Western Australia, Faunal Stage D_1 includes the Mingenew Formation (Perth Basin), the Byro Group (Carnarvon Basin), the Noonkanbah Formation (Canning Basin), and the limestone member of the Fossil Head Formation (Bonaparte Basin). Faunal Stage D_1 has been correlated with the Gebbie Subgroup and the Lakes Creek Beds (Bowen Basin, Queensland), in addition to the Branxton Formation (Sydney Basin, New South Wales). Cockbain (1980) indicated that Faunal Stage D_1 was Baigendzhinian because of the species similarity to *Neochonetes fredericksi* from the Baigendzhinian of the southern Urals. Archbold et al. (1993) considered that Faunal Stage D_1 is post-Early Artinskian (Aktastinian) and represents the beginning of the Late Artinskian (Baigendzhinian).

Chapter 2: Global setting and Permian stratigraphy

Cisuralian palaeogeography

Global

Two main features dominate the global palaeogeography during the Cisuralian: the supercontinent of Gondwana in the south; and the tropical Tethyan Ocean located just to the north of the equator (Figure 6). Australia formed a component of the supercontinent of Gondwana, which also consisted of the continental masses of South America, Africa, Malagasy, Arabia, Iran, Turkey, India, Antarctica, greater New Zealand (including the New Zealand Plateau), the submerged Lord Howe and Norfolk Ridges, and parts of Afghanistan, southeast Asia, and Indonesia (Coleman, 1993; Scotese and McKerrow, 1990; Li and Powell, 2001). During the Cisuralian the western margin of Australia was joined to the northeastern edge of greater India (Veevers et al., 1975, Scotese et al., 1979; Scotese and McKerrow, 1990; Li and Powell, 2001) (Figure 7). A number of authors have argued for a more northerly position of India (e.g. Archbold, 1983), but the northeastern placement is preferred, as it permits reasonably accurate backtracking of India along the path indicated by Cretaceous-Tertiary magnetic anomaly patterns (Talent, 1984; Coleman, 1993; Li and Powell, 2001).

The Tethyan Realm encompassed most of Europe, North America, and parts of Asia and is generally represented in the geological record by shallow-water deposits with significant amounts of carbonate deposition and with such fossil forms as fusuline foraminifera, compound rugose coral, and goniatitic ammonoids widespread. The northern part of the Tethyan Realm, the continent of Laurussia, is characterised by the occasional development of restricted seas with high levels of salinity (Zechstein, Phosphoria, and the Russian Kazanian-Kungarian sedimentary sequences). In northeastern Siberia the deposits of Verchoyan and Kolyma, which lack the fusuline foraminifera and compound rugose corals of typical Tethyan faunas, represent northern polar regions (Hill 1958; Waterhouse 1988; Chaloner and Creber, 1988; Bondareva and Foster, 1993).

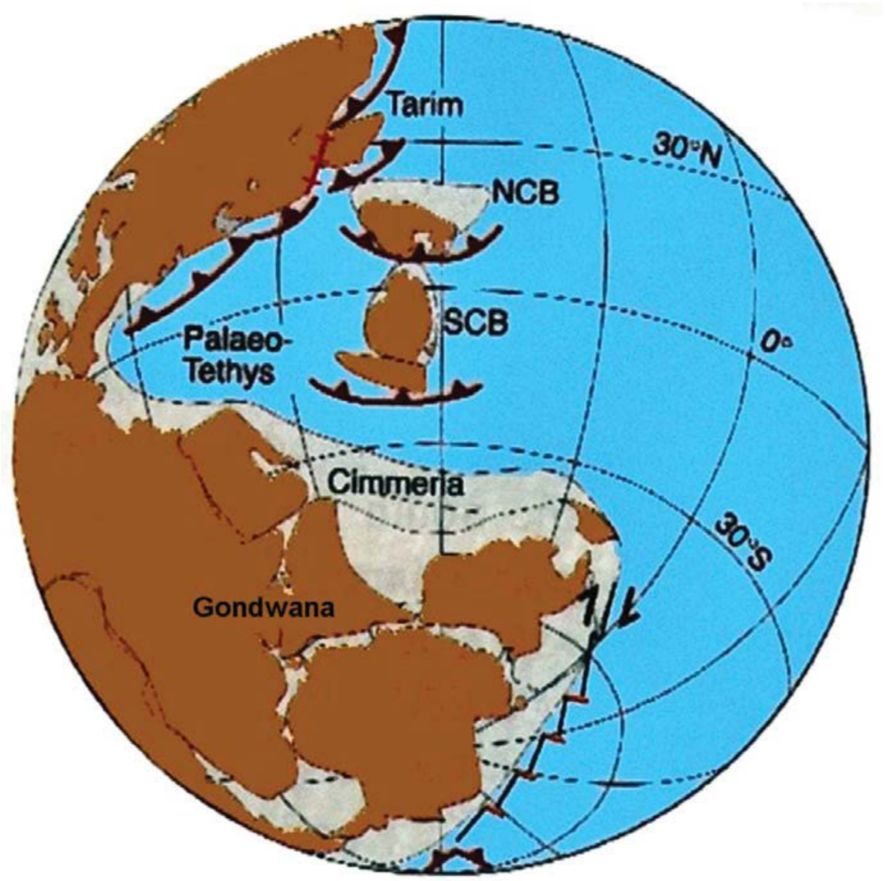


Figure 6. Global reconstruction of the Earth 280 Ma. Continental areas above sea-level are shown in brown; Continental areas below sea-level are shown in white; Oceanic areas are shown in blue; NCB = North China Block; SCB = South China Block (from Li and Powell, 2001).

Gondwana was amalgamated at the end of the Neoproterozoic (Burke and Dewey, 1973) and, as part of Pangaea, was dismembered drastically in the late Mesozoic to early Cainozoic, roughly 110 to 50 million years ago. Pangaea itself was a result of the conjugation of the supercontinents of Gondwana, Laurussia (joining with Siberia to form Laurasia), and most probably a number of east Asian continental masses (Scotese et al., 1979; Veevers, 1984; Coleman, 1993; Li and Powell, 2001). The Gondwanan continent was intermittently inundated by marine incursions along lines of pending dismemberment by epeiric or epicratonic seas or covered by great lake systems. Veevers (1995) attributed the emergent and long-lived nature of Gondwana to the presence of buoyant mafic underplating of the supercontinental crust and judged that the Laurasian continent lacked this and as a result was short-lived and generally submergent, forming the large shallow seas of the Tethys.

The influence of Gondwana and the Tethys ocean resulted in the establishment of two major palaeogeographic realms, the warm-temperate to tropical Tethyan Realm, and the glacially dominated Gondwanan Realm, with the much smaller Boreal Realm situated in the northern polar region. Overall, the Cisuralian world possessed a great degree of asymmetry in climate, with southern glaciation extending much closer to the equator than glaciation from the north (Waterhouse and Bonham-Carter, 1976; Waterhouse, 1988). The rapid onset of glaciation in Gondwana, starting in the early Visean (Late Carboniferous) and with a second pulse in the late Visean (Wright and Vanstone, 2001) is thought to have been related to a change in oceanic and atmospheric circulation patterns that resulted from the closing of the equatorial seaway between Gondwana and Laurussia (Archbold, 1998; Smith and Read, 2000).

Gondwana

Palaeogeography during the Sakmarian was dominated by the establishment of a series of marine or brackish-water embayments that extended into the Gondwanan continent as a result of the melting of the continental ice sheet or ice sheets. Cisuralian marine faunas that have been recovered from the Himalayas, Parana, Kalahari, Ventania, peninsular Indian, and Australian basins confirm the existence of widespread marine conditions. The marine transgression is also evident in many other areas of Gondwana by the occurrence of trace fossils, acritarchs, pelitic facies, and sedimentary structures within the Indian continental basins, the Karoo and Transantarctic Basins, and other regions indicating brackish-water conditions during the period of widespread glaciation and immediately following glaciation (Lindsay, 1970; Dickins, 1977; Rocha-Campos and Rosler, 1978; Dickins and Shah, 1980; Casshyap and Srivastava, 1987; Casshyap and Terawi, 1987; Visser, 1989; Barrett, 1991; Kalia et al., 2000).

During the Early Sakmarian the central and eastern Tethyan margin was generally characterised by cold climates reflected in the low diversity of marine faunas. The cold-water bivalves *Eurydesma* and *Deltopecten* have been recovered from many sequences along the Tethyan margin, indicating a strong Gondwanan element in faunal assemblages. These conditions were replaced by warmer climates later in the Sakmarian and Artinskian (Dickins, 1977, 1985; Archbold, 1983). Similarly, cold-water Sakmarian faunas are found in western India (Kalia et al., 2000) and eastern Oman and along the

Western Australian margin. Cold-water conditions also existed along the eastern and southern margin of Gondwana, typified by faunas such as those from the Bonete Formation in eastern Argentina, the upper part of the Itarare Group in Brazil (Parana Basin), and the Allandale Formation in the northern Sydney Basin (Rocha-Campos and Rosler, 1978; Dickins, 1977; Langford, 1991).

In contrast to the cold-water conditions found around the Gondwana landmass, warm temperate to subtropical conditions were present during the deposition of the shallow-marine Copacabana Formation in Bolivia and southern Peru (Newell et al., 1953; Chamot, 1965; Wilson, 1990). Further to the north in Venezuela, subtropical to tropical waters supported a rich and diversified fauna in low latitude troughs (Arnold, 1966; Hoover, 1981).

During the Asselian and Sakmarian glaciation was prevalent across Gondwana, extending as far north as palaeolatitude 30°S (Chaloner and Creber, 1988; Waterhouse, 1988). Beginning in the Late Carboniferous, this glacial period deposited thick tillite sequences in many sedimentary basins, striated basement rocks, and formed glacial valleys across the continent of Gondwana (Visser, 1987, Playford, 2001). Gondwanan sedimentary deposits of the Asselian to Sakmarian are characterised by fine- to medium-grained terrigenous clastic sedimentation, with associated glacial debris such as such drop-stones in the higher-latitude regions. *Glossopteris* flora and *Eurydesma* fauna (Dickins 1977) characterised the fossil record during this glacial period, with the faunas generally having a low diversity.

Throughout the Asselian to Sakmarian, Gondwana had a high degree of faunal provincialism (Bambach, 1990). Archbold (1983, 2000b) used chonetidine brachiopods and other fossil groups to identify five distinct faunal provinces within Gondwana during this period: the Andean, Paratinan, Austrazean, Cimmerian, and Westralian Provinces (Figure 7). These provinces have faunal characteristics ranging from almost Tethyan in the northernmost Andean Province, to the characteristic Gondwanan cold-water faunas of the Austrazean Province. Water temperatures ranged from warm-temperate to subpolar in these provinces (Tarling, 1981; Waterhouse, 1980a, 1980b; Sporli and Gregory, 1981; Singh, 1987; Archbold, 2000b). These endemic centres were also influenced in part by land barriers (Archbold, 1983; Hill, 1958). During the Late Sakmarian (Sterlitamakian) the climate ameliorated, and glaciation began to retreat from all but the southernmost regions of Gondwana, resulting in the appearance of highly diverse and abundant faunal assemblages and a decrease in endemic faunas in the warmer regions of Gondwana (Hill, 1958; Archbold, 1983; Visser, 1987).

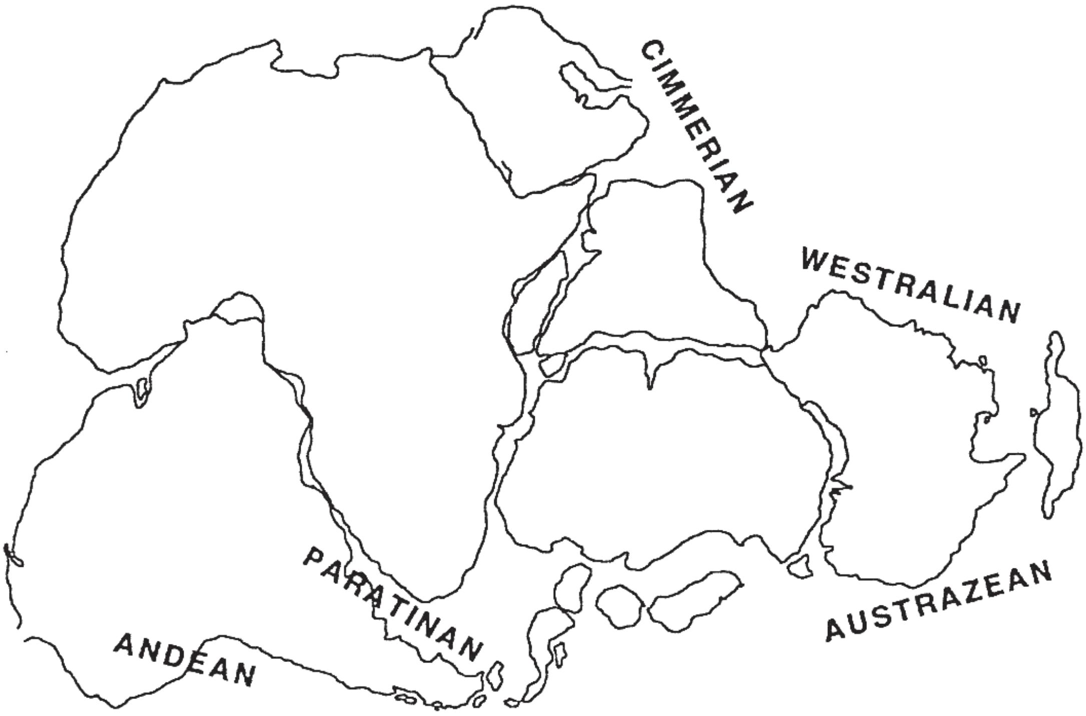


Figure 7. Reconstruction of Gondwana, showing faunal Provinces (modified from Archbold, 1983; and Coleman, 1993).

Australia

During the Asselian to Early Sakmarian, Australia occupied high southern latitudes, with the South Pole lying just west-southwest of Tasmania (Veevers, 1976; Bradshaw et al., 1988; Scotese and Barrett, 1990; Li and Powell, 2001); this resulted in widespread glacigene sedimentation across Australia during this time. (Figure 8).

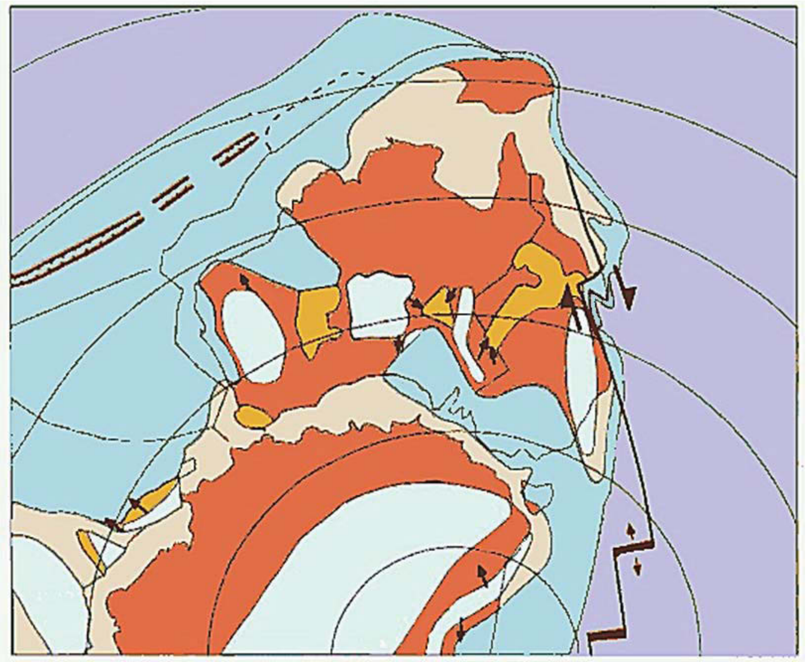


Figure 8. Reconstruction of Australia during the Asselian to Sakmarian (~280 Ma), showing position of Antarctica and Greater India. Orange = emergent continent above sea-level; cream = emergent continent below sea level; yellow = terrestrial sedimentary basin; pale blue = continental ice cover; light blue = shallow-marine; purple/blue = oceanic area (adapted from Li and Powell, 2001).

The ice sheet covering much of western, central, and southern Australia retreated during the Late Sakmarian, leaving only the central cores of the ice sheets (Brackel et al., 1988). On the outer and periglacial edges of the core areas, terrestrial and glaciomarine sedimentation occurred. Marine inundation also occurred along the west of the Australian continent, locally depositing cold to cool-temperate-water carbonates, with cool-temperate terrigenous clastics and carbonates deposited to the north in western Timor (Bird et al., 1987).

In eastern Australia a magmatic arc stretched from Cape York in the north to the Bowen-Sydney Basin in the southeast, and emplacement of granitoid plutons, as well as felsic and intermediate volcanism, occurred along this magmatic arc. Active submarine volcanism also occurred in the allochthonous Gympie Terrane (Veevers, 1976; Brackel and Totterdell, 1995; Li and Powell, 2001). Thick fluviolacustrine sediments including coal measures were deposited in the Denison Trough on the western margin of the Bowen Basin, and marine deposition occurred in parts of the Sydney Basin (Scheibnerová, 1982; Langford, 1991). Cool temperate to subpolar climatic conditions in the region inhibited arborescent plant growth across eastern Australia (Draper and

Beeston, 1985). Farther south in the Tasmania Basin, thin coals, which contain virtually no woody tissue, were deposited in a wet, treeless moor environment (Bacon, 1986).

By the Late Sakmarian (Sterlitamakian), the continent was no longer affected by glaciation or associated isostatic effects. The base of this period corresponds to a depositional hiatus in the Canning Basin (Crowe et al., 1983; Towner et al., 1983), the temporary end of sedimentation in Victoria, the beginning of deposition in parts of the New England Orogen, and a change from marine to non-marine deposition in Tasmania (Langford 1991; Brackel and Totterdell, 1995; Li and Powell, 2001).

Western Australia

The Fossil Cliff Member of the Holmwood Shale is situated at the northern end of the Perth Basin within the Irwin Terrace. During the late Palaeozoic, the Perth Basin was one of a number of rift-graben systems that existed along the western margin of the Australian Craton, which also included the Carnarvon and Canning Basins to the north (Falvey, 1974; Veevers and Cotterill, 1978; Falvey and Mutter, 1981; Veevers and Hansen, 1981; Lavering, 1985; and Coleman, 1993). The detached rifted portions of this margin are found, at least in part, along the eastern margin of India or in the general area northwest of the Bramahputa Bend as metamorphosed imbricated slices or as underthrust tectonic flakes (Veevers et al., 1975).

The Perth Basin has a history of rifting that extends from the Cisuralian to the separation of greater India and Australia during the Neocomian (Larson et al., 1979; Veevers et al., 1985). In the northern Perth Basin the initial phase of rifting in the Cisuralian was followed by a prolonged period of subsidence and normal faulting (Smith and Cowley, 1987; Marshall and Lee, 1987, 1988). The development of the Perth Basin is a direct result of movement on the Darling Fault caused by this rifting (Jones, 1976; Playford et al., 1976). The combination of faulting and rifting produced a basin that is essentially a series of en echelon troughs separated by block-faulted structural highs (Veevers, 1984).

During the Permian the Perth and Southern Carnarvon Basins formed one continuous depocentre (along with the smaller Collie, Wilga, and Boyup Basins in the southwest of Western Australia), which has been named the Westralian Superbasin

(Yeates et al., 1987; Geological Survey of Western Australia, 1990; Hocking 1994). An epeiric sea covered the Westralian Superbasin and extended west across to the landmass of greater India (Veevers, 1976; Bradshaw et al., 1988; Scotese and McKerrow, 1990). This epeiric sea covered a failed rift arm, with a triple point located at the northern part of the Northern Carnarvon Basin (Veevers, 1984). The basins forming the Westralian Superbasin were not stable, with a vertical jostling between blocks. Consequently, variation occurred in the amount and rates of sedimentation within grabens and between grabens. The thickness of a formation is thus likely to vary greatly even over small areas within a basin (Mory, A. J., 2001, pers comms).

The Westralian Superbasin is thought to have been a gently undulating low-land area etched by the erosive action of glacial ice sheets that covered it during the Late Carboniferous to Cisuralian, with a topographic gradient existing from south to north (Teichert, 1941; Hocking et al., 1987; Le Blanc Smith, 1993). The broad depocentre was surrounded by a Precambrian hinterland comprising hills formed by the Darling and Urella faults that delineated the superbasin margin to the east and were active during the Permian (Hocking et al., 1987). The Precambrian inliers of the Northampton and Mullingarra Blocks and the Yandanooka and Moora Groups are thought to have been exposed during the Permian and formed topographic highs within the shallow sea (Le Blanc Smith and Mory, 1995).

On the western margin of the Australian Craton, the extensive Late Carboniferous glaciers that had covered large portions of Gondwanaland were beginning to retreat with the climatic amelioration that was initiated during the Late Sakmarian (Playford, 2001). At the base of the Permian sequence in the Irwin River area, the glacigene Nangetty Formation was laid down in a marginal marine environment. Smith and Cowley (1987) consider this thick sequence to be the result of extremely rapid subsidence associated with initial rifting. At the start of the Late Sakmarian a richly fossiliferous, shallow-marine, carbonate-lutite sequence (Fossil Cliff Member) was deposited, followed by shallow-marine sandstone, which may have been partly littoral in origin (Playford et al., 1976). At the close of Late Sakmarian, the fluvial facies of the Irwin River Coal Measures extended across the region following a marine regression (Figure 9).

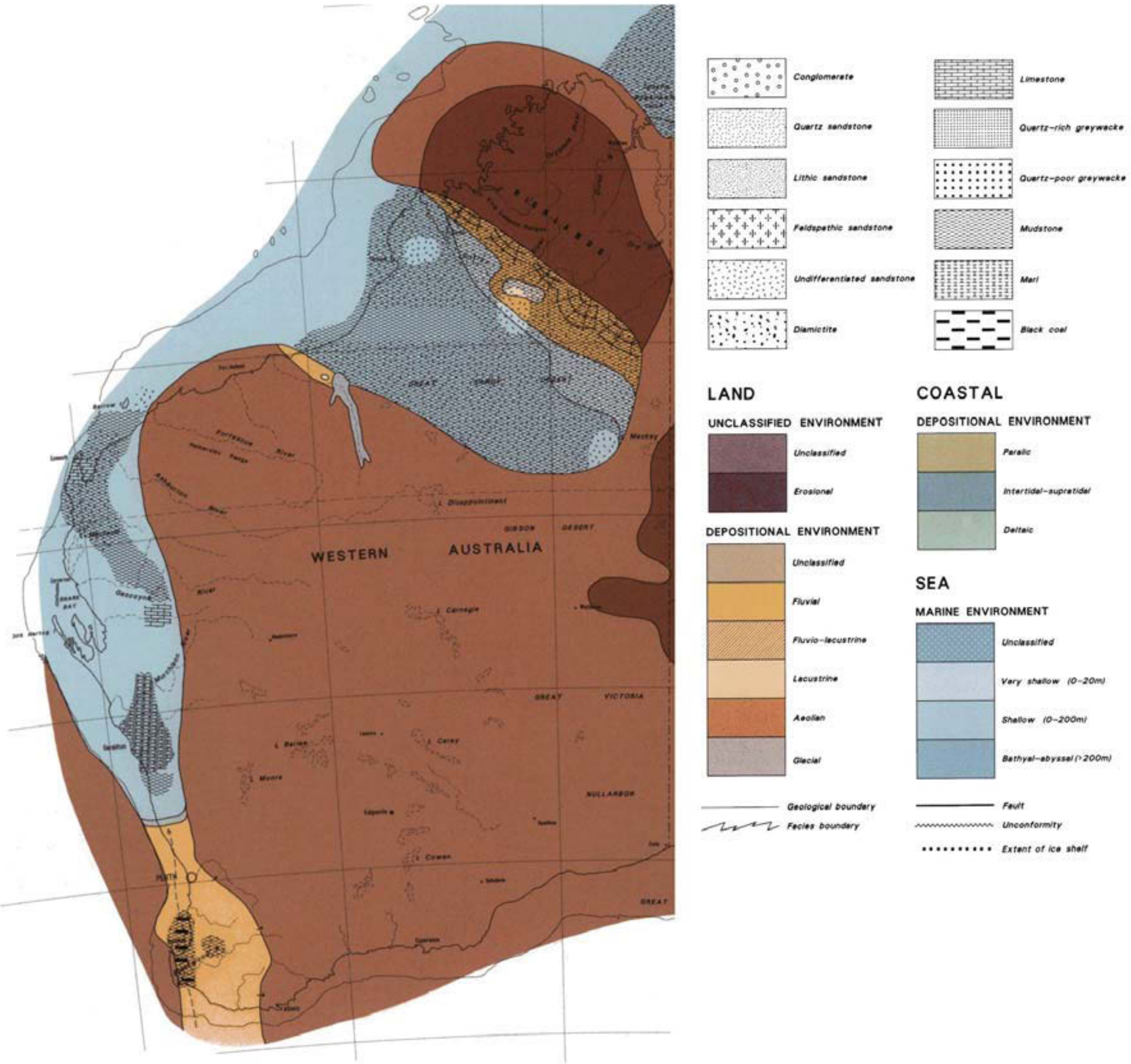


Figure 9. Palaeogeographic reconstruction of Western Australia during the Cisuralian, ~285Ma (adapted from Brackel and Totterdell, 1995).

Temperatures in the western part of Australia were warmer than those in the east due to both the lower palaeolatitude in the west and the presence of warm water currents from the southernmost Tethyan ocean along the northwest of the Australian Craton (Veevers, 1988; Bradshaw et al., 1988; Dickins, 1993; Archbold 1998). Water temperatures in the Westralian Province during the Sakmarian, after the cold episode in the Asselian, became cool-temperate. Towards the end of the Cisuralian however, minor glaciation in the southeast and southwest of Australia indicates a regional drop in temperatures (Compston, 1960; Archbold, 1983; Wilson, 1989).

While the Asselian and Early Sakmarian faunas of Westralian Province possessed a strong affinity to those of the Austrazean Province of Archbold (1983), the climatic amelioration in the Westralian Province during the late Sakmarian saw these links with the cold-water faunas to the southeast severed (Archbold, 1983, 2000b).With climatic warming, the fauna of the Westralian Province became more diverse, and the fossil assemblages have strong links with those from the eastern Himalayan faunas of the Cimmerian Province, as well as some similarities with faunas from the Andean Province and the Tethyan Realm (Archbold, 1983, 2000b; Kalia et al., 2000; Mertmann, 2000).

The Permian succession in the northern Perth Basin

The Permian sedimentary succession in the northern Perth Basin is a mixture of marine and continental deposits, ranging from glacial marine tillite to cool-temperate fluvial sediments. The sequence commences with the basal Nangetty Formation, which unconformably overlies Precambrian rocks, and is successively overlain by the Holmwood Shale (including the Fossil Cliff Member), High Cliff Sandstone, Irwin River Coal Measures, and the Carynginia Formation, with the Late Permian Wagina Sandstone disconformably overlying this sequence (Figure 10). Apart from the contact between the Carynginia Formation and the Wagina Sandstone, all these units conformably overlie each other or are separated by only minor hiatuses.

Nangetty Formation

The Nangetty Formation is the basal unit of the Permian sequence in the northern Perth Basin. It was initially named the Nangetty Glacial Formation by Clarke et al. (1951), and this was later amended to the Nangetty Formation by Playford and Willmott (in McWhae et al., 1958). The type area is in a region of poor and discontinuous exposure in the Nangetty Hills region, and no specific type section has been designated.

The maximum measured exposed thickness of the Nangetty Formation is around 130 m (Playford et al., 1976), and the maximum thickness of the formation in the subsurface is greater than 1500 m adjacent to the Urella Fault, just east of Eradu. Gravity modelling of the Irwin Terrace by Le Blanc Smith and Mory (1995) gave a maximum thickness of greater than 1000 m for the Nangetty Formation.

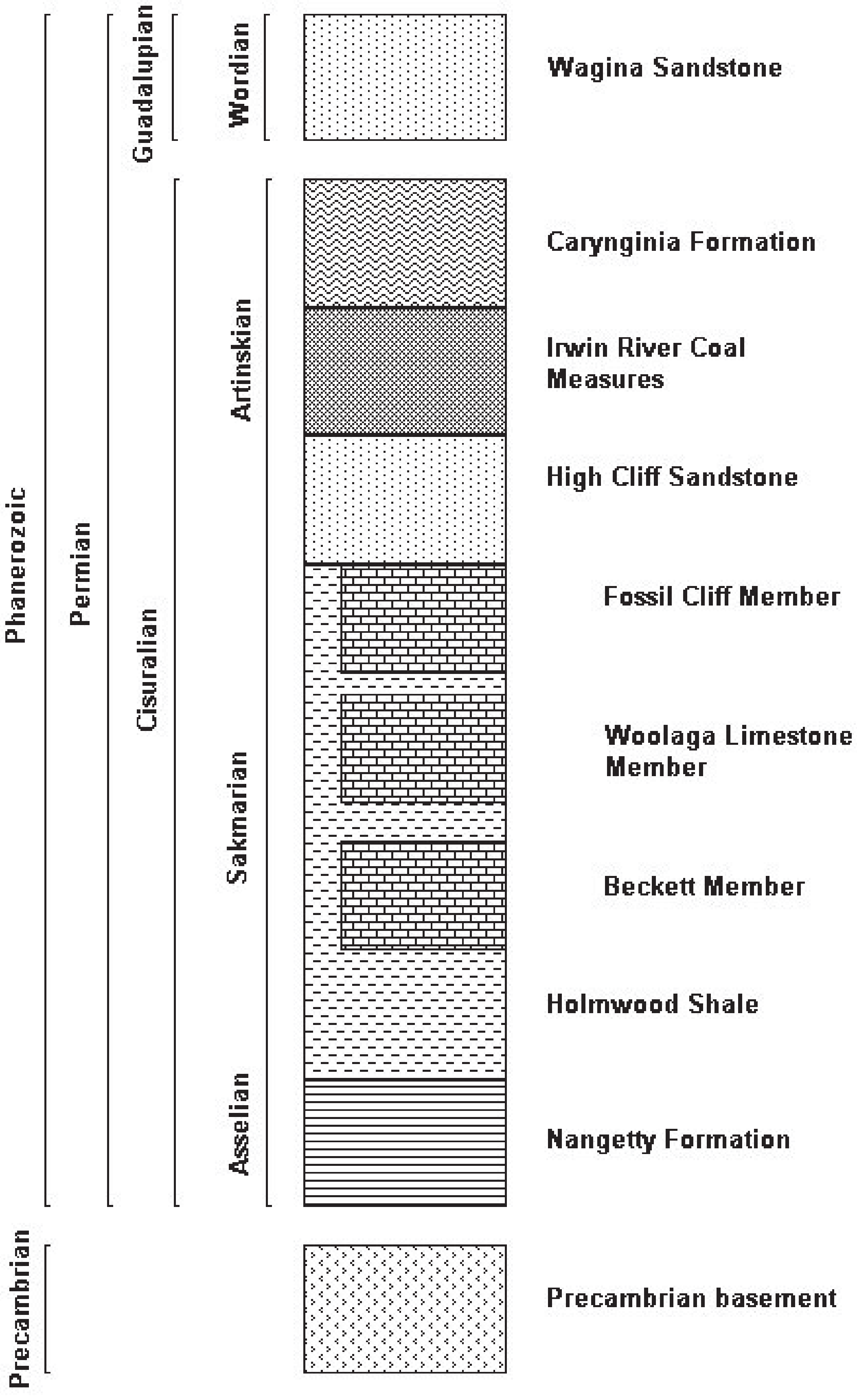


Figure 10. Permian stratigraphy of the Irwin River area, northern Perth Basin, Western Australia (stratigraphy from Geological Survey of Western Australia, 1990).

The Nangetty Formation comprises a sequence of massive to crudely bedded tillite, shale, sandstone, and conglomerate with erratic boulders (up to 6 m across), cobbles, and pebbles set in a matrix of sandy silts and clays. These erratic boulders were derived mainly from the Precambrian Yandanooka and Moora Groups, with some metamorphic and granitic Archaean rocks derived from the Yilgarn Craton also present as erratics. These erratics are faceted and striated, indicative of glacial processes, and some cannon-ball limestone concretions are present within the formation (Le Blanc Smith and Mory, 1995). The contact of the Nangetty Formation with the Holmwood Shale is conformable and gradational, with the principal discriminators for the contact being the blue-green shale and mudstone of the Nangetty Formation grading into the black-grey shales and siltstones of the Holmwood Formation, a decrease in the frequency of erratics, and the prevalence of mica in the overlying Holmwood Shale.

Crespin (1958) recorded the foraminifera *Hemigordius schlumbergeri* and *Hyperammina elegantissima* from the formation, although Mory (1995) believed these specimens are from the overlying Holmwood Shale. Work by Backhouse (1993) recorded Stage 2 palynomorphs from the formation and he assigned an age of latest Carboniferous to Asselian (Cisuralian) to the Nangetty Formation.

Holmwood Shale

The Holmwood Shale was defined by Clarke et al. (1951) as the black shale overlying the Nangetty Formation and underlying the Fossil Cliff Formation. Johnson et al. (1954) redefined the Holmwood Shale Formation to include the Fossil Cliff Formation as they felt that it was not sufficiently different to warrant formation status; however, Playford and Willmott (in McWhae et al., 1958) did not adopt this new nomenclature, although Playford and Willmott did note that there was some merit in the proposal of Johnson et al. (1954). While they agreed that the Fossil Cliff Formation could justifiably be regarded as an upper, more calcareous facies of the Holmwood Shale, they felt that the name Fossil Cliff Formation was firmly entrenched in the literature and that it would be advisable to continue to recognise it as a separate formation. Playford et al. (1976) decided that this entrenchment was not a sufficient reason to justify retaining the unit as a formation based upon its difficulty to map and that it differs significantly from the Holmwood Shale only in that it contains lenticular beds of fossiliferous limestone. It was on this basis that they changed the name of the Fossil Cliff Formation to the Fossil Cliff Member of the Holmwood Shale. The Holmwood Shale contains three members, the Beckett Member in the lower part of the Holmwood Shale and the Woolaga Limestone and Fossil Cliff Members in the upper part of the formation.

The type section of the Holmwood Shale is along Beckett's Gully and is both poorly exposed and faulted, so that its total measured thickness is not reliable. Playford and Willmott (in McWhae et al., 1958) measured the type section as 566 m thick, and later work by Le Blanc Smith and Mory (1995) estimated that Holmwood Shale ranges from 400 to 700 m thick in the northern Perth Basin. The type section illustrates the range of rock types found throughout the formation: shales, sandy siltstones, and thin, lenticular carbonate bands. The lower part of the Holmwood Shale comprises grey-green shales with thin beds of cone-in-cone limestones and also encompasses the Beckett Member, which consists of alternating bands of shale and limestone with a thin band of phosphatic limestone containing goniatitic ammonoids. Rare glacial erratics occur within this part of the Holmwood Shale, especially near the base. The upper part of the Holmwood Shale mainly consists of micaceous, well-bedded clayey siltstone. Veins of gypsum running subparallel to bedding and jarosite staining of the siltstone are diagenetic features of the formation. This upper part of the unit also contains thin, lenticular, fossiliferous limestone beds, especially towards the top of the unit where they characterise the Fossil Cliff Member. A conspicuous richly fossiliferous limestone bed lower in this part of the unit called the Woolaga Limestone Member was documented by Playford (1959) and has been mapped only in the Woolaga Creek area, about 25 km to the south of the Irwin River locality. The subsurface Holmwood Shale is a monotonous sequence of siltstone, sandy siltstone, and mudstone with rare limestone beds (Mory and Iasky, 1996).

The fauna of the Holmwood Shale is mainly agglutinated foraminiferids (Crespin, 1958), sparse fenestrate bryozoans, and thin-shelled, dwarfed brachiopods (Playford et al., 1976). Palynomorphs from the lower part of the Holmwood Shale are from just below the *Pseudoreticulatispora confluens* Zone of Foster and Waterhouse (1988) (Backhouse, 1993). The upper part of the Holmwood Shale lies with the *P. confluens* palynomorph Zone (Backhouse 1998). This gives an age of Asselian (Cisuralian) or earlier for the lowest part of the Holmwood Shale and a Sakmarian (Cisuralian) age for the upper part of the formation (Backhouse, 1993; Foster et al., 1985). The Beckett Member contains a goniatite fauna that includes the species *Juresanites jacksoni*, *Uraloceras irwinensis*, and *Metalegoceras kayi* (Miller, 1932; Glenister and Furnish, 1961). The presence of these species is a further indication of a Sakmarian age for the Holmwood Shale (Glenister and Furnish, 1961). The Fossil Cliff and Woolaga Limestone Members contain a very rich and diverse fauna of macro- and microfossils along with a palynomorph flora. Playford et al. (1976) listed a large variety of species that have been described from the Holmwood Shale and each of its members.

Fossil Cliff Member

The Fossil Cliff Member is exposed only in the small area from the north branch of the Irwin River to 6.5 km south of Beckett Gully. It may also occur north of the Irwin River, although the characteristic limestones that define the member have not been seen in this area. Correlatives of the member have been reported from a number of wells drilled in the Irwin Sub-basin, extending as far south as Cadda No. 1 (Playford et al., 1976). McTavish (1965) also tentatively identified beds belonging to the Fossil Cliff Member from the BMR 10 stratigraphic well. The thickest measured section of the member is 45 m from Beckett Gully, and the type section at Fossil Cliff was measured at 27 m thick by Playford et al. (1976), who included more than 14 m of rock from the opposite bank of the south branch of the Irwin River that may not belong to the Fossil Cliff Member facies. The Fossil Cliff Member consists of interbedded dark siltstone, sandy siltstone, and richly fossiliferous limestone. The limestone beds, mainly bioclastic calcarenites that characterise the member are thin and markedly lenticular (Figure 11). The siltstones are sparsely fossiliferous.

The Fossil Cliff Member contains a rich and diverse fauna consisting of brachiopods, bivalves, gastropods, crinoids, solitary rugose corals, bryozoa, nautiloids, ammonoids, palaeoniscoid teeth and scales, foraminifera, ostracodes, and trilobites (Playford et al., 1976; Daymond, 1999). The only ammonoid species found within the Fossil Cliff Member, *Metalegoceras kayi*, provides an age of Sterlitamakian (Late Sakmarian), and Foster et al. (1995) recorded palynomorphs from the *Pseudoreticulatispora pseudoreticulata* Zone of Foster and Waterhouse (1988), that also confirm a Sterlitamakian age for the Fossil Cliff Member.

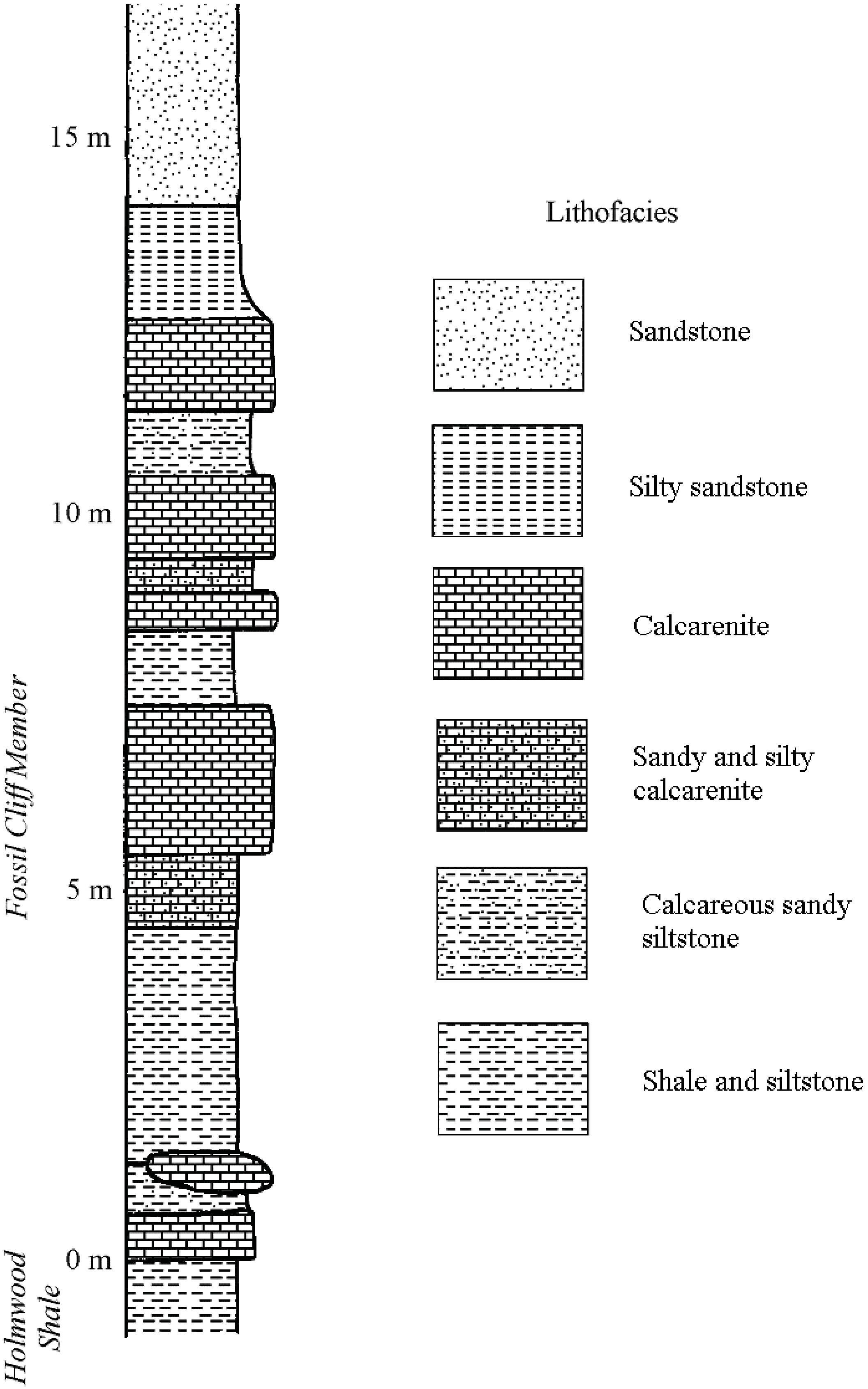


Figure 11. Simplified stratigraphic log of the type section of the Fossil Cliff Member of the Holmwood Shale.

High Cliff Sandstone

The name High Cliff Sandstone was introduced by Clarke et al. (1951) for the unit of cross-bedded sandstone lying between the Irwin River Coal Measures and the Fossil Cliff Formation (Playford et al., 1976). The type section is at High Cliff on the north branch of the Irwin River. The formation ranges from a thickness of 24 m at High Cliff to 42 m at Woolaga Creek.

The High Cliff Sandstone consists of fine-grained quartzose sandstone, which is in part silty and contains lesser amounts of coarse-grained, cross-bedded sandstone and thin beds of siltstone. The sandstone is generally massive, although cross-bedding is recognised in the upper part of the unit in the Irwin River area. Thin beds of boulder and pebble conglomerate with clasts of granite, quartzite, and chert have been recorded in the Irwin River, Beckett Gully, and Woolaga Creek areas.

The High Cliff Sandstone conformably overlies the Holmwood Shale, although it is possible there was a slight hiatus between the deposition of the two units where sandstone beds prograded over the Holmwood Shale at a low angle. The High Cliff Sandstone is overlain conformably by the Irwin River Coal Measures. Playford et al. (1976) recorded that the grain size of the sandstone increases towards the Darling Fault and that in places much of the unit becomes conglomeratic, with well rounded quartz pebbles. Similarly they recorded an increase in grain size near the Urella Fault and postulated that these faults were slightly active during the Cisuralian, being marked by weak scarps.

The High Cliff Sandstone is generally unfossiliferous, except for the base of the formation, especially in the Woolaga Creek area (Playford, 1959) where a number of brachiopod and bivalve species have been found. Based upon brachiopods and bivalve assemblages present near the base of the High Cliff Sandstone, Dickins (1957) and Archbold (1993) considered the formation to be of Artinskian (Cisuralian) age, with its shelly fauna distinct from the Sakmarian (Cisuralian) Fossil Cliff Member. Although no palynoflora has been recovered from the formation, probably because the predominance of sandstone hinders preservation of spores and pollen, Backhouse (1993) believed the unit probably lies within the Artinskian (Cisuralian) *Striatopodocarpites fusus* Zone of Foster and Waterhouse (1988).

Irwin River Coal Measures

The Irwin River Coal Measures were named by Clarke et al. (1951) for the coal-bearing sequence lying between the High Cliff Sandstone and the Carynginia Formation. The type section extends along the north branch of the Irwin River, commencing at High Cliff. The Irwin River Coal Measures rests conformably on the High Cliff Sandstone and are conformably overlain by the Carynginia Formation. The lower contact is at the base of the main carbonaceous shale and siltstone beds in the coal measures, and the upper boundary is placed at the base of the jarositic micaceous siltstone, which characterises much of the Carynginia Formation (Playford et al., 1976). Johnson et al. (1954) had included the Carynginia Formation in the Irwin River Coal Measures; however, Playford et al. (1976) named the Carynginia Formation as a separate unit, although they did note that the differences in the units are less well marked in the Woolaga Creek area than in the Irwin River area.

The Irwin River Coal Measures extend on the surface from the Greenough River, east of the Northampton Block, to Woolaga Creek; however, the exposures in the Greenough River area are extremely poor. The unit occurs in the subsurface through much of the northern Perth Basin, but it is commonly difficult to distinguish it from the High Cliff Sandstone in well sections. Johnson and Willmott (1966) noted that the combined thickness of the two units is generally about 300 m in subsurface drillholes. In outcrop the Irwin River Coal Measures range in thickness from 63 m in the north branch of the Irwin River to 123 m in Woolaga Creek (Playford et al., 1976).

The formation is an alternating sequence of very coarse to very fine-grained sandstone, siltstone, and claystone, with lenticular beds of sub-bituminous coal. The sandstones are often strongly cross-bedded, in places with current ripple marks (Playford et al., 1976). Strata within the Irwin River Coal Measures are distinctly lenticular in the lower part and show rapidly alternating rock types. In the upper part, the lithologies are more uniform and consist of fine- to medium-grained, massively bedded sandstone with common small-scale current bedding and slump structures. Occasional boulders and cobbles of granite, quartzite, and chert are found within the deposits from the Irwin River Coal Measures. These were thought by Playford et al. (1976) to represent material rafted in by floating vegetation rather than by ice.

The Irwin River Coal Measures contain a rich *Glossopteris*-style macroflora that is typical of Gondwana terrestrial sedimentary deposits, as well as abundant spores and pollen. Backhouse (1993) recorded palynomorphs from the Irwin River Coal Measures from the *S. fusus* and *Microbaculispora trisina* Zones of Foster and Waterhouse (1988), indicating an Artinskian (Cisuralian) age. McLoughlin (1991) stated that the floras of the Irwin River Coal Measures contain a high proportion of herbaceous plants that are considered characteristic of a lower deltaic setting rather than upper deltaic to fluvial plain settings.

Carynginia Formation

The Carynginia Formation was originally named the Carynginia Shale, this being modified to the Carynginia Formation by Playford and Willmott (in McWhae et al., 1958) as it consists predominantly of interbedded siltstone and sandstone, with only minor shale beds. The unit overlies conformably the Irwin River Coal Measures and is overlain disconformably or with a slight angular unconformity by the Wagina Sandstone (Playford et al., 1976). The type locality of the formation is in Carynginia Gully, but no detailed section has been measured, as exposures in the area are discontinuous and poor. Playford and Willmott (in McWhae et al., 1958) designated the main reference section as the exposure along Woolaga Creek.

The Carynginia Formation crops out in the Irwin River and Woolaga Creek areas. The best exposures are along Woolaga Creek and Carynginia Gully. Clarke et al. (1951) measured the unit at 244 m thick along Carynginia Gully, while the section at Woolaga Creek was measured as 257 m thick. The formation is recognised subsurface across a wide area of the northern Perth Basin (Playford et al., 1976).

The Carynginia Formation consists predominantly of jarositic black micaceous siltstone or quartzose sandstone, with thin beds of conglomerate. Erratic blocks up to boulder size occur in the lower part of the Carynginia Formation. These consist mainly of granitic gneiss and quartzite and are generally rounded to subrounded. The sandstones and conglomerates are lenticular, typically showing internal cross laminae and have been reworked commonly by wave and storm action into symmetrical ripples and hummocky cross stratification (Mory and Iasky, 1996).

Microfossils, particularly spores and pollen, are common in the Carynginia Formation; however, no macrofossils are known from outcrops of the formation; those recorded by Clarke et al. (1951) are now considered to have come from the Fossil Cliff Member of the Holmwood Shale (Playford et al., 1976). Trace-fossil assemblages are present in the unit, dominated by *Skolithos*-style burrows. A few macrofossils have been identified from the subsurface Carynginia Formation from the BMR No. 10 bore (Dickins in McTavish, 1965). Foraminifera have been recorded from the formation and consist of an assemblage of agglutinated forms including species of the genera *Ammodiscus, Hyperammina*, and *Sacammina* (Crespin, 1958). Playford et al. (1976) assigned the Carynginia Formation an Artinskian (Cisuralian) age based upon the foraminiferal and macrofossil fauna. Seagroves (1969, 1970, 1971) and Backhouse (1993) recorded palynofloras from the *Praecolpatites sinuosus* and *Microbaculispora villosa* Zone of Foster and Waterhouse (1988), which indicate an Artinskian (Cisuralian) age for the Carynginia Formation.

Depositional environments of the Permian succession

Glacial conditions existed over most of the Perth Basin in the earliest Permian, and much of the Nangetty Formation may have originated from the mass movement of glacial till, although melt-stream deposits, glacial-lake sediments, and possible moraine deposits also occur (Playford et al., 1976; Cockbain, 1990; Mory, 1995; Mory and Iasky, 1996). The presence of foraminifera in the Nangetty Formation suggests that part of the formation was laid down under marine conditions, and the shales at the top of the formation grade into those of the Holmwood Shale, which contains a marine fauna. It is considered probable that most of the coarser sediment in the upper part of the formation was dropped from melting icebergs, and the presence of sporadic glacial erratics in the Holmwood Shale demonstrates the continued presence of ice after the deposition of the Nangetty Formation (Cockbain, 1990; Le Blanc Smith and Mory, 1995).

The marine transgression reached its peak in the Sakmarian with the deposition of the Holmwood Shale. Quiet-water conditions prevailed, and the dark colour of the shale and lack of benthos in most of the formation suggest a reducing (dysoxic to suboxic) environment on the sea floor. There were periods when the sea floor was well aerated (oxic), however, enabling invertebrates to flourish, and these are marked by the presence of fossiliferous limestone beds, such as those found within the Fossil Cliff, Beckett, and Woolaga Limestone Members. The lenticular nature of these carbonate beds indicates that the conditions conducive to a rich, diverse fauna were limited in both temporal and geographic extent. During the latest Sakmarian to earliest Artinskian a marine regression occurred, leading to deposition of the High Cliff Sandstone, which may contain beach deposits (Playford et al., 1976; Cockbain, 1990; McLoughlin, 1991; Le Blanc Smith and Mory, 1995).

Following the retreat of the sea, the continental conditions that prevailed in the southern Perth Basin spread northward. The whole basin was the site of fluvial, lacustrine, and paludal sedimentation. Coal-forming swamps abounded in the presumably low relief area, and the maximum extent of the coal-forming environments occurred during the Artinskian (Cockbain, 1990; McLoughlin, 1991). The upper part of the unit where it grades into the marine Carynginia Formation was probably deposited in a paralic environment (McLoughlin, 1991).

In the late Artinskian the sea transgressed the northern Perth Basin with the deposition of the Carynginia Formation. Scattered erratic boulders suggest there may have been some sea ice present at this time, and the presence of trace fossils, localised hummocky cross-stratification, lenses of sandstone and conglomerate, and wave ripples suggest that the Carynginia Formation was deposited in shallow water in a proglacial environment.

Uplift and erosion then took place in the northern Perth Basin, probably associated with uplift of the Northampton Block to the north. Renewed sedimentation in the Guadalupian deposited the fluvial Wagina Sandstone over the Carynginia Formation with a slight angular unconformity (Cockbain, 1990).

Chapter 3: Ostracode Taxonomy

The taxonomic hierarchy used to describe the suprageneric classification of the ostracodes from the Fossil Cliff Member is based upon the taxonomic framework used to describe the Ostracoda in the *Treatise on Invertebrate Paleontology* (Moore, 1961), and modified to reflect current usage based upon work by Sohn (1965, 1972, 1983), Bless and Jordan (1971), Hoare (1988), Jones (1989), Melnyk and Maddocks (1988a, b), Vannier et al. (1989), Becker and Shang-Qi (1992), Becker (1997a-d, 1998a-b, 2000a-e, 2001a-e), Becker and Blumenstegel (1997), and Becker et al. (1998). All superfamily names have been modified to bear the -oidea ending as per the 1999 ICZN recommendation.

New species of ostracode from the Fossil Cliff Member were described on the basis of adequate preservation; occurrence at more than one sample, or if from a single sample at least 10 specimens recovered; and when present ontogenetic series, adductor attachment muscle patterns, hingement, and dimorphic features.

Adductor muscle scar attachment diagrams are taken from SEM micrographs, with the exception of those from species of *Healdia*, which are determined from SEM micrographs and transmitted light photography.

All figured specimens are stored within the University of Western Australia Geology Museum.

The following abbreviations are used in the ostracode species descriptions: LV = left valve; RV = right valve; L = length; H = height; W = width; H/L = height:length ratio; L1 = lobe 1; L2 = lobe 2; L3 = lobe 3; S1 = sulcus 1; S2 = sulcus 2; S3 = sulcus 3, AMS = adductor muscle scar. All dimensions are given in millimetres (mm).

Class OSTRACODA LATREILLE, 1802

Order MYODOCOPIDA SARS, 1866

Suborder CLADOCPINA, SARS, 1866

Superfamily POLYCOPOIDEA SARS, 1866

Family QUASIPOLYCOPIDAE JONES, 1995

Genus *QUASIPOLYCOPE* JONES, 1995

Type Species: ***Quasipolycope lefevrei*** Jones, 1995

Diagnosis: See Jones (1995).

Remarks: *Quasipolycope* Jones (1995) was erected to contain Late Devonian to Triassic species formerly referred to *nomen dubium Discoidella* Croneis and Gale, 1938. *Discoidella* was determined by Sohn (1993) to be invalid as the type species and many of the other species assigned to this genus are not bivalved and thus are not ostracodes, although some authors (e.g. Hoare, 1998) continue to use the genus.

***?Quasipolycope* sp. A**

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33’E.

Figured Specimens: Plate 1, figures 1, 2.

Material Studied: 2 RV.

Diagnosis: Carapace small, with reticulate ornamentation, and subrounded. Dorsal margin gently curved, and ventral margin curved. Anterior is well rounded, and posterior straight near the dorsal end and then well rounded ventrally. An indistinct rim surrounds the free margins, and a number of spines protrude from this rim. L=0.42, W=0.25, H=0.32, H/L=0.76.

Remarks: This species is tentatively placed in *Quasipolycope*, based upon its morphological similarity with *Q. lefevrei* and *Q.* sp. A of Jones (1995). It differs from *Q. lefevrei* by having an elongate posterior relative to the rounded posterior on *Q. lefevrei*.

Distribution: *Q.* sp. A., is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the calcareous units of the member. *Q.* sp. A. is extremely rare, and has only been recorded from the middle carbonate bed of the member.

Order PALAEOCOPIDA HENNINGSMOEN, 1953

Suborder PALAEOCOPINA HENNINGSMOEN, 1953

Superfamily HOLLINOIDEA SWARTZ, 1936

Family HOLLINELLIDAE BLESS and JORDAN, 1971

Genus *HOLLINELLA* CORYELL, 1928, emended KELLETT, 1929

Type Species: ***Hollinella dentata*** Coryell, 1928

Diagnosis: See Kellett (1929).

Remarks: The genus *Hollinella* Coryell, 1928, has been noted to display distinct sexual dimorphism (Kellett, 1929; Bless, 1968). This is predominantly exhibited in the nature of the ventral frill, with the males possessing a flattened, somewhat shorter frill and the females having a longer frill that also acts as a brood pouch. In addition, the sizes of the L1 and L3 lobes differ, with males having larger lobes than females. Bless (1968) also noted that this genus is rarely found amongst faunas that are dominated by a sessile macrofauna, presumably because the substrate conditions are not favourable to them, indicating that species of *Hollinella* Coryell, 1928, lived in direct contact with the substrate. *Hollinella* Coryell, 1928, has not been previously recorded from the Permian of Australia, although Jones (1989) has recorded members of this genus from the Early Carboniferous of the Bonaparte Basin in northwestern Australia. Bless and Jordan (1971) divided the genus into three subgenera, *H.* (*Hollinella*) Coryell, 1928, *H.* (*Keslingella*) Bless and Jordan, 1970, and *H.* (*Praehollinella*) Bless and Jordan, 1971. For the purposes of these studies, these subgenera have not been used as the distinguishing features between *H.* (*Hollinella*) and *H.* (*Keslingella*) are features only found in juvenile species, and all the specimens found in the Fossil Cliff Member are mature carapaces.

Hollinella pirajnoensis sp. nov.

Holotype: UWA 128889.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33’E.

Derivation of name: Named in recognition of the work Dr. Franco Pirajno of the Geological Survey of Western Australia has done to help document fully the sedimentary sequences of the Glengarry and Earaheedy Basins in Western Australia.

Figured Specimens: Plate 1, figures 3-16.

Material Studied: 4 LV, 2 RV, and 30 fragments.

Diagnosis: Carapace large, subrectangular, and with granulose to spinose ornamentation. Dorsal margin is straight, with an anterior cardinal angle of 120° and a posterior cardinal angle of 135°. Anterior straight to gently curved. Posterior broadly rounded, and ventral border straight at the midpoint and curving slightly on the anterior and posterior margins. A well-developed frill is present on both the heteromorph and tecnomorph of the species, and on the tecnomorph the frill has developed into a brood pouch and extends from the midanterior along to the midposterior along the ventral side. The heteromorph has a much flatter ventral frill extending from the anterodorsal border along the ventral border to the posteroventral margin of the carapace. Both the heteromorph and the tecnomorph frills are relatively smooth on the inner portion of the frill, with some small tubercles near the exterior, and then possessing ornamentation on the outermost edge of the frill. On the heteromorph this ornamentation is a series of parallel striated ridges offset at about 10° to the perpendicular from the edge of the frill. The ornamentation on the tecnomorph is finely spinose. The carapace ornamentation is spinose, although on some specimens this spinose ornamentation is very fine and gives a granulose appearance. The spinose ornamentation on the tecnomorph is much coarser than on the heteromorph, and some smaller, secondary spines are present between the spines on the tecnomorph. Two distinct lobes are present, L1 and L3, with the posterior L3 much larger than L1. The S2 sulcus is also well developed between these lobes. The L3 on the heteromorph is significantly larger than on the tecnomorph, and the smaller L1 is better developed on the male. No AMS is visible on the internal surface of the carapace, although circular depressions for

L1 and L3 are distinct. The hinge is straight and consists of a simple ridge with interlocking groove on the opposite valve. L=1.83, H=1.03, W=0.63, H/L=0.55.

Remarks: *Hollinella pirajnoensis* sp. nov. is broadly similar to *H. cristinae* Bless, 1965, from Carboniferous of Spain, notably in the size and shape of the marginal frill and the positioning of L1 and L3. *H. cristinae*, however, has a distinct ridge on the medial side of the lobes that is not present on *H. pirajnoensis.* It is also similar in profile to *H.* (*Hollinella*.) *warthini* Cooper, 1946 and *H.* (*H.*) *regularis* Coryell, 1928 from the USA; however, both these species have a large spine that protrudes from the posterior cardinal region that is not present in *H. pirajnoensis*. *H. (H.) dentata* Coryell, 1928 displays a positioning of lobes and marginal frill similar to *H. pirajnoensis*; however, *H. (H.) dentata* has a single spine at the end of the marginal frill on the male, whereas *H. pirajnoensis* has multiple spines, and the frill has striations along the outer edge. Only one male LV and two female RV have been recovered, along with a number of fragments of both male and female carapaces. No juvenile specimens have been identified from the Fossil Cliff material indicating that the material may have been transported. It is unlikely, however, that this material was transported far as the carapaces are extremely fragile and would not remain intact in a high-energy environment, so it is probable that the species was broadly autochthonous to the Fossil Cliff palaeoenvironment.

Distribution: *H. pirajnoensis* is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the calcareous units of the member. The species is rare and has been found only from the middle to upper carbonate beds of the member.

Superfamily DREPANELLOIDEA Ulrich and Bassler, 1923

Family AECHMINELLIDAE Sohn, 1961

Judahellid? sp.

1985 *Hollinella*? sp. Fleming in Foster et al., p. 99, pl. 10, fig. 1.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33’E.

Figured Specimens: Plate 1, figures 17, 18.

Material Studied: 1 RV.

Diagnosis: Carapace medium sized, with reticulate ornamentation and subovate shape. Dorsal border straight, and ventral border curving slightly. Posterior margin rounded and less inflated than the anterior. Anterior margin broken on the recovered specimen but assumed to be rounded also. Four spherical lobes are present medially on the carapace, two large ones located dorsally and two smaller ones located ventrally opposite the larger ones. S2 is present between the larger lobes (L2? and L3?). On both the anterior and posterior ends of the carapace a large ridge is present, with the posterior ridge being more pronounced than the anterior. Internal details of the carapace are unknown, as the one valve that has been recovered is full of sediment. L=0.62, H=0.40, W=0.28 mm, H/L=0.65.

Remarks: Fleming (in Foster et al., 1985) illustrated a broken portion of a RV of this species, assigning it at the time to *Hollinella*. The species, however possesses too many nodes to be placed within *Hollinella* and is closer to *Judahella* Sohn, 1968, although more specimens are required to be able to confidently assign it to a genus.

Distribution: *Judahellid* sp. is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin. Only one specimen has been recovered intact from the middle carbonate beds of the member.

Family AECHMINIDAE Boucek, 1936

Genus *AECHMINA* Jones and Holl, 1869

Type Species: ***Aechmina cuspidata*** Jones and Holl, 1869

Diagnosis: See Levinson (1961).

Remarks: The genus *Aechmina* Jones and Holl, 1869, has not been recorded previously in any of the Permian strata in Australia and recorded only twice in the Australian Palaeozoic (De Deckker and Jones, 1978). In Europe and America most species are found within Silurian to Devonian sediments, and the number of species assigned to this genus decreases in the upper Palaeozoic (Sohn, 1961a). The presence of a spine in the dorsomedial region is characteristic of this genus.

Aechmina reticulata sp. nov.

Holotype: UWA 128890.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33’E.

Derivation of name: Named for the distinctive reticulate ornamentation found on the spine.

Figured Specimens: Plate 1, figures 19-28.

Material Studied: 20 LV, 12 RV, 14 carapaces.

Diagnosis: Carapace medium sized, smooth, and ovate with RV slightly larger than LV. Possesses a single spine that protrudes from just inside the midpoint of the dorsal margin and slightly to the posterior. Posterior and anterior borders well rounded, with the ventral border straight to gently curved. Dorsal border straight along hingeline and giving the impression in dorsal view of being slightly curved due to the growth of the spine. Slight ridge present on the valve margin along the anterior, ventral, and posterior margins but absent from the dorsal margin where the hinge is located, this being an external expression of the contact margin that is present on the inner surface of the valve. Single spine (L3?) with a distinct reticulate ornamentation starting just above the base of the spine and extending to just below the point of the spine where it terminates in a nipple-like point. Spine broad and conical, with its height approximately the same as its width, and with a discernible lean to the posterior side, resulting in a greater slope on the anterior side of the spine, and nearly vertical slope on the posterior side when seen in dorsal view. Apart from L3?, no other lobes are developed in the species. Normal pores are present on the inner surface of the carapace and extend into the cavity created by the spine. A marginal contact line is present all along the rim of the inner surface, except where the simple ridge and groove hinge is located dorsally. AMS located just to the anterior and dorsal side of the middle of the valve and is a tight, circular arrangement of between ten to eleven ovate to subovate platforms (Figure 12 and Figure 13). L=0.73, H=0.33, W=0.46, H/L=0.64 (Figure 14).

Remarks: *Aechmina reticulata* is the first record of this genera being found within the Permian of Australia. Sohn (1961a) restricted the genus to the Ordovician to the mid-Mississippian, however, it is felt that this species falls within the diagnosis of the genus and has thus been assigned to *Aechmina*. It shows some similarity with *A. perpendicularis* Lundin, 1965, from the Silurian Henryhouse Formation of Oklahoma, although the spine on *A. perpendicularis* is much straighter on the dorsal side, elongate, and lacks the reticulate ornamentation of *A. reticulata.* Kesling (1953) described *A. phantastica* from the Devonian Arkona Formation of Ontario which possesses a similar reticulate ornamentation on the spine and valve profile, although the dorsum of *A. phantastica* has a longer hingeline, and the spine displays a pinched profile at its base. *A. serrata* Coryell and Cuskley, 1934, from the Devonian Haragan Formation of Oklahoma has an almost identical valve shape, positioning of the spine, and spine shape. *A. serrata*, however, lacks the reticulate ornamentation found on the spine and has a granulose ornamentation on the carapace surface.

Distribution: *A. reticulata* is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the calcareous units of the member. The species is uncommon and is present throughout all the calcareous beds within the member, although it is somewhat more frequent in the lower carbonate units.

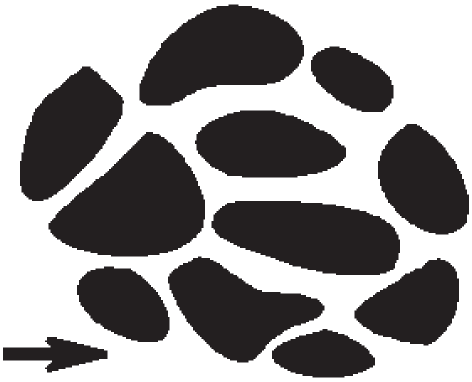


Figure 12. AMS pattern of *A. reticulata* (LV, L=0.70).

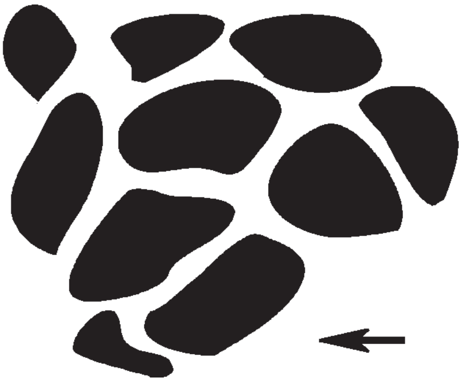


Figure 13. AMS pattern of *A. reticulata* (RV, L=0.76).

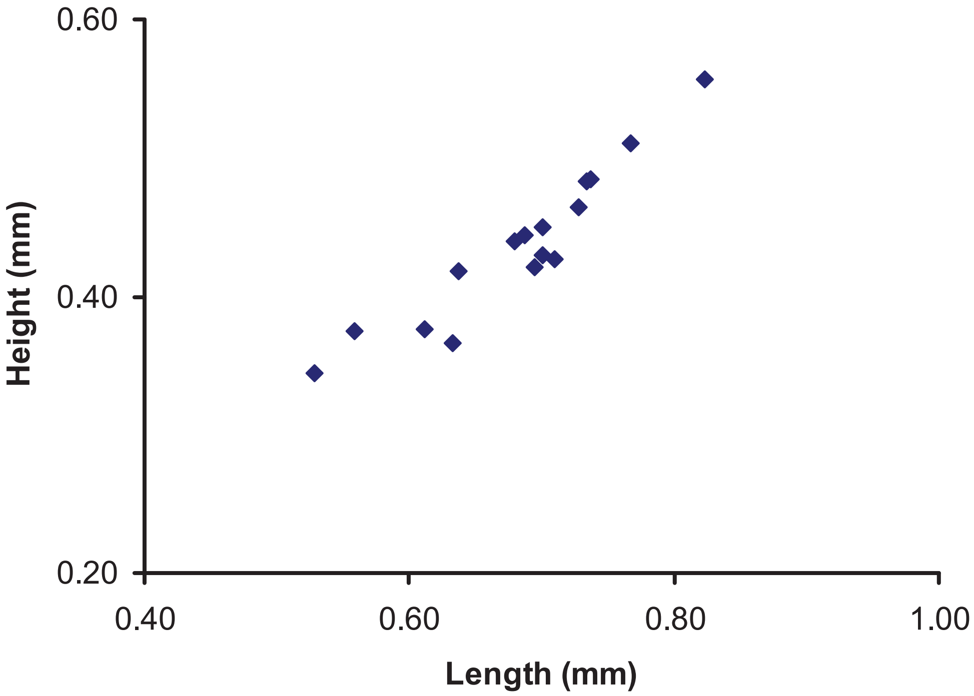


Figure 14. Biometric data for *A. reticulata* (17 valves measured).

Superfamily KIRKBYOIDEA ULRICH AND BASSLER, 1906

Family AMPHISSITIDAE KNIGHT, 1928

Genus *AMPHISSITES* GIRTY, 1910, emended COOPER, 1941

Subgenus *AMPHISSITES* GIRTY, 1910

Type Species: ***Amphissites rugosus*** Girty, 1910

Diagnosis: See Sohn (1954).

Remarks: Sohn (1954) noted that this genus is either a form genus or very stable as many of the species in it have very long distribution ranges, notably *A. centronotus* (Ulrich and Bassler), 1906, which ranges from the Early Carboniferous to the Permian. Sohn (1954) also noted that because of this, slight variations in ornamentation may be used as criteria for differentiating species from this genus.

Amphissites (Amphissites) centronotus (Ulrich and Bassler, 1906)

1906 *Kirkbya centronota* Ulrich and Bassler, p. 159, pl. 11, figs 16, 17.

1961e *Amphissites centronotus* (Ulrich and Bassler); Sohn, p. 118, pl. 7 figs 8-10 (see for synonymy up to this date).

1964 *Amphissites centronotus* (Ulrich and Bassler); Thompson and Shaver, fig. 2.

1966 *Amphissites centronotus* (Ulrich and Bassler); Shneider, p. 110.

1974 *Amphissites centronotus* (Ulrich and Bassler); Shaver and Smith, p. 35, pl. 1, figs 1-5.

1977 *Amphissites centronotus* (Ulrich and Bassler); Sanchez de Posada, p. 416, pl. 2, figs 9-11.

1985 *Amphissites centronotus* (Ulrich and Bassler); Burke, fig. 4.12.

1988b *Amphissites centronotus* (Ulrich and Bassler); Melnyk and Maddocks, pl. 2, fig. 14.

1989 *Amphissites* aff. *centronotus* (Ulrich and Bassler); Jones, p. 44, pl. 10, figs 1a-2d; text fig. 19b.

1989 *Amphissites* cf. *A. centronotus* (Ulrich and Bassler); Lethiers et al., p. 230, pl. 1, fig. 1.

1990 *Amphissites (Amphissites) centronotus* (Ulrich and Bassler); Christopher et al., p. 979, fig 4.16-4.20.

1992 *Amphissites (Amphissites) centronotus* (Ulrich and Bassler); Becker and Shang-Qi, p. 12, pl. 1, fig. 5.

1994 *Amphissites (Amphissites) centronotus* (Ulrich and Bassler); Crasquin-Soleau and Orchard, pl. 3, fig. 2.

1997 *Amphissites (Amphissites) centronotus* (Ulrich and Bassler); Crasquin-Soleau, p. 51, pl. 2, figs 9-11.

1997b *Amphissites (Amphissites) centronotus* (Ulrich and Bassler); Becker, pl. 3, figs 1-2.

Holotype: United States National Museum #35628.

Type Locality: Two miles east of Cottonwood Falls, Chase County, Kansas in the Cottonwood Formation.

Figured Specimens: Plate 1, figures 29, 30; Plate 2, figures 1-8.

Material Studied: 1 LV, 3 RV, and a number of fragmented carapaces.

Diagnosis: *A. (Amphissites)* species with moderately large, subcentral node. Lateral shoulders with distinct, symmetrically sickle-shaped ridges. Carapace surface with distinct reticulation, more delicate on subcentral node than on lateral surface (Becker and Shang-Qi, 1992).

Description: Carapace large, with reticulate ornamentation, and subrectangular. Dorsal margin generally straight, with a slight concavity in the middle and a gentle concave curvature on the anterior and posterior ends. Ventral margin straight to gently curved in the middle then broadly curved on both the anterior and posterior ends. Cardinal angles for both the posterior and anterior obtuse, with the anterior cardinal angle 90° and the posterior cardinal angle at 110°. Anterior end slightly inflated relative to the posterior end. Large node situated dorsomedially and just to the posterior, and subovate adductorial pit located on the edge of the node in the centre of the valve. Median node flanked by short carina on both anterior and posterior sides, with the anterior carina slightly more prominent than the posterior. Two marginal rims present along the free margin, with lower rim more pronounced than upper and having a spinose ornamentation. On the internal surface of the carapaces are a large number of sieve-type pores that are grouped in a loosely hexagonal fashion, and these hexagonal groupings of pores are found across the internal surface. No AMS has been observed. Hinge is composed of a ridge and groove, with a large socket located at each end. L=1.01, H=0.60, W=0.42 mm, H/L=0.59 (Figure 15).

Remarks: Knox et al. (1993) believed that *A. (A.) centronotus* characterises a nearshore environment. Becker (1997b) noted that the Amphissitidae are eurytopic and have a wide range of depth distributions.

Distribution: *A. (A.) centronotus* is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin. The species is rare and has been recorded from only the middle beds of the calcareous facies. *A. (A.) centronotus* ranges from the Lower Carboniferous to Cisuralian, and has a global distribution.

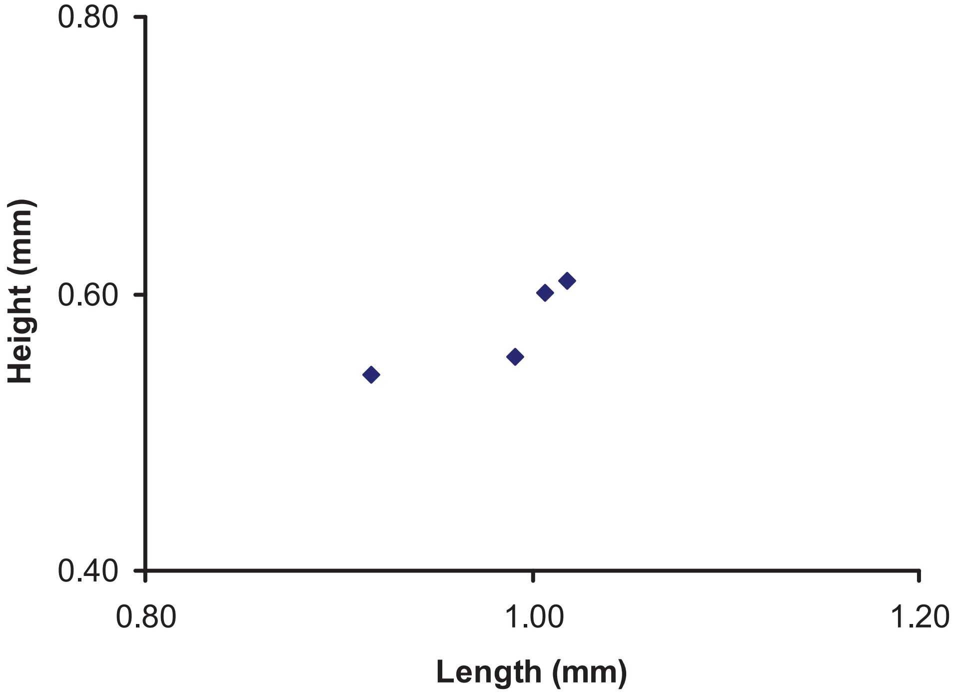


Figure 15. Biometric data for *A. (A.) centronotus* (4 measured valves).

Family KIRKBYIDAE ULRICH AND BASSLER, 1906

Genus *KIRKBYA* JONES, 1859, emended SOHN, 1954

Type Species: ***Kirkbya permiana*** (Jones), 1850

Diagnosis: See Sohn (1954).

Remarks: In Sohn's (1954) redefinition of the *Kirkbya* Jones, 1859, he removed a number of species from the genus and placed them in the genera *Aurikirkbya* Sohn, 1950, and *Coronakirkbya* Sohn, 1954, which along with *Knightina* Kellett, 1933, formed all the genera in the Kirkbyidae (Sohn, 1961b). P.J. Jones (1989) recorded a number of species of *Kirkbya* from the Lower Carboniferous of Western Australia, however apart from this, there are no other records of *Kirkbya* from the Upper Palaeozoic of Western Australia. Becker (1997c) considers *Knightina* to be a synonym of *Kirkbya*. *Kirkbya* was considered by Becker (1997c) to form part of the *Kirkbya* line representing an advanced evolutionary lineage within the Kirkbyidae. Species from the Kirkbyidae are thought to be shallow-water marine forms belonging to the Eifelian ecotype of Becker (in Bandel and Becker, 1975; Becker, 1997c).

Kirkbya fossilcliffi sp. nov.

Holotype: UWA 128891.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33'E.

Derivation of name: Named after Fossil Cliff, the locality where the species was found.

Figured Specimens: Plate 2, figures 9-13.

Material Studied: 3 LV, 1 RV, 13 fragmented carapaces.

Diagnosis: Carapace medium sized, surface reticulate, and with a subrectangular profile. Dorsal margin straight and long. Ventral margin straight in middle and curving gently to anterior and posterior ends, with a greater angle of curvature on the anterior end. Anterior broadly rounded with an anterior cardinal angle of 90°. Posterior is straight at the dorsal end, and gently curved ventrally, the posterior cardinal angle is 75°. Ornamentation reticulate with the reticulation elongated along the anterior/posterior axis. Adductorial pit shallow with two small and indistinct lobes present on either side of the adductorial pit. Along the margins of the valves, except for the dorsal margin, two distinct rims are present, one at the base of the valve, and another slightly higher, giving the valve a rectangular appearance in lateral view. The ornamentation between these ridges is obscured by detritus that is attached to the valves and thus unknown. Across the internal surface of the carapace are small sub-circular groupings of pores. No AMS is visible on the internal surface. Hinge is a simple ridge and groove arrangement that extends for the whole dorsal length, with rounded sockets present on the terminus of each ridge. L=0.81, H=0.34, W=0.25, H/L=0.43 (Figure 16).

Remarks: *Kirkbya fossilcliffi* is similar to *K. punctata* Kellett, 1933, having a small adductorial pit in between two low nodes and an elongation of the reticulate ornamentation that is stretched along the anterior-posterior axis. *K. punctata*, however, has a much straighter anterior margin than *K. fossilcliffi*, which is more rounded anteriorly.

Distribution: *K. fossilcliffi* is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin.

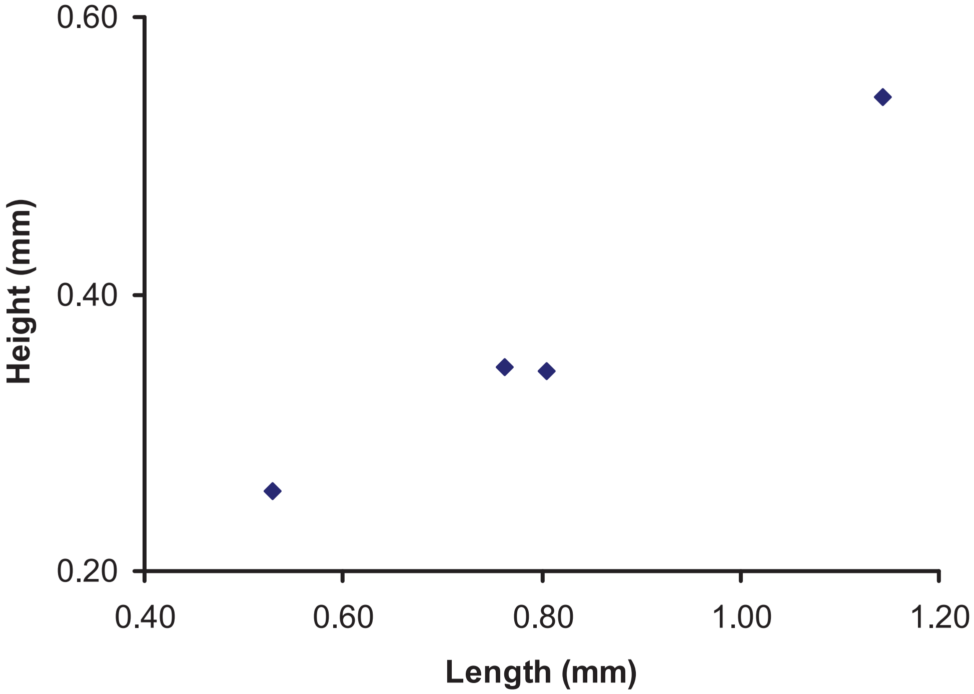


Figure 16. Biometric data for *K. fossilcliffi* (4 measured valves).

Kirkbya mingenewensis sp. nov.

Holotype: UWA 128892.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33’E.

Derivation of name: Named after the town of Mingenew, located to the west of the Fossil Cliff type locality.

Figured Specimens: Plate 2, figures 14-25; Plate 3, figures 1-4.

Material Studied: 7 LV, 3 RV, 15 carapace fragments.

Diagnosis: Carapace large with reticulate ornamentation and subrectangular. Dorsal margin straight and long. Ventral margin straight to gently curved centrally and broadly curved at the anterior and posterior ends. Anterior and posterior margins straight on the dorsal side, and then curved ventrally, both anterior and posterior cardinal angles at about 95°. Anterior end slightly more inflated than posterior, which slopes slightly downwards. Double rim present around the free margin, and lower of these two rims has a regular spinose ornamentation. Between the two rims the ornamentation also reticulate. Ornamentation on valves is reticulate with small, fine ‘spines’ protruding inwards in each of the cavities created by the ornamentation. There are generally six of these ‘spines’ in each cavity, although the number of ‘spines’ varies between three to six. Adductorial pit located ventromedially and flanked by two low nodes that sit just to the dorsal side of it. AMS area circular, but displays no distinct platforms. Interior of the carapace contains sieve-type pores arranged in a hexagonal fashion.. Hinge extends along the length of the dorsal margin and consists of a simple groove and interlocking ridge, and on some specimens terminal sockets are preserved at the ends of the ridge. L=1.04, H=0.55, W=0.32, H/L=0.53 (Figure 17).

Remarks: *Kirkbya mingenewensis* is recorded from the Permian of Australia for the first time. This species differs from recorded Pennsylvanian and Permian species of *Kirkbya* in the much lower profile of the two nodes and the more subrectangular profile of the valve.

Distribution: *K. mingenewensis* is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin. The species is rare and has been recorded from both the lower and middle beds of the calcareous facies.

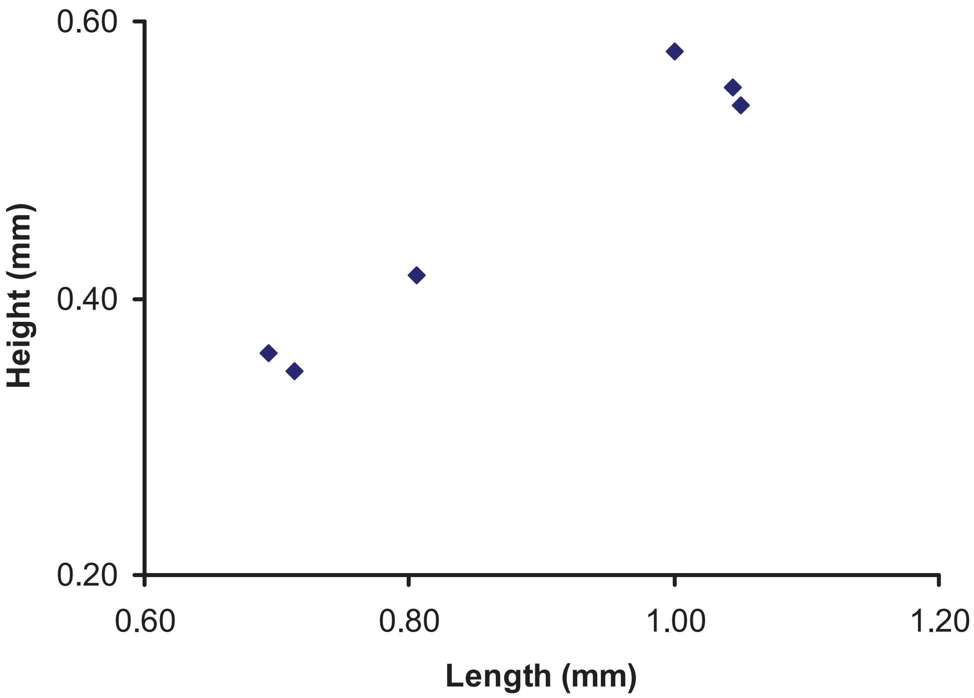


Figure 17. Biometric data for *K. mingenewensis* (6 measured valves).

***Kirkbya* sp. A**

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33'E.

Figured Specimens: Plate 3, figures 5-9.

Material Studied: 1 LV, 2 RV, and 4 carapace fragments.

Diagnosis: Carapace large, with reticulated ornamentation and subrectangular. Dorsal margin long and straight, with both the posterior and anterior cardinal angles slightly greater than 90°. Ventral border straight in the middle and curving on anterior and posterior margins. Both the anterior and posterior margins straight dorsally and then become broadly curved ventrally, and anterior slightly inflated relative to posterior. Double rim found along the free margin, and the lowermost of these rims contains a spinose ornamentation. Valve ornamentation reticulate, with small pustules along the top of the ornamentation. Adductorial pit present in the medial region of the carapace and marked by a distinct break in the ornamentation. No distinct nodes present on the carapace. Sieve-type pores cover the internal surface of the carapace, arranged in loosely in sub-hexagonal groups. No AMS patterns have been observed on the internal surface. The hinge is a ridge and groove arrangement that extends along the entire dorsal margin, with rounded sockets at on both ends of the hinge. L=1.53, H=0.76, W=0.33, H/L=0.50.

Remarks: *Kirkbya* sp. A's lack of distinct nodes on the carapace, reticulogranulose ornamentation and presence of spines on the lower marginal rim distinguish this species from others in this genus.

Distribution: *Kirkbya* sp. A is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin.

Order PODOCOPIDA Sars, 1866

Suborder METACOPINA SYLVESTER-BRADLEY, 1961

Superfamily HEALDIOIDEA HARLTON, 1933

Family HEALDIIDAE HARLTON, 1933

Genus *HEALDIA* ROUNDY, 1926

Type Species: ***Healdia simplex*** Roundy, 1926

Diagnosis: See Shaver (1961a).

Remarks: There is some dispute as to whether the Healdiidae and the genus *Healdia* Roundy, 1926, specifically, belong in the suborder Metacopina or the Podocopina, based primarily upon the arrangement of the AMS patterns (Gramm, 1982, 1987; Gramm et al., 1972; Sohn, 1965; McKenzie, 1982). This work adopts the views of Gramm and McKenzie that the Healdiidae belong to the Metacopina and not the Podocopina. This is based on the distinctive rosette arrangement of the AMS that distinguish the Healdiidae from other families in the Podocopina, whereas they satisfy the criteria established for the Metacopina. Unfortunately the taxonomic bases of the two suborders are different in that the Podocopina are based upon both extant and extinct species, whereas the Metacopina are based upon extinct species (with the exception of the genus *Saipanetta* McKenzie, 1967, an extant genus tentatively assigned to the Metacopina). This has created confusion regarding the assumed location and function of body parts on extinct species and how they are taxonomically related to each suborder. The importance of the AMS arrangement as a suprageneric, generic, or specific character in this superfamily is also uncertain, and this work adopts the view of Gramm (1982) that the AMS arrangement is of taxonomic importance at the generic level and higher, based upon the lack of systematic variability of the arrangement of the AMS within species and genera of the Healdiidae. Work by Kristan-Tollman (1977) suggested that only in the latest Permian to Early Triassic did the AMS arrangement in the Healdiidae change from a "clumped" pattern to an ordered one. Systematic work on the AMS arrangements on the Healdiidae from the Fossil Cliff Member shows that the change to the ordered pattern of AMS (as in *H. chapmani* Crespin, 1945, *H. crespinae* sp. nov*., H. irwinensis* Fleming, 1985, and *Waylandella holmwoodensis* sp. nov.) occurred much earlier than this, starting in the Cisuralian. All the *Healdia* Roundy, 1926, species described herein from the Fossil Cliff Member display an AMS arrangement that has a central arrangement of 2 rows of primary scars (the "constant group" of Gramm, 1982) surrounded by a set of smaller, secondary scars.

Healdia bradmani sp. nov.

Holotype: UWA 128898.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33'E.

Derivation of name: Named after the late Sir Donald Bradman, cricketing icon, and Australian sporting hero.

Figured Specimens: Plate 3, figures 10-12.

Material Studied: 2 LV, 4 carapaces.

Diagnosis: Carapace small, reniform, and surface smooth. Posterior slightly inflated relative to anterior, and both posterior and anterior ends are well rounded. Ventral margin straight on LV and straight to slightly concave on the RV. LV overlaps RV along the margin except at the extreme posterior and anterior ends where there is no overlap. On the posterior a slight ridge is present, made distinct by a sharp decrease in thickness of the carapace laterally. Normal pore canals are present on the outer surface of the carapace. Greatest height is posteriorly, and the carapace has a distinct wedge-shaped appearance in profile. AMS a simple 'healdoid' aggregate. L=0.63, H=0.37, W=0.31, H/L=0.59 (Figure 18).

Remarks: *Healdia bradmani* is similar to *H. reniformis* Guseva, 1971, from Russia in the general morphology of the posterior ridge; however, the overall carapace morphology differs. Similarly *H. ovalis* Guseva, 1971, also possesses a posterior ridge that is similar to one on *H. bradmani*, and while the carapace morphology is similar, *H. bradmani* shows a more rounded dorsal region and pointed anterior and posterior.

Distribution: This species is rare within the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, although its distribution spans the calcareous units.

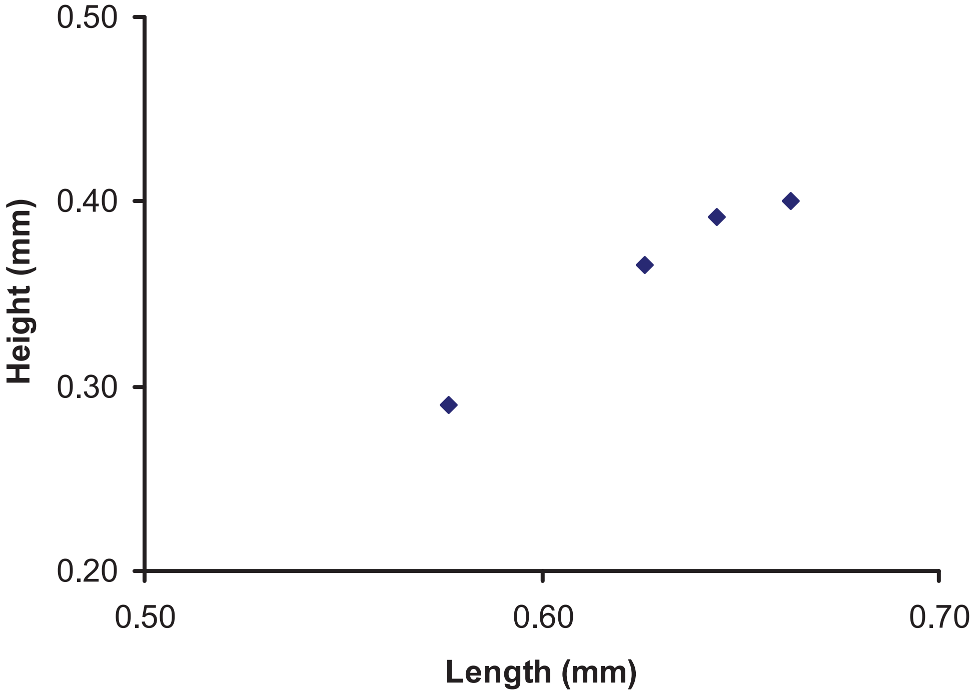


Figure 18. Biometric data for *H. bradmani* (4 measured valves).

Healdia chapmani Crespin, 1945, emended Ferdinando

1945a *Healdia chapmani* Crespin, p. 32, pl. 4, figs 3a, b, 4, 5.

1971 *Healdia chapmani* Crespin; Guseva, p. 202-203, pl. 54, figs 4, 5.

1985 *Healdia chapmani* Crespin; Fleming in Foster et al., p. 98, pl. 11, figs 16-17.

Holotype: Commonwealth Palaeontological Collection #261.

Type Locality: Cattle Creek Formation, Bowen Basin. 14 miles South-east of Springsure, Queensland, Australia.

Figured Specimens: Plate 3, figures 13-24.

Material studied: 18 LV, 21 RV, 9 carapaces.

Diagnosis: Carapace small, subtriangular, smooth, and equivalved. Anterior end roundly curved, dorsal margin strongly convex with margin straight towards posterior end. Highest point of curve in middle portion. Posterior end subangulate, ventral margin straight to slightly curved inwards. Two spines located at posterior end, one near dorsal margin and one on ventral margin, both protruding backwards. Surface otherwise smooth. LV overlaps and overreaches the RV, notably along the dorsal margin. Dorsal hingement a simple groove and bevel type, and covers one third of the length of the dorsal margin. Simple pore structures located over the surface of the carapace, although not numerous in any given part of the carapace. AMS a "healdoid" aggregate (Figure 19 and Figure 20), located posteromedially, with up to 33 platforms arranged circularly with 3 rows of primary scars, with 2-3 subovate scars in each row, located centrally and surrounded by 17-22 subcircular secondary scars on the adult instar. Juvenile instars display 2-3 rows of primary scars and a lesser number of secondary scars, depending upon the maturity of the moult. The constant group of primary muscle scars (Gramm, 1982) consists of between seven and eight large ovate scars arranged biarcuately. L=0.70, H=0.45, W=0.38, H/L=0.67 (Figure 21).

Remarks: This species is similar to *H. limacoidea* Knight, 1928, found in the Pennsylvanian of eastern Missouri (Knight, 1928), differing in the profile of the carapace, not in the positioning or the shape of the muscle scars (Crespin, 1945a; Fleming in Foster et al., 1985). *H. chapmani* also shows similarities to *H. umariensis* Bhatia, 1959, from central India (Bhatia, 1959) but has a less pronounced overlap and larger, more pronounced posterior spines.

Distribution: This species has been described from the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia (Foster et al., 1985) as well as in the Lower Permian Cattle Creek Formation in the Bowen Basin of Queensland (Crespin, 1945a) and from the Pechora Coal Basin in Russia (Guseva, 1971). It is common within the lower calcareous beds of the Fossil Cliff Member, and is found throughout the calcareous beds of the member. It has not been recorded from any of the shale and silt beds of the Fossil Cliff Member.

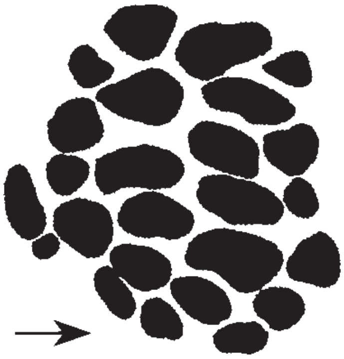


Figure 19. AMS pattern of adult *H. chapmani* (LV, L=0.68).

Figure 20. AMS pattern of *H. chapmani* juvenile instar (RV, L=0.43).

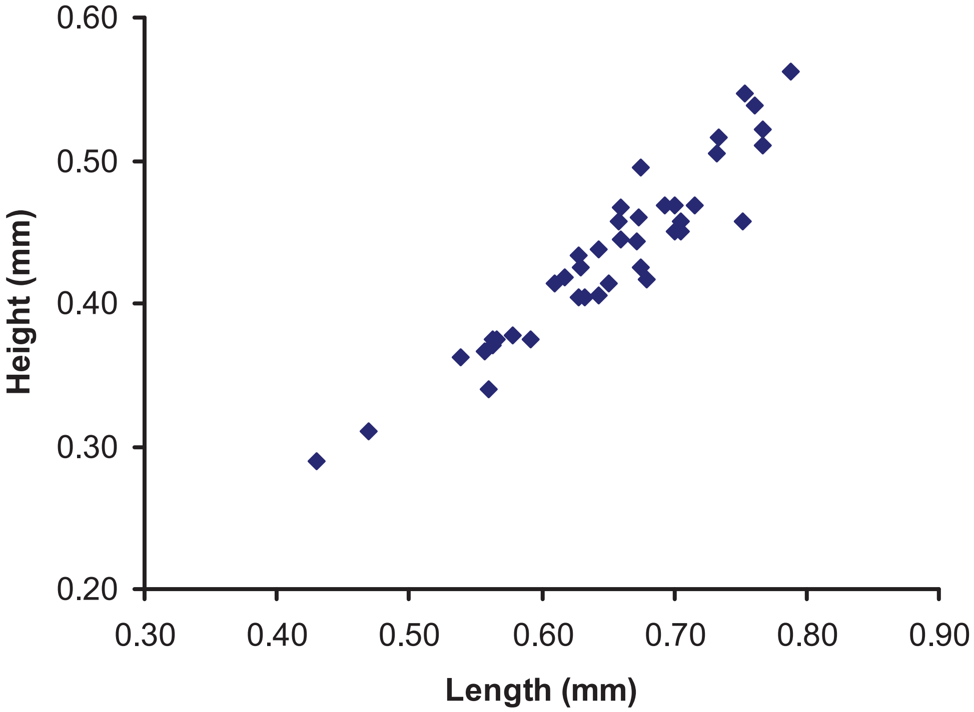


Figure 21. Biometric data for *H. chapmani* (41 measured valves).

Healdia crespinae sp. nov.

Holotype: UWA 128894

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33'E.

Derivation of name: This species is named after Dr Irene Crespin in honour of the work she undertook into Australian Permian ostracodes.

Figured Specimens: Plate 3, figures 25-29; Plate 4, figures 1-5.

Material Studied: 22 LV, 17 RV, 18 carapaces.

Diagnosis: Carapace small, triangular, equivalved, with smooth surface. Anterior end broadly curved and posterior margin more sharply rounded than the anterior. Dorsal margin straight and slightly rounded at the anterior and posterior margins. Ventral margin rounded at the centre, then straight towards the anterior and posterior margins giving a triangular outline to the carapace. Two posterior pointing spines are located near the posterior margin. Dorsal spine located close to the dorsal margin and the ventral spine located at the posteromedian and posteroventral junction. A ridge or horse-shoe like depression is present between the two spines and lip discernible on the posterior margin between the spines. AMS "healdoid", forming a cluster with up to 30 platforms in adult instars, arranged ovately to circularly, with the constant group of primary scars arranged biarcuately in 2 rows generally consisting of 4 large ovate scars in each row (Figure 22 and Figure 23). In the adult instars these are surrounded by between 10 to 18 smaller circular to subovate secondary muscle scars, and an additional row of three large subrounded scars on the dorsal side of the main ovate scars. In the juvenile instars the number of secondary AMS is reduced. Normal pore canals are found on the carapace surface, and are most frequent on the posterior margin. LV shows strong overlap and overreach with the RV, especially along the dorsal margin. The hinge attachment is a simple groove and bevel, and extends for approximately one third the length of the dorsal margin. L=0.63, H=0.42, W=0.20, H/L=0.67 (Figure 24).

Remarks: This species is very similar to *H. chapmani*, differing in the ornamentation and sculpturing between the two posterior pointing spines, with *H. crespinae* showing either a ridge or horse-shoe like depression and the holotype and topotypes of *H. chapmani* lacking this. There are also slightly fewer AMS present in *H. crespinae*. Other than these differences *H. crespinae* is similar to

H. chapmani. *H. normalis* Guseva, 1971, from Russia possesses a similar depression between the spines; however, the spines of *H. normalis* are not as well developed as those of *H. crespinae*, and the profile along the dorsal margin differs.

Distribution: *H. crespinae* is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the calcareous units of the member. It is generally present in the lower calcareous beds of the member, although its range does extend to the upper calcareous beds.

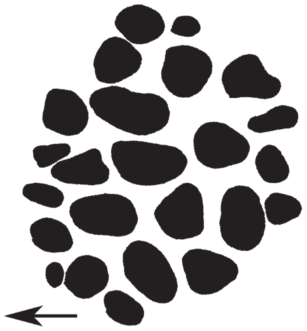


Figure 22. AMS pattern of adult *H. crespinae* (RV, L=0.65).

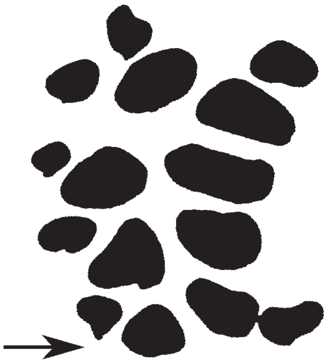


Figure 23. AMS pattern of juvenile *H. crespinae* instar (stage 7 or 8) (LV, L=0.52).

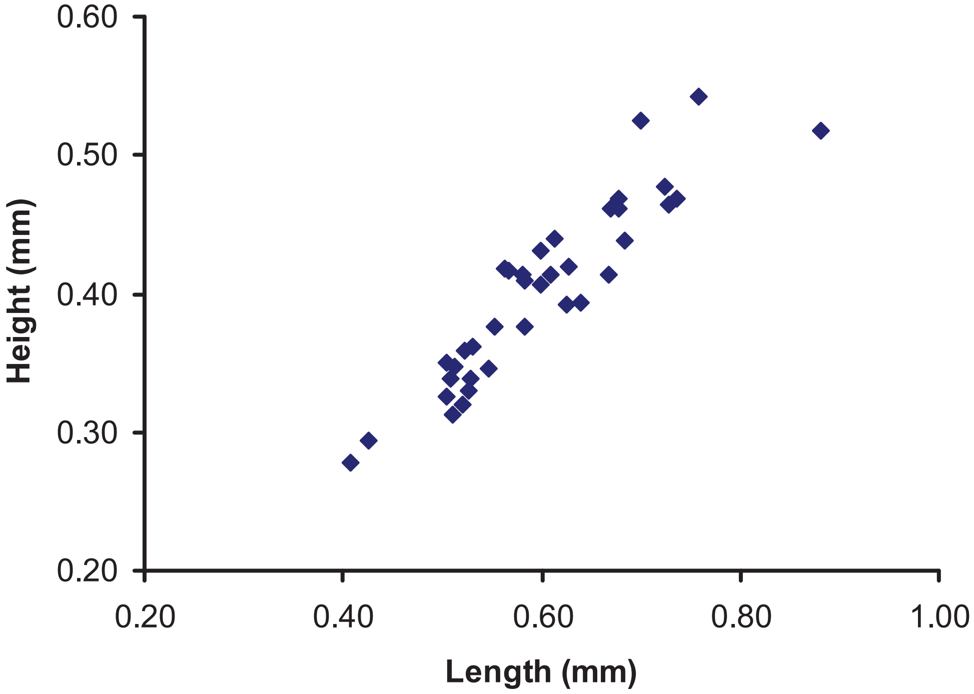


Figure 24. Biometric data for *H. crespinae* (37 measured valves).

Healdia gregoryi sp. nov.

Holotype: UWA 128895.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33’E.

Derivation of name: This species is named after the Gregory brothers who discovered exposures of coal in the Irwin River, Western Australia, in the late 1800’s.

Figured Specimens: Plate 4, figures 6-10.

Material Studied: 1 LV, 4 RV, 2 carapaces.

Diagnosis: Elongate, subovate ostracode with a smooth surface. Anterior margin ovately rounded, with posterior margin almost flat and slightly curving to the dorsal and ventral sides. Ventral margin straight to slightly concave with a broad curve at the anterior and posterior margins. Dorsal side subtriangular with a gentle curve to the anterior and posterior margins. Greatest height in posteroventral region. One backwards pointing spine located inside the posteroventral margin, just before the point of maximum height. Spine short and does not extend beyond the carapace margin. Slight lip on anterior margin of the RV. LV slightly overlaps and overreaches the RV, with a simple groove and bar hingement. AMS attachment “healdoid” aggregate. L=0.71, H=0.42, W=0.29, H/L=0.62 (Figure 25).

Remarks: This species is placed in the *Healdia* Roundy, 1926 rather than *Waylandella* Coryell and Billings, 1932, on the basis of its broad mid-region and reniform shape, whereas *Waylandella* possesses a more elongate profile. No single-spined species of *Healdia* have been previously described from the Cisuralian of Australia.

Distribution: Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin. This species is found within the calcareous units of the member, and is uncommon in the lowermost beds, its range extends throughout the calcareous beds of the member.

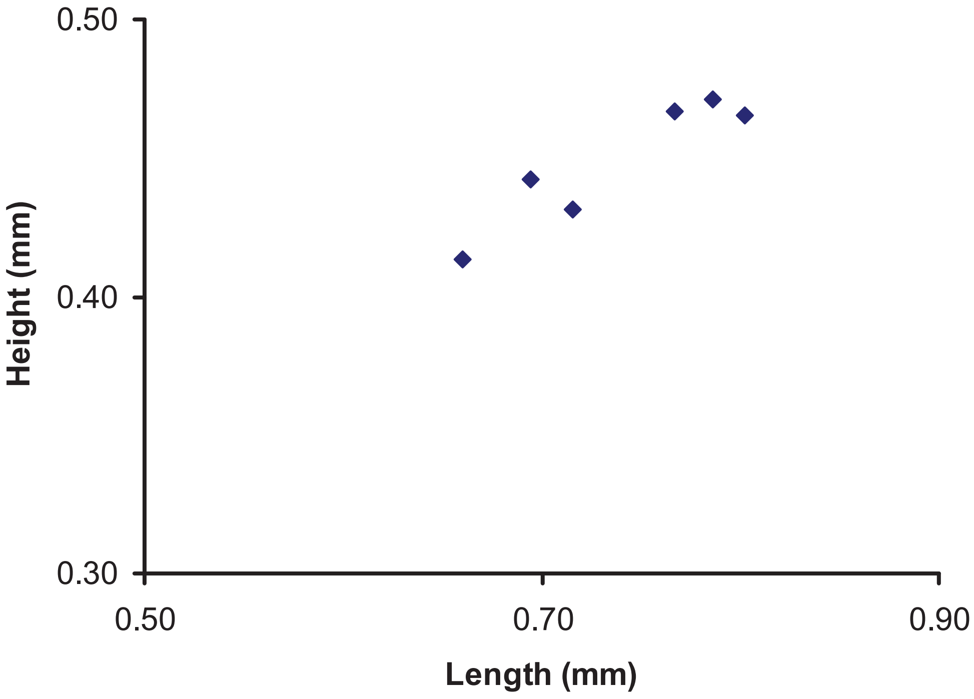


Figure 25. Biometric data for *H. gregoryi* (6 measured valves).

Healdia irwinensis Fleming, 1985, emended Ferdinando

1985 *Healdia irwinensis* Fleming in Foster et al., p. 97, pl. 11, figs. 11-15.

Holotype: Western Australian Museum #83.2733.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33’E.

Figured Specimens: Plate 4, figures 11-28; Plate 5, figures 1-6.

Material Studied: 29 LV, 49 RV, 20 carapaces.

Diagnosis: Smooth, elongate, reniform, with distinct ventral sinus. Anterior and posterior margins evenly and broadly rounded. Dorsal and ventral posteriorly-directed spines placed almost at rear of margin and extend beyond the posterior margin. Distinct horseshoe shaped depression present between the spines, sometimes with slight ridge located on the anterior side of the depression. Extremely fine, normal pore canals present on the surface of the carapace. Hinge and marginal structures very fine, with hingement consisting of an interlocking groove and bevel, located centrally and extending one third the length of the dorsal margin. LV over RV overlap and overreach is distinct across whole margin, except for anterodorsal margin, where no overlap is present. AMS attachment a "healdoid" aggregate and located centrally with up to 25 platforms arranged ovately in 2 biarcuate rows of primary platforms each containing 3 circular to subovate adductor scars surrounded by up to 19 circular to ovate secondary platforms (Figure 26 and Figure 27). L=0.70, H=0.40, W=0.20, H/L=0.59 (Figure 28).

Remarks: This species, originally described by Fleming (in Foster et al., 1985), is found throughout the calcareous beds of the formation and is generally well preserved. *H. irwinensis* is absent from the shale facies of the member. It can be distinguished from *H. chapmani* and *H. crespinae* by its lower, elongate, reniform profile and centrally positioned AMS. *H. irwinensis* shows a similar depression between the posterior spines to *H. overbrookensis* Harlton, 1927, from the USA, however, *H. overbrookensis* has a more inflated convex ventral margin. *H. sakmaraensis* Kochetkova and Guseva, 1972, from the Russian Urals also shows a similarity with a horseshoelike depression between the posterior spines, however the posterior of *H. sakmaraensis* is far more inflated than *H. irwinensis*.

Distribution: Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin. This species is found within the calcareous units of the member, and is common in the lowermost beds, its range extends throughout the calcareous beds of the member.

Figure 26. AMS pattern of adult *H. irwinensis* (RV, L=0.67).

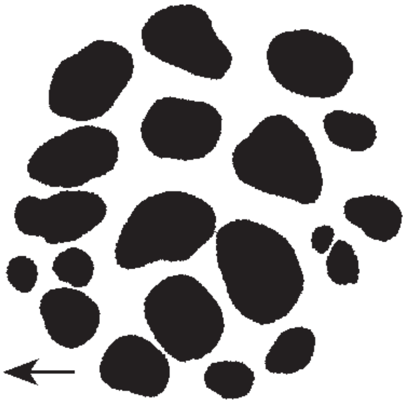


Figure 27. AMS pattern of adult *H. irwinensis* (RV, L=0.71).

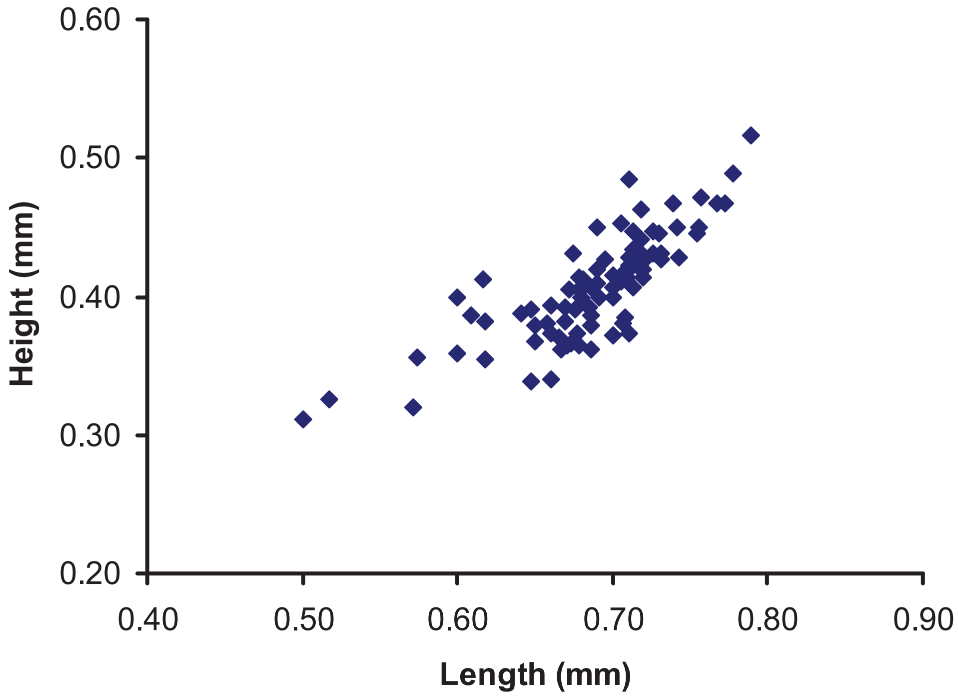


Figure 28. Biometric data for *H. irwinensis* (86 measured valves).

Healdia obtusa sp. nov.

Holotype: UWA 128896

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33'E.

Derivation of name: Derived from the Greek word for obtuse, describing its broad carapace profile.

Figured Specimens: Plate 5, figures 19, 23, 26.

Material Studied: 5 LV, 7 RV.

Diagnosis: Carapace smooth, rounded, and subtriangular. One backward pointing spine protrudes from the ventromedian area on the posterior margin of both valves. The single spine is large and thick, and protrudes from carapace at a high angle, but does not extend beyond the margin of the carapace. On the LV a small lip may be present on the posterior border beneath the spine, this feature is absent on the RV. A small rim extends along the posterior margin in some well preserved specimens, and is also present on the anterior as a slightly larger rim. Posterior more inflated than anterior, and is broadly rounded. Ventral margin straight, with dorsal margin rounded and subtriangular. Greatest height in the posteromedian region near the spine. The carapace profile slopes gently to the anterior, and steeply to the posterior just beyond the spine. Normal pore canals are located around the marginal regions of the carapace. Hingement is a simple groove and bar located in the centre of the dorsal border and extends for about 40% of the length of the dorsal margin. AMS is ovate and forms a 'healdoid' aggregate, with 9 primary platforms arranged biserially, surrounded by up to 15 secondary platforms (Figure 29). L=0.65, H=0.45, W=0.30, H/L=0.67 (Figure 30).

Remarks: This single spined species of *Healdia* shows no distinct resemblance to any described species of *Healdia* or closely-related genera, although the profile and position of the posterior spine are superficially similar to that of *H. glennensis* Harlton, 1927, from the Pennsylvanian of southern USA.

Distribution: This species is uncommon within the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, and is found throughout the carbonate beds, especially in the middle beds of the member.

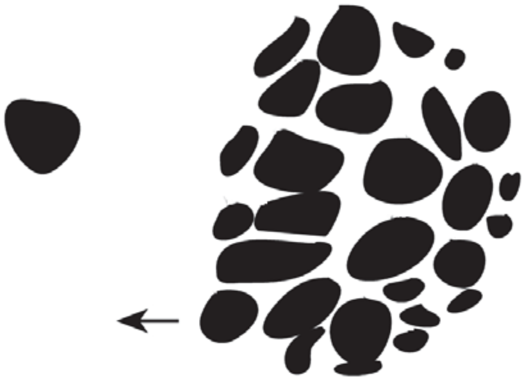


Figure 29. AMS pattern of adult *H. obtusa* (RV, L=0.57).

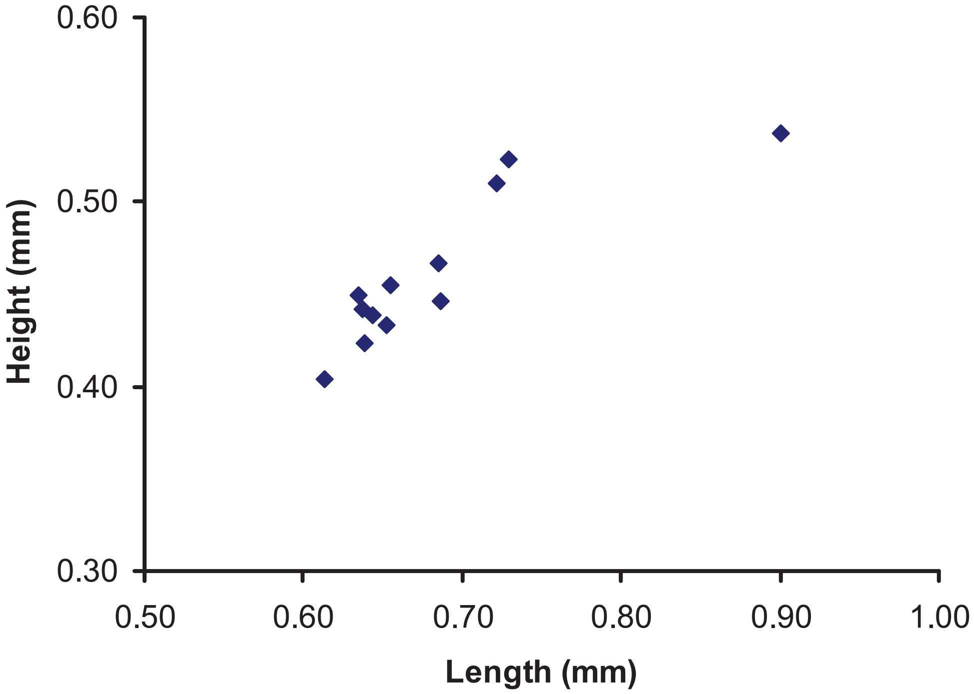


Figure 30. Biometric data for *H. obtusa* (12 measured valves).

Healdia petchorica Guseva, 1971.

1971 *Healdia petchorica* Guseva, p. 206-207, pl. 55, figs 1a, b, 2a, b, 3a, b.

1985 *Healdia* sp. A Fleming in Foster et al., p. 98, pl. 11, figs. 5-6

1985 *Healdia grayi* (Crespin); Fleming in Foster et al., p. 98, pl. 11, fig. 10.

Holotype: F. N. Chernyshev Central Scientific-Research Geological-Prospecting Museum (TsNIGR) #834/9585.

Type Locality: Kozhim River, Pechora Coal Basin, western flank of the Northern Urals, Russia.

Figured Specimens: Plate 5, figures 8-18, 20-22.

Material Studied:18 LV, 10 RV, 5 carapaces.

Diagnosis: “Carapace ovally triangular, half again as long as high, moderately convex, medium sized. Dorsal margin arcuate, gently descends towards posterior end and more steeply toward anterior end. Bend in dorsal margin lies toward anterior end. Anterior end higher and shorter than posterior end, broadly and asymmetrically rounded about the midline of the carapace or slightly lowered towards ventral margin. Posterior end broadly rounded. In some specimens a posteroventral slant is distinctly visible. Ventral margin straight or slightly concave centrally LV overlaps RV all around, greatest overlap along dorsal margin and middle of ventral margin. Along posterodorsal slope RV curves at almost a right angle with the formation of a small triangular area, on passing over to the posterior end the contour of the bend flattens out. Carapace evenly convex, median part of valve somewhat flattened. Greatest length in lower third; greatest height lies towards anterior end. Muscle scars are seen in many specimens and are typical of the family, consist of a round spot in the central part of the valve. Surface smooth" (Guseva, 1971)[Translated from Russian]. Simple healdioidean AMS pattern with approximately 9 primary platforms arranged biserially in a semi-arcuate pattern, with up to 25 secondary platforms surrounding the primary platforms (Figure 31 and Figure 32). Interior of LV shows a distinct marginal groove where the RV fits into it. This groove extends around the interior valve margin, except at the anterior end where it becomes indistinct. Hinge is a simple groove and bar arrangement and extends along half the length of the dorsal margin. L=0.89, H=0.59, W=0.32, H/L=0.66 (Figure 33).

Remarks: This species of *Healdia* lacks the posterior spines that are almost characteristic of the genus; however, the AMS pattern, lack of a calcified inner lamellae, and prominent LV over RV overlap and overreach indicate that it should be placed in *Healdia. H. petchorica* displays similarity to the type species of *Healdia, H. simplex* Roundy, 1926; however, *H. simplex* is more ovate than *H. petchorica*, which has a distinct subtriangular profile.

Distribution: This species is common within the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, and is found distributed throughout all the calcareous units. Guseva (1971) first recorded it from the Cisuralian rocks of Pechora Coal Basin in Russia.

Figure 31. AMS pattern of juvenile *H. petchorica* instar (RV, L=0.73)

Figure 32. AMS pattern of adult *H. petchorica* instar (RV, L=0.89).

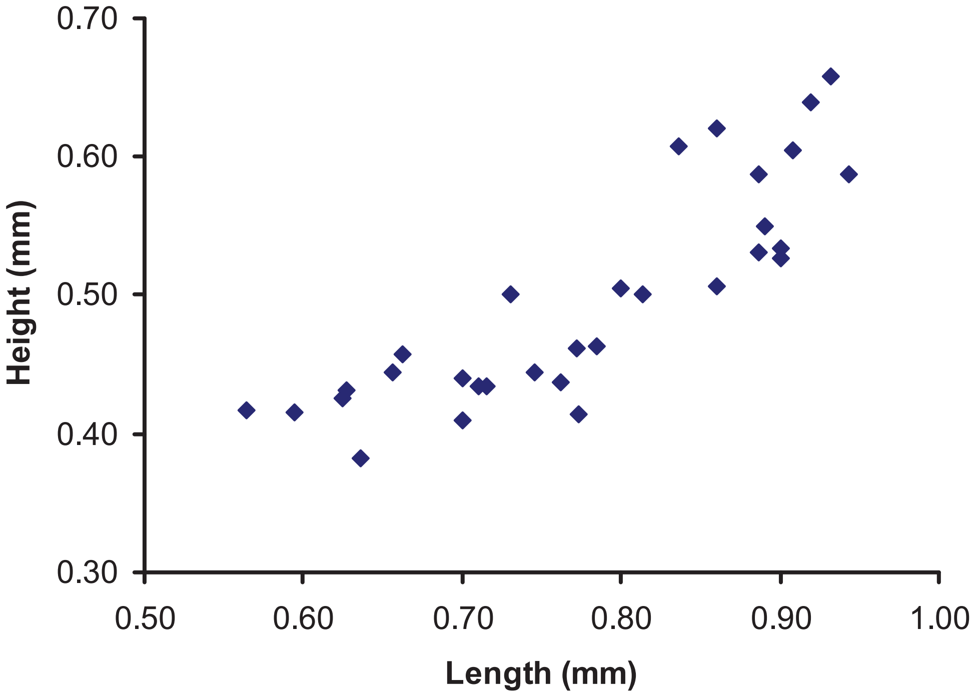


Figure 33. Biometric data for *H. petchorica* (33 measured valves).

Healdia springsurensis (Crespin), 1945 emended Ferdinando

1945a *Cavellina springsurensis* Crespin, p. 33, pl. 4, figs 6a, b.

1985 *Healdioides* sp. A Fleming in Foster et al., p. 98, pl. 11, fig. 18.

Holotype: Commonwealth Palaeontological Collection #266.

Type Locality: Cattle Creek, 14 miles SE of Springsure, Queensland, below waterfall (Lower Bowen Series).

Figured Specimens: Plate 5, figures 24, 25.

Material Studied: 1 LV, 3 RV.

Diagnosis: Surface smooth, with a broad carapace, and occasional normal pore canals. Ventral margin straight, with dorsum rounded and subtriangular. Posterior and anterior margins both broadly rounded, with the posterior end slightly blunter. Greatest height in the dorsomedian region. On the posterior end there is a strong ridge present which extends up the posterodorsal margin, this ridge varies from being parallel to the posterior margin to being oblique to the posterior margin at an angle of up to 20°. On both the anterior and posterior margins a rim is formed, which on the anterior margin extends from anteroventral to anterodorsal and is noticeably thicker at the very edge of the margin. LV overlaps and overreaches RV. Hinge occupies half the length of the dorsal margin and consists of a simple groove with interlocking bar. AMS arrangement a "healdoid" aggregate. L=0.81, H=0.49, W=0.35, H/L=0.61.

Remarks: *H. springsurensis* was originally placed within *Cavellina* by Crespin (1945a); however, examination of the holotype indicates that it should be placed within the *Healdia* as the holotype has LV over RV overlap which is not present in *Cavellina* (Benson, 1961). The species also does not fit within the genus *Healdioides* Coryell and Rozanski, 1942, as it does not possess a depression in the carapace on either side of the posterior ridge. This species was also recorded by Fleming (in Foster et al., 1985); however, only 2 intact specimens have been recovered, precluding a detailed description of this species. Fleming (in Foster et al. 1985) compared *Healdioides* sp. A sensu Fleming, 1985, with *Healdia cara* Bradfield, 1935, from the Pennsylvania of the USA; however, he assigned it to *Healdioides*.

Distribution: This species is very rare within the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin and is restricted to the lowermost carbonate beds of the member. It has also been recorded from the Cattle Creek Formation of the Bowen Basin, Queensland (Crespin 1945a).

Healdia westraliaensis sp. nov.

Holotype: UWA 128897.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33'E..

Derivation of name: Named derived from Western Australia, the Australian state where the type specimen was located.

Figured Specimens: Plate 6, figures 1-4.

Material Studied: 5 LV, 3 RV.

Diagnosis: Carapace small and subtriangular with a smooth surface. Anterior inflated and broadly curved. Posterior narrow and rounded. Dorsal margin convex, with the posterodorsal and anterodorsal margins straight and meeting mid-dorsally in a curved apex, and ventral margin gently curved convexly. Normal pore canals are present on the external surface of the carapace. Hingement a simple groove and bar arrangement, extends along roughly one third the length of the dorsal margin. LV overlaps and overreaches RV. AMS pattern a simple "healdoid" rosette arrangement, with eight primary platforms arranged biserially with 5 platforms on the anterior side and 3 on the anterior, with 3-5 secondary platforms present around these, mainly concentrated on the dorsal side of the muscle scar (Figure 34). Greatest width posteromedially, and carapace wedge-shaped in profile. L=0.65, H=0.42, W=0.35, H/L=0.67 (Figure 35).

Remarks: This species' carapace is very inflated dorsally relative to *H. petchorica*, to which it appears to be similar, and like *H. petchorica* it lacks the spines or ridges that typify the genus *Healdia*. The subtriangular profile differentiates it from the majority of other non-spinose species in this genus. *H. westraliaensis* is similar in profile *to H. oklahomaensis* Harlton, 1927, but lacks spines on the RV that characterise *H. oklahomaensis*.

Distribution: This species is uncommon within the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, although it is found distributed throughout the calcareous units.

Figure 34. AMS pattern of *H. westraliaensis* (LV, L=0.77).

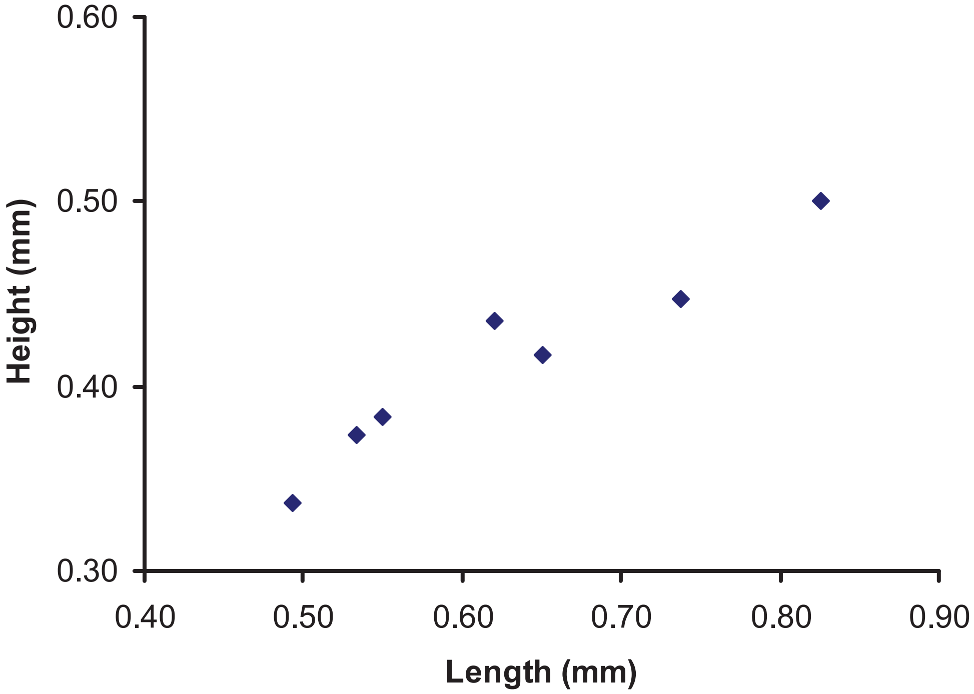


Figure 35. Biometric data for *H. westraliaensis* (7 measured valves).

***Healdia* sp. A**

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33'E.

Figured Specimens: Plate 6, figure 5.

Material Studied: 2 carapaces.

Diagnosis: Carapace small, subreniform, and with a smooth surface. Posterior slightly inflated and well rounded, anterior rounded. Venter straight and dorsum gently curved at mid-point and straight on anterodorsal and posterodorsal margins. LV slightly larger than RV and overlaps along the whole margin of the carapace. Greatest height is posteromedially. Normal pore canals present on the surface of the carapace. L=0.63, H=0.42, W=0.35, H/L=0.67.

Remarks: Only two specimens of this species has been found, both with the LV and RV articulated, so no information on the internal structure has been determined. This specimen shows some similarity to *H. simplex*; however, a lack of comparative material and too few specimens precludes this comparison.

Distribution: This species is extremely rare within the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, and is found within the middle calcareous units.

Genus *CRIBROCONCHA* COOPER, 1941

Type species: ***Cribroconcha costata*** Cooper, 1941

Diagnosis: See Cooper (1941).

Remarks: Fleming (in Foster et al. 1985) erected the monospecific genus *Zarinia* Fleming, 1985, which herein is considered to be a junior synonym of *Cribroconcha* Cooper, 1941, as the type species of *Zarinia*, and only species assigned to this genus, *Zarinia ludbrookae* Fleming, 1985, is now placed within the *Cribroconcha*. Gramm and Yegorov (1989) noted that the presence of pits behind the spines in *Cribroconcha* is a feature typical of not only *Cribroconcha*, but that the AMS pattern is a defining feature of the genus with its inner group of larger scars arranged biserially, with the anterior row more elongate.

Cribroconcha ludbrookae (Fleming), 1985, emended Ferdinando

1985 *Zarinia ludbrookae* Fleming in Foster et al., p. 99, pl. 12, figs. 11-14.

Holotype: WAM 83.2750

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33’E.

Derivation of name: Named in honour of Dr Nell Ludbrook for her contributions to Australian palaeontology.

Figured Specimens: Plate 6, figures 6-17.

Material Studied: 5 LV, 4 RV, 7 carapaces.

Diagnosis: Small, trapezoid carapace, with LV larger than RV, displaying a slight overreach on dorsal margin. Anterior and posterior ends broadly rounded, with dorsum and venter straight. Posterior end of the carapace narrower than the anterior. Hinge line straight, and hingement a simple ridge and groove. Marginal border present around the carapace. Main ornamentation is reticulate, with the surface appearing deeply pitted except over AMS attachment area where it is smooth. Reticulate area separated from border and completely surrounded by a smooth to slightly crenulated flat ridge with a slight thickening on the margins forming a ridge that is most noticeable around the anterior margin. Small backwards-pointing triangular-shaped spine present on the posteroventral edge of the raised area of the carapace on the LV. On some specimens two backwards pointing triangular-shaped spines are present on the posterodorsal and posteroventral areas of the raised area on the RV as well, possibly as a dimorphic feature. AMS attachment rosette, with five primary scars divided into two rows having two and three scars respectively, surrounded by up to seven secondary scars. L=0.52, H=0.32, W=0.13. H/L=0.61 (Figure 36).

Remarks: The two specimens of *C. ludbrookae* illustrated by Fleming (in Foster et al. 1985) are both immature moults and lack the broad border and posteroventral spine on the LV that are typical of the adult carapaces, as well as the more defined reticulate ornamentation of the adult specimens. The biometric data for *C. ludbrookae* (Figure 36) is extremely scattered and does not display a strong linear growth pattern. This may be a result of sexual dimorphism within the species, or simply that more specimens are required to normalise the growth relationship. *C. ludbrookae* is extremely similar to *C. faveolata* Guseva, 1971, from Russia, however, *C. ludbrookae* possesses a distinct ridge on the anterior of the carapace when viewed laterally, in addition to having a slightly more rectangular profile than *C. faveolata*. These two features distinguish the species, although it is possible that the illustrations of *C. faveolata* given by Guseva (1971) are of immature moults that have not yet developed the anterior ridge or adult carapace shape. Another Russian species, *C. scrobiculate* Khivintseva, 1969, also displays a similar reticulated carapace, although the dorsal profile is slightly more inflated and the anterior is less prominent compared to *C. ludbrookae*.

Distribution: *C. ludbrookae* is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin. This species is uncommon, and found in all the carbonate units of the member, especially the lower and middle carbonate units.

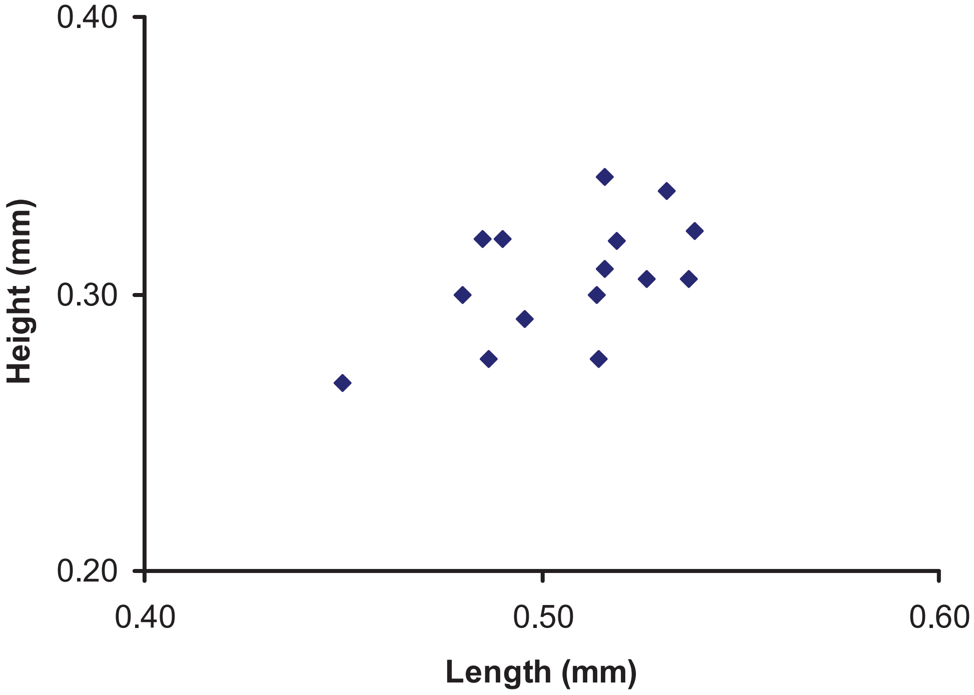


Figure 36. Biometric data for *C. ludbrookae* (15 measured valves).

Genus *HEALDIANELLA* Posner, 1951

Type species: ***Healdianella darwinuloides*** Posner, 1951

Diagnosis: See Posner (1951).

Remarks: In his original description of this genus, Posner (1951) placed the genus *Healdianella* Posner, 1951, within the family Healdiidae based upon the AMS arrangement, and differing from the genus *Healdia* in the character of the hinge and lack of spines. Shaver (1961a) placed the genus *Healdianella* with the family Bairdiocyprididae based upon a similarity to *Cytherellina* Jones and Holl, 1869. Gramm (1982) placed the genus *Healdianella* back within the Healdiidae based upon detailed work on the AMS arrangement, hinge structure, and contact groove arrangement. Gramm (1982) also noted that the “healdoid” AMS arrangement is not a sufficient character to place a genus within the Metacopina without other supporting characteristics. This study accepts Gramm’s (1982) stance that *Healdianella* is part of the family Healdiidae.

Healdianella? moryi sp. nov.

Holotype: UWA 128900.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33’E.

Derivation of name: Named after Dr Arthur Mory for his work in elucidating the stratigraphy and depositional environments of the Permian sedimentary sequences in the Perth and Carnarvon Basins.

Figured Specimens: Plate 6, figures 18-24.

Material Studied: 10 LV, 3 RV.

Diagnosis: Carapace medium sized, reniform, and smooth. Valves slightly inequal with LV overlapping RV. Dorsal margin curved, and ventral margin straight to slightly convex. Anterior inflated relative to posterior, with both ends broadly rounded and displaying a slight rim on the border of both the anterior and posterior. Contact groove present around the interior margin of the valves. Greatest width anteromedially. Hinge a ridge and groove type. AMS arrangement a simple circular rosette consisting of between 6 to 8 circular primary platforms with a number of secondary platforms surrounding the primary scars (Figure 37). L=0.68, H=0.43, W=0.31, H/L=0.63 (Figure 38).

Remarks: *H? moryi* is tentatively placed within the genus *Healdianella* on the basis of its carapace shape, hingement style, and contact margin. The AMS arrangement is not as complex as those in other species of *Healdianella* that have been illustrated and it is the lack of a complex muscle scar that precludes definite assignment to the *Healdianella*. *H? moryi* is similar to the type species *H. darwinuloides* Posner, 1951; however, *H. darwinuloides* is slightly more elongate on the posterior end. It is also similar to two Devonian species from the Russian Platform, *H. distincta* Polenova, 1952, and *H. karlensis* Rozhdestvenskaya, 1962; however, *H? moryi* shows a greater inflation of the carapace medially and anteriorly.

Distribution: This species is uncommon within the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, and is found distributed throughout the lower and middle calcareous units.

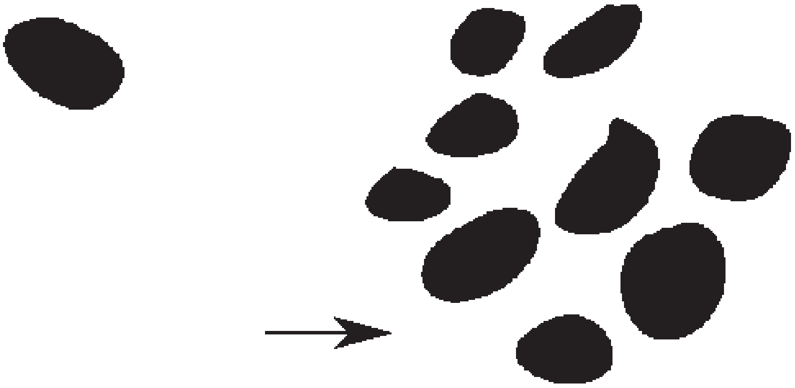


Figure 37. AMS pattern of *H?. moryi* (LV, L=0.64), showing mandibular scar to the left.

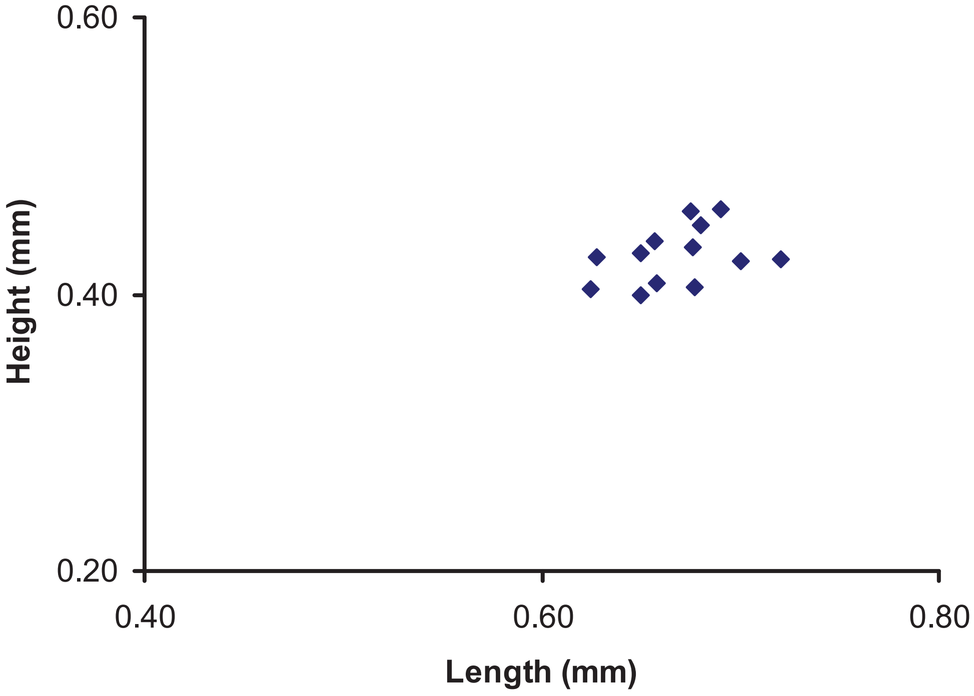


Figure 38. Biometric data for *H? moryi* (13 measured valves).

Genus *WAYLANDELLA* CORYELL AND BILLINGS, 1932

Type Species: ***Waylandella spinosa*** Coryell and Billings, 1932

Diagnosis: See Coryell and Billings (1932) and Shaver (1961a)

Remarks: In Shaver (1961a) *Waylandella* Coryell and Billings, 1932, is differentiated from *Healdia* by generally having a more elongate outline in lateral view, lacking dorsal angulation, and as having either 1 or 2 spines, or a ridge located posteriorly on each valve**.** This genus is similar to *Bythocypris* Brady, 1880, in the overlap of the valves. It differs from *Bythocypris* in the presence of posterior spines. No record of detailed AMS pattern analysis has been found for species of *Waylandella*.

Waylandella holmwoodensis sp. nov.

Holotype: UWA 128901.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33'E.

Derivation of name: Named after the Holmwood Shale, which the Fossil Cliff Member belongs to.

Figured Specimens: Plate 6, figures 25-30; Plate 7, figures 1-7.

Material Studied: 6 LV, 11 RV, 4 carapaces.

Diagnosis: Smooth, elongate, reniform to subelliptical carapace with a slightly concave ventral border and convex dorsal border. One backward pointing spine that may extend beyond the edge of the carapace on each valve is located on the posteroventral margin. Small lip present underneath the spine extending along the posterior margin. Lip present on both RV and LV, but slightly more distinct and prominent in the RV. Overlap of LV over RV slight, but distinguishable, extending over the entire margin. Anterior and posterior margins broadly rounded with the posterior slightly larger than the anterior. Marginal structures are very fine, and hinge consists of a groove and bevel and extends for 40% the length of the dorsal margin. AMS attachment a "healdoid" aggregate with from 20 to 22 platforms arranged concentrically in the centre of the carapace, with 2 rows of primary platforms with each row containing 3 to 4 primary scars arranged biarcuately in an ovate to subcircular shape, surrounded by between 13 to 15 smaller circular secondary platforms (Figure 39). L=0.88, H=0.45, W=0.19, H/L=0.52 (Figure 40).

Remarks: This species displays a typical "healdoid" aggregate AMS, and is similar to *Waylandella cuyleri* Coryell and Booth, 1933, of the USA in its general morphology of the carapace, although the presence of a lip underneath the posterior spine distinguishes this species from *W. cuyleri* in addition to a lack of increased overlap centroventrally. *W. dispar* Cooper, 1946, is also similar; however, *W. holmwoodensis* has a much larger posterior spine and a lip beneath it, which is not present in *W. dispar*. Although *W. holmwoodensis* has a comparable profile to *W. deesensis* Bradfield, 1935, *W. holmwoodensis* has only one posterior spine. The presence of a distinct posterior lip also distinguishes it from *W. regularis* Cooper, 1946, and *W. symmetrica* Cooper, 1946, whilst the slightly concave ventral margin separates this species from *W. obesa* Cooper, 1946. It differs from *W. spinosa* Coryell and Billings, 1932, by having only one posterior spine, having a concave ventral border, and being of greater adult size.

Distribution: This species is uncommon within the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, although it is found throughout the carbonate beds.

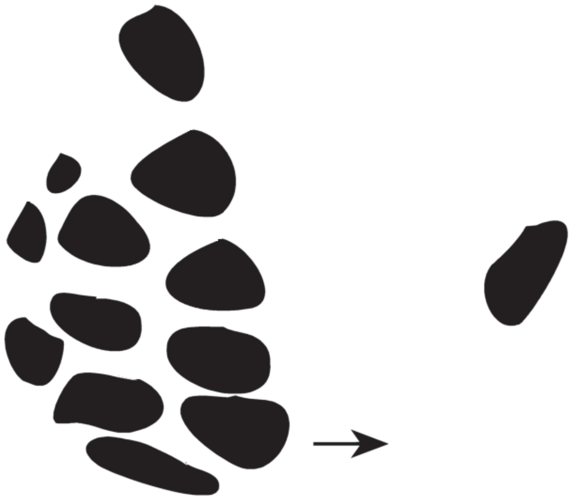


Figure 39. AMS pattern of *W. holmwoodensis* (LV, L=0.78), showing mandibular scar to the right.

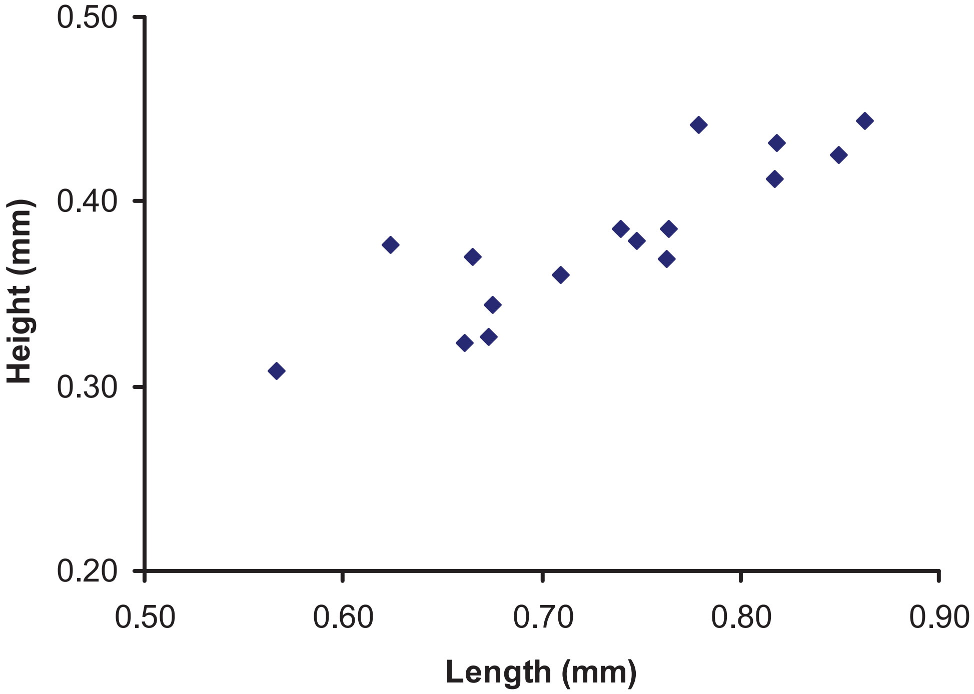


Figure 40. Biometric data for *W. holmwoodensis* (16 measured valves).

***Waylandella?* sp. A**

Holotype: UWA 128902.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33'E.

Figured Specimens: Plate 7, figure 8.

Material Studied: 1 LV, 1 carapace.

Diagnosis: Carapace elongate, smooth, and reniform, with a slightly concave ventral margin, and a broadly rounded dorsal margin. One backward pointing spine is located midposteriorly on the RV, extending just past the edge of the carapace. LV over RV overlap present, and extends along the whole margin of the specimen. Normal pore canals present on the carapace, with the greatest concentration of pores on the anterior. The hinge poorly preserved and appearing to be a groove and bar type. L=0.74, H=0.39, W=0.30, H/L=0.53.

Remarks: *W?*. sp. A shows distinct characteristics of *Waylandella* in profile, except for having a single spine located on the RV. This may be as result of the spine on the LV having been broken, although no definite evidence remains on the LV to indicate a spine was attached. The generic description of *Waylandella* by Shaver (1961) notes that spines are present on both valves, although in the original generic description given by Coryell and Billings (1932), no note of this was made, thus the tentative inclusion of this species into *Waylandella*.

Distribution: This species is found within the lowermost calcareous beds of the Fossil Cliff Member.

Waylandella? **sp. B**

Holotype: UWA 128903.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33'E.

Figured Specimens: Plate 7, figure 9.

Material Studied: 1 RV.

Diagnosis: Carapace elongate, smooth, and reniform, with a straight ventral margin, and a broadly rounded dorsal margin. One thick backward pointing spine is located dorso-posteriorly on the RV, extending beyond the edge of the carapace. Overlap and overreach of the valves not determined. Normal pore canals present on the carapace, with the greatest concentration of pores on the anterior. The hinge is poorly preserved and appears to be a groove and bar type. L=0.90, H=0.49, W=0.38, H/L=0.54.

Remarks: Only one RV of this species has been found within the Fossil Cliff material. The internal details of the valve are obscured by sediment cemented to the inside of the valve, so no AMS have been observed. This species has been tentatively placed within the *Waylandella,* as the valve shows the general characteristics of the genus; however' features such as valve overlap, lack of calcified inner lamellae, and AMS pattern, which help define the genus, are either obscured or missing. It may be possible that that this specimen is related to *W?* sp. A, although the location of the single spine on the posterodorsal part of the carapace instead of the midposterior as in *W?*. sp. A makes this a tenuous relationship.

Distribution: This species is very rare within the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, and has been found within the lowermost calcareous bed of the Fossil Cliff Member.

***Waylandella?* sp. C**

Holotype: UWA 128904.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33'E.

Figured Specimens: Plate 7, figures 10, 11.

Material Studied: 2 LV.

Diagnosis: Carapace elongate, smooth, and reniform, with a slightly concave ventral margin and a convex dorsal margin. Very low profile in lateral view, with greatest height just medially from the base of spines on posterior end. Two backward pointing spines extend from midposterior to beyond the posterior margin. Spines equally spaced from the midpoint of the posterior margin on the dorsal and ventral sides. Rim evident along the posterior margin. Anterior and posterior ends equal in width, with the posterior having a greater height than anterior end. Normal pore canals present across the carapace, with the greatest concentration of them on the posterior end, near the spines. Ventral margin almost straight with a slight concavity, and a sharp termination to the anterior and posterior margins. Dorsal margin gently rounded with a sharp termination on the posterior margin, and an ovate shape on the anterodorsal end. Hinge located in the mid-dorsal region and extends for about a third the length of the margin, and is a simple groove and bar arrangement. LV overlaps RV and overreaches on all margins. Internal details are unknown as no specimens have been recovered that illustrate AMS arrangement or the hinge morphology. *W?*. sp. C is relatively large and has a H/L=ratio of 0.53. L=0.84, H=0.44, W=0.30.

Remarks: This species is far more elongate than similar, dual-spined species previously described from both the Mississippian of Northern America, and the Permian of Europe.

Distribution: This species is very rare within the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, and has been found only within the middle carbonate units of the Fossil Cliff Member.

Superfamily THLIPSUROIDEA Ulrich, 1894

Family QUASILLITIDAE Coryell and Malkin, 1936

Genus *GRAPHIADACTYLLIS* Roth, 1929 emended. Green, 1963

Type species: ***Graphiadactyllis arkansana*** (Girty), 1910

Diagnosis: See Green (1963).

Remarks: Green's (1963) modifications to *Graphiadactyllis* Roth, 1929, included broadening the range of the genus to include those species with a posterior spine. In the original Roth (1929a) diagnosis, a false keel, or marginal frill, is also noted to be characteristic for the genera. This resulted in the definition of the genera becoming broad enough to overlap with *Graphiadactylloides* Green, 1963, necessitating the amendment of the original description. In this work, specimens that display the marginal frill without a posterodorsal spine are assigned to the *Graphiadactyllis*. Those specimens that display both the marginal frill and posterior spine are assigned to the *Graphiadactylloides* on the basis that *Graphiadactylloides* was erected as an intermediate genus between *Graphiadactyllis* and *Quasillites* Coryell and Malkin, 1936. Roth (1929b), also noted that in his original work describing *Graphiadactyllis* he misspelt the generic name and it should have been *Graphiodactylus*. As modern usage of the generic name seems to have adopted the original spelling and not the corrected spelling, this work will use the widely adopted spelling of *Graphiadactyllis* for simplicity.

Graphiadactyllis australae (Crespin), 1945, emended Ferdinando

1945 *Basslerella australae* Crespin, p. 34, pl. 4, figs 9a, b, 10.

1985 *Graphiadactyllis alveiformis* Fleming in Foster et al., p. 98, pl. 12, figs. 6-10.

Holotype: Commonwealth Palaeontological Collection #269.

Type Locality: Cattle Creek, 14 miles SE of Springsure, Queensland, below waterfall (Lower Bowen Series).

Figured Specimens: Plate 7, figures 12-19.

Material Studied: 54 LV, 65 RV, 28 carapaces.

Diagnosis: Carapace large and subtriangular. Surface smooth to pustulose, especially on carapace margins, and on anterior and posterior ends the pustules may become hornlike, with each pustule hosting a normal pore canal. Dorsal margin long and straight on the LV, and the same on the RV except for bumps on the posterior and anterior ends of the dorsal margin where the hinge socket is located. RV larger than LV. Anterior and posterior rounded, with greatest height located medially. Hinge merodont, with finely ridged teeth. Margin contact is a ridge and groove and extends along the entire valve margin. Anterior frill extending from anteroventer to midanterior, and present on both valves and flat internally, with the frill terminating into a distinct horn. AMS a clustered aggregate with up to 40 platforms arranged circularly. Most platforms have an ovate to subtriangular profile and are of approximately the same size. The AMS location is variable between medially to just to the posterodorsal of the medial point. L=1.78, H=0.98, W=0.75, H/L=0.59 (Figure 41).

Remarks: *G. australae* was described by Fleming (in Foster et al., 1985) as *G. alveiformis* Fleming, 1985, and in his description he stated that the LV was larger than the RV, however further investigation has shown that the specimens described by Fleming (in Foster et al., 1985) do have the RV larger than the LV. Additional material has provided the opportunity to give a more detailed diagnosis of this species, especially in relation to the AMS pattern and surface ornamentation. Some of the larger pustules on the posterior margin maybe mistaken for spines, however this enlargement of the pustules occurs in a number of the pustules in the posterior region, and thus distinguishes this species from *Graphiadactylloides flemingi* sp. nov. which has a single backwards pointing spine located on the posterior, and is very similar in appearance to *G. australae*. This species has also been recorded from the Cisuralian Mostyndale Member of the Cattle Creek Formation, Denison Trough, central Queensland (Foster et al., 1985 p. 99). The ornamentation on this species is dissimilar to the common “fingerprint” style of ornamentation of species of *Graphiadactyllis*, although a number of species assigned to the genus do not have this pattern, and it is not considered to be a diagnostic feature. *G. petchoricus* Guseva, 1971, from Russia is very similar to *G. australae* and may be a junior synonym, however based upon the figured specimens in Guseva (1971) it is difficult to be certain, and the holotype and paratype material need to examined to confirm this relationship.

Distribution: *G. australae* is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, and has also been recorded from the Cisuralian Mostyndale Member of the Cattle Creek

Formation. It is common within all the calcareous units within the Fossil Cliff Member.

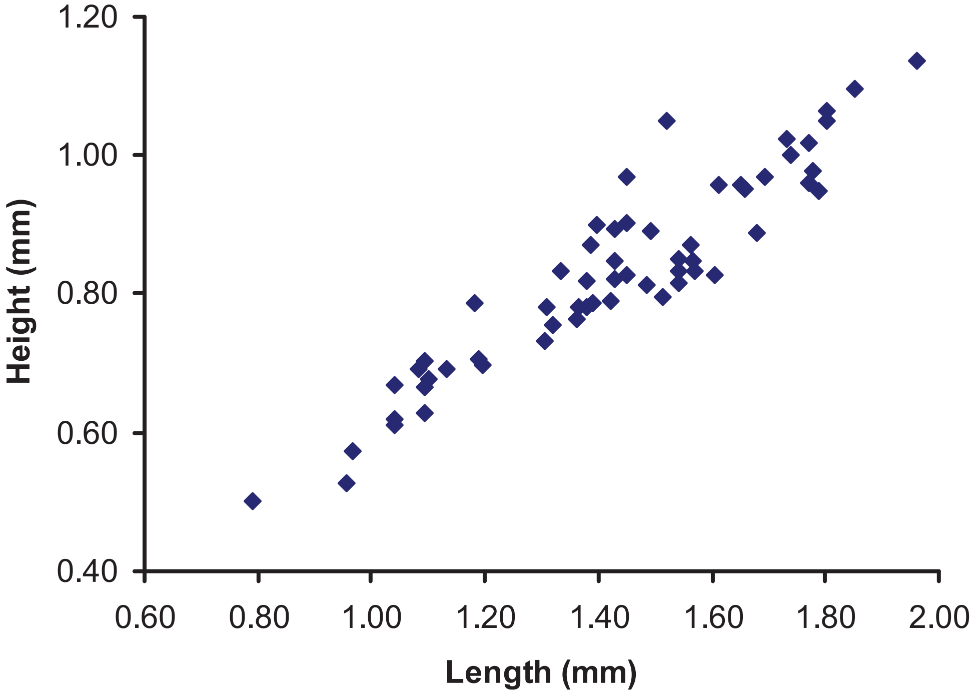


Figure 41. Biometric data for *G. australae* (63 measured valves).

Graphiadactyllis jonesi sp. nov.

Holotype: UWA 128905.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33'E.

Derivation of name: Named after Dr Peter Jones of the Australian Geological Survey for his work on the Palaeozoic ostracode faunas of Australia.

Figured Specimens: Plate 7, figures 20-29.

Material Studied: 7 LV, 20 RV.

Diagnosis: Carapace large and subtriangular, with a smooth surface. Anterior well rounded and inflated relative to the posterior which is rounded and blunt. Ventral border slightly concave, and dorsum curved at the midpoint with the antero- and posterodorsal borders straight. Posterior end displays a slight ridge before it thins sharply towards the posterior border. Anterior shows a poorly developed, indistinct marginal flange. Valve surface displays numerous normal pore canals of two distinct sizes, the larger roughly double the diameter of the smaller pores. AMS arrangement circular to slightly ovate, with up to 10 primary platforms surrounded by 10 to 15 slightly smaller secondary platforms. Hinge is a ridge and groove arrangement that extends along the posterodorsal margin. L=0.94, H=0.56, W=0.47, H/L=0.59 (Figure 42).

Remarks: *Graphiadactyllis jonesi* lacks the pustulose ornamentation and distinctive anterior frill present on *G. australae* and the profile of the carapace is slightly more triangular than in *G. australae*. The presence of a marginal frill is characteristic for this genus, and *G. jonesi* displays a very indistinct frill visible in only well-preserved specimens that indicates that it belongs as part of this genus.

Distribution: *G. jonesi* is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin. This species is common in all the calcareous beds of the Fossil Cliff Member.

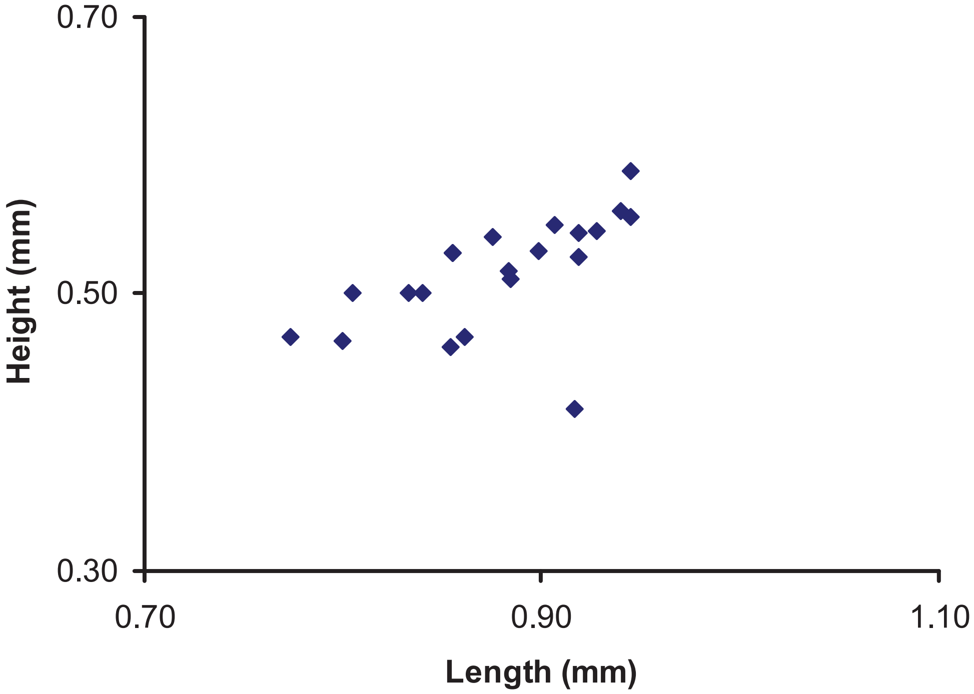


Figure 42. Biometric data for *G. jonesi* (23 measured valves).

Genus *GRAPHIADACTYLLOIDES* Green, 1963

Type species: ***Graphiadactylloides moreyi*** Green, 1963

Diagnosis: See Green (1963).

Remarks: This genus was erected by Green (1963) as an intermediate genus between *Quasillites* and *Graphiadactyllis*. *Graphiadactylloides* displays both the marginal frill of *Graphiadactyllis* and the posterior spine of *Quasillites*. Other than this, *Graphiadactylloides* is the same in all respects as *Graphiadactyllis*.

Graphiadactylloides flemingi sp. nov.

Holotype: UWA 128906.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33’E.

Derivation of name: Named after Mr P. Fleming for his work on identifying Australian Cisuralian ostracode faunas.

Figured Specimens: Plate 8, figures 1-10.

Material Studied: 3 LV, 6 RV, 2 carapaces.

Diagnosis: Carapace large with rhomboidal shape. Anterior larger than posterior, and both rounded. Dorsum and venter both straight. Marginal frill located anteroventrally, and extends from anteroventral area to mid-point of the anterior margin, and at the midanterior point becomes slightly detached from the valve and ends in a small triangular horn. Small backwards pointing spine located on the RV posteroventrally. Surface pustulose, except medially where the ornamentation becomes indistinct and on some specimens becomes smooth. Valves subequal, with the RV overlapping the LV. Hingement consists of a smooth tooth at each end of hingeline, with a simple bar connecting the teeth. Hinge approximately three quarters the length of the dorsal margin. AMS a circular rosette of about 30 small subcircular to subovate platforms, all of similar size, and with no distinct primary platforms. AMS located just to the anterior side of the centre of the carapace on both valves. L=1.66, H=0.89, W=0.69, H/L=0.56 (Figure 43).

Remarks: This species is similar to *Graphiadactyllis australae* from the Cisuralian Cattle Creek Formation of the Denison Trough in Queensland, although *G. flemingi* differs by displaying a small spine on the posterior of the RV in addition to showing a distinct anterior flange. Whilst *Graphiadactyllis australae* is diagnosed as having a marginal flange, the flanges displayed in both Crespin's (1945a) and Fleming's (in Foster et al., 1985) figures are not as prominent as those on *G. flemingi*. The species has been placed in *Graphiadactylloides* as it displays both the marginal flange and also a posterior spine.

Distribution: This species is common and is found within all the calcareous units of the Fossil Cliff Member.

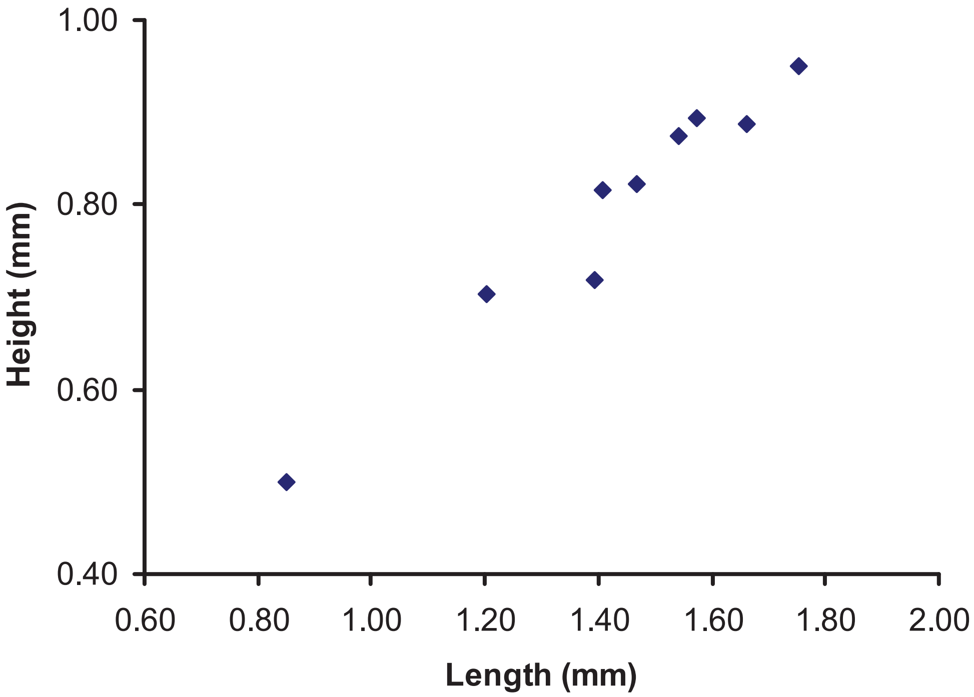


Figure 43. Biometric data for *G. flemingi* (9 measured valves).

Suborder PODOCOPINA SARS, 1866

Superfamily CYTHEROIDEA BAIRD, 1850

Family BYTHOCYTHERIDAE SARS, 1926

Genus *MONOCERATINA* ROTH, 1929

Type Species: ***Monoceratina ventrale*** Roth, 1928

Diagnosis: See Sylvester-Bradley and Kesling (1961).

Remarks: *Monoceratina* Roth, 1928, is placed into the Podocopina due to the presence of a calcified inner lamella, something that occurs only in the Palaeozoic species of this genus.

Monoceratina granulosa sp. nov.

Holotype: UWA 128907.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33’E.

Derivation of name: Named for the granulose ornamentation found on the carapace and spine.

Figured Specimens: Plate 8, figures 11-24.

Material Studied: 6 LV, 8 RV.

Diagnosis: Carapace medium sized, subrectangular, and with a granulose ornamentation on the surface that have a weakly reticulated pattern. Dorsal margin long and straight, meeting anterior border at a right angle. Anterior margin straight, and curves to meet ventral region where it becomes straight to gently curved and slopes down to the dorsal border. L3 strongly developed, forming a prominent tubular spine on the posteroventral region of the valve. Small L1 lobe located on the anteroventro border and forms a subrounded lump, with an associated smaller lobe situated on the dorsal margin just above it in dorsal view. On some specimens the S2 pit is well developed and is situated medially. L4 lobe weakly developed and found near the posterodorsal border. The linear arrangement of the granulose ornament is most noticeable medially and on the L3 spine. The hinge is a simple ridge and groove, and at both ends of the hinge some fine striations may be present, indicating a ridged tooth. No AMS attachments have been observed on the interior surface of the carapace, and a large depression is present where the L1 spine extends from the outer valve surface. L=0.89, H=0.44, W=0.33, H/L=0.50 (Figure 44).

Remarks: This species is placed in the genus *Monoceratina* rather than *Aechmina* because of the distinct L3 spine that has formed on the ventral rather than dorsal side. *M. granulosa* also displays development of L1, which, whilst unusual in *Aechmina*, is common in Palaeozoic *Monoceratina*. This species is also similar to species assigned to the genus *Ovornina* Gründel, 1966, however *Ovornina* has been recorded only from lower Palaeozoic (Ordovician and Silurian) strata in Europe and Canada (Gründel, 1966; Copeland, 1977, 1982). On the specimens found, L1 appears more distinct on the LV than on the RV, but with such a small population of specimens this may not be statistically significant. Copeland (2000) illustrated a specimen from the Ordovician of Canada he described as *Aechmina*. sp. that displays a similar ventral profile to *M. granulosa*; however, the asymmetry of the valves and the positioning of the L3 spine differ. *M. granulosa* is broadly similar to *M. winifrediana* Sohn, 1983, of the USA, except that L1 on *M. winifrediana* is absent and *M. granulosa* has greater elongation on the posterior end.

Distribution: *M. granulosa* is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the calcareous units of the member. *M. granulosa* is rare, and is found predominantly in the middle and upper carbonate beds of the member, although specimens have been recovered from the lower carbonate beds.

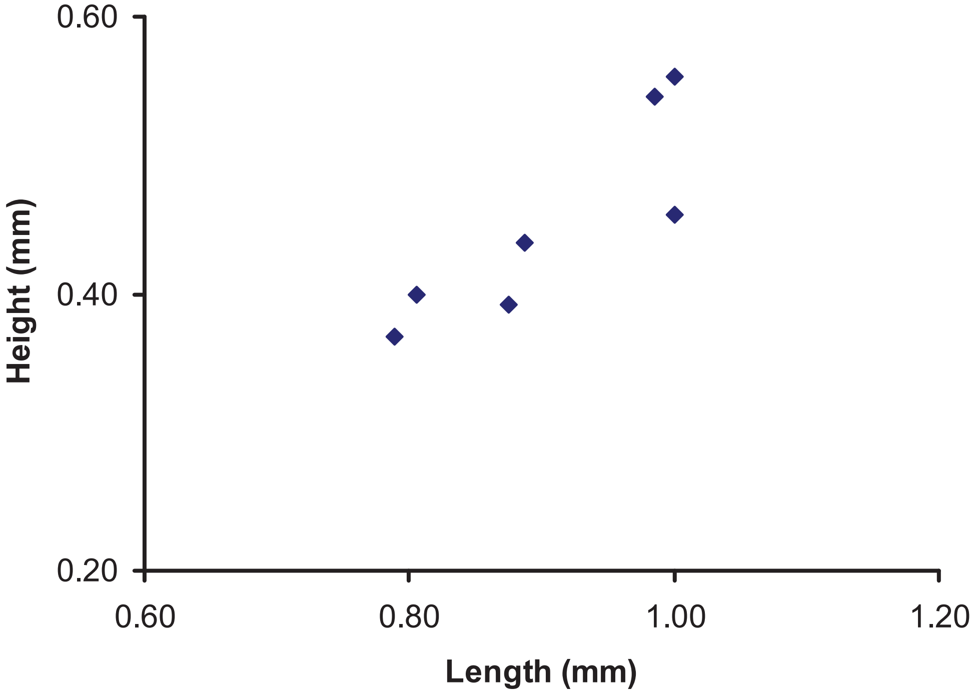


Figure 44. Biometric data for *M. granulosa* (7 measured valves).

Superfamily BAIRDIOCYPRIDOIDEA SHAVER, 1961

Family BAIRDIOCYPRIDIDAE SHAVER, 1961

Genus *PSEUDOBYTHOCYPRIS* SHAVER, 1958

Type Species: ***Pseudobythocypris pediformis*** (Knight), 1928

Diagnosis: See Shaver (1958).

Remarks: Shaver (1958) erected *Pseudobythocypris* Shaver, 1958 as a genus for those species intermediate between the Bairdiidae and Healdiidae, specifically the Healdiidae genus *Waylandella*. Becker (2000d), however, refuted this, stating that the reason for placing them as intermediates between the Bairdiidae and Healdiidae, and thus within the Metacopina, was based upon the presence of a clustered AMS, which was not considered by him to be a diagnostic element at this level, and that evolutionary trends and other features of the carapace place this genus within the Podocopina, not the Metacopina.

Pseudobythocypris hockingi sp. nov.

Holotype: UWA 128908.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33’E.

Derivation of name: Named after Roger Hocking of the Geological Survey of Western Australia in recognition of his work on the stratigraphy of the Phanerozoic sedimentary strata of Western Australia.

Figured Specimens: Plate 8, figures 25-27; Plate 9, figures 1-6.

Material Studied: 4 LV, 5 RV, 3 carapaces.

Diagnosis: Medium sized reniform carapace, with a smooth surface. LV overlaps RV and overreaches along all the margins. Dorsal margin broadly curved convexly, with the ventral margin straight to slightly concave at its mid-point. Anterior broadly rounded, posterior rounded, but meets the posteroventral border at an angle of around 80°, forming a distinct point. AMS attachment an ovate aggregate, located just to the anterior of the midpoint of the carapace, with a biserial arrangement of 6 to 7 rounded to ovate primary platforms, closely grouped with between 5 to 9 secondary platforms (Figure 45). Hinge a simple bar and groove type and extends for 50% the length of the dorsal margin.

Normal pore canals are found across the surface, but are well spaced. L=0.79, H=0.40, W=0.29, H/L=0.50 (Figure 46).

Remarks: This species displays the characteristic features of the genus *Pseudobythocypris* namely LV over RV overlap, an aggregate AMS pattern, lack of a calcified inner lamellae, and a elongate reniform to trapezoid lateral outline (Shaver, 1958; Becker 2000d). This species differs from the recorded species of *Pseudobythocypris* in its elongate profile and the angle at which the posteromedial and posterodorsal borders intersect.

Distribution: This species is found within the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin. It is distributed throughout all the calcareous units of the Fossil Cliff Member, and occurs infrequently.

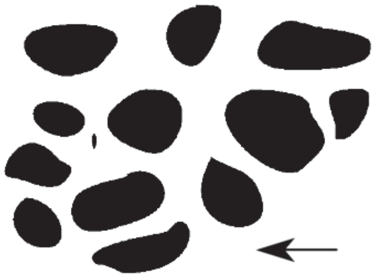


Figure 45. AMS pattern of *P. hockingi* sp. nov. (RV, L=0.82).

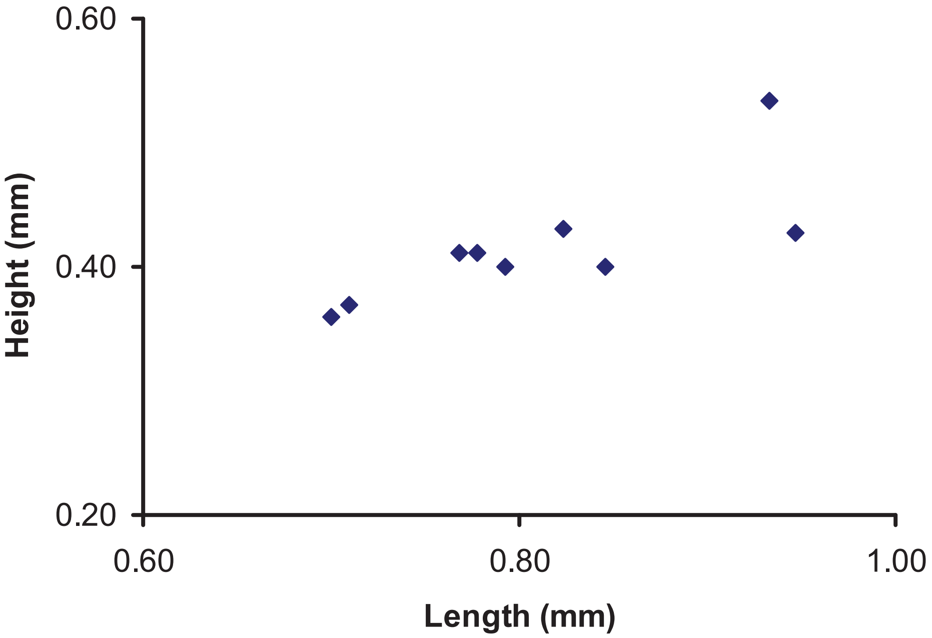


Figure 46. Biometric data for *P. hockingi* (9 measured valves).

Pseudobythocypris lordi sp. nov.

Holotype: UWA 128909.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33’E.

Derivation of name: Named after Joe Lord, past Director of the Geological Survey of Western Australia in recognition of his work in overseeing the completion of geological mapping Western Australia at 1:250 000 scale.

Figured Specimens: Plate 9, figures 7-15.

Material Studied: 1 LV, 6 RV, 3 carapaces.

Diagnosis: Carapace medium sized, reniform, and smooth. LV overlaps RV except at the posterior margin where a slight frill is developed extending along the posterodorsal to the posteroventral border. Dorsal margin straight medially, and curving down on the posterior and anterior ends. Ventral margin long and straight, although on the RV a slight concavity developed at the mid-point of the margin. Posterior end rounded, with the anterior broadly rounded and inflated, and meeting the ventral border at 90°, although the point of intersection is well rounded. Hinge a simple groove and bar. Normal pore canals found across the surface, but well spaced. AMS a small clustered ovate aggregate of 7 to 9 primary scars arranged biserially surrounded by up to 10 secondary scars L=0.64, H=0.34, W=0.24, H/L=0.53 (Figure 47).

Remarks: *P. lordi* sp. nov., differs from *P. hockingi* by having an inflated posterior, anterior frill, and lacking the distinctive pointed posteroventral border.

Distribution: This species is found within the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin This species is distributed throughout the middle and upper calcareous units of the member, and occurs very infrequently.

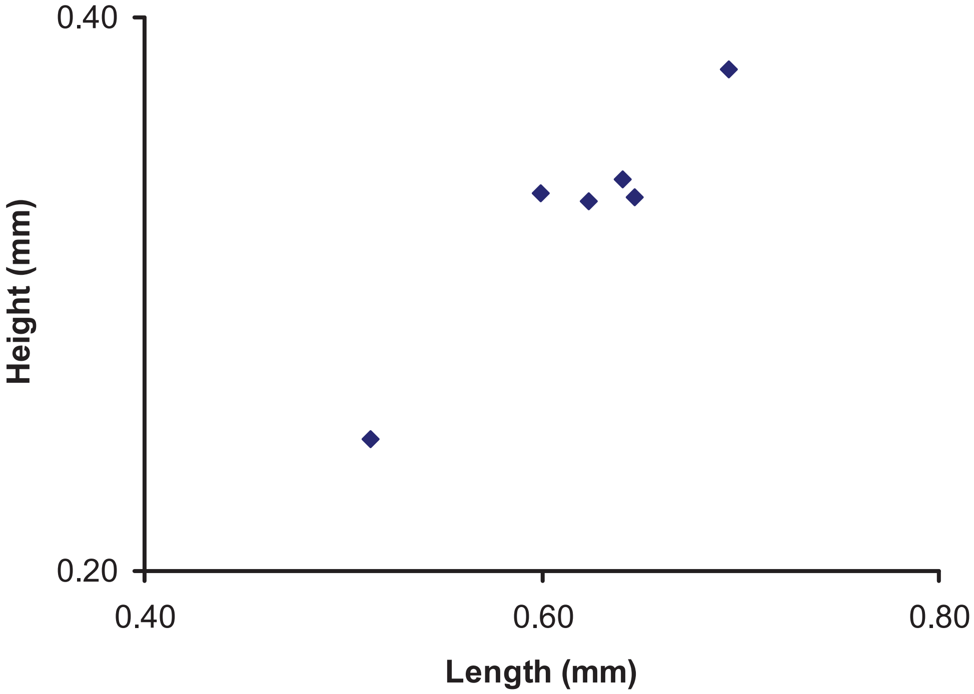


Figure 47. Biometric data for *P. lordi* (6 measured valves).

Superfamily BAIRDIOIDEA SARS, 1888

Family BAIRDIIDAE SARS, 1888

Genus *BAIRDIA* M^{C} COY, 1844

Subgenus *BAIRDIA (BAIRDIA)* M^{C} COY, 1844

Type species: ***Bairdia curtus*** M^{c} Coy, 1844

Diagnosis: See Shaver (1961c).

Remarks: Kellett (1934) expanded upon McCoy's (1844) original description of the genus, illustrating the range in the hinge and marginal structures, the morphology of the AMS pattern, and importantly the composition of the shell wall, which is composed of calcified outer and inner lamellae. Kellett (1934) also described the internal morphology of the valves noting the inner margin and the line of concrescence almost coincide ventrally, with the area between them being prominent only anteroventrally and posteriorly. Specific criteria for *Bairdia* McCoy, 1844, according to Kellett (1934) were the position of the anterior and posterior extremities in relation the midheight of the valve, general shape in outline, the shape of the extremities, and the amount and character of the dorsal overlap. Kellett (1934) also noted the large degree of variation within species of *Bairdia* especially in the ratio of length to height, and the effects that this variance has upon the outline of the specimen in side views. Variation between adults and juvenile instars was also noted, with the variation usually expressed in the more pointed ends of the juvenile instars. Sohn (1960) proposed radical changes to the genus *Bairdia* which included limiting the range of the genus from Middle Devonian to uppermost Permian and splitting the Palaeozoic *Bairdia* into a number of new genera, including *Orthobairdia* Sohn, 1960*, Rectobairdia* Sohn, 1960*, Cryptobairdia* Sohn, 1960*, Pustulobairdia* Sohn, 1960, and *Bairdiocypris* Sohn, 1960. Adamczak (1976) agreed with limiting the range of *Bairdia*; however, he questioned the validity of the new genera erected by Sohn and argued that they had no meaning even as subgenera, a suggestion also made by Becker (1965, 2001a). Adamczak's basis for this was that the new genera erected by Sohn were based merely upon superficial carapace characters, such as carapace outline, and that the internal morphology had not been taken into account, and as such they were not relevant as either genera or subgenera. Within this study, the stance of Becker (2001a) is accepted, that some of the genera proposed by Sohn (1960) are either subgenera of *Bairdia*, or in the case of *Orthobairdia* a synonym of *Bairdia (Rectobairdia)*.

Bairdia (Bairdia) grayi Crespin, 1945 emended Ferdinando

1945a *Bairdia grayi* Crespin, p. 32, pl. 4, figs 1a, b.
1960 *Silenites grayi* (Crespin); Sohn, p. 74.
1989 *Silenites* cf. *S. grayi* (Crespin); Lethiers et al., p. 230, pl. 3, fig. 5.

Holotype: Commonwealth Palaeontological Collection #261.

Type Locality: Cattle Creek, 14 miles southeast of Springsure, Queensland.

Figured Specimens: Plate 9, figures 16-20.

Material Studied: 1 LV, 4 carapaces.

Diagnosis: Carapace large, subovate, slightly inflated, and with a slightly pustulose surface. Valves asymmetric, with the LV overlapping RV, most notably on the dorsal and ventral margins. Dorsal margin rounded, with the posterodorsal and anterodorsal borders straight to gently rounded. On the RV, the posterodorsal margin shows a distinct kink at the point where it meets the dorsal margin. Ventral margin straight to gently concavely curved on the LV, and displaying a slight indentation on the RV. Anterior inflated and broadly rounded. Posterior displays a prominent beak with a slight upturn, with associated flattening of the carapace. Greatest height medially. Hinge consisting of interlocking ridge and groove which extends for about 70% of the length of the dorsal margin. AMS consists of a sub-circular pattern of six primary platforms arranged biserially surrounded by 6 to 7 secondary platforms. Normal pore canals present in the centre of each of the indistinct pustules on the surface and evenly scattered across the carapace. L=1.10, H=0.71, W=0.62, H/L=0.67 (Figure 48).

Remarks: The author has examined the holotype of *B. (B.) grayi*, and feels that this species belongs to the *Bairdia (Bairdia)* rather than *Silenites*, to which Sohn (1960) tentatively assigned the species. *B. (B.) grayi* is similar to *B.* sp. cf. *B. (B.) hassi* although *B. (B.) grayi* displays a more prominent posterior beak and has a slightly more inflated mid region. *B. (B.) beedei* has a very similar pronounced overlap on the dorsal and ventral margins, however it is not as inflated as *B. (B.) grayi*.

Distribution: *B. (B.) grayi* is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin. This species is present in the upper calcareous units of the member, where it is found very rarely. It has also been recorded from the Cattle Creek Formation, Bowen Basin, Queensland.

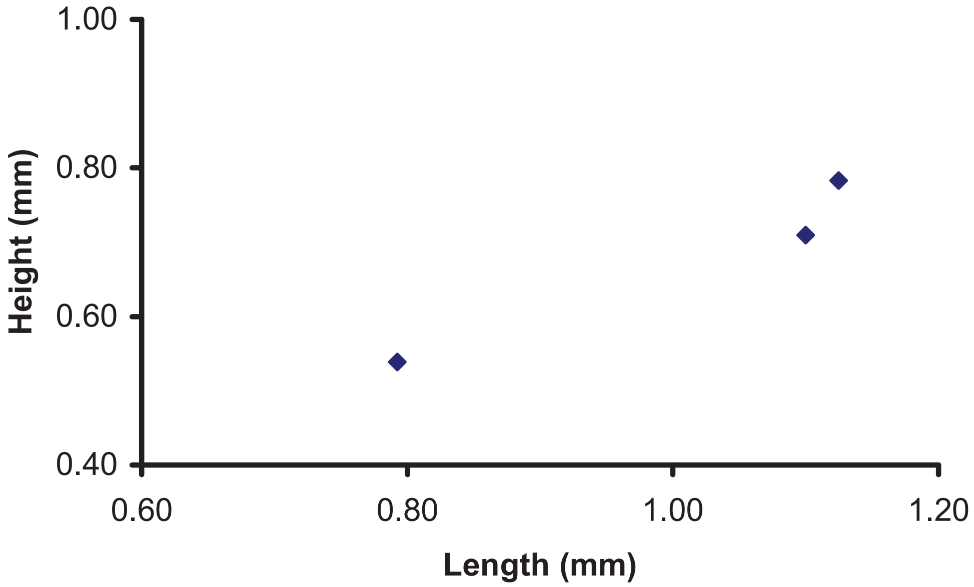


Figure 48. Biometric data for *B. (B.)* grayi (3 measured valves).

Bairdia* sp. cf. *Bairdia (Bairdia) beedei Ulrich and Bassler, 1906

1906 *Bairdia beedei* Ulrich and Bassler, p. 161, pl. 11, figs 19-20, 22.

1960 *Bairdia beedei* Ulrich and Bassler; Sohn, p. 23, pl. 1 figs 4, 5, 7, 8, 11-14 (see for synonymy up to this date).

1985 *Bairdia* sp. A Fleming (in Foster et al.), p. 97, pl. 10, figs 8-14.

1986 *Bairdia beedei* Ulrich and Bassler; De-Qiong and Hong, p. 110.

1999 *Bairdia beedei* Ulrich and Bassler; Hoare et al., p. 439, figs 2.7-2.9.

Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33'E.

Figured Specimens: Plate 9, figures 21-26; Plate 10, figures 1-19.

Material Studied: 28 LV, 19 RV, 18 carapaces.

Diagnosis: Carapace reniform, with a blunt posterior end and slightly protruding but curved anterior margin. Valves asymmetric, with LV larger than RV, overlapping on all sides. Greatest overlap on dorsal and ventral sides. Ventral margin straight to gently curved convexly, dorsal margin strongly convex. RV shows a prominent beak on the posterior margin, whereas the LV has a far more blunted and rounded posterior beak. Hinge line straight, not parallel to ventral margin but slightly oblique to the posterior and consisting of a simple groove and interlocking bar. Calcified inner lamellae present inside the carapace. Dorsal flexure prominent, with the contact margin curving towards the venter. Valves uniformly inflated, reaching greatest thickness medially. Carapace lenticular, biconvex in dorsal or ventral view, surface of valves punctate to slightly granulose at posterior end with numerous small normal pore canals located over surface. AMS arranged in an ovate pattern, with 5 to 6 primary platforms lined up biserially, with one larger platform on dorsal side of the biserial arrangement the size of two primary platforms (Figure 49). L=1.41, H=0.95, W=0.65, H/L=0.62 (Figure 50).

Remarks: This species is comparable to *B. (B.) beedei*; however, the profile of the posterior and overlap of valves differs slightly from *B. (B.) beedei*.

Distribution: *B.* sp. cf. *B. (B.) beedei* is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin. It is uncommon within all calcareous beds within the member, and it increases its frequency in the upper calcareous units of the Fossil Cliff Member.

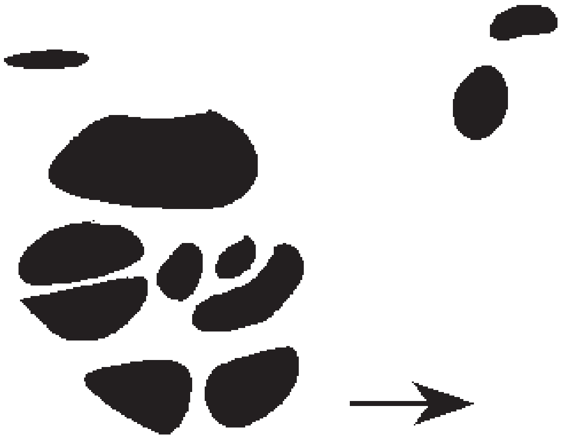


Figure 49. AMS pattern of adult *B.* sp. cf. *B. (B.) beedei*., also showing mandibular scars to the right (LV, L=1.58).

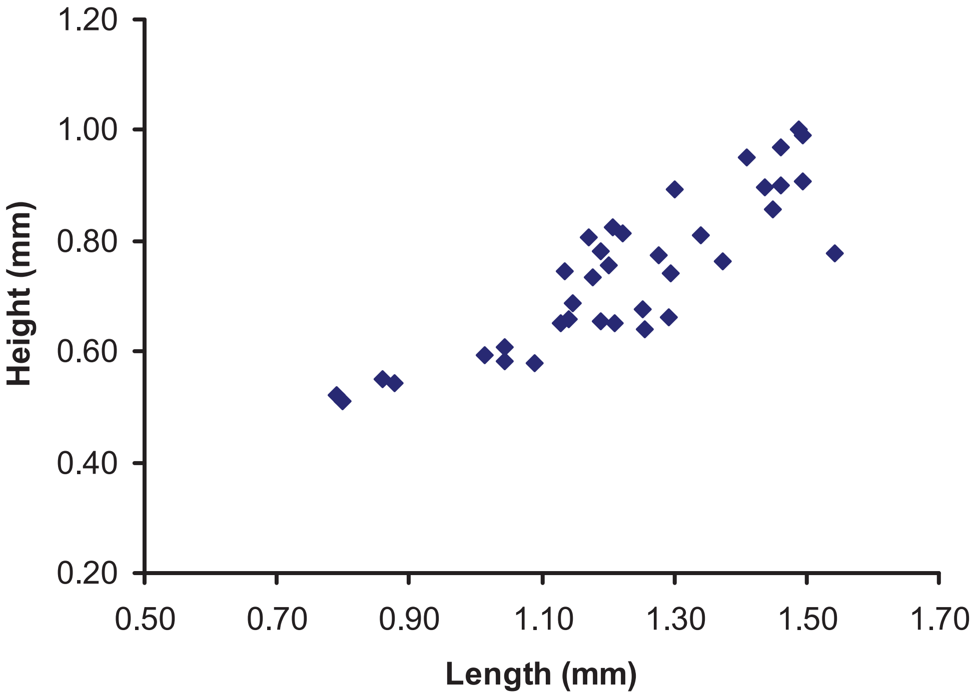


Figure 50. Biometric data for *B.* sp. cf. *B. (B.) beedei* (54 measured valves).

Bairdia* sp. cf. *Bairdia (Bairdia) hassi Sohn, 1960

1960 *Bairdia hassi* Sohn, p. 27, pl. 1 figs 28, 29 (see for synonymy up to this date).

1985 *Bairdia* sp. B Fleming in Foster et al., p. 97, pl. 11 fig. 4.

1985 *Bairdia* sp. C Fleming in Foster et al., p. 97, pl. 11 figs 1-3.

Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33'E.

Figured Specimens: Plate 10, figures 20-26; Plate 11, figures 1-7.

Material Studied: 10 LV, 4 RV, 6 carapaces.

Diagnosis: Carapace irregularly ovate, with asymmetric valves. Dorsal margin high and arcuate, steeply descending towards anterior and posterior ends, with small depression running parallel to the hinge on some specimens. Anterior margin high, evenly rounded. Ventral margin slightly convex on LV and slightly convex to straight on RV. Posterior end low, with blunt beak extending from the antero-ventral to the antero-medial regions, acuminate, and up-turned. LV overlapping the RV with greatest overlap on dorsal and ventral margins. Flexure prominent on dorsal view. Carapace high, with height 3/4 of length of valves and carapace inflated in the middle. On the anterior and posterior margins the ornamentation is pustulose, with the apex of each pustule hosting a normal pore canal, becoming smooth medially. Hinge a simple bar and groove type; hinge extending for about 70% of the length of the dorsal margin. Calcified inner lamellae present. L: 1.30, H=0.82, W=0.63, H/L=0.61 (Figure 51).

Remarks: This species differs from *B. (B.) hassi* only in possessing a slight depression just below the dorsal margin where the hinge is located and in all other aspects is the same as *B. (B.) hassi*. On some specimens of this species the pustules on the surface are very prominent, suggesting it may be better placed within *Pustulobairdia* Sohn, 1960; however, within this species there is a gradation between specimens with a smooth surface and those showing distinct pustules, so assignment to *Pustulobairdia* was not warranted.

Distribution: *B.* sp. cf. *B. (B.) hassi* is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin. It is common throughout the calcareous units of the member, especially in the upper beds.

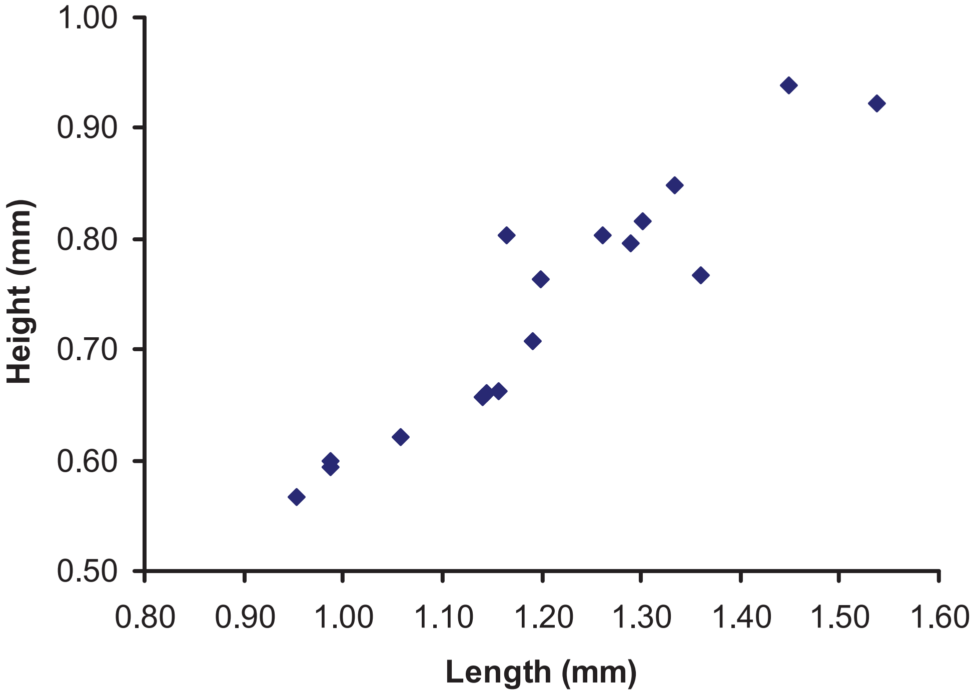


Figure 51. Biometric data for *B.* sp. cf. *B. (B.) hassi* (17 measured valves).

Bairdia **sp. cf.** ***Bairdia (Bairdia) pompillioides*** Harlton, 1928

1928 *Bairdia pompillioides* Harlton, p. 140, pl. 21, fig. 13.

1960 *Bairdia pompillioides* Harlton; Sohn, p. 30 (see for synonymy up to this date).

1999 *Bairdia pompillioides* Harlton; Hoare et al., p. 441-442, figs 3.1-3.4.

Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33'E.

Figured Specimens: Plate 11, figures 8-20.

Material Studied: 4 LV, 4 RV, 4 carapaces.

Diagnosis: Carapace large and elongate with asymmetrical valves. LV overlapping the RV along the entire margin, with greatest overlap dorsally and ventrally. Height approximately half that of the length. Dorsal margin slightly arched with anteriodorsal slope straight to slightly concave, posterodorsal margin convex with greatest curvature near the middle with extremities of the margin straightening. Ventral margin straight on LV and slightly concave on RV. Anterior extremity rounded with pronounced flattening of carapace along margin. Posterior extremely acuminate, especially on the RV, terminating in a pronounced, rounded beak. Surface pitted and pustulose, with greatest concentration of pustules at anterior and posterior extremities, pore canal morphology simple, with normal pore canals present. Dorsal flexure prominent. AMS consists of a simple clustered arrangement of up to 8 primary platforms surrounded by 5 to 10 secondary scars (Figure 52). L=1.09, H=0.65, W=0.59, H/L=0.56 (Figure 53).

Remarks: This species is very similar to *B. (B.) pompillioides*, and differs only in having its anterior extremity slightly higher than in *B. (B.) pompillioides* and in having a noticeably pustulate surface.

Distribution: *B.* sp. cf. *B. (B.) pompillioides* is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin. This species is distributed throughout the calcareous units of the member, and is initially rare in the lower calcareous units and increases in frequency up the sequence to become uncommon in the calcareous upper units.

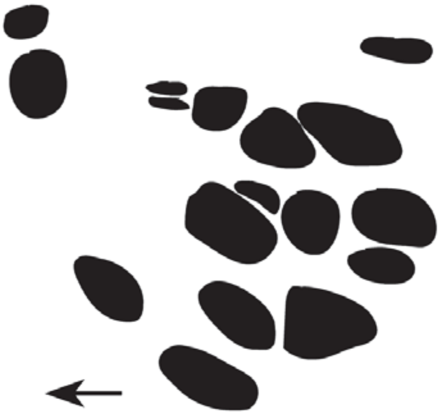


Figure 52. AMS pattern of adult *B*. cf. *B. (B.) pompillioides* also showing mandibular scars to the left (RV, L=1.24).

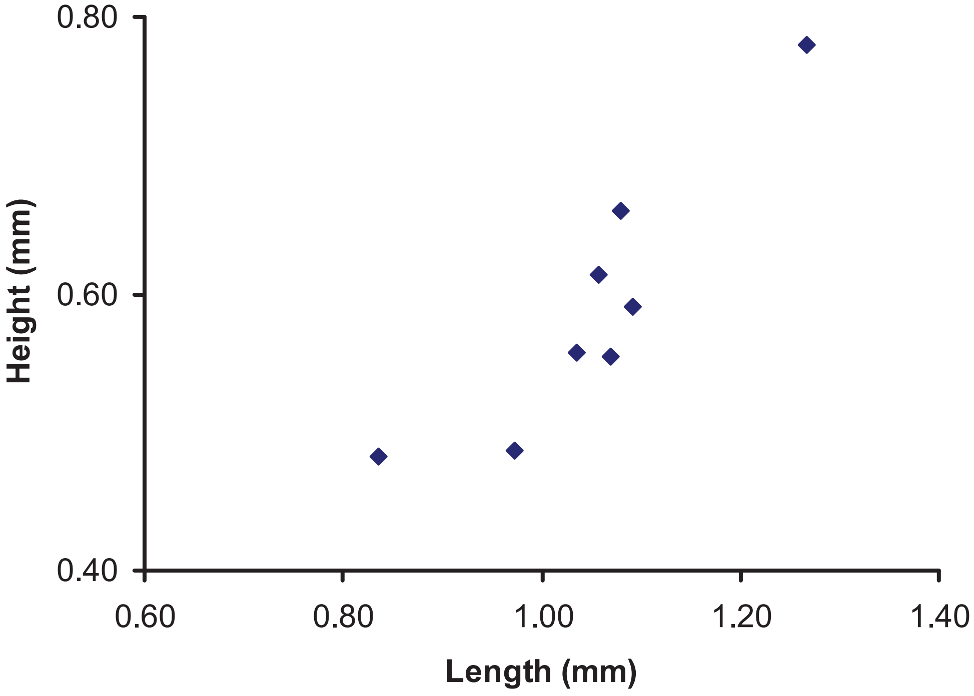


Figure 53. Biometric data for *B.* sp. cf. *B. (B.) pompillioides* (8 measured valves).

Bairdia* sp. cf. *Bairdia (Bairdia) reussiana (Kirkby), 1858

1858 *Cythere (Bairdia) reussiana* Kirkby, p. 326, pl. 10, fig. 6.

1960 *Bairdia reussiana* (Kirkby); Sohn, p. 41 (see for synonymy up to this date).

Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33’E.

Figured Specimens: Plate 11, figures 21-26.

Material Studied: 2 LV, 2 RV, 5 carapaces.

Diagnosis: Carapace large, smooth, and elongate with asymmetric valves. LV overlaps RV along the entire margin except for the anterior end. Dorsal margin straight to gently concavely rounded. Ventral margin straight to slightly convexly rounded. Posterior displays a well rounded beak, which is slightly upturned posterodorsally. Anterior rounded and elongate. Calcified inner lamella well preserved between posteroventral to ventral to anterodorsal margins. Some specimens slightly pustulose, notably on posterior and anterior ends. Pustules host a normal pore canal. Hingement a simple ridge and groove and extends along the whole dorsal margin. AMS attachment simple, consisting of 6 to 8 attachment scars arranged in an ovate pattern, with mandibular scars to the dorsal and posterodorsal of the AMS (Figure 54). L=1.83, H=0.98, W=0.59, H/L=0.51 (Figure 55).

Remarks: *B.* cf. *B. (B.) reussiana* shows a similar elongate profile to *B.* (*Rectobairdia) legumen* (Jones and Kirkby), 1886, from Britain, although the posterior beak on *B. (R.) legumen* is longer and more pronounced than that of *B*. sp. cf. *B. (B.) reussiana*. The LV of *B.* sp. cf. *B. (B.) reussiana* may be slightly curved dorsally; however, the RV generally displays a straight dorsal margin, and some variation does exist within this species. It is also similar to *B. aculeala* Cooper, 1941, from the USA, in the elongated profile, although *B. aculeala* has a higher dorsal margin. This species differs from *B. (B.) reussiana* in having a slightly more broad and rounded anterior margin.

Distribution: This species is distributed throughout the calcareous units of the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin. It is rare in the lower calcareous units and increases frequency up the sequence to become uncommon in the upper units.

Figure 54. AMS pattern of *B.* cf. *B. (B.) reussiana* (LV, L=1.15).

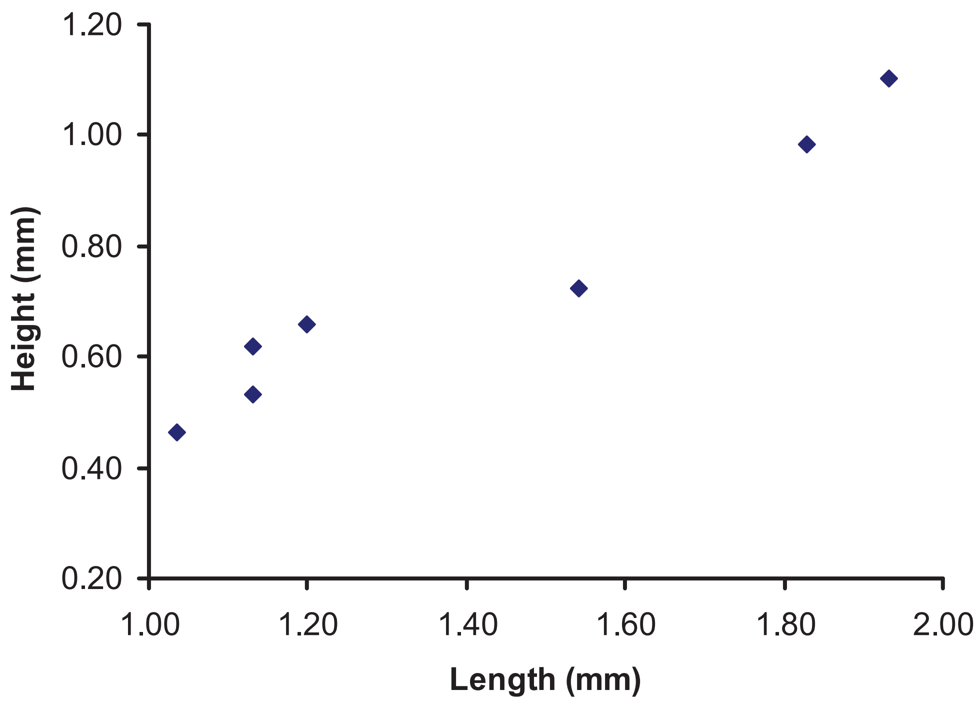


Figure 55. Biometric data for *B.* cf. *B. (B.) reussiana* (7 measured valves).

Genus *BAIRDIACYPRIS* BRADFIELD, 1935

Subgenus *BAIRDIACYPRIS (BAIRDIACYPRIS)* BRADFIELD, 1935

Type Species: ***Bairdiacypris deloi*** Bradfield, 1935

Diagnosis: See Becker (2001c).

Remarks: *Bairdiacypris* contains 2 subgenera, *B. (Bairdiacypris)* and *B. (Fabalicypris)*, which Shaver (1961b) had listed into 2 separate genera (Becker, 2001c).

Bairdiacypris (Bairdiacypris) badgerai sp nov.

1985 Bairdiocyprididae indet. Fleming in Foster et al., p. 99, pl. 12, fig. 3.

Holotype: UWA 128914.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33'E.

Derivation of name: Named after Badgera Pool, located roughly 5 km to the north-northeast of the Fossil Cliff Member type locality.

Figured Specimens: Plate 12, figures 1-5, 7, 8.

Material Studied: 5 LV, 1 RV, 1 carapace.

Diagnosis: Elongate, reniform carapace, with LV overlapping and overreaching the RV along the whole margin. Surface smooth with infrequent normal pores scattered across carapace. Ventral margin generally straight, with small concavity located on the anteromedian margin. Dorsal margin straight to gently rounded, with anterior end well rounded. Posterior end of carapace roughly rhomboid, with a distinct beak-like protrusion on the posteroventral apex. AMS simple and arranged in a small ovate pattern containing between 10 to 16 platforms (Figure 56). Hinge a simple ridge and groove arrangement and the hinge covers approximately 60% of the dorsal margin. L=0.68, H=0.32, W=0.21, H/L=0.50 (Figure 57).

Remarks: Fleming (in Foster et al., 1985) illustrated a specimen of this species and described it as Bairdiocyprididae indet. (Foster et al., 1985 pl. 12, fig. 3). With more material it is now apparent that this species does belong within *Bairdiacypris (Bairdiacypris)*. *B. (B.) badgerai* is similar to *Bythocypris elongata* Hessland, 1949, from the Lower Ordovician of Sweden; however, the arrangement of the AMS, and the prominence of the posteroventral beak distinguish it from *Bythocypris elongata*. *Bairdiacypris (Bairdiacypris) badgerai* is not placed within *Bythocypris*, as Shaver (1961c) noted that *Bythocypris* is unlikely to be a valid genus within the Palaeozoic, a view which was apparently supported by Becker (2001c) who does not list *Bythocypris* as part of the Bairdiidae. Work by Gramm and Stepanaytys (1991) on the AMS patterns of *Bairdiacypris* showed a similar AMS pattern to that of *B. (B.) badgerai,* which supported the assignment of this species to the *Bairdiacypris (Bairdiacypris)*.

Distribution: This species is common within the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin and is found within all the carbonate units of the units.

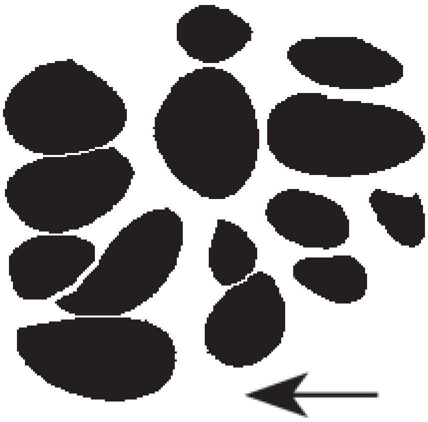


Figure 56. AMS pattern of adult *B. (B.) badgerai* (RV, L=0.65).

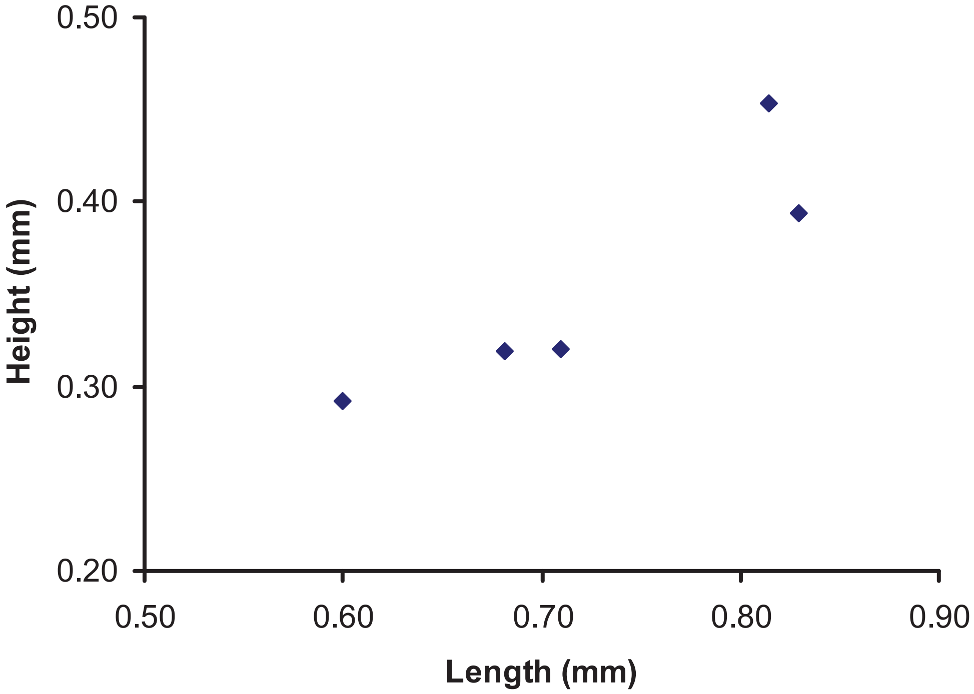


Figure 57. Biometric data for *B. (B.) badgerai* (5 measured valves).

Bairdiacypris (Bairdiacypris) sp. A

1985 Healdiacean indet. Fleming in Foster et al., p. 99, pl.12, figs 1-2.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33'E.

Figured Specimens: Plate 12, figures 6, 9-18.

Material Studied: 2 LV, 5 RV, 1 carapace.

Diagnosis: Carapace elongated, medium sized, and smooth. Dorsal margin generally straight on periphery and slightly curved at mid-point of dorsal border; although may be slightly upturned on the anterodorsal border. Venter generally straight with a slight concave curve just to the anterior of the mid-point. Anterior broadly curved, with posterior straight and meeting with ventral border at an angle of about 70° posteroventrally. Normal pore canals found across the carapace, although not in large concentrations. L=0.94, H=0.44, W=0.28, H/L=0.45 (Figure 58).

Remarks: This species is similar to *B. (B.) deloi* Bradfield, 1935, however *B. (B.) deloi* has a prominent ridge on the posterodorsal border that *B. (B.)* sp. A lacks, in addition *B. (B.) deloi* has a more acute and rounded posteroventral joining angle with the ventral border. *B. (B.) curvis* (Cooper), 1946, possesses a similar elongate profile, however the anterior and posterior are more curved than in *B. (B.)* sp. A.

Distribution: This species is uncommon within the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, and is found within all the carbonate units of the member.

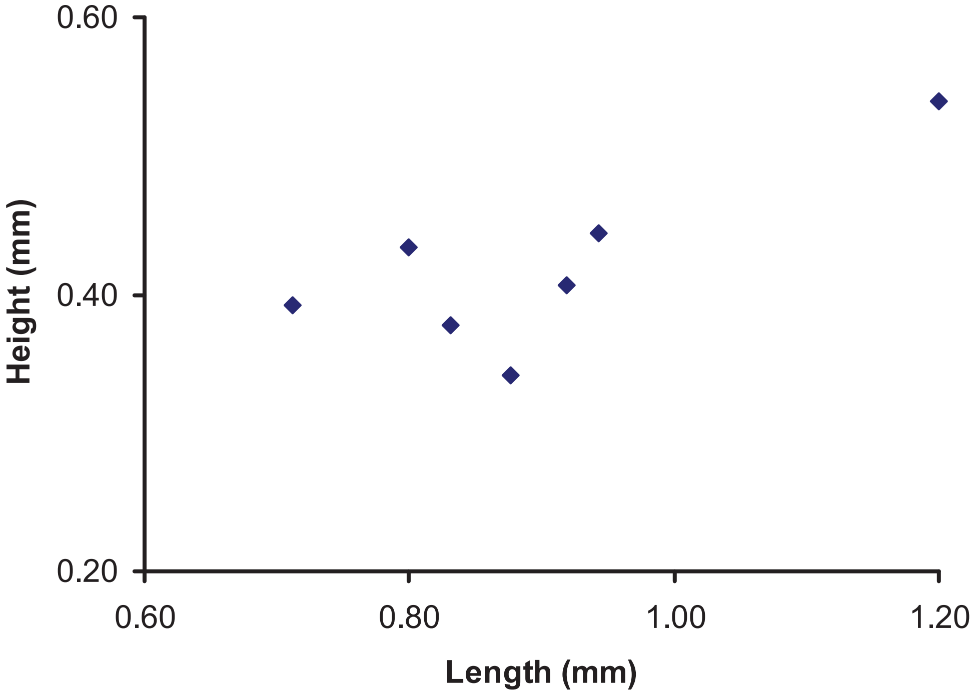


Figure 58. Biometric data for *B. (B.)* sp. A (7 measured valves).

Suborder UNCERTAIN

Superfamily PARAPARCHITOIDEA Scott, 1959

Family PARAPARCHITIDAE Scott, 1959

Genus *PROPARAPARCHITES* Cooper, 1941.

Type Species: ***Proparaparchites ovatus*** Cooper, 1941

Diagnosis: See Scott (1961b).

Remarks: Sohn (1972) noted that species of *Proparaparchites* Cooper, 1941, are generally small (less than 1 mm in length) and thin-shelled. Tibert and Scott (1999) believe the Paraparchitoidea are opportunists tolerant of a wide range of salinity conditions (eurytropic).

***Proparaparchites?* sp. A**

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33'E.

Figured Specimens: Plate 12, figures 19-22, 25.

Material Studied: 4 RV.

Diagnosis: Carapace large, subovate, smooth. Dorsal margin straight in the centre and slightly curved on the anterior and posterior ends. Ventral margin gently curved. Anterior larger than posterior and broadly rounded. Posterior rounded. Valve has greatest inflation in posteromedial region and then thins rapidly to posterior border. Surface smooth and contains numerous normal pore canals. Hinge consists of a groove and interlocking ridge, extending for 60% of the dorsal margin. AMS arrangement unknown as all internal carapaces examined are poorly preserved. L=1.51, H=0.96, W=0.63, H/L=0.64 (Figure 59).

Remarks: This species is tentatively placed in the *Proparaparchites* Cooper, 1941, because of its valve profile. It is broadly similar to *P. ovatus*, Cooper, 1941, from the Upper Mississippian of North America, although much larger and with a noticeable slope on the posterior. No similar species have been noted from the upper Palaeozoic of Australia.

Distribution: *P?* sp. A is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin. The species is rare, and is found within the lower calcareous facies of the Fossil Cliff Member.

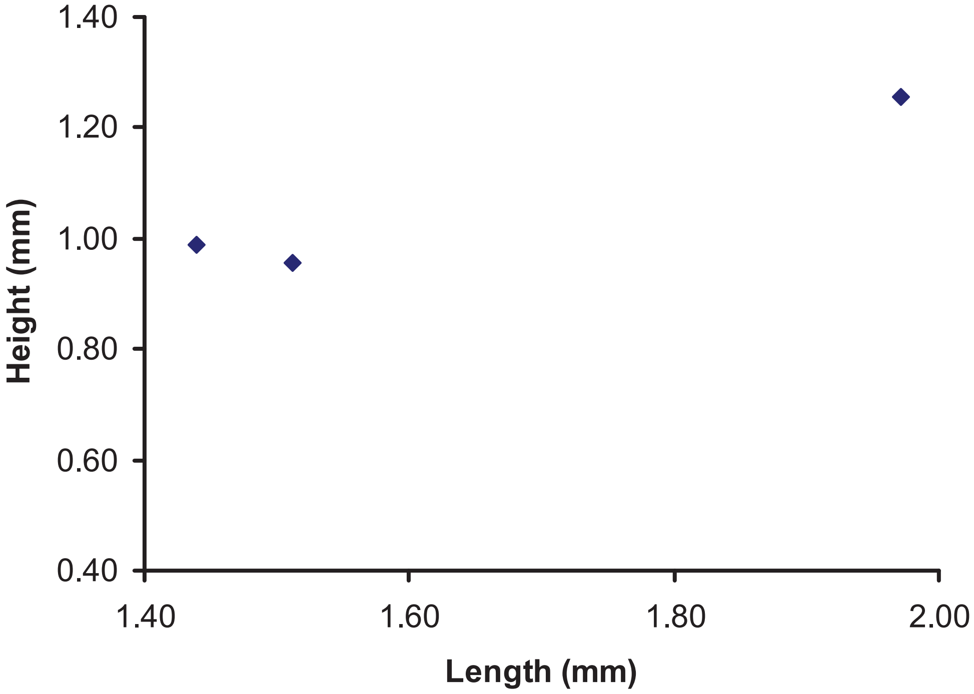


Figure 59. Biometric data for *P?* sp. A (3 measured valves).

***Proparaparchites?* sp. B**

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33'E.

Figured Specimens: Plate 12, figures 23, 24.

Material Studied: 2 LV.

Diagnosis: Carapace large, subrectangular, generally smooth. Dorsal margin straight, and shorter than ventral margin. Ventral margin slightly concave in centre and straight on margins. Anterior and posterior ends are rounded, with anterior higher than posterior. On anterior and posterior ends of the carapace a pustulose ornamentation is present, with each pustule hosting a normal pore canal. L=1.51, H=0.89, W=0.59, H/L=0.53 (Figure 60).

Remarks: This species is tentatively placed in the *Proparaparchites* because of its rectangular valve profile. It differs from previously recorded species of

Proparaparchites in possessing a pustulose ornamentation on the anterior and posterior ends of the valve. *P?* sp. B has a more rectangular outline than in *P?* sp. A.

Distribution: *P?* sp. B is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin. The species is rare, and is found within the middle calcareous facies of the Fossil Cliff Member.

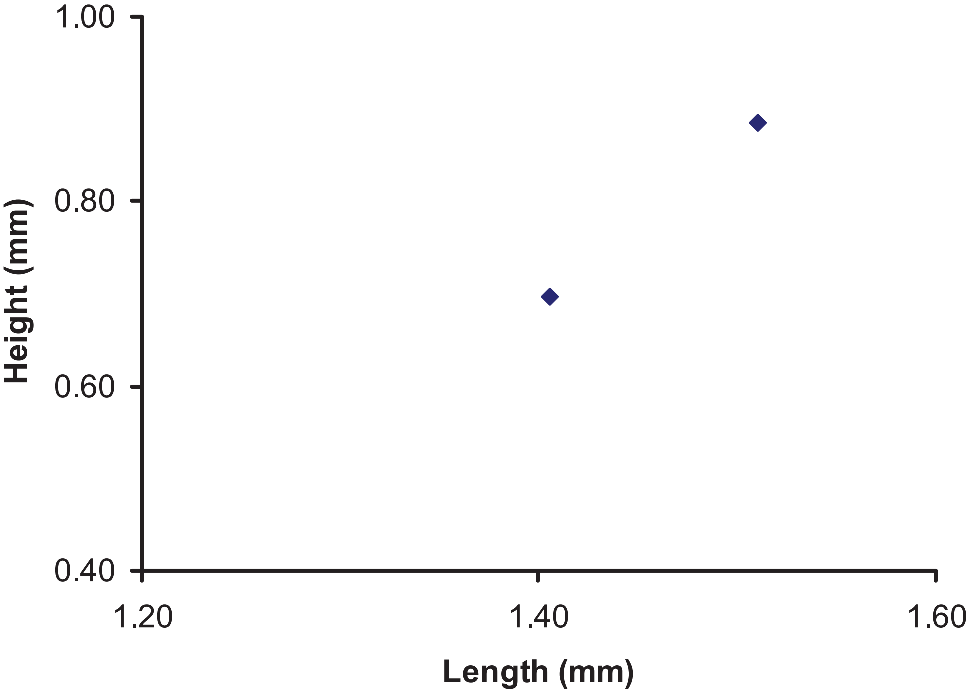


Figure 60. Biometric data for *P?* sp. B (2 measured valves).

Suborder UNCERTAIN

Superfamily ?YOUNGIELLOIDEA KELLETT, 1933

Family YOUNGIELLIDAE KELLETT, 1933

Genus *YOUNGIELLA* JONES AND KIRKBY, emended WILSON, 1933

Type Species: ***Youngiella rectidorsalis*** (Jones and Kirkby), 1886

Diagnosis: See Sohn (1961d).

Remarks: Species from this genus have not been previously recognised from the Permian of Western Australia, although Fleming (in Foster et al., 1985) illustrated what is herein defined as *Y. deweyensis* sp. nov., informally naming it as Kirkbyacean? indet. sp. B (Pl. 10 fig. 3). Melnyk and Maddocks (1988a) list this genus as being predominantly a shallow water (less than 15 m water depth) inhabitant. In the original Jones and Kirkby (1895) description of the genus, they noted that a slight reticulation of the surface ornamentation was present on some specimens. The genus *Moorites* Coryell and Billings, 1932, was erected to accommodate those species that possessed a strong reticulation; however, those that display a weak or indistinct reticulation still fall within the definition of *Youngiella*.

Youngiella deweyensis sp. nov.

1985 Kirkbyacean indet. sp. B Fleming in Foster et al., p. 99, pl. 10, fig. 3.

Holotype: UWA 128918.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33’E.

Derivation of name: Named in honour of Dr. Chris Dewey for his work on Carboniferous and Permian ostracodes.

Figured Specimens: Plate 12, figures 26-28; Plate 13, figures 1-9.

Material Studied: 13 LV, 4 RV, 2 carapaces.

Diagnosis: Carapace small, surface smooth and with a subrectangular profile. Anterior margin rounded with more forward swing than posterior margin. Posterior end well rounded and slightly less inflated than the anterior end. Dorsal margin straight. Ventral margin slightly compressed in the middle to straight. Valves equal in size and shape, with no overlap noted on either the LV or RV. Normal pore canals are present on the surface of the carapace. Hinge extends along length of dorsal margin and consists of numerous small interlocking teeth. No AMS pattern has been observed on the internal surface of the carapace. L=0.52, H=0.26, W=0.12, H/L=0.50 (Figure 61).

Remarks: *Youngiella deweyensis* is very similar to *Y. knighti* Wilson, 1933, of the USA, with the most notable difference the greater swelling of the anterior end of the valve and that *Y. knighti* possesses a slightly different profile on the anterior margin, which on *Y. deweyensis* is gently curved all around the anterior margin, and on *Y. knighti* is straight on the dorso-anterior margin. In addition, the adult *Y. deweyensis* carapace is slightly larger than that of *Y. knighti* which has a recorded length of 0.35 mm and height of 0.17 mm for the holotype. *Y.*

deweyensis is also similar to the type species *Y. rectidorsalis* Jones and Kirkby, 1886. However, the presence of slight reticulation on *Y. rectidorsalis* and a straight anterodorsal margin distinguish *Y. deweyensis* from it.

Distribution: *Y. deweyensis* is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin. The species is rarely found in the lower calcareous beds, and found uncommonly in the middle and upper carbonate beds.

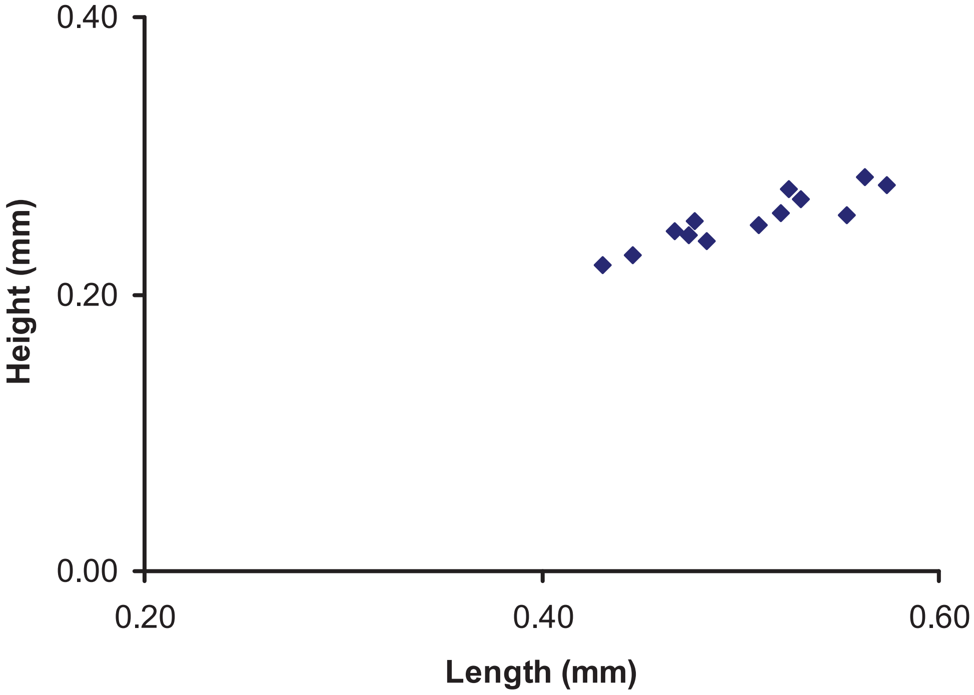


Figure 61. Biometric data for *Y. deweyensis* (13 measured valves).

***Youngiella* sp. A**

Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33'E.

Figured Specimens: Plate 13, figures 10-16; Plate 14, figure 13.

Material Studied: 5 LV, 4 RV.

Diagnosis: Carapace medium sized, surface smooth, valves equal in size and with a subovate profile. Dorsal margin straight, with ventral margin straight and curving slightly on the anterior and posterior ends. Anterior inflated relative to the posterior and well rounded. Posterior end rounded. Normal pore canals present on the surface. L=0.79, H=0.49, W=0.26, H/L=0.63 (Figure 62).

Remarks: *Youngiella* sp. A shows a similar inflation of the anterior to *Y*? *convergens* Bradfield, 1935. This inflation distinguishes it from *Y. deweyensis*.

Distribution: *Y.* sp. A is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin. The species is rare, and is found throughout the middle and upper calcareous facies of the Fossil Cliff Member.

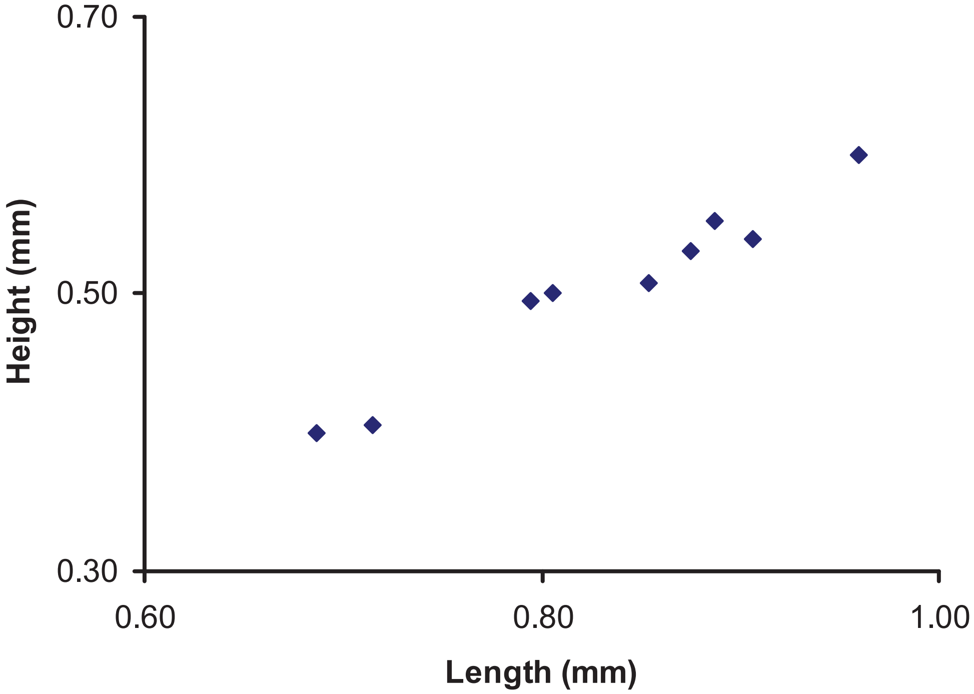


Figure 62. Biometric data for *Y.* sp. A (9 measured valves).

Genus *MOORITES* CORYELL AND BILLINGS, 1932

Type Species: ***Moorites hewetti*** Coryell and Billings, 1932

Diagnosis: See Sohn (1961d).

Remarks: Both Sohn (1983) and Hoare (1998) listed the range of *Moorites* Coryell and Billings, 1932, as Devonian to Pennsylvanian, and their presence in the Fossil Cliff Member is the first record of *Moorites* in the Cisuralian of Australia. Melnyk and Maddocks (1988a) listed *Moorites* as an indicator of a nearshore environment.

Moorites irwini sp. nov.

Holotype: UWA 128920.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33'E.

Derivation of name: Named after the Irwin River, which runs past the type section of the Fossil Cliff Member of the Holmwood Shale.

Figured Specimens: Plate 13, figures 17-29; Plate 14, figures 1-6.

Material Studied: 11 LV, 7 RV.

Diagnosis: Carapace medium sized, subrectangular, and with a reticulate ornamentation. Dorsal margin is straight and long, with obtuse anterior and posterior cardinal angles of 110° and 125° respectively. Ventral margin is straight in the centre and gently curves on both the anterior and posterior ends. Anterior margin straight at dorsal margin and then curves broadly to the ventral margin and slightly higher relative to the posterior. Posterior margin broadly curved with a slight lean to posterior. On adult specimens ornamentation is reticulate with large cavities in the centre of valve, these cavities disappear on the margins of carapace and ornamentation becomes simply reticulate, this is most noticeable on the anterior and posterior ends. Large adductorial pit present dorsomedially and has a circular primary expression with a subtriangular indentation coming off towards the dorsal margin. Juvenile specimens display a non-reticulated ridge along the ventral side of the carapace and a coarser ornamentation. As the instars get closer to maturity this ridge becomes less distinct and the reticulation becomes finer. Hingement appears to be a simple ridge and groove arrangement and extends along the length of the dorsal margin, although fine striations that may be poorly preserved teeth can be seen on some specimens. Normal pore canals cover the internal surface surrounded by a pustule-like raised area. No distinct AMS present, although a circular raised platform about 0.08 mm in diameter is present dorsomedially which may represent the muscle scar clump. L=0.79, H=0.49, W=0.21, H/L=0.63 (Figure 63).

Remarks: This is the first record of *Moorites* in the Permian of Australia, and the species is assigned to the genus on the basis of the reticulated ornamentation, characteristic lean to the posterior, and inflation of the anterior of the carapace.

The presence of a strong adductorial pit (sulcus?) is unusual, and none of the species of *Moorites* have adductorial pits associated with them.

Distribution: *M. irwini* is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin. The species is rare and found throughout the lower and middle calcareous facies of the Fossil Cliff Member.

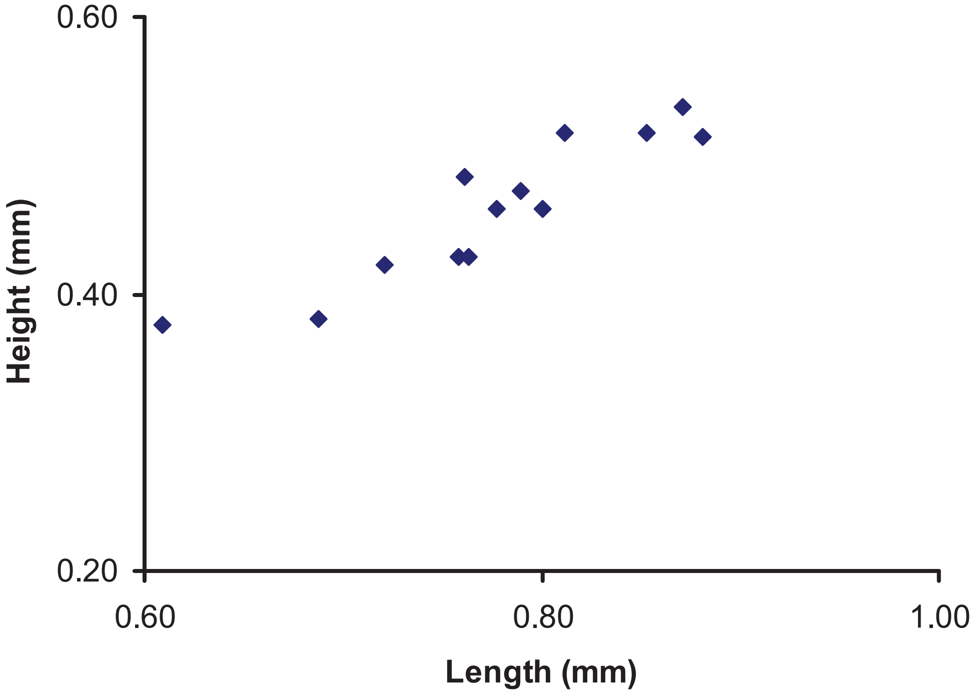


Figure 63. Biometric data for *M. irwini* (13 measured valves).

Suborder UNCERTAIN

Superfamily TRICORNINOIDEA BLUMENSTEGEL, 1965

Family TRICORNIDAE BLUMENSTEGEL, 1965

Genus *RECTOSPINELLA* BLUMENSTEGEL and BECKER, 1990

Type species: ***Rectospinella alta*** (Blumenstegel), 1965

Diagnosis: See Blumenstegel (1965).

Remarks: This genus is tentatively placed as part of the Tricornidae by Blumenstegel (1965). It is characterised by the distinct spines that protrude from each end of the dorsal margin. It has previously been recorded only from the Devonian of Germany and Permian rocks from Timor. The family Tricornidae is thought by

Crasquin-Soleau (1997) to be restricted to the Thuringian ecotype which she described as a deep, calm, cold and oxygen-deficient palaeoenvironment with a high level of dissolved silica, although Becker and Bless (1990) revised the definition of the Thuringian ecotype to include both basinal and shelf facies. Work by Crasquin-Soleau (1997) also noted that when the species is present with neritic species it is indicative of a protected environment on a shallow platform. The genus was initially named *Spinella*; however, this name was already in use, and Blumenstegel and Becker (1990) proposed the new name *Rectospinella* for the genus.

Rectospinella australica sp. nov.

Holotype: UWA 128921.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33’E.

Derivation of name: Name derived from the continent it was found in, Australia.

Figured Specimens: Plate 14, figures 7-12.

Material Studied: 3 LV, 3 RV.

Diagnosis: Medium sized, surface smooth, and subovate. Dorsal margin slightly curved convexly, and ventral margin straight to curved on the anterior and posterior ends. Anterior and posterior well rounded, with the anterior higher than the posterior. A spine protrudes from the dorsal margin on both anterior and posterior sides, with posterior spine slightly larger than anterior. Small normal pore canals present across surface. Hingement a simple interlocking ridge and groove that extends for about 90% of the dorsal margin. AMS consists of three primary platforms surrounded by 3 to 4 secondary platforms in a ‘clumped’ arrangement (Figure 64). L=0.51, H=0.34, W=0.15, H/L=0.63 (Figure 65).

Remarks: This species of *Rectospinella* is dissimilar to *R. alta* (Blumenstegel), 1965, and *R. longa* (Blumenstegel), 1965, that were described from the Devonian in Germany in having a smooth surface and spines that are significantly shorter. It differs from *R. bitauniensis* (Bless), 1987, from the Cisuralian of Timor in that the larger posterior spine of *R. australica* emerges from the posterior margin, whereas the large posterior spine of *R. bitauniensis* emerges from a posteromedial location, and in addition *R. australica* is more ovate along the ventral margin. *R. australica*, however, is very similar to *R. bitauniensis*, and a evolutionary link may be present between the two species.

Distribution: *R. australica* is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the calcareous units of the member. The species is rare, and is generally found in the middle carbonate beds of the member.

Figure 64. AMS pattern of *R. australica* (RV, L=0.62).

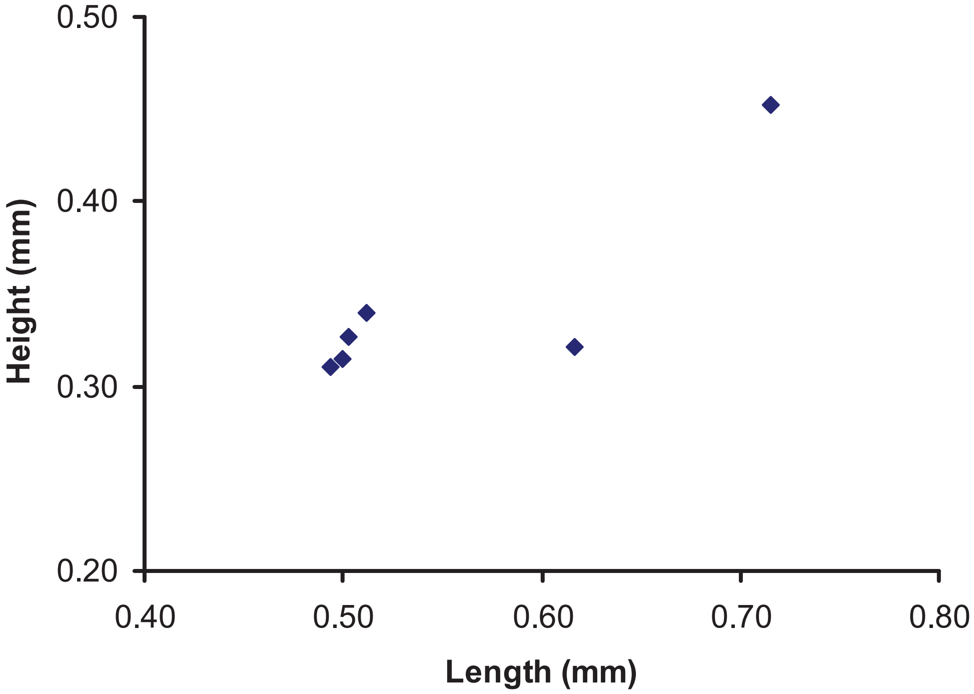


Figure 65. Biometric data for *R. australica* (6 measured valves).

Order PARAPODOCOPIDA GRAMM, 1984

Suborder and Superfamily UNCERTAIN

Family INDIVISIIDAE EGOROV, 1954

Genus SULCOINDIVISIA EGOROV, 1954

Type species: ***Sulcoindivisia svinordensis*** Egorov, 1954

Diagnosis: See Egerov (1954).

Remarks: The family Indivisiidae was initially a subfamily of the Kloedenellidae (Egorov, 1954); however, work by Gramm (1992) elevated the Indivisiidae to family level, and he placed the new family into the Parapodocopida. This removal from the Kloedenellidae appears to be supported by work from Adamczak (1991) on kloedenellid morphology. The validity of this assignment is yet to be demonstrated as little work on this genus has been done.

Sulcoindivisia crasquinsoleauella sp. nov.

Holotype: UWA 128922.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33’E.

Derivation of name: Named in honour of Dr. Sylvie Crasquin-Soleau for her work on Upper Palaeozoic ostracodes.

Figured Specimens: Plate 14, figures 14-25.

Material Studied: 12 LV, 11 RV, 1 carapace.

Diagnosis: Carapace medium sized, surface smooth, valves equal in size and with a subrectangular profile. Anterior end inflated relative to posterior, and both anterior and posterior ends well rounded. Dorsal margin straight, with ventral margin slightly rounded on the posterior and anterior margins and straight along the medioventral border. On some specimens a slight reticulate ornamentation is visible along the ventral and postero- and anteroventral margins, with the medial and dorsal surfaces of the valve smooth. A slight rim also extends along the ventral margin. Sulcus present on LV of some specimens located dorsomedially. Very small, normal pore canals are present across the surface of the carapace. No AMS visible, although a large, smooth ovate platform is present medially on the internal surface of carapace. Hinge extends along full length of dorsal margin, and appears to consist of a ridge and groove arrangement; interlocking teeth have not been observed along the hinge, although this may be a result of poor preservation. L=0.74, H=0.43, W=0.25, H/L=0.59 (Figure 66).

Remarks: *Sulcoindivisia crasquinsoleauella* differs from *S. ilmenica* Zaspelova, 1959, of Russia, in having a rectangular outline, with the ventral margin straight, in addition to the sulcus being located slightly towards the posterior on the figured specimens of *S. ilmenica*. *S. crasquinsoleauella* is also similar to the boreal Cisuralian species *S. jurezanensis* Kochetkova, 1972, although in *S. jurezanensis* the anterior meets the dorsal margin at a much sharper angle than in *S. crasquinsoleauella*, and the posterior end is more rounded. *Perprimitia laevis* Guseva, 1971, of Russia is very similar to *S. crasquinsoleauella*, and may belong to *Sulcoindivisia*, the main difference between these two species is the depth of the sulcus in *P. laevis*.

Distribution: *S. crasquinsoleauella* is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin. The species is rare, but its distribution extends throughout all the calcareous facies of the Fossil Cliff Member.

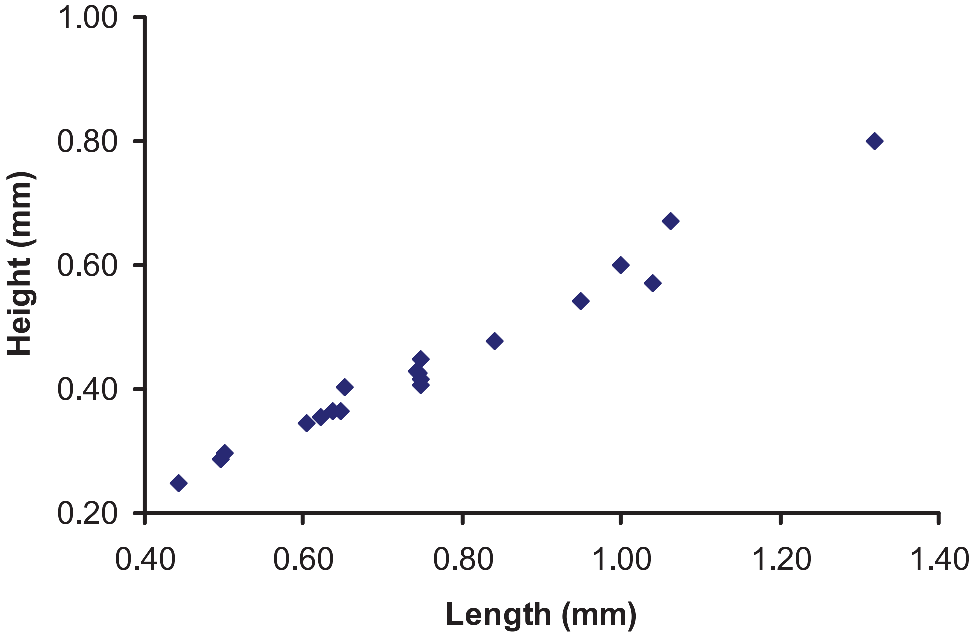


Figure 66. Biometric data for *S. crasquinsoleauella* (19 measured valves).

Order, Suborder, and Superfamily UNCERTAIN

Family SCROBICULIDAE POSNER, 1951

Genus *ROUNDYELLA* BRADFIELD, 1935

Type Species: ***Roundyella simplicissima*** (Knight), 1928

Diagnosis: See Sohn (1961c).

Remarks: Sohn (1954) noted that *Youngiella* Bradfield, 1935 does not belong in the Kirkbyidae and, whilst retaining it in the Kirkbyoidea, did not assign it to a family. Sohn (1961c) placed it under the family Scrobiculidae with a note stating that the taxonomic position of this family was in doubt due to Sohn's (1954) work, where he felt *Roundyella* did not possess a kirkbyoidean pit and the muscle arrangement in *Roundyella* was closer to the metacopines than the palaeocopines. Later work (Sohn, 1961c; Melnyk and Maddocks, 1988b), however, has placed them within the Kirkbyoidea. Becker (2000f) placed *Roundyella* within Order, Suborder, and Superfamily uncertain, and this taxonomy is used here.

Roundyella ludbrookae Fleming, 1985, emended Ferdinando

1985 *Roundyella ludbrookae* Fleming in Foster et al., p. 97, pl. 10, figs. 4-7.

Holotype: WAM 83.2722.

Type Locality: Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, Western Australia. Latitude 28°55'S, Longitude 115°33'E.

Figured Specimens: Plate 14, figures 26-28; Plate 15, figures 1-19.

Material Studied: 20 LV, 16 RV.

Diagnosis: Carapace medium sized, surface reticulate with a subrectangular profile. Dorsal margin straight with a slight concavity on the anterior side. Ventral margin straight. Anterior and posterior ends well rounded. Ornamentation is finely granuloreticulate with no large pits or cavities between the reticulation. The free margins of the carapace are also spinose, especially on anterior and posterior borders. Shallow adductorial pit present antero-medially on both RV and LV, and pit contains a number of muscle-scar like platforms, usually numbering around 3 to 7, although some valves may display as many as 20 in a circular arrangement. Hinge a simple ridge and groove extending for about 75% of the total dorsal length. AMS attachment a circular arrangement of 4 to 5 primary platforms surrounded by up to ten secondary platforms, all with a subovate to subtriangular shape (Figure 67 and Figure 68). L=0.97, H=0.55, W=0.19, H/L=0.57 (Figure 69).

Remarks: *Roundyella ludbrookae* Fleming, 1985, is very similar to *R. simplicissima* (Knight), 1928, in profile and ornamentation; however, it lacks a distinct adductorial pit. Fleming (in Foster et al., 1985) compared this species to *R. nodomarginata* (Bradfield), 1935, and *R. dorsopapillosa* Sohn, 1954. The ornamentation on these Permian species from North America, however, is very different from that of *R. ludbrookae*. *R. ludbrookae* is very similar to *R. bellatula* Bradfield, 1935, from the Lower Pennsylvanian of North America, possessing a very similar profile, adductorial pit style, and ornamentation; *R. bellatula* does differ in not possessing the spinose ornamentation along the free margins of the carapace. There is a variation in the carapace morphology that can be attributed to immature moults; this is most noted in the shape and presence of the adductorial pit and the amount of pustules present on the reticulate ornamentation, with the more mature instars possessing a greater number of pustules on well-preserved specimens.

Distribution: *R. ludbrookae* is has been recorded only from the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin. The species is uncommon and has been recovered from all the calcareous beds of the member.

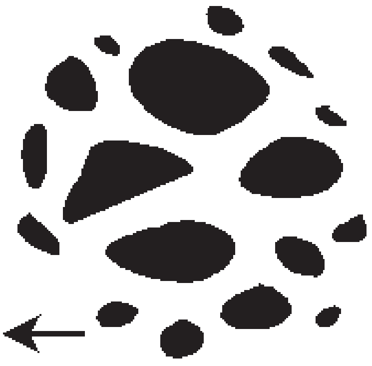


Figure 67. AMS pattern of *R. ludbrookae* (RV, L=0.65).

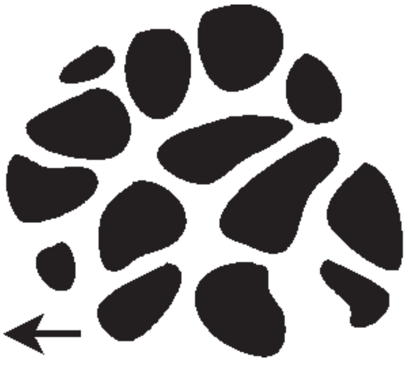


Figure 68. AMS pattern of *R. ludbrookae* (RV, L=0.95).

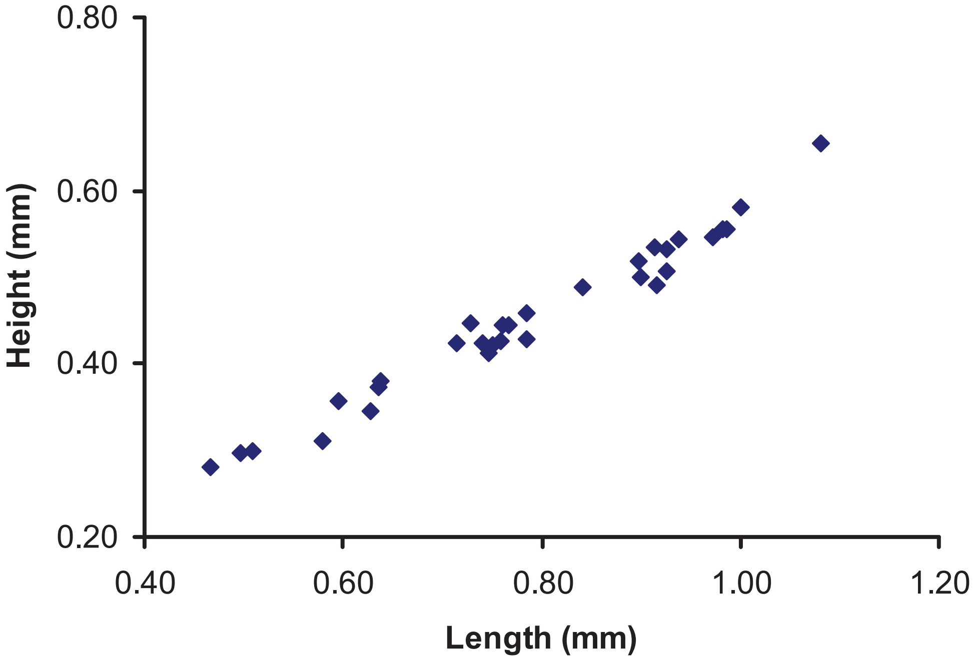


Figure 69. Biometric data for *R. ludbrookae* (31 measured valves).

Chapter 4: Foraminiferal taxonomy

The taxonomic hierarchy used to describe the suprageneric classification of the foraminifera from the Fossil Cliff Member is based upon the taxonomic framework used by Loeblich and Tappan (1987), but differs slightly for the Lagenina where the emended diagnosis of Palmieri (1994) is used. All superfamily names have been modified to bear the "-oidea" ending as per the 1999 ICZN opinion.

Order FORAMINIFERA EICHWALD, 1830
  Suborder TEXTULARIINA DELAGE and HEROUARD, 1896
    Superfamily ASTRORHIZOIDEA BRADY, 1881
      Family HIPPOCREPINELLIDAE LOEBLICH and TAPPAN, 1984
        Genus *HIPPOCREPINELLA* HERON-ALLEN and EARLAND, 1932

Type Species: ***Hippocrepinella hirudinea*** Heron-Allen and Earland, 1932.

Diagnosis: See Loeblich and Tappan (1987).

Hippocrepinella biaperta Crespin, 1958

1958 *Hippocrepinella biaperta* Crespin, p. 37-38, pl. 1, figs 1-8.
1967 *Hippocrepinella biaperta* Crespin; Ludbrook, p. 73, pl. 3, fig. 1.
1982 *Hippocrepinella biaperta* Crespin; Scheibnerová, p. 53.
1994 *Hippocrepinella biaperta* Crespin; Palmieri, p. 6, pl. 6, figs 6, 7.

Holotype: Commonwealth Palaeontological Collection #2351.

Type Locality: Road cutting near Oonah, northwest Tasmania, 23 miles west of Waratah on the main Somerset-Waratah Road, Quamby Mudstone.

Figured Specimens: Plate 15, figures 20-25.

Material studied: 5 tests.

Diagnosis: "Free, elongate, finely siliceous, tubular form with apertural openings at both ends of the test" (Crespin, 1958).

Remarks: Fragments of a medium sized, tubular agglutinated foraminifera are attributed this species. *H. biaperta* Crespin, 1958, has a slight tapering at the ends of the test, irregular growth, and constrictions of the test. The surface is finely agglutinated with siliceous grains.

Distribution: *H. biaperta* Crespin, 1958, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the shale and siltstone units of the member. *H. biaperta* Crespin, 1958, is extremely rare, and only five partially fragmented specimens has been found from the lower shale and siltstone beds of the member. It has also been recorded from the Bowen Basin of Queensland in the Cattle Creek Formation (Mostyndale, Moorooloo, and Sirius Mudstone Members), and the Blenheim Formation (Palmieri, 1994). In New South Wales from the Wandravandian Siltstone and Branxton Formations of the Sydney Basin (Scheibnerová, 1982). The Quamby Mudstone from the Golden Valley Group in Tasmania (Crespin, 1958). In South Australia from the Arkaringa and Trowbridge Basins, as well as the Renmark Trough (Crespin, 1958; Ludbrook, 1967). In Western Australia the species has also been described from the Carynginia Formation of the Perth Basin; Callytharra Formation of the Carnarvon Basin; and Noonkanbah Formation of the Canning Basin (Crespin, 1958).

Family PSAMMOSPHAERIDAE HAECKEL, 1894

Subfamily PSAMMOSPHAERINAE HAECKEL, 1894

Genus *THURAMMINOIDES* PLUMMER, 1945

Type Species: ***Thuramminoides sphaeroidalis*** Plummer, 1945.

Diagnosis: See Loeblich and Tappan (1987).

?Thuramminoides pusilla (Parr), 1942

1942 *Psammosphaera pusilla* Parr, p. 106, pl. 1, figs 6, 7.

1958 *Psammosphaera pusilla* Parr; Crespin, p. 38, pl. 2, figs 4, 5.

1968 *Psammosphaera pusilla* Parr; Belford, p. 17, pl. 1, figs 2, 3.

1982 *Psammosphaera pusilla* Parr; Scheibnerová, p. 56, pl. 5, figs 1-3; pl. 6, figs 1, 2, 4, 5; pl. 7, fig. 1.

1994 *Psammosphaera pusilla* Parr; Palmieri, p. 7, pl. 7, fig. 29.

Holotype: Geology Department, University of Western Australia, #20680.

Type Locality: "Lingula Beds" (Wandagee Formation), south side of Minilya River, near Coolkilyia Pool, Wandagee Station, in a brown, impure, limestone.

Figured Specimens: Plate 16, figures 1-4.

Material studied: 10 tests.

Diagnosis: "Test very small, spherical, consisting of a single chamber; wall comparatively thick, formed of fine quartz grains, very firmly cemented, the cement apparently siliceous; surface smoothly finished" (Parr, 1942).

Remarks: This species has been moved from the genus *Psammosphaera* and tentatively placed into *Thuramminoides* based upon the type species of *Psammosphaera* possessing a coarsely agglutinated wall composed of a single layer of grains with little cement, whereas this species has a thick test wall, composed of finely agglutinated grains that is well cemented. *?Thuramminoides pusilla* (Parr) is distinguished from both *T. sphaeroidalis* Plummer, 1945, and *Teichertina teicherti* (Parr), 1942, in its smaller spherical test size and a lack of distinct openings, as well as a much thicker and stronger test wall. *?T. pusilla* (Parr), 1942, also has a smoother agglutinated surface than *Teichertina teicherti* (Parr), 1942.

Distribution: *?T. pusilla* (Parr), 1942, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the shale and siltstone units of the member. This species is rare, and has been found from all the shale and siltstone beds of the member. It has also been recorded from the Bowen Basin of Queensland in the Sirius Mudstone Member of the Cattle Creek Formation (Palmieri, 1994). In New South Wales from the Wandravandian Siltstone and Branxton Formation of the Sydney Basin (Scheibnerová, 1982). In Western Australia the species has also been described from the Holmwood Shale of the Perth Basin; the Bulgadoo Shale of the Byro Group, Carnarvon Basin; and Noonkanbah Formation of the Canning Basin (Crespin, 1958).

Thuramminoides sphaeroidalis Plummer, 1945, emended Conkin, 1961

1945 *Thuramminoides sphaeroidalis* Plummer, p. 218, pl. 15, figs 4, 6, 10a-b; *non* figs 5, 8 (=?*Thuramminoides* sp.); *non* figs 7, 9 (=?*Teichertina* sp.).

1958 *Thuramminoides sphaeroidalis* Plummer; Crespin, p. 40-41, pl. 3, figs 9, 11; *non* pl. 3 fig. 10 (=?*Thurammina* sp.); *non* pl. 31 figs 1, 2 (=*Teichertina teicherti*).

1961 *Thuramminoides sphaeroidalis* Plummer; Conkin, p. 243, pl. 17, figs1-10; pl. 18, figs 1-4; pl. 26, figs 1-3.

1967 *Thuramminoides sphaeroidalis* Plummer; Ludbrook, p. 76-77, pl. 3, figs 15, 16.

1968 *Thuramminoides sphaeroidalis* Plummer; Belford, p. 177, pl. 1, fig. 4.

1982 *Thuramminoides sphaeroidalis* Plummer; Scheibnerová, p. 57, pl. 7 figs 2a-c.

1994 *Thuramminoides sphaeroidalis* Plummer; Palmieri, p. 7-8, pl. 4, figs 1, 2; pl. 7, fig. 21.

Holotype: Holotype placed in Plummer's personal collection. Other specimens deposited in the collections of the Bureau of Economic Geology, Austin Texas; the British Museum (Natural History), London; and the United States National Museum, Washington, D.C.

Type Locality: Lower part of Strawn Group, Middle Pennsylvanian, San Saba County, Texas.

Figured Specimens: Plate 16, figures 5-7.

Material studied: 54 tests.

Diagnosis: "Test spheroidal to discoidal, often centrally depressed, wall moderately thick to thick, agglutinated, siliceous, of fine to medium sized quartz grains, surface smooth, periphery rounded, no visible openings" (Conkin, 1961; Palmieri, 1994).

Remarks: Specimens of this species recovered from the Fossil Cliff Member have a spheroidal test, with the central region generally depressed. The test wall is very finely agglutinated and has a smooth appearance under reflected light. Many of the specimens previously assigned to this species by previous authors either belong to *Teichertina teicherti* (Parr), 1942, or a different species of *Thuramminoides*.

Distribution: *T. sphaeroidalis* Plummer, 1945, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the shale and siltstone units of the member, especially at the base. This species is uncommon, but has been found from all the shale and siltstone beds of the member. It has also been recorded from the Bowen Basin of Queensland in the Cattle Creek, Freitag, Ingelara, Peawaddy, Barfield, and Flat Top Formations (Crespin, 1958; Palmieri, 1994). In Tasmania from the Quamby Mudstone (Crespin, 1958), as well as from the Stuart Range Formation in the Archaringa Basin of South Australia (Scheibnerová, 1982). In Western Australia the species has also been recorded from the Holmwood Shale, High Cliff Sandstone, and Carynginia Formation of the Perth Basin; the Callytharra

Formation and basal Byro Group of the Carnarvon Basin; and Noonkanbah Formation and Grant Group of the Canning Basin (Crespin, 1958). In addition the species has been recorded from the Late Palaeozoic sediments of southern North America (Plummer, 1945; Conkin, 1961).

Genus *TEICHERTINA* PALMIERI, 1994

Type Species: ***Teichertina teicherti*** (Parr), 1942.

Diagnosis: See Palmieri (1994).

Remarks: This genus was erected by Palmieri (1994) to cover those species previously assigned to *Thuramminoides* Plummer, 1945, that no longer fell within the new definition of the genus as given by Loeblich and Tappan (1987). *Teichertina* Palmieri, 1994, differs from *Thuramminoides* Plummer, 1945, in possessing a pitted internal surface, which expresses itself on the outer surface through a number of small pores on the surface of the test.

Teichertina teicherti (Parr), 1942

1942 *Crithionina teicherti* Parr, p. 107, pl. 1, figs 9, 10.

1958 *Thuramminoides sphaeroidalis* Plummer; Crespin, p. 40-41, pl. 31 figs 1, 2.

1958 *Thuramminoides teicherti* (Parr); Crespin, p. 41-42, pl. 2, figs 12, 13.

1961 *Oryctoderma teicherti* (Parr); Loeblich and Tappan, p. 217-218.

1982 *Thuramminoides teicherti* (Parr); Scheibnerová, p. 57-58, pl. 8, figs 1, 2a-c.

1994 *Teichertina teicherti* (Parr); Palmieri, p. 8-9, pl. 4, figs 3, 4; pl. 7, figs 24-26.

Holotype: Geology Department, University of Western Australia, #20674.

Type Locality: “Lingula Beds” (Wandagee Formation), south side of Minilya River, near Coolkilyia Pool, Wandagee Station, in a brown, impure, limestone.

Figured Specimens: Plate 23, figures 26-31.

Material studied: 18 tests.

Diagnosis: “Test free, comparatively large, spherical, thick-walled, but variable in this respect, central cavity large, connected with the outside surface by numerous moderately-sized pits which extend irregularly through the thickness of the test wall and reach the exterior surface through minute openings; wall composed of fine sandy material fairly well cemented, with a thin compact surface layer” (Palmieri, 1994).

Remarks: This species is slightly larger than *Thuramminoides sphaeroidalis* Plummer, 1945, and the presence of numerous small pores on the outer surface of the test, a pitted inner test surface, as well as variable wall thickness distinguish *Teichertina teicherti* Palmieri, 1994. Internally the pores that extend through the test wall are pronounced and it is this feature that characterises this species and separates it from the other spheroidal agglutinated species that are present during the Permian.

Distribution: *T. teicherti* Palmieri, 1994, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the shale and siltstone units of the member, especially at the base. This species is uncommon, and has been found from all the shale and siltstone beds of the member. It has also been recorded from the Bowen Basin of Queensland in the Cattle Creek Formation (Moorooloo and Sirius Mudstone Members) (Palmieri, 1994). As well as from the Branxton and Mulbring Formations in the Sydney Basin of New South Wales (Scheibnerová, 1982). In Western Australia the species has also been recorded from the Holmwood Shale of the Perth Basin; the Callytharra Formation and Byro Group of the Carnarvon Basin; and Noonkanbah Formation and Grant Group of the Canning Basin (Crespin, 1958).

Family SACCAMMINIDAE BRADY, 1884

Subfamily SACCAMMININAE BRADY, 1884

Genus *SACCAMMINA* CARPENTER, 1869

Type Species: ***Saccammina sphaerica*** Brady, 1871.

Diagnosis: See Loeblich and Tappan (1987).

Saccammina arenosa (Crespin), 1958

1958 *Proteonina arenosa* Crespin, p. 38-39, pl. 2, figs 6, 7.

1994 *Saccammina arenosa* (Crespin); Palmieri, p. 10, pl. 7, figs 6, 7.

Holotype: Commonwealth Palaeontological Collection, Australian Geological Survey, Canberra, Australia, #2359.

Type Locality: Wooramel River, 2.25 miles west of the junction with Madeline Creek, Madeline Formation, Carnarvon Basin, Western Australia.

Figured Specimens: Plate 16, figure 8.

Material studied: 8 tests.

Diagnosis: "Globular test composed of large and small quartz grains and a short apertural neck" (Crespin, 1958).

Remarks: This species was originally placed in the genus *Proteonina* Williamson, 1858, which is now considered a junior synonym of *Reophax* de Monfort, 1808. Palmieri (1994) considered this species is now best placed under the genus *Saccammina* Carpenter, 1869.

Distribution: *S. arenosa* (Crespin), 1958, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin. This species is rare, and has been recorded from the shale and siltstone beds of the member. It has also been recorded from the Bowen Basin of Queensland in the Cattle Creek Formation (Mostyndale and Sirius Mudstone Members) (Palmieri, 1994). In Western Australia the species has also been recorded from the Holmwood Shale, High Cliff Sandstone, and Carynginia Formation of the Perth Basin; the Byro Group of the Carnarvon Basin; and Noonkanbah Formation of the Canning Basin (Crespin, 1958).

Superfamily HIPPOCREPINOIDEA RHUMBLER, 1895

Family HIPPOCREPINIDAE RHUMBLER, 1895

Subfamily HYPERAMMININAE EIMER and FICKERT, 1899

Genus *HYPERAMMINA* BRADY, 1878

Type Species: ***Hyperammina elongata*** Brady, 1878.

Diagnosis: See Loeblich and Tappan (1987).

Hyperammina callytharraensis Crespin, 1958

1958 *Hyperammina callytharraensis* Crespin, p. 45-46, p 206-207, pl. 4, figs 1-5.

1982 *Hyperammina callytharraensis* Crespin; Scheibnerová, p. 53, pl. 1, fig. 4.

Holotype: Commonwealth Palaeontological Collection, Australian Geological Survey, Canberra, Australia, #2382.

Type Locality: Callytharra Springs, 22-35 feet above the base of the Callytharra Formation, Carnarvon Basin, Western Australia.

Figured Specimens: Plate 16, figures 9-18.

Material studied: over 70 tests.

Diagnosis: "Short, slightly sinuous test of almost uniform width; aperture at the end of a smooth constricted neck" (Crespin, 1958).

Remarks: This species is common in the Fossil Cliff Member and is differentiated from the other species of *Hyperammina* Brady, 1878, that are found in the unit by its much thicker test with broad middle section, coarse agglutination, and indistinct proloculus.

Distribution: *H. callytharraensis* Crespin, 1958, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the shale and siltstone units of the member, especially at the base. This species is ubiquitous, and has been found from all the shale and siltstone beds of the member. It has also been recorded from the Hunter Valley of New South Wales in the Branxton Formation and Mulbring Siltstone, as well as the Sydney Basin in the Wandravandian Siltstone and Berry Formation (Crespin, 1958; Scheibnerová, 1982). In Western Australia the species has also been recorded from the Holmwood Shale, basal High Cliff Sandstone, and Carynginia Formation of the Perth Basin; and the Callytharra Formation of the Carnarvon Basin (Crespin, 1958).

Hyperammina coleyi Parr, 1942

1942 *Hyperammina coleyi* Parr, p. 104-105, pl. 2, fig. 3.
1958 *Hyperammina coleyi* Parr; Crespin, p. 46-47, pl. 6, figs 5, 6; pl. 7, figs 3-5; pl. 33, figs 1-2.
1967 *Hyperammina coleyi* Parr; Ludbrook, p. 74, pl. 3, figs 8, 9.
1968 *Hyperammina coleyi* Parr; Belford, pl. 1, figs 16-18.
1982 *Hyperammina coleyi* Parr; Scheibnerová, p. 54, pl. 4, fig. 1.

Holotype: Geology Department, University of Western Australia, #20676.

Type Locality: Wandagee Formation, Carnarvon Basin, south side of Minilya River, near Coolkilyia Pool, Wandagee Station, Western Australia.

Figured Specimens: Plate 16, figures 19-22.

Material studied: 48 tests.

Diagnosis: "Test elongate, cylindrical, consisting of sub-globular proloculus and long slender tubular chamber of lesser diameter than proloculus, widest in the middle portion, occasionally slightly constricted at irregular intervals; wall thick, composed of medium sized grains firmly cemented, surface rough, interior not smoothly finished; aperture circular, formed by open end of tube" (Parr, 1942).

Remarks: This species, along with *H. callytharraensis* Crespin, 1958, is characteristic of the fine-grained terrigenous facies of the Fossil Cliff Member. The specimens from the Fossil Cliff Member have a slightly finer grained agglutinated wall than those illustrated by Parr (1942) and Crespin (1958) from the Carnarvon Basin.

Distribution: *H. coleyi* Parr, 1942, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the shale and siltstone units of the member, especially at the base. This species is uncommon, but has been found from most the shale and siltstone beds of the member. It has also been recorded from the Hunter Valley of New South Wales in the Branxton Formation and Mulbring Siltstone (Crespin, 1958; Scheibnerová, 1982). In Western Australia the species has also been recorded from the Quinnanie Shale, Coyrie Formation, Bulgadoo Shale, Cundlego Formation, Wandagee Formation, and Callytharra Formation of the Carnarvon Basin, and the Noonkanbah Formation of the Canning Basin (Parr, 1942; Crespin, 1958; Belford, 1968).

Hyperammina elegans (Cushman and Waters), 1928

1928a *Hyperamminella elegans* Cushman and Waters, p. 36.
1928b *Hyperamminoides elegans* (Cushman and Waters); Cushman and Waters, p. 112.
1930 *Hyperamminoides elegans* (Cushman and Waters); Cushman and Waters, p. 175, pl. 10, figs 8, 9.
1954 *Hyperammina elegans* (Cushman and Waters); Conkin, p. 168.
1958 *Hyperammina elegans* (Cushman and Waters); Crespin, p. 47-48, pl. 5, figs 1-5.
1982 *Hyperammina elegans* (Cushman and Waters); Scheibnerová, p. 54, pl. 4, figs 2a-b.

Holotype: Cushman Laboratory for Foraminiferal Research, #7603.

Type Locality: Pennsylvannian Graham Formation, below the Bunger Limestone, on Cad road, 14.7 miles north of Ranger, Stephens County, Texas.

Figured Specimens: Plate 16, figures 23-30.

Material studied: over 150 tests.

Diagnosis: “Test elongate, tapering, microspheric form with large bulbous proloculum and breadth of chamber not greatly increasing towards aperture; interior of tubular chamber slightly compressed but not divided; wall siliceous, very finely grained, exterior smooth and polished; aperture at constricted end of tubular chamber, rounded or elliptical” (Cushman and Waters, 1928a).

Remarks: This species has a very fine-grained and slightly polished agglutinated test wall, and is found exclusively in the terrigenous sediments of the Fossil Cliff Member. It is distinguished from *H. elegantissima* Plummer, 1945, by its greater test width and constrictions, especially in the later stages of growth.

Distribution: *H. elegans* (Cushman and Waters), 1928, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the shale and siltstone units of the member, especially at the base. This species is common, and has been found from all the shale and siltstone beds of the member. It has also been recorded from the Hunter Valley of New South Wales in the Maitland Group, and in the Illawarra Coal Measures from the southern Sydney Basin (Scheibnerová, 1982), in addition to the Golden Valley Group of Tasmania (Crespin, 1958). In Western Australia the species has also been recorded from the Carynginia Formation of the Perth Basin, the Bulgadoo Shale, Wandagee Formation, and Callytharra Formation of the Carnarvon Basin, and the Noonkanbah Formation of the Canning Basin (Crespin, 1958).

Hyperammina elegantissima Plummer, 1945

1945 *Hyperammina elegantissima* Plummer, p. 222, pl. 15, figs 17-25.
1958 *Hyperammina elegantissima* Plummer; Crespin, p. 48-49, pl. 7, figs 8-10.
1982 *Hyperammina elegantissima* Plummer; Scheibnerová, p. 54.

Holotype: Holotype placed in Plummer's personal collection. Other specimens deposited in the collections of the Bureau of Economic Geology, Austin Texas; the British Museum (Natural History), London; and the United States National Museum, Washington, D.C.

Type Locality: Lower part of Strawn Group, Middle Pennsylvanian, San Saba County, Texas.

Figured Specimens: Plate 16, figures 31-36.

Material studied: over 200 tests.

Diagnosis "Slender, usually rather glossy, smooth test with a very narrow rounded initial extremity, and straight to arcuate, gradually expanding tubular chamber, which is only rarely separated from megalosphere by faint constricting. Microspheric form finely tapering. Shell wall composed of minute siliceous granules, is thin, so that most tests are strongly compressed or otherwise deformed, but considerable proportion of siliceous cement makes them unusually rigid for size. Oral extremity somewhat constricted around circular terminal aperture" (Crespin, 1958).

Remarks: This species has a very fine-grained agglutinated wall, and is extremely long and slender. It is distinguished from *H. elegans* (Cushman and Waters), 1928, by its thin width and lack of constrictions along the second, expanding chamber. Until the work of Scheibnerová (1982) recorded this species from a number of localities in New South Wales, it had only previously been recorded in Australia from Western Australia.

Distribution: *H. elegantissima* Plummer, 1945, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the shale and siltstone units of the member, especially at the base. This species is very common, and has been found from all the shale and siltstone beds of the member. It has also been recorded from the Hunter Valley of New South Wales in the Mulbring Siltstone, and the Wandravandian Siltstone from the southern Sydney Basin (Scheibnerová, 1982). In Western Australia the species has also been recorded from the Nangetty Formation of the Perth Basin, and the Callytharra Formation of the Carnarvon Basin (Crespin, 1958).

Family HYPERAMMINOIDIDAE LOEBLICH and TAPPAN, 1984

Genus *KECHENOTISKE* LOEBLICH and TAPPAN, 1984

Type Species: ***Kechenotiske expansus*** (Plummer), 1945.

Diagnosis: See Loeblich and Tappan (1984).

Kechenotiske hadzeli (Crespin) 1958

1958 *Hyperammina hadzeli* Crespin, p. 51-52, 207, pl. 5, figs 6-10.
1968 *Hyperammina hadzeli* Crespin; Belford, p. 5, pl. 1, fig. 24.
1982 *Hyperammina coleyi* Parr; Scheibnerová, p. 54, pl. 4, fig. 1.

Holotype: Commonwealth Palaeontological Collection, Australian Geological Survey, Canberra, Australia, #2410.

Type Locality: Callytharra Springs, 180-230 feet above the base of the Callytharra Formation, Carnarvon Basin, Western Australia.

Figured Specimens: Plate 16, figures 37-40; Plate 17, figures 1-3.

Material studied: 52 tests.

Diagnosis: "Proloculus small, followed by a long tubular second chamber, which expands rapidly towards the apertural opening. Test finely arenaceous" (Crespin, 1958).

Remarks: This species is characterised by the flaring second chamber on the test and finely agglutinated test wall.

Distribution: *K. hadzeli* (Crespin), 1958, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the shale and siltstone units of the member, especially at the base. This species is uncommon, and has been found in the lower shale and siltstone beds of the member. It has also been recorded from the Mostyndale Mudstone Member of the Cattle Creek Formation in the Bowen Basin of Queensland (Palmieri, 1994). In Western Australia the species has also been recorded from the Holmwood Shale of the Perth Basin, the Callytharra Formation and Byro Group of the Carnarvon Basin, and the Grant Group of the Canning Basin (Crespin, 1958).

Superfamily AMMODISCOIDEA REUSS, 1862

Family AMMODISCIDAE REUSS, 1862

Subfamily AMMODISCINAE REUSS, 1862

Genus *AMMODISCUS* REUSS, 1862

Type Species: ***Ammodiscus infimus*** Bornemann, 1874.

Diagnosis: See Loeblich and Tappan (1987).

Ammodiscus multicinctus Crespin and Parr, 1941

1941 *Ammodiscus multicinctus* Crespin and Parr, p. 303-304, pl. 12, figs 1a, b.

1958 *Ammodiscus multicinctus* Crespin and Parr; Crespin, p. 67-68, pl. 12, figs 4-6.

1982 *Ammodiscus multicinctus* Crespin and Parr; Scheibnerová, p. 58, pl. 14, fig. 4.

1985 *Ammodiscus multicinctus* Crespin and Parr; Palmieri in Foster et al., p. 79, pl. 4, figs 2, 3.

1994 *Ammodiscus multicinctus* Crespin and Parr; Palmieri, p. 15-16, pl. 4, figs 5, 7; pl. 7, figs 22, 23; pl. 8, figs 15, 17.

2000 *Ammodiscus multicinctus* Crespin and Parr; Kalia et al., p. 211, figs 2E-I.

Holotype: Commonwealth Palaeontological Collection, Australian Geological Survey, Canberra, Australia, #149.

Type Locality: Railroad cutting about 4 chains west of Farley Station, Hunter River area, New South Wales.

Figured Specimens: Plate 17, figures 4-22.

Material studied: over 300 tests.

Diagnosis: "Test planispiral, circular, with parallel sides, consisting of about six whorls, the coiled chamber nearly circular in section increasing slowly and regularly in diameter and constricted at short, fairly regular intervals, giving a lobulated periphery and undulate surface; wall moderately thick, coarsely arenaceous, the sand grains cemented with a small proportion of cement giving a roughened surface; spiral suture distinct; aperture generally circular, at end of the tubular chamber" (Crespin and Parr, 1941).

Remarks: *A. multicinctus* Crespin and Parr, 1941, is found in close association with *A. nitidus* Parr, 1942. *A. multicinctus* Crespin and Parr, 1941, differs from *A. nitidus* Parr, 1942, in the regular constrictions around the planispiral whorls, the increased diameter of the final whorl relative to the other whorls in the test, and a slightly fewer number of whorls in the adult test.

Distribution: *A. multicinctus* Crespin and Parr, 1941, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the shale and siltstone units of the member, especially at the base. This species is ubiquitous, and has been recorded from all the terrigenous sediment beds of the member. It has also been recorded from the Cattle Creek, Tiverton, Freitag, Ingelara, Peawaddy, Barfield, Flat Top, Maria, and Blenheim Formations of the Bowen Basin of Queensland (Crespin, 1958; Palmieri, 1994); the Dalwood, Maitland, Singleton, and Conjola Groups of the New South Wales Sydney Basin, in addition to the Berry Formation of the Sydney Basin (Crespin, 1958; Scheibnerová, 1982); and in Tasmania from the Quamby Mudstone (Crespin, 1958). In Western Australia the species has also been recorded from the Holmwood Shale of the Perth Basin, the Callytharra Formation and the Byro Group of the Carnarvon Basin (Crespin, 1958). Kalia et al. (2000) recorded this species from Arunachal Pradesha, in the eastern Himalaya's of India.

Ammodiscus nitidus Parr, 1942

1942 *Ammodiscus nitidus* Parr, p. 103, pl. 1, figs 1a, b.

1958 *Ammodiscus nitidus* Parr; Crespin, p. 68-69, pl. 12, figs 7-9.

1968 *Ammodiscus nitidus* Parr; Belford, pl. 1, figs 5-7.

1982 *Ammodiscus nitidus* Parr; Scheibnerová, p. 58, pl. 11, fig. 2; pl. 13, figs 2, 4; pl. 14, figs 1, 3a, b, 5.

1985 *Ammodiscus nitidus* Parr; Palmieri in Foster et al., p. 79, pl. 4, figs 4, 5.

1994 *Ammodiscus nitidus* Parr; Palmieri, p. 16, pl. 4, figs 6, 8-13; pl. 30, fig. 9.

2000 *Ammodiscus nitidus* Parr; Kalia et al., p. 211, figs 2J-K.

Holotype: Geology Department, University of Western Australia, #20670.

Type Locality: Wandagee Formation, Carnarvon Basin, east of Coolkilyia Pool, Wandagee Station, Western Australia.

Figured Specimens: Plate 17, figures 23-35; Plate 18, figures 1-8.

Material studied: over 300 tests.

Diagnosis: “Test small, free, composed of minute proloculus and an elongate, tubular chamber, almost semicircular in section and slowly increasing in diameter, often transversely ridged, number of whorls usually seven or eight, each whorl overlapping to a considerable extent its predecessor; spiral suture only slightly depressed; wall thin for its genus, composed of very small quartz grains with little visible cement; shell surface comparatively smooth; aperture semicircular, formed by open end of tube” (Parr, 1942)

Remarks: *A. nitidus* Parr, 1942, is found in close association with *A. multicinctus* Crespin and Parr, 1941. *A. nitidus* Parr, 1942, is distinguished from *A. multicinctus* Crespin and Parr, 1941, by its finely agglutinated test wall, and by having 7 to 8 whorls in the test that significantly overlap the earlier whorl. Kalia et al. (2000) believe that the presence of this species across eastern and Western Australia, as well as in north east India, may make it a characterisitic taxon for Gondwanan marine sedimentary sequences.

Distribution: *A. nitidus* Parr, 1942, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the shale and siltstone units of the member. This species is ubiquitous, and has been recorded from all the terrigenous sediment beds of the member. It has also been recorded from the Cattle Creek and Tiverton Formations of the Bowen Basin of Queensland (Palmieri, 1994); the Dalwood, Maitland, Singleton, and Conjola Groups of the New South Wales Sydney Basin, in addition to the Berry Formation of the Sydney Basin (Crespin, 1958;

Scheibnerová, 1982). In Western Australia the species has also been recorded from the Holmwood Shale, High Cliff Sandstone, and Carynginia Formation of the Perth Basin, the Callytharra Formation and Byro Group of the Carnarvon Basin, and the Nura Nura Member of the Poole Sandstone and Noonkanbah Formation of the Canning Basin (Crespin, 1958). Kalia et al. (2000) recorded this species from Arunachal Pradesha, in the eastern Himalaya's of India.

Subfamily AMMOVERTELLININAE SAIDOVA, 1981

Genus *GLOMOSPIRELLA* PLUMMER, 1945

Type Species: ***Glomospira umbilicata*** (Cushman and Waters), 1927.

Diagnosis: See Loeblich and Tappan (1987).

Glomospirella nyei Crespin, 1958

1958 *Glomospirella nyei* Crespin, p. 70-71, 207, pl. 13, figs 1-5.
1967 *Glomospirella nyei* Crespin; Ludbrook, p. 79, pl. 4, fig. 13.
1968 *Glomospirella nyei* Crespin; Belford, pl. 2, fig. 2.
1982 *Glomospirella nyei* Crespin; Scheibnerová, p. 59.
1985 *Glomospirella nyei* Crespin; Palmieri in Foster et al., p. 79, pl. 4, figs 6, 7.
1994 *Glomospirella nyei* Crespin; Palmieri, p. 17, pl. 8, figs 24-27.

Holotype: Commonwealth Palaeontological Collection, Australian Geological Survey, Canberra, Australia, #2475.

Type Locality: Cundlego Formation, Carnarvon Basin, Western Australia, just near Cundlego Crossing, Minilya River.

Figured Specimens: Plate 18, figures 9-26.

Material studied: over 300 tests.

Diagnosis: "A finely arenaceous tubular chamber, which, after coiling itself in different directions in the initial portion, becomes planispiral for two or three whorls. Spiral suture distinct and periphery rounded" (Crespin, 1958).

Remarks: This very distinctive species is found throughout the cold-water terrigenous sediments of Western Australia, Queensland, and parts of New South Wales in the Cisuralian. It is differentiated from the species of *Ammodiscus* Reuss, 1862, that are found in the Fossil Cliff Member in that it does not coil exclusively in one plane and has a roughened and slightly polished agglutinated test.

Distribution: *G. nyei* Crespin, 1958, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the shale and siltstone units of the member. This species is ubiquitous, and has been recorded from all the terrigenous sediment beds of the member. It has also been recorded from the Freitag, Ingelara, Catherine, Peawaddy, Barfield, Flat Top and Blenheim Formations of the Bowen Basin of Queensland (Crespin, 1958; Palmieri, 1994); the Branxton Formation of the New South Wales Sydney Basin (Crespin, 1958; Scheibnerová, 1982). In Western Australia the species has also been recorded from the Holmwood Shale of the Perth Basin, the Callytharra Formation and Byro Group of the Carnarvon Basin, and the Nura Nura Member of the Poole Sandstone, Noonkanbah Formation, and Grant Group of the Canning Basin (Crespin, 1958). A species comparable to *G. nyei* Crespin, has been recorded from north east India by Kalia et al. (2000)

Superfamily LITUOLOIDEA de Blainville, 1827

Family LITUOLIDAE de Blainville, 1827

Subfamily AMMOMARGINULININAE Podobina, 1978

Genus *AMMOBACULITES* Cushman, 1910

Type Species: ***Ammobaculites agglutinans*** (d'Orbigny), 1846.

Diagnosis: See Loeblich and Tappan (1987).

Ammobaculites woolnoughi Crespin and Parr, 1941

1941 *Ammobaculites woolnoughi* Crespin and Parr, p. 304-305, pl. 12, figs 2a, b, 3a, b.
1942 *Ammobaculites woolnoughi* Crespin and Parr; Parr, p. 108, pl. 1, fig. 11.
1945b *Ammobaculites woolnoughi* Crespin and Parr; Crespin, p. 25, pl. 3, fig. 11.
1947 *Ammobaculites woolnoughi* Crespin and Parr; Crespin, p 19, 22, pl. 1, fig. 4; pl. 2, figs 16, 17.
1958 *Ammobaculites woolnoughi* Crespin and Parr; Crespin, p. 75-76, 206, pl. 14, figs 10, 11.
1968 *Ammobaculites woolnoughi* Crespin and Parr; Belford, p. 4, pl. 1, fig. 10.
1982 *Ammobaculites woolnoughi* Crespin and Parr; Scheibnerová, p. 63, pl. 18, figs 2, 5; pl. 21, figs 1, 6; pl. 22, fig. 2.
1982 *Ammobaculites crescendo* Scheibnerová, p. 62, pl. 18, fig. 6, pl. 21, fig. 5.
1985 *Ammobaculites woolnoughi* Crespin and Parr; Palmieri in Foster et al., p. 79-80, pl. 4, fig. 1.

1994 *Ammobaculites woolnoughi* Crespin and Parr; Palmieri, p. 21, pl. 3, figs 1-6; pl. 6, fig. 10; pl. 7, figs 27, 28.

Holotype: Commonwealth Palaeontological Collection, Australian Geological Survey, Canberra, Australia, #151.

Type Locality: Farley road, 300 yards north-east of Farley Station, Hunter River District, New South Wales.

Figured Specimens: Plate 18, figures 27-29.

Material studied: 7 tests.

Diagnosis: "Test crozier-shaped, with the early portion closely coiled and consisting of a single whorl of five or six inflated chambers, in rectilinear series, frequently gradually increasing in size as added; slightly compressed; sutures depressed; wall coarsely arenaceous with a rough surface; aperture terminal and nearly circular" (Crespin and Parr, 1941).

Remarks: *A. crescendo* Scheibnerová, 1982, is considered by Palmieri (1994) to fall within the range of *A. woolnoughi* Crespin and Parr, 1941. The species is rare within the Fossil Cliff Member and is generally preserved as broken tests.

Distribution: *A. woolnoughi* Crespin and Parr, 1941, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the shale and siltstone units of the member. This species is rare, and has been recorded from all the terrigenous sediment beds of the member. It has also been recorded from the Cattle Creek, Freitag, and ?Ingelara Formations of the Bowen Basin of Queensland (Palmieri, 1994); the Dalwood Group, Capertree Group, Maitland Group, and Wandravandian Siltstone of the New South Wales Sydney Basin (Scheibnerová, 1982); and the Quamby Mudstone of Tasmania (Crespin, 1958). In Western Australia the species has also been recorded from the Holmwood Shale of the Perth Basin, the Byro Group of the Carnarvon Basin, and the Noonkanbah Formation of the Canning Basin (Crespin, 1958).

Superfamily TROCHAMMINOIDEA SCHWAGER, 1877

Family TROCHAMMINIDAE SCHWAGER, 1877

Subfamily TROCHAMMININAE SCHWAGER, 1877

Genus *TROCHAMMINA* PARKER and JONES, 1859

Type Species: ***Trochammina inflatus*** (Montagu), 1808.

Diagnosis: See Loeblich and Tappan (1987).

Trochammina subobtusa Parr, 1942

1942 *Trochammina subobtusa* Parr, p. 109, pl. 1, figs 14a-c.
1958 *Trochammina subobtusa* Parr; Crespin, p. 92, 207, pl. 21, figs 5, 6.
1968 *Trochammina subobtusa* Parr; Belford, p. 17, pl. 2, figs 1, 2.
1982 *Trochammina subobtusa* Parr; Scheibnerová, p. 65-66, pl. 25, fig. 7; pl. 29, figs 2-4.
1994 *Trochammina subobtusa* Parr; Palmieri, p. 24, pl. 12, figs 14-23.

Holotype: Geology Department, University of Western Australia, #20683.

Type Locality: From Wandagee Formation, Carnarvon Basin, to the south side of Minilya River, near Coolkilyia Pool, Wandagee Station, Western Australia.

Figured Specimens: Plate 18, figures 30-41; Plate 19, figures 1-8.

Material studied: over 250 tests.

Diagnosis: "Test subglobose, trochoid, spire low, under side umbilicate, composed of three whorls; chambers strongly inflated, with four in the last-formed whorl, the chambers of which are so much larger than those in the preceding whorl that they form the greater part of the test; sutures distinct and depressed; wall finely arenaceous, with the surface smoothly finished but not polished; aperture an arched slit at the base of the last-formed chamber, opening into the umbilical depression" (Parr, 1942).

Remarks: *Trochammina subobtusa* Parr, 1942, is trochoid shaped with three whorls forming a low spire. The test wall is finely agglutinated, with a smooth surface. The species is rare within the Fossil Cliff Member.

Distribution: *T. subobtusa* Parr, 1942, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the shale and siltstone units of the member, especially at the base. This species is ubiquitous, and has been found from all the shale and siltstone beds of the member. It has also been recorded from the Sirius Mudstone Member of the Cattle Creek Formation, Cattle Creek Formation, and Buffel Formation of the Bowen Basin of Queensland (Palmieri, 1994); the Dalwood Group, Singleton Supergroup, and Wandravandian Siltstone of the New South Wales Sydney Basin (Scheibnerová, 1982). In Western Australia the species has also been recorded from the Holmwood Shale of the Perth Basin, the Callytharra

Formation and Byro Group of the Carnarvon Basin, and the Noonkanbah Formation of the Canning Basin (Crespin, 1958).

Suborder FUSULININA WEDEKIND, 1937

Superfamily TETRATAXOIDEA GALLOWAY, 1933

Family TETRATAXIDAE GALLOWAY, 1933

Genus *TETRATAXIS* EHRENBERG, 1843

Type Species: ***Tetrataxis conica*** Ehrenberg, 1854.

Diagnosis: See Loeblich and Tappan (1987).

Remarks: The original description of this genus was not provided by Ehrenberg, who simply illustrated the genus, and the genus has been redescribed fully by Moller (1879).

Tetrataxis conica Ehrenberg, 1854

1843 *Tetrataxis conica* Ehrenberg, p. 106, nomen nudem.

1854 *Tetrataxis conica* Ehrenberg; Ehrenberg, p. 24, pl. 37, fig. 12.

1879 *Tetrataxis conica* Ehrenberg; Moller, p. 71, pl. 2, figs 3a-g; pl. 7, figs 1, 2, text fig. 30.

1927 *Tetrataxis conica* Ehrenberg; Cushman, p. 42, pl. 6, fig. 3.

1958 *Tetrataxis conica* Ehrenberg; Crespin, p. 93, pl. 23, figs 1-5; pl. 31, fig. 31.

1985 *Tetrataxis conica* Ehrenberg; Palmieri in Foster et al., p. 80, pl. 4, figs 8-10.

Holotype: Repository not given.

Type Locality: Kohlen Formation, Tula, Russia.

Figured Specimens: Plate 19, figures 9, 14, 15.

Material studied: 7 tests.

Diagnosis: “Shell, more or less conical, flat or a little concave on bottom side. Aperture divided into 4 or, in exceptional cases, 3 or 5 parts. Top of shell more or less pointed, sometimes a little rounded or shifted to one side. Vertex angle varies between 70°-85°. Chambers very flat, trapezoidal, more or less distinctly spirally arranged and not divided into cells. Every whorl has 4, or rarely 3, such chambers, which on the bottom part of the shell are separated by more or less distinct, arched, radial furrows. On top part, the separations between those chambers are less distinct, a direct connection between chambers missing. Only connections, if they are so, are made through pores in the chamber wall. All chambers provided with septal openings towards central cavity, occupying about a quarter or less of entire interior of shell. Septal openings about 0.045 mm high and 0.075 mm wide. Chamber walls not of same thickness throughout, outside wall not more than 0.037 mm thick. Pores of last group, 0.012-0.018 mm. Besides radial furrows of chambers previously mentioned, the indentations between each round of chambers and the oblique grooves of outer chamber walls, the surface shows more or less distinct radial striae. Measurements of shell vary according to the age of individuals" (Crespin, 1958).

Remarks: This species is rare within the Fossil Cliff Member, and its conical test makes it distinctive within the member. It is trochospirally coiled, with three to four chambers per whorl, and a microgranular, calcareous, perforate wall.

Distribution: *T. conica* Ehrenberg, 1843, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the calcarenite of the member. This species is extremely rare and present within the middle and upper calcarenite units. It has also been recorded from the Callytharra Formation of the Carnarvon Basin (Crespin, 1958), and Schwager (1883) noted the species from both China and Japan.

Suborder MILIOLINA DELAGE and HEROUARD, 1896

Superfamily CORNUSPIROIDEA SCHULTZE, 1854

Family CORNUSPIRIDAE SCHULTZE, 1854

Subfamily CALCIVERTELLINAE LOEBLICH and TAPPAN, 1964

Genus *CALCITORNELLA* CUSHMAN and WATERS, 1928

Type Species: ***Calcitornella elongata*** Cushman and Waters, 1928.

Diagnosis: See Loeblich and Tappan (1987).

Remarks: Scheibnerová (1980) in her work on Permian foraminifera from eastern Australia noted an abundance of attached forms such as *Calcitornella* indicate shallow water depths, probably within the photic zone.

Calcitornella elongata Cushman and Waters, 1928

1928a *Calcitornella elongata* Cushman and Waters, p. 47, pl. 6, fig. 5.

1958 *Calcitornella elongata* Cushman and Waters; Crespin, p. 82-83, pl. 17, figs 1-3.

1982 *Calcitornella elongata* Cushman and Waters; Scheibnerová, p. 68, pl. 34, figs 2a-b.

1985 *Calcitornella elongata* Cushman and Waters; Palmieri in Foster et al., p. 80, pl. 5, figs 11-13.

1994 *Calcitornella elongata* Cushman and Waters; Palmieri, p. 28-29, pl. 13, figs 6-8, 13.

2000 *Calcitornella elongata* Cushman and Waters; Kalia et al., p. 219, fig. 5C.

Holotype: Cushman Laboratory for Foraminiferal Research, #7684.

Type Locality: Near Graham, Young County, Texas, USA, in Graham Formation, six inches below the Gunsight Limestone.

Figured Specimens: Plate 19, figures 10-13, 16-26.

Material studied: over 150 tests.

Diagnosis: “Test elongate, attached, consisting of a close coiled early portion and an elongate later growth, tubular chamber bending back and forth on itself along a nearly straight axis, attached side conforming to the surface to which it is attached, outer surface convex and the structure obscured; sutures very distinct on attached side; wall calcareous, imperforate, more or less roughened and irregular on the outer surface; aperture formed by open end of tubular chamber” (Cushman and Waters, 1928).

Remarks: This species is very common within the Fossil Cliff Member and is usually found encrusting productiid brachiopod spines. The species shows an undivided second chamber that is formed by an irregular zigzag pattern. It is differentiated from *Trepeilopsis australiensis* Crespin, 1958, in having a slightly looser coiling pattern, and a thick, granular ornamentation on the outer surface similar to that of *C. heathi* Cushman and Waters, 1928.

Distribution: *C. elongata* Cushman and Waters, 1928, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the calcarenite of the member. This species is common, and has been recorded from all the carbonate beds of the member, although it becomes ubiquitous in the upper calcarenite beds. It has also been recorded from the Cattle Creek (Riverstone and Sirius Members), Tiverton, Ingelara, Peawaddy, Oxtrack and Buffel Formations, and Catherine Sandstone of the Bowen Basin of Queensland (Palmieri, 1994); the Rutherford Formation of the New South Wales Sydney Basin (Scheibnerová, 1982). In Western Australia the species has also been recorded from the Callytharra Formation of the Carnarvon Basin, and the Noonkanbah Formation of the Canning Basin (Crespin, 1958). Kalia et al. (2000) recorded the species from the eastern Himalayas in India.

Calcitornella heathi Cushman and Waters, 1928

1928a *Calcitornella heathi* Cushman and Waters, p. 48, pl. 6, figs 8a-b.

1958 *Calcitornella heathi* Cushman and Waters; Crespin, p. 83, pl. 13, figs 8-11; pl. 19, fig. 11.

1968 *Calcitornella heathi* Cushman and Waters; Belford, p. 4, pl. 2, figs 17, 18.

1982 *Calcitornella heathi* Cushman and Waters; Scheibnerová, p. 68, pl. 34, figs 3, 4.

1985 *Calcitornella heathi* Cushman and Waters; Palmieri in Foster et al., p. 80-81, pl. 5, fig. 14; pl. 6, figs 15, 16.

1994 *Calcitornella heathi* Cushman and Waters; Palmieri, p. 29, pl. 13, fig. 12.

2000 *Calcitornella heathi* Cushman and Waters; Mertmann, p. 142, fig. 5.3.

Holotype: Cushman Laboratory for Foraminiferal Research, #7688.

Type Locality: Near Graham, Young County, Texas, USA, in Graham Formation, five feet above the Gunsight Limestone.

Figured Specimens: Plate 19, figures 27-33; Plate 20, figures 1-3.

Material studied: 86 tests.

Diagnosis: "Test attached, compressed and scalelike, ventral side conforming to surface to which attached, dorsal side irregular and earlier coils obscured; consisting of a proloculum and elongate tubular second chamber, early portion definitely spiral, later ones bending back and forth about the periphery of the earlier ones, often partially involute; sutures distinct on ventral side; wall calcareous, imperforate, exterior roughened; aperture formed by open end of tubular chamber" (Cushman and Waters, 1928).

Remarks: This species is very common within the Fossil Cliff Member and is commonly found encrusting brachiopod shells and other macrofaunal elements. The species shows a tubular second chamber that forms an early spiral, and then later ones bend back and forth along the periphery of the earlier spirals. Test wall is calcareous and imperforate.

Distribution: *C. heathi* Cushman and Waters, 1928, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the calcarenite of the member. This species is common, and has been recorded from all the carbonate beds of the member, although it becomes ubiquitous in the upper calcarenite beds. It has also been recorded from the Cattle Creek (Riverstone and Sirius Members), Tiverton, Ingelara, Peawaddy, Oxtrack and Buffel Formations, and Catherine Sandstone of the Bowen Basin of Queensland (Palmieri, 1994); the Rutherford Formation of the New South Wales Sydney Basin (Scheibnerová, 1982). In Western Australia the species has also been recorded from the Callytharra Formation of the Carnarvon Basin, and the Noonkanbah Formation of the Canning Basin (Crespin, 1958). Mertmann (2000) recorded this species from Kungurian to Changhsingian (Late Cisuralian to Lopingian) marine carbonates from the Salt Range and Trans Indus Ranges in Pakistan.

Calcitornella stephensi (Howchin), 1894

1882 *Cornuspira* sp., Jones, p. 6.

1894 *Nubecularia lucifuga* Defrance var. *stephensi*, Howchin, p. 345, pl. 1, figs 10a-11a.

1905 *Nubecularia stephensi* Howchin; Chapman and Howchin, p. 5, pl. 1, figs 1, 2; pl. 3, figs 3, 4; pl. 5, figs 1-4.

1934 *Calcitornella stephensi* (Howchin); Chapman et al., p. 187.

1945b *Calcitornella stephensi* (Howchin); Crespin, p. 24, pl. 3, fig. 3.

1958 *Calcitornella stephensi* (Howchin); Crespin, p. 84-85, pl. 17, figs 4-8; pl. 32, figs 1, 2, 4, 9.

1968 *Calcitornella stephensi* (Howchin); Belford, p. 4, 5, pl. 2, figs 19, 20.

1982 *Nubecularia stephensi* Howchin; Scheibnerová, p. 68-69, pl. 32, figs 1-4; pl. 33, figs 1-3; pl. 34, fig. 1.

1985 *Calcitornella stephensi* (Howchin); Palmieri in Foster et al., p. 81, pl. 5, figs 1-4.

1993 *Calcitornella stephensi* (Howchin); Bondareva and Foster, p. 5.

1994 *Calcitornella stephensi* (Howchin); Palmieri, p. 29-30.

Holotype: Repository not given.

Type Locality: Outcrop on the right bank of the Piper River, near Lilydale, northeastern district of Tasmania (Darlington Limestone).

Figured Specimens: Plate 20, figures 4-7.

Material studied: 49 tests.

Diagnosis: "Initial chamber globular. Subsequent chambers, elongated and slightly inflated. Chambers arranged, either on a spiralline plan, in rectilinear order, or in irregular acervilline masses. Walls of test, thin, uniform in thickness, and sharply defined in outline. Septal divisions marked on exterior surface by sunken lines" (Howchin, 1894).

Remarks: This species is common within the Fossil Cliff Member, and is found both encrusting brachiopod shells and other macrofaunal elements and as a free test. Test wall is calcareous and imperforate, and is differentiated from *C. heathi* Cushman and Waters, 1928, in possessing a tight, helical coiling pattern, almost at right angles to the brachiopod spine it encrusts.

Distribution: *C. stephensi* (Howchin), 1894, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the calcarenite of the member. This species is uncommon, and has been recorded from all the carbonate beds of the member, although it becomes common in the upper calcarenite beds. It has also been recorded from Camboon Volcanics, Tiverton, Cattle Creek, Buffel, and Oxtrack Formations of the Bowen Basin of Queensland (Palmieri, 1994); the Darlington Limestone and Golden Valley Group of Tasmania (Crespin, 1958); and the Pokolbin Limestone and Dalwood Group of the New South Wales Sydney Basin (Scheibnerová, 1982). In Western Australia the species has also been recorded from the Callytharra Formation of the Carnarvon Basin, and the Nura Nura Member of the Poole Sandstone, Noonkanbah Formation, and Port Keats Group of the Canning Basin (Crespin, 1958). Bondareva and Foster (1993) noted that this species has also been recorded from the Cisuralian (Asselian to Kungurian) deposits of Novaya Zemlya and Spitsbergen of Russia.

Genus *TREPEILOPSIS* CUSHMAN and WATERS, 1928

Type Species: ***Trepeilopsis grandis*** (Cushman and Waters), 1928.

Diagnosis: See Loeblich and Tappan (1987).

Trepeilopsis australiensis Crespin, 1958

1958 *Trepeilopsis australiensis* Crespin, p. 86-88, pl. 18, figs 1-4; pl. 22, figs 3, 5-8.
1968 *Trepeilopsis australiensis* Crespin; Belford, p. 4-5, pl. 3, figs 1-3.
1982 *Trepeilopsis australiensis* Crespin; Scheibnerová, p. 59, pl. 34, fig. 5.
1985 *Trepeilopsis australiensis* Crespin; Palmieri in Foster et al., p. 81, pl. 5, figs 8-10.
1993 *Trepeilopsis australiensis* Crespin; Bondareva and Foster, p. 5.
1994 *Trepeilopsis australiensis* Crespin; Palmieri, p. 30-31, pl. 13, figs 10, 11.
2000 *Trepeilopsis australiensis* Crespin; Kalia et al., p. 219, figs 5D-E.

Holotype: Commonwealth Palaeontological Collection, Australian Geological Survey, Canberra, Australia, #2606.

Type Locality: Callytharra Springs, 22-41 feet above base of the Callytharra Formation, Carnarvon Basin, Western Australia.

Figured Specimens: Plate 20, figures 8-14.

Material studied: 80 tests.

Diagnosis: "Undivided tubular chamber which coils itself in a close helical spiral around a productid spine" (Crespin, 1958).

Remarks: This species is extremely common within the Fossil Cliff Member and is found encrusting productiid brachiopod spines. The test wall is calcareous and imperforate, the proloculus is small, and the test coils in a tight spiral around the spines.

Distribution: *T. australiensis* Crespin, 1958, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the calcarenite of the member. This species is common, and has been recorded from all the carbonate beds of the member, although it becomes very common in the upper calcarenite beds. It has also been recorded from the Camboon Volcanics, Catherine Sandstone, Cattle Creek (Riverstone Sandstone and Sirius Mudstone Members), Tiverton, Buffel, Barfield, Flat Top, Peawaddy and Oxtrack Formations of the Bowen Basin of Queensland (Palmieri, 1994); the Gray Limestone of Tasmania (Crespin, 1958); and the Dalwood Group and Mulbring Siltstone of the New South Wales Sydney Basin (Scheibnerová, 1982). In Western Australia the species has also been recorded from the Callytharra Formation of the Carnarvon Basin, and the Nura Nura Member of the Poole Sandstone in the Canning Basin (Crespin, 1958). Bondareva and Foster (1993) noted that this species has also been recorded from the Asselian to Kazanian deposits of Novaya Zemlaya in Russia. Kalia et al. (2000) recorded this species from the eastern Himalayas in India.

Family HEMIGORDIOPSIDAE NIKITINA, 1969

Subfamily HEMIGORDIOPSINAE NIKITINA, 1969

Genus *HEMIGORDIUS* SCHUBERT, 1908

Type Species: ***Hemigordius schlumbergeri*** (Howchin), 1895.

Diagnosis: See Loeblich and Tappan (1987).

Hemigordius schlumbergeri (Howchin), 1895

1895 *Cornuspira schlumbergi* Howchin, p. 195, pl. 10, figs 1-3.

1908 *Hemigordius schlumbergi* (Howchin); Schubert, p. 381

1928a *Hemigordius schlumbergi* (Howchin); Cushman and Waters, p. 16, pl. 53, figs 5-7.

1950 *Hemigordius schlumbergi* (Howchin); Cushman, p. 192, pl. 15, fig. 7; pl. 16, figs 6, 7.
1958 *Hemigordius schlumbergi* (Howchin); Crespin, p. 81, pl. 16, figs 7-9; pl. 21, figs 4, 5.
1964 *Hemigordius schlumbergeri* (Howchin); Loeblich and Tappan, p. C440, figs 333(1a-1c).
1982 *Hemigordius schlumbergeri* (Howchin); Scheibnerová, p. 67-68, pl. 11, fig. 3; pl. 13, fig. 5.
1985 *Hemigordius schlumbergeri* (Howchin); Palmieri in Foster et al., p. 81-82, pl. 6, figs 1-9.
1997 *Hemigordius schlumbergeri* (Howchin); Groves and Wahlman, pl. 7, figs 27-31.
2000 *Hemigordius schlumbergeri* (Howchin); Groves, pl. 3, figs 21-28.

Holotype: Repository not given.

Type Locality: Fossil Cliff Member of the Holmwood Shale, south branch of the Irwin River.

Figured Specimens: Plate 20, figures 15-31.

Material studied: over 300 tests.

Diagnosis: "Test discoidal, flat or biconvex, convoluted; consisting of a non-septate tube, slightly increasing in diameter, but with varying dimensions. Initial end of chamber spherical, and of greater diameter than tube. Convolutions, about five in number, more or less asymmetrical, particularly in the earlier growth. Test-walls investing, each successive whorl enclosing all the preceding by alar extensions over the lateral surface of shell. Periphery rounded and somewhat irregular in outline. Septation obscured exteriorly by lamination of shell-walls, except near the orifice, where a sutural depression is visible for about half the length of final convolution. Transverse section of tube round or with slight vertical compression. Aperture formed by open end of tube, more or less constricted at vent" (Howchin, 1895).

Remarks: This species is extremely common within the Fossil Cliff Member and is found as a free test. The test wall is calcareous and imperforate, and the test is discoidal. This species is the genotype for the genus, and one of the first foraminifera recorded from the Fossil Cliff Member. The species name was changed from *H. schlumbergi* to *H. schlumbergeri* by Loeblich and Tappan (1964) to reflect the correct latinization of the root name.

Distribution: *H. schlumbergeri* (Howchin), 1895, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the calcarenite of the member. This species is common, and has been recorded from all the carbonate beds of the member, although it becomes very common in the upper calcarenite beds. It has also been recorded from the Mostyndale Mudstone Member of the Cattle Creek Formation of the Bowen Basin of Queensland (Palmieri, 1994); the Golden Valley Group of

Tasmania (Crespin, 1958); and the Dalwood Group, Erins Vale Formation, and Mulbring Siltstone of the New South Wales Sydney Basin (Scheibnerová, 1982). In Western Australia the species has also been recorded from the Nangetty Formation of the Perth Basin, the Callytharra Formation of the Carnarvon Basin, and the Nura Nura Member of the Poole Sandstone in the Canning Basin (Crespin, 1958). Groves and Wahlman (1997) recorded this species from an Upper Carboniferous to Cisuralian sequence in the Barents Sea, near Norway, and Groves (2000) recorded the species from the Late Carboniferous to Cisuralian Chase, Council Grove, and Admire Groups in the mid-continent of USA.

Hemigordius voltus Palmieri, 1985

1985 *Hemigordius voltus* Palmieri, in Foster et al., p. 82, pl. 6, figs 10-14.

Holotype: Western Australian Museum, WAM 83-2785.

Type Locality: Fossil Cliff Member of the Holmwood Shale, south branch of the Irwin River.

Figured Specimens: Plate 20, figures 32-37; Plate 21, figures 1-4.

Material studied: 92 tests.

Diagnosis: "Test oblong, convolute, consisting of proloculus followed by undivided chamber coiled in milioline (quinqueloculine) manner in the first five whorls, then planispirally; tubular chamber subdivided into rudimentary septa in last whorl; transverse section of tube round, tending to be compressed in last whorl; alar extension of tube calcitic wall covering preceding whorls; aperture at open end of the tube. The test wall consists of a calcareous imperforate, porcellanous layer on a thin, dark pseudochitinous lining" (Palmieri in Foster et al., 1985).

Remarks: This species differs from *H. schlumbergeri* (Howchin), 1895, in its more flattened test shape, and quinqueloculine coiling pattern in the initial whorls.

Distribution: *H. voltus* Palmieri, 1985, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the calcarenite of the member. This species is common, and has been recorded from all the carbonate beds of the member, although it is uncommon within the lower calcarenite beds and increases in frequency up the sequence. It has not been recorded from any other Permian strata within Australia.

Suborder LAGENINA Delage and Herouard, 1896

Superfamily ROBULOIDOIDEA Reiss, 1963

Family SYZRANIIDAE Vachard in Vachard and Montenat, 1981

Genus *SYZRANIA* Reitlinger, 1950

Type Species: ***Syzrania bella*** Reitlinger, 1950.

Diagnosis: See Groves (2000).

Syzrania condoni **(**Crespin), 1958

1958 *Earlandia condoni* Crespin, p. 58-59, 207, pl. 23, figs 6-8.

1994 *Earlandia condoni* Crespin; Palmieri, p. 27, pl. 14, fig. 13.

Holotype: Commonwealth Palaeontological Collection, Australian Geological Survey, Canberra, Australia, #2433.

Type Locality: Giralia No. 1 Bore at 3,115-3,120 feet (core 66), in equivalent of Callytharra Formation, Carnarvon Basin, Western Australia.

Figured Specimens: Plate 21, figures 5-7.

Material studied: 2 tests.

Diagnosis: "Test elongate, slender, straight or gently curved, calcareous, imperforate, consisting of a large globular proloculus, followed by a long tubular chamber and with a rounded aperture at end of tube" (Crespin, 1958).

Remarks: This tubular species has been moved from the fusuline genus *Earlandia* Plummer, 1930, into the lageniid genus *Syzrania* Reitlinger based on the presence of both an inner microgranular test wall, and an outer radial-fibrous, and a lack of constrictions or wall thickenings within the tubular second chamber. The species is very simple, consisting of a proloculus and a long, tubular second chamber. Palmieri (1994) considered this species indicative of cold and cold temperate waters of a shallow marginal sea.

Distribution: *Syzrania condoni* (Crespin), 1958, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the calcarenite of the member. This species is extremely rare, and only two specimens have been recovered from the member, from the middle calcarenite unit. It has also been recorded from the Mostyndale Mudstone Member, Riverstone Sandstone Member, and lower part of the Moorooloo Mudstone Member of the Cattle Creek Formation of the Bowen Basin of

Queensland (Palmieri, 1994); the Dalwood Group, and Rutherford Formation of the New South Wales Sydney Basin (Scheibnerová, 1982); and the Gray Limestone of Tasmania (Crespin, 1958). In Western Australia the species has also been recorded from the Callytharra Formation of the Carnarvon Basin (Crespin, 1958).

Superfamily GEINITZINOIDEA BOZORGNIA, 1973

Family GEINITZINIDAE BOZORGNIA, 1973

Genus *HOWCHINELLA* PALMIERI, 1985

Type Species: ***Howchinella woodwardi*** (Howchin), 1895.

Diagnosis: See Loeblich and Tappan (1987).

Howchinella woodwardi (Howchin), 1895

1895 *Frondicularia woodwardi* Howchin, p. 197-198, pl. 10, figs 4-6.
1905 *Frondicularia woodwardi* Howchin; Chapman and Howchin, p.16, pl. 3, fig. 2.
1945b *Frondicularia woodwardi* Howchin; Crespin, p. 28, pl. 3, fig. 12.
1947 *Frondicularia woodwardi* Howchin; Crespin, p. 21, pl. 1, fig. 12
1958 *Frondicularia woodwardi* Howchin; Crespin, p. 115-116, pl. 29, figs 10-12.
1968 *Frondicularia woodwardi* Howchin; Belford, pl. 3, fig. 16.
1982 *Frondicularia woodwardi* Howchin; Scheibnerová, p. 71, pl. 35, figs 1-2; pl. 37, figs 1-5; pl. 38, figs 5, 8; pl. 39, figs 2, 3.
1985 *Howchinella woodwardi* (Howchin); Palmieri in Foster et al., p. 84, pl. 9, figs 5-20.
1994 *Howchinella woodwardi* (Howchin); Palmieri, p. 36-37, pl. 14, figs 1, 2, 5, 17-19; pl. 15 figs 5-9; pl. 17, fig. 9; pl. 19, figs 4-6; pl. 21, figs 7, 8; pl. 27, figs 1, 2, 8.
1994 *Frondicularia prima* (Gerke); Palmieri et al., p. 363.

Holotype: Repository not given.

Type Locality: Fossil Cliff Member of the Holmwood Shale, south branch of the Irwin River.

Figured Specimens: Plate 21, figures 8-34; Plate 22, figures 1-10.

Material studied: over 300 tests.

Diagnosis: “Test elongate, tapering, compressed and subject to considerable variation in external form. Oral end broad, rounded and regularly curved. Aboral extremity obtusely pointed. Peripheral margins rounded. Segments from seven to ten in number, gradually increasing in size, acutely arched. Final chamber relatively large, inflated and lobulated. Sutures flush, marked by clear shell substance. Length of shell twice or three times breadth" (Howchin, 1895).

Remarks: This species shows a large degree of variation in the shape of its test. The species is considered to be a zonal index marker for the Cisuralian throughout Australia (Crespin, 1958; Palmieri, 1994). This species is found in close association with *Lunucammina triangularis* (Chapman and Howchin), 1905, and transitional forms between the two forms are present. Bondareva and Foster (1993) consider this species to be very similar to *Frondicularia prima* Gerke from the Nordvik Basin of Russia. Palmieri et al. (1994) considered *H. woodwardi* (Howchin) to be a probable synonym of *F. prima* Gerke; however, Howchin described *H. woodwardi* (Howchin) in 1895, much earlier than Gerke described *F. prima* Gerke in 1962, and so *H. woodwardi* (Howchin) is the valid name if these species are shown to be the same.

Distribution: *H. woodwardi* (Howchin), 1895, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the calcarenite of the member. This species is common, and has been recorded from all the carbonate beds of the member, although it is very common in the lower and middle calcarenite beds. It has also been recorded from the Catherine Sandstone, Cattle Creek, Ingelara, Peawaddy, Blenheim, Tiverton, Buffel, Oxtrack, Barfield and Flat Top Formations of the Bowen Basin of Queensland (Palmieri, 1994); the Golden Valley Group and Gray Limestone of Tasmania (Crespin, 1958); and the Dalwood Group, Branxton Formation, and Maitland Group of the Sydney Basin in New South Wales (Scheibnerová, 1982). In Western Australia the species has also been recorded from the Callytharra Formation and Byro Group of the Carnarvon Basin, and the Nura Nura Member of the Poole Sandstone, Noonkanbah Formation, and Liveringa Group in the Canning Basin (Crespin, 1958). Palmieri et al. (1994) stated that this species is also present within the Nordvik Basin, Arctic Russia.

Genus *LUNUCAMMINA* SPANDEL, 1898

Type Species: ***Lunucammina permiana*** (Spandel), 1898.

Diagnosis: See Loeblich and Tappan (1987).

Lunucammina triangularis (Chapman and Howchin), 1905

1905 *Geinitzina triangularis* Chapman and Howchin, p. 16, pl. 2, figs 9a, b, 10.
1915 *Geinitzina chapmani* Schubert, p. 58, pl. 39(1), fig. 4.
1945b *Geinitzina triangularis* Chapman and Howchin; Crespin, p. 29, pl. 3, figs 14, 15.
1947 *Geinitzina triangularis* Chapman and Howchin; Crespin, p. 21, pl. 1, figs 14, 15.
1958 *Geinitzina triangularis* Chapman and Howchin; Crespin, p. 118-119, pl. 30, figs 8-11; pl. 31, fig. 8.
1968 *Geinitzina triangularis* Chapman and Howchin; Belford, p. 3, 5, pl. 3, figs 17, 18.
1982 *Geinitzina triangularis* Chapman and Howchin; Scheibnerová, p. 72, pl. 38, fig. 7.
1985 *Lunucammina triangularis* (Chapman and Howchin); Palmieri in Foster et al., p. 83, pl. 8, figs 1-17.
1994 *Lunucammina triangularis* (Chapman and Howchin); Palmieri, p. 38, pl. 12, fig. 1; pl. 16 figs 1-21.
2000. *Lunucammina triangularis* (Chapman and Howchin); Kalia et al., p.215, fig. 3K.

Holotype: Repository not given.

Type Locality: Branxton Formation, Sydney Basin, in the parish of Mulbring, Northumberland, New South Wales.

Figured Specimens: Plate 22, figures 11-27.

Material studied: over 300 tests.

Diagnosis: “Test subtriangular or triangular, compressed, decidedly hollowed along the median longitudinal axis. Primordial chamber globular, the remainder crescentic or feebly chevroned one within the other. More rarely the shells exhibit a flabelline commencement” (Chapman and Howchin, 1905).

Remarks: *L. triangularis* (Chapman and Howchin), 1905, is morphologically quite variable. This species is found in close association with *H. woodwardi* (Howchin), 1895, and transitional forms between the two forms are present. This species is very similar to *Frondicularia? pseudotriangularis* Gerke, from the Nordvik Basin of Russia (Bondareva and Foster, 1993).

Distribution: *L. triangularis* (Chapman and Howchin), 1905, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the calcarenite of the member. This species is common and has been recorded from all the carbonate beds of the member, although it is very common in the lower and middle calcarenite beds. It has also been recorded from the Camboon Volcanics, Cattle Creek, Ingelara, Peawaddy, Blenheim, Tiverton, Buffel, Oxtrack, Barfield and Flat Top Formations of the Bowen Basin of Queensland (Palmieri, 1994); the Darlington Limestone of

Tasmania (Crespin, 1958); and the Dalwood Group, Branxton Formation, and Mulbring Siltstone of the Sydney Basin in New South Wales (Scheibnerová, 1982). In Western Australia the species has also been recorded from the Callytharra Formation of the Carnarvon Basin, and the Noonkanbah Formation in the Canning Basin (Crespin, 1958). Kalia et al. (2000) have recorded this species from the eastern Himalayas in India.

Superfamily NODOSARIOIDEA EHRENBERG, 1838

Family PROTONODOSARIIDAE MAMET AND PINARD, 1992

Genus *PROTONODOSARIA* GERKE, 1959

Type Species: ***Protonodosaria proceraformis*** (Gerke), 1952.

Diagnosis: See Loeblich and Tappan (1987).

Protonodosaria irwinensis (Howchin), 1895

1895 *Nodosaria irwinensis* Howchin, p. 196-197, pl. 10, figs 7-8.
1958 *Nodosaria irwinensis* Howchin; Crespin, p. 103, pl. 25, figs 4-8; pl. 31, figs 8, 11.
1968 *Nodosaria irwinensis* Howchin; Belford, p. 5, pl. 3, fig. 10.
1985 *Protonodosaria irwinensis* (Howchin); Palmieri in Foster et al., p. 82, pl. 7, figs 11-20.
2000 *Protonodosaria irwinensis* (Howchin); Kalia et al., p. 222, fig. 5J.

Holotype: Repository not given.

Type Locality: Fossil Cliff Member of the Holmwood Shale, south branch of the Irwin River.

Figured Specimens: Plate 22, figures 28-30; Plate 23, figures 1-13.

Material studied: over 300 tests.

Diagnosis: “Test elongate, straight, or very slightly arcuate tapering. Segments about eight in number. The shell either slightly inflated near centre or gradually increasing in size. Chambers of greater width than length. Sutural lines straight, thick and slightly depressed. Surface of test ornamented with numerous, closely set, longitudinal and continuous costae. Length 1.9 mm” (Howchin, 1895).

Remarks: *P. irwinensis* (Howchin), 1895, is a characteristic species of the Fossil Cliff Member. It is distinguished by its small size, with seven or eight chambers which have a greater width than height and distinct striated surface ornamentation. Crespin (1958) noted there is wide variation in this species between the localities from which it is recorded, and that the species from the Fossil Cliff Member may represent a new species. For this study, the population of *P. irwinensis* (Howchin), 1895, from the Fossil Cliff Member are considered to fit within the original description of the species given by Howchin (1895).

Distribution: *P. irwinensis* (Howchin), 1895, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the calcarenite of the member. This species is common and has been recorded from all the carbonate beds of the member although it is very common in the lower and middle calcarenite beds. It has also been recorded from the Cattle Creek Formation of the Bowen Basin of Queensland (Palmieri, 1994); the Gray and Berriedale Limestones of Tasmania (Crespin, 1958); and the Dalwood Group and Polkobin Limestone of the Sydney Basin in New South Wales (Scheibnerová, 1982). In Western Australia the species has also been recorded from the Callytharra Formation of the Carnarvon Basin (Crespin, 1958). Kalia et al. (2000) have recorded this species from the eastern Himalayas in India.

Protonodosaria tereta (Crespin), 1958

1958 *Nodosaria tereta* Crespin, p. 99-100, pl. 26, figs 1-4; pl. 31, figs 9, 10, 12.
1982 *Nodosaria tereta* Crespin; Scheibnerová, p. 69, pl. 33, fig. 4.
1985 *Protonodosaria tereta* (Crespin); Palmieri in Foster et al., p. 82-83, pl. 7, figs 1-10.
1994 *Protonodosaria tereta* (Crespin); Palmieri, p. 47, pl. 14, figs 10, 22, 26; pl. 26, fig. 7a, b; pl. 30, fig. 4.
2000 *Protonodosaria tereta* (Crespin); Kalia et al., p. 222, fig. 5K.

Holotype: Commonwealth Palaeontological Collection, Australian Geological Survey, Canberra, Australia, #2542.

Type Locality: Callytharra Springs, 0-12 feet above the base of the Callytharra Formation, Carnarvon Basin, Western Australia.

Figured Specimens: Plate 23, figures 14-23.

Material studied: 46 tests.

Diagnosis: “Seven to twelve chambers, which gradually increase in size; straight sides, aperture non-radiate” (Crespin, 1958)

Remarks: *P. tereta* (Crespin), 1958, is similar to *P. irwinensis* (Howchin), 1895, however the ornamentation is smooth, and *P. tereta* (Crespin), 1958, has a greater number of chambers in the mature test.

Distribution: *P. tereta* (Crespin), 1958, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the calcarenite of the member. This species is uncommon, but has been recorded from all the carbonate beds of the member, although it is more frequent in the lower and middle calcarenite beds. It has also been recorded in the Bowen Basin of Queensland from the Mostyndale Mudstone Member of the Cattle Creek Formation, Buffel Formation, and Tiverton Formation (Palmieri, 1994); the Gray Limestone of Tasmania (Crespin, 1958); and the Dalwood and Maitland Groups of the Sydney Basin in New South Wales (Scheibnerová, 1982). In Western Australia the species has also been recorded from the Callytharra Formation of the Carnarvon Basin; and the Grant Group, Nura Nura Member of the Poole Sandstone, and Noonkanbah Formation of the Canning Basin (Crespin, 1958). Kalia et al. (2000) have recorded this species from the eastern Himalayas in India.

Genus *VERVILLEINA* GROVES in GROVES AND BOARDMAN, 1999

Type Species: ***Vervilleina bradyi*** (Spandel), 1901.

Diagnosis: See Groves (2000).

Vervilleina? grayi (Crespin), 1945

1945b *Dentalina grayi* Crespin, p. 27 pl. 3, fig. 8.

1958 *Dentalina grayi* Crespin; Crespin, p. 97, pl. 24, figs 4, 5.

1994 *Dentalina grayi* Crespin; Palmieri, p. 49, pl. 15, figs 11-13; pl. 20, fig. 23; pl. 25, figs 7a, b, 9a, b.

2000 *Vervilleina?* cf *V? grayi* (Crespin); Groves, p. 312, pl. 7, figs 21-23.

Holotype: Commonwealth Palaeontological Collection, Australian Geological Survey, Canberra, Australia, #278.

Type Locality: Lower part of the exposure on Argus's Selection, Springsure, Sirius Mudstone Member of the Cattle Creek Formation, Bowen Basin, Queensland.

Figured Specimens: Plate 23, figures 24, 25.

Material studied: 13 tests.

Diagnosis: "Test small, elongate, slender, gently curved and tapering, with greatest width in apertural chamber. Chambers even, slightly inflated and gradually increasing in size towards the apertural end. Sutures distinct, straight, depressed. Aperture terminal, radiate" (Crespin, 1958).

Remarks: *V?. grayi* (Crespin), 1945, lacks the surface ornamentation that is typical of the genus. This species is previously unrecorded from the Fossil Cliff Member. Bondareva and Foster (1993) noted that this species is very similar to *Dentalina kalinkoi* Gerke, from the Kazanian of the Nordvik Basin in Russia. Groves (2000) identified a number of specimens comparable to *V?. grayi* (Crespin) from the midwestern North America and tentatively assigned it to *Vervilleina* Groves, noting that *Dentalina* Risso, 1826, where the species was previously assigned, ranged only from the Holocene to Cretaceous.

Distribution: *V?. grayi* Crespin, 1945, is found in the Sterlitamakian (Sakmarian, Cisuralian) Fossil Cliff Member of the Holmwood Shale, northern Perth Basin within the calcarenite of the member. This species is rare, and has been recorded from the lower and middle calcarenite beds of the member. It has also been recorded in the Bowen Basin of Queensland from the Sirius Mudstone Member of the Cattle Creek Formation, Ingelara Formation, Catherine Sandstone, and Peawaddy Formation (Palmieri, 1994); and the Maitland Group of the Sydney Basin in New South Wales (Scheibnerová, 1982). In Western Australia the species has also been recorded from the Byro Group of the Carnarvon Basin; and the Noonkanbah Formation of the Canning Basin (Crespin, 1958).

Chapter 5: Lithostratigraphy of the Fossil Cliff Member

The Fossil Cliff Member consists of alternating beds of silty shale and muddy calcarenite that can be divided into three parasequences forming a progradational parasequence set and that grade into fine- to medium-grained quartzose sandstone at the top. At the type locality, the member is exposed as a steep bank between 2 and 4 m high along the northern side of the Irwin River, dips to the west from 5° to 12°, conformably overlies the Holmwood Shale, and is disconformably overlain by Quaternary alluvium. Each parasequence consists of a basal, black, finely laminated micaceous shale overlain by muddy calcarenite beds, the uppermost bedding surface of which marks the parasequence boundary (Figure 70). Above the third parasequence is a unit of siltstone that grades upwards into a fine- to medium-grained sandstone. Within the Fossil Cliff Member, a diverse fossil assemblage is present, dominated by bryozoa and productid and spiriferid brachiopods, especially in the second and third parasequences. The thickness of the shale beds at the base of each parasequence decreases up the parasequence set. The coding scheme used for the facies outlined below follow that used by Le Blanc Smith and Mory (1995) and is summarised in Table 1.

Terrigenous facies

Al	Laminated shale and siltstone
(S/A)b	Bioturbated muddy fine-grained sandstone
Sm	Massive, coarse-grained sandstone

Calcareous facies

(L/A)bs	Bioturbated, shelly, muddy calcarenite
(A/L)bs	Bioturbated, shelly, calcareous siltstone
Lbs	Bioturbated, shelly, indurated calcarenite to wackestone

Table 1. Facies coding scheme used in this study.

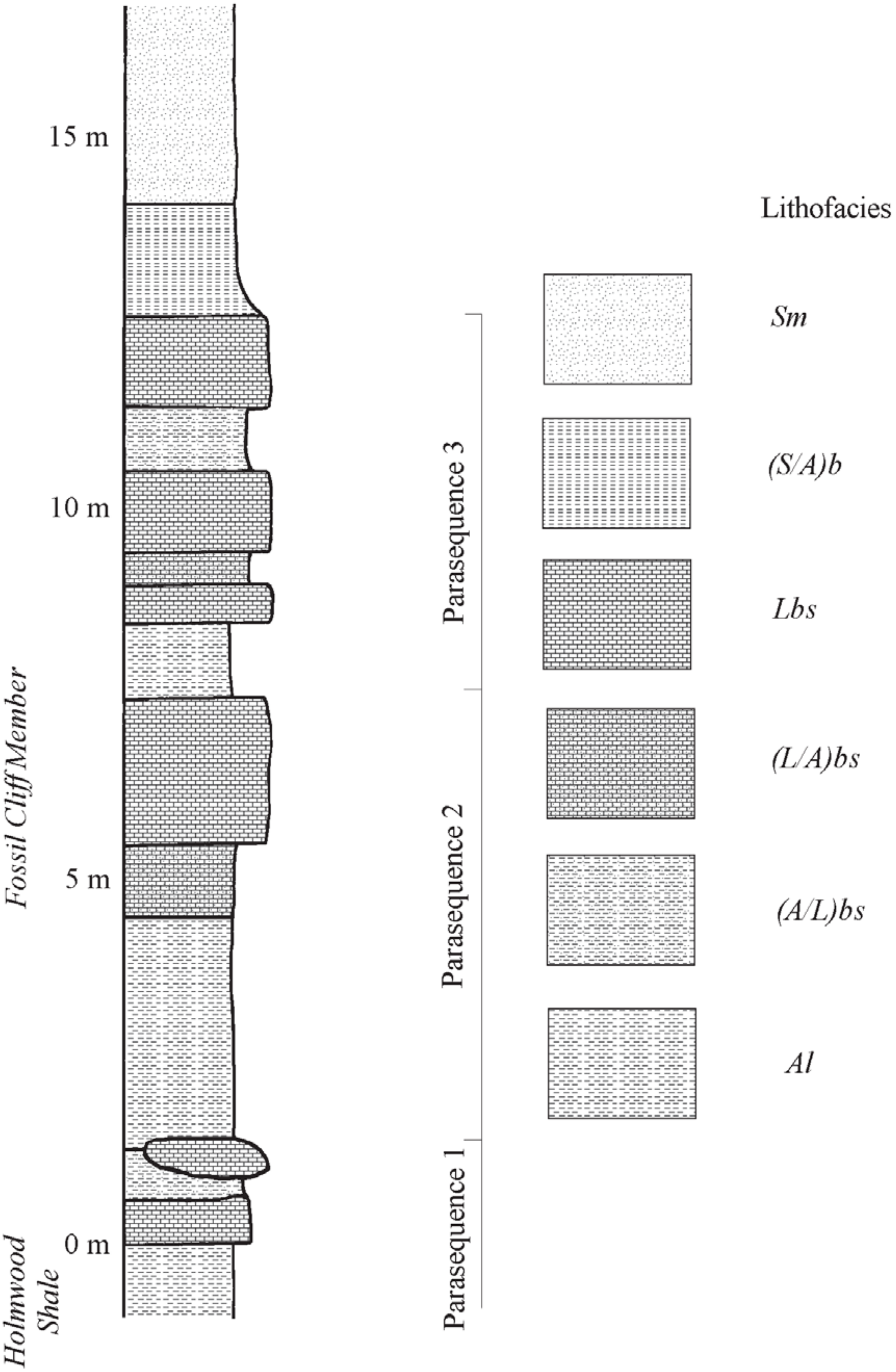


Figure 70. Simplified lithostratigraphic log of the Fossil Cliff Member.

Lithofacies

The lithofacies of the Fossil Cliff Member can be divided into two broad associations, the terrigenous-dominated lithofacies and the calcareous-dominated lithofacies. The terrigenous lithofacies consists of the shale to muddy siltstone units and the quartzose sandstone units, while the calcareous lithofacies comprises the calcarenite, calcareous siltstones, and calcsiltite units.

Terrigenous lithofacies

The shale lithofacies (*Al*) at the base of each parasequence consists of a very fine-grained, dark black to grey micaceous mud and silt that displays thin, planar laminae up to 5 cm apart, but generally in the region of 3 to 5 mm apart, with bed thicknesses ranging from 20 cm to 4 m. Numerous veinlets of late diagenetic gypsum are parallel to subparallel with the shale laminations, and jarosite staining of fracture surfaces in the shale, formed from the alteration of pyrite during diagenesis in a hydrated environment, is visible in most shale beds.

The sandstone lithofacies (*Sm* and *(S/A)b*) above the third parasequence ranges in composition from quartzwacke to subarkose and in parts has an arenitic composition. This facies is only found overlying the third parasequence, and is presumably conformably overlain by the High Cliff Sandstone. The grain size of the sandstones increases upwards, from muddy fine-grained sandstone (*(S/A)b*) to well-sorted, coarse-grained quartz sandstone (*Sm*) at the top of the exposure. The bedding surface is planar, although there are no distinct sedimentary structures visible within these units, and beds are up to 80 cm thick. Fossil assemblages from this lithofacies include a fauna of fragmented bryozoans and agglutinated foraminifera.

The shale lithofacies contains a sparse fossil assemblage consisting of small crinoid ossicles, fenestrate bryozoan moulds, the thin-shelled chonetid brachiopod *Neochonetes (Sommeria) pratti*, and agglutinated foraminifera, dominated by species of *Ammodiscus* and *Hyperammina*. The delicate macrofossils are usually preserved in the shale as moulds along bedding planes, although some poorly preserved original carbonate material can be found. The foraminiferal fauna in the terrigenous lithofacies is diverse, with in excess of eighteen species present, predominantly agglutinated forms, although rare specimens of the nodosariid foraminifera *Protonodosaria irwinensis* and *Howchinella woodwardi* are present in some of the shale and siltstone units.

Calcareous lithofacies

Within the calcareous beds of the Fossil Cliff Member four facies are evident. The first is a friable buff-coloured muddy calcarenite (*(L/A)bs*) containing an assortment of fragmented and intact bioclasts of varying sizes and shell strengths. The muddy calcarenite beds are generally 10 to 60 cm thick.

The second calcareous lithofacies is a brown, poorly-sorted friable packstone with 20 to 40% matrix (*(A/L)bs*). Bioclasts in this facies appear to have undergone very little transportation, as such fragile components as bryozoans, crinoid stems, and thin-shelled brachiopods are generally intact. Beds of this facies are 10 to 30 cm thick and have planar bedding surfaces.

The third calcareous lithofacies is an indurated grey wackestone (*Lbs*) containing bioclasts similar in style and preservation to those of the second facies, with between 40 and 65% matrix. This facies crops out as distinctly lenticular beds, which extend laterally up to 20 m and are 20 to 50 cm thick.

The fossil assemblages of the calcareous beds are extremely diverse, with over 70 species present (Playford et al., 1976), most being brachiopod species, notably productids and spiriferiids. Other groups present include solitary rugose corals, crinoids, blastoids, bryozoans, bivalves, gastropods, ammonoids, nautiloids, nodosariid and milioliid foraminifers, ostracodes, and rare trilobites. The abundance of the various species and groups in the carbonate beds differs between the parasequences. Significant variations between the calcareous beds include a decrease in abundance of spiriferiid brachiopods upwards through the member, which coincides with a decrease in the abundance of rugose corals and an increase in the abundance of species of productid brachiopods upwards through the sequence.

Parasequences

The Fossil Cliff Member can be divided into three cyclic sequences, each with a basal shale bed overlain by a set of calcareous beds, that are in turn overlain by another shale bed that marks the base of the next cycle. The basal shale of each parasequence becomes progressively thinner, and the calcareous units become correspondingly thicker until, in the last parasequence, the total thickness of the calcareous units is almost three times that of the basal shale unit. A detailed stratigraphic log of the Fossil Cliff Member is shown in Figure 71.

Parasequence 1

The base of the first parasequence starts within the shale and siltstone of the Holmwood Shale. This basal shale (*Al*) is extremely fine-grained, laminated, and has a high white-mica (probably muscovite) content, indicating a felsic source for this component of the sediment. Diagenetic staining of the shale by jarosite indicates that pyrite may have been part of the prediagenetic mineralogy of the shale. Within this shale and siltstone, infrequent moulds of fenestrate bryozoans and rare moulds of thin-shelled productiid brachiopods may be found along lamination planes. Agglutinated foraminifera species of the genera *Ammodiscus*, *Glomospira*, and *Hyperammina* are the dominant microfossil element within this shale facies, and rare palaeoniscoid teeth and scales have also been recovered from the top part of this facies just before it grades into a muddy calcarenite. The topmost 10 cm of this shale and siltstone unit is massive and contains an abundant fauna of fenestrate bryozoans and productiid brachiopods.

Conformably overlying this shale is a friable buff-coloured muddy calcarenite (*(L/A)bs*) that grades from a grey shale to muddy calcarenite over 10 cm of thickness. This material is very fine-grained and increases in carbonate content upwards through the bed. It marks the base of the Fossil Cliff Member. The bed is massive, possibly due to intense bioturbation, and contains a well-preserved macrofossil fauna that increases in abundance and diversity upward, and includes species of brachiopods, bryozoans (fenestrate and gymnolaemate), crinoids, bivalves, gastropods, and solitary rugose corals. The microfossil assemblage is similarly diverse and includes an abundant fauna of calcareous foraminifera and ostracodes. This muddy calcarenite bed then grades upwards into a series of calcareous siltstones to sandy calcarenites, with lenses of indurated grey calcsiltite and calcarenite (*Lbs*) at the top of the parasequence. Within this are a number of thin, reddish, sandy calcarenite beds (*Lbs*) that represent slightly ferruginised limestones, and these beds are more indurated and resistant to weathering than most of the friable, buff-coloured muddy calcarenite beds. With the exception of some poorly preserved trough cross-bedding up to 10 cm thick in the middle of the calcareous sequence, all the calcareous beds are massive, and the entire muddy calcarenite component of the shale-calcarenite couplet is 1.5 m thick. The indurated lensoidal calcsiltites and calcarenites in the uppermost 0.6 m contain a very diverse, and undeformed fauna, including a number of species of the bivalve *Deltopecten* and *Bellerophon* gastropods that are not found in the friable muddy calcarenites. These limestone lenses are up to 2 m in length and are scattered along the strike of the bed and are hosted in a silty sand matrix that is calcareous at the base and becomes more terrigenously dominated upwards until it conformably and gradationally grades into the laminated grey-black shale of parasequence 2.

Parasequence 2

The base of the second parasequence is marked by a conformable interfingering and undulose contact with the underlying calcsiltite lenses and calcareous siltstone. The base of this parasequence is a grey to black shale (*Al*) that is generally finely laminated and contains veins of gypsum running parallel to subparallel with the laminations and jarosite staining. Towards the top, this shale unit takes on a yellowish tint as a result of the dissemination of jarosite within the shale instead of concentrating along bedding and fracture planes within the shale. The shale bed is almost 4 m thick, and contains a very sparse fauna of fenestrate bryozoans and rare small brachiopods, including some spiriferiid forms. The microfossil assemblage is dominated by agglutinated foraminifera with a similar diversity to that found in the shale from parasequence 1.

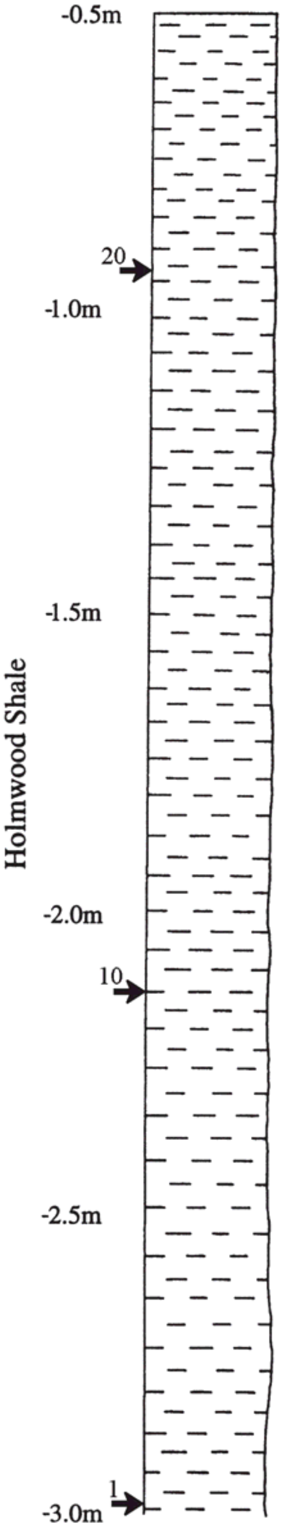
The first calcareous bed overlying this shale unit is weakly bedded and grades from a shale at the base to a friable, brown, bioclastic calcareous sandy siltstone (*(A/L)/bs*) over a thickness of 10 cm. This calcareous unit is weakly planar bedded in parts, and has been bioturbated. The induration of the calcareous beds increases upwards through the unit with small lenses of semi-indurated brown calcarenite (*Lbs*) in the friable calcareous sandy siltstones in the middle part of the unit and becomes a weakly bedded to massive semi-indurated calcsiltite to calcarenite (*Lbs*) at the topmost 2 m of the calcareous unit, with intensive bioturbation in the topmost 1.5 m of the bed. The macrofauna within this unit is diverse and abundant, and most of the macrofossil material is fragmented, especially towards the top of this unit. The assemblage is similar to that of the calcareous beds of the first parasequence, although solitary rugose corals are less abundant. The microfossil assemblage is dominated by ostracodes and calcareous porcellaneous and calcareous hyaline foraminifera with infrequent palaeoniscoid teeth and scale fragments also present.

Parasequence 3

The third parasequence overlies the calcsiltite and calcarenite of the second parasequence in a sharp conformable contact. The base of the parasequence consists of 60 cm of finely laminated micaceous shale (*Al*), with some gypsum veins running subparallel to the laminations. The shale grades from black-grey in the bottom 20 cm to brown towards the top of the unit. The macrofossil assemblage consists of a sparse fauna of fenestrate bryozoans and small productiid brachiopods that are present as moulds along the lamination planes. A microfossil assemblage of agglutinated foraminifera is present through the shale unit.

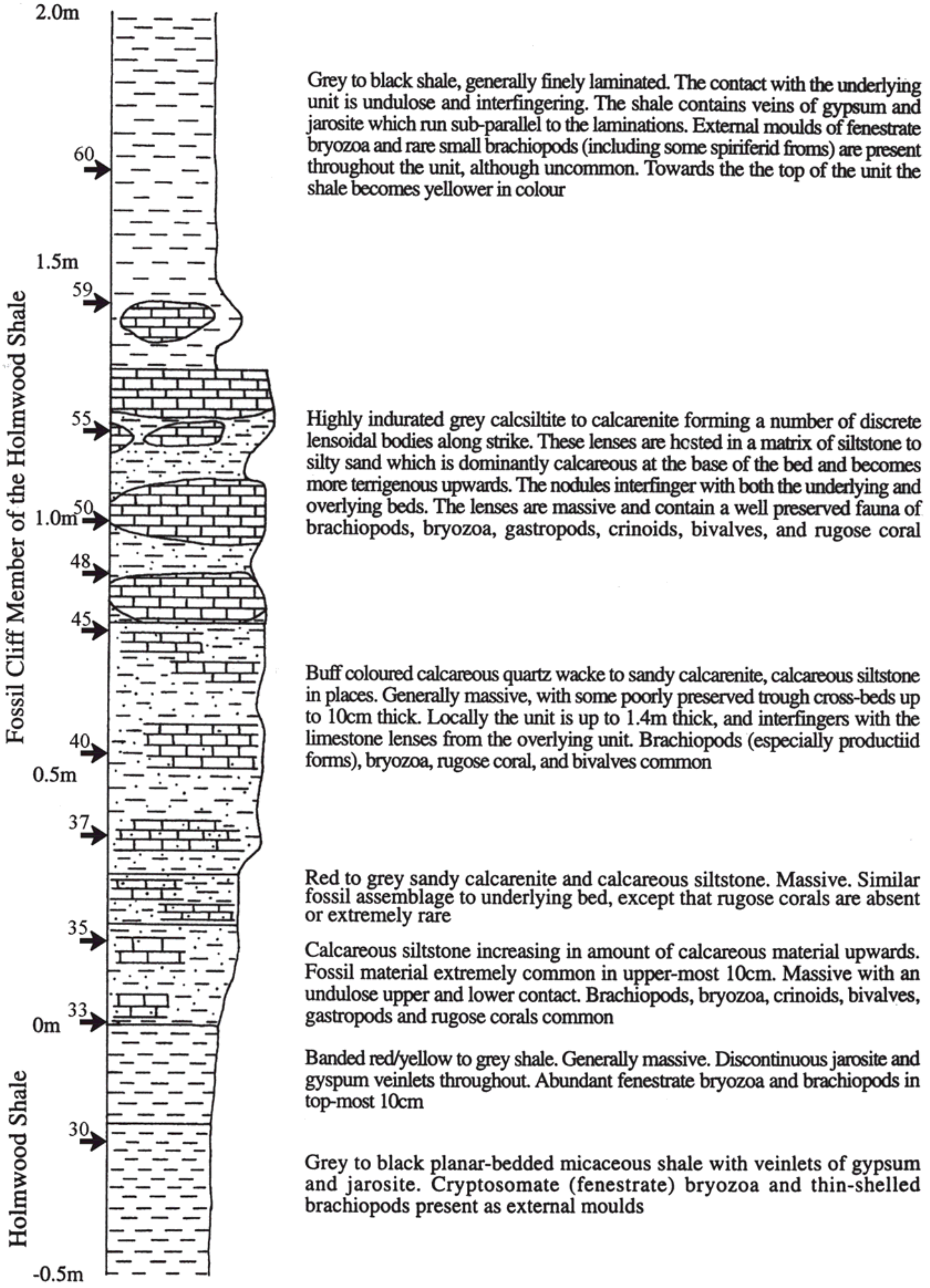
Conformably overlying the shale unit with a sharp contact is a lensoidal, massive, highly indurated, bioclastic grey calcarenite with a micritic matrix (*Lbs*). This bed has a maximum thickness of 0.5 m and a very diverse and abundant macrofossil fauna dominated by brachiopods, crinoids, bryozoans (both fenestrate and gymnolaemate), and solitary rugose corals. The microfossil assemblage consists of calcareous foraminifera and a diverse assemblage of ostracodes, with a sparse to rare fauna of palaeoniscoid teeth and scales. Most bioclasts within this bed are fragmented, and its massive nature suggests that it has undergone intense bioturbation. The indurated calcarenite is overlain with sharp contact by a bioclastic, buff-coloured sandy calcarenite to calcareous sandstone and siltstone (*(L/A)bs*) that thins along strike to the southeast. The sandy calcarenite is massive to very weakly planar bedded and contains a fragmented microfossil fauna of brachiopods (dominantly productiid forms), crinoid ossicles, and gymnolaemate bryozoans. The microfossil fauna is similar to the underlying indurated calcarenite. Overlying this in a sharp planar contact is the topmost calcareous bed of the parasequence, a prominent bed of bioclastic grey to reddish indurated calcarenite (*Lbs*) that is 1.3 m thick. The bed is massive to weakly bedded, with planar bedding surfaces between 5 cm and 20 cm apart, with bioturbation a probable cause of the massive nature of parts of the bed. The reddish colouring of the bed may be a result of slight weathering of the exposure. The macrofossil assemblage of the bed is extremely fragmented, although some thick-shelled productiid brachiopods are preserved intact. The fauna is a very abundant and diverse assemblage of brachiopods (dominantly productiid), bryozoans (gymnolaemate and fenestrate), and crinoids, with some rare solitary rugose corals and bivalve fragments also present. The microfossil assemblage is dominated by the calcareous porcellaneous foraminifera *Hemigordius schlumbergeri* and consists of calcareous porcellaneous and calcareous hyaline species in addition to a diverse ostracode fauna. Palaeoniscoid teeth and scales, although rare, are present within the assemblage.

This calcareous bed is then overlain with sharp contact by 0.7 m of white sandy shale (*(S/A)b*) that progressively fines upwards into a white shale. This unit is weakly laminated to massive and contains a sparse bryozoan fauna similar to that in the basal shales of the other parasequences. The sandy shale is conformably overlain by a red-white mottled sandstone with a clay to silt matrix (*Sm*) that grades upwards from a fine-grained sandy siltstone to a medium-grained sandstone. This sandstone bed is massive, intensely bioturbated, and consisting dominantly of subrounded to well-rounded quartz grains with a minor component of fine white mica flakes. The topmost contact of this bed is a disconformity, with Quaternary alluvium from the Irwin River overlying it.



Grey to black shale, generally finely laminated. The contact with the underlying unit is undulose and interfingering. The shale contains veins of gypsum and jarosite which run sub-parallel to the laminations. External moulds of fenestrate bryozoa and rare small brachiopods (including some spiriferid froms) are present throughout the unit, although uncommon. Towards the the top of the unit the shale becomes yellower in colour

Figure 71. Stratigraphic log of the topmost Holmwood Shale and the Fossil Cliff Member. Arrows alongside the stratigraphic log with numbers indicate some of the sampling points and sample numbers used in this study.



Grey to black shale, generally finely laminated. The contact with the underlying unit is undulose and interfingering. The shale contains veins of gypsum and jarosite which run sub-parallel to the laminations. External moulds of fenestrate bryozoa and rare small brachiopods (including some spiriferid froms) are present throughout the unit, although uncommon. Towards the the top of the unit the shale becomes yellower in colour

Highly indurated grey calcsiltite to calcarenite forming a number of discrete lensoidal bodies along strike. These lenses are hosted in a matrix of siltstone to silty sand which is dominantly calcareous at the base of the bed and becomes more terrigenous upwards. The nodules interfinger with both the underlying and overlying beds. The lenses are massive and contain a well preserved fauna of brachiopods, bryozoa, gastropods, crinoids, bivalves, and rugose coral

Buff coloured calcareous quartz wacke to sandy calcarenite, calcareous siltstone in places. Generally massive, with some poorly preserved trough cross-beds up to 10cm thick. Locally the unit is up to 1.4m thick, and interfingers with the limestone lenses from the overlying unit. Brachiopods (especially productiid forms), bryozoa, rugose coral, and bivalves common

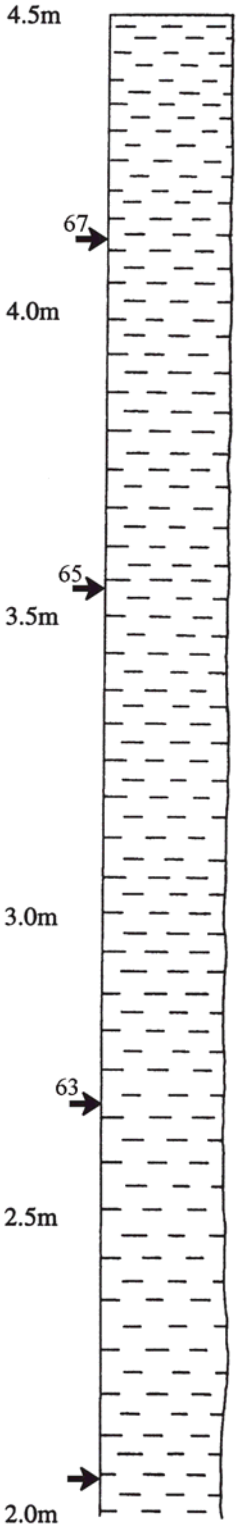
Red to grey sandy calcarenite and calcareous siltstone. Massive. Similar fossil assemblage to underlying bed, except that rugose corals are absent or extremely rare

Calcareous siltstone increasing in amount of calcareous material upwards. Fossil material extremely common in upper-most 10cm. Massive with an undulose upper and lower contact. Brachiopods, bryozoa, crinoids, bivalves, gastropods and rugose corals common

Banded red/yellow to grey shale. Generally massive. Discontinuous jarosite and gyspum veinlets throughout. Abundant fenestrate bryozoa and brachiopods in top-most 10cm

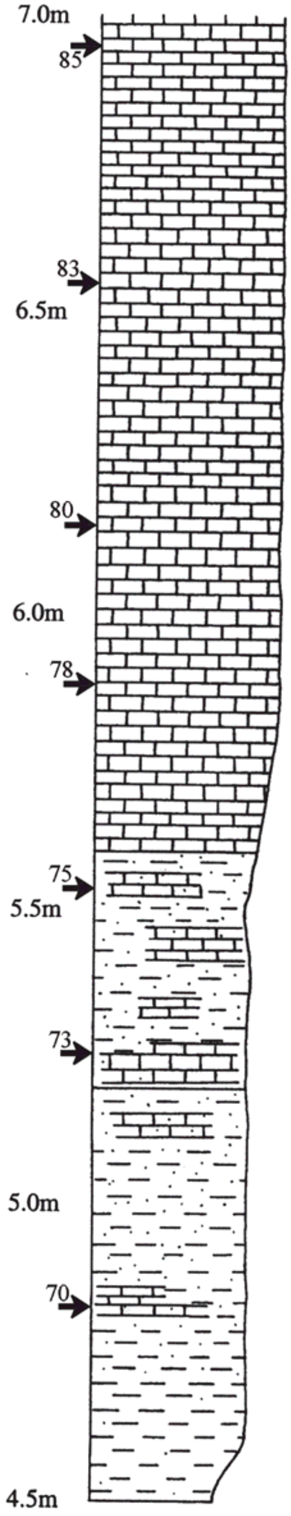
Grey to black planar-bedded micaceous shale with veinlets of gypsum and jarosite. Cryptosomate (fenestrate) bryozoa and thin-shelled brachiopods present as external moulds

Figure 71 cont.



Grey to black shale, generally finely laminated. The contact with the underlying unit is undulose and interfingering. The shale contains veins of gypsum and jarosite which run sub-parallel to the laminations. External moulds of fenestrate bryozoa and rare small brachiopods (including some spiriferid froms) are present throughout the unit, although uncommon. Towards the the top of the unit the shale becomes yellower in colour

Figure 71 cont.

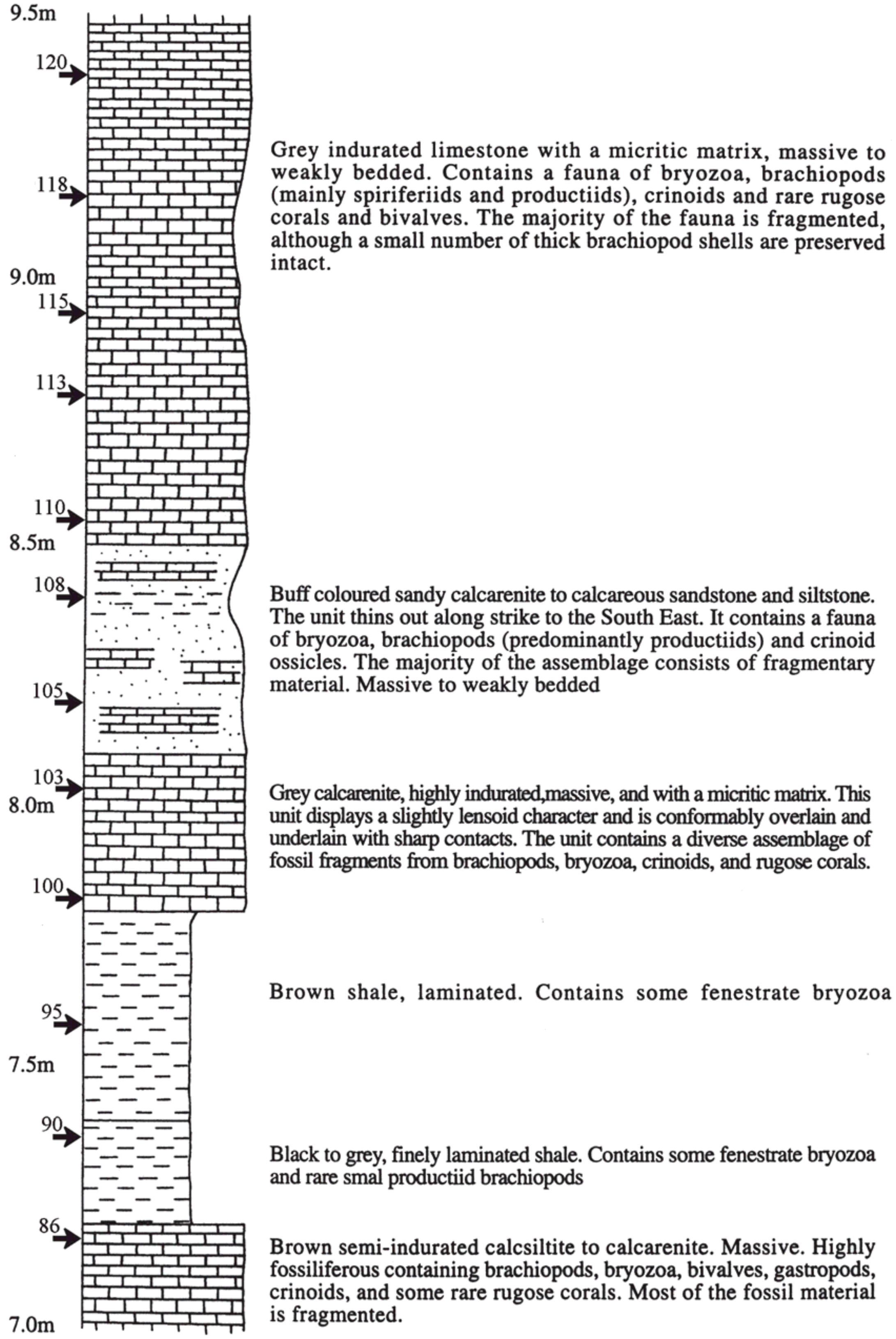


Brown semi-indurated calcsiltite to calcarenite. Massive. Highly fossiliferous containing brachiopods, bryozoa, bivalves, gastropods, crinoids, and some rare rugose corals. Most of the fossil material is fragmented.

Brown semi-indurated calcareous siltstone to calcsiltite. Weakly bedded to massive. Highly fossiliferous with a similar fauna to the underlying bed, although abundances are lower and the material is far more fragmented

Brown calcareous siltstone. Weakly bedded. Grades upwards at base from shale into a sandy siltstone over 10cm. Highly fossiliferous with bryozoa, brachiopods (predominatly productiid forms, although spiriferiids are present), crinoids, bivalves, gastropods and ruogse coral

Figure 71 cont.



Grey indurated limestone with a micritic matrix, massive to weakly bedded. Contains a fauna of bryozoa, brachiopods (mainly spiriferiids and productiids), crinoids and rare rugose corals and bivalves. The majority of the fauna is fragmented, although a small number of thick brachiopod shells are preserved intact.

Buff coloured sandy calcarenite to calcareous sandstone and siltstone. The unit thins out along strike to the South East. It contains a fauna of bryozoa, brachiopods (predominantly productiids) and crinoid ossicles. The majority of the assemblage consists of fragmentary material. Massive to weakly bedded

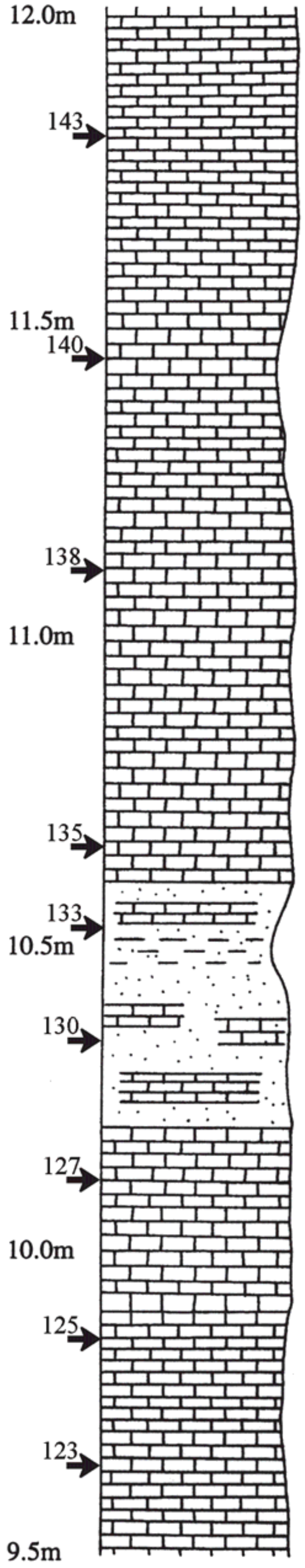
Grey calcarenite, highly indurated,massive, and with a micritic matrix. This unit displays a slightly lensoid character and is conformably overlain and underlain with sharp contacts. The unit contains a diverse assemblage of fossil fragments from brachiopods, bryozoa, crinoids, and rugose corals.

Brown shale, laminated. Contains some fenestrate bryozoa

Black to grey, finely laminated shale. Contains some fenestrate bryozoa and rare smal productiid brachiopods

Brown semi-indurated calcsiltite to calcarenite. Massive. Highly fossiliferous containing brachiopods, bryozoa, bivalves, gastropods, crinoids, and some rare rugose corals. Most of the fossil material is fragmented.

Figure 71 cont.



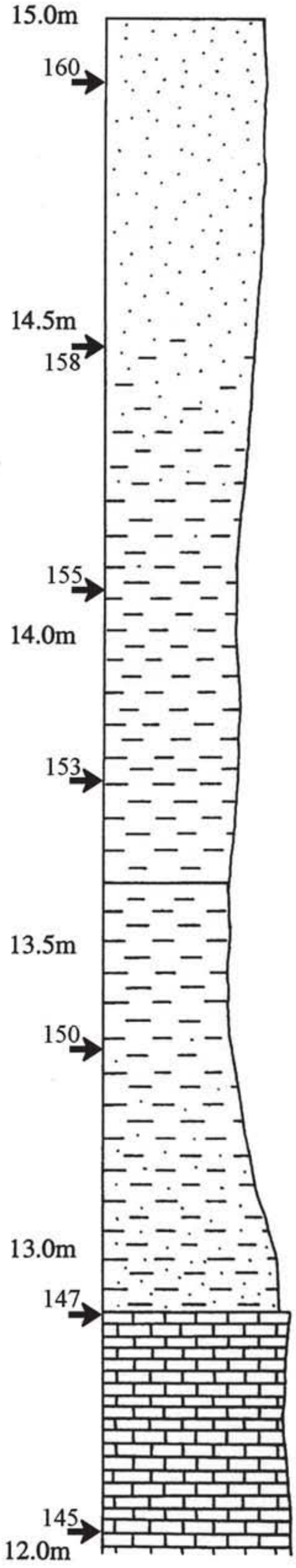
Grey indurated limestone with a micritic matrix, massive to weakly bedded. Contains a fauna of bryozoa, brachiopods (mainly spiriferiids and productiids), crinoids and rare rugose corals and bivalves. The majority of the fauna is fragmented, although a small number of thick brachiopod shells are preserved intact.

Buff coloured sandy calcarenite to calcareous sandstone and siltstone. The unit thins out along strike to the South East. It contains a fauna of bryozoa, brachiopods (predominantly productiids) and crinoid ossicles. The majority of the assemblage consists of fragmentary material. Massive to weakly bedded

Grey calcarenite, highly indurated,massive, and with a micritic matrix. This unit displays a slightly lensoid character and is conformably overlain and underlain with sharp contacts.

Grey indurated limestone with a micritic matrix, massive to weakly bedded. Contains a fauna of bryozoa, brachiopods (mainly spiriferiids and productiids), crinoids and rare rugose corals and bivalves. The majority of the fauna is fragmented, although a small number of thick brachiopod shells are preserved intact.

Figure 71 cont.



Mottled sandstone with a clay to silt matrix. Grades upwards from a silty shale to a medium-grained sandstone. Massive, possibly bioturbated. Rare external mould of fenestrate bryozoa are present in the lower and middle parts of the bed.

White sandy shale, progressively fining upwards into shale. Weakly laminated to massive. Contains a fauna of fenestrate bryozoa preserved as external moulds

Grey indurated limestone with a micritic matrix, massive to weakly bedded. Contains a fauna of bryozoa, brachiopods (mainly spiriferiids and productiids), crinoids and rare rugose corals and bivalves. The majority of the fauna is fragmented, although a small number of thick brachiopod shells are preserved intact.

Figure 71 cont.

Chapter 6: Biostratigraphic Framework

Introduction

The main fossil elements used for biostratigraphic work in the Cisuralian are palynomorphs, fusuline foraminifera, ammonoids, and conodonts. Apart from palynomorphs, these fossil groups were rare outside of the tropical Tethyan regions during the Cisuralian. Within the Gondwanan regions other fossil groups have been used as biostratigraphic markers, namely bivalves, brachiopods, and smaller foraminifera (Crespin, 1958; Dickins, 1970; Archbold. 1982, 1993, 1998, 2000a; Archbold and Dickins, 1991; Palmieri, 1998).

The fauna of Cisuralian sequences in Western Australia is noted for its marked provincialism, especially within the glacially dominated Gondwanan deposits (Archbold, 1983, 2000b). With the type and reference sections for the Cisuralian and its stages having been defined in eastern Europe, North America, and China (Yugan et al., 1997; Davydov et al. 1998), all of which are Tethyan deposits, many of the fossil groups and species that are used as biostratigraphic markers in these deposits are not found within the largely endemic Gondwanan Realm (Archbold, 2000b). Thus secondary biostratigraphic schemes have been erected to correlate between deposits in the Gondwanan Realm based upon species found within the realm.

The main faunal elements used for global correlation of fossiliferous sequences in the Cisuralian have provided a broad biostratigraphic framework for the Permian as a whole, especially the conodont biostratigraphy (Figure 4). Unfortunately conodonts are extremely rare within rocks of the Cisuralian in Western Australia. Nicholl (1976) attempted to collect conodonts from the Cisuralian of Western Australia (mainly in the Carnarvon Basin) and was largely unsuccessful, although later studies did record representatives of *Mesogondolella*, *Vjalovognathus*, and *Hindeoudus* from the Cisuralian of the Canning and Southern Carnarvon Basins (Nicoll, 1984; Nicoll and Metcalfe, 1998). Reeves (1949) reported a fragment of a possible conodont from the Sterlitamakian Nura Nura Member of the Poole Sandstone (Canning Basin). Glenister et al. (1993) noted that the Cisuralian ammonoid faunas of Western Australia are strikingly endemic on a species level, while having common genera with the Boreal Realm in the Northern Hemisphere during this period. The Western Australian ammonoid assemblages are dominated by species from the groups Metalegoceratidae and Paragastrioceratidae. Fusuline foraminifera, which are used to correlate the Tethyan Cisuralian sequences, have not been found amongst the cold-water foraminiferal assemblages of Australia (Scheibnerová, 1980), rendering this group unsuitable for biostratigraphic work within Gondwana faunas, although they have been recorded from Cisuralian deposits in Timor, to the north of Australia (Crespin, 1958) and from allochthonous deposits in New Zealand (Archbold, 2000b).

Australian biostratigraphic zonations

Within the cold-water faunas of Gondwana, especially around eastern and Western Australia, the global biostratigraphic marker groups such as fusuline foraminifera, ammonoids, and conodonts are generally absent or comprise endemic species that are not found in rocks deposited in the warmer waters that lay to the north (Nicoll and Metcalfe, 1998; Archbold, 2000b). This has lead to the development of regional biostratigraphic schemes, especially within Australia where they are used to correlate the Cisuralian faunas of the eastern and western margins of the continent. Brachiopods and bivalves are two of the most prolific macrofossil elements in the fossiliferous deposits of the Cisuralian in Australia and are important biostratigraphic marker groups used to correlate between Australian Cisuralian sequences (Coleman, 1957; Dickins, 1970, 1978; Archbold, 1982, 1993, 1998, 2000a, 2001; Archbold and Dickins, 1991; Archbold et al, 1993; Archbold and Shi, 1995). In addition, palynology is in widespread use as a biostratigraphic tool across Australia (Balme and Hennelley, 1956; Kemp et al, 1977; Balme, 1980; Foster et al., 1985; Foster and Waterhouse, 1988; Backhouse 1990, 1998; Balme and Backhouse, 1993; Mory and Backhouse, 1997). Balme and Backhouse (1993) noted a number of shortcomings in using palynology to correlate between Western and eastern Australia above the boundaries of the Asselian, although they felt confident that correlation between the Cisuralian sequences of Western Australia using palynology was a viable biostratigraphic tool.

The Fossil Cliff Member belongs to Zone B (*Strophalosia irwinensis* zone) of Archbold et al. (1993) and Archbold (2000b). Correlation of the brachiopod faunas from the Fossil Cliff Member (Perth Basin) and the Callytharra Formation (Carnarvon Basin) to Cisuralian deposits within Southeast Asia and then correlating this fauna to late Sakmarian faunas in Russia using ammonoid biostratigraphy has provided a tie point for the Australian Cisuralian with global biostratigraphic schemes (Archbold and Shi, 1995; Archbold, 1996; Shi et al., 1996).

Ostracodes

Very little detailed biostratigraphic work has been done on the Permian ostracode faunas of Australia. Crespin (1945) described seven new species from Cisuralian deposits in the Hunter River area of the Sydney Basin and Springsure area of the Bowen Basin associated with a foraminiferal fauna including the species *Calcitornella stephensi*, *Howchinella woodwardi*, and *Lunucammina triangularis*. Fleming (in Foster et al., 1985) recorded an ostracode assemblage from the middle of the Fossil Cliff Member associated with foraminifera and palynomorphs from the *Pseudoreticulatispora pseudoreticulata* Zone of Foster and Waterhouse (1988). Ferdinando (1990) recorded ostracode assemblages from the Fossil Cliff Member along with the foraminiferal assemblages; however, he provided only a limited biostratigraphic zonation with the ostracode assemblages.

Foraminifera

Crespin (1958) recorded eight foraminiferal assemblage zones within the Permian of Australia and identified three of these as unique to Western Australia. The fauna from the Fossil Cliff Member was placed in the first of these assemblages, although it also has elements common to Crespin's Assemblages 2, 3, 7, and 8. Crespin also outlined three broad palaeoecological associations within the foraminiferal assemblages of the Australian Permian.

The Fossil Cliff Member belongs to Assemblage 1 of Crespin (1958) (Table 2) and was correlated with the Callytharra Formation (Carnarvon Basin), Nura Nura Member of the Poole Sandstone (Canning Basin), the Cattle Creek Formation (Bowen Basin), the Dalwood Group (Hunter River area, Sydney Basin), the Darling Limestone (Tasmania), and the lower part of the Gray Limestone (Tasmania).

Calcitornella stephensi	*Howchinella woodwardi*
Syzrania condoni	*Lunucammina triangularis*
Giraliarella angulata	*Hemigordius schlumbergeri*
Protonodosaria tereta	*Protonodosaria irwinensis*
Stracheia dickinsi	*Tetrataxis conica*
Streblospira australae	*Trepeilopsis australiensis*
Hyperammina callytharraensis	*Kechenotiske hadzeli*

Table 2. Foraminifera in Assemblage 1 of Crespin (1958).

Of these species, Crespin (1958) believed that *Protonodosaria tetra*, *P. irwinensis*, *Syzrania condoni*, and *Trepeilopsis australiensis* are restricted to this assemblage in both eastern and Western Australia. *Giraliarella angulata*, *Stracheia dickinsi*, *Hyperammina callytharraensis*, *Kechenotiske hadzeli*, and *Tetrataxis conica* are, according to Crespin, restricted to the Callytharra Formation, although *Hyperammina callytharraensis*, *Kechenotiske hadzeli*, and *Tetrataxis conica* I have herein identified from the Fossil Cliff Member. *Hemigordius schlumbergeri* has been recorded from the Fossil Cliff Member (Perth Basin), Callytharra Formation (Carnarvon Basin), Nura Nura Member of the Poole Sandstone (Canning Basin), Cattle Creek Formation (Bowen Basin), Golden Valley Group (Tasmania), Erins Vale Formation (Sydney Basin), Mulbring Siltstone (Sydney Basin), and the Dalwood Group (Sydney Basin). *Calcitornella stephensi* was previously considered to be exclusive to this assemblage; however, work by Crespin (1958) indicated that *Calcitornella stephensi* is found in stratigraphically higher formations than those correlated to Assemblage 1, notably subsurface in the Noonkanbah Formation (Canning Basin) and the limestones of the Matuan Productus Beds (Bowen Basin). *Lunucammina triangularis* and *Howchinella woodwardi* are characteristic species of this assemblage, although they are also found stratigraphically higher in both eastern and Western Australia. *Streblospira australae* is abundant within the Callytharra Formation (Carnarvon Basin) and has also been found within an unnamed locality in the Dalwood Group of the Hunter River area (Sydney Basin). Crespin (1958) believed this species to be of considerable value in the correlation of the Permian deposits of eastern and Western Australia; however, Crespin did not record the presence of this species within the Fossil Cliff Member, and in this study it has not been found within the member.

Crespin believed that most of the species in Assemblage 2 (Table 3) were restricted to formations within the Carnarvon Basin that are stratigraphically higher than the

Callytharra Formation (Artinskian). The current study has recorded the presence of *Howchinella woodwardi, Ammodiscus nitidus, Hyperammina expansa,* and *Thuramminoides sphaeroidalis* within the assemblage, and this extends the range for these species down into Assemblage 1. Future work on the foraminiferal assemblages of Artinskian deposits of Western Australia is required to redefine this assemblage.

Flectospira prima	*Howchinella parri*
Howchinella woodwardi	*Lunucammina caseyi*
Lunucammina striatosulcata	*Hemigordius harltoni*
Protonodosaria raggatti	*Protonodosaria spiculata*
Rectoglandulina serocoldensis	*Streblospira kimberleyensis*
Streblospira meandrina	*Ammodiscus nitidus*
Hyperammina expansa	*Pseudohyperammina*
Sacculinella australae	*Reophax ellipsiformis*
Thurammina phialaeformis	*Thuramminoides sphaeroidalis*

Table 3. Foraminifera in Assemblage 2 of Crespin (1958).

Foraminiferal Assemblage 3 was defined by Crespin (1958) as being dominated by arenaceous foraminifera (Table 4). Many of these forms are found within the shale and silt beds of the Fossil Cliff Member, notably *Ammodiscus nitidus, Hyperammina coleyi, Thuramminoides sphaeroidalis*, and *Teichertina teicherti*.

Crespin (1958) placed the foraminiferal assemblages from the High Cliff Sandstone and Carynginia Formation into Assemblage 3, giving it an Artinskian age. As this assemblage is composed exclusively of agglutinated forms, it is highly likely that Assemblage 2 and 3 have significant chronostratigraphic overlap, and their distribution is related to facies controls rather than biostratigraphy.

Ammodiscus nitidus	*Ammodiscus wandageeensis*
Hyperammina acicula	*Hyperammina coleyi*
Hyperammina expansa	*Hyperamminita rudis*
Reophax ellipsiformis	*Reophax subasper*
Reophax tricameratus	*Thurammina phialaeformis*
Thuramminoides sphaeroidalis	*Teichertina teicherti*
Tolypammina undulata	*Trochammina subobtusa*

Table 4. Foraminifera in Assemblage 3 of Crespin (1958).

Scheibnerová (1982) in her work on Permian foraminifera of the Sydney Basin established age ranges for a number of species common to the Fossil Cliff Member and the Sydney Basin. While a number of the foraminiferal species recorded from the Fossil Cliff Member are not included in Scheibnerová's age ranges, in the Sydney Basin the common species are generally found in younger strata than in the Perth Basin (Table 5).

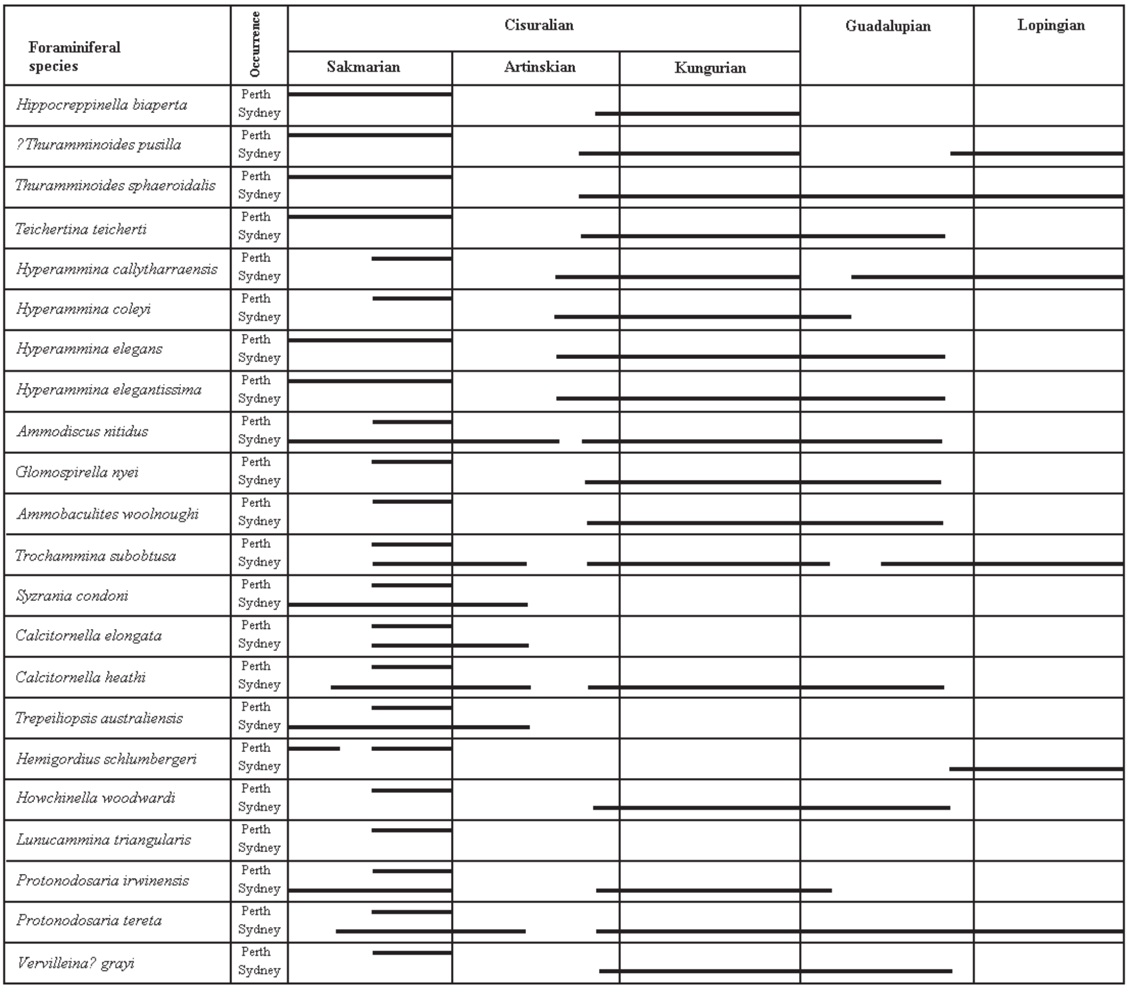


Table 5. Correlation of Permian foraminiferal species between the Perth and Sydney Basins (modified from Scheibnerová, 1982)

Palmieri (1983, 1990, 1994, 1998) in his studies of the Permian foraminifera of Queensland has recorded a number of species in common between the Bowen and Perth Basins (Table 6). The age ranges of these species between the Perth and Bowen Basins show a similar pattern to those species found in the Sydney Basin, with the species generally having a later first appearance in the Bowen Basin and a longer age range (Table 7).

Hippocrepinella biaperta
Thuramminoides sphaeroidalis
Sacammina arenosa
Ammodiscus multicinctus
Glomospirella nyei
Trochammina subobtusa
Calcitornella elongata
Trepeilopsis australiensis
Lunucammina triangularis
Vervilleina? grayi
?Thuramminoides pusilla
Teichertina teicherti
Kechenotiske hadzeli
Ammodiscus nitidus
Ammobaculites woolnoughi
Syzrania condoni
Calcitornella heathi
Howchinella woodwardi
Protonodosaria tereta

Table 6. Common species of Permian foraminifera between the Fossil Cliff Member and the Bowen Basin (Qld).

Species	Western Australian age range	Queensland age range
Thuramminoides sphaeroidalis	Sakmarian – Artinskian	Artinskian – Kazanian
Teichertina teicherti	Sakmarian – Artinskian	Late Artinskian
Kechenotiske hadzeli	Sakmarian – Artinskian	Early Artinskian
Ammodiscus multicinctus	Sakmarian – Artinskian	Artinskian – Kazanian
Ammodiscus nitidus	Sakmarian – Artinskian	Artinskian
Glomospirella nyei	Sakmarian – Artinskian	Ufimian – Kazanian
Trochammina subobtusa	Late Sakmarian – Late Artinskian	Late Artinskian
Syzrania condoni	Late Sakmarian	Early Artinskian
Calcitornella elongata	Late Sakmarian	Early Artinskian – Kazanian
Calcitornella heathi	Late Sakmarian – Artinskian	Artinskian – Kazanian
Trepeilopsis australiensis	Late Sakmarian	Late Sakmarian – Kazanian
Howchinella woodwardi	Late Sakmarian – Kazanian	Late Sakmarian – Kazanian
Lunucammina triangularis	Late Sakmarian – Artinskian	Late Sakmarian – Kazanian

Table 7. Age ranges for selected species of Cisuralian foraminifera between Western Australia and Queensland (modified from Palmieri, 1994, 1998).

While much of the basic stratigraphic and taxonomic work on the Cisuralian foraminifera has been completed, the correlation of Cisuralian foraminifera across Australia has not yet been researched in a systematic manner. While such an undertaking is beyond the scope of this study, with the increasing economic importance of this interval in terms of hydrocarbon production, especially within the northern Perth Basin, there is a definite future need for this work.

Chapter 7: Ostracode Assemblage Zones

Distribution within lithofacies types

The ostracodes of the Fossil Cliff Member are strongly controlled by lithofacies and are found only within calcareous units (lithofacies *Lbs*, *(L/A)bs*, and *(A/L)bs*), with the exception of a small number of specimens of *Healdia bradmani*, *Graphiadactyllis australae*, and *G. jonesi* recovered from the base of the silty shale units (lithofacies *Al*). The distribution and relative abundances of ostracodes recovered from the samples taken from the Fossil Cliff Member are given in Figure 72. In addition to being affected by substrate type, the ostracodes vary somewhat within similar sediment types between each of the parasequences, although not as markedly as the variations of the foraminifera.

The distribution of ostracodes between the parasequences of the Fossil Cliff Member does not reflect fully the parasequences determined using lithofacies analysis, with four Assemblage Zones apparent in the ostracode distributions and three lithological sequences determined from the lithofacies. These Ostracode Assemblage Zones will be fully discussed later in this thesis, and are briefly listed here for comparision to the lithologic parasequences. The first ostracode Assemblage Zone starts in the Holmwood Shale (sample 1, 3 m below base of the Fossil Cliff Member) and ends 1.4 m above the base of the Fossil Cliff Member (sample 59); the second Assemblage Zone starts at 1.5m above the base of the Fossil Cliff Member (sample 60) and ends at 6.9 m above the base of the Fossil Cliff Member (sample 85); the third Assemblage Zone starts at 7.0 m above the base of the Fossil Cliff Member (sample 86) and ends at 10.2 m above the base of the Fossil Cliff Member (sample 127); and the fourth Assemblage Zone goes from 10.3 m above the base of the Fossil Cliff Member (sample 128) to 12.8m above the base of the Fossil Cliff Member (sample 147), with the sandy silt to sandstone facies above the last calcareous unit to the top of the Fossil Cliff Member at the type section being barren of ostracodes (samples 148 to 160). In relation to the parasequences determined from the lithofacies, Ostracode Assemblage Zones 1 and 2 are found within lithofacies parasequence 1; Ostracode Assemblage Zone 3 occurs within lithofacies parasequence 2; and Ostracode Assemblage Zone 4 is occurs in lithofacies parasequence 3. The close similarity between Ostracode Assemblage Zones 1 and 2 and lithofacies parasequence 1 is also reflected in the similarity of the key species in the ostracode fauna from Assemblage Zones 1 and 2.

Terrigenous lithofacies

Apart from some rare occurrences of *Healdia bradmani, Graphiadactyllis australae*, and *G. jonesi* ostracodes have not been recovered from the terrigenous lithofacies of the Fossil Cliff Member. The occurrence of these three species within the terrigenous lithofacies is probably a result of reworking of the sediment, possibly through bioturbation, or by parautochthonous transportation of the valves to this area, either through reworking of underlying sediments or through current transportation from a nearby area that hosted an ostracode fauna. Dissolution of a pre-existing ostracode fauna from this lithofacies leaving only these few specimens remaining is unlikely, as the specimens are well preserved and show no evidence of dissolution.

Calcareous lithofacies

Ostracodes from the Fossil Cliff Member are found almost exclusively within the calcareous units. Within the calcareous sediments, the ostracode abundance is relatively constant, except for within the indurated reddish calcarenites (*Lbs*) at the top of the member (Ostracode Assemblage Zones 3 and 4) where *Graphiadactyllis australae*, *Healdia westraliaensis*, *H. irwinensis*, *Bairdia* cf. *Bairdia (Bairdia) beedei*, *B.* cf. *B. (B.) hassi,* and *Roundyella ludbrookae* are extremely abundant. Within all of the calcareous lithofacies *G. australae* and *H. irwinensis* are common elements of the ostracode fauna.

In the muddy calcarenites and calcareous siltstones (*(L/A)bs* and *(A/L)bs*) the ostracode valves are generally well preserved with little fragmentation and in some instances the valves are still articulated; however, such fragile and thin-valved species as *Hollinella pirajnoensis* are rarely found intact in these beds. Within the indurated calcarenites (*Lbs*) at the top of the member and the semi-indurated calcarenites (*Lbs*) in the middle of the member, a much higher portion of the ostracode valves are disarticulated and fragmented, including the more robust forms such as *H. irwinensis*, *G. australae*, *Bairdia* sp. cf. *B. (B.) beedei*, and *Kirkbya mingenewensis*.

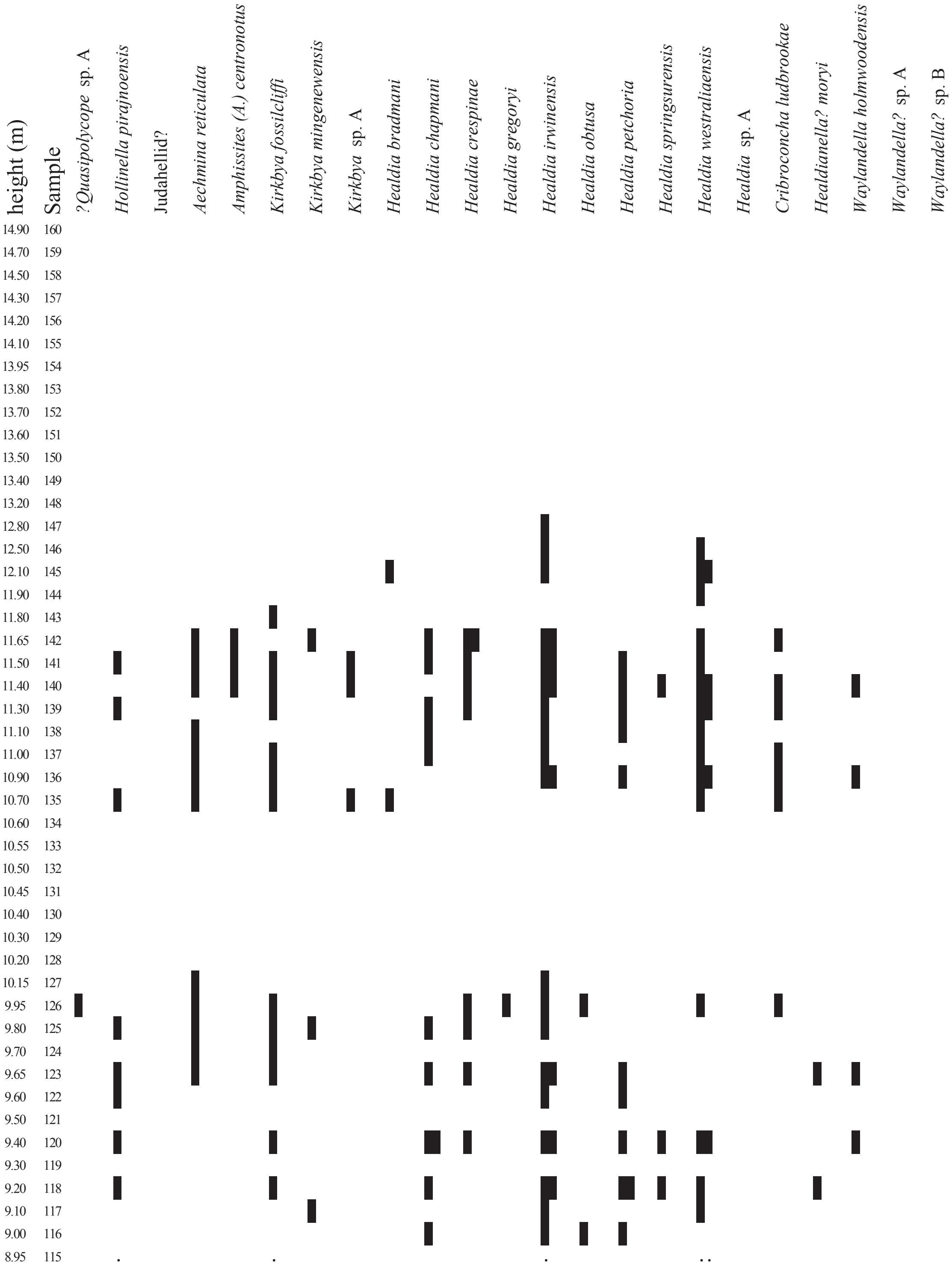


Figure 72. Ostracode distribution within the Fossil Cliff Member; line thickness indicates relative abundance of species; height is given as metres above base of Fossil Cliff Member.

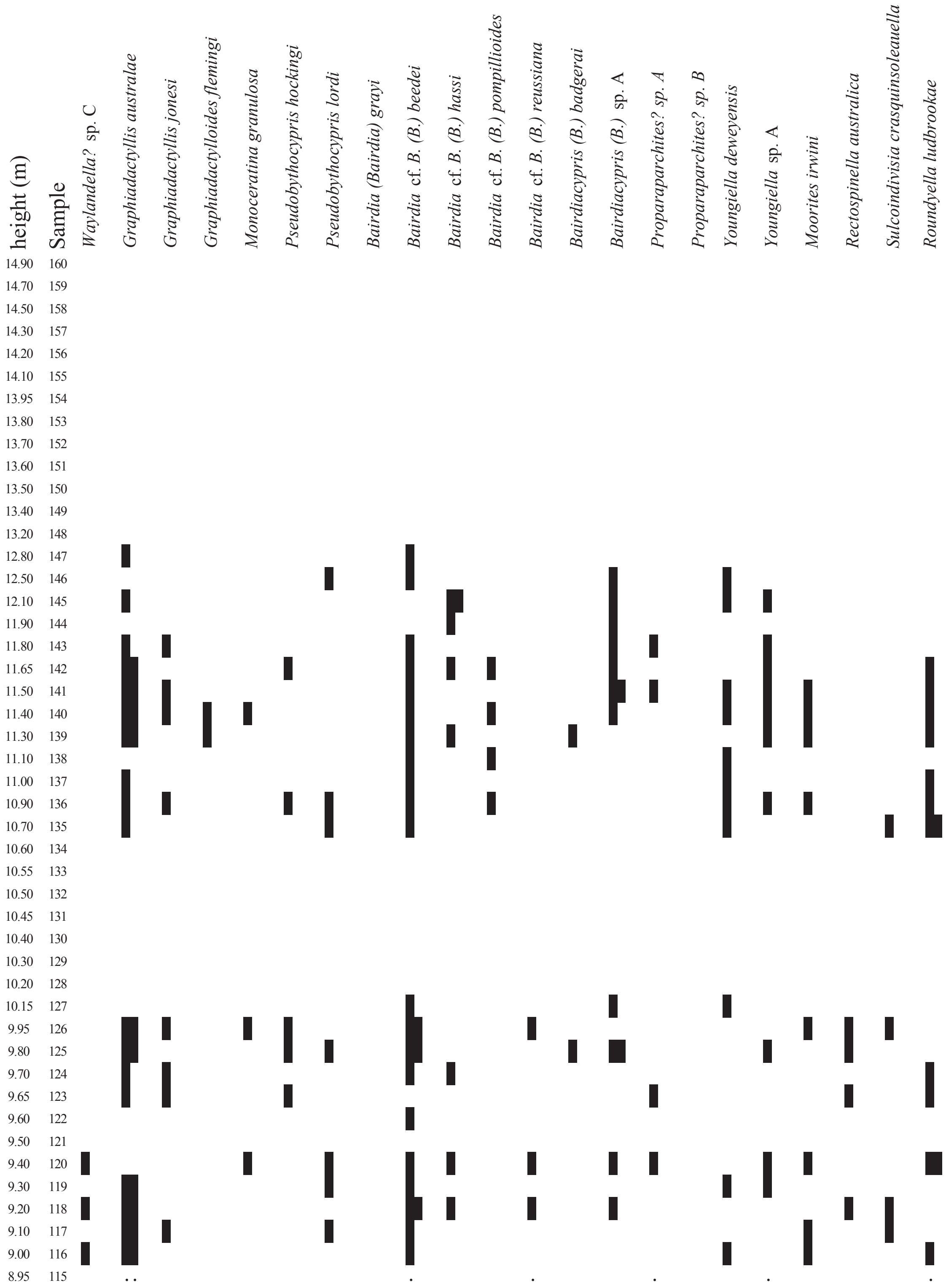


Figure 72 cont.

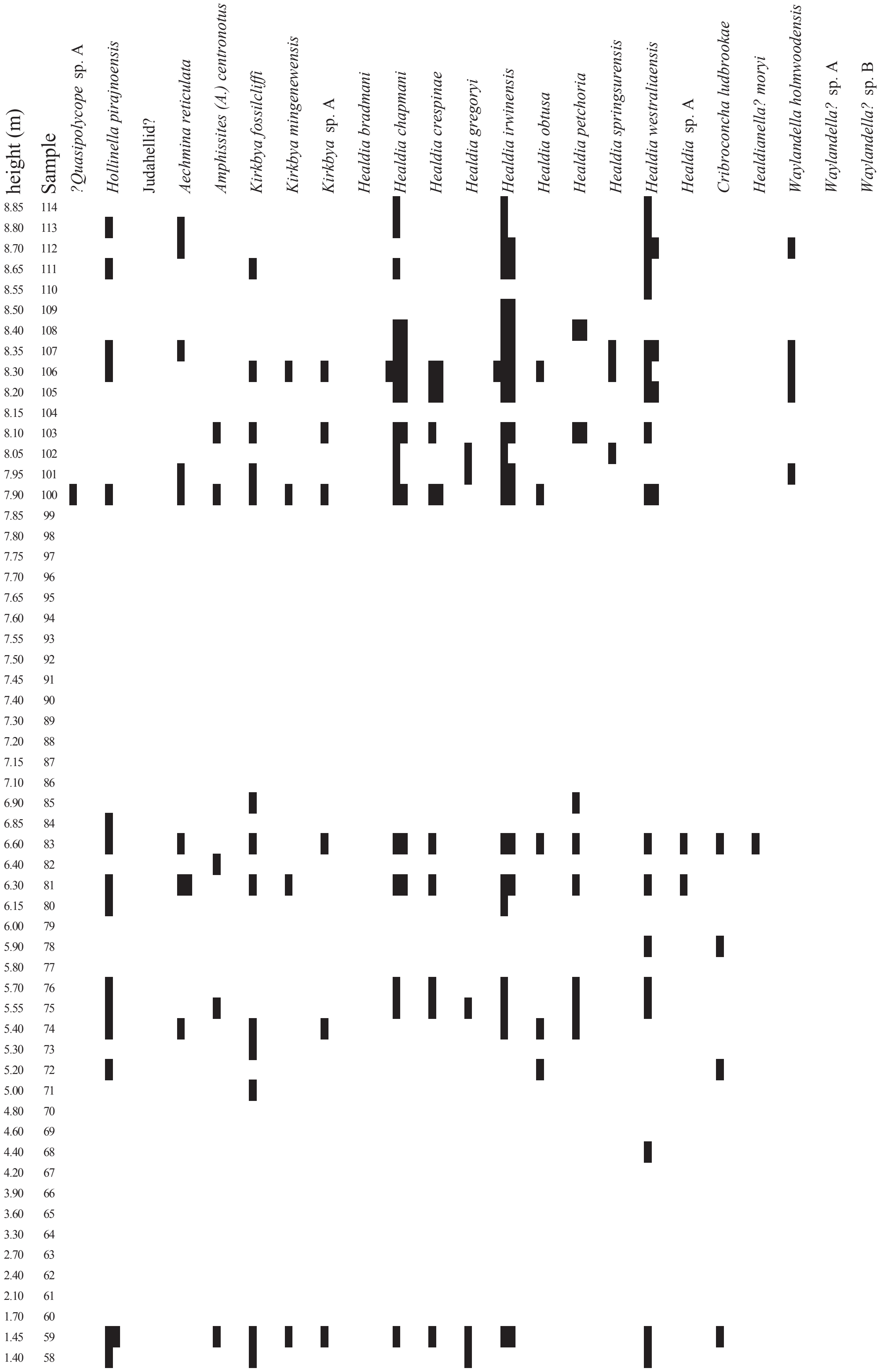


Figure 72 cont.

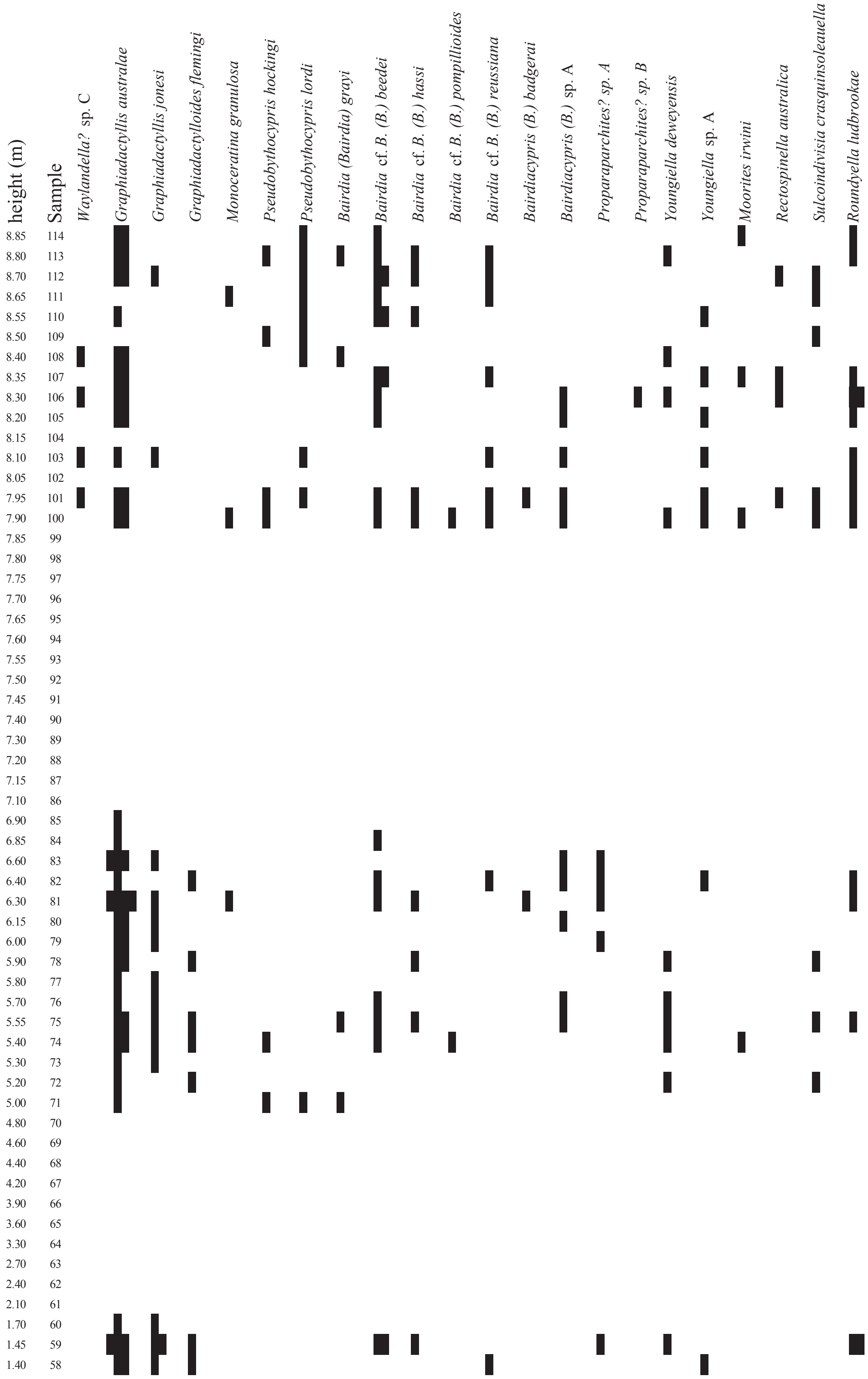


Figure 72 cont.

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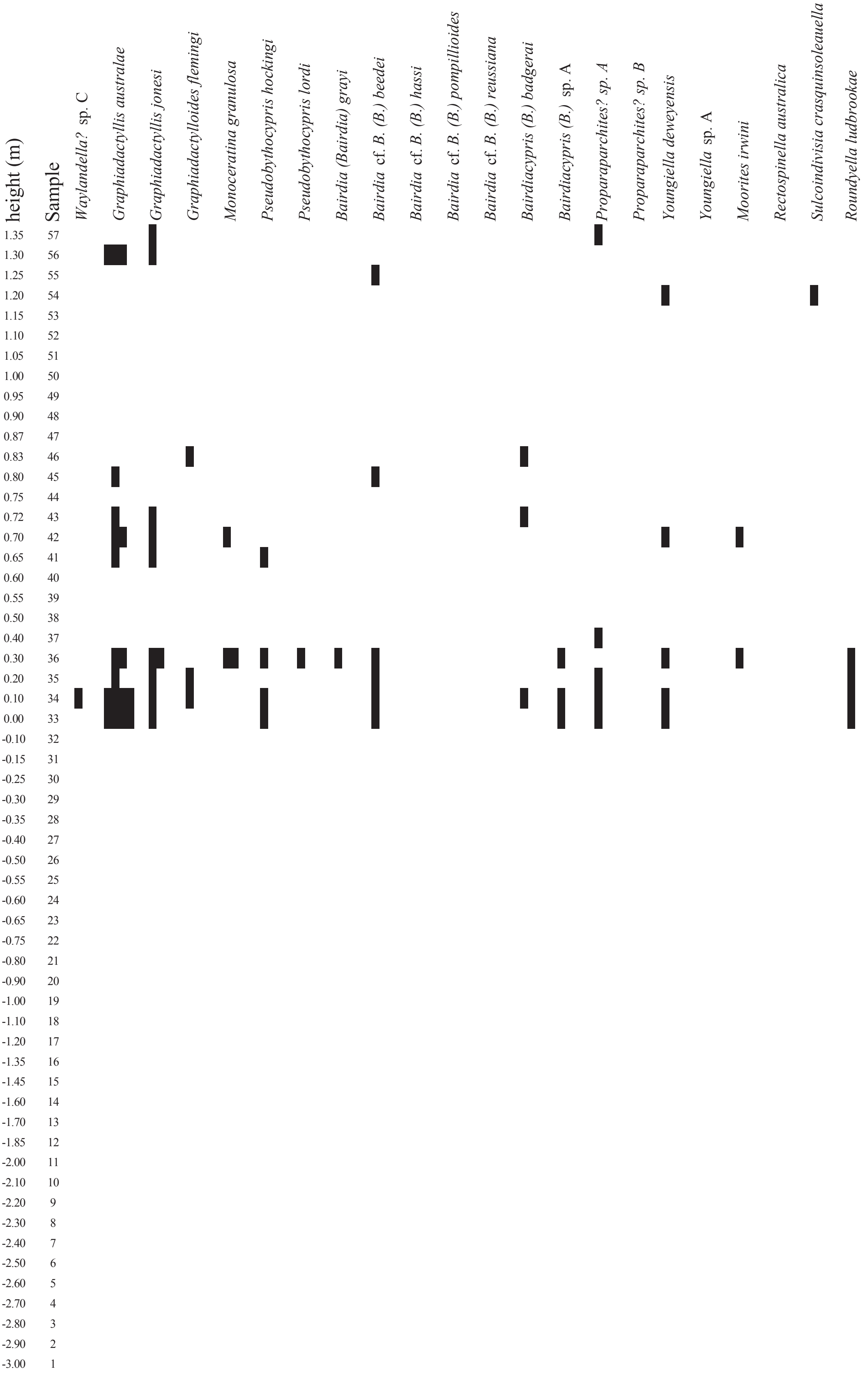

Figure 72 cont.

Distribution within Assemblage Zones

The greatest variations in the ostracode distribution occurs between ostracode Assemblage Zones from different lithological parasequences, so while the faunas in Ostracode Assemblage Zones 1 and 2 are broadly similar, they are distinct from the fauna in Ostracode Assemblage Zone 3, which is also distinct from the fauna in Ostracode Assemblage Zone 4. Within each of these Assemblage Zones a number of species are dominant throughout; however, there are strong variations in the relative abundances of some of the more uncommon elements.

The palaeoecological characteristics of these Assemblage Zones can be assessed by looking at the composition of the fauna in terms of the relative abundance of ostracode superfamilies and families (Crasquin-Soleau, 1997). Many ostracode superfamilies and families have distinct palaeoecological affinities and characteristic palaeoenvironments. A summary of the inferred palaeoenvironments of the ostracode superfamilies and families recognised in this study is listed in Table 8. Although most of this work has come from ostracode assemblages in the warmer-water Tethyan deposits from the Carboniferous and Permian, work on the palaeoenvironment of other Gondwanan ostracode assemblages in the Permian (Lethiers et al., 1989; Crasquin-Soleau et al., 1999) indicates that these broad palaeoecological affinities still hold true at southern palaeolatitudes.

The Hollinoidea are inferred to have been ubiquitous within the marine environments of the Late Palaeozoic with species diversity increasing offshore. The larger, heavily frilled species, such as *Hollinella pirajnoensis*, appear to have tolerated higher sedimentation rates and thrived closer to the palaeoshoreline (Melynk and Maddocks, 1988a). Lethiers et al. (1989) and Crasquin-Soleau et al. (1999) considered those species of *Hollinella* with such well-developed adventral structures to characterize environments such as interdistributary bays, prodelta and interdeltaic embayments, and lagoons.

Hollinoidea	Crawling/swimming; very shallow to shallow water with firm and stable substrates in euryhaline conditions.
Healdiidae	Burrowing; shallow water terrigenous soft muds in normal-marine conditions.
Bairdiocyprididae	Burrowing; shallow water terrigenous soft muds in normal-marine conditions.
Quasillitidae	Crawling; shallow water terrigenous muds in normal-marine conditions.
Bythocytheridae	Vagile benthic feeder?; shallow water terrigenous muds in-normal marine conditions.
Bairdioidea	Crawling; shallow to deep water firm calcareous muds in normal-marine conditions.
Paraparchitoidea	Crawling; very shallow to shallow water firm terrigenous muds in euryhaline to normal-marine conditions.
Amphissitidae	Crawling and possibly swimming; shallow to offshore calcareous muds in normal-marine conditions.
Kirkbyidae	Crawling and swimming; sublittoral to offshore firm calcareous muds in normal-marine conditions.
Scrobiculinidae	Vagile benthic feeder?; shallow to offshore calcareous or terrigenous muds in normal-marine conditions.
Youngiellidae	Crawling; shallow water firm terrigenous muds in normal-marine conditions.
Tricornidae	Crawling; shallow to deep water, terrigenous muds in low energy euryhaline to normal-marine conditions.

Table 8. Summary of the palaeoenvironmental characteristics of ostracode families found within the Fossil Cliff Member (adapted from Lethiers and Crasquin, 1987; Melnyk and Maddocks 1988a, b; Crasquin-Soleau, 1997; Lundin and Sumrall, 1999, Becker 1997b, 2000a, d, 2001a).

Species of the family Healdiidae, including the genera *Healdia* and *Waylandella* are considered to be good indicators of relatively nearshore muddy conditions, and diversity appears to be highest for this superfamily under these conditions (Becker, 2000a), although smaller healdiids appear to have lived farther offshore than the larger species

(Melnyk and Maddocks, 1988a). Sohn (1983) considered *Healdia* to be a burrowing genus.

The Bairdiocypridae (such as *Pseudobythocypris*) are considered to be ubiquitous within marine environments (Becker, 2000d), although Melnyk and Maddocks (1988a) noted that their diversity is highest in nearshore, muddy environments, and Sohn (1983) considered *Pseudobythocypris* to feed by burrowing into the sediment.

The Quasillitidae are considered to have had greatest diversity in muddy nearshore environments under normal salinity conditions (Melnyk and Maddocks, 1988a).

Monoceratina is the only genus of the family Bythocytheridae found in Fossil Cliff Member samples. Melnyk and Maddocks (1988a) determined that large species of this family were distributed closer to the palaeoshoreline than smaller species, and Sohn (1983) considered them to be probable burrowers based upon the morphology of the genera making them incapable of swimming. The large spine, however and ornamentation found on *M. granulosa* would preclude a burrowing lifestyle, making it likely that this species crawled across the substrate.

Species of the Bairdioidea, especially *Bairdia s.l.*, have their highest diversity in offshore environments with low rates of terrigenous sedimentation (Becker, 2001a), although several species were noted by Melnyk and Maddocks (1988a) in their study of Permian ostracodes from Texas to have tolerated muddier, shallower-water conditions. In addition, Melnyk and Maddocks (1988a) noted that *Bairdia* (*Rectobairdia*) were more eurytopic than *Bairdia* (*Bairdia*) and generally inhabited shallower areas. *Bairdia* (*Bairdia*) are thought to be burrowing ostracodes by Sohn (1983). Kohn and Dewey (1990) believed that the bairdioideans through analogy to both Holocene and Palaeozoic faunas show a preference for clear, warm, offshore, normal-salinity marine conditions with a low terrigenous input.

The Paraparchitoidea are generally widely distributed in the marine palaeoenvironments; however, Melnyk and Maddocks (1988a) noted that the number of species present from this group increases offshore. Dewey (1987, 1988) and Kaesler et al. (1988) considered that *Paraparchites* were able to withstand high levels of salinity and desiccation. They considered the smooth, larger forms to have tolerated muddier, shallow water conditions.

The Amphissitidae generally have the highest diversity close to the palaeoshoreline in areas of carbonate banks (Lethiers and Crasquin, 1987), although Melnyk and Maddocks (1988a) stated that the well-ornamented species of this family were largely restricted to offshore environments. Sohn (1983) believed that members of this family were swimmers as the large marginal frill structures and flanges would serve as obstacles to burrowing activity. Kaesler (pers comms, 2001) believed they may have been too dense to swim.

Crasquin-Soleau et al. (1999) and Becker (1997c) considered that the Kirkbyidae are most diverse in subtidal normal marine conditions; however, Melnyk and Maddocks (1988a) believed that the heavily ornamented Kirkbyidae are predominantly offshore dwellers.

The family Scrobiculinidae, of which *Roundyella ludbrookae* is the only species present in the Fossil Cliff Member, was thought by Melnyk and Maddocks (1988a) to have been largely restricted to offshore conditions based upon heavily ornamented species, whereas Crasquin-Soleau et al. (1999) considered the Scrobiculinidae to be indicative of shallow-water environments. It may be that the degree of ornamentation in the Scrobiculinidae, along with the Amphissitidae and Kirkbyidae can give an empirical measure of the relative water depth the species inhabited.

Youngiellidae appear to have inhabited onshore conditions (Melnyk and Maddocks, 1988a), and *Youngiella* and *Moorites* were considered to be good indicators of a nearshore palaeoenvironment. Crasquin-Soleau et al. (1999) considered the Youngiellidae to be characteristic of shallow, normal-marine conditions.

The Tricornidae, of which only *Rectospinella australica* has been found in the Fossil Cliff Member, was considered by Crasquin-Soleau and Orchard (1994) to be characteristic of the "Thuringian ecotype" and restricted to this ecotype. The "Thuringian ecotype" was initially defined as a marker of deep environments under the thermocline (Bandel and Becker, 1975); however, subsequent work by Becker and Bless (1990) extended the palaeoenvironment of the Thuringian ecotype into shallow-marine conditions based upon a number of indicative biotopes. Typical species of this ecotype tend to have long spines or are ovoid and smooth or delicately reticulated. Apart from the Tricornidae, other genera that come from this ecotype may contain neritic species, but the Thuringian species of these genera lighten their carapace (*Amphissites*), have more pointed extremities (*Bairdia*), or add spines to their carapace (*Hollinella*, *Healdia*) (Becker and Bless, 1990; Lethiers and Crasquin, 1987; Crasquin-Soleau and Orchard, 1994). Crasquin-Soleau and Orchard (1994) noted that towards the higher latitudes (cooler surface waters) or in areas of upwelling, the Thuringian ecotype probably became more abundant on the marine shelf. Whilst within the Fossil Cliff Member the only representative of the family Tricornidae is *Rectospinella australica*, found within Ostracode Assemblage Zone 3, some ostracode assemblages from this ecotype contain common genera with the ostracode assemblages of the Fossil Cliff Member (Becker and Bless, 1990).

Of the other ostracode genera recorded from the Fossil Cliff Member in this study, Melnyk and Maddocks (1988a) considered *Polycope* (which they attributed to the nomen dubium *Discoidella*) to have thrived in relatively nearshore conditions.

Ostracode Assemblage Zone 1

Assemblage Zone 1 is dominated by *Graphiadactyllis australae*, *G. jonesi*, *G. flemingi*, *Healdia westraliaensis*, *H. petchorica*, *Aechmina reticulata*, *Bairdia* cf. *Bairdia (Bairdia) beedei*, and *Youngiella deweyensis*. The characteristic species of this Assemblage Zone are listed in Table 9, and a full list of the species found within this assemblage and their relative occurrence in Ostracode Assemblage Zone 1 is listed in Figure 73.

Graphiadactyllis australae	*Graphiadactyllis jonesi*.
Graphiadactylloides flemingi	*Aechmina reticulata*
Bairdia cf. *Bairdia (Bairdia) beedei*	*Youngiella deweyensis*
Healdia petchorica	*Healdia westraliaensis*
Proparaparchites sp. A.	*Roundyella ludbrookae*

Table 9. Characteristic species in Ostracode Assemblage Zone 1.

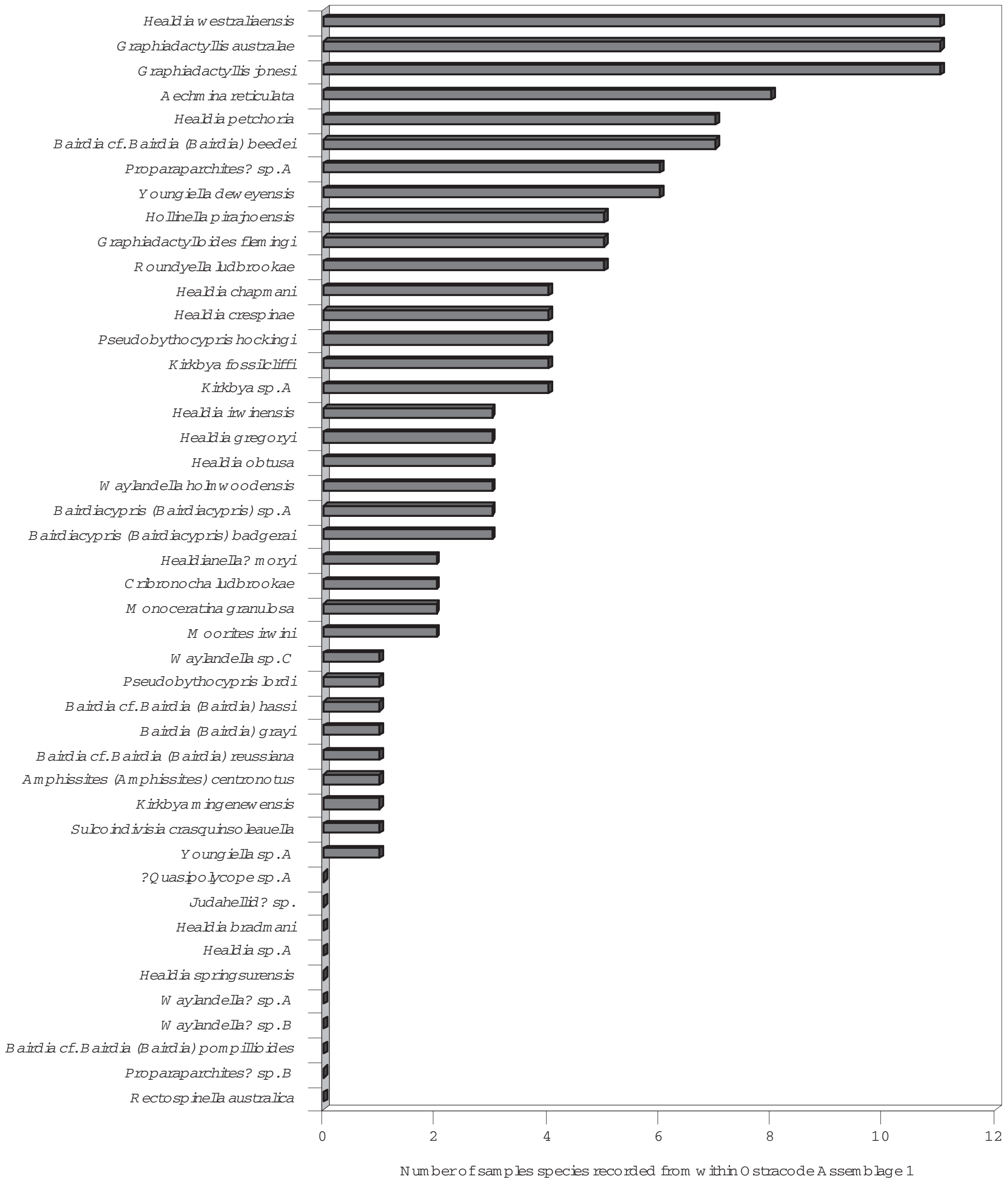

Figure 73. Graph of species occurrence in Ostracode Assemblage Zone 1

The superfamilies Healdioidea, Bairdioidea, and Thlipsuroidea are the dominant elements in this ostracode assemblage, and species of Hollinoidea and Kirkbyoidea also form a significant portion of the ostracode assemblage. The relative number of species from the major ostracode superfamilies and families found within the Fossil Cliff Member are plotted for each sample within Ostracode Assemblage Zone 1 (Figure 74). The ostracode species distribution within Ostracode Assemblage Zone 1 shows a considerable degree of variation with the average number of species recorded from ostracode-bearing samples being 8.12. The Healdiidae are a dominant element in the species distribution along with the Bairdioidea and Quasillitidae.

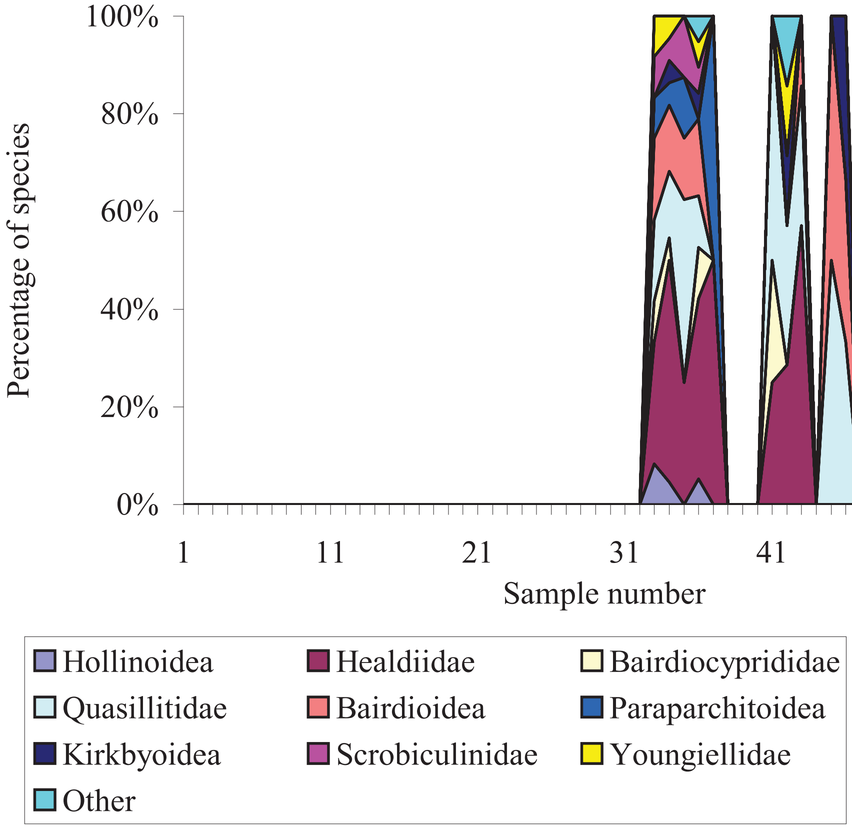

Figure 74. Distribution of ostracode species for each sample in percentage of selected families and superfamilies in Ostracode Assemblage Zone 1.

When the species distribution is averaged over the assemblage the abundance of species from these three groups is more apparent, and the contributions of the minor elements such as Youngiellidae is clearer (Figure 75).

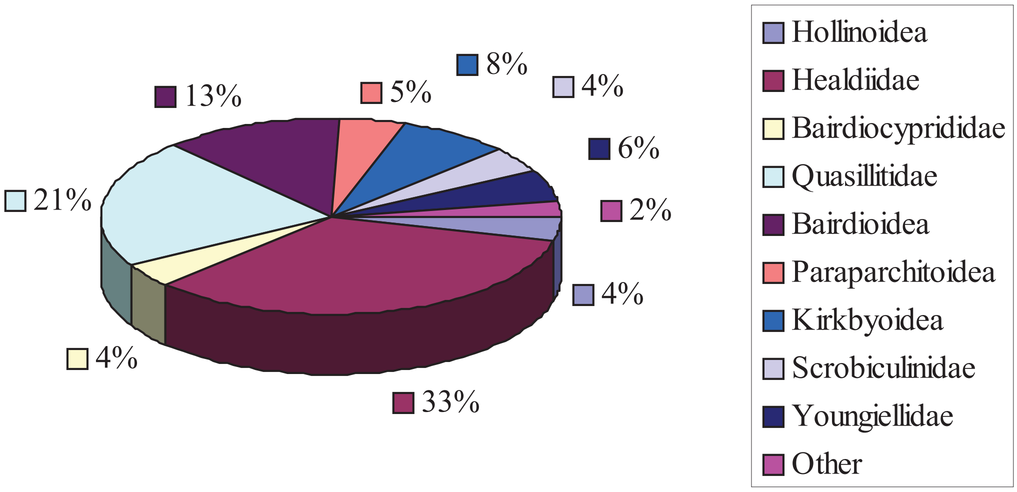

Figure 75. Relative distribution of ostracode species in percentage of selected families and superfamilies in Ostracode Assemblage Zone 1.

Within Ostracode Assemblage Zone 1, 85% of the ostracode species come from five superfamilies and families, namely: the Healdiidae (33%), Quasillitidae (21%), Bairdioidea (13%), Kirkbyoidea (8%), Youngiellidae (6%), and Paraparchitoidea (5%). This assemblage indicates that the water depths were relatively shallow, and the assemblage is dominated by species that prefer a terrigenous or muddy substrate. This is seen in the lithofacies where the substrate consists mainly of fine-grained friable silty calcareous sediment. The significant Bairdioidea presence indicates that there may be some deeper-water influence in the assemblage. *Aechmina reticulata* and *Healdia petchorica* also make up a significant portion of the species from this assemblage, and the presence of the smooth ovoid shaped *Aechmina reticulata* with its reticulated spine may be an indicator of a Thuringian ecotype influence on the fauna.

Ostracode Assemblage Zone 2

The fauna of Ostracode Assemblage Zone 2 is dominated by *Graphiadactyllis australae* which is present throughout this assemblage. Species abundance within Ostracode Assemblage Zone 2 is listed in Figure 76.

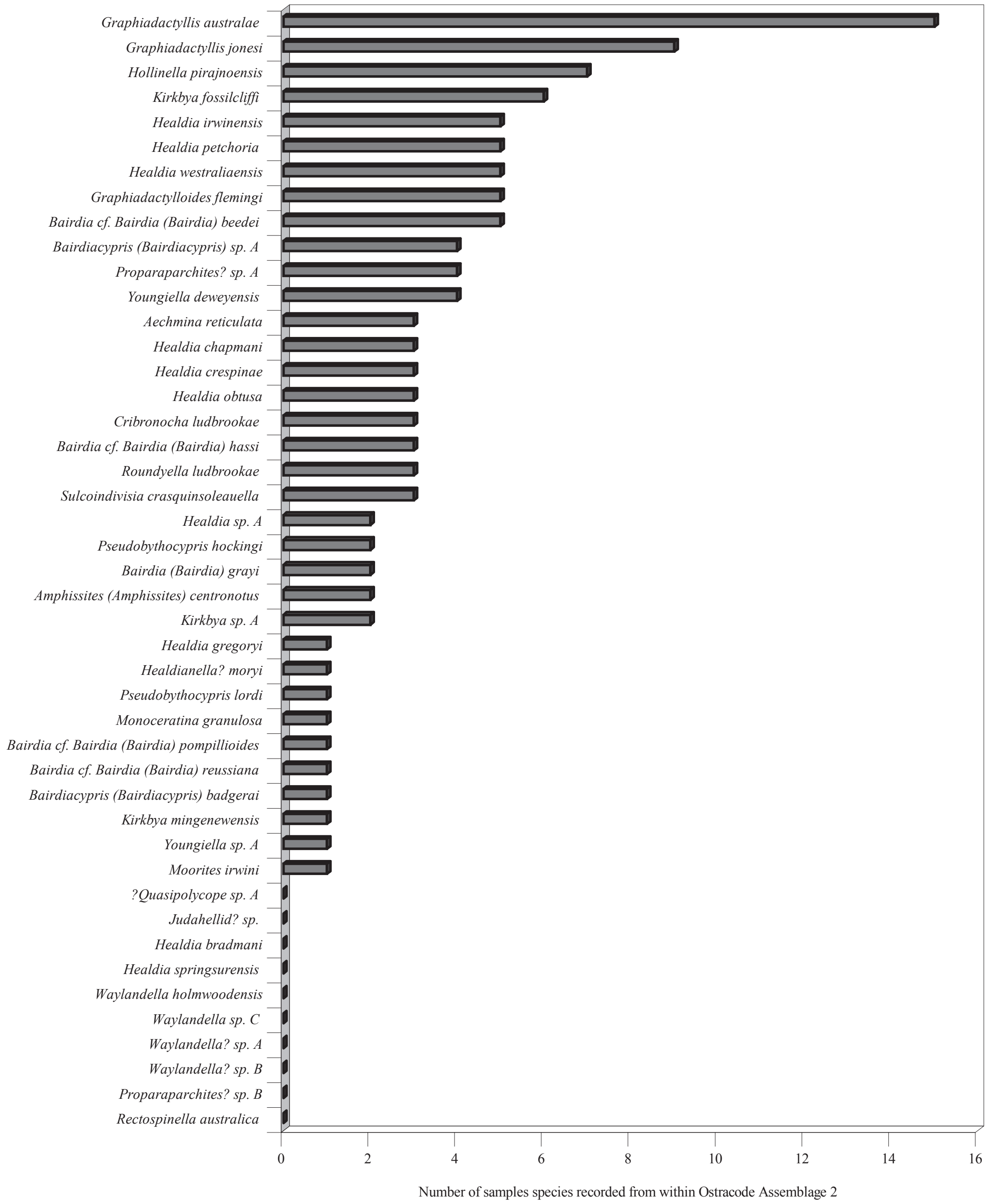

Figure 76. Graph of species occurrence in Ostracode Assemblage Zone 2

Other abundant species within this assemblage include *Graphiadactyllis jonesi*, *Hollinella pirajnoensis*, *Kirkbya fossilcliffi*, *Healdia irwinensis*, *H. westraliaensis*, *Graphiadactylloides flemingi*, and *Bairdia* cf. *Bairdia (Bairdia) beedei*. The characteristic species of this Assemblage Zone are listed in Table 10.

Graphiadactyllis australae	*Graphiadactyllis jonesi*
Hollinella pirajnoensis	*Kirkbya fossilcliffi*
Healdia irwinensis	*Bairdiacypris (Bairdiacypris)* sp. A
Healdia westraliaensis	*Bairdia* cf. *Bairdia (Bairdia) beedei*
Graphiadactylloides flemingi	

Table 10. Characteristic species in Ostracode Assemblage Zone 2.

Waylandella holmwoodensis which was present in Ostracode Assemblage Zone 1 does not occur within this Assemblage Zone, along with *W.* sp. C, both of which were minor faunal elements of Ostracode Assemblage Zone 1. Similar to Ostracode Assemblage Zone 1, Ostracode Assemblage Zone 2 is dominated by species from the Quasillitidae, Healdiidae, and Bairdioidea, with the Hollinoidea, Youngiellidae, and Kirkbyoidea also forming a significant portion of the assemblage. The distribution of species from the major ostracode superfamilies and families found within each sample from Ostracode Assemblage Zone 2 are plotted in Figure 77. Across this Assemblage Zone there is a large degree of variation, however the Healdiidae spike at sample 68 is due to 2 specimens of *Healdia* being recovered from a generally barren shale sample, and similarly the Quasillitidae spikes over samples 60 and 77 are from silty-shale samples that contained only a sparse fossil fauna. The average number of species recorded from ostracode-bearing samples of Ostracode Assemblage Zone 2 is 7.38. Species from the Healdiidae, Quasillitidae, and Bairdioidea dominate the assemblages in all the samples.

Averaging the species distribution within the selected superfamilies and families across the Assemblage Zone (Figure 78) shows a distribution very similar to that observed in Ostracode Assemblage Zone 1.

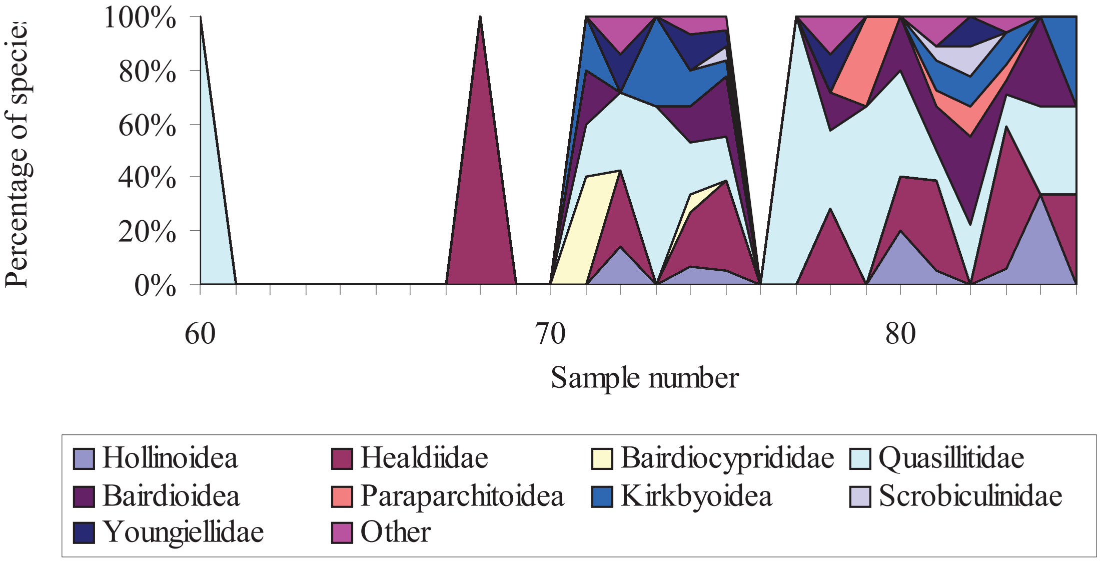

Figure 77. Distribution of ostracode species for each sample in percentage of selected families and superfamilies in Ostracode Assemblage Zone 2.

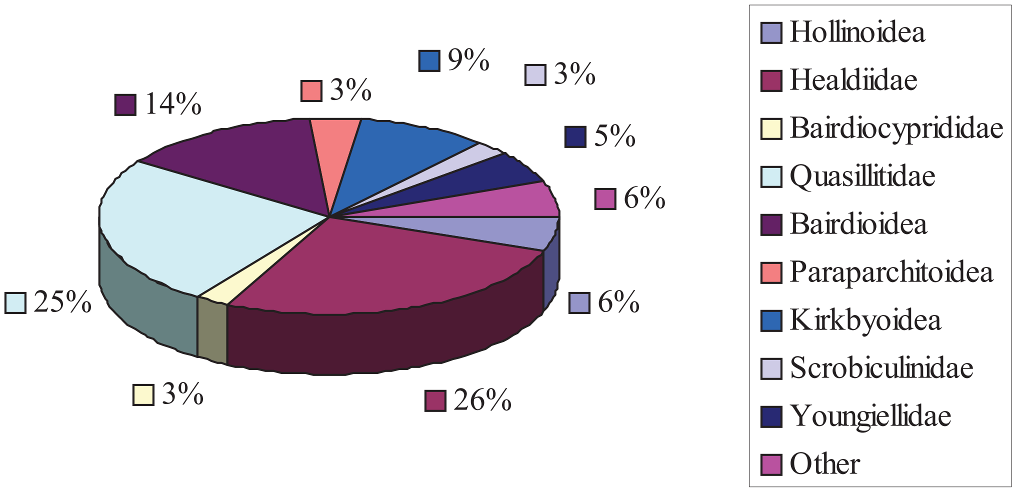

Figure 78. Relative distribution of ostracode species in percentage of selected families and superfamilies in Ostracode Assemblage Zone 2.

In Ostracode Assemblage Zone 2, nearly 85% of the ostracode species recovered from this Assemblage Zone of the Fossil Cliff Member come from the same five superfamilies and families that dominated the fauna from Ostracode Assemblage Zone 1. The abundance of the Healdiidae, however, has decreased relative to Ostracode Assemblage Zone 1 (down 7% to 26%), and the Quasillitidae has almost become the most frequent element within the Assemblage Zone (up 4% to 25%), with the proportion of the Bairdioidea (14%) remaining relatively constant, along with the Kirkbyoidea (9%), Youngiellidae (5%), and Paraparchitoidea (3%). Most of the ostracode species from the Fossil Cliff Member come from groups that, similar to Ostracode Assemblage Zone 1, are indicative of shallow water and preferred terrigenous or calcareous muddy substrates. The presence of the Bairdioidea within the Assemblage Zone may indicate that there was some offshore marine influence on the assemblage.

Ostracode Assemblage Zone 3

Ostracode Assemblage Zone 3 is characterised by a fauna of *Healdia irwinensis*, *H. chapmani*, *H. westraliaensis*, *Bairdia* cf. *Bairdia (Bairdia) beedei*, *Graphiadactyllis australae*, *Roundyella ludbrookae*, and *Pseudobythocypris lordi*. Species considered characteristic of this Assemblage Zone are listed in Table 11, and a full list of the species found within this fauna and the number of samples from this Assemblage Zone they have been recovered from are listed in Figure 79.

Healdia irwinensis	*Bairdia* cf. *Bairdia (Bairdia) beedei*
Graphiadactyllis australae	*Healdia chapmani*
Healdia westraliaensis	*Roundyella ludbrookae*
Pseudobythocypris lordi	*Kirkbya fossilcliffi*
Hollinella pirajnoensis	*Bairdia* cf. *Bairdia (Bairdia) reussiana*

Table 11. Characteristic species in Ostracode Assemblage Zone 3.

Within Ostracode Assemblage Zone 3, the tricorniid ostracode *Rectospinella australica* makes its first appearance. *Waylandella holmwoodensis* and *W.* sp. C reappear in this Assemblage Zone, from being absent within the second Assemblage Zone. *Graphiadactylloides flemingi* after being a dominant element in Ostracode Assemblage Zone 1 and 2, is absent from the fauna of Ostracode Assemblage Zone 3.

The Bairdioidea and the Healdiidae account for nearly half the species found within this Assemblage Zone, and the abundance of Quasillitidae within this Assemblage Zone has decreased markedly relative to their abundance within the first two Assemblage Zones, and the Youngiellidae have slightly increased their relative abundance within the fauna compared to Ostracode Assemblage Zone 2. The relative number of species from the major ostracode superfamilies and families for each sample within Ostracode Assemblage Zone 3 are plotted in Figure 80, and the average number of species from each of the ostracode-bearing samples of this Assemblage Zone is 11.76. The superfamily and family distribution within this Assemblage Zone between individual samples is more constant than seen in Ostracode Assemblage Zone 1 and 2, and this is accompanied by a higher average number of species per sample. Costanzo and Kaesler (1987) in their study of ostracode faunas from Kansas during marine regression events noted that ostracode assemblages from nearshore, unstable environments displayed unevenness in their distributions. Conversely it was noted that assemblages from offshore, stable environments had a higher species diversity and were more even in their distribution patterns (Brondos and Kaesler, 1976; Haack and Kaesler, 1980; Peterson and Kaesler, 1980; Costanzo and Kaesler, 1987). This may imply that this Assemblage Zone is relatively stable compared to Ostracode Assemblage Zones 1 and 2.

Average species distribution within the selected superfamilies and families across the Assemblage Zone shows a significant change in the faunal content relative to the underlying Ostracode Assemblage Zones, with the Healdiidae dominating the Assemblage Zone along with the Bairdioidea and Youngiellidae (Figure 81).

In Ostracode Assemblage Zone 3, the dominant faunal elements are the Healdiidae (31%), Bairdioidea (18%), Quasillitidae (9%), Youngiellidae (8%), Bairdiocyprididae (7%), and Kirkbyoidea (7%), which make up more than 85% of ostracode species identified from this Assemblage Zone. The composition of the fauna marks a distinct divergence from the faunas of the first two Assemblage Zones, although the dominance of the Healdiidae and presence of the Youngiellidae and Quasillitidae along with the Bythocytheridae indicate that the substrate was still composed of terrigenous and calcareous muds in shallow-water, normal-marine conditions.

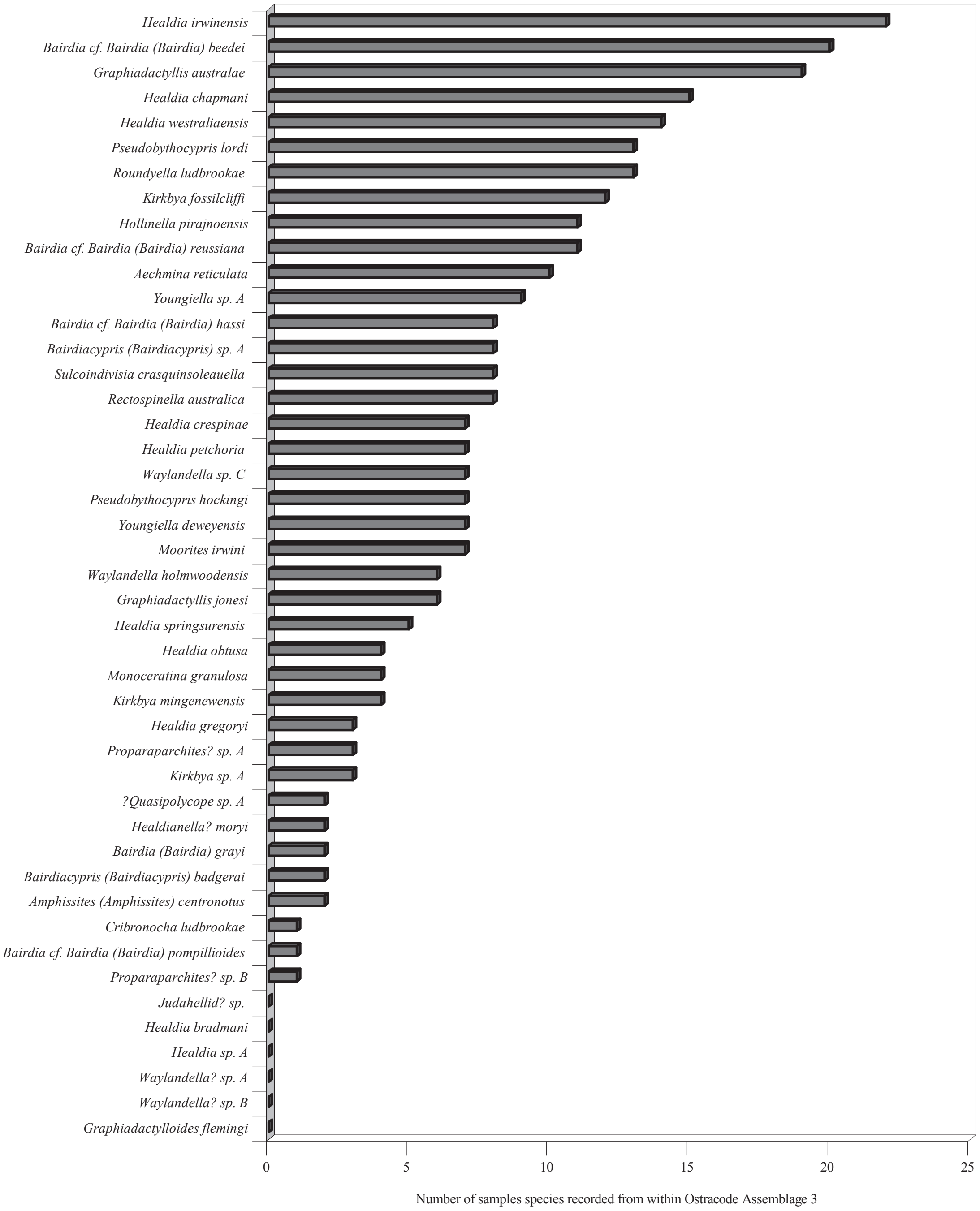

Figure 79. Graph of species occurrence in Ostracode Assemblage Zone 3.

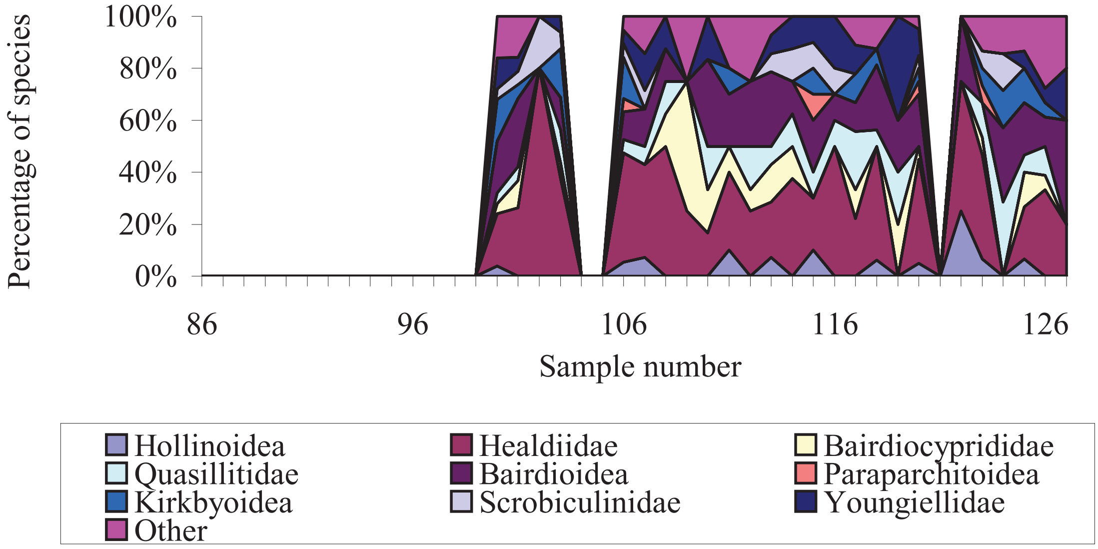

Figure 80. Distribution of ostracode species for each sample in percentage of selected families and superfamilies in Ostracode Assemblage Zone 3.

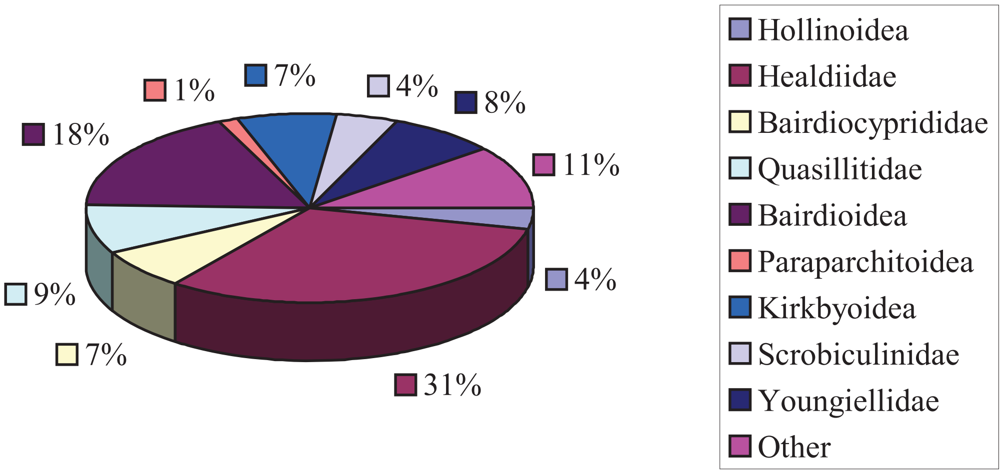

Figure 81. Relative distribution of ostracode species in percentage of selected families and superfamilies in Ostracode Assemblage Zone 3.

Ostracode Assemblage Zone 4

Ostracode Assemblage Zone 4 contains an assemblage that is dominated by *Healdia westraliaensis*, *Bairdia* sp. cf. *Bairdia (Bairdia) beedei*, *Graphiadactyllis australae*, *H. irwinensis*, *Bairdiacypris (Bairdiacypris)* sp. A, *Youngiella deweyensis*, and *Y.* sp. A. Species considered characteristic of this Assemblage Zone are listed in

Table 12, and a full list of the species found within this Assemblage Zone and the number of samples from this Assemblage Zone they have been recovered from are listed in Figure 82.

Healdia westraliaensis	*Bairdia* cf. *Bairdia (Bairdia) beedei*
Graphiadactyllis australae	*Healdia irwinensis*
Bairdiacypris (Bairdiacypris) sp. A	*Youngiella deweyensis*
Youngiella sp. A	*Roundyella ludbrookae*
Aechmina reticulata	*Kirkbya fossilcliffi*
Healdia petchorica	*Cribroconcha ludbrookae*

Table 12. Characteristic species in Ostracode Assemblage Zone 4.

In this Assemblage Zone, *Cribroconcha ludbrookae,* a rare species in the first three ostracode Assemblage Zones, becomes a common component of the fauna. *Bairdia* sp. cf. *Bairdia (Bairdia) reussiana* and *Rectospinella australica,* both key elements of Ostracode Assemblage Zone 3, disappear from the fauna. *Healdia irwinensis,* the dominant species in the third Assemblage Zone, is still common within this Assemblage Zone along with *Graphiadactyllis australae* and *Bairdia* sp. cf. *Bairdia (Bairdia) beedei*. *Waylandella* sp. C disappears from the Assemblage Zone, and *Waylandella holmwoodensis* becomes a minor element of the fauna. *Graphiadactylloides flemingi,* absent from Ostracode Assemblage Zone 3, is an infrequent element within the ostracode fauna of the fourth Assemblage Zone.

Within Ostracode Assemblage Zone 4 the Healdiidae, Bairdioidea, Youngiellidae, and Quasillitidae comprise nearly three quarters of the total number of species identified. Species from the Youngiellidae have increased their abundance in this Assemblage Zone compared to the first three Assemblage Zones, while relative abundances of the Healdiidae, Bairdioidea, and Quasillitidae have only changed marginally. The relative abundance of species from the major ostracode superfamilies and families for each sample within Ostracode Assemblage Zone 4 are plotted in Figure 83. Similar to Ostracode Assemblage Zone 3, the relative abundances of the selected ostracode superfamilies and families remain relatively constant throughout all the samples from this Assemblage Zone, possibly indicating a stable environment. The average number of species recorded from each of the ostracode-bearing samples of this Assemblage Zone is 11.50, similar to that found within Ostracode Assemblage Zone 3, and significantly higher than in the first two ostracode Assemblage Zones.

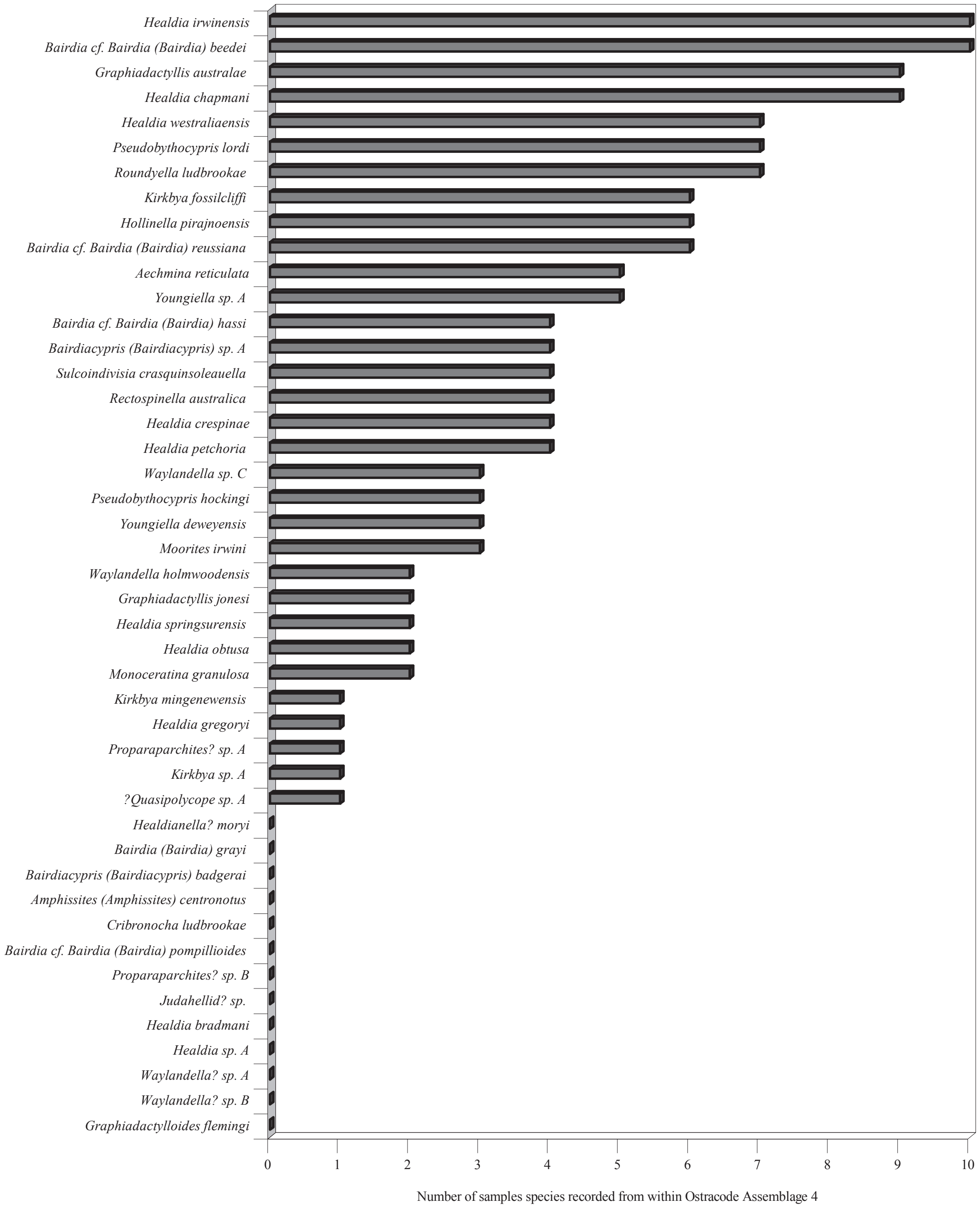

Figure 82. Graph of species occurrence in Ostracode Assemblage Zone 4.

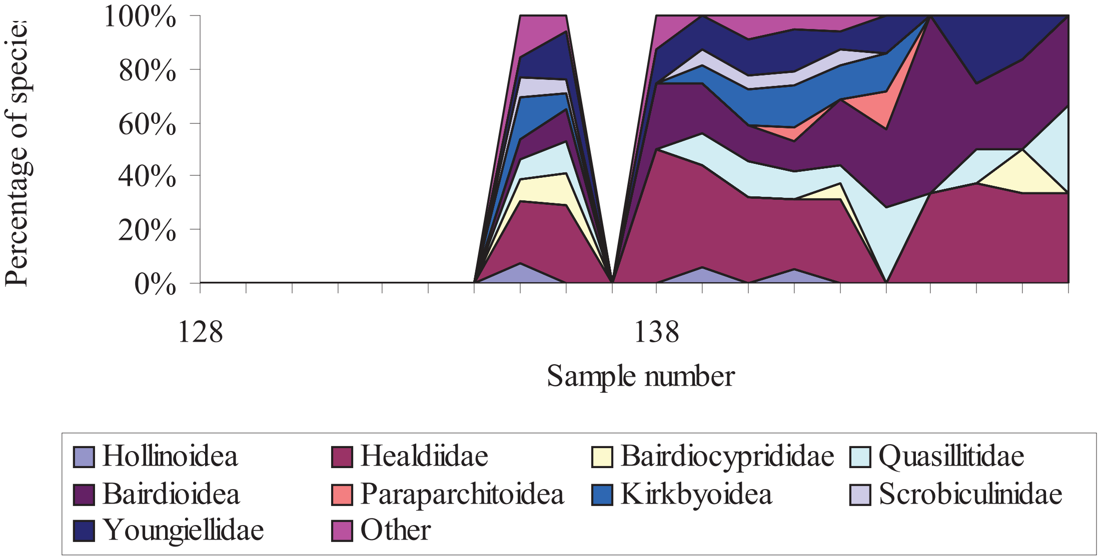

Figure 83. Distribution of ostracode species for each sample in percentage of selected families and superfamilies in Ostracode Assemblage Zone 4.

The overall species distribution of the major superfamilies and families across Ostracode Assemblage Zone 4 shows a similar pattern to that seen in Ostracode Assemblage Zone 3, with the Healdiidae forming the major component of the ostracode fauna, and the Bairdioidea and Youngiellidae also forming significant elements within the fauna (Figure 84).

The Healdiidae (31%), Bairdioidea (19%), Youngiellidae (13%), Quasillitidae (11%), Kirkbyoidea (9%), Scrobiculinidae (4%), and Bairdiocyprididae make up over 90% of the ostracode species recovered from samples taken from this Assemblage Zone. The ostracode Assemblage Zone is similar to that found within the third Assemblage Zone in terms of relative abundance of the major superfamily and family groups, although there is a slight decrease in the relative abundance of species from the Healdiidae, with an increase in the relative abundance of species from the Bairdioidea, and especially the Youngiellidae. The overall abundance of species from the Healdiidae, Youngiellidae, and Quasillitidae found within samples from this Assemblage Zone suggests that the fauna was from shallow water conditions with a terrigenous to calcareous substrate under normal marine conditions.

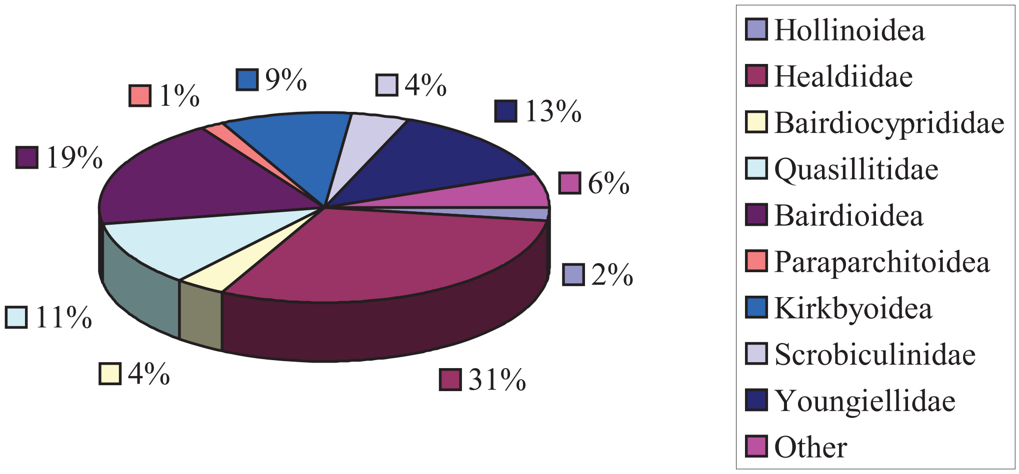

Figure 84. Relative distribution of ostracode species in percentage of selected families and superfamilies in Ostracode Assemblage Zone 4.

Assemblage Zone trends

Vannier et al. (1989) in their work on the Ordovician ostracodes of Western Europe noted that ostracode communities in unstable environments (and low spatial heterogeneity) are expected to have low faunal diversities, large numbers of individuals per species population, significant morphological variations within species, low rates of evolution, and hence persistence of stable community structures; and they are less severely affected by sudden environmental change. Communities of stable environments (and high spatial heterogeneity) are usually characterised by high faunal diversities, relatively small numbers of individuals per species population, limited morphological variation, high rates of evolution and hence frequent faunal reorganisations and changes in community structure, and are normally adversely affected by sudden environmental changes. Unstable environments are considered to be nearshore areas, and stable environments are more offshore areas (Bretsky and Lorenz, 1970; Eldredge, 1974).

The ostracode Assemblage Zones within the Fossil Cliff Member are gradational from a relatively unstable assemblage in the lower two Assemblage Zones to more stable assemblages in the upper two Assemblage Zones based upon the relative abundances of species from the major superfamilies and families (Figure 85). This is at odds with the overall stratigraphy of the Cisuralian sequence within the Irwin River area, where the sequences are interpreted to have undergone a marine regression, with the marine Fossil Cliff Member overlain by the High Cliff Sandstone which is interpreted to have been deposited in nearshore to beach conditions (Mory, 1995; Le Blanc Smith and Mory, 1995; Mory and Iasky, 1996). The ostracode assemblage expected from such conditions would be either unstable throughout the Fossil Cliff Member or stable at the base and tending to become unstable towards the top. This effect may been somewhat muted within the Fossil Cliff Member due to its location at the southern end of the large epeiric sea that extended between Greater India and the west coast of Australia and opened to the north during the Cisuralian. The shallow conditions of the epeiric sea and its effects in reducing the wave base may have provided some degree of stability within some sheltered facies in shallow water.

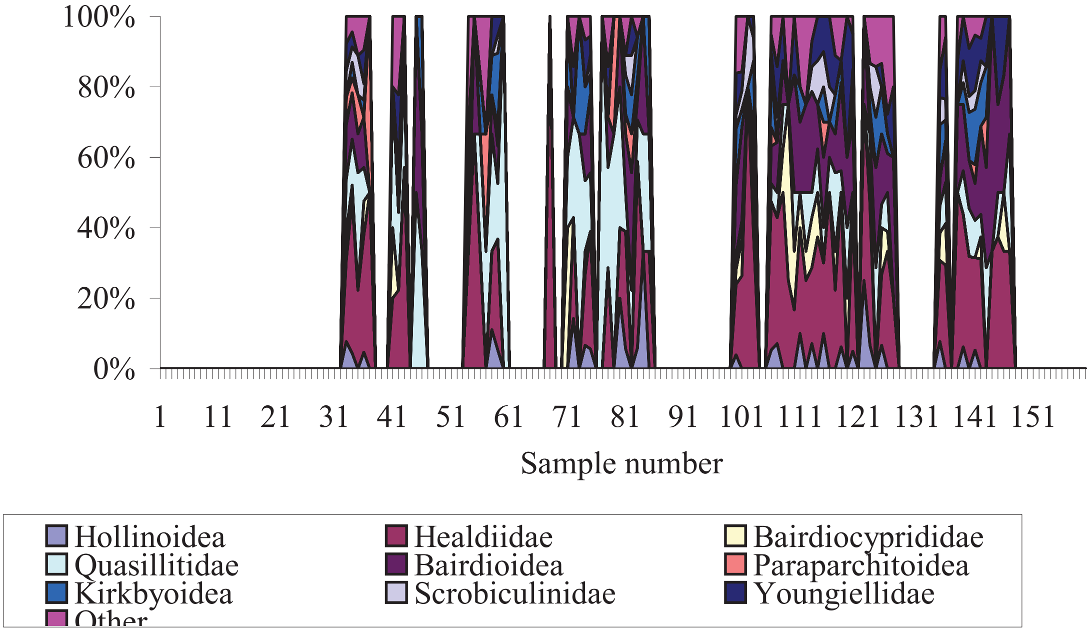

Figure 85. Variation of the ostracode assemblage through the Fossil Cliff Member section, based upon relative abundances from superfamilies and families of species from each sample.

Dewey et al. (1990), looking at the ostracode distributions in the Mississippian Black Warrior Basin in northwestern Alabama where the overall assemblage was dominated by healdioidean, bairdioidean, and kirkbyoidean ostracodes, observed that the interaction of two depositional systems controlled the ostracode distributions: the effects of clastic progradation onto the shelf and the effects of carbonate-producing transgressive cycles on the shelf. Similar to the situation within the Fossil Cliff Member, Dewey et al. (1990) also noted that changes in ostracode diversity and abundance occurred in sections where there was no noticeable change in lithology or macrofaunal content. Dewey et al. (1990) believed that the bairdioidean and kirkbyoidean faunas were controlled by substrate, whereas faunas of healdioidean ostracodes in this area were not controlled by substrate as several species occurred in both clastic and carbonate substrates. It is important to note that within the study of Dewey et al. (1990) both the shales and terrigenous sediments of the sequence were ostracode bearing. This may indicate that within the Fossil Cliff Member the distribution of the ostracode assemblages is not controlled directly by substrate type but by another mechanism, possibly a deepening of the water into a dysaerobic zone that controlled both the style of sedimentation and other palaeoenvironmental conditions such as oxygen levels and salinity.

Studies by Brouwers (1988a) and Díaz Saravia and Jones (1999) on ostracodes from the modern Gulf of Alaska and the Late Carboniferous of Argentina respectively have analysed the number of species within a sample to determine depth of deposition. In comparing the modern Gulf of Alaska studies to the Late Carboniferous of Argentina, Díaz Saravia and Jones (1999) used the ratio of species richness to the number of specimens as a method of characterising in general the depths of the faunas. The results of the two studies are summarised in Table 13.

	Inner sublittoral	Middle sublittoral	Outer sublittoral	Upper bathyal
Number of species	14.4	16.7	12.6	7
Specimen abundance	464	503	132	19
Ratio of species:specimens	0.031	0.033	0.095	0.368

Table 13. Range of values used to characterize ostracode depths based upon the modern Gulf of Alaska (modified from Brouwers, 1988a; Díaz Saravia and Jones, 1999).

These studies by Brouwers (1988a) and Díaz Saravia and Jones (1999) show that with increasing depth the ratio of species to specimens increases. The number of species and specimens from each of the four ostracode Assemblage Zones from the Fossil Cliff Member and the ratio of species to specimens is given in Table 14.

	Ostracode Assemblage Zone 1	Ostracode Assemblage Zone 2	Ostracode Assemblage Zone 3	Ostracode Assemblage Zone 4
Average number of species	8.12	7.38	11.76	11.50
Average abundance	33.12	30.43	54.96	51.33
Ratio of species:specimens	0.245	0.242	0.213	0.224

Table 14. Ratio of species to specimens for the Ostracode Assemblage Zones from the Fossil Cliff Member.

Table 14 shows that the ratio of species to specimens from the Fossil Cliff Member falls between what Brouwers (1988a) interpreted as outer sublittoral and upper bathyal from the modern Alaskan Gulf assemblages. As Brouwers (1988a) work was based upon modern faunas that included live specimens and had not undergone burial or fossilisation, the ratios from a fossil fauna would be much higher than in a modern fauna simply because fewer of the specimens are preserved relative to the original number of specimens in the assemblage.

The other features that Brouwers (1988a) noted within each of her depth assemblages were the changes in ornamentation characteristics of the ostracode carapaces and the ratio of adult ostracode instars to juvenile instars decreasing with depth (Table 15). Within the Fossil Cliff Member instars are infrequent, and this in conjunction with the ornamentation characteristics of the ostracode fauna from the Fossil Cliff Member where there are a number of large, highly calcified species present such as *Amphissites (Amphissites) centronotus* and *Graphiadactyllis australae*, in addition to species from *Bairdia* and *Healdia,* contradict the depth estimate from the species to specimens ratio. Most of the ostracodes recovered from the Fossil Cliff, whilst having thick carapaces, are generally smooth-shelled (such as *Bairdia*, *Healdia* and *Graphiadactyllis*). This contradiction may be explained by the taphonomic loss of specimens from the ostracode fauna of the Fossil Cliff Member, and thus the likely depth biofacies for the deposition of the Fossil Cliff Member may be between inner sublittoral and middle sublittoral based upon the ornamentation characteristics.

	Ornamentation characteristics	Adult to juvenile ratio
Inner sublittoral	Massive, heavy calcification; low thick reticulation or smooth with some pits, large size, elongate subquadrate carapace	Mostly adults sand facies: 0.90 – 1.81 silt facies: 0.26-0.40
Middle sublittoral	Robust, elaborate ornament, well calcified; flat venters, protruding spine networks, or completely smooth long low carapace with tapered ends	50-60 m: 0.94-1.37 90-100 m: 0.21-0.35
Outer sublittoral	Weak-moderate calcification; elaborate, delicate ornament, low reticulation, spines or alae, pitting, small size, subtriangular to elongate carapace	Average 0.65
Upper bathyal	Small compactly ornamented forms; smooth to very alate forms; very small size, subtriangular or elongate carapace	Average 1.13

Table 15. Assemblage characteristics of the modern Gulf of Alaska depth biofacies (from Brouwers, 1988a).

Costanzo and Kaesler (1987) noted that within the Florena Shale of northeastern Kansas that highest species diversity occurs within a transitional fauna or is the result of postmortem mixing of two assemblages by bioturbation, transportation by currents, or time averaging as a result of subtle environmental changes and can be tracked by ostracodes. These effects may be recorded in the ostracode assemblages of the Fossil Cliff Member, and the lack of instars within the assemblages indicates that transportation as well as bioturbation have affected the ostracode postmortem assemblages. The lack of juveniles amongst the ostracode assemblage has been termed high-energy biocoenosis by Whatley (1988b), and is interpreted to indicate the presence of moderate current activity removing the smaller and lighter instars, and is common in marine environments.

Crasquin-Soleau and Baud (1998) in their study of Permian ostracodes from Greece noted that the carapaces of the specimens were often broken and that most species were represented only by adult and last-larval stage carapaces, similar to what is observed within the Fossil Cliff Member ostracode assemblages, especially in Ostracode

Assemblage Zones 3 and 4. They believe this to be a result of high-energy biocenosis or thanatocenosis (Whatley 1983, 1988b; Brouwers, 1988a, b). They also noted that due to the number of closed carapaces (which indicates a soft substrate with relatively high sedimentation rates (Oertli, 1971)) that transportation of carapaces must have been limited, another feature that is also true of the ostracode faunas of the Fossil Cliff Member, especially amongst specimens of Bairdioidea and Healdioidea.

Chapter 8: Foraminiferal Assemblage Zones

Distribution within lithofacies types

The distribution of foraminifera within the samples taken from the Fossil Cliff Member show a very strong delineation between the agglutinated foraminifera and those that form calcareous tests (Figure 86). Of the 28 species of foraminifera identified from the Fossil Cliff Member in this study, 15 of then are found almost exclusively within the terrigenous sediments of the member. The remaining 13 species are generally found exclusively within the calcareous sediments of the member. In addition, a strong cyclicity between the distributions of the agglutinated and calcareous forms is apparent from the relative abundance chart, and seven couplets of alternating agglutinated and calcareous dominated facies are evident, which can be grouped into 4 major couplets which broadly conform with the positions of the ostracode Assemblage Zones.

Within the Fossil Cliff Member, two factors appear to be correlated with the foraminiferal distributions. The first of these factors is substrate type, either calcareous or terrigenous, and the second is the parasequences defined from the lithostratigraphy, with a variation in the foraminiferal distribution from the lower parasequence to the top parasequence of the member. This has produced two broad foraminiferal assemblage zones, one of which can be further subdivided.

The first assemblage zone is dominated by agglutinated foraminifera and is found within the terrigenous lithofacies such as the black-grey siltstone and shales (*Al*), sandstone (*Sm*), and silty sandstone (*(S/A)b*). The second assemblage is dominated by foraminifers that secrete calcareous tests and is restricted to the calcareous lithofacies of calcarenite (*Lbs*), calcareous siltstone (*(A/L)bs*), and silty and sandy calcarenite (*(L/A)bs*). The calcareous foraminiferal assemblage can be further subdivided into a calcareous hyaline assemblage and a calcareous porcellanous assemblage. The hyaline and porcellanous assemblages are intermixed and the degree of intermixing varies from the bottom to the top of the member.

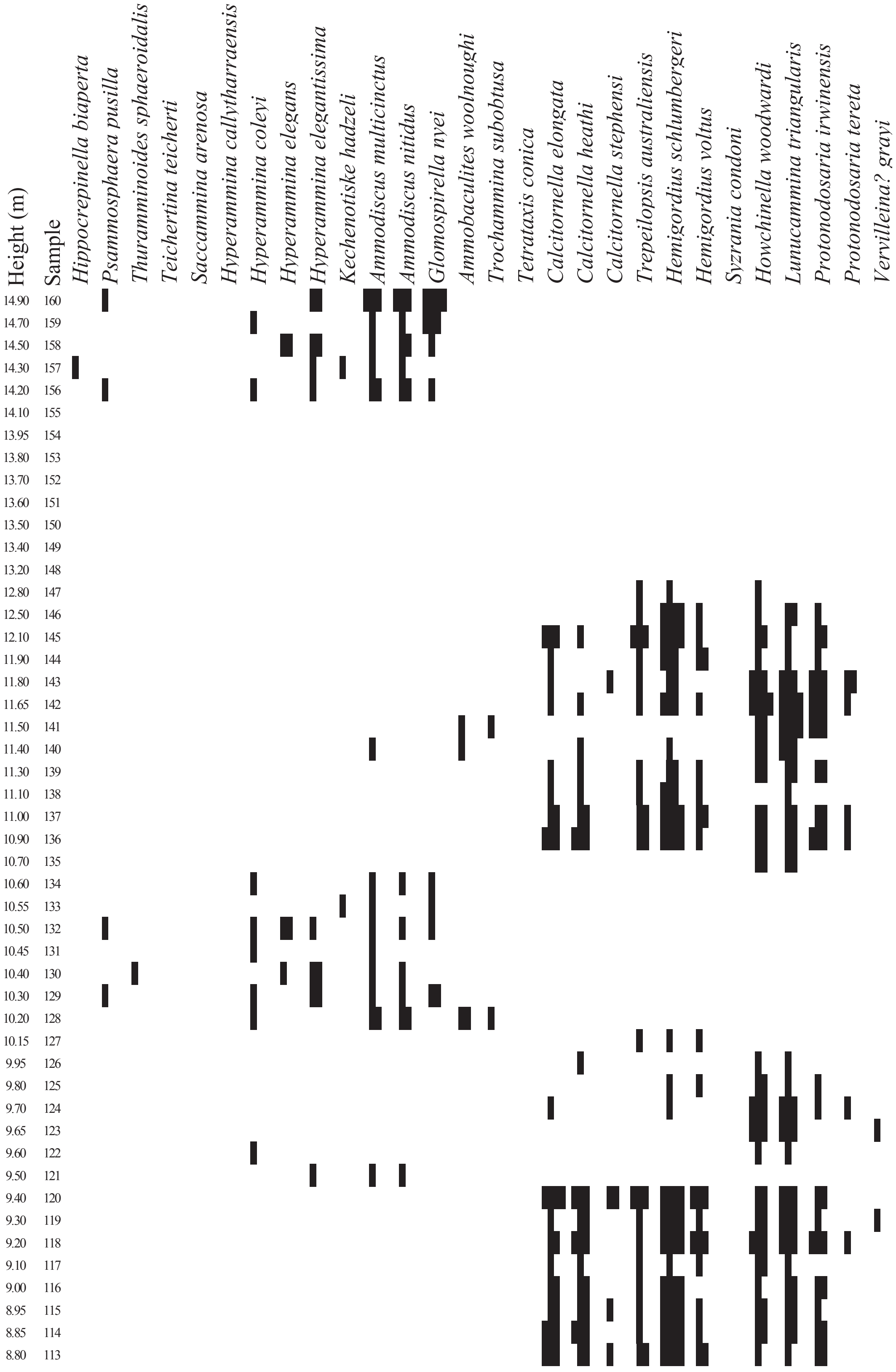

Figure 86. Foraminiferal distribution within the Fossil Cliff Member; line thickness indicates relative abundance of species; height is given as metres above base of Fossil Cliff Member.

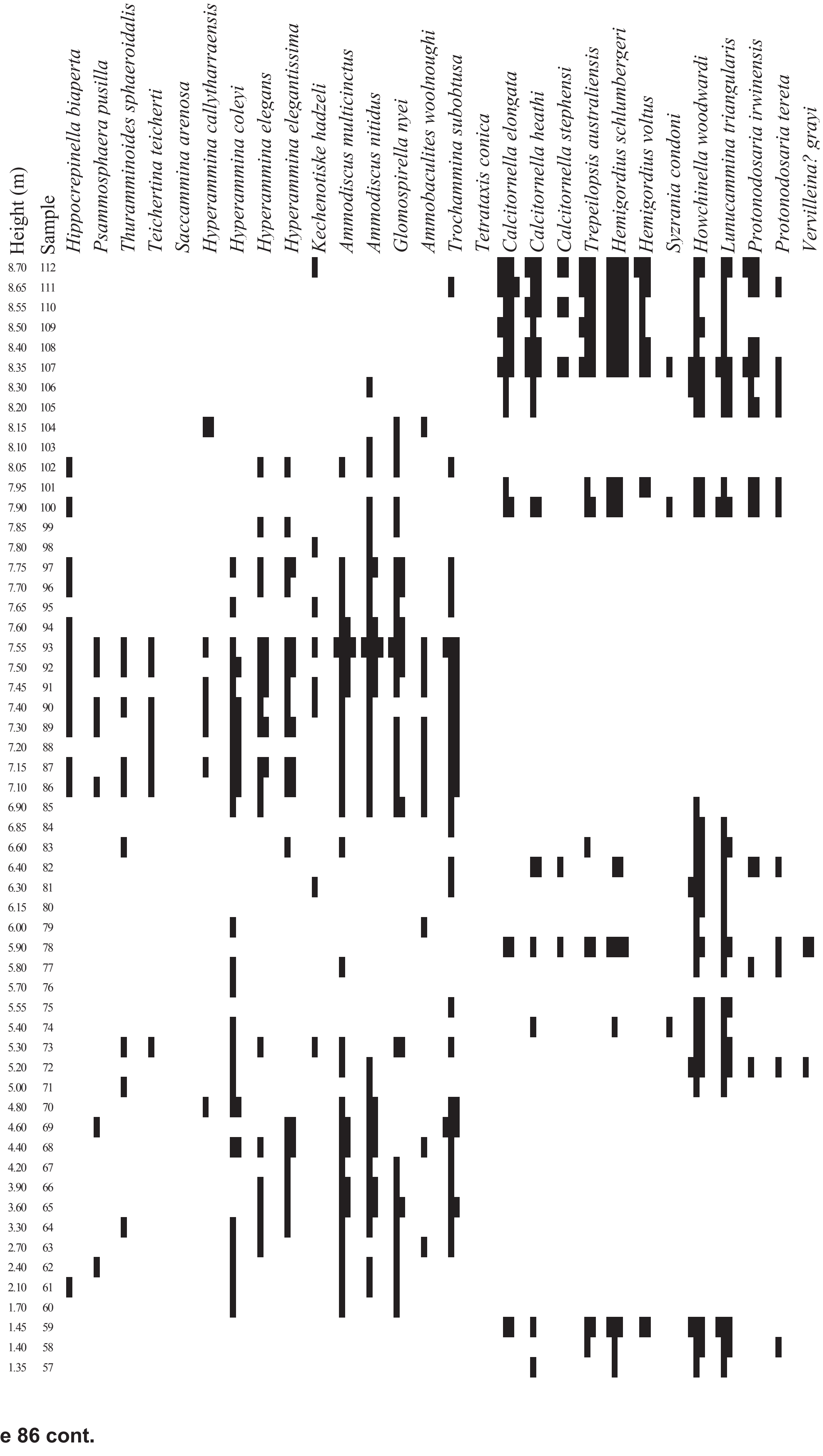

Figure 86 cont.

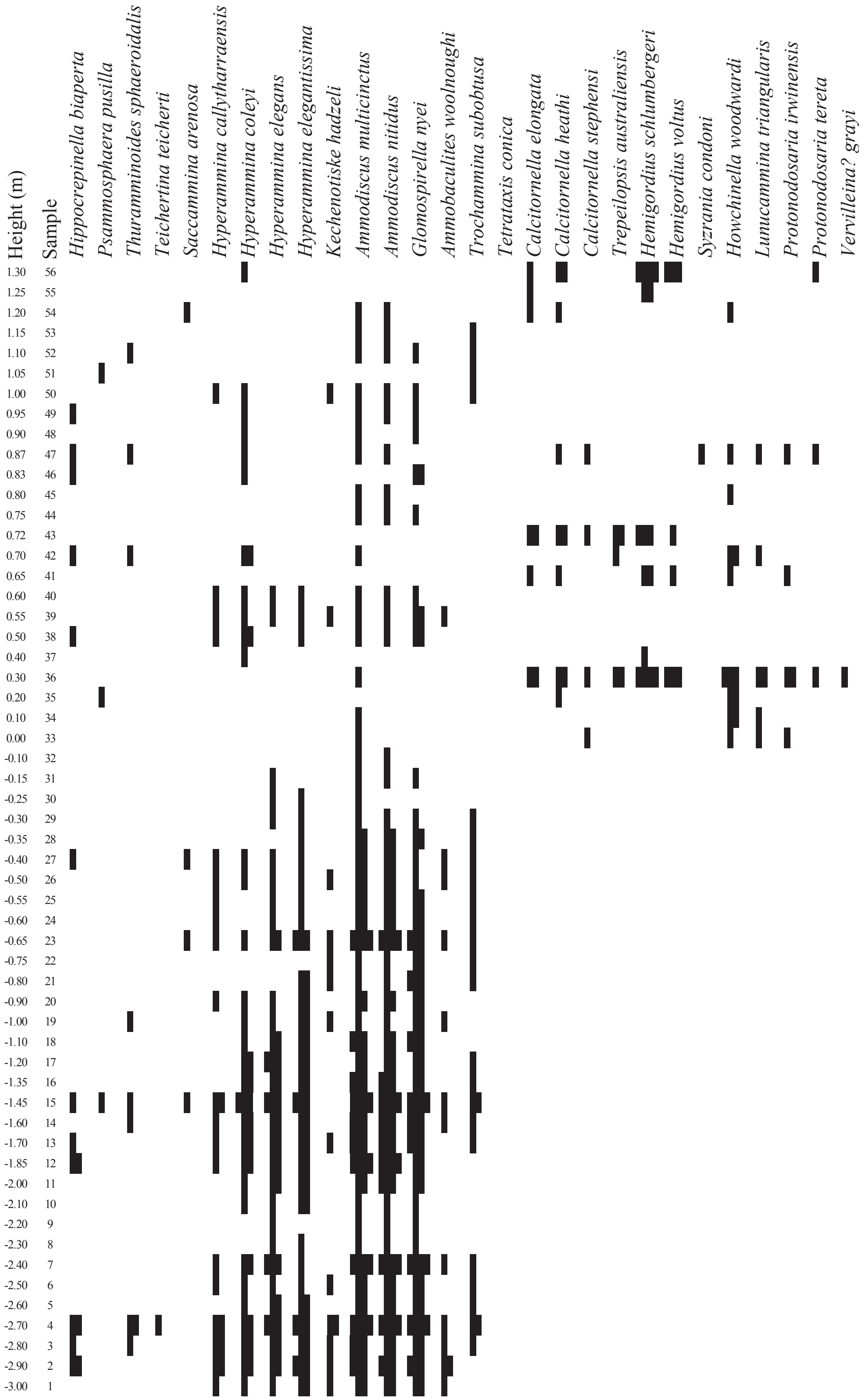

Figure 86 cont.

These assemblages broadly correspond to the palaeoecological assemblages listed by Crespin (1958), who identified an arenaceous assemblage, a calcareous perforate assemblage, and a calcareous imperforate assemblage. Transitions between the agglutinated and calcareous foraminiferal assemblages are generally sharp and are strongly controlled by palaeoenvironmental conditions, whereas the transition between the calcareous hyaline and the calcareous porcellanous foraminiferal assemblages are extremely gradational.

The arenaceous assemblage of Crespin (1958) consisted predominantly of arenaceous foraminifera in a low to medium abundance with moderate diversity. Of the arenaceous genera that range through the Upper Palaeozoic to Holocene, Crespin (1958) noted those that occur abundantly throughout the Permian of Australia are *Hyperammina*, *Ammodiscus*, and *Thurammina*. All three of these genera are known to thrive in cold water, where temperatures most probably have more control on species distribution than depth (Galloway, 1933; Tyszka, 1994; Groves and Wahlman, 1997). The presence of delicate tests of arenaceous foraminifera within the glacial deposits of the Nangetty Formation and the Holmwood Shale in addition to the Grant Group of the Canning Basin suggests the extreme environment under which arenaceous foraminifera survived (Crespin, 1958). The robust forms of other localities indicate cool but not cold waters.

Crespin's (1958) calcareous perforate assemblage consists mainly of the Lagenidae, such as the genera *Protonodosaria*, *Vervilleina*, and *Howchinella*, that thrived in moderately shallow, warm to temperate waters of the open sea. Crespin (1958) assumed that the associated but restricted genus *Lunucammina* survived under similar ecological conditions. *Protonodosaria* and *Vervilleina*, although widely distributed bathymetrically, are common in warm to temperate shallow-water environments, usually interpreted to have been deposited in between 100 to 500 m water depth. *Howchinella*, *Lunucammina*, and *Protonodosaria* dominate the assemblage of calcareous perforate foraminifera of the Fossil Cliff Member and Callytharra Formation, and Crespin (1958) believed that this assemblage suggests open-gulf conditions with temperate waters.

The calcareous imperforate assemblage of Crespin (1958) includes *Hemigordius*, *Calcitornella*, and *Trepeilopsis*, all of which are restricted to the Upper Palaeozoic, and consequently little is known directly about the ecological conditions under which they survived. *Calcitornella* and *Trepeilopsis* are usually found attached to bryozoans, brachiopod shells, or productiid brachiopod spines, and Crespin (1958) believed that their association with bryozoans suggested temperate to warm clear water with adequate circulation. Crespin (1958) recorded a personal communication from Dr J. A. Waters discussing the palaeoecology of *Hemigordius* and *Calcitornella*, in which it was noted that *Hemigordius* and *Calcitornella* tolerated a very precise environment, and with any change of depth, temperature, or salinity, they slowly migrated to more suitable conditions. Provided no distinct unconformities existed, this migration resulted in a considerable vertical range of different genera. A summary of the preferred palaeoenvironments for the main types of foraminifera recorded in this study is given in Table 16.

Hyperammina	Very shallow to shallow, euryhaline, terrigenous muds, epifaunal suspension feeder
Ammodiscus, *Glomospirella*	Very shallow to shallow, euryhaline, terrigenous muds, epifaunal active deposit feeder
Ammobaculites	Very shallow to shallow, euryhaline, terrigenous muds, infaunal detrital and bacterial scavenger
Trochammina	Very shallow to shallow, euryhaline, terrigenous muds, epifaunal active feeder
Textulariids	Shallow water, terrigenous muds, epifaunal active feeder
Encrusting foraminifera	Shallow, normal marine, hard stable substrate, attached, epifaunal suspension feeder
Nodosariid foraminifera	Shallow to offshore, normal marine, soft substrate, epifaunal active feeder

Table 16. Summary of the palaeoenvironmental characteristics of foraminifera found within the Fossil Cliff Member (adapted from Crespin, 1958; Lane, 1964; Stevens, 1966, 1971; Ellison, 1972; Bless, 1973; Buzas, 1974; Scheibnerová, 1980; Melnyk and Maddocks, 1988a, b; Tyszka, 1994; Wightman et al., 1994).

Calcareous benthic foraminifera are sensitive indicators of dissolved oxygen, as there are obvious differences between the characteristics of foraminiferal tests formed under oxic (>1.5 mL/LO$_2$) and dysoxic conditions (0.1-0.3 mL/LO$_2$) (Kaiho, 1994). Common morphological features of foraminifera from oxic environments include thick test walls and large tests. Indicators of dysoxic environments include a thin wall and small test size. Kaiho (1994) also noted that variations in salinity had no major effect on the foraminiferal oxygen requirements.

The cyclic sedimentology of the Fossil Cliff Member, with each cycle composed of a basal shale unit overlain by a carbonate unit, is reflected in the foraminiferal distributions, with a broadly corresponding cyclicity of an agglutinated foraminiferal assemblage overlain by a calcareous foraminiferal assemblage formed what is termed here as a agglutinated-calcareous foraminiferal couplet. Four broad agglutinated and calcareous foraminiferal associations are identified in the Fossil Cliff Member, and these correspond with the four associations defined for the ostracodes. The first of these agglutinated-calcareous foraminiferal couplets commences in the Holmwood Shale. Its base is unknown, but it ends at 1.4 m above the base of the Fossil Cliff Member (samples 1 to 59; identical to Ostracode Assemblage Zone 1); the second couplet is recognised between 1.5 m to 6.8 m above the base of the Fossil Cliff Member (samples 60 to 84; Ostracode Assemblage Zone 2 terminates at sample 85); the third couplet is found between 6.9 m to 10.2 m above the base of the Fossil Cliff Member (samples 85 to 127; corresponding to the top of Ostracode Assemblage Zone 3); and the fourth couplet is from 10.3 m to 12.8 m above the base of the Fossil Cliff Member (samples 128 to 147; identical to Ostracode Assemblage Zone 4); in addition an agglutinated foraminifera fauna is also found between 14.2 m to 14.9 m above the base of the Fossil Cliff Member (samples 156 to 160), at the top of the exposed surface of the type section of the Fossil Cliff Member.

Agglutinated foraminiferal Assemblage Zones

Species within the agglutinated foraminiferal assemblages from the terrigenous sediments of the Fossil Cliff Member, which comprises the lithofacies *Al*, *(S/A)b*, and *Sm*, include *Ammodiscus nitidus*, *A. multicinctus*, *Hyperammina callytharraensis*, *H. coleyi*, *H. elegans*, *Sacammina arenosa*, *Thuramminoides sphaeroidalis*, and *Glomospirella nyei*. A full listing of the species recovered from the agglutinated foraminiferal assemblages is given in Table 17. There is a moderate variation in the species diversity and suprageneric distributions within the individual beds of lithofacies *Al*, although in lithofacies *(S/A)b* and *Sm*, found at the top of the Fossil Cliff Member, there is a marked decrease in the abundance of slender, tubular genera such as *Hyperammina*, with more robust forms such as *Trochammina subobtusa*, *Ammodiscus nitidus*, *A. multicinctus*, *Glomospirella nyei*, and *Thuramminoides sphaeroidalis* being dominant.

Hippocrepinella biaperta
Kechenotiske hadzeli
Saccammina arenosa
Teichertina teicherti
Ammodiscus multicinctus
Ammodiscus nitidus
Glomospirella nyei
Trochammina subobtusa
?Thuramminoides pusilla
Thuramminoides sphaeroidalis
Hyperammina callytharraensis
Hyperammina elegans
Hyperammina elegantissima
Hyperammina coleyi
Ammobaculites woolnoughi

Table 17. Species found in the Agglutinated Foraminiferal Assemblages.

Agglutinated Foraminiferal Assemblage Zone 1

In the first agglutinated foraminiferal fauna, the Assemblage Zone is dominated by species from the Ammodiscoidea and Hippocrepinoidea, which account for 75% of the species present, with the Astrorhizoidea making up a further 13% of the species found in the Assemblage Zone (Figure 87).

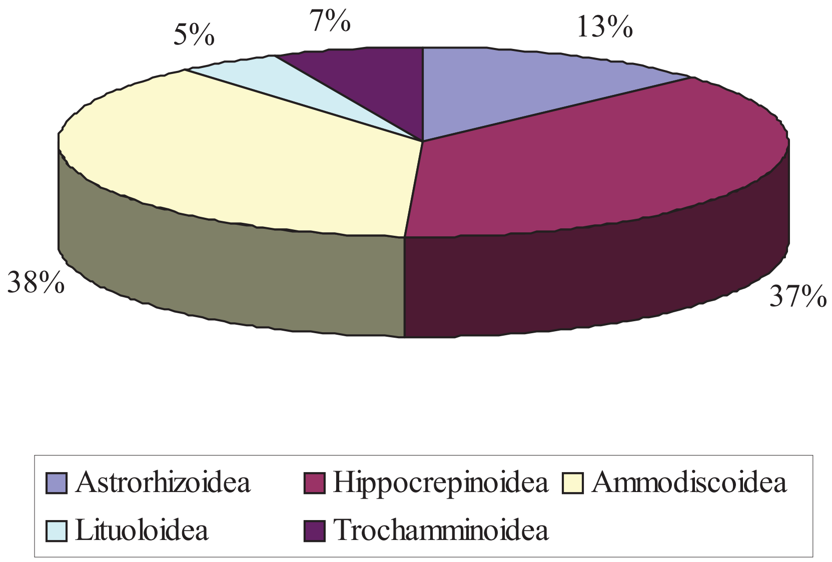

Figure 87. Relative distribution of foraminiferal superfamilies in Agglutinated Foraminiferal Assemblage Zone 1.

The Assemblage Zone is dominated by *Ammodiscus multicinctus*, *A. nitidus*, *Hyperammina coleyi*, and *Glomospirella nyei*. A full listing of the species occurrence frequency within Agglutinated Foraminiferal Assemblage Zone 1 is given in Figure 88.

The agglutinated foraminiferal species that are commonly found within samples from this Assemblage Zone are listed in Table 18.

Ammodiscus multicinctus	*Ammodiscus nitidus*
Hyperammina coleyi	*Glomospirella nyei*
Hyperammina callytharraensis	*Hyperammina elegans*
Hyperammina elegantissima	*Trochammina subobtusa*
Ammobaculites woolnoughi	*Hippocrepinella biaperta*

Table 18. Characteristic species in Agglutinated Foraminiferal Assemblage Zone 1.

The dominance of epifaunal species of *Ammodiscus* and *Hyperammina* within the fauna suggests the main nutrient source for this fauna was obtained through either suspension feeding or through deposit feeding over the surface of the substrate. The infaunal species *Ammobaculites woolnoughi* is present within this Assemblage Zone in significant numbers and characteristic of the Assemblage Zone, indicating that the conditions below the substrate, at least to a depth of 10-15 cm (Wightman et al., 1994), were dysoxic or suboxic. The small numbers of infaunal species in the assemblage, however, indicates that either nutrient or oxygen levels below the substrate were not sufficient to support a diverse or abundant fauna of infaunal agglutinated foraminifera.

The species distribution of this Assemblage Zone suggests that the palaeoenvironment at this time was low enough in oxygen content to inhibit a calcareous foraminiferal fauna from developing, probably within the dysoxic to suboxic zone as some dwarfed calcareous faunas have been recorded from oxic-dysoxic conditions (Jones and Charnock, 1985; Wightman et al., 1994). The water was relatively shallow, and water energy was low. The salinity level may have also been slightly brackish, however there is little evidence apart from the agglutinated foraminifera to substantiate this, and the abundance of agglutinated foraminifera within this Assemblage Zone may be solely a factor of low oxygen levels at the seafloor within the northern Perth Basin at this time.

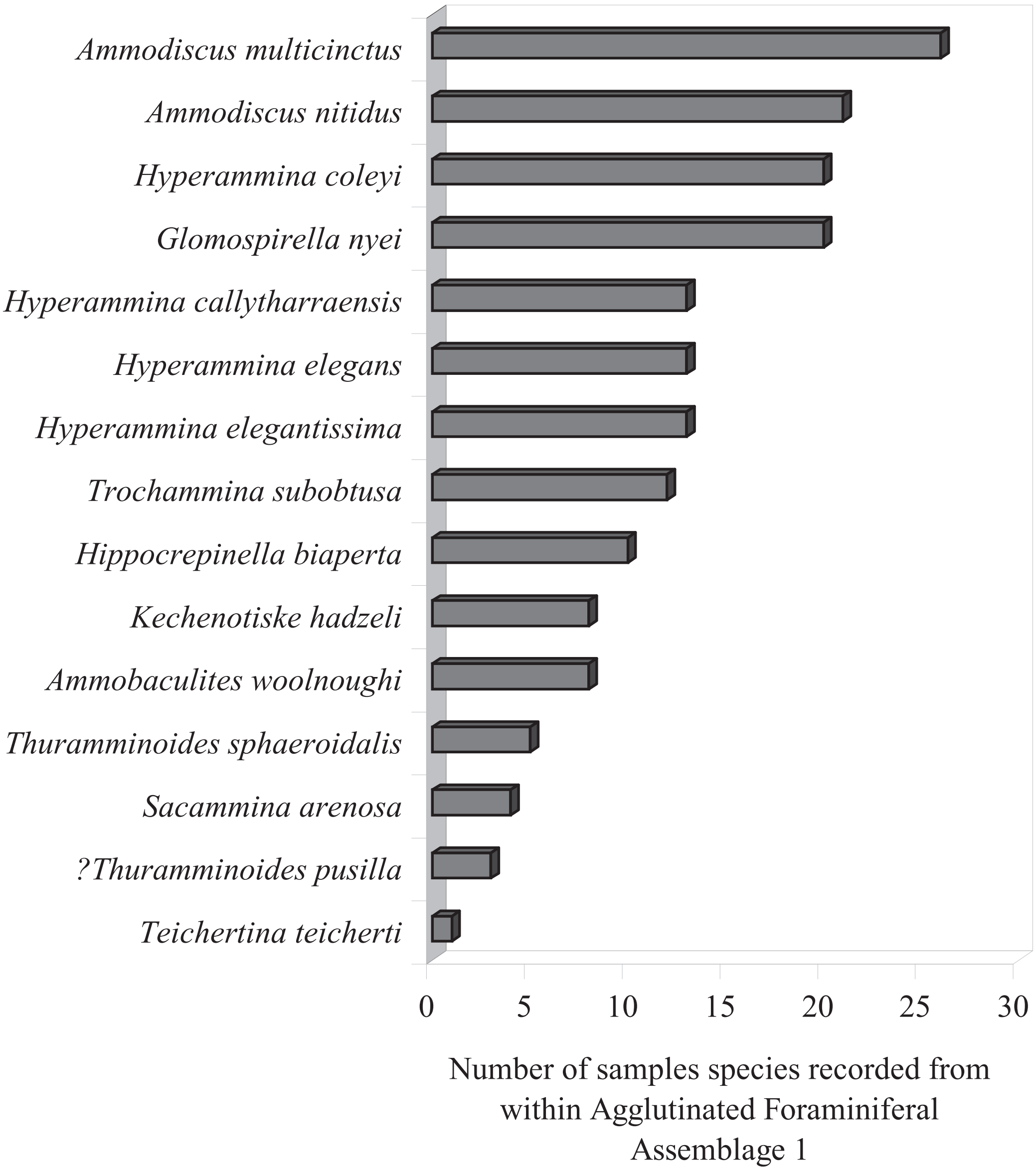

Figure 88. Graph of species occurrence in Agglutinated Foraminiferal Assemblage Zone 1.

Agglutinated Foraminiferal Assemblage Zone 2

The second agglutinated foraminiferal Assemblage Zone shows a similar abundance of species from the Hippocrepinoidea and Ammodiscoidea to that found in Agglutinated Foraminiferal Assemblage Zone 1; however, the abundance of the Trochamminoidea has increased, and the Lituoloidea are almost absent from this Assemblage Zone (Figure 89).

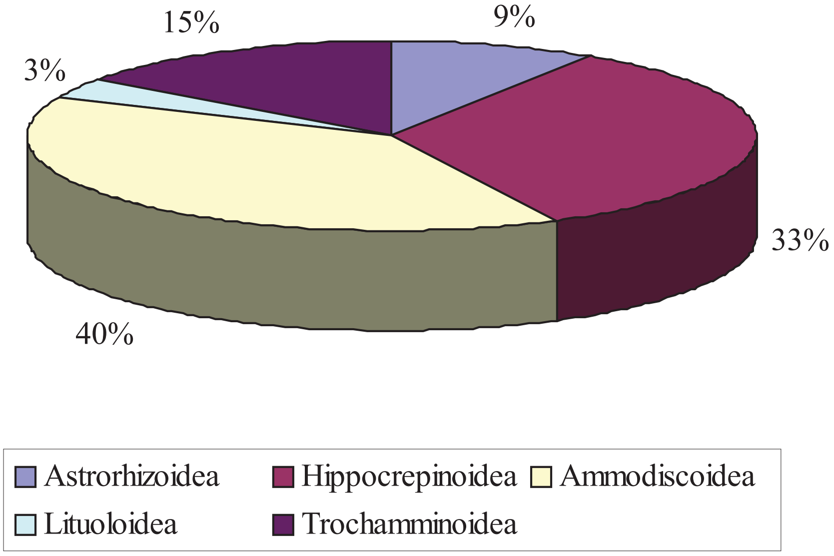

Figure 89. Relative distribution of foraminiferal superfamilies in Agglutinated Foraminiferal Assemblage Zone 2.

The most abundant species within this Assemblage Zone are *Ammodiscus multicinctus*, *A. nitidus*, *Trochammina subobtusa*, *Hyperammina coleyi*, and *Glomospirella nyei*. The abundance of most of the species found in this Assemblage Zone is similar to that in Agglutinated Foraminiferal Assemblage Zone 1, with the exception of *Ammobaculites woolnoughi*, which has become a rarer component of the fauna (Figure 90). The most abundant species of foraminifera found within this Assemblage Zone are listed in Table 19.

Ammodiscus nitidus	*Ammodiscus multicinctus*
Hyperammina coleyi	*Hyperammina elegantissima*
Hyperammina elegans	*Trochammina subobtusa*
Glomospirella nyei	*Thuramminoides sphaeroidalis*

Table 19. Characteristic species in Agglutinated Foraminiferal Assemblage Zone 2.

The abundance of epifaunal genera such as *Ammodiscus*, *Hyperammina*, *Glomospirella*, and *Trochammina* indicate that seafloor conditions were very similar to Agglutinated Foraminiferal Assemblage Zone 1, where epifaunal species also flourished with a similar level of diversity, with the oxygen levels in the dysoxic to suboxic range (0.1-1.5 mL/LO_2), and the nutrient levels in the water sufficiently high to support a moderately diverse fauna with low populations. The decrease in abundance of infaunal foraminiferal genera, such as *Ammobaculites,* within this Assemblage Zone suggests a change in the substrate conditions that adversely affected those genera that inhabited the muddy substrate (Wightman et al., 1994). The likely factor affecting this is a change in the oxygen levels in the substrate, towards a more anoxic environment below the surface of the substrate (Wightman et al., 1994).

Hyperammina callytharraensis, which was a common element in the first Assemblage Zone, recognised in 15 of the samples, is only found within one of the samples from Agglutinated Foraminiferal Assemblage Zone 2. *H. callytharraensis* is a large, robust form that agglutinates fine- to medium-grained quartz grains to form its test. It is likely that its decrease in abundance is related to a change in either sea-level or substrate type, as the other species of *Hyperammina*, which except for *H. coleyi*, are finely agglutinated, slender forms display a relative abundance in this fauna that is similar to their abundance in Agglutinated Foraminiferal Assemblage Zone 1.

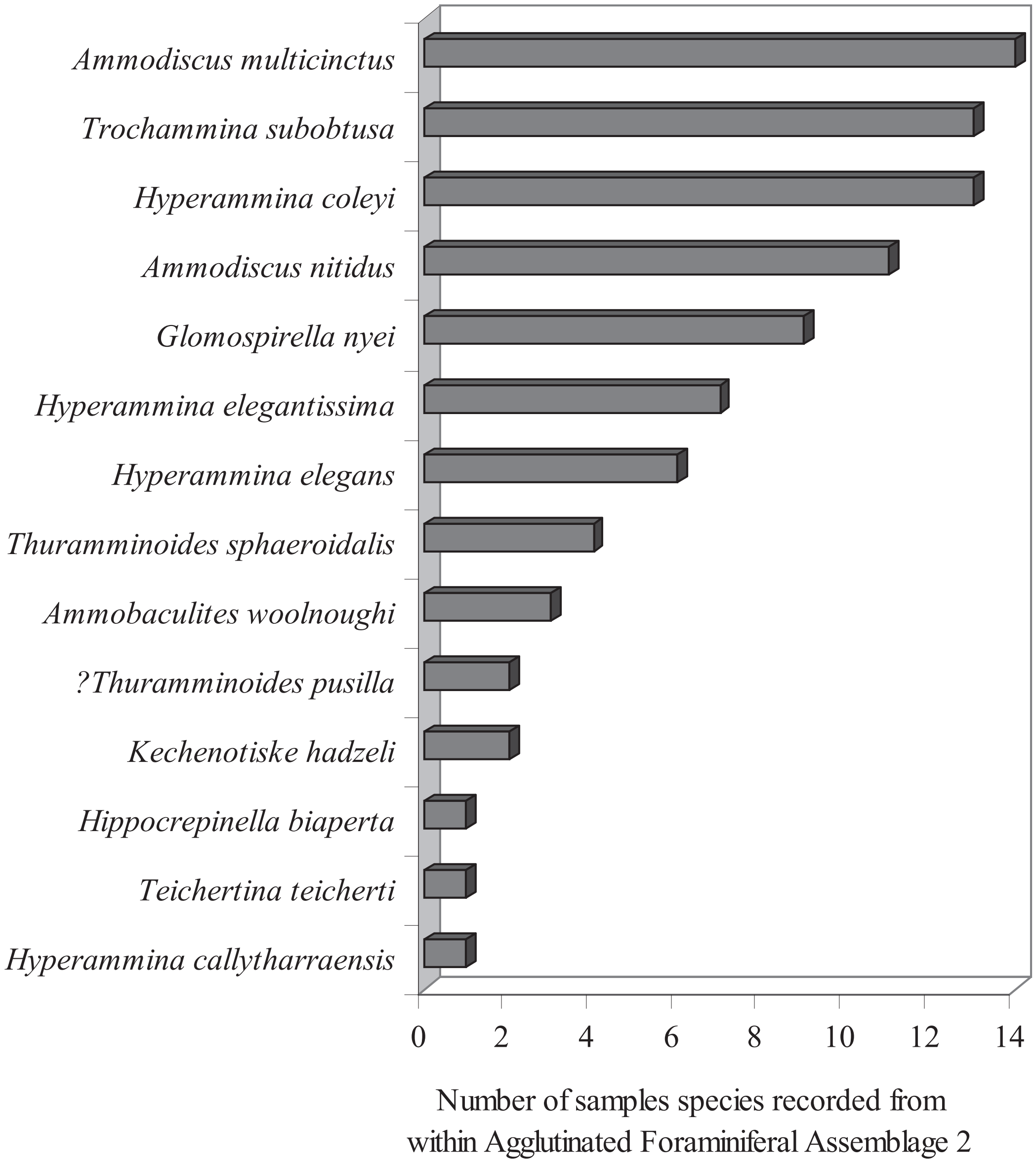

Figure 90. Graph of species occurrence in Agglutinated Foraminiferal Assemblage Zone 2.

Agglutinated Foraminiferal Assemblage Zone 3

In Agglutinated Foraminiferal Assemblage Zone 3 the Assemblage Zone is predominantly comprised of species from the superfamilies Astrorhizoidea, Hippocrepinoidea, and Ammodiscoidea, which combined account for 84% of the species found within this Assemblage Zone (Figure 91). The abundance of species from the Astrorhizoidea and Hippocrepinoidea has increased through the first two Assemblage Zones to now be a significant component of the foraminiferal fauna.

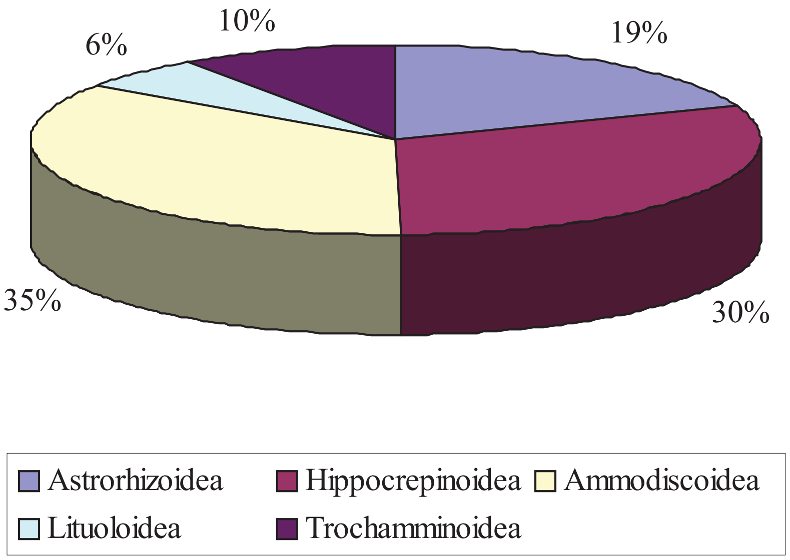

Figure 91. Relative distribution of foraminiferal superfamilies in Agglutinated Foraminiferal Assemblage Zone 3.

The foraminiferal fauna in Agglutinated Foraminiferal Assemblage Zone 3 is predominantly comprised of *Ammodiscus multicinctus*, *A. nitidus*, *Glomospirella nyei*, and *Trochammina subobtusa*. The common species found within this Assemblage Zone are listed in Table 20.

Ammodiscus nitidus	*Ammodiscus multicinctus*
Glomospirella nyei	*Trochammina subobtusa*
Hippocrepinella biaperta	*Hyperammina coleyi*
Hyperammina elegans	*Hyperammina elegantissima*

Table 20. Characteristic species in Agglutinated Foraminiferal Assemblage Zone 3.

Species of *Hyperammina* have slightly decreased in abundance in this Assemblage Zone relative to the underlying two Assemblage Zones, although they are still common elements of the fauna. Species of Astrorhizoidea such as *Hippocrepinella biaperta* and *Teichertina teicherti* are frequent throughout this Assemblage Zone, whereas in the lower two Assemblage Zones they were rare to infrequent. *Ammobaculites woolnoughi* has been recovered from roughly half the samples taken from this Assemblage Zone and its abundance within the assemblage is similar to its abundance in Agglutinated Foraminiferal Assemblage Zone 1.

The increase in the abundance of the infaunal dwelling species *Ammobaculites woolnoughi* suggests a change in the substrate environment back to conditions similar to those found in Agglutinated Foraminiferal Assemblage Zone 1, where the substrate was inferred to have been within the dysoxic to suboxic oxygenation range. The abundance of epifaunal agglutinated foraminifera in the Assemblage Zone indicates that the palaeoenvironmental conditions on the sea-floor remained generally similar to those found within the first two Assemblage Zones. The reduction in abundance of species of *Hyperammina*, which feed through suspension filtering (Wightman et al. 1994), may indicate a change in water current conditions, reducing the amount of nutrients in the water that were available through filter feeding mechanisms.

The composition of the Assemblage Zone suggests deposition in shallow-marine conditions under dysoxic to suboxic conditions, with a possible brackish water component, similar to the palaeoenvironment proposed for Agglutinated Foraminiferal Assemblage Zone 1.

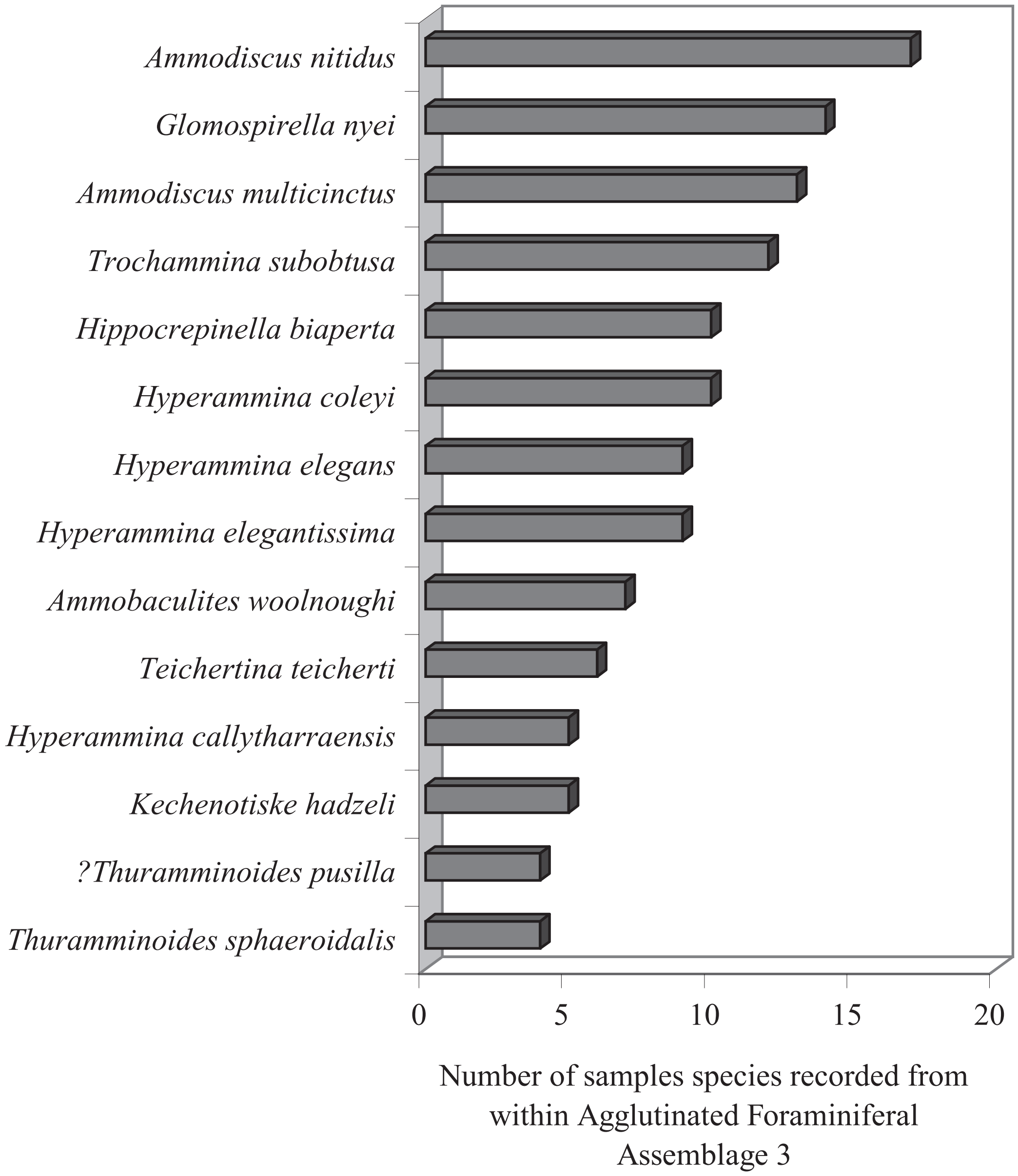

Figure 92. Graph of species occurrence in Agglutinated Foraminiferal Assemblage Zone 3.

Agglutinated Foraminiferal Assemblage Zone 4

Agglutinated Foraminiferal Assemblage Zone 4 lies near the top of the Fossil Cliff Member and is the last Assemblage Zone within a complete agglutinated-calcareous foraminiferal couplet. The Assemblage Zone is mainly composed of species from the Ammodiscoidea and Hippocrepinoidea, with the Lituoloidea, Astrorhizoidea, and Trochamminoidea forming a minor component of the Assemblage Zone (Figure 93).

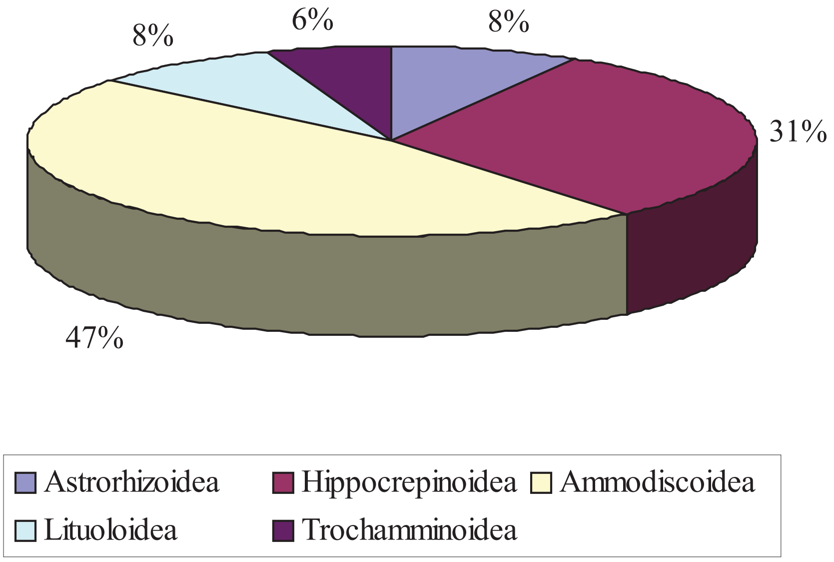

Figure 93. Relative distribution of foraminiferal superfamilies in Agglutinated Foraminiferal Assemblage Zone 4.

The fauna within this Assemblage Zone has less diversity and abundance of species than that in the three underlying Assemblage Zones, with only eleven species recorded from this Assemblage Zone compared to fifteen from Agglutinated Foraminiferal Assemblage Zone 1. *Ammodiscus multicinctus* is the most common species within this Assemblage Zone, recorded from eight of the nine samples that contain this fauna. *Hyperammina coleyi*, *A. nitidus*, and *Glomospirella nyei* comprise the other species that are found in approximately half or more of the samples. The species that are common within this Assemblage Zone are listed in Table 21.

Ammodiscus nitidus	*Ammodiscus multicinctus*
Hyperammina coleyi	*Hyperammina elegantissima*
Glomospirella nyei	*Ammobaculites woolnoughi*

Table 21. Characteristic species in Agglutinated Foraminiferal Assemblage Zone 4.

Hyperammina callytharraensis, *Teichertina teicherti*, and *Hippocrepinella biaperta* are notably absent from this Assemblage Zone, especially as they were among the more common species found within Agglutinated Foraminiferal Assemblage Zone 3. Apart from the species listed in Table 21, the foraminiferal fauna within this Assemblage Zone is very sparse, with most species only recorded from one or two samples from the Assemblage Zone (Figure 94).

Despite the decrease in diversity, the relative abundance of infaunal to epifaunal species is similar to that found in Agglutinated Foraminiferal Assemblage Zone 1 and 2, indicating that the oxygen conditions in the substrate remained in the dysoxic to suboxic range. The decrease in abundance and diversity of the agglutinated foraminiferal fauna suggests that the palaeoenvironmental conditions became more inhospitable to the foraminiferal fauna, either through a decrease in the level of oxygen or nutrients in the area, or through an influx of brackish to fresh water during deposition.

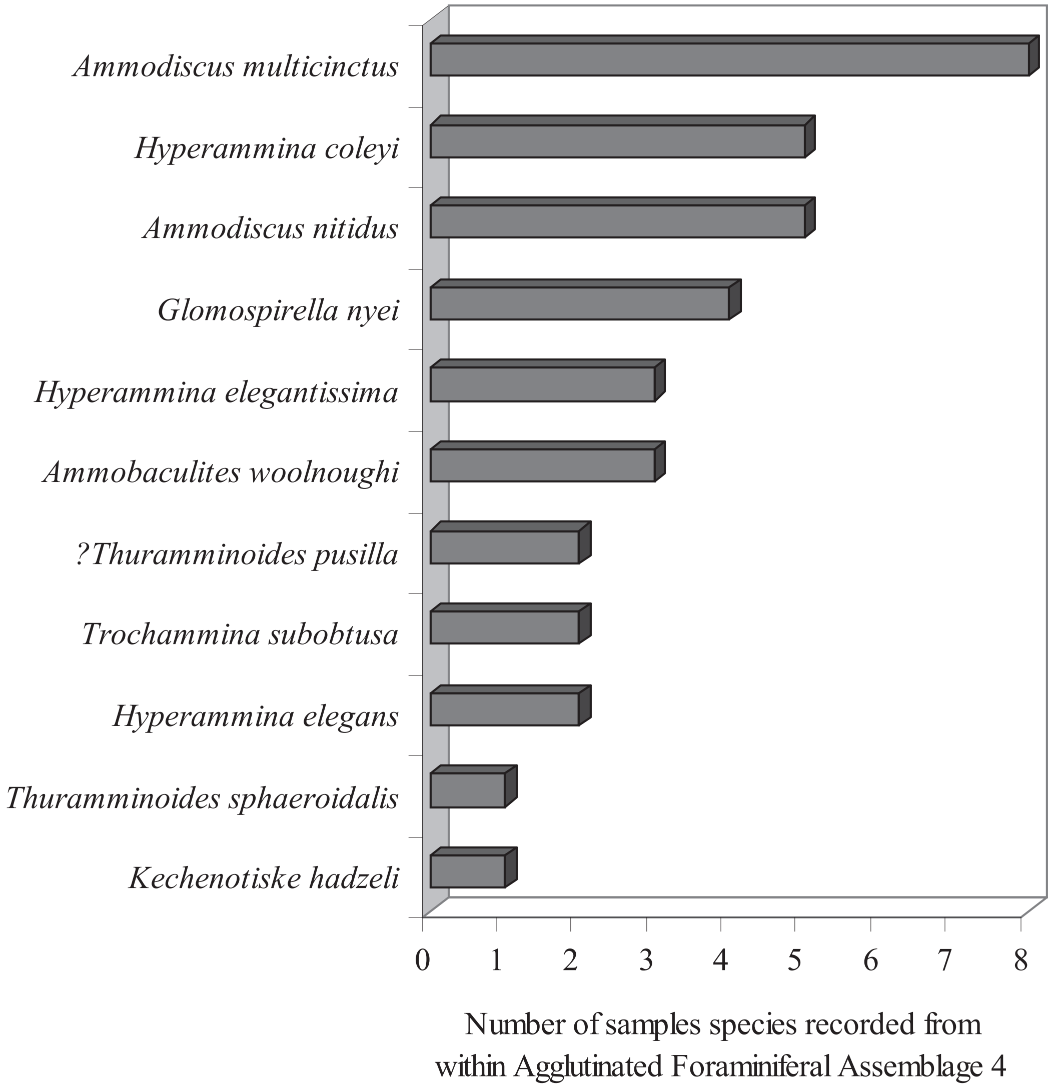

Figure 94. Graph of species occurrence in Agglutinated Foraminiferal Assemblage Zone 4.

Agglutinated Foraminiferal Assemblage Zone 5

Agglutinated Foraminiferal Assemblage Zone 5 consists of a sparse agglutinated foraminiferal fauna recovered from five samples at the top of the type section of the Fossil Cliff Member from a silty medium-grained sandstone. This Assemblage Zone is dominated by Ammodiscoidea, with the Hippocrepinoidea and Astrorhizoidea forming the remainder of the Assemblage Zone (Figure 95).

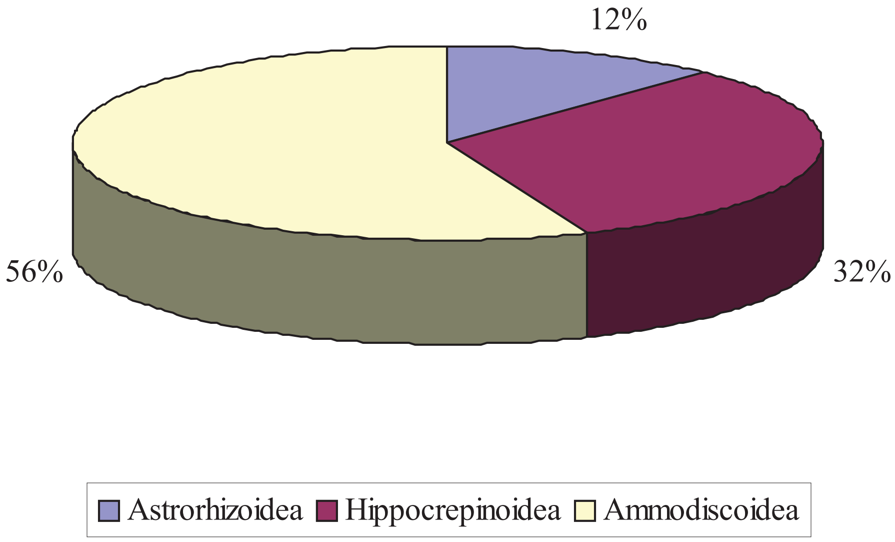

Figure 95. Relative distribution of foraminiferal superfamilies in Agglutinated Foraminiferal Assemblage Zone 5.

The diversity of this fauna is low, with only nine of the fifteen agglutinated foraminiferal species recorded from the Fossil Cliff Member present, and of those, three are rare within this Assemblage Zone. The Assemblage Zone is mainly composed of *Ammodiscus multicinctus*, *A. nitidus*, *Glomospirella nyei*, and *Hyperammina elegantissima*, although the abundance of specimens from these species is low relative to the abundance in the first four Agglutinated Foraminiferal Assemblage Zones. The most frequent foraminiferal species recovered from this Assemblage Zone are listed in Table 22.

Ammodiscus nitidus	*Ammodiscus multicinctus*
Glomospirella nyei	*Hyperammina elegantissima*
Hyperammina coleyi	*?Thuramminoides pusilla*

Table 22. Characteristic species in Agglutinated Foraminiferal Assemblage Zone 5.

Ammobaculites woolnoughi, which has been present in the other Assemblage Zones of the Fossil Cliff Member, is absent from this Assemblage Zone along with *Trochammina subobtusa*. Agglutinated Foraminiferal Assemblage Zone 5 is characterised by its low diversity and abundance.

The absence of infaunal feeders from the Assemblage Zone suggests that substrate conditions were unsuitable, and that paucity of epifaunal specimens indicates that conditions on the surface of the substrate were less than ideal for agglutinated foraminifera. The lack of calcareous foraminifera and ostracodes in the fauna indicates that the palaeoenvironmental conditions, such as dissolved oxygen levels or salinity in the water, were unfavourable to them. This Assemblage Zone may have been deposited in a shallow deltaic environment, with a significant brackish water component, in addition to possibly low dissolved oxygen levels in the dysoxic to suboxic range (0.1-1.5 mL/LO_2).

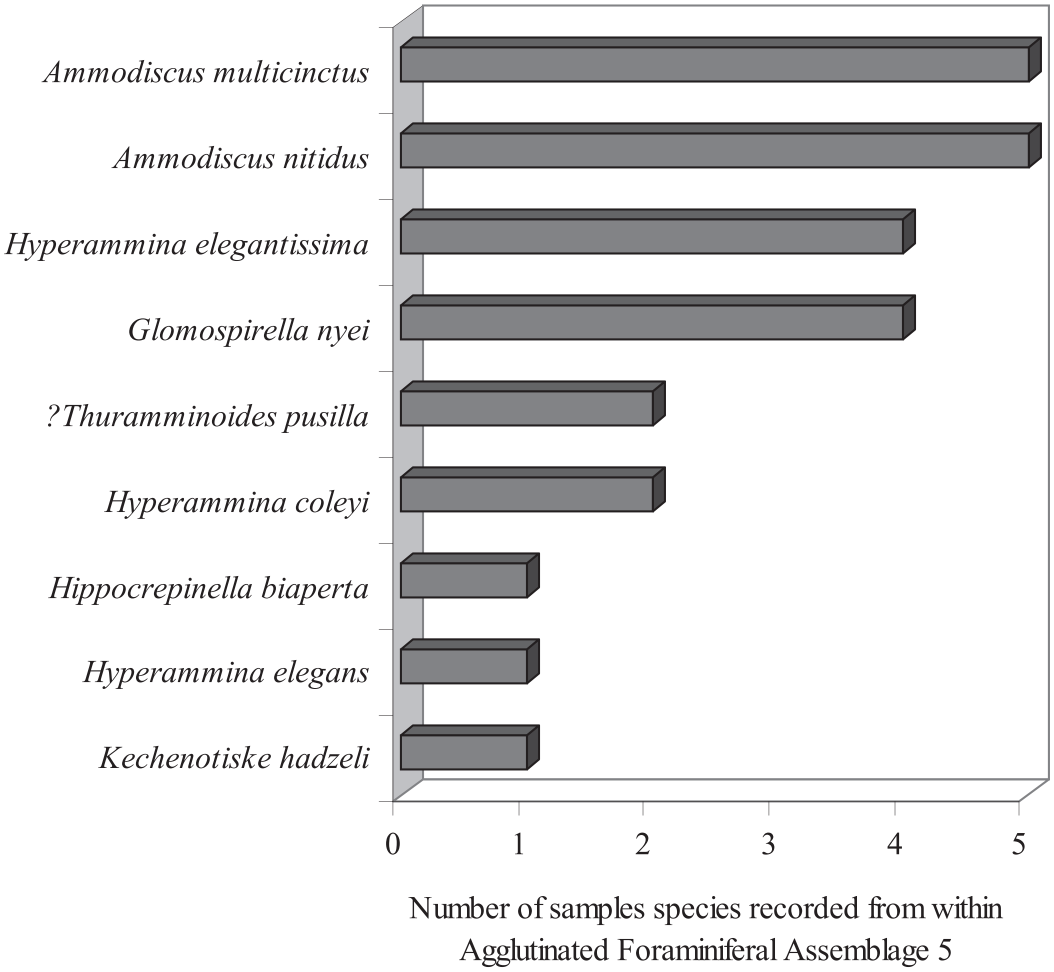

Figure 96. Graph of species occurrence in Agglutinated Foraminiferal Assemblage Zone 5.

Overall features of the Agglutinated Foraminiferal Assemblage Zones

Overall, the more than 85% of the agglutinated foraminiferal species present throughout the Fossil Cliff Member belong to the Ammodiscoidea, Hippocrepinoidea, or Astrorhizoidea (Figure 97). This association remains moderately constant throughout the Fossil Cliff Member, dominated throughout by *Ammodiscus multicinctus*, *A. nitidus*, *Hyperammina coleyi*, *H. elegantissima*, and *Glomospirella nyei*.

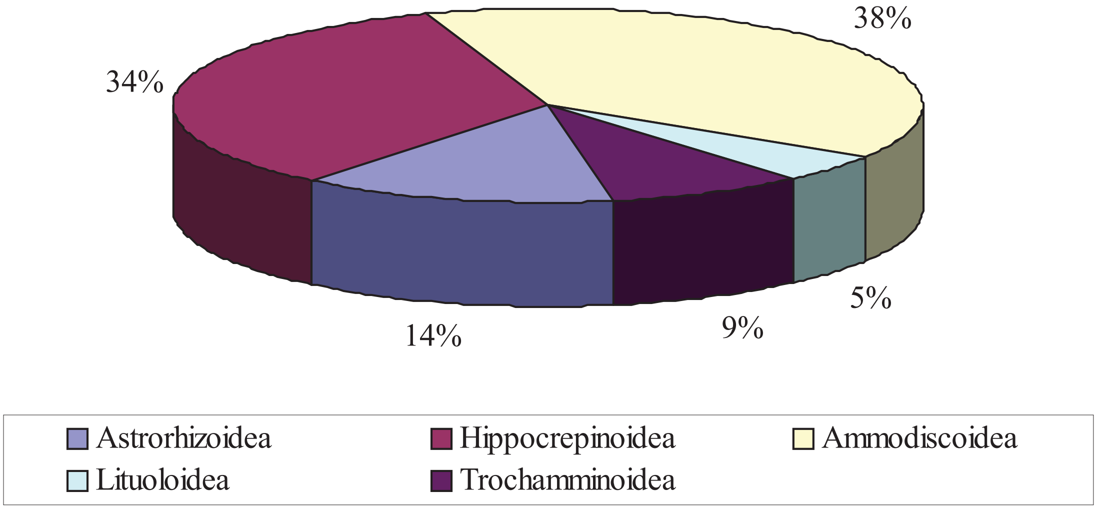

Figure 97. Relative distribution of foraminiferal superfamilies throughout the Agglutinated Foraminiferal Assemblage Zones.

Hyperammina callytharraensis, which has been recorded in formations younger than the Fossil Cliff Member (Crespin, 1958; Scheibnerová, 1982; Palmieri, 1994, 1998), is recorded only from the first and second Assemblage Zones of the Fossil Cliff Member, and its disappearance is probably a result of unfavourable palaeoenvironmental conditions. This trend is noted in a number of other species such as *Sacammina arenosa*, which has only recorded from Agglutinated Foraminiferal Assemblage Zone 1, and *Teichertina teicherti*, which is absent from Agglutinated Foraminiferal Assemblage Zones 4 and 5. These absences coincide with a broader decline in both diversity and abundance within the Agglutinated Foraminiferal Assemblage Zones.

The absence of benthic calcareous foraminifera within these Assemblage Zones and the dominance of epifaunal agglutinated forms indicate these agglutinated foraminiferal Assemblage Zones probably inhabited dysoxic to suboxic waters with a dysoxic to anoxic substrate (Ludbrook, 1956; Kaiho, 1994; Tyszka 1994; Wignall, 1994). The lituolid *Ammobaculites woolnoughi*, which is infrequent throughout most of the shale beds of the Fossil Cliff Member, although not present within the topmost Assemblage Zone, is thought to live infaunally and fed on detritus, a habitat and feeding strategy that suggests high ambient suspended particulate matter concentrations during deposition, which may be associated with estuarine to marine transition zones (Jones and Charnock, 1985; Wightman et al. 1994).

Towards the top of the Fossil Cliff Member, palaeoenvironmental conditions became less favourable to many of the agglutinated foraminiferal species, especially within the silty fine- to medium-grained quartzose sandstones (*Sm*) at the top of the member within Agglutinated Foraminiferal Assemblage Zone 5. This change in the fauna of the agglutinated foraminiferal Assemblage Zones reflects either a decrease in oxygen levels or salinity, with a decrease in salinity more likely given the nature of the sediment the assemblage was recovered from, which is likely to have been transported by alluvial processes (Le Blanc Smith and Mory, 1995).

Calcareous Foraminiferal Assemblage Zones

The calcareous lithofacies, *Lbs, (A/L)bs*, and *(L/A)bs*, of the Fossil Cliff Member contains a varied fauna of calcareous benthic foraminifera, which can be divided into two groups, the calcareous hyaline foraminifera and the calcareous porcellanous foraminifera. Four Assemblage Zones of calcareous foraminifera have been identified, and of these the first, third, and to a lesser degree the fourth are dominated by calcareous porcellanous species, while the second is dominated by calcareous hyaline species.

The characteristic species of the calcareous hyaline foraminifera are *Howchinella woodwardi*, *Lunucammina triangularis*, and *Protonodosaria irwinensis*. Within the calcareous porcellanous foraminifera, the characteristic species are *Hemigordius schlumbergeri*, *H. voltus*, *Calcitornella heathi*, *C. stephensi*, and *Trepeilopsis* *australiensis*. A full listing of the foraminiferal species recorded from the Calcareous Foraminiferal Assemblage Zones is given in Table 23.

Calcitornella stephensi
Calcitornella heathi
Syzrania condoni
Hemigordius voltus
Tetrataxis conica
Protonodosaria tereta
Protonodosaria irwinensis
Calcitornella elongata
Trepeilopsis australiensis
Hemigordius schlumbergeri
Vervilleina? grayi
Howchinella woodwardi
Lunucammina triangularis

Table 23. Species found the Calcareous Foraminiferal Assemblage Zones.

Calcareous Foraminiferal Assemblage Zone 1

The basal calcareous foraminiferal Assemblage Zone of the Fossil Cliff Member is dominated by species from the superfamily Cornuspiroidea, which accounts for 57% of the species recorded from the Assemblage Zone. The Geinitzinoidea (29%) and Nodosarioidea (13%) form most of the remainder of the Assemblage Zone, with a small component (1%) coming from the superfamily Robuloidoidea (Figure 98).

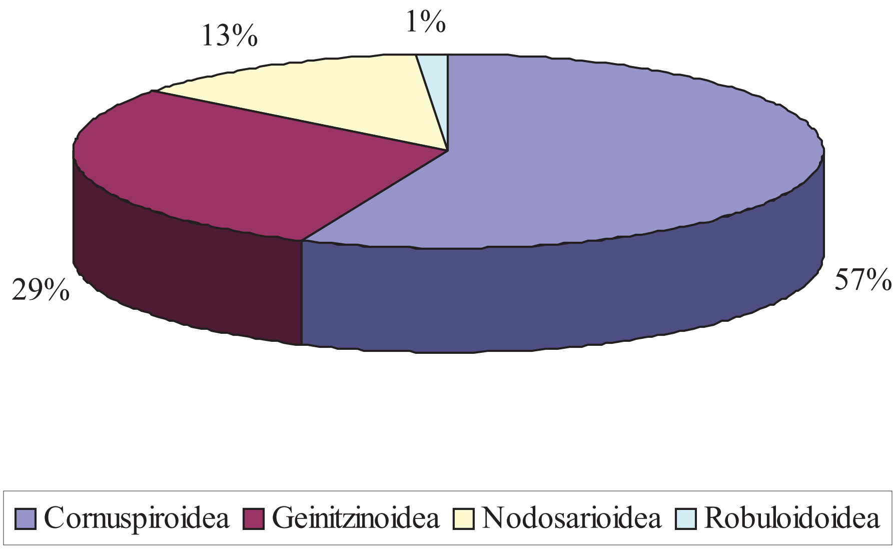

Figure 98. Relative distribution of foraminiferal superfamilies in Calcareous Foraminiferal Assemblage Zone 1.

The Assemblage Zone is dominated by the geinitzinoidean species *Howchinella woodwardi*, with *Calcitornella heathi*, *C. elongata*, *Hemigordius schlumbergeri,* and *Lunucammina triangularis* also abundant within the Assemblage Zone. A list of the most common foraminifera from this Assemblage Zone is given in Table 24, and a full listing of the species recovered from the Assemblage Zone along with their frequency in samples taken from within the Assemblage Zone is illustrated in Figure 99.

Trepeilopsis australiensis	*Calcitornella heathi*
Howchinella woodwardi	*Calcitornella elongata*
Hemigordius schlumbergeri	*Lunucammina triangularis*
Hemigordius voltus	

Table 24. Characteristic species in Calcareous Foraminiferal Assemblage Zone 1.

The overall dominance of the robust, thick-shelled calcareous porcellanous species such as *Calcitornella heathi*, *C. elongata*, *Hemigordius schlumbergeri*, *H. voltus*, and *Trepeilopsis australiensis*, indicates that water conditions were oxic (>1.5 mL/LO_2), water salinity was normal marine (about 35 parts per thousand), and the substrate depth was shallow-marine. The presence of these thick-walled porcellanous species also indicates that there was an abundance of dissolved carbonate in the water to allow them to secrete their tests. The encrusting porcellanous species such as *Trepeilopsis australiensis*, *Calcitornella heathi*, *C. elongata*, and *C. stephensi* suggests that the substrate was firm, however the majority of these species are found encrusting brachiopod spines or shells rather than the substrate, so this may indicate that the substrate during deposition was not a preferred medium for attachment for these species. The nodosarioidean species *Protonodosaria irwinensis*, *P. tereta*, and *Vervilleina? grayi* are also present in a number of samples from this Assemblage Zone. These species prefer a soft muddy substrate, so this, in conjunction with the attachment habits of the encrusting foraminifera, indicates that the substrate was probably soft calcareous muds.

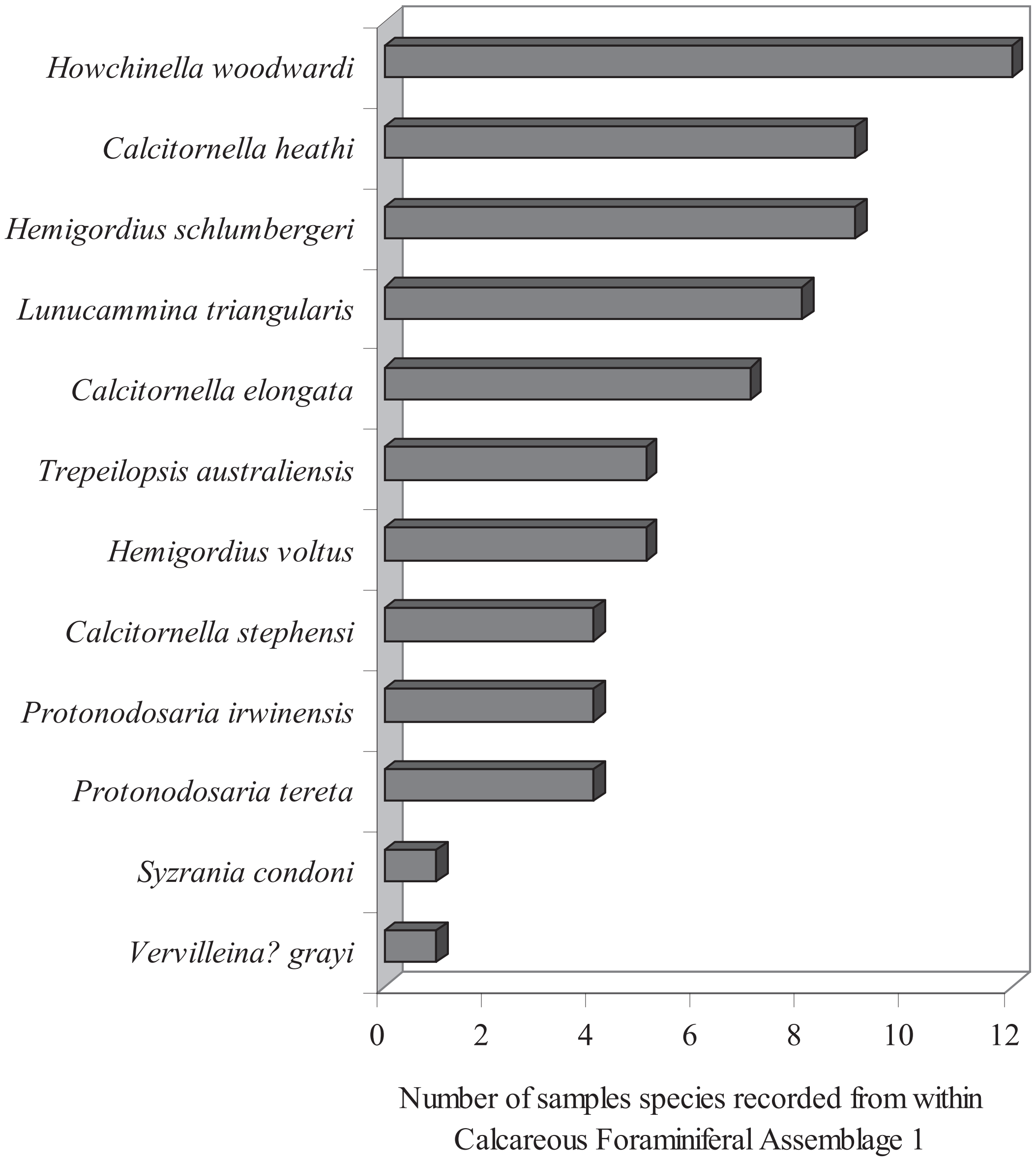

Figure 99. Graph of species occurrences in Calcareous Foraminiferal Assemblage Zone 1.

Calcareous Foraminiferal Assemblage Zone 2

The second calcareous foraminiferal Assemblage Zone is dominated by the superfamily Geinitzinoidea, which forms 55% of the species distribution, and with the Nodosarioidea, the calcareous hyaline species make up over 70% of the species distribution within the Assemblage Zone (Figure 100). The Cornuspiroidea make up a further quarter of the distribution with the Robuloidoidea (2%) and Tetrataxoidea (2%) forming the remainder of the Assemblage Zone.

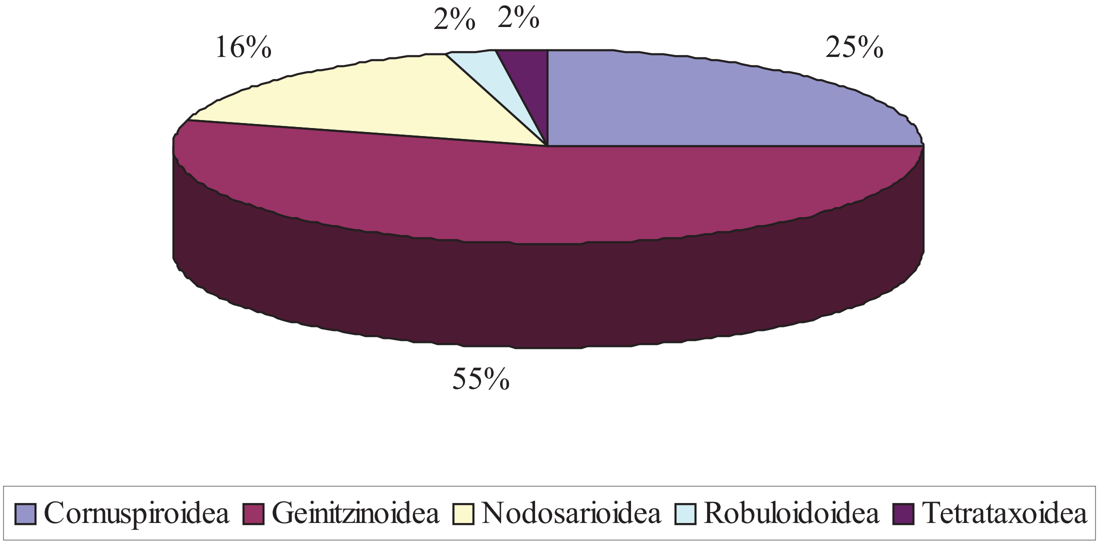

Figure 100. Relative distribution of foraminiferal superfamilies in Calcareous Foraminiferal Assemblage Zone 2.

The Assemblage Zone contains a diverse fauna with twelve foraminiferal species recorded, and the most common of these are listed in Table 25. A full listing of the species found within the Assemblage Zone and their relative occurrence is given in Figure 101.

Howchinella woodwardi	*Calcitornella heathi*
Calcitornella stephensi	*Hemigordius schlumbergeri*
Lunucammina triangularis	

Table 25. Characteristic species in Calcareous Foraminiferal Assemblage Zone 2.

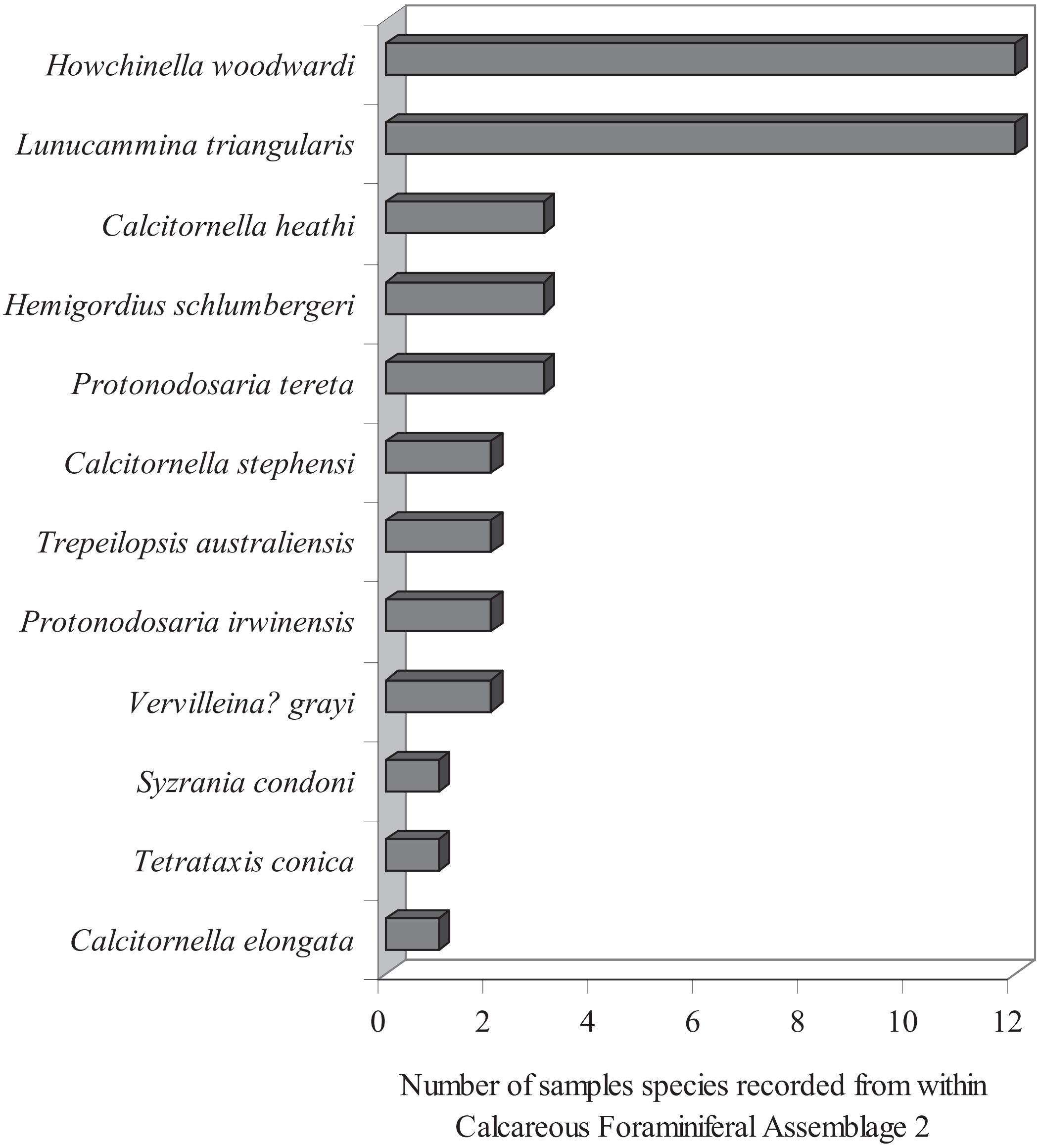

Figure 101. Graph of species occurrences in Calcareous Foraminiferal Assemblage Zone 2.

The Assemblage Zone is dominated by the geinitzinoidean species *Howchinella woodwardi* and *Lunucammina triangularis*, which are found in almost all the calcareous samples taken from this Assemblage Zone and are abundant within each individual sample. The cornuspiroidean species *Calcitornella heathi*, *C. stephensi*, *Trepeilopsis australiensis*, and *Hemigordius schlumbergeri* are minor components of the foraminiferal fauna, along with the nodosarioideans *Protonodosaria tereta*, *P. irwinensis*, and *Vervilleina? grayi*. In addition, the rare species *Tetrataxis conica* and *Syzrania condoni* are recorded from samples within this Assemblage Zone.

The dominance of the geinitzinoidean foraminifera indicates that the palaeoenvironment during the deposition of this Assemblage Zone was probably normal marine conditions in shallow water. The reduction of the abundance of calcareous porcellanous foraminifera is either due to conditions that did not favour them, such as a lack of suitable surfaces for attachment, or palaeoenvironmental conditions that encouraged the development of geinitzinoidean foraminifera such as an algal rich substrate.

Calcareous Foraminiferal Assemblage Zone 3

Calcareous Foraminiferal Assemblage Zone 3 displays a similar distribution of superfamilies within the Assemblage Zone to that of Calcareous Foraminiferal Assemblage Zone 1, with species belonging to the Cornuspiroidea forming 56% of the recorded species. The Geinitzinoidea and Nodosarioidea combined make up 42% of the recorded species, with species from the Robuloidoidea and Tetrataxoidea making up the remaining 2% (Figure 102).

Thirteen species have been recorded from this Assemblage Zone, eight of which are found in more than half the samples. The most common species from Calcareous Foraminiferal Assemblage Zone 3 are listed in Table 26, and a full listing of the species recorded and their sample frequency is given in Figure 103.

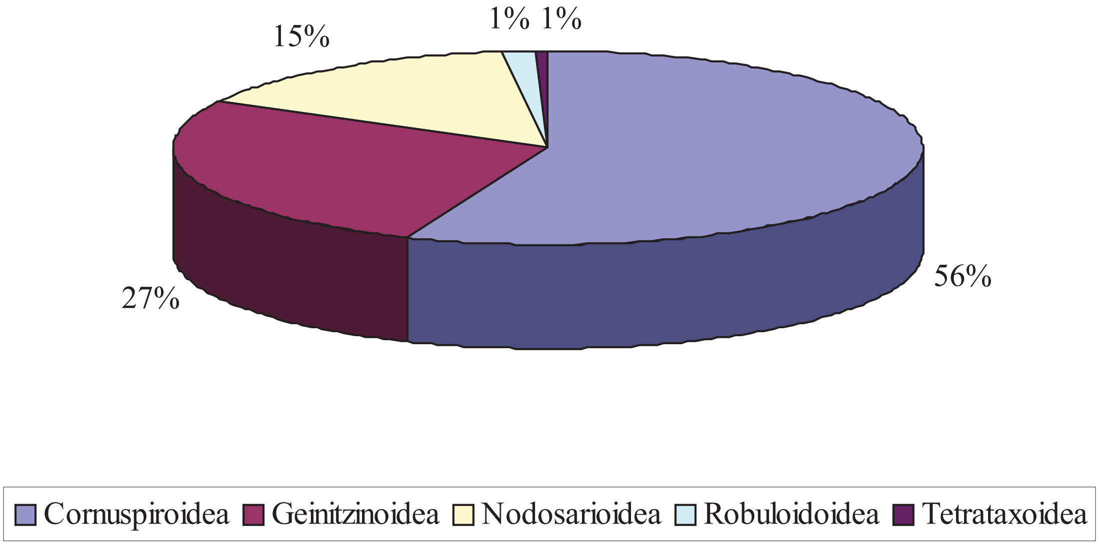

Figure 102. Relative distribution of foraminiferal superfamilies in Calcareous Foraminiferal Assemblage Zone 3.

Howchinella woodwardi
Trepeilopsis australiensis
Calcitornella elongata
Hemigordius voltus
Protonodosaria irwinensis
Calcitornella heathi
Hemigordius schlumbergeri
Lunucammina triangularis

Table 26. Characteristic species in Calcareous Foraminiferal Assemblage Zone 3.

Similar to Calcareous Foraminiferal Assemblage Zone 2, *Howchinella woodwardi* and *Lunucammina triangularis* are found in the majority of the samples taken from this fauna; however, the cornuspiroidean species *Hemigordius schlumbergeri*, *H. voltus*, *Calcitornella elongata*, *C. heathi*, and *Trepeilopsis australiensis* as well as the nodosarioidean *Protonodosaria irwinensis* are all common elements of the Assemblage Zone.

This fossil Assemblage Zone suggests that it was deposited under normal marine palaeoenvironmental conditions in shallow water, with a muddy substrate and abundant brachiopod shells and spines to which encrusting foraminifera could attach.

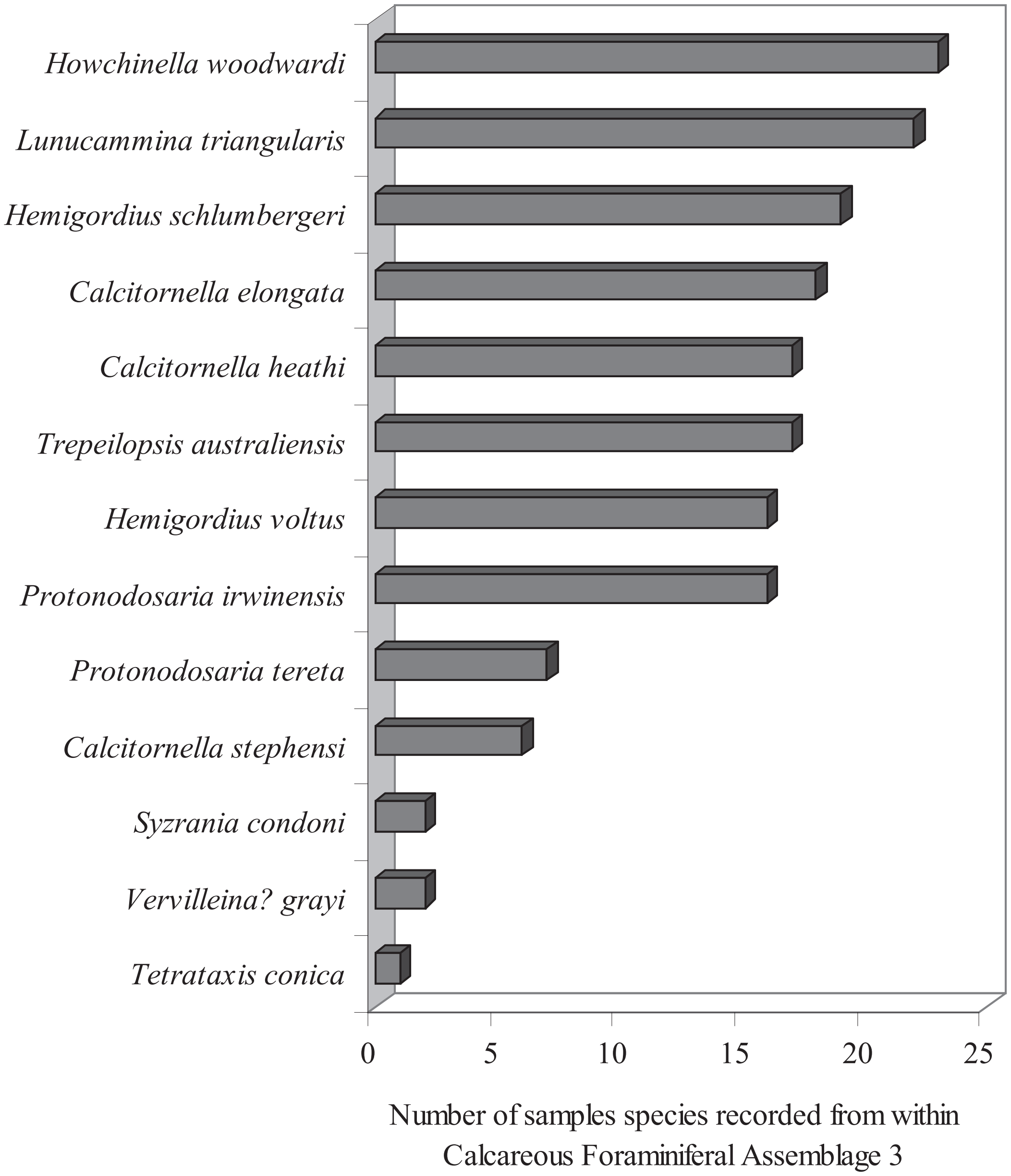

Figure 103. Graph of species occurrences in Calcareous Foraminiferal Assemblage Zone 3.

Calcareous Foraminiferal Assemblage Zone 4

The fourth calcareous foraminiferal Assemblage Zone recognised within the Fossil Cliff Member displays a similar superfamily distribution to Calcareous Foraminiferal Assemblage Zones 1 and 3, with the Cornuspiroidea forming just over half the species distribution within the samples from the Assemblage Zone and the calcareous hyaline superfamilies Geinitzinoidea and Nodosarioidea forming the remainder (Figure 104).

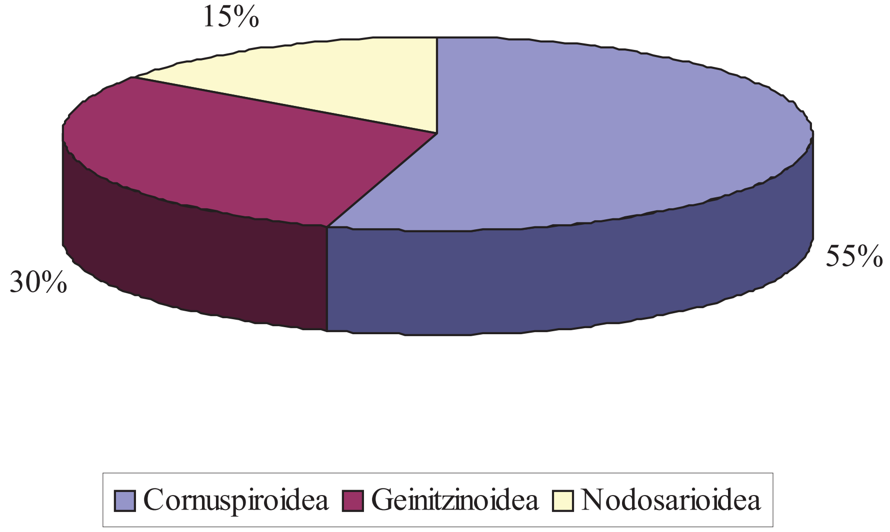

Figure 104. Relative distribution of foraminiferal superfamilies in Calcareous Foraminiferal Assemblage Zone 4.

The diversity of foraminifera from this Assemblage Zone is slightly less than the underlying three Assemblage Zones, with only ten species recorded, however the species that are present are generally found in more than half of the samples from this Assemblage Zone. The most common species are listed in Table 27, and a full listing of the species recorded and their sample frequency is given in Figure 105.

Howchinella woodwardi	*Protonodosaria irwinensis*
Trepeilopsis australiensis	*Calcitornella heathi*
Calcitornella elongata	*Hemigordius schlumbergeri*
Hemigordius voltus	*Lunucammina triangularis*

Table 27. Characteristic species in Calcareous Foraminiferal Assemblage Zone 4.

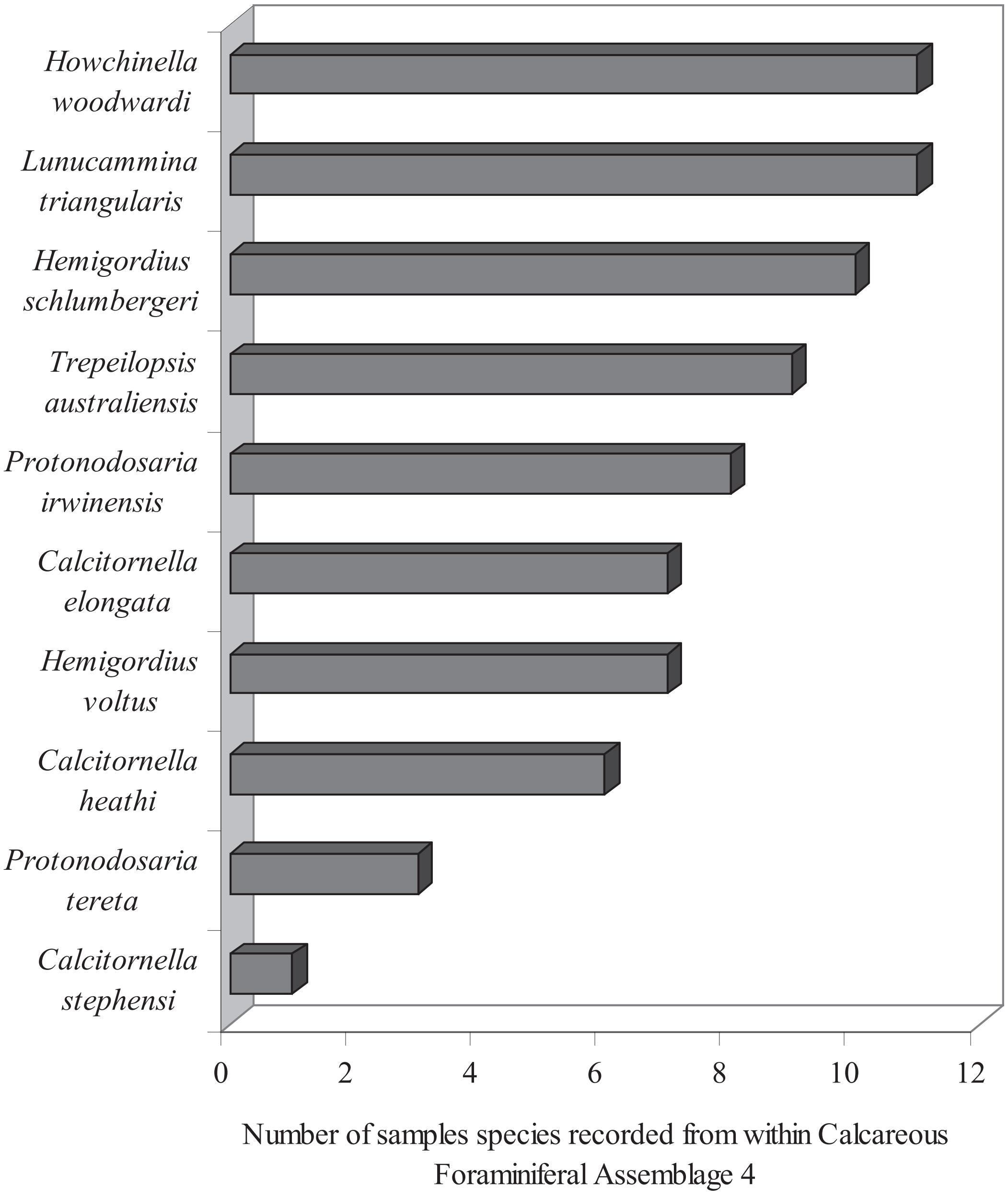

Figure 105. Graph of species occurrences in Calcareous Foraminiferal Assemblage Zone 4.

Howchinella woodwardi and *Lunucammina triangularis* are found in the majority of the samples taken from this Assemblage Zone, with the cornuspiroideans *Hemigordius schlumbergeri*, *H. voltus*, *Calcitornella elongata*, *C. heathi*, and *Trepeilopsis australiensis*, as well as the nodosarioidean *Protonodosaria irwinensis*, all common elements of the Assemblage Zone. This is extremely similar to the species distribution found in Calcareous Foraminiferal Assemblage Zone 3. The rare elements of the calcareous Assemblage Zones such as *Tetrataxis conica* and *Syzrania condoni* are absent from this Assemblage Zone and the encrusting foraminifera *Calcitornella stephensi* is extremely rare along with *Protonodosaria tereta*.

This fossil assemblage suggests that the Assemblage Zone was deposited under normal marine palaeoenvironmental conditions in shallow water, with a muddy substrate and abundant brachiopod shells and spines for encrusting foraminifera to attach to. The reduction in the diversity of the Assemblage Zone indicates there might have been some palaeoenvironmental changes within the Assemblage Zone. The absent species are rare within all the Calcareous Foraminiferal Assemblage Zones, and this may be a result of sampling rather than a complete absence from the Assemblage Zone.

Overall features of the Calcareous Foraminiferal Assemblage Zones

Overall, roughly half of the foraminiferal species within the Calcareous Foraminiferal Assemblage Zones belong to the calcareous porcellanous superfamily Cornuspiroidea, and the other half belong to the calcareous hyaline superfamilies Geinitzinoidea and Nodosarioidea (Figure 106). The foraminiferal assemblage remains relatively constant throughout the Fossil Cliff Member, with the exception of Calcareous Foraminiferal Assemblage Zone 2, which is dominated by the Geinitzinoidea and Nodosarioidea. *Howchinella woodwardi*, *Lunucammina triangularis*, *Calcitornella heathi*, *C. elongata*, *Trepeilopsis australiensis*, *Protonodosaria irwinensis*, and *Hemigordius schlumbergeri* are generally found within the fauna of each of the Calcareous Foraminiferal Assemblage Zones and are characteristic of the overall Calcareous Foraminiferal Assemblage Zones.

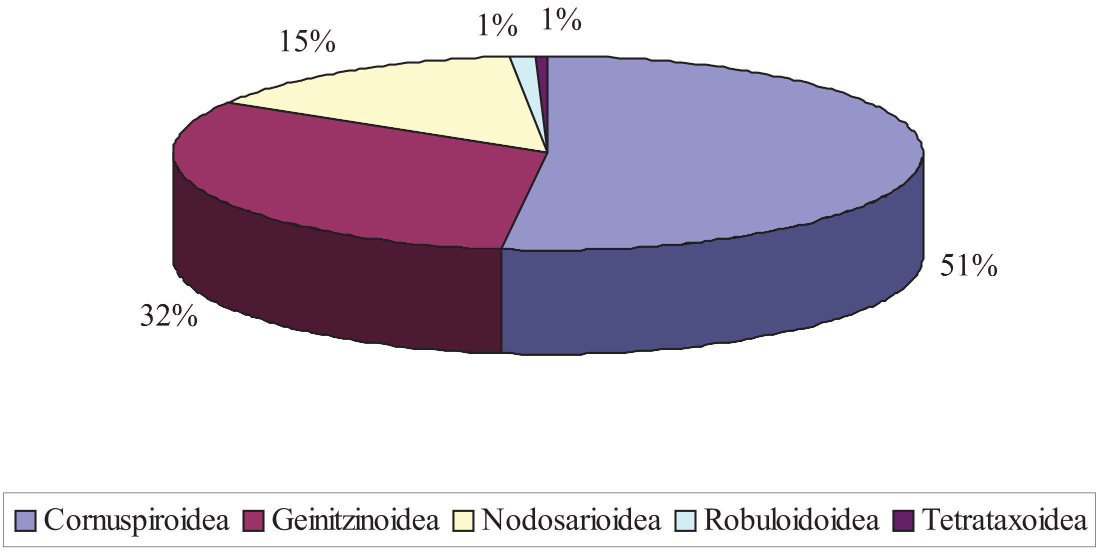

Figure 106. Relative distribution of foraminiferal superfamilies throughout the Calcareous Foraminiferal Assemblage Zones.

The fauna in all the Calcareous Foraminiferal Assemblage Zones is characteristic of shallow water with normal marine conditions (Crespin, 1958; Lane, 1964; Stevens, 1966, 1971; Buzas, 1974). A number of species from the Calcareous Foraminiferal Assemblage Zones are also recorded from the Tethyan region (Crespin 1958), which indicates that during the deposition of these Assemblage Zones the water temperature was cool-temperate or warmer.

Calcareous Foraminiferal Assemblage Zone 2 differs significantly from the other three Assemblage Zones in that it is not dominated by the Cornuspiroidea. This is a result of either shallowing water depths, a decrease in water temperature, a decrease in dissolved carbonate levels, or a lack of suitable attachment sites across the substrate at this time, all factors which do not suit the development of an abundant cornuspiroidean fauna (Crespin, 1958).

Foraminiferal Assemblage Zone trends

The major feature in the foraminiferal Assemblage Zones within the Fossil Cliff Member is the division of the agglutinated and calcareous foraminifera. This appears to be a result of dissolved oxygen levels at the substrate, with the calcareous species present when the bottom waters and substrate are within the oxic zone and agglutinated species forming the foraminiferal fauna when the bottom waters and substrate are in the dysoxic to suboxic oxygen levels. This cyclic change in the foraminiferal fauna is also evident in the substrate type, with silty calcareous sediments in the oxic cycles and silty shales in the dysoxic to suboxic cycles, as well as in the ostracode Assemblage Zones where the ostracode fauna is present within the oxic cycles, but absent from the dysoxic to suboxic cycles.

Overprinting this trend within the oxic cycle is a variation within the dominance of the cornuspiroidean and the geinitzinoidean-nodosarioidean foraminifera, which may be related to water depths or substrate conditions. Within the dysoxic to suboxic cycle the ammodiscoideans increased their dominance of the Assemblage Zone towards the top of the Fossil Cliff Member in what is interpreted to reflect a shallowing of the water depths. Within both the agglutinated and calcareous foraminiferal faunas a decrease in species diversity is noted towards the top of the type section, and this may have resulted from a decrease in water depth upwards through the member.

Chapter 9: Depositional environment of the Fossil Cliff Member

The Fossil Cliff Member has been the focus of a number of studies dealing with the palaeoecology of the diverse fauna found within it and the environment in which it was deposited. Woolnough (1938) believed the Fossil Cliff Member to have been deposited during a period of aridity; however, Clarke et al. (1951) refuted that and postulated that the Fossil Cliff Member was laid down "…in a cool climate associated with euxinic (Black Sea) conditions ranging to super-saline (Caspian-type) conditions of a periodically barred basin" Clarke et al. (1951) also noted the cyclic nature of the sedimentation of the Fossil Cliff Member and stated that this indicated a periodic recurrence of closed-basin conditions with stagnant bottom water which was then inundated by normal marine conditions but with the deeper part of the basin still poorly aerated. Recent studies (e.g. Le Blanc Smith and Mory, 1995; Mory, 1995; Mory and Iasky, 1996) have supported the model proposed by Clarke et al. (1951).

Work on the palaeoecology of macrofossil groups of the Fossil Cliff Member, notably on the brachiopods (Rudwick 1970; Heuer, 1973; Archbold et al., 1993), bryozoans (Stevens, 1966; McLeod, 1982), and bivalves (Dickins, 1963, 1978; Waterhouse, 1980b), indicate that on a broad scale the carbonate beds of the Fossil Cliff Member were deposited in shallow water with low to moderate turbidity. Despite the Fossil Cliff Member being deposited in an epeiric sea and not in open-marine conditions, it is thought that the palaeodepth estimates based upon these fossil groups correlate broadly with depth estimates determined from sedimentology for the northern Perth Basin during this time (Le Blanc Smith and Mory, 1995; Mory and Iasky, 1996).

The northern Perth Basin was located in high latitudes within the Southern Hemisphere during the Cisuralian (Thomas, 1976; Scotese & Barrett, 1990). Temperature estimates of the Fossil Cliff Member from carbon isotopes taken from brachiopod shells show that the average temperature was in the region of 8°C (Compston, 1960). Water depths within the northern Perth basin during the Cisuralian were shallow (Clarke et al., 1951; Teichert and Glenister, 1952; Thomas, 1976). During the climatic amelioration that occurred during the Late Carboniferous to Cisuralian

(Thomas, 1976), eustatic sea level changed in the region of 20 m to more than 60 m, related to Gondwanan glacial-interglacial episodes (Bloch, 1965; Veevers and Powell, 1987; Soreghan and Giles, 1999; Smith and Read, 2000; Miller and Eriksson, 2000), which resulted from the melting of ice sheets that had covered Gondwana (Cockbain, 1990). During deposition of the Fossil Cliff Member, the eustatic sea level, which was inferred to have been an abrupt rather than gradual event commencing during the latest Carboniferous and possibly having two or more deglaciation events (Veevers and Powell, 1987; Smith and Read, 2000), was in its regressive phase.

Within the epeiric sea that covered the northern Perth Basin during the Sakmarian, water circulation is thought to have been minimal, with a wave base reaching down to a depth of 10 to 20 m (Brenner, 1980). This would have limited the mixing of oxic top waters and suboxic to dysoxic bottom waters and produced an upper oxic water layer extending down to approximately this depth. The eustatic sea-level oscillations that occurred from periodic deglaciation and glaciation over Gondwana during the Cisuralian as well as from regional isostatic rebound and local tectonic movement, resulted in the upper layer of oxic water penetrating the substrate during sea-level lows, encouraging the establishment of a diverse benthic fauna. During marine transgressive events, suboxic to dysoxic substrate conditions would have prevailed, as the upper oxic water layer would not have extended down as far as the substrate. This restricted the benthic fauna during the transgressions to species able to survive in oxygen-deprived conditions (Ferdinando, 2002). Within the northern Perth Basin, these global eustatic sea-level oscillations are overprinted by a series of regional marine regressions that occurred throughout the Cisuralian basins in Western Australia (Mory and Iasky, 1996; A. Mory pers comms, 2001).

Ostracode palaeoecology

The ostracode fauna of the Fossil Cliff Member is characterised by the presence of marine species mainly of *Bairdia*, *Graphiadactyllis*, and *Healdia*. The absence of species of nonmarine ostracode genera that may have been distributed passively as described in Victor et al. (1981), indicates that the Fossil Cliff Member was deposited at a distance sufficiently removed from the delta plain that contemporaneous freshwater ostracodes did not reach the area through estuarine outwash (Sohn, 1983).

Boomer and Whatley (1992) and Lethiers and Whatley (1994) described a method for determining substrate oxygenation based on percentage of filter-feeding ostracodes in a fauna. This work was based on northern hemisphere ostracode faunas from the Late Palaeozoic and Jurassic. They concluded that the Palaeocopida, Metacopina, Platycopina, Kloedenellacea, and the Paraparchitacea were filter-feeder. Within the Fossil Cliff Member these group form between 60 to 85% of the ostracode species present in a sample. Using the model proposed by Lethiers and Whatley (1994) this indicates that the oxygen levels these faunas were in ranged from marginally oxic to dysoxic. When these oxygen conditions determined by the ostracode species are looked at relative to the foraminiferal and macro-fossil faunas, they are at odds, with the foraminiferal and macro-fossil faunas indicating that substrate was well-oxygenated. It is unclear why this empirical measure is not valid within the Fossil Cliff Member, however, it may be related to the cold-water conditions or a widening of ecological niches in the highly endemic Westralian Province.

The overall ostracode fauna of the Fossil Cliff Member is dominated by adult carapaces, and instars are rare. As benthic ostracodes generally pass through eight moults between hatching and maturity, the lack of juvenile moults is possibly indicative of removal of the smaller juvenile instars by high water current energies (Whatley 1998a, b; Brouwers, 1988b). This style of assemblage corresponds to a high energy biocoenosis (Type B high energy biocoenosis of Whatley 1988b), which Whatley (1988b) believed to be typical of sublittoral continental shelf environments with moderate to high water current energies, in the region of 20 m depth (Figure 107).

Water depths determined by the generic composition of the ostracode fauna indicate shallow to offshore deposition in the Fossil Cliff Member where ostracodes are present. Knox (1990) described a fauna with species from the genera *Healdia*, *Bairdia*, *Amphissites*, and *Pseudobythocypris* that was dominated by species of *Healdia* and *Bairdia*, similar to the Assemblage Zones found the Fossil Cliff Member, and considered the water depth to be between 50 to 100 m in normal-marine conditions. Costanzo and Kaesler (1987), however, noted an ostracode assemblage from northeastern Kansas deposited during a marine regression, consisting of the genera *Pseudobythocypris*, *Healdia*, *Moorites*, and *Hollinella*, although lacking in the abundance of *Bairdia* that is characterised by the Fossil Cliff Member, and based upon sedimentological, faunal, and stratigraphic evidence believed the ostracode fauna occupied a quiet-water, very shallow, nearshore marine environment with a muddy substrate.

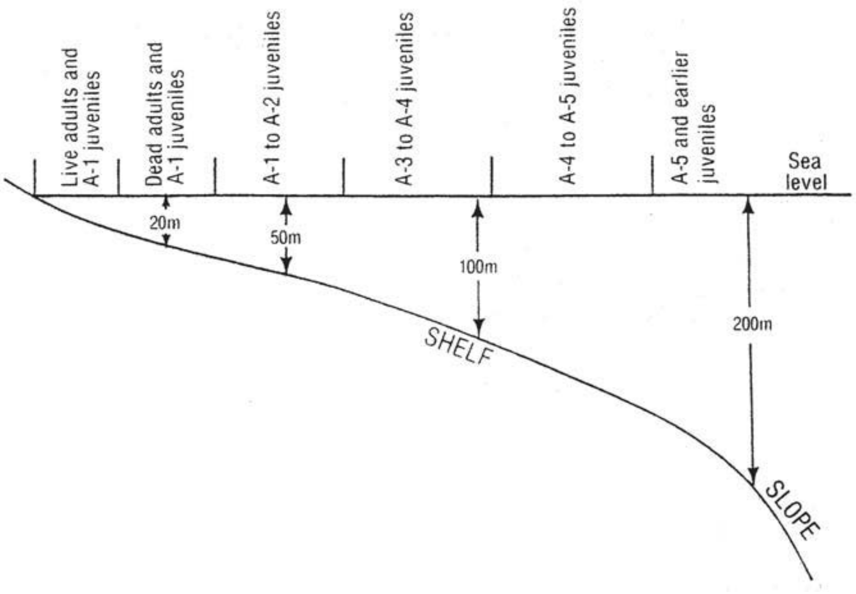

Figure 107. Idealised diagram showing depth estimates based upon the distribution of ostracode carapaces (from Whatley, 1988b).

Tibert and Scott (1999) in their work on Early Carboniferous ostracode faunas of Canada recorded that deeper water phases are characterised by more reticulate, lobate, cruminate, and spinose ostracodes, such as *Amphissites*, while high-energy nearshore sediments contain large, robust, smooth-shelled forms, such as *Healdia*. This is at odds with work by Brouwers (1988b) and Becker (1997b), who considered *Amphissites* and the robust reticulate morphotypes to be characteristic of high-energy, shallow-water environments. Knox et al. (1993) in a palaeoecological study of Late Carboniferous ostracodes from cyclic limestone and shale formations in North America noted that nearshore environments contained abundant specimens of *Amphissites* spp., intermediate depth environments were dominated by species of *Healdia*, and offshore environments were characterised by abundant species of *Mammoides*. From this study it appears that the palaeodepth of the Fossil Cliff Member was in the intermediate depth range, with some elements of nearshore environments present.

Work by Becker and Bless (1990) on the biotopic features of ostracodes and their relationship to palaeoenvironment indicates that the Fossil Cliff Member has a fauna that is comparable to the Eifelian Assemblage, which has faunas of thick-shelled, frequently heavily-lobed and ornamented ostracodes, characterising essentially high-energy environments. Although in this comparison the ostracode assemblage from the Fossil Cliff Member is dominated by thick-shelled species, the majority of these tend to have smooth shells and lack ornamentation, such as *Bairdia*, *Healdia*, and *Graphiadactyllis*. Some species of the Fossil Cliff Member are also linked to the low-water current energy Thuringian Assemblage (Thuringian Ecotype of Becker in Bandel and Becker, 1975), specifically the nearshore niche (see Becker and Bless, 1990, fig. 12), containing the spinose *Rectospinella australica*, *Quasipolycope*? sp. A (*Discoidella* of Becker and Bless, 1990), bairdioideans, and some kirkbyoidean ostracodes. These Thuringian Assemblage indicators, however, are relatively rare within the ostracode fauna of the Fossil Cliff Member, and as such the fauna indicates a Mixed Assemblage (sensu Becker and Bless, 1990), although with a strong Eifelian Assemblage component.

Within the Fossil Cliff Member, Ostracode Assemblage Zone 1 was deposited under normal marine conditions in shallow water with a muddy terrigenous to calcareous substrate. The Assemblage Zone is dominated by species from the burrowing Healdioidea and large thick-walled, vagile species of *Graphiadactyllis*, in addition to species of *Bairdia*, and *Youngiella*. The robust species of *Graphiadactyllis* indicate it is adapted for shallow water depths with high energy conditions, whilst the presence of *Bairdia* may suggest an offshore environment (Sohn, 1983), however Becker (2001a) stated that the *Bairdia* may be more common in inner to middle sublittoral environments.

Ostracode Assemblage Zone 2 appears to have been laid down under similar conditions to the first ostracode Assemblage Zone, although robust species from the Quasillitidae, such as *Graphiadactyllis* are more abundant. This Assemblage Zone appears to have been deposited under normal marine conditions in slightly shallower water than the first Assemblage Zone. The abundance of species with thick, robust carapaces within the fauna also emphasise the higher-energy, nearshore link.

The third ostracode Assemblage Zone is significantly different in fauna relative to Ostracode Assemblage Zones 1 and 2, with species from the Healdioidea, Bairdioidea, and Youngiellidae dominating the Assemblage Zone in addition to elements of the Thuringian Assemblage, such as *Rectospinella australica*. The decrease in the abundance of thick-carapaced species of the Quasillitidae and appearance of Thuringian Assemblage species may indicate a possible deepening of the water within this Assemblage Zone, or may be related to a decrease in water energy with no change in depth. Normal marine conditions persisted during deposition of this facies.

Ostracode Assemblage Zone 4 represents a return to the depositional style found within the first two ostracode Assemblage Zones, with the ostracode fauna indicating deposition under shallow-marine conditions with a muddy substrate. The absence of the eurytropic genus *Proparaparchites* from the Assemblage Zone along with species of the Thuringian Assemblage support this.

Overall the ostracode Assemblage Zones show that during deposition of the calcareous sediments of the Fossil Cliff Member normal marine conditions prevailed, with a small marine regressive event in the second Assemblage Zone followed by a possible transgressive event in the third Assemblage Zone, which then once again became regressive during the deposition of the fourth ostracode Assemblage Zone. Similar bathymetric oscillations have recorded previously by Knox (1990) and Knox et al. (1993) in ostracode faunas from North America, and are well documented as being related to glacioeustatic sea-level changes within the Late Carboniferous to Cisuralian (Bloch, 1965; Veevers and Powell, 1987; Soreghan and Giles, 1999; Smith and Read, 2000; Miller and Eriksson, 2000).

Foraminiferal palaeoecology

Foraminifera in the Fossil Cliff Member display two main trends in their distribution. The first is a change based upon palaeoenvironmental conditions, from the agglutinated foraminiferal Assemblage Zones in lithofacies *Al* found at the base of each parasequence, to the calcareous dominated foraminiferal Assemblage Zones in the carbonate-rich lithofacies *Lbs* and *(L/A)bs* at the top of each parasequence. The other palaeoecological trend that overprints the first is the variance between the ratios of calcareous hyaline species and calcareous porcellanous species within the carbonate beds of the Fossil Cliff Member.

Palaeoecology of the Agglutinated Foraminiferal Assemblage Zones

Within the sediments hosting the agglutinated foraminiferal Assemblage Zones there are abundant veins and veinlets of gypsum and jarosite, both formed from diagenetic processes. The gypsum is thought (Clarke et al, 1951; Playford, 1959; Playford et al., 1976) to be indicative of either slightly raised salinity levels during deposition which were then diagenetically precipitated, or saline fluids passing through the sediment during diagenesis. The jarosite is a weathering product of pyrite, which is present in sediments with high levels of H_2S either present in the bottom waters or below the water/sediment interface, and deposited under reducing, rather than oxidising conditions. The presence of these minerals within the sediments of the Agglutinated Foraminiferal Assemblage Zones indicates that bottom-water conditions were dysoxic to suboxic (0.1-1.5 mL/LO_2).

The foraminifera from the Agglutinated Foraminiferal Assemblage Zones are almost exclusively organic-cemented types, with the exception of a small number of calcareous specimens recovered from the bottom- and topmost samples within these Assemblage Zones where they grade from or into the calcareous facies. Organic-cemented foraminifera require low amounts of dissolved carbonate and oxygen in the seawater relative to the calcareous species (Murray, 1973), and are associated with bryozoa and brachiopod species that are sessile filter-feeders requiring low levels of dissolved oxygen (McKinney and Jackson, 1989; Tyszka, 1994). In addition, Bernhard (1986) recognised that the relative proportions of benthic foraminiferal morphogroups are influenced by variations in the oxygen and organic carbon content of surficial sediments and that agglutinated foraminiferal faunas flourish in low oxygen conditions with high organic carbon content in the sediment. Wignall (1994) reviewed the biotic evidence for low oxygen or dysoxic conditions near the substrate. While he found no particular group of organisms were diagnostic of these conditions throughout geologic time, he did suggest a number of indicators, including overall diversity and the presence or absence of burrowing organisms, from which to interpret relative oxygenation. Within this facies, the species diversity is relatively high, with a small number of infaunal genera present, such as *Ammobaculites* which are well-documented as infaunal inhabitants of modern estuaries living at depths of 10-15 cm below the sediment surface (Ellison, 1972; Buzas, 1974; Wightman et al., 1994), indicating that the oxygen levels at the water-sediment interface were dysoxic to suboxic. The presence of intact, delicate fenestrate bryozoa in addition to the thin, delicate test walls possessed by the agglutinated foraminifera, especially those of the *Hyperammina*, suggests that overall the water energy was extremely low, with the substrate well below the storm wave base, possibly in a protected embayment.

Previous work on the Cisuralian agglutinated foraminiferal assemblages of Australia indicated that a number of genera found in the Fossil Cliff Member, such as *Ammodiscus, Hippocrepinella, Ammobaculites*, and *Sacammina* are known to favour cold water (Scheibnerová, 1980). Scheibnerová (1980, 1982) also noted no evidence for deposition deeper than inner to outer shelf regions based on the agglutinated foraminiferal faunas recovered from in eastern Australia, which show a marked similarity to the faunas found within the agglutinated foraminiferal Assemblage Zones of the Fossil Cliff Member. Palmieri (1994), in his study of Permian foraminifera from the Bowen Basin in Queensland, however, noted that the offshore faunas do not vary strongly with depth, nor do the marginal and coastal faunas show appreciable diversity in depth factor. All these previous studies indicate that the agglutinated foraminiferal fauna found within the Fossil Cliff Member flourished in offshore or shallower cold water conditions with low levels of dissolved oxygen.

Within Agglutinated Foraminiferal Assemblage Zone 1, the depositional environment is interpreted as shallow water below wave base (less than 50 m depth), with the bottom water having a low level of dissolved oxygen, probably in the dysoxic to suboxic range (0.1-1.5 mL/LO_2), and salinity conditions possibly being slightly euryhaline. The fauna within this Assemblage Zone belongs to the Holmwood Shale *sensu stricto*, and shows a high level of epifaunal species diversity indicating that conditions were favourable for the development of an agglutinated foraminiferal fauna. Within the substrate, infaunal species diversity was low, although an infaunal foraminiferal assemblage was established.

Agglutinated Foraminiferal Assemblage Zone 2 possesses a similar foraminiferal association to the first Assemblage Zone, although there is a decrease in the diversity of infaunal species. The depositional environment for this Assemblage Zone is interpreted as being similar to Agglutinated Foraminiferal Assemblage Zone 1, although the oxygen levels within the substrate are likely to have been slightly lower, possibly indicating a slight increase in sea-level relative to the first Assemblage Zone.

Agglutinated Foraminiferal Assemblage Zone 3 shows an increase in the diversity and abundance of infaunal species relative to the second Assemblage Zone, and a decrease in the abundance and diversity of such filter-feeding genera as *Hyperammina*. Apart from these differences, the foraminiferal Assemblage Zone is broadly similar to that found within the first two agglutinated foraminiferal Assemblage Zones. The depositional environment for this Assemblage Zone is interpreted to have been deposited in an environment similar to that postulated for Agglutinated Foraminiferal Assemblage Zone 1, with an increase in the current energy, possibly due to a slight decrease in water depth, responsible for the decline in the epifaunal suspension feeding agglutinated foraminifera.

Agglutinated Foraminiferal Assemblage Zone 4 has decreased in abundance and diversity of the foraminifera, with a number of the rare and uncommon species found within the three lower agglutinated foraminiferal Assemblage Zones absent from this Assemblage Zone. The agglutinated foraminiferal species that characterise the overall agglutinated foraminiferal Assemblage Zone, however, are present within this Assemblage Zone in similar relative abundances to those found within the lower three Assemblage Zones. This indicates that the depositional environment was still in generally shallow water conditions, although below wave base, with dysoxic to suboxic bottom water. The decrease in diversity may be due to either a decrease in the dissolved oxygen level in the bottom waters or to an influx of fresh to brackish water in the area.

Agglutinated Foraminiferal Assemblage Zone 5 shows a distinct difference in sedimentological characteristic from the other four Assemblage Zones, with the substrate becoming dominated by fine-grained quartzose sands. The foraminiferal fauna has a low diversity and abundance, and this, in conjunction with the sandy substrate, indicates a shallower-water depositional environment than the other four Assemblage Zones, possibly in a deltaic environment, although dysoxic to suboxic conditions still prevailed.

The overall agglutinated foraminiferal Assemblage Zones indicate that oxygen levels were consistently low, within the dysoxic to suboxic range, and that sea-level was relatively shallow, although deeper than wave base (>20 m). Variations in species diversity within the agglutinated foraminifera may give an indication of relative sea-level change, as Brett (1998) noted that the level of bottom-water oxygenation is highly sensitive to relative rise and fall of sea level. This implies that Agglutinated Foraminiferal Assemblage Zone 2 is slightly deeper than the first Assemblage Zone, with a decrease in the diversity of infaunal foraminifera and a corresponding shallowing within the third agglutinated foraminiferal Assemblage Zone based upon the re-establishment of the infaunal species from the Assemblage Zone and a possible increase in water energy levels. Agglutinated Foraminiferal Assemblage Zone 4 records a drop in species diversity which may indicate a decrease in dissolved oxygen levels and a marine transgression, however this decrease in diversity may also be related to a decrease in water salinity, so eustatic sea-level change here is inconclusive. The fifth agglutinated foraminiferal assemblage records a strong decrease in species diversity; however, this may not be related to a sea-level rise, and instead related to a marine regression with corresponding influx of brackish waters carrying quartzose sediment, possibly in a deltaic or nearshore environment.

Palaeoecology of the Calcareous Foraminiferal Assemblage Zones

Foraminifera in the Calcareous Foraminiferal Assemblage Zones are found in association with a diverse ostracode and macrofossil fauna containing sessile filter-feeding spiriferiid brachiopods and solitary rugose corals indicating that oxygen, nutrient, and dissolved carbonate levels in the water were high, the substrate was within the photic zone, and that the water turbidity was low. This assemblage is found within calcareous sandy siltstones (*(A/L)bs*) to silty calcarenites (*(L/A)bs*).

Within the Calcareous Foraminiferal Assemblage Zone, four subdivisions have been recorded, each having a differing foraminiferal fauna. Samples taken from the base and top of each these Assemblage Zones also contain some elements of the Agglutinated Foraminiferal Assemblage Zones, such as specimens of *Ammodiscus* spp. and *Glomospirella nyei*. This mixing is probably the result of bioturbation, which is intense within the carbonate beds of the Fossil Cliff Member.

Within Calcareous Foraminiferal Assemblage Zone 1, the foraminiferal fauna indicates that the water was oxic (>1.5 mL/LO_2), with normal-marine conditions. The Cornuspiroidea make up roughly 60% of the species recorded from this Assemblage Zone, with the hyaline forms from the Geinitzinoidea and Nodosarioidea constituting most of the remaining 40%. The presence of large numbers of intact specimens of delicate macrofossils such as fenestrate bryozoans associated with this Assemblage Zone indicates that while the water depth was shallow it was either below wave base (>20 m) or deposition was rapid, covering skeletal remains before they could undergo significant abrasion and fragmentation.

Calcareous Foraminiferal Assemblage Zone 2 differs from the first Assemblage Zone in that its fauna is dominated by species from the Geinitzinoidea and Nodosarioidea, which make up about 75% of the species recorded, with the Cornuspiroidea comprising most of the remaining 25%. This Assemblage Zone is inferred to have been deposited under normal-marine conditions in shallow water, with the amount of fragmentation of delicate micro- and macrofossil elements being extremely low. Additionally, a number of macrofossil specimens are found in life positions, such as solitary rugose corals. This is either a result of a slight deepening of the water reducing the current energy of the water, deposition in more protected waters, or high sedimentation rate that rapidly buried the bioclasts before abrasion could take place. The increase in the abundance of epifaunal vagile species such as *Howchinella woodwardi* and *Lunucammina triangularis*, as well as an inferred shallowing of the water from the ostracode Assemblage Zone seems to indicate that this Assemblage Zone was deposited in slightly shallower water than the first Assemblage Zone, but in a protected, high productivity palaeoenvironment such as an algal sea-weed bank.

Calcareous Foraminiferal Assemblage Zone 3 is very similar to the Calcareous Foraminiferal Assemblage Zone 1, with the Cornuspiroidea dominating the Assemblage Zone. This foraminiferal fauna is inferred to represent normal-marine conditions in a similar palaeoenvironment to that found in the first calcareous foraminiferal Assemblage Zone. The high amount of fragmentation of both microfossil and macrofossil material in the assemblage, however, may indicate that water depths were slightly shallower or the fauna was deposited in a higher energy environment.

The species diversity in Calcareous Foraminiferal Assemblage Zone 4 decreases relative to the other calcareous foraminiferal Assemblage Zones, with a slight increase in the ratio of hyaline calcareous foraminiferal species to porcellanous foraminiferal species. Robust porcellanous species such as *Hemigordius schlumbergeri*, *Calcitornella heathi*, and *Trepeilopsis australiensis*, however, are extremely abundant in this Assemblage Zone. This abundance in conjunction with a decrease in foraminiferal diversity and the large amount of fragmented macrofossil material in the samples, indicates that this Assemblage Zone was deposited in normal marine conditions in shallower water than Calcareous Foraminiferal Assemblage Zones 1 and 3.

Overall the calcareous foraminiferal Assemblage Zones indicate that the environment during deposition was oxic with normal marine salinities (~35 parts per thousand), and with generally shallow water depths. The Assemblage Zones record a change from a shallow water environment to a protected algal bank, which may have been in slightly shallower water relative to the first Assemblage Zone, then back to similar initial conditions in the third Assemblage Zone, with slightly increased water energy. The fourth calcareous foraminiferal Assemblage Zone records a marine regression to what is interpreted to be a shallower-marine palaeoenvironment.

Overall foraminiferal palaeoecology

The foraminiferal distribution across the whole of the Fossil Cliff Member shows a cyclic trend of an agglutinated foraminiferal fauna in the silty shales (*Al*) and silty sandstones (*(S/A)b*) to a calcareous foraminiferal fauna in the calcareous siltstone (*(L/A)bs*) and silty calcarenites (*(A/L)bs*). This trend is a result of sea-level oscillation, related to eustatic sea-level change from deglaciation of Gondwana during the latest Carboniferous and earliest Cisuralian. During the deposition of the upper part of the Holmwood Shale in the type area of the Fossil Cliff Member, the substrate lay in dysoxic to suboxic waters, giving rise to an agglutinated foraminiferal assemblage. With decreasing water depth due to eustatic sea-level change, the oxic water layer was brought into contact with substrate and a diverse calcareous foraminiferal fauna flourished within the carbonate sediments at the base of the Fossil Cliff Member. This trend is then overprinted by a decrease in species diversity upwards through the sequence, related to an overall shallowing of the depositional environment (Figure 109). This sea-level oscillation produced cyclic variations in the foraminiferal faunas. Similar cyclic alternations of limestone and shale within the Late Carboniferous and Early Permian of the Midcontinent of North America have been termed cyclothems and are widely interpreted as transgressive-regressive sequences (e.g. Knox et al., 1993).

Palaeoecology of the Fossil Cliff Member

Parasequence 1

Parasequence 1 contains the topmost part of the Holmwood Shale, as well as the basal carbonate beds of the Fossil Cliff Member. This parasequence includes Ostracode Assemblage Zones 1 and 2, Agglutinated Foraminiferal Assemblage Zones 1 and 2, and Calcareous Foraminiferal Assemblage Zones 1 and 2. The base of this parasequence (Agglutinated Foraminiferal Assemblage Zone 1) was deposited under dysoxic to suboxic water conditions (Figure 108), resulting in an impoverished macrofossil fauna containing unfragmented, infrequent fenestrate bryozoa and dwarfed brachiopods. The agglutinated foraminiferal fauna within this portion of the parasequence is generally diverse, although the number of specimens of each species is low. The unfragmented nature of the fossil assemblage in this part of the parasequence indicates that water energy was very low, and sedimentological evidence suggests the environment below the substrate was dysoxic to suboxic. The environment then changed into a normal-marine environment with oxic conditions supporting a rich and diverse fauna that forms the base of the Fossil Cliff Member (Ostracode Assemblage Zone 1 and Calcareous Foraminiferal Assemblage Zone 1). The marine regression event lowered the sea-level so that the substrate was within the oxic upper layer of the epeiric basin’s water column, resulting in normal marine conditions across the substrate.

Parasequence 1 represents a small marine transgression resulting in a return to dysoxic to suboxic conditions that is not readily apparent from the lithofacies of Parasequence 1, possibly due to intense bioturbation within the calcareous sediment extending down into part of the underlying terrigenous facies. This small dysoxic-suboxic-oxic couplet is recorded within the ostracode and foraminiferal assemblages as Ostracode Assemblage Zone 2, Agglutinated Foraminiferal Assemblage Zone 2, and Calcareous Foraminiferal Assemblage Zone 2. The contact between the carbonate beds at the top of the underlying cycle and the shale beds at the base of this cycle is sharp, and the shale unit here represents a short-lived return to dysoxic-suboxic conditions characterised by the establishment of an agglutinated foraminiferal fauna (Figure 108). Agglutinated Foraminiferal Assemblage Zone 2 is interpreted to have been deposited in slightly deeper water than the first agglutinated foraminiferal fauna of Parasequence 1 based upon the decrease in diversity and abundance of infaunal agglutinated foraminiferal species. The transition from dysoxic-suboxic conditions to oxic conditions within this cycle is sharply marked in the ostracode and foraminiferal faunas. The oxic component at the top of Parasequence 1, while having an ostracode fauna similar to the lower oxic beds of the parasequence, shows a marked difference in the foraminiferal faunas, with geinitzinoidean and nodosarioidean foraminifera dominating the assemblage. This palaeoenvironment is inferred to have been deposited in slightly shallower water than the carbonate beds of Ostracode Assemblage Zone 1 and Calcareous Foraminiferal Assemblage Zone 1, but in an area unsuitable to the robust and generally attached cornuspiriid foraminifera. It is interpreted that these assemblages were deposited in a localised algal bank under normal-marine conditions based upon the foraminiferal assemblage along with evidence from the macrofossil fauna.

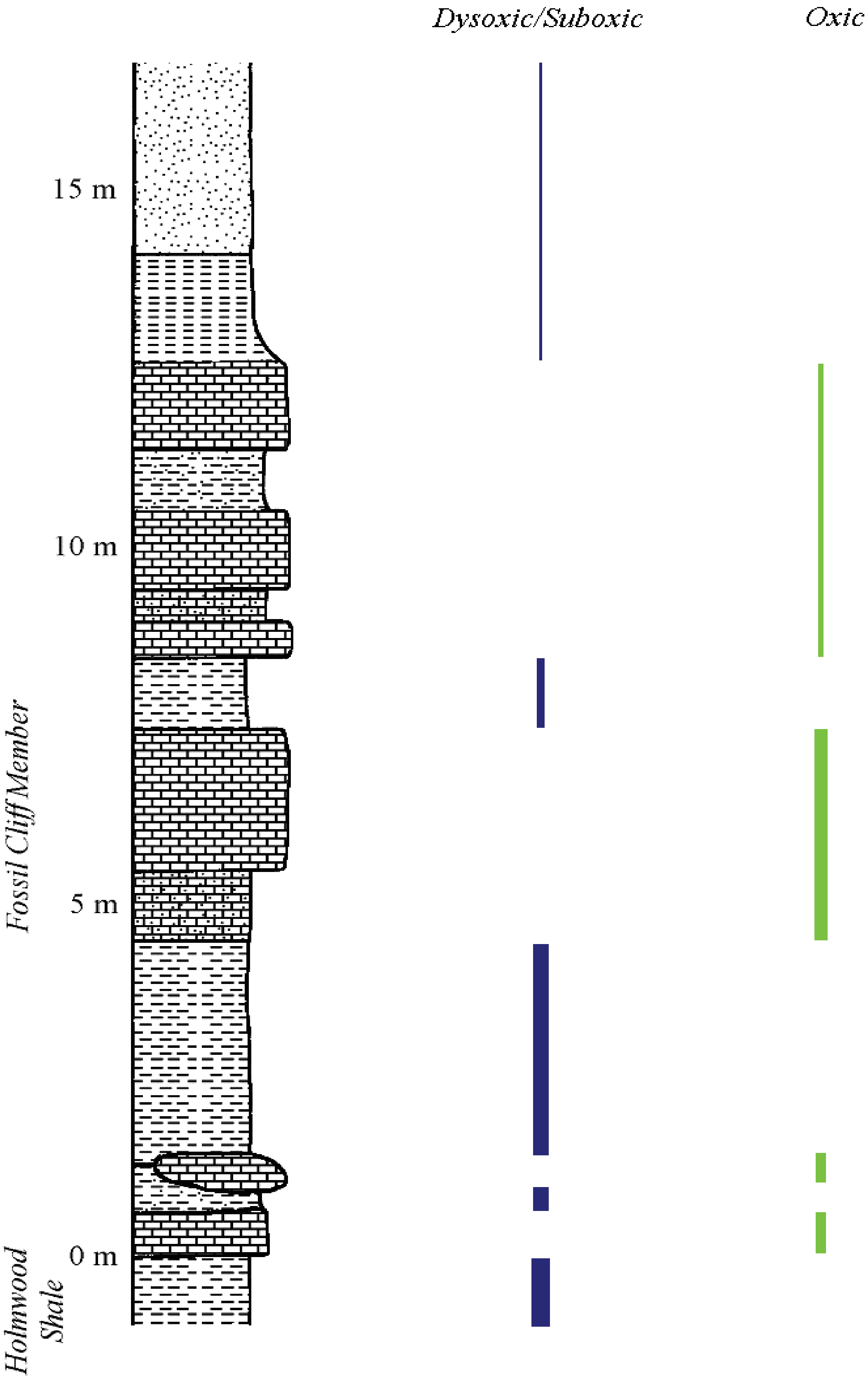

Figure 108. Relative species diversity within the dysoxic-suboxic and oxic cycles in the Fossil Cliff Member. Line thickness corresponds to relative abundance of species within each foraminiferal Assemblage Zone.

Parasequence 2

The second parasequence contains Ostracode Assemblage Zone 3, Agglutinated Foraminiferal Assemblage Zone 3, and Calcareous Foraminiferal Assemblage Zone 3. The base of Parasequence 2 is represented by Agglutinated Foraminiferal Assemblage Zone 3 and is interpreted to have been deposited under dysoxic-suboxic conditions. An increase in the infaunal diversity and abundance relative to Agglutinated Foraminiferal Assemblage Zone 2 indicates that the water depth was probably slighter lower than in Agglutinated Foraminiferal Assemblage Zone 2. Depositional environment conditions based upon the agglutinated foraminiferal assemblage are inferred to have been similar to those of the dysoxic-suboxic facies in the first dysoxic-suboxic-oxic couplet of Parasequence 1 (Agglutinated Foraminiferal Assemblage Zone 1). Overlying this dysoxic-suboxic assemblage are the calcareous lithologies that host Ostracode Assemblage Zone 3 and Calcareous Foraminiferal Assemblage Zone 3. These Assemblage Zones are inferred to have been deposited in shallow water within the oxic zone under normal-marine conditions. Water depths within this part of Parasequence 2, based upon the evidence from both the microfossil and macrofossil assemblages, were probably at approximately the same depth as the first oxic component of Parasequence 1, where Ostracode Assemblage Zone 1 and Calcareous Foraminiferal Assemblage Zone 1 are found, and above wave base (<20 m). Within the ostracode assemblage of this parasequence rare elements of the Thuringian Assemblage are present, which represent low current energy palaeoenvironments. Within the Fossil Cliff Member this does not reflect a deepening of the palaeoenvironment, and instead, when viewed in conjunction with the foraminiferal and macrofossil evidence, suggests that either the fauna was deposited in a low-energy environment or that some part of the ostracode fauna is the result of thanatocenosis from a nearby low-energy facies.

Parasequence 3

The third parasequence contains Agglutinated Foraminiferal Assemblage Zones 4 and 5, Ostracode Assemblage Zone 4, and Calcareous Foraminiferal Assemblage Zone 4. At the base of this parasequence is the dysoxic-suboxic facies of Agglutinated Foraminiferal Assemblage Zone 4, which has a sharp transition from the underlying calcareous lithologies of Parasequence 2. This dysoxic-suboxic facies contains an agglutinated foraminiferal assemblage that is lower in species diversity than the underlying dysoxic-suboxic facies of Agglutinated Foraminiferal Assemblage Zone 3. This may be due to either an increase in water depth to place the substrate closer to anoxic conditions or a result of cold, fresh to brackish water entering the region and sitting in the dysoxic-suboxic waters and being overlain by the relatively warmer oxic upper water layer.

Overlying this dysoxic-suboxic facies is the uppermost carbonate facies of the Fossil Cliff Member. This carbonate facies is represented by Ostracode Assemblage Zone 4 and Calcareous Foraminiferal Assemblage Zone 4 which form a relatively sharp transition with the dysoxic-suboxic facies below, although some agglutinated foraminiferal species characteristic of the underlying dysoxic-suboxic facies have been recovered from within this oxic facies, probably a result of post-depositional mixing from intense bioturbation. Both the calcareous foraminiferal and ostracode assemblages within this oxic facies have decreased species diversity relative to the underlying Assemblage Zones, and the fauna is inferred to represent a normal-marine environment with water depths relatively shallower than those found within the other carbonate-bearing facies. While water depths are inferred to be shallower here, the lack of eurytropic ostracodes within the assemblage indicates that in this region, freshwater input was minimal.

The final facies recorded in the Fossil Cliff Member is Agglutinated Foraminiferal Assemblage Zone 5, which overlies the oxic facies of Parasequence 3. This assemblage is distinctly different from the other agglutinated foraminifera-bearing assemblages, in that it has a significantly reduced species diversity and abudance and found within a sandy sediment instead of shale. This assemblage represents either a shallow water dysoxic-suboxic palaeoenvironment or a system that is stagnant and relatively brackish. Given that the conformably overlying High Cliff Sandstone is inferred to be deltaic to estuarine (Playford et al, 1976), and that the overall trend within the Fossil Cliff Member is a marine regression marked by increasingly shorter lived transgressive events, it is possible that this assemblage represents an oxygen-depleted nearshore environment in brackish water.

Depositional model for the Fossil Cliff Member

From interpretations of the palaeoenvironments of the foraminiferal and ostracode faunas, it is apparent that a broad, overall marine regression occurred as the top of the Holmwood Shale to the top of the type section of the Fossil Cliff Member were being deposited (Figure 109).

The diversity and abundance of species within the Fossil Cliff Member, especially within the calcareous facies, are considered to be correlatable with environmental conditions, especially environmental stability (Bretsky and Lorenz, 1970; Eldredge 1974; Fortey, 1984). Veevers and Powell (1987) in their work on Euramerican cyclothems believed that the sea-level fluctuations recorded in these cyclothems resulted from eustatic changes due to glacial melting in Gondwana and inferred depositional periods for each of these cyclothems as ranging between 0.250 to 0.375 Ma. Soreghan and Giles (1999), measuring eustatic sea-level changes in North America during the Late Carboniferous and earliest Permian, suggested that sea-level changes due to glacioeustasy ranged from 90 to 100 m. It is not unreasonable to assume that within the Fossil Cliff Member similar levels of glacioeustatic sea-level changes occurred, although at a smaller amplitude due both to the length of time after deglaciation and to the negating effect of isostatic rebound in the eustatic rise resulting from the removal of the glacial mass from the Perth Basin and adjoining Yilgarn Craton. The lensoidal nature of the Fossil Cliff Member and its lack of lateral continuity indicate that while the distribution of its facies within the type section was controlled by relative sea-level change, other processes influenced its distribution on a regional scale. The Fossil Cliff Member has been recognised only in outcrop at the type section in the Irwin River and at Beckett’s Gully 7 km to the south. Subsurface, the Fossil Cliff Member has been identified only tentatively in BMR 10 (McTavish, 1965; Mory and Iasky, 1996).

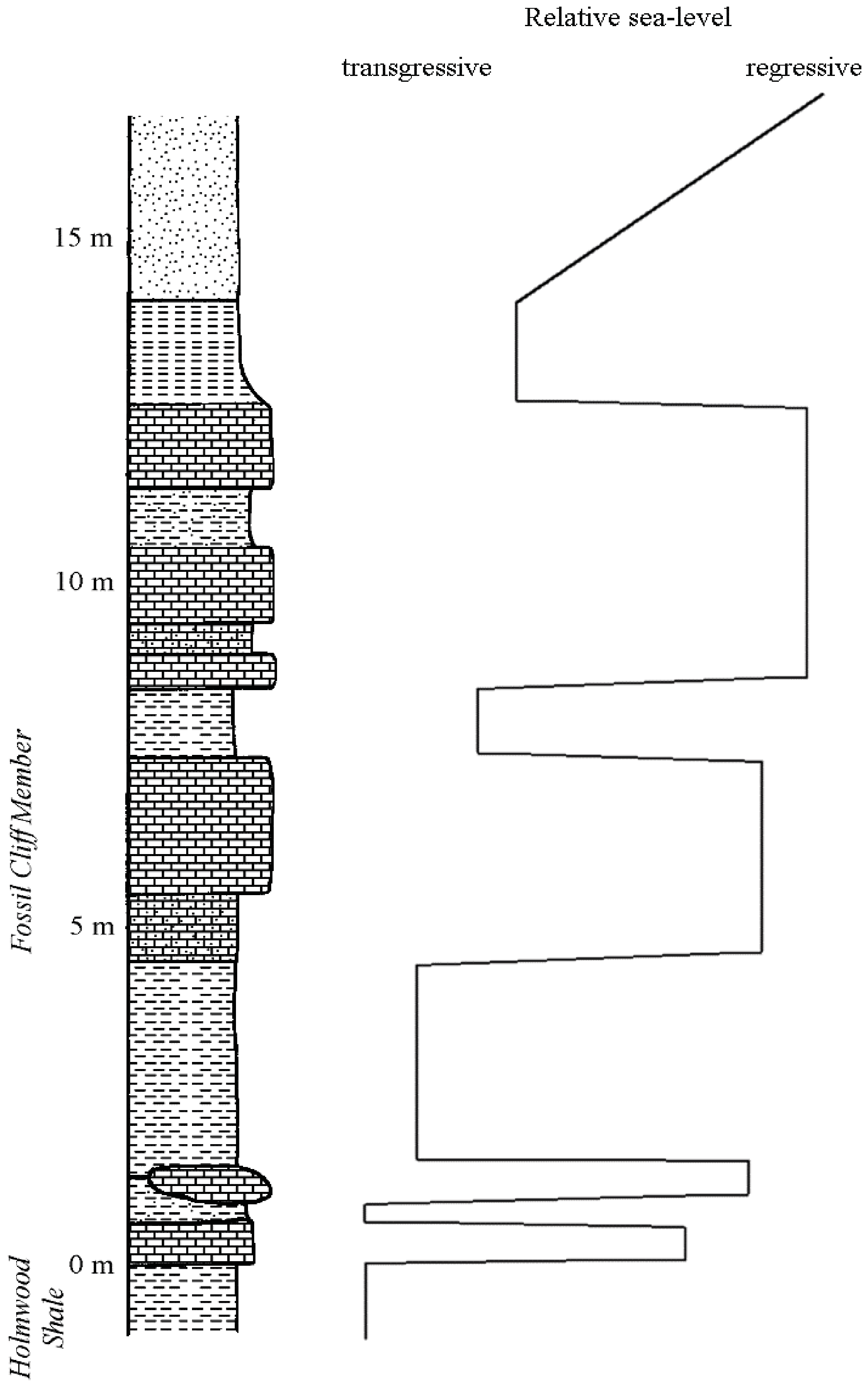

Figure 109. Relative sea-level curve for the Fossil Cliff Member.

The discontinuous nature of the Fossil Cliff Member indicates that the palaeoenvironmental conditions under which it was deposited were not widespread across the northern Perth Basin during the Sakmarian. If the environment of deposition was based solely upon substrate position relative to the dysoxic-suboxic-oxic layer within the epeiric sea at this time, then the environment is likely to have been continuous, although not necessarily laterally extensive, across the northern Perth Basin, which is not the case. The reason for the discontinuous, lensoidal nature of the carbonate facies may be that the areas where this facies are recorded were, during the Sakmarian, areas of topographic highs within the basin, and during marine regressive periods were placed within the oxic water layers, while the lower lying areas remained within the dysoxic-suboxic waters. This is supported by Le Blanc Smith and Mory (1995), who noted that the Permian sediments of northern Perth Basin were deposited over an irregular pre-Permian topography.

It is also possible that the carbonate facies of the Fossil Cliff Member were formed by localised carbonate shoals within the basin at this time, which migrated across the basin in response to eustatic sea-level change (R. M. Hocking pers comms). Brett (1998) noted that the recurrence of highly similar fossil assemblages in analogous portions of sedimentary cycles indicates that associations of species that require particular combinations of depositional environments persist with relatively little change through long intervals of time. These associations appear to shift laterally over considerable distances during intervals ranging from a few thousand to a few million of years, and rather than adapting to the stress of changing environments, marine organisms most commonly appear to track their favoured environments. Provided that lateral migration of these environments was not too rapid or that these environments did not disappear altogether from the local basin, most organisms appear to be able to keep up with the shift of environments produced by sea-level fluctuation. This model of shifting carbonate shoals does imply that while the facies may be lensoidal in nature their lateral migration may be able to be tracked in outcrop.

It is likely that the palaeoenvironment of the Fossil Cliff Member is a combination of these two processes, formed when oxic bottom waters penetrated the substrate of a topographic high during marine regression (Figure 110). This then initiated the formation of a carbonate shoal supporting a rich and diverse marine fauna that migrated slowly across the topographic high until a marine transgression raised the water depth and inundated the carbonate shoal with dysoxic-suboxic waters, and terrigenous sediment input again outweighed the production of carbonate sediment (Figure 111).

A diagram of the proposed model of the palaeoenvironment of the Fossil Cliff Member is illustrated in Figure 112. In this model, the outwash plains and sands are represented in the Irwin River sequence by the cross-bedded sandstones of the High Cliff Sandstone and the swampy deltaic and estuarine muds of the Irwin River Coal Measures. The sediments of the Holmwood Shale are deposited in the proximal and distal varved silts and diamictites, while the carbonate facies of the Fossil Cliff Member are deposited on the discrete topographic highs located in the offshore regions.

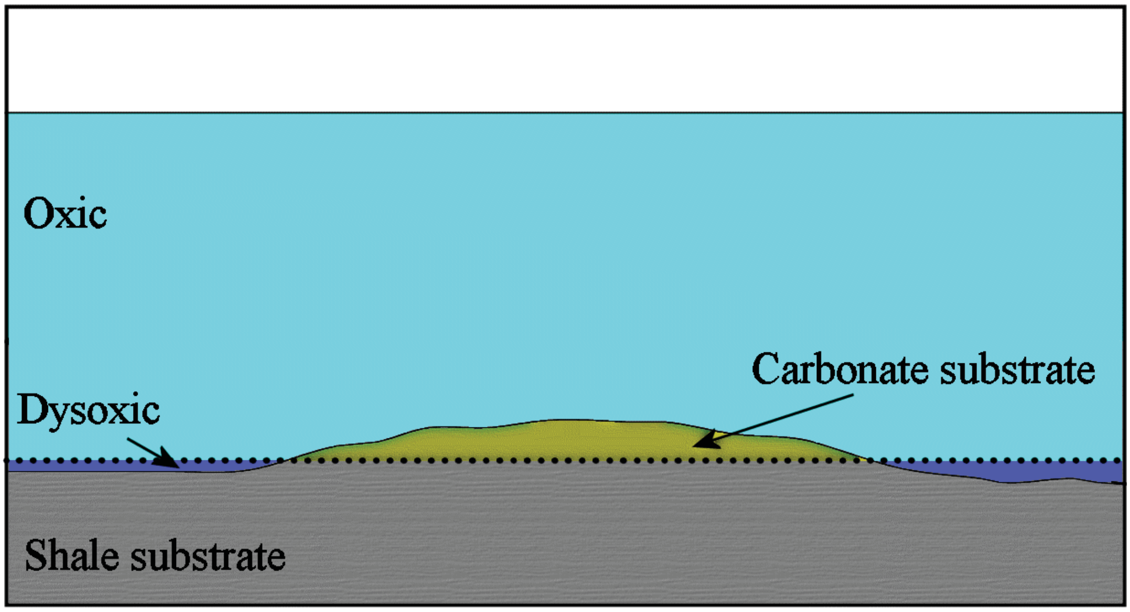

Figure 110. Substrate conditions during the deposition of the oxic lithofacies of the Fossil Cliff Member, with the oxic upper water (light blue) reaching parts of the substrate that are located on topographic highs, resulting in lensoidal carbonate deposition in these areas (yellow), while the low lying areas are still in dysoxic conditions (dark blue = dysoxic water; grey = shale substrate).

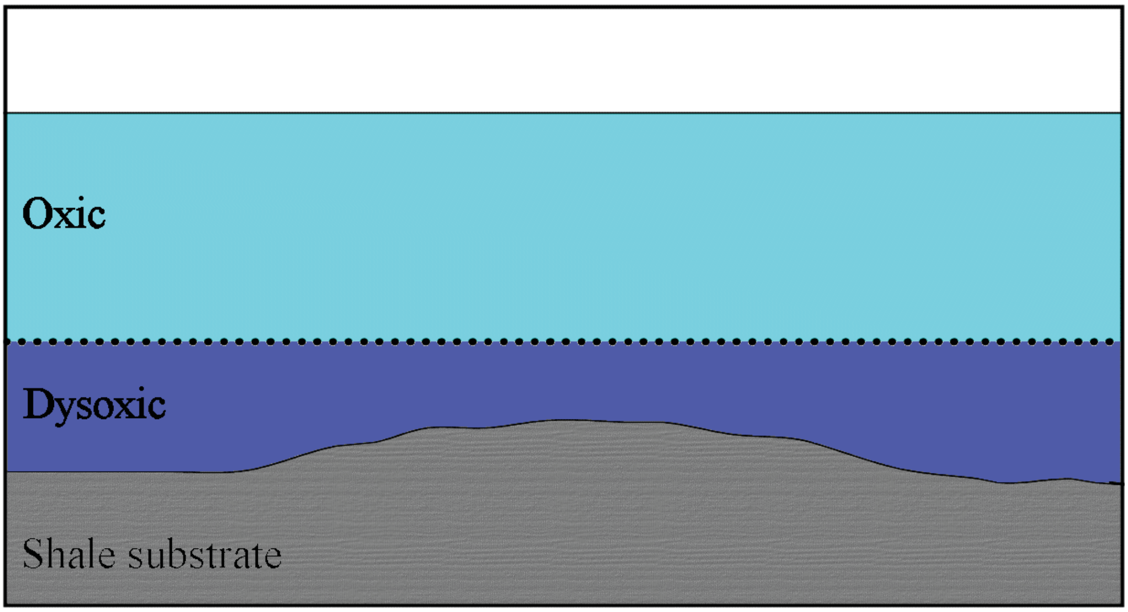

Figure 111. Substrate conditions during the deposition of the dysoxic lithofacies of the Fossil Cliff Member, with the oxic upper water (light blue) not reaching to the substrate, and dysoxic water penetrating the substrate (dysoxic water = blue; shale substrate = grey).

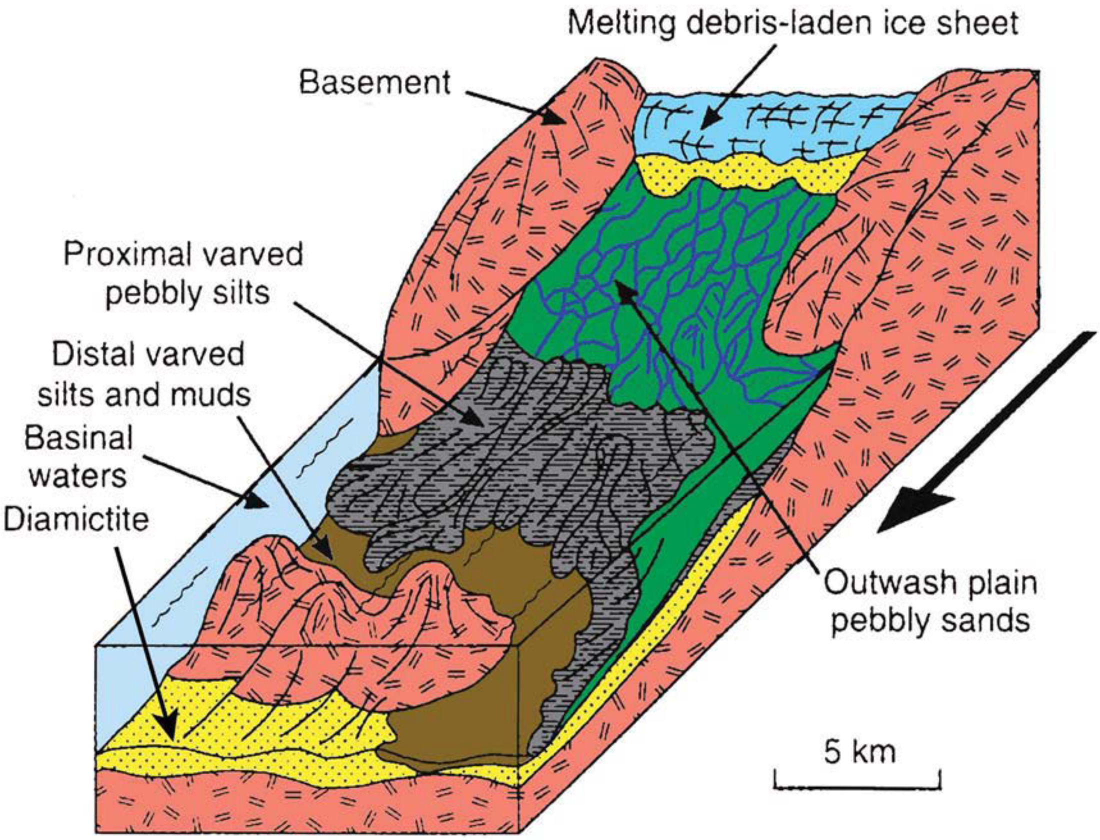

Figure 112. Proposed palaeoenvironmental model for the Fossil Cliff Member. Fossil Cliff Member carbonate faunas were formed on topographic highs (in red) surrounded by dysoxic silts, distal muds, and diamictites of the Holmwood Shale (shown in grey, brown, and yellow), with nearshore deltaic and fluvial swamps of the High Cliff Sandstone and Irwin River Coal Measures (shown in green) (modified from Geological Survey of Western Australia, 1990).

Chapter 10: Global synthesis

The fauna of the Fossil Cliff Member is similar in a number of ways to other Cisuralian faunas, both within Australia and globally. The northern Perth Basin was part of the Westralian Province during the Cisuralian (Archbold, 1983) and during the Asselian tha fauna had a strong affinity with the cold-water fauna of the Austrazean Province. With climatic amelioration in the Sakmarian, these links to the Austrazean Province weakened, and the fauna of the Fossil Cliff Member developed similarities with broadly coeval faunas from the Cimmerian and Andean Provinces of the northern part of Gondwana, as well as the equatorial Tethyan Realm and the Boreal Realm of the Northern Hemisphere polar region (Archbold, 1983, 2000b, 2001; Palmieri, 1994; Palmieri et al., 1994). The fauna of the Fossil Cliff Member is almost identical to the coeval faunas of the Westralian Superbasin: the Callytharra Formation (Carnarvon Basin) and Nura Nura Member of the Poole Sandstone (Canning Basin) (Playford et al. 1975).

Within the macrofauna of the Fossil Cliff Member, taxonomy is linked to species outside of Gondwana. Recent research has shown links between the faunas of the Western Australian Sakmarian and those from the southern regions of the Tethys, especially among the brachiopods (Grant 1993; Archbold and Shi, 1995; Shi et al., 1996; Archbold, 1998, 2000a, 2000b, 2001). The ostracode and foraminiferal faunas are also linked taxonomically to the faunas of the Northern Hemisphere, and within the foraminiferal fauna of the Fossil Cliff Member a number of common species are shared with the Tethyan and Boreal Realms (Palmieri et al. 1994; Groves 2000). The ostracode faunas of the Fossil Cliff Member also share a number of common species and many common genera with the Tethyan and Boreal Realms. The lack of previous specific correlation between the ostracode fauna of the Fossil Cliff Member and the other Gondwanan ostracode faunas is most likely a direct result of the lack of research on these faunas.

Comparison of ostracode fauna

Gondwanan faunas

Cisuralian ostracodes are poorly recorded from Australia; however, a small number of species from eastern Australia have been described by Crespin (1945a). Of the species recorded by Crespin, *Healdia chapmani, H. springsurensis,* and *Bairdia (Bairdia) grayi* occur in the Fossil Cliff Member. These common species confirm that taxonomic similarities between the faunas of the Austrazean and Westralian Provinces occur between the ostracodes, in addition to the well-documented links between the two provinces recorded in the foraminifera (e.g. Crespin 1958; Scheibnerová, 1982; Palmieri, 1994) and the macrofossil groups.

Outside Australia, Gondwanan ostracode faunas from the Cisuralian have been studied little. Sohn and Rocha-Campos (1990) described a poorly preserved nonmarine ostracode assemblage from Brazil, which shows little similarity to the Fossil Cliff Member ostracode Assemblage Zones; however, this is most likely due to widely differing depositional environments (brackish vs normal marine). Hoover (1981) described an assemblage of marine ostracodes from Venezuela containing species of the genera *Roundyella*, *Healdia*, and *Bairdia*. Whilst these species look superficially similar to species from the Fossil Cliff Member, silicification and poor preservation precludes a detailed comparison. Lethiers et al. (1989) documented an ostracode fauna from Tunisia that they interpreted to have both Tethyan and Gondwanan influences. Within the assemblage they recorded a species comparable to *Bairdia (Bairdia) grayi* (Crespin), as well as *Amphissites* sp. cf. *A. centronotus* (Ulrich and Bassler), both of which are present in the Fossil Cliff Member. Gründel and Kozur (1975) and Bless (1987) both studied Permian ostracode faunas from Timor; however, no specific links occur between the Timorese Permian ostracode faunas and those from the Fossil Cliff Member, although *Rectospinella australica* is very similar to *Rectospinella bitauniensis* from West Timor (Bless, 1987). McKenzie (1983) also disputed the claims of Gründel and Kozur (1975) in regards their depth estimates, stating that the assemblage was more likely to be an offshore assemblage than a psychrospheric assemblage as interpreted by Gründel and Kozur (1975).

The paucity of studies on Gondwanan ostracode faunas from the Cisuralian makes comparison of the faunas impossible at this point. However, some genera do appear to be similar, and to a lesser degree, species level similarities are also present between the faunas from the Fossil Cliff Member and those from the regions near the Gondwanan-Tethyan boundary.

Boreal faunas

The Boreal regions of the Northern Hemisphere contain a diverse ostracode fauna, that has some similarity with the Fossil Cliff Member at the species level, such as *Healdia petchorica*. A number of common, cosmopolitan genera such as *Healdia* and *Bairdia* occur in boreal assemblages from Russia (Khivintseva, 1969; Ivanova and Blymakova, 1980; Kochetkova, 1984) and from Thuringian Assemblage deposits in China (Chen, 1958; De-Quiong and Hong, 1986; Becker and Shang-Qi, 1992), and in addition the cosmopolitan species *Amphissites (Amphissites) centronotus* has been recorded from the Permian of the Russian Platform (Shneider, 1966). A number of species appear to be very similar to boreal ones, such as *Graphiadactyllis australae* and *G. petchoricus*, *Sulcoindivisia crasquinsoleauella* and *Perprimitia laevis,* as well as *Cribroconcha ludbrookae* and *C. faveolata*. Strong links are apparent between the Russian boreal faunas and those of the Fossil Cliff Member (e.g. Guseva, 1971; Kochetkova and Guseva, 1972), a link that is also reflected in the similarity between the foraminiferal faunas.

Tethyan faunas

Tethyan faunas from the Midcontinent of North America, where large volumes of work on ostracode taxonomy and palaeoecology have taken place, are somewhat similar to the ostracode fauna of the Fossil Cliff Member. On a generic level, none of the taxa from the Fossil Cliff Member are endemic to the Westralian Province, and each species belongs to cosmopolitan genera from the Tethyan Realm, and in nearly all the Cisuralian provinces. At the species level *Amphissites (Amphissites) centronotus* is the only species in common between the Fossil Cliff Member and the Tethyan Realm, although a number of *Bairdia* species are closely comparable. *A*. sp. aff. *A. centronotus* has been recorded previously from Western Australia in the Lower Carboniferous of the

Bonaparte Basin by Jones (1989), and this species is inferred to represent a long-ranged, stable morphotype of the genus *Amphissites* with a correspondingly long time range (Jones, 1989).

The similarities between the faunas of the Sakmarian Fossil Cliff Member and the Tethyan Realm during the Cisuralian, both in terms of generic taxonomy and also in species associations, indicate that some dispersal occurred between these two regions. With the warming of Gondwana during the Sakmarian, it is likely that species inhabiting the marine-shelf regions of the Tethys migrated to suitable environments along the continental shelf of Gondwana, including areas of the Westralian Superbasin. Work on the ostracode faunas of the Carnarvon and Canning Basins is required to confirm this.

Comparison of foraminiferal fauna

Gondwanan faunas

The foraminiferal faunas of Australia are well described relative to the ostracode faunas, and numerous authors have identified the similarities between the faunas from Western Australia and eastern Australia (e.g. Crespin, 1945b, 1958; Ludbrook, 1956, 1967; Scheibnerová, 1982; Foster et al., 1985; Palmieri, 1990, 1994). Within the Westralian and Austrazean Provinces, the agglutinated foraminifera share a number of common species, although the distributions differ between the western coast of Australia and the eastern coast. A number of shared species of calcareous foraminifera are also found between the two regions. The calcareous foraminifera, however, are more diverse and abundant in Western Australia and, to a degree, in Queensland than in the south-eastern parts of Australia during the Cisuralian.

Only limited work has been done on the foraminiferal distributions in the rest of Gondwana. Lethiers et al. (1989) recorded fusulinid foraminifera along with *Climacammina valvulinoides* Lange and *Globivalvulina graeca* Reichel from Tunisia; however, Cisuralian smaller foraminifera from South America or Africa have not been documented.

Kalia et al. (2000) recorded a foraminiferal assemblage from the Arunchal Pradesh in the eastern Himalayas of India, which included the species *Ammodiscus multicinctus*, *A. nitidus*, *Calcitornella elongata*, *Trepeilopsis australiensis*, *Lununcammina triangularis*, *Protonodosaria irwinensis*, and *P. tereta*. This assemblage is closely similar to the dominant species of the foraminiferal Assemblage Zones from the Fossil Cliff Member and indicates that intermixing occurred between the foraminiferal faunas between the Westralian Province and the Cimmerian Province across the epeiric sea that separated Western Australia and Greater India. Similarly Mertmann (2000) recorded *Calcitornella heathi* from the Salt Range and Trans-Indus Ranges in Pakistan.

Boreal faunas

Recent work by Bondareva and Foster (1993), Palmieri et al. (1994), Groves and Wahlman (1997), and Palmieri (1998) has highlighted the close affinity between the foraminiferal assemblages in Australia and those of the Boreal basins during the Cisuralian. A number of similar species of calcareous foraminifera occur in the Fossil Cliff Member and the Nordvik Basin of Russia (Bondareva and Foster, 1993) (Table 28). Gerke (1961; translated from Russian by Palmieri et al., 1994) noted that the species *Hyperammina elegans*, *H. coleyi*, and *Kechenotiske hadzeli*, amongst others are very similar and possibly the same species as foraminifera from within the Nordvik Basin. In addition *Trepeilopsis australiensis* and *Calcitornella stephensi* occur in the Cisuralian deposits of Novaya Zemlya and Spitsbergen in Russia (Bondareva and Foster, 1993). Groves and Wahlman (1997) in their study of smaller foraminifera from the Cisuralian Boreal Realm assemblages found within the Barents Sea recorded *Hemigordius schlumbergeri* and documented a number of species of *Protonodosaria* that are morphologically very similar to those found within the Fossil Cliff Member. Age ranges given for the species of foraminifera shared between the Boreal Realm and Westralian Province indicate that the earliest appearance of these species is in the Westralian Province, with the last appearance of these species being within the Boreal Realm (Bondareva and Foster, 1993).

Australian species	**Equivalent Russian species**
Howchinella woodwardi (Howchin)	*Frondicularia prima* (Gerke)
Lunucammina triangularis (Crespin)	*Frondicularia? pseudotriangularis* Gerke
Vervilleina? grayi (Crespin)	*Dentalina kalinkoi* Gerke

Table 28. Similar species of foraminifera between the Fossil Cliff Member and the Cisuralian of Russia (adapted from Bondareva and Foster, 1993).

Palmieri et al. (1994) attributed the close affinity of the foraminiferal assemblages of the southern and northern polar and subpolar regions during the Cisuralian to migration by means of cold-water currents, possibly at abyssal depths. A dispersal mechanism is required, however, and currently oceanic currents proposed for this time did not move from pole to pole (Archbold, 1998).

Tethyan faunas

Foraminifera within the tropical to subtropical water of the Tethys consisted mainly of larger fusuline forms; however, studies of the smaller foraminifera have been undertaken, although at a limited rate when compared with the fusuline foraminifera (e.g. Ireland, 1956; Groves, 2000). Within the Tethyan smaller foraminiferal assemblages a number of shared species with the Fossil Cliff Member have been identified, including *Hemigordius schlumbergeri*, possibly *Vervilleina? grayi* (Groves, 2000), and the thick-walled milioline forms *Calcitornella elongata* and *C. heathi* (Cushman and Waters, 1928a, 1930). All these species have stratigraphic ranges starting in either the Late Carboniferous or early Cisuralian. Based upon this, the Tethys was probably the generation point for these species, and they then migrated southwards during the Sakmarian climatic amelioration. No shared agglutinated species between the Tethys and the Fossil Cliff Member have been recorded.

The foraminiferal species that the Fossil Cliff Member have in common with the Tethyan region are calcareous species that, with the exception of *Vervilleina? grayi*, are milioline and interpreted to have inhabited warmer water (Crespin 1958). Migration of these species would have occurred during the commencement of the Sakmarian climatic amelioration and as these species favoured shallow water, they would have dispersed across the shallow Tethys to the northern part of Gondwana and then along the coastline of Gondwana using nearshore currents as a transportation mechanism.

Overall global affinities of the fauna

The ostracodes and foraminifera within the Fossil Cliff Member each display an affinity with faunas from outside of Gondwana. Within the ostracode fauna, the strongest links to other global faunas are with the Russian Boreal and North American Tethyan faunas. Between the Gondwanan and Tethyan faunas, however, the only shared species are what is interpreted to be a cosmopolitan form (*Amphissites (Amphissites) centronotus*), which is also recorded in the Boreal Cisuralian faunas, and the other links are between comparable species belonging to a very large group, the *Bairdia*. The generic compositions do, however, match with similar generic compositions from Tethyan faunas that are interpreted to have been deposited under similar palaeoenvironment conditions. Further work is required on the Cisuralian ostracodes of Western Australia to document thoroughly the ostracode assemblages present before anything more than a tentative link with Tethyan faunas can be established. The link with the ostracode faunas of the Boreal Realm is much stronger, with a number of species either identical (such as *Healdia petchorica* and *Amphissites (Amphissites) centronotus*) or very similar (*Graphiadactyllis australae* and *G. petchoricus; Cribroconcha ludbrookae* and *C. faveolata*; *Sulcoindivisia crasquinsoleauella* and *Perprimita laevis*). This link is possibly the result of ostracode faunas flourishing in similar cold-temperature conditions. Given the strong link between the ostracode faunas of the Fossil Cliff Member and the Boreal Realm, further work on the ostracode faunas may provide enough material to use ostracodes to correlate biostratigraphic horizons between the Cisuralian of Western Australia and the International Stratotypes for the Cisuralian from Russia.

The foraminiferal fauna of the Fossil Cliff Member and other coeval faunas from across Australia have been well documented (eg. Crespin 1958; Scheibnerová, 1982; Palmieri, 1990, 1994) and share a number of common species with both the Boreal and Tethyan Realms. The migration of boreal species may have occurred via abyssal ocean circulation (Palmieri et al., 1994) or across shallow seas and coastlines in the case of the Tethyan species. The biostratigraphic value of these species is limited, however, as their stratigraphic ranges are broad (Groves, 2000).

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Appendix 1: Sample details

Sample number	Height above base of Fossil Cliff Member (m)	Unit name	Lithology	Assemblage number
1	-3.00	Holmwood Shale	Black-grey shale	1
2	-2.90	Holmwood Shale	Black-grey shale	1
3	-2.80	Holmwood Shale	Black-grey shale	1
4	-2.70	Holmwood Shale	Black-grey shale	1
5	-2.60	Holmwood Shale	Black-grey shale	1
6	-2.50	Holmwood Shale	Black-grey shale	1
7	-2.40	Holmwood Shale	Black-grey shale	1
8	-2.30	Holmwood Shale	Black-grey shale	1
9	-2.20	Holmwood Shale	Black-grey shale	1
10	-2.10	Holmwood Shale	Black-grey shale	1
11	-2.00	Holmwood Shale	Black-grey shale	1
12	-1.85	Holmwood Shale	Black-grey shale	1
13	-1.70	Holmwood Shale	Black-grey shale	1
14	-1.60	Holmwood Shale	Black-grey shale	1
15	-1.45	Holmwood Shale	Black-grey shale	1
16	-1.35	Holmwood Shale	Black-grey shale	1
17	-1.20	Holmwood Shale	Black-grey shale	1
18	-1.10	Holmwood Shale	Black-grey shale	1
19	-1.00	Holmwood Shale	Black-grey shale	1
20	-0.90	Holmwood Shale	Black-grey shale	1
21	-0.80	Holmwood Shale	Black-grey shale	1
22	-0.75	Holmwood Shale	Black-grey shale	1
23	-0.65	Holmwood Shale	Black-grey shale	1
24	-0.60	Holmwood Shale	Black-grey shale	1
25	-0.55	Holmwood Shale	Black-grey shale	1
26	-0.50	Holmwood Shale	Black-grey shale	1
27	-0.40	Holmwood Shale	Black-grey shale	1
28	-0.35	Holmwood Shale	Black-grey shale	1
29	-0.30	Holmwood Shale	Black-grey shale	1
30	-0.25	Holmwood Shale	Red-yellow shale	1
31	-0.15	Holmwood Shale	Red-yellow shale	1
32	-0.10	Holmwood Shale	Red-yellow shale	1
33	0.00	Fossil Cliff Member	Calcareous siltstone with bioclasts	1
34	0.10	Fossil Cliff Member	Calcareous siltstone with bioclasts	1
35	0.20	Fossil Cliff Member	Calcareous siltstone with bioclasts	1
36	0.30	Fossil Cliff Member	Calcareous siltstone with bioclasts	1
37	0.40	Fossil Cliff Member	Sandy calcarenite	1
38	0.50	Fossil Cliff Member	Sandy calcarenite	1
39	0.55	Fossil Cliff Member	Sandy calcarenite	1
40	0.60	Fossil Cliff Member	Sandy calcarenite	1
41	0.65	Fossil Cliff Member	Calcareous silt and sandstone	1
42	0.70	Fossil Cliff Member	Calcareous silt and sandstone	1
43	0.72	Fossil Cliff Member	Calcareous silt and sandstone	1
44	0.75	Fossil Cliff Member	Calcareous silt and sandstone	1
45	0.80	Fossil Cliff Member	Calcareous silt and sandstone	1
46	0.83	Fossil Cliff Member	Calcareous silt and sandstone	1
47	0.87	Fossil Cliff Member	Calcareous silt and sandstone	1
48	0.90	Fossil Cliff Member	Calcareous silt and sandstone	1
49	0.95	Fossil Cliff Member	Calcareous silt and sandstone	1
50	1.00	Fossil Cliff Member	Indurated grey calcsiltite	1

Sample number	Height above base of Fossil Cliff Member (m)	Unit name	Lithology	Assemblage number
51	1.05	Fossil Cliff Member	Calcareous silt and sandstone	1
52	1.10	Fossil Cliff Member	Indurated grey calcsiltite	1
53	1.15	Fossil Cliff Member	Calcareous silt and sandstone	1
54	1.20	Fossil Cliff Member	Calcareous silt and sandstone	1
55	1.25	Fossil Cliff Member	Indurated grey calcsiltite	1
56	1.30	Fossil Cliff Member	Indurated grey calcsiltite	1
57	1.35	Fossil Cliff Member	Indurated grey calcsiltite	1
58	1.40	Fossil Cliff Member	Black-grey shale	1
59	1.45	Fossil Cliff Member	Indurated grey calcsiltite	1
60	1.70	Fossil Cliff Member	Black-grey shale	2
61	2.10	Fossil Cliff Member	Black-grey shale	2
62	2.40	Fossil Cliff Member	Black-grey shale	2
63	2.70	Fossil Cliff Member	Black-grey shale	2
64	3.30	Fossil Cliff Member	Black-grey shale	2
65	3.60	Fossil Cliff Member	Black-grey shale	2
66	3.90	Fossil Cliff Member	Black-grey shale	2
67	4.20	Fossil Cliff Member	Black-grey shale	2
68	4.40	Fossil Cliff Member	Black-grey shale	2
69	4.60	Fossil Cliff Member	Black-grey shale	2
70	4.80	Fossil Cliff Member	Calcareous siltstone with bioclasts	2
71	5.00	Fossil Cliff Member	Calcareous siltstone with bioclasts	2
72	5.20	Fossil Cliff Member	Calcareous siltstone with bioclasts	2
73	5.30	Fossil Cliff Member	Calcareous siltstone with bioclasts	2
74	5.40	Fossil Cliff Member	Semi-indurated calcareous siltstone	2
75	5.55	Fossil Cliff Member	Semi-indurated calcareous siltstone	2
76	5.70	Fossil Cliff Member	Semi-indurated calcareous siltstone	2
77	5.80	Fossil Cliff Member	Semi-indurated calcareous siltstone	2
78	5.90	Fossil Cliff Member	Semi-indurated calcareous siltstone	2
79	6.00	Fossil Cliff Member	Semi-indurated calcareous siltstone	2
80	6.15	Fossil Cliff Member	Semi-indurated calcareous siltstone	2
81	6.30	Fossil Cliff Member	Semi-indurated calcareous siltstone	2
82	6.40	Fossil Cliff Member	Semi-indurated calcareous siltstone	2
83	6.60	Fossil Cliff Member	Semi-indurated calcareous siltstone	2
84	6.85	Fossil Cliff Member	Semi-indurated calcareous siltstone	2
85	6.90	Fossil Cliff Member	Semi-indurated calcareous siltstone	2
86	7.10	Fossil Cliff Member	Black-grey shale	3
87	7.15	Fossil Cliff Member	Black-grey shale	3
88	7.20	Fossil Cliff Member	Black-grey shale	3
89	7.30	Fossil Cliff Member	Black-grey shale	3
90	7.40	Fossil Cliff Member	Black-grey shale	3
91	7.45	Fossil Cliff Member	Black-grey shale	3
92	7.50	Fossil Cliff Member	Black-grey shale	3
93	7.55	Fossil Cliff Member	Black-grey shale	3
94	7.60	Fossil Cliff Member	Black-grey shale	3
95	7.65	Fossil Cliff Member	Black-grey shale	3
96	7.70	Fossil Cliff Member	Black-grey shale	3
97	7.75	Fossil Cliff Member	Black-grey shale	3
98	7.80	Fossil Cliff Member	Black-grey shale	3
99	7.85	Fossil Cliff Member	Black-grey shale	3
100	7.90	Fossil Cliff Member	Indurated grey calcarenite	3
101	7.95	Fossil Cliff Member	Indurated grey calcarenite	3
102	8.05	Fossil Cliff Member	Indurated grey calcarenite	3
103	8.10	Fossil Cliff Member	Indurated grey calcarenite	3
104	8.15	Fossil Cliff Member	Indurated grey calcarenite	3
105	8.20	Fossil Cliff Member	Sandy calcareite	3

Sample number	Height above base of Fossil Cliff Member (m)	Unit name	Lithology	Assemblage number
106	8.30	Fossil Cliff Member	Sandy calcareite	3
107	8.35	Fossil Cliff Member	Sandy calcareite	3
108	8.40	Fossil Cliff Member	Sandy calcareite	3
109	8.50	Fossil Cliff Member	Sandy calcareite	3
110	8.55	Fossil Cliff Member	Indurated grey calcarenite	3
111	8.65	Fossil Cliff Member	Indurated grey calcarenite	3
112	8.70	Fossil Cliff Member	Indurated grey calcarenite	3
113	8.80	Fossil Cliff Member	Indurated grey calcarenite	3
114	8.85	Fossil Cliff Member	Indurated grey calcarenite	3
115	8.95	Fossil Cliff Member	Indurated grey calcarenite	3
116	9.00	Fossil Cliff Member	Indurated grey calcarenite	3
117	9.10	Fossil Cliff Member	Indurated grey calcarenite	3
118	9.20	Fossil Cliff Member	Indurated grey calcarenite	3
119	9.30	Fossil Cliff Member	Indurated grey calcarenite	3
120	9.40	Fossil Cliff Member	Indurated grey calcarenite	3
121	9.50	Fossil Cliff Member	Indurated grey calcarenite	3
122	9.60	Fossil Cliff Member	Indurated grey calcarenite	3
123	9.65	Fossil Cliff Member	Indurated grey calcarenite	3
124	9.70	Fossil Cliff Member	Indurated grey calcarenite	3
125	9.80	Fossil Cliff Member	Indurated grey calcarenite	3
126	9.95	Fossil Cliff Member	Indurated grey calcarenite	3
127	10.15	Fossil Cliff Member	Indurated grey calcarenite	3
128	10.20	Fossil Cliff Member	Sandy calcarenite	4
129	10.30	Fossil Cliff Member	Sandy calcarenite	4
130	10.40	Fossil Cliff Member	Sandy calcarenite	4
131	10.45	Fossil Cliff Member	Sandy calcarenite	4
132	10.50	Fossil Cliff Member	Sandy calcarenite	4
133	10.55	Fossil Cliff Member	Sandy calcarenite	4
134	10.60	Fossil Cliff Member	Sandy calcarenite	4
135	10.70	Fossil Cliff Member	Indurated grey to red calcarenite	4
136	10.90	Fossil Cliff Member	Indurated grey to red calcarenite	4
137	11.00	Fossil Cliff Member	Indurated grey to red calcarenite	4
138	11.10	Fossil Cliff Member	Indurated grey to red calcarenite	4
139	11.30	Fossil Cliff Member	Indurated grey to red calcarenite	4
140	11.40	Fossil Cliff Member	Indurated grey to red calcarenite	4
141	11.50	Fossil Cliff Member	Indurated grey to red calcarenite	4
142	11.65	Fossil Cliff Member	Indurated grey to red calcarenite	4
143	11.80	Fossil Cliff Member	Indurated grey to red calcarenite	4
144	11.90	Fossil Cliff Member	Indurated grey to red calcarenite	4
145	12.10	Fossil Cliff Member	Indurated grey to red calcarenite	4
146	12.50	Fossil Cliff Member	Indurated grey to red calcarenite	4
147	12.80	Fossil Cliff Member	Indurated grey to red calcarenite	4
148	13.20	Fossil Cliff Member	White sandy shale	5
149	13.40	Fossil Cliff Member	White sandy shale	5
150	13.50	Fossil Cliff Member	White sandy shale	5
151	13.60	Fossil Cliff Member	White silty sandstone	5
152	13.70	Fossil Cliff Member	White silty sandstone	5
153	13.80	Fossil Cliff Member	White silty sandstone	5
154	13.95	Fossil Cliff Member	White silty sandstone	5
155	14.10	Fossil Cliff Member	Fine-grained sandstone	5
156	14.20	Fossil Cliff Member	Fine-grained sandstone	5
157	14.30	Fossil Cliff Member	Fine-grained sandstone	5
158	14.50	Fossil Cliff Member	Fine-grained sandstone	5
159	14.70	Fossil Cliff Member	Medium-grained sandstone	5
160	14.90	Fossil Cliff Member	Medium-grained sandstone	5

Plates

Plate 1

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *?Quasipolycope* sp. A, UWA 128888, right lateral view.
2. *?Quasipolycope* sp. A, stereo pair with figure 1.
3. *Hollinella pirajnoensis* sp. nov., UWA 128889, right lateral view, male, holotype.
4. *Hollinella pirajnoensis* sp. nov., UWA 128923, left lateral view, female, paratype.
5. *Hollinella pirajnoensis* sp. nov., enlargement of posterior of figure 3.
6. *Hollinella pirajnoensis* sp. nov., enlargement of L1 on figure 3.
7. *Hollinella pirajnoensis* sp. nov., enlargement of ventral margin on figure 3.
8. *Hollinella pirajnoensis* sp. nov., enlargement of ventral margin on figure 4.
9. *Hollinella pirajnoensis* sp. nov., enlargement of spines on figure 11.
10. *Hollinella pirajnoensis* sp. nov., enlargement of spines on figure 11.
11. *Hollinella pirajnoensis* sp. nov., UWA 128924, right lateral view, female, paratype.
12. *Hollinella pirajnoensis* sp. nov., UWA 128925, right lateral view, female, paratype.
13. *Hollinella pirajnoensis* sp. nov., UWA 128926, right internal view, female.
14. *Hollinella pirajnoensis* sp. nov., stereo pair with figure 13.
15. *Hollinella pirajnoensis* sp. nov., UWA 128927, right lateral view, female.
16. *Hollinella pirajnoensis* sp. nov., UWA 128928, left internal view, male.
17. Judahellid? sp., enlargement of L1 on figure 18.
18. Judahellid? sp., UWA 128929, right lateral view.
19. *Aechmina reticulata* sp. nov., UWA 128890, right lateral view, holotype.
20. *Aechmina reticulata* sp. nov., enlargement of L3? on figure 19.
21. *Aechmina reticulata* sp. nov., UWA 128930, left lateral view, paratype.
22. *Aechmina reticulata* sp. nov., UWA 128931, right internal view, paratype.
23. *Aechmina reticulata* sp. nov., enlargement of AMS on figure 22.
24. *Aechmina reticulata* sp. nov., UWA 128932, dorsal view, paratype.
25. *Aechmina reticulata* sp. nov., UWA 128933, right internal view, paratype.
26. *Aechmina reticulata* sp. nov., enlargement of AMS on figure 25.
27. *Aechmina reticulata* sp. nov., UWA 128934, left lateral view, paratype.
28. *Aechmina reticulata* sp. nov., UWA 128935, dorsal view, paratype.
29. *Amphissites (Amphissites) centronotus* (Ulrich and Bassler), 1906, UWA 128936, left lateral view.
30. *Amphissites (Amphissites) centronotus* (Ulrich and Bassler),1906, enlargement of figure 29 showing details of surface ornamentation on reticulation (scale bar is 10 µm).

Plate 1

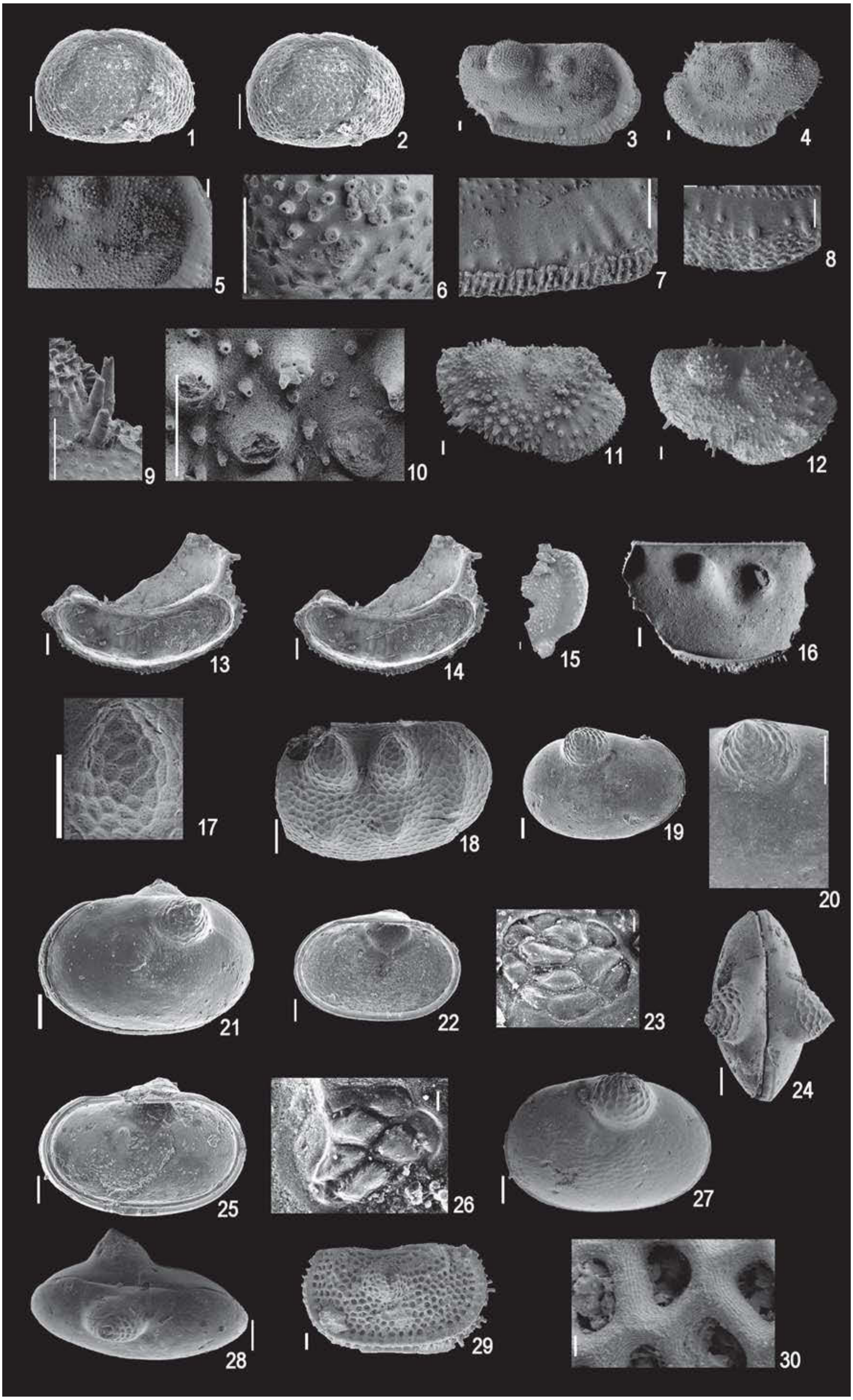
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Plate 2

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *Amphissites (Amphissites) centronotus* (Ulrich and Bassler), 1906, UWA 128937, right lateral view.
2. *Amphissites (Amphissites) centronotus* (Ulrich and Bassler), 1906, enlargement of figure 1 showing medial node.
3. *Amphissites (Amphissites) centronotus* (Ulrich and Bassler), 1906, UWA 128938, right lateral view
4. *Amphissites (Amphissites) centronotus* (Ulrich and Bassler), 1906, stereo pair with figure 3.
5. *Amphissites (Amphissites) centronotus* (Ulrich and Bassler), 1906, enlargement of figure 3 showing medial node.
6. *Amphissites (Amphissites) centronotus* (Ulrich and Bassler), 1906, UWA 128939, right lateral view.
7. *Amphissites (Amphissites) centronotus* (Ulrich and Bassler), 1906, UWA 128940, right internal view.
8. *Amphissites (Amphissites) centronotus* (Ulrich and Bassler), 1906, UWA 128941, right internal view.
9. *Kirkbya fossilcliffi* sp. nov., UWA 128891, right lateral view, holotype.
10. *Kirkbya fossilcliffi* sp. nov., stereo pair with figure 9.
11. *Kirkbya fossilcliffi* sp. nov., UWA 128942, left lateral view, paratype
12. *Kirkbya fossilcliffi* sp. nov., stereo pair with figure 11.
13. *Kirkbya fossilcliffi* sp. nov., UWA 128943, left internal view, paratype.
14. *Kirkbya mingenewensis* sp. nov., UWA 128944, right internal view, paratype.
15. *Kirkbya mingenewensis* sp. nov., UWA 128945, left lateral view, paratype.
16. *Kirkbya mingenewensis* sp. nov., enlargement of figure 15 showing fine detail of reticulation.
17. *Kirkbya mingenewensis* sp. nov., UWA 128946, left lateral view, paratype.
18. *Kirkbya mingenewensis* sp. nov., enlargement of figure 17 showing fine detail of reticulation.
19. *Kirkbya mingenewensis* sp. nov., UWA 128947, left lateral view, paratype.
20. *Kirkbya mingenewensis* sp. nov., enlargement of figure 19 showing fine detail of reticulation.
21. *Kirkbya mingenewensis* sp. nov., UWA 128892, left lateral view, holotype.
22. *Kirkbya mingenewensis* sp. nov., UWA 128948, left lateral view, paratype.
23. *Kirkbya mingenewensis* sp. nov., UWA 128949, right internal view, paratype.
24. *Kirkbya mingenewensis* sp. nov., enlargement of figure 23 showing AMS.
25. *Kirkbya mingenewensis* sp. nov., enlargement of figure 23 showing sieve-type pores.

Plate 2

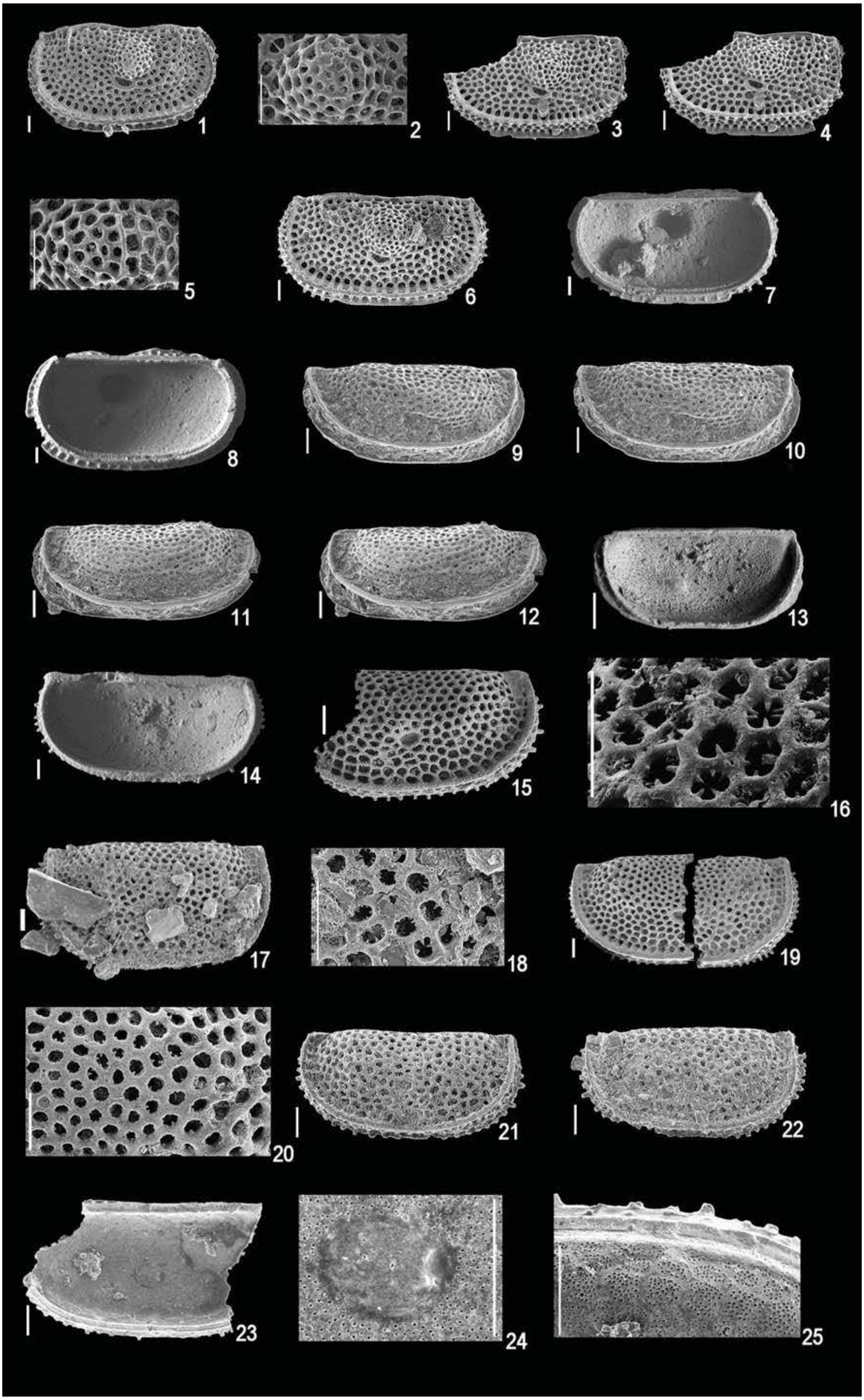

Plate 3

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *Kirkbya mingenewensis* sp. nov., UWA 128950, left lateral view, paratype.
2. *Kirkbya mingenewensis* sp. nov., stereo pair with figure 1.
3. *Kirkbya mingenewensis* sp. nov., UWA 128951, right internal view, paratype.
4. *Kirkbya mingenewensis* sp. nov., enlargement of figure 3 showing AMS.
5. *Kirkbya* sp. A, UWA 128952, right lateral view.
6. *Kirkbya* sp. A, stereo pair with figure 5.
7. *Kirkbya* sp. A, UWA 128953, left internal view.
8. *Kirkbya* sp. A, UWA 128893, left lateral view.
9. *Kirkbya* sp. A, stereo pair with figure 8.
10. *Healdia bradmani* sp. nov., UWA 128898, right lateral view, holotype.
11. *Healdia bradmani* sp. nov., UWA 128954, ventral view, paratype.
12. *Healdia bradmani* sp. nov., UWA 128955, left lateral view, paratype.
13. *Healdia chapmani* (Crespin), 1945, UWA 128956, right lateral view.
14. *Healdia chapmani* (Crespin), 1945, enlargement of figure 13 showing posterior margin.
15. *Healdia chapmani* (Crespin), 1945, UWA 128957, left lateral view.
16. *Healdia chapmani* (Crespin), 1945, stereo pair with figure 15.
17. *Healdia chapmani* (Crespin), 1945, enlargement of figure 15 showing posterior margin.
18. *Healdia chapmani* (Crespin), 1945, UWA 128958, left lateral view.
19. *Healdia chapmani* (Crespin), 1945, UWA 128959, left internal view.
20. *Healdia chapmani* (Crespin), 1945, stereo pair with figure 19.
21. *Healdia chapmani* (Crespin), 1945, enlargement of figure 19 showing AMS.
22. *Healdia chapmani* (Crespin), 1945, UWA 128960, left lateral view.
23. *Healdia chapmani* (Crespin), 1945, UWA 128961, right lateral view.
24. *Healdia chapmani* (Crespin), 1945, stereo pair with figure 23.
25. *Healdia crespinae* sp. nov., UWA 128962, right internal view, paratype.
26. *Healdia crespinae* sp. nov., enlargement of figure 25 showing AMS.
27. *Healdia crespinae* sp. nov., UWA 128963, left lateral view, paratype.
28. *Healdia crespinae* sp. nov., UWA 128894, left lateral view, holotype.
29. *Healdia crespinae* sp. nov., stereo pair with figure 28.

Plate 3

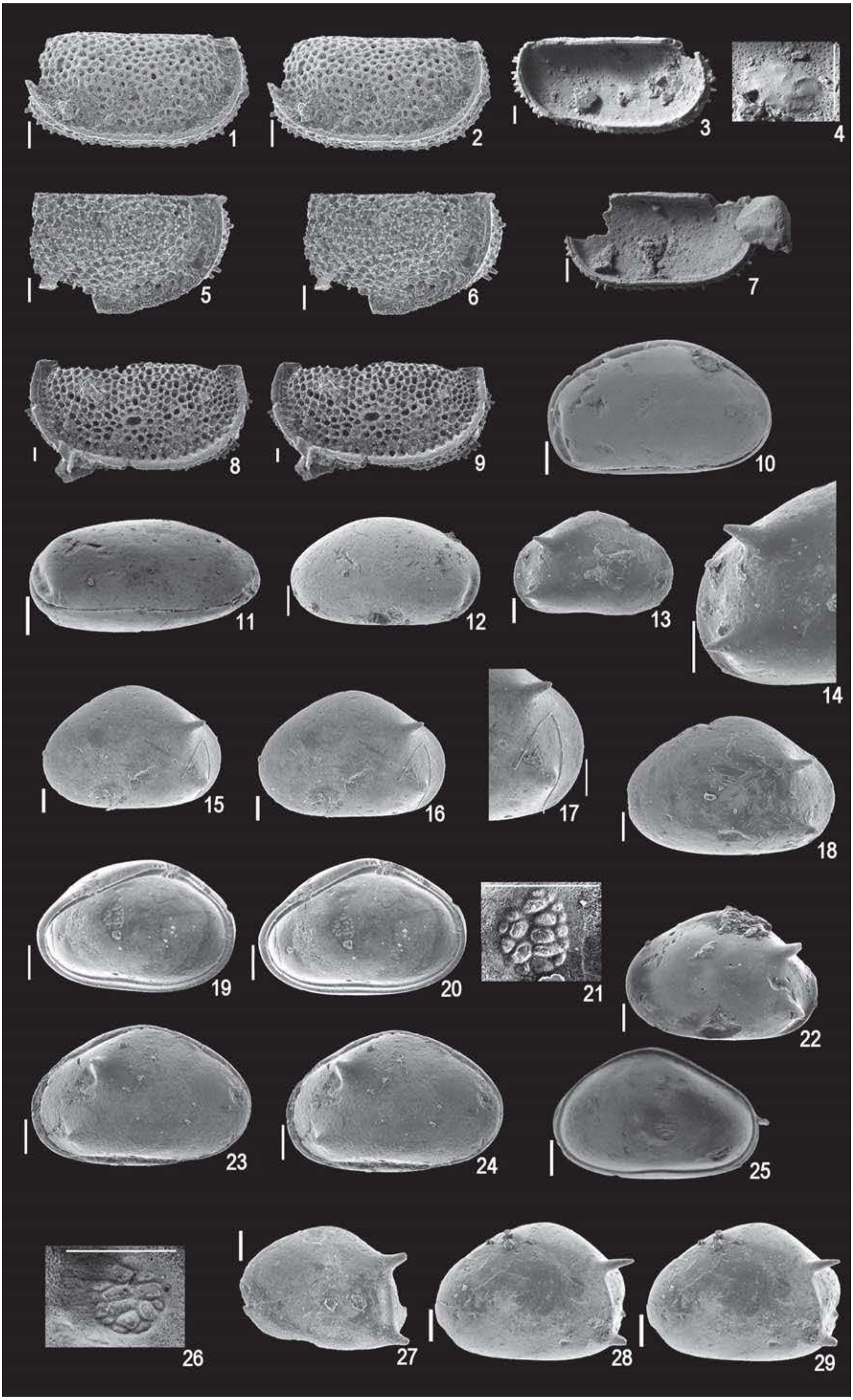

Plate 4

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *Healdia crespinae* sp. nov., UWA 128964, right lateral view, paratype.
2. *Healdia crespinae* sp. nov., stereo pair with figure 1.
3. *Healdia crespinae* sp. nov., UWA 128965, ventral view, paratype.
4. *Healdia crespinae* sp. nov., UWA 128966, left lateral view, paratype.
5. *Healdia crespinae* sp. nov., stereo pair with figure 4.
6. *Healdia gregoryi* sp. nov., UWA 128967, right lateral view, paratype.
7. *Healdia gregoryi* sp. nov., UWA 128968, left lateral view, paratype.
8. *Healdia gregoryi* sp. nov., UWA 128895, right lateral view, holotype.
9. *Healdia gregoryi* sp. nov., UWA 128969, right lateral view, paratype.
10. *Healdia gregoryi* sp. nov., UWA 128970, right lateral view, paratype.
11. *Healdia irwinensis* Fleming, UWA 128971, dorsal view.
12. *Healdia irwinensis* Fleming, UWA 128972, right lateral view.
13. *Healdia irwinensis* Fleming, UWA 128973, right lateral view.
14. *Healdia irwinensis* Fleming, stereo pair with figure 13.
15. *Healdia irwinensis* Fleming, enlargement of figure 13 showing details of posterior spines and margin.
16. *Healdia irwinensis* Fleming, UWA 128974, right internal view.
17. *Healdia irwinensis* Fleming, stereo pair with figure 16.
18. *Healdia irwinensis* Fleming, enlargement of figure 16 showing AMS.
19. *Healdia irwinensis* Fleming, enlargement of figure 16 showing ventral margin.
20. *Healdia irwinensis* Fleming, enlargement of figure 16 showing dorsal margin and hinge.
21. *Healdia irwinensis* Fleming, UWA 128975, right lateral view.
22. *Healdia irwinensis* Fleming, stereo pair with figure 21.
23. *Healdia irwinensis* Fleming, UWA 128976, left lateral view.
24. *Healdia irwinensis* Fleming, stereo pair with figure 23.
25. *Healdia irwinensis* Fleming, UWA 128977, right lateral view.
26. *Healdia irwinensis* Fleming, UWA 128978, left lateral view.
27. *Healdia irwinensis* Fleming, stereo pair with figure 26.
28. *Healdia irwinensis* Fleming, UWA 128979, left lateral view.

Plate 4

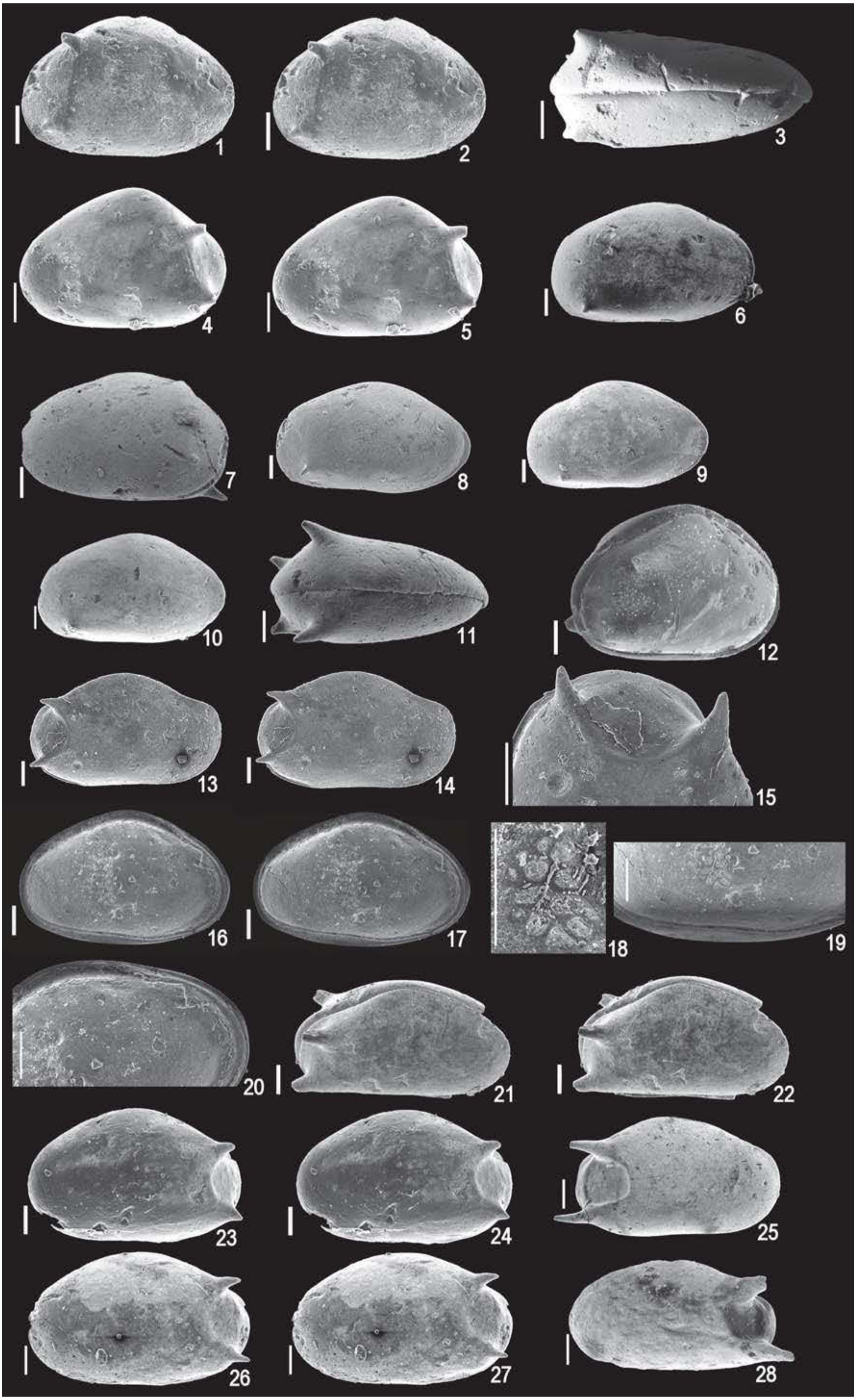

Plate 5

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *Healdia irwinensis* Fleming, UWA 128980, left internal view.
2. *Healdia irwinensis* Fleming, stereo pair with figure 1.
3. *Healdia irwinensis* Fleming, enlargement of figure 1 showing AMS.
4. *Healdia irwinensis* Fleming, UWA 128981, AMS on RV.
5. *Healdia irwinensis* Fleming, UWA 128982, AMS on LV.
6. *Healdia irwinensis* Fleming, UWA 128983, AMS on LV.
7. *Healdia petchorica* Guseva, 1971, UWA 128984, left lateral view.
8. *Healdia petchorica* Guseva, 1971, UWA 128985, right internal view.
9. *Healdia petchorica* Guseva, 1971, enlargement of figure 8 showing AMS.
10. *Healdia petchorica* Guseva, 1971, UWA 128986, left lateral view.
11. *Healdia petchorica* Guseva, 1971, UWA 128987, left lateral view.
12. *Healdia petchorica* Guseva, 1971, stereo pair with figure 11.
13. *Healdia petchorica* Guseva, 1971, enlargement of figure 11 showing pores.
14. *Healdia petchorica* Guseva, 1971, UWA 128988, left lateral view.
15. *Healdia petchorica* Guseva, 1971, stereo pair with figure 14.
16. *Healdia petchorica* Guseva, 1971, enlargement of figure 14 showing pores (scale bar is 10 µm).
17. *Healdia petchorica* Guseva, 1971, UWA 128989, left lateral view.
18. *Healdia petchorica* Guseva, 1971, stereo pair with figure 17.
19. *Healdia obtusa*, sp. nov.,UWA 128990, left lateral view, paratype.
20. *Healdia petchorica* Guseva, 1971, UWA 128991, dorsal view.
21. *Healdia petchorica* Guseva, 1971, UWA 128992, left internal view.
22. *Healdia petchorica* Guseva, 1971, enlargement of figure 21 showing AMS.
23. *Healdia obtusa*, sp. nov., UWA 128896, right lateral view, holotype.
24. *Healdia springsurensis* (Crespin), 1945, UWA 128993, right lateral view.
25. *Healdia springsurensis* (Crespin), 1945, UWA 128994, right lateral view.
26. *Healdia obtusa*, sp. nov., UWA 128995, right lateral view, paratype.

Plate 5

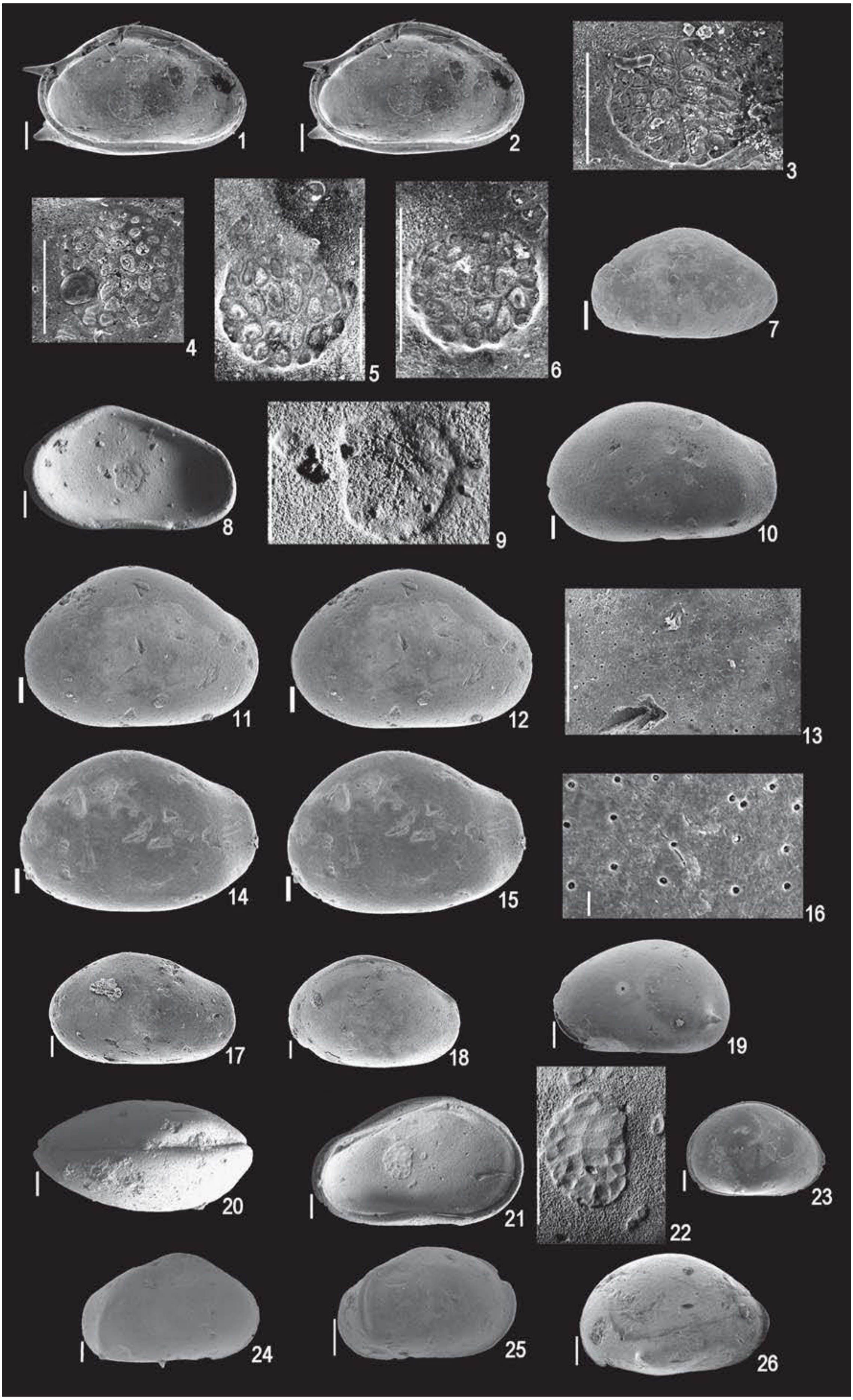

Plate 6

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *Healdia westraliaensis* sp. nov., UWA 128996, left lateral view, paratype.
2. *Healdia westraliaensis* sp. nov., UWA 128897, left lateral view, holotype.
3. *Healdia westraliaensis* sp. nov., UWA 128997, left internal view, paratype.
4. *Healdia westraliaensis* sp. nov., enlargement of figure 3 showing AMS.
5. *Healdia* sp. A., UWA 128899, left lateral view.
6. *Cribroconcha ludbrookae* (Fleming), 1985, UWA 128998, right lateral view.
7. *Cribroconcha ludbrookae* (Fleming), 1985, UWA 128999, right lateral view.
8. *Cribroconcha ludbrookae* (Fleming), 1985, UWA 129000, left lateral view.
9. *Cribroconcha ludbrookae* (Fleming), 1985, UWA 132322, right lateral view.
10. *Cribroconcha ludbrookae* (Fleming), 1985, UWA 129002, right lateral view.
11. *Cribroconcha ludbrookae* (Fleming), 1985, enlargement of figure 10 showing posterior spines.
12. *Cribroconcha ludbrookae* (Fleming), 1985, 1985, enlargement of figure 10 showing anterior margin.
13. *Cribroconcha ludbrookae* (Fleming), 1985, 1985, UWA 129003, right lateral view.
14. *Cribroconcha ludbrookae* (Fleming), 1985, 1985, UWA 129004, left lateral view.
15. *Cribroconcha ludbrookae* (Fleming), 1985, 1985, UWA 129005, ventral view.
16. *Cribroconcha ludbrookae* (Fleming), 1985, 1985, UWA 129006, left lateral view, juvenile instar.
17. *Cribroconcha ludbrookae* (Fleming), 1985, 1985, UWA 129007, dorsal view.
18. *Healdianella? moryi* sp. nov., UWA 129008, right lateral view, paratype.
19. *Healdianella? moryi* sp. nov., UWA 129009, right internal view, paratype.
20. *Healdianella? moryi* sp. nov., enlargement of figure 19 showing AMS.
21. *Healdianella? moryi* sp. nov., UWA 129010, left lateral view, paratype.
22. *Healdianella? moryi* sp. nov., UWA 128900, left lateral view, holotype.
23. *Healdianella? moryi* sp. nov., stereo pair with figure 22.
24. *Healdianella? moryi* sp. nov., UWA 129011, right lateral view, paratype.
25. *Waylandella holmwoodensis* sp. nov., UWA 129001, left lateral view, holotype.
26. *Waylandella holmwoodensis* sp. nov., UWA 129012, right lateral view, paratype.
27. *Waylandella holmwoodensis* sp. nov., UWA 129013, left lateral view, paratype.
28. *Waylandella holmwoodensis* sp. nov., UWA 129014, right lateral view, paratype.
29. *Waylandella holmwoodensis* sp. nov., UWA 129015, dorsal view, paratype.
30. *Waylandella holmwoodensis* sp. nov., UWA 129016, left lateral view, paratype.

Plate 6

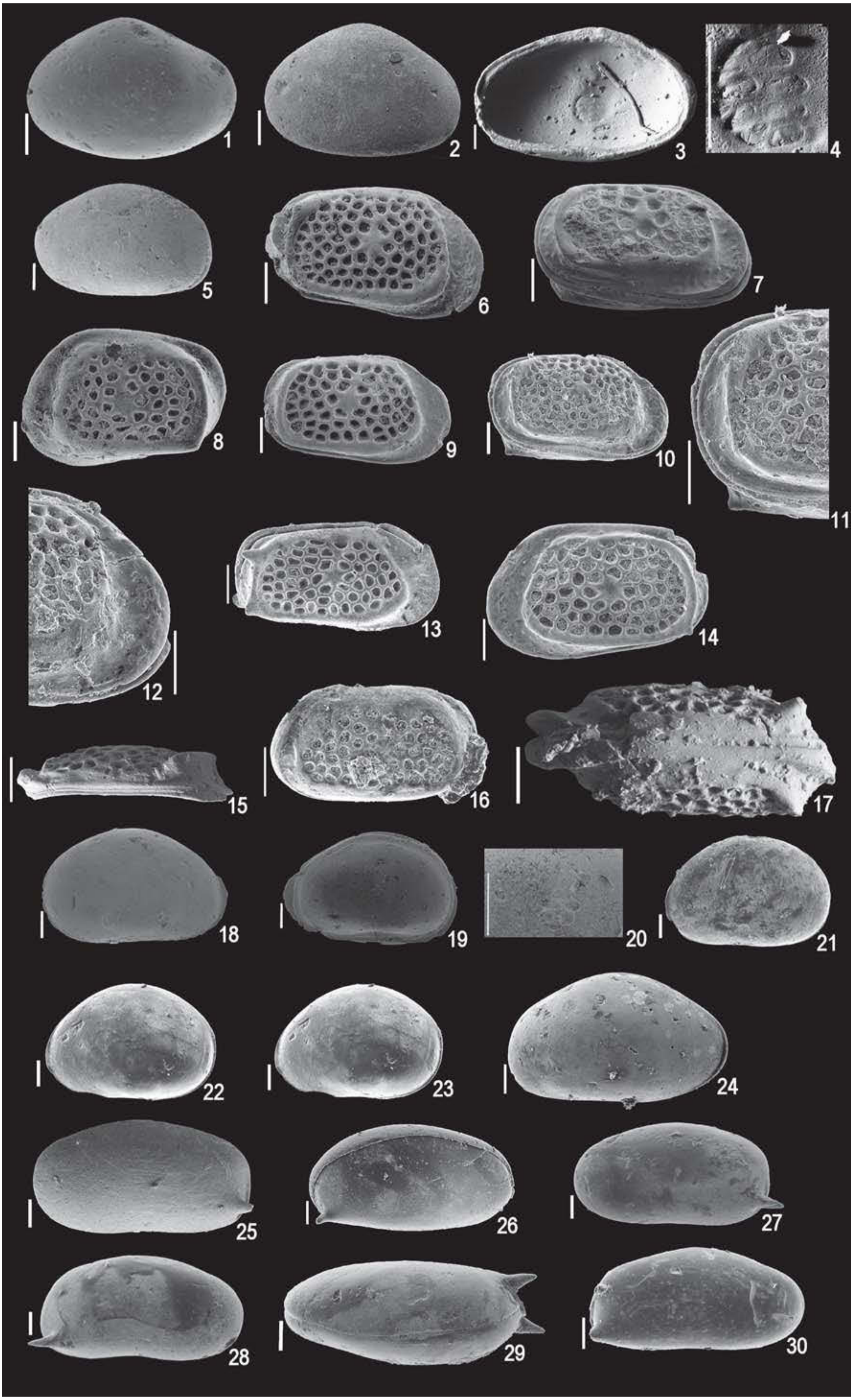
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Plate 7

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *Waylandella holmwoodensis* sp. nov., UWA 129017, right lateral view, paratype.
2. *Waylandella holmwoodensis* sp. nov., UWA 129018, right lateral view, paratype.
3. *Waylandella holmwoodensis* sp. nov., stereo pair with figure 2.
4. *Waylandella holmwoodensis* sp. nov., UWA 129019, right lateral view, paratype.
5. *Waylandella holmwoodensis* sp. nov., UWA 129020, left internal view, paratype.
6. *Waylandella holmwoodensis* sp. nov., enlargement of figure 5 showing AMS.
7. *Waylandella holmwoodensis* sp. nov., UWA 129021, left lateral view.
8. *Waylandella* sp. A, UWA 128902, left lateral view.
9. *Waylandella* sp. B, UWA 128903, right lateral view.
10. *Waylandella* sp. C, UWA 128904, left lateral view.
11. *Waylandella* sp. C, stereo pair with figure 10.
12. *Graphiadactyllis australae* (Crespin), 1945, UWA 129022, right lateral view.
13. *Graphiadactyllis australae* (Crespin), 1945, UWA 129023, left lateral view.
14. *Graphiadactyllis australae* (Crespin), 1945, UWA 129023, left lateral view.
15. *Graphiadactyllis australae* (Crespin), 1945, UWA 129024, left lateral view.
16. *Graphiadactyllis australae* (Crespin), 1945, UWA 129025, right lateral view.
17. *Graphiadactyllis australae* (Crespin), 1945, UWA 129026, left lateral view.
18. *Graphiadactyllis australae* (Crespin), 1945, UWA 129027, left lateral view.
19. *Graphiadactyllis australae* (Crespin), 1945, UWA 129028, right lateral view.
20. *Graphiadactyllis jonesi* sp. nov., UWA 129029, right lateral view, paratype.
21. *Graphiadactyllis jonesi* sp. nov., enlargement of figure 20 showing pores on surface (scale bar is 10 µm).
22. *Graphiadactyllis jonesi* sp. nov., UWA 129030, right lateral view, paratype.
23. *Graphiadactyllis jonesi* sp. nov., enlargement of figure 22 showing pores on surface (scale bar is 10 µm).
24. *Graphiadactyllis jonesi* sp. nov., UWA 129031, right lateral view, paratype.
25. *Graphiadactyllis jonesi* sp. nov., UWA 128905, right lateral view, holotype.
26. *Graphiadactyllis jonesi* sp. nov., UWA 129032, right lateral view, paratype.
27. *Graphiadactyllis jonesi* sp. nov., UWA 129033, right lateral view, paratype.
28. *Graphiadactyllis jonesi* sp. nov., UWA 129034, right internal view, paratype.
29. *Graphiadactyllis jonesi* sp. nov., enlargement of figure 28 showing AMS.

Plate 7

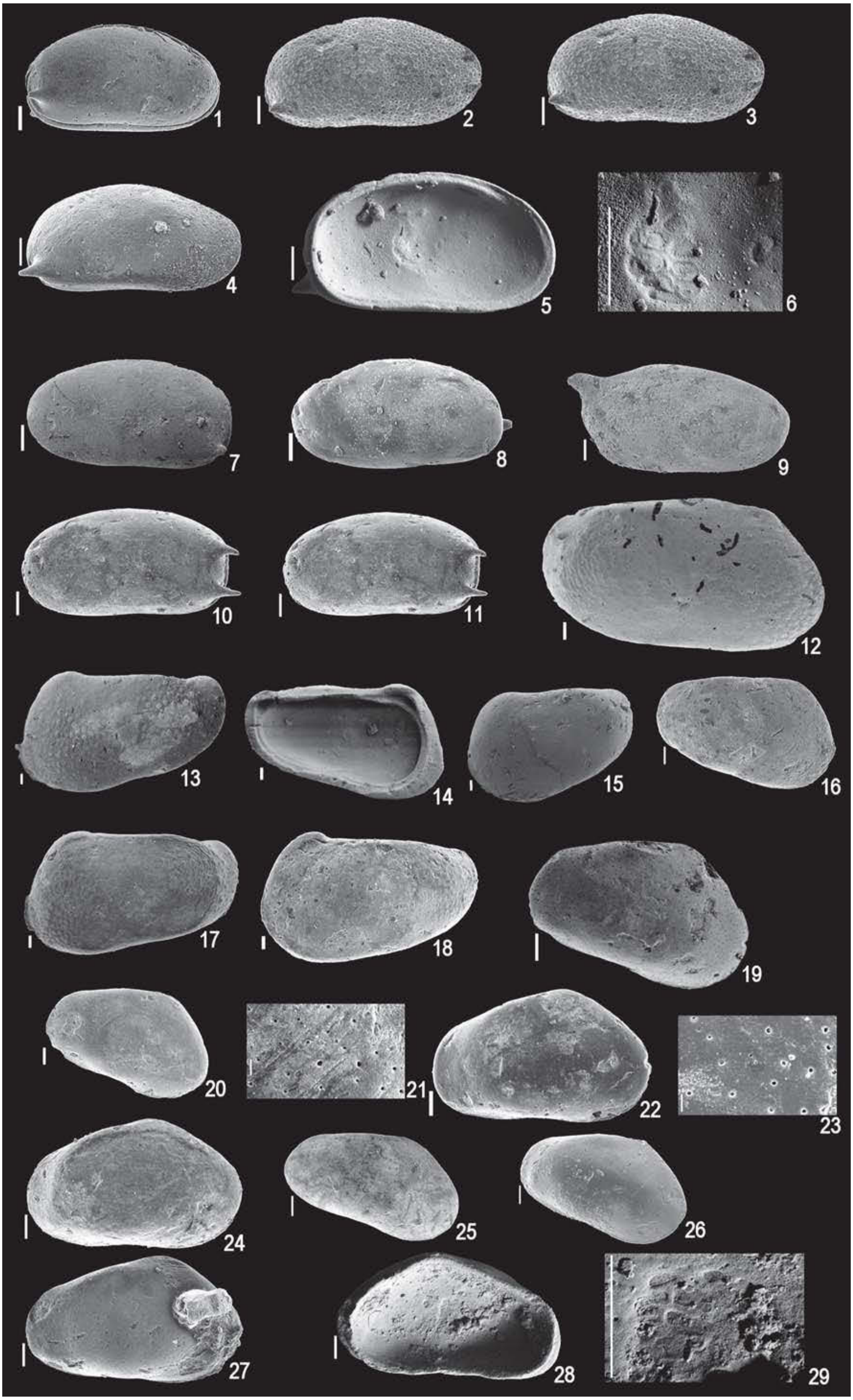

Plate 8

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *Graphiadactylloides flemingi* sp. nov., UWA 129035, left lateral view, paratype.
2. *Graphiadactylloides flemingi* sp. nov., UWA 129036, right lateral view, paratype.
3. *Graphiadactylloides flemingi* sp. nov., enlargement of figure 2 showing posterior spine.
4. *Graphiadactylloides flemingi* sp. nov., UWA 129037, right lateral view, paratype.
5. *Graphiadactylloides flemingi* sp. nov., UWA 128906, left lateral view, holotype.
6. *Graphiadactylloides flemingi* sp. nov., stereo pair with figure 5.
7. *Graphiadactylloides flemingi* sp. nov., enlargement of figure 5 showing posterior pustules.
8. *Graphiadactylloides flemingi* sp. nov., enlargement of figure 5 showing anterior frill.
9. *Graphiadactylloides flemingi* sp. nov., UWA 129038, right lateral view, paratype.
10. *Graphiadactylloides flemingi* sp. nov., UWA 129039, right lateral view, paratype.
11. *Monoceratina granulosa* sp. nov., UWA 129040, right lateral view, paratype.
12. *Monoceratina granulosa* sp. nov., UWA 129041, right lateral view, paratype.
13. *Monoceratina granulosa* sp. nov., stereo pair with figure 12.
14. *Monoceratina granulosa* sp. nov., enlargement of figure 12 showing surface ornament.
15. *Monoceratina granulosa* sp. nov., enlargement of figure 12 showing spine.
16. *Monoceratina granulosa* sp. nov., UWA 129042, right lateral view, paratype.
17. *Monoceratina granulosa* sp. nov., stereo pair with figure 16.
18. *Monoceratina granulosa* sp. nov., UWA 128907, left lateral view, holotype.
19. *Monoceratina granulosa* sp. nov., UWA 129043, right lateral view, paratype.
20. *Monoceratina granulosa* sp. nov., stereo pair with figure 19.
21. *Monoceratina granulosa* sp. nov., UWA 129044, left lateral view, paratype.
22. *Monoceratina granulosa* sp. nov., UWA 129045, left lateral view, paratype.
23. *Monoceratina granulosa* sp. nov., stereo pair with figure 22.
24. *Monoceratina granulosa* sp. nov., UWA 129046, right internal view, paratype.
25. *Pseudobythocypris hockingi* sp. nov., UWA 129047, left lateral view, paratype.
26. *Pseudobythocypris hockingi* sp. nov., UWA 132323, left lateral view, paratype.
27. *Pseudobythocypris hockingi* sp. nov., UWA 132324, left lateral view, paratype.

Plate 8

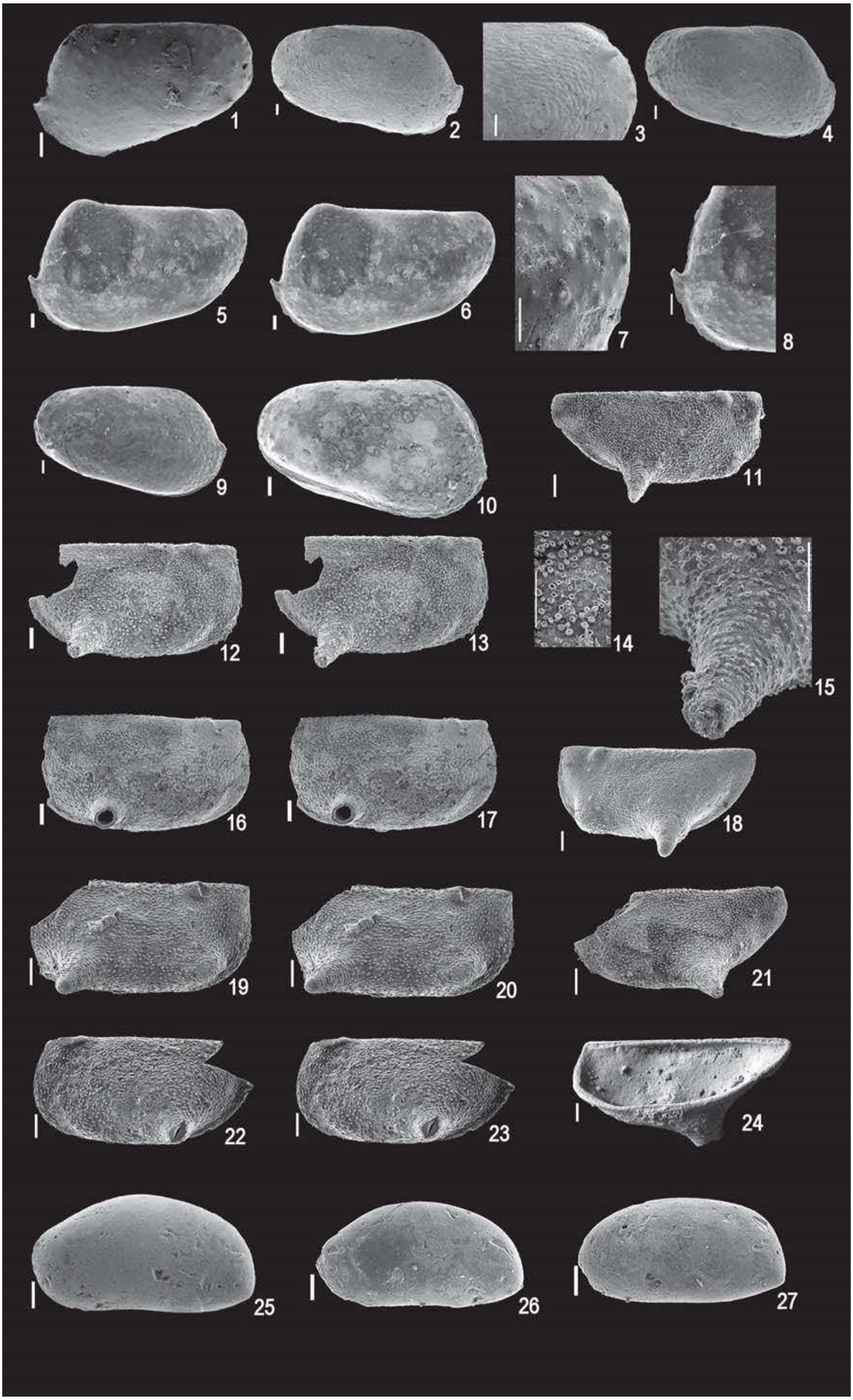

Plate 9

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *Pseudobythocypris hockingi* sp. nov., UWA 128908, right lateral view, holotype.
2. *Pseudobythocypris hockingi* sp. nov., enlargement of figure 1 showing posterior.
3. *Pseudobythocypris hockingi* sp. nov., UWA 132325, right internal view, paratype.
4. *Pseudobythocypris hockingi* sp. nov., enlargement of figure 3 showing AMS.
5. *Pseudobythocypris hockingi* sp. nov., UWA 132326, right internal view, paratype.
6. *Pseudobythocypris hockingi* sp. nov., enlargement of figure 5 showing AMS.
7. *Pseudobythocypris lordi* sp. nov., UWA 132327, right lateral view, paratype.
8. *Pseudobythocypris lordi* sp. nov., UWA 128909, right lateral view, holotype.
9. *Pseudobythocypris lordi* sp. nov., UWA 132328, right lateral view, paratype.
10. *Pseudobythocypris lordi* sp. nov.,UWA 132329, left lateral view, paratype.
11. *Pseudobythocypris lordi* sp. nov., UWA 132330, left lateral view, paratype.
12. *Pseudobythocypris lordi* sp. nov., UWA 132331, right lateral view, paratype.
13. *Pseudobythocypris lordi* sp. nov., UWA 132332, right lateral view, paratype.
14. *Pseudobythocypris lordi* sp. nov., UWA 132333, dorsal view, paratype.
15. *Pseudobythocypris lordi* sp. nov., UWA 132334, dorsal view, paratype.
16. *Bairdia (Bairdia) grayi* Crespin, 1945, UWA 132335, right lateral view.
17. *Bairdia (Bairdia) grayi* Crespin, 1945, UWA 132336, left lateral view.
18. *Bairdia (Bairdia) grayi* Crespin, 1945, UWA 132337, right lateral view.
19. *Bairdia (Bairdia) grayi* Crespin, 1945, UWA 132338, dorsal view.
20. *Bairdia (Bairdia) grayi* Crespin, 1945, UWA 132339, ventral view.
21. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, UWA 132340, right lateral view.
22. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, enlargement of figure 21 showing anterior margin.
23. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, enlargement of figure 21 showing pores on surface of valve (scale bar is 10 µm)
24. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, UWA 132341, right lateral view.
25. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, UWA 132342, right lateral view.
26. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, stereo pair with figure 25.

Plate 9

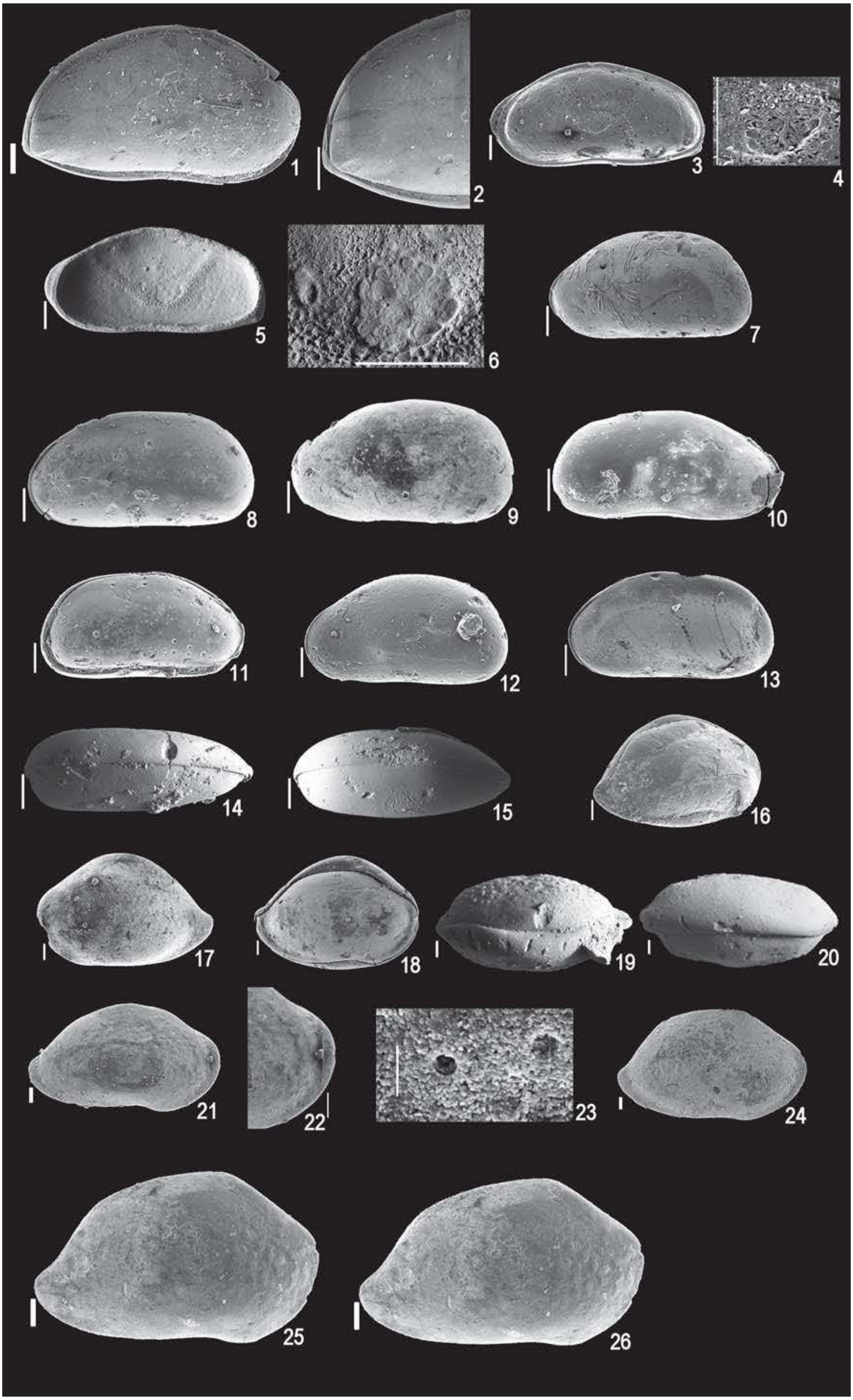

Plate 10

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, UWA 132343, right lateral view.
2. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, UWA 132344, right lateral view.
3. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, stereo pair with figure 2.
4. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, UWA 132345, left lateral view.
5. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, UWA 132346, left lateral view.
6. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, UWA 132347, right lateral view.
7. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, UWA 132348, left lateral view.
8. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, UWA 132349, right lateral view.
9. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, UWA 132350, right internal view.
10. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, UWA 132351, right lateral view.
11. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, UWA 132352, right lateral view.
12. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, UWA 132353, left lateral view.
13. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, UWA 132354, right lateral view.
14. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, UWA 132355, right lateral view.
15. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, UWA 132356, left internal view.
16. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, enlargement of figure 15 showing AMS.
17. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, UWA 132357, right internal view.
18. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, enlargement of figure 17 showing AMS.
19. *Bairdia* sp. cf. *Bairdia (Bairdia) beedei* Ulrich and Bassler, 1906, UWA 132358, dorsal view.
20. *Bairdia* sp. cf. *Bairdia (Bairdia) hassi* Sohn, 1960, UWA 132359, left lateral view.
21. *Bairdia* sp. cf. *Bairdia (Bairdia) hassi* Sohn, 1960, enlargement of figure 20 showing posterior.
22. *Bairdia* sp. cf. *Bairdia (Bairdia) hassi* Sohn, 1960, enlargement of figure 20 showing pustules.
23. *Bairdia* sp. cf. *Bairdia (Bairdia) hassi* Sohn, 1960, UWA 132360, left lateral view.
24. *Bairdia* sp. cf. *Bairdia (Bairdia) hassi* Sohn, 1960, UWA 132361, left lateral view.
25. *Bairdia* sp. cf. *Bairdia (Bairdia) hassi* Sohn, 1960, stereo pair with figure 24.
26. *Bairdia* sp. cf. *Bairdia (Bairdia) hassi* Sohn, 1960, UWA 132362, left lateral view.

Plate 10

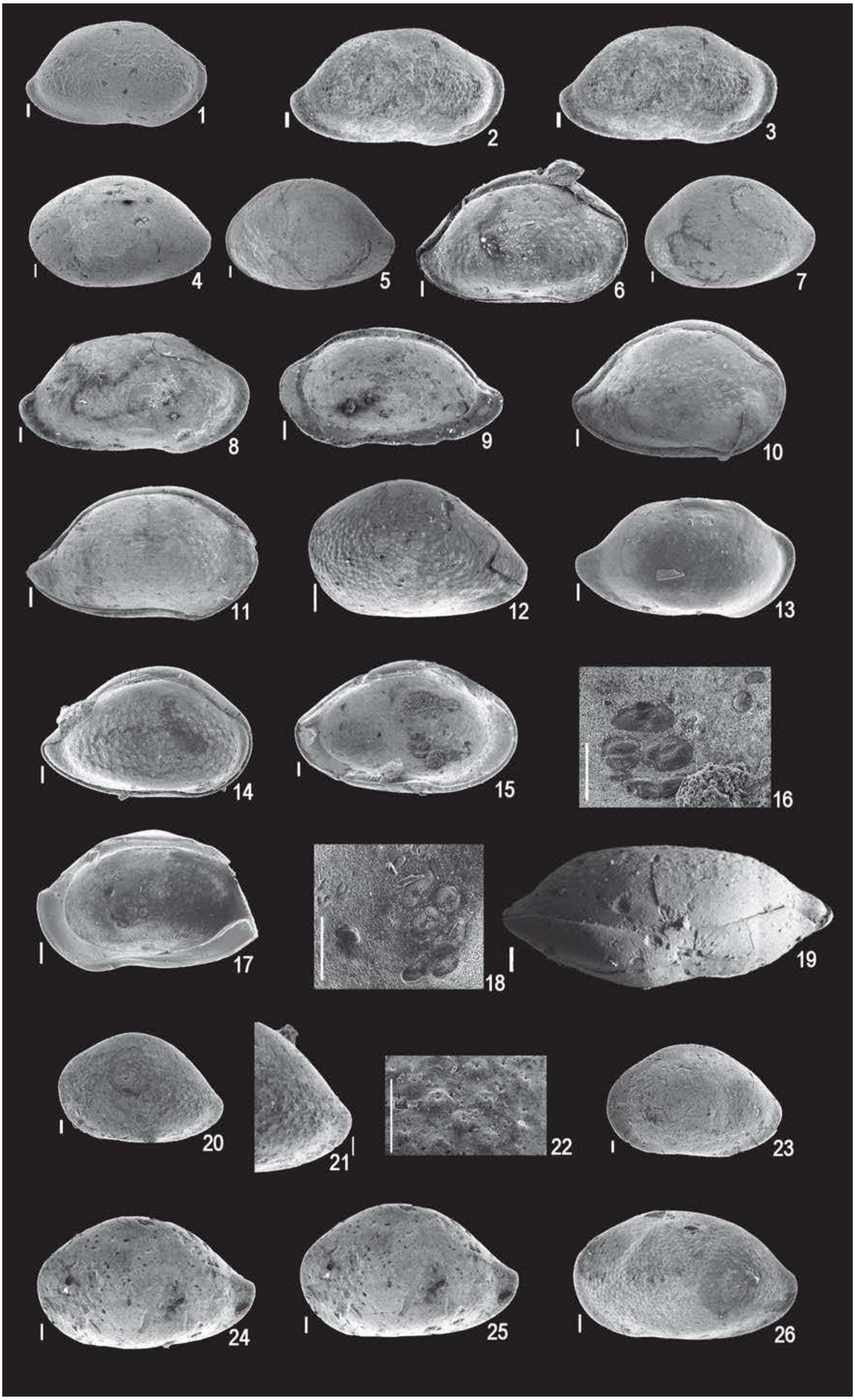

Plate 11

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *Bairdia* sp. cf. *Bairdia (Bairdia) hassi* Sohn, 1960, UWA 132363, left lateral view.
2. *Bairdia* sp. cf. *Bairdia (Bairdia) hassi* Sohn, 1960, enlargement of figure 1 showing dorsal margin.
3. *Bairdia* sp. cf. *Bairdia (Bairdia) hassi* Sohn, 1960, UWA 132364, dorsal view.
4. *Bairdia* sp. cf. *Bairdia (Bairdia) hassi* Sohn, 1960, UWA 132365, right lateral view.
5. *Bairdia* sp. cf. *Bairdia (Bairdia) hassi* Sohn, 1960, stereo pair with figure 4.
6. *Bairdia* sp. cf. *Bairdia (Bairdia) hassi* Sohn, 1960, UWA 132366, right lateral view.
7. *Bairdia* sp. cf. *Bairdia (Bairdia) hassi* Sohn, 1960, stereo pair with figure 6.
8. *Bairdia* sp. cf. *Bairdia (Bairdia) pompillioides* Harlton, 1928, UWA 132367, right lateral view.
9. *Bairdia* sp. cf. *Bairdia (Bairdia) pompillioides* Harlton, 1928, UWA 132368, left lateral view.
10. *Bairdia* sp. cf. *Bairdia (Bairdia) pompillioides* Harlton, 1928, stereo pair with figure 9.
11. *Bairdia* sp. cf. *Bairdia (Bairdia) pompillioides* Harlton, 1928, UWA 132369, left lateral view.
12. *Bairdia* sp. cf. *Bairdia (Bairdia) pompillioides* Harlton, 1928, stereo pair with figure 11.
13. *Bairdia* sp. cf. *Bairdia (Bairdia) pompillioides* Harlton, 1928, UWA 132370, right lateral view.
14. *Bairdia* sp. cf. *Bairdia (Bairdia) pompillioides* Harlton, 1928, UWA 132371, left lateral view.
15. *Bairdia* sp. cf. *Bairdia (Bairdia) pompillioides* Harlton, 1928, UWA 132372, right lateral view.
16. *Bairdia* sp. cf. *Bairdia (Bairdia) pompillioides* Harlton, 1928, stereo pair with figure 15.
17. *Bairdia* sp. cf. *Bairdia (Bairdia) pompillioides* Harlton, 1928, UWA 132373, right internal view.
18. *Bairdia* sp. cf. *Bairdia (Bairdia) pompillioides* Harlton, 1928, enlargement of figure 17 showing AMS.
19. *Bairdia* sp. cf. *Bairdia (Bairdia) pompillioides* Harlton, 1928, UWA 132374, right internal view.
20. *Bairdia* sp. cf. *Bairdia (Bairdia) pompillioides* Harlton, 1928, enlargement of figure 19 showing AMS.
21. *Bairdia* sp. cf. *Bairdia (Bairdia) reussiana* (Kirkby), 1858, UWA 132375, right lateral view.
22. *Bairdia* sp. cf. *Bairdia (Bairdia) reussiana* (Kirkby), 1858, UWA 132376, left internal view.
23. *Bairdia* sp. cf. *Bairdia (Bairdia) reussiana* (Kirkby), 1858, enlargement of figure 22 showing AMS.
24. *Bairdia* sp. cf. *Bairdia (Bairdia) reussiana* (Kirkby), 1858, UWA 132377, right lateral view.
25. *Bairdia* sp. cf. *Bairdia (Bairdia) reussiana* (Kirkby), 1858, UWA 132378, dorsal view.
26. *Bairdia* sp. cf. *Bairdia (Bairdia) reussiana* (Kirkby), 1858, UWA 132379, right lateral view.

Plate 11

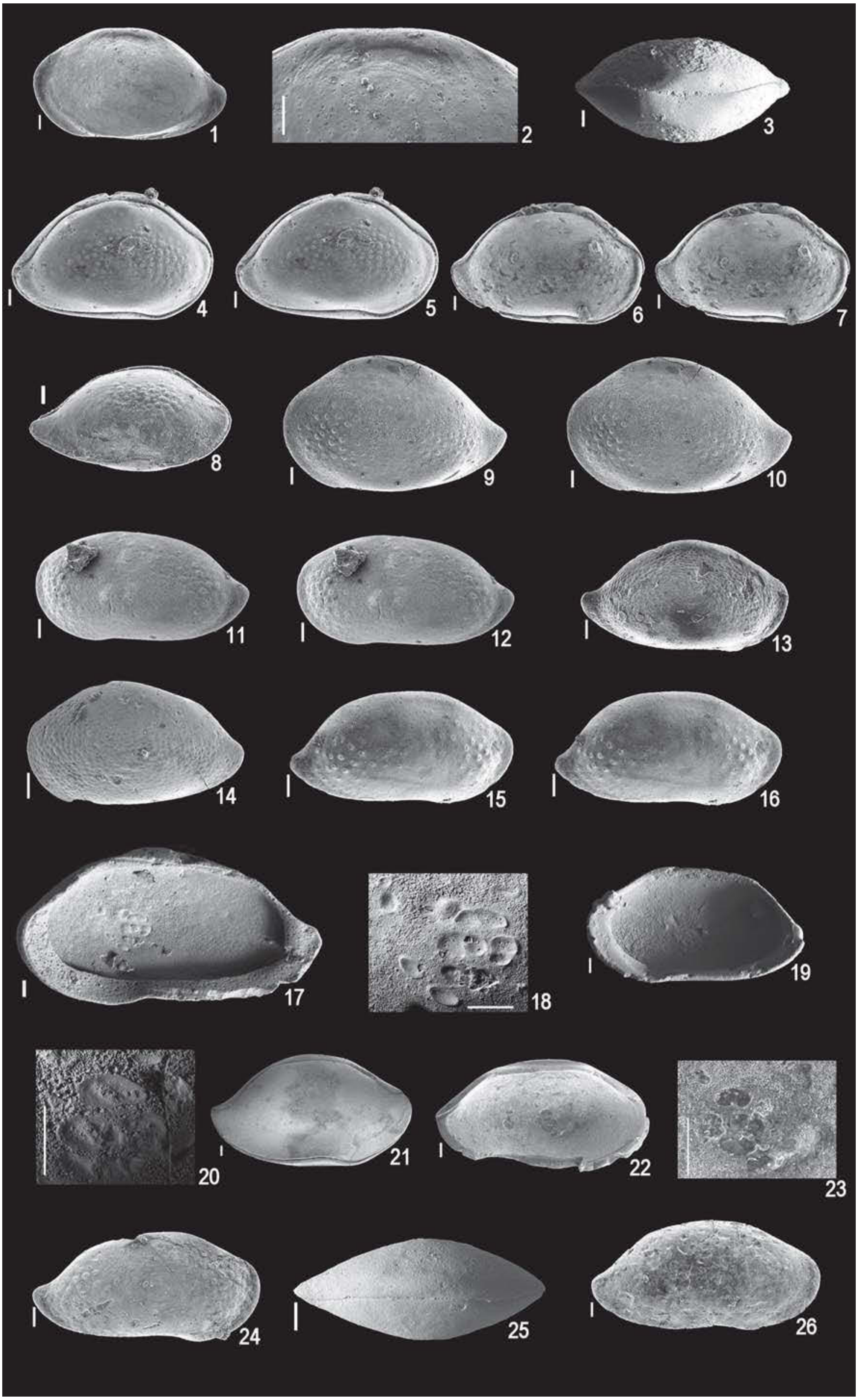

Plate 12

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *Bairdiacypris* (*Bairdiacypris*) *badgerai* sp. nov., UWA 132380, right internal view, paratype.
2. *Bairdiacypris* (*Bairdiacypris*) *badgerai* sp. nov., enlargement of figure 1 showing AMS.
3. *Bairdiacypris* (*Bairdiacypris*) *badgerai* sp. nov., UWA 132381, left internal view, paratype.
4. *Bairdiacypris* (*Bairdiacypris*) *badgerai* sp. nov., UWA 128914, left lateral view, holotype.
5. *Bairdiacypris* (*Bairdiacypris*) *badgerai* sp. nov., stereo pair with figure 4.
6. *Bairdiacypris* (*Bairdiacypris*) sp. A, UWA 132382, right lateral view.
7. *Bairdiacypris* (*Bairdiacypris*) *badgerai* sp. nov., UWA 132383, left lateral view, paratype.
8. *Bairdiacypris* (*Bairdiacypris*) *badgerai* sp. nov., stereo pair with figure 7.
9. *Bairdiacypris* (*Bairdiacypris*) sp. A, UWA 132384, right lateral view.
10. *Bairdiacypris* (*Bairdiacypris*) sp. A, UWA 132385, left lateral view.
11. *Bairdiacypris* (*Bairdiacypris*) sp. A, UWA 132386, right lateral view.
12. *Bairdiacypris* (*Bairdiacypris*) sp. A, UWA 132387, right lateral view.
13. *Bairdiacypris* (*Bairdiacypris*) sp. A, UWA 128915, right lateral view.
14. *Bairdiacypris* (*Bairdiacypris*) sp. A, stereo pair with figure 13.
15. *Bairdiacypris* (*Bairdiacypris*) sp. A, UWA 132388, right lateral view.
16. *Bairdiacypris* (*Bairdiacypris*) sp. A, UWA 132389, left lateral view.
17. *Bairdiacypris* (*Bairdiacypris*) sp. A, UWA 132390, right internal view.
18. *Bairdiacypris* (*Bairdiacypris*) sp. A, enlargement of figure 17 showing AMS.
19. *Proparaparchites* sp. A., UWA 128916, right lateral view.
20. *Proparaparchites* sp. A., UWA 132391, right lateral view.
21. *Proparaparchites* sp. A., UWA 132392, right lateral view.
22. *Proparaparchites* sp. A., UWA 132393, right internal view.
23. *Proparaparchites* sp. B., UWA 132394, right lateral view.
24. *Proparaparchites* sp. B., UWA 128917, right lateral view.
25. *Proparaparchites* sp. B., enlargement of posterior margin showing ornamentation.
26. *Youngiella deweyensis* sp. nov., UWA 132395, right lateral view, paratype.
27. *Youngiella deweyensis* sp. nov., UWA 132396, right lateral view, paratype.
28. *Youngiella deweyensis* sp. nov., stereo pair with figure 27.

Plate 12

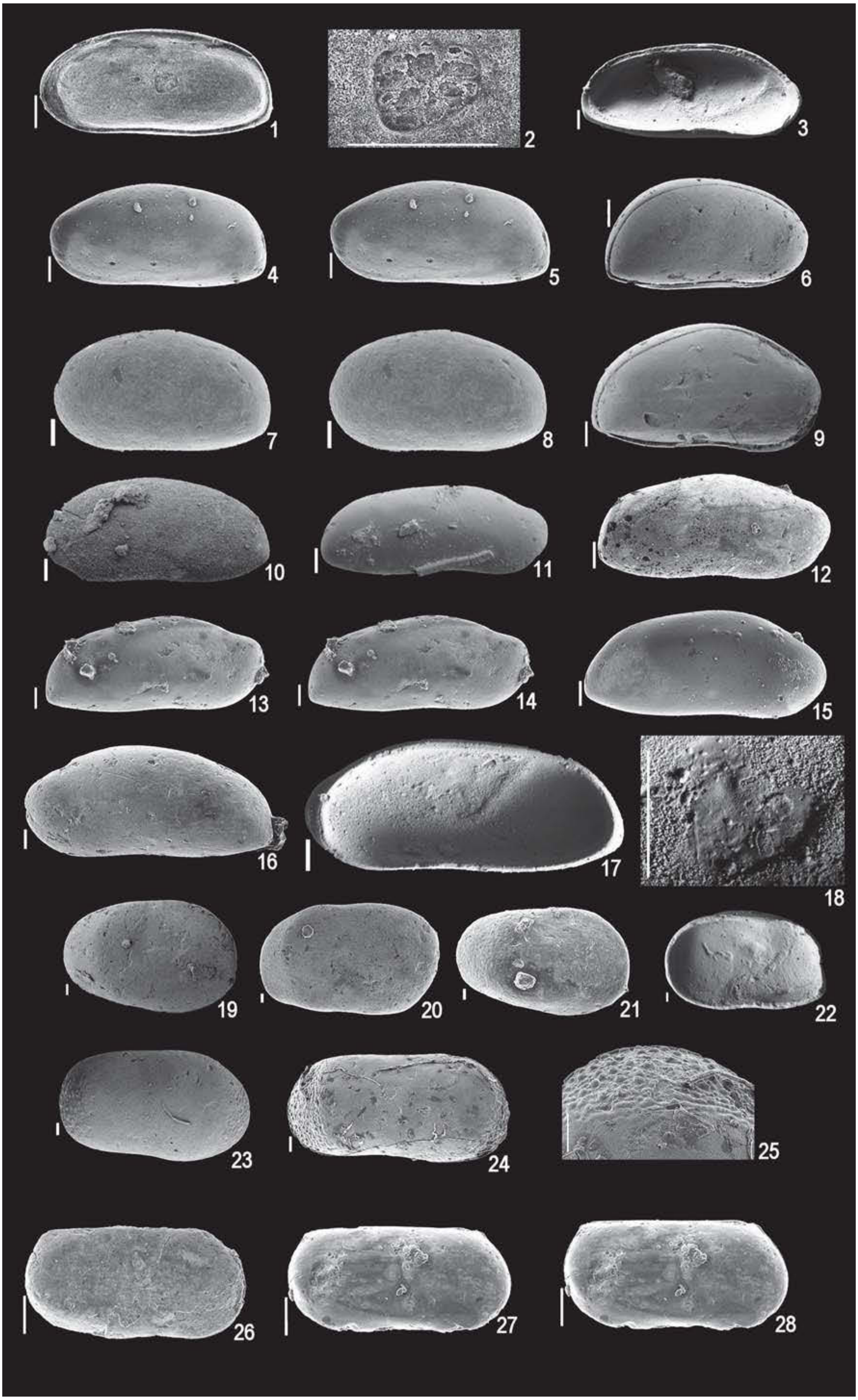

Plate 13

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *Youngiella deweyensis* sp. nov., UWA 132397, left lateral view, paratype.
2. *Youngiella deweyensis* sp. nov., UWA 132398, left lateral view, paratype.
3. *Youngiella deweyensis* sp. nov., UWA 128918, left lateral view, holotype.
4. *Youngiella deweyensis* sp. nov., UWA 132399, right lateral view, paratype.
5. *Youngiella deweyensis* sp. nov., stereo pair with figure 4.
6. *Youngiella deweyensis* sp. nov., UWA 132400, left lateral view, paratype.
7. *Youngiella deweyensis* sp. nov., UWA 132401, dorsal view, paratype.
8. *Youngiella deweyensis* sp. nov., UWA 132402, left internal view, paratype.
9. *Youngiella deweyensis* sp. nov., stereo pair with figure 8.
10. *Youngiella* sp. A, UWA 132403, right lateral view.
11. *Youngiella* sp. A, UWA 132404, right lateral view.
12. *Youngiella* sp. A, UWA 132405, left lateral view.
13. *Youngiella* sp. A, UWA 132406, left lateral view.
14. *Youngiella* sp. A, UWA 128919, right lateral view.
15. *Youngiella* sp. A, UWA 132407, left lateral view.
16. *Youngiella* sp. A, stereo pair with figure 15.
17. *Moorites irwini* sp. nov., UWA 132408, right lateral view, paratype.
18. *Moorites irwini* sp. nov., UWA 132409, right lateral view, juvenile instar, paratype.
19. *Moorites irwini* sp. nov., UWA 132410, left lateral view, paratype.
20. *Moorites irwini* sp. nov., UWA 132411, right lateral view, paratype.
21. *Moorites irwini* sp. nov., UWA 132412, right lateral view, paratype.
22. *Moorites irwini* sp. nov., UWA 132413, left lateral view, paratype.
23. *Moorites irwini* sp. nov., UWA 132414, left lateral view, paratype.
24. *Moorites irwini* sp. nov., UWA 132415, left lateral view, paratype.
25. *Moorites irwini* sp. nov., UWA 132416, left lateral view, paratype.
26. *Moorites irwini* sp. nov., UWA 132417, left lateral view, juvenile instar, paratype.
27. *Moorites irwini* sp. nov., UWA 132418, left lateral view, paratype.
28. *Moorites irwini* sp. nov., stereo pair with figure 27.
29. *Moorites irwini* sp. nov., UWA 128920, left lateral view, holotype.

Plate 13

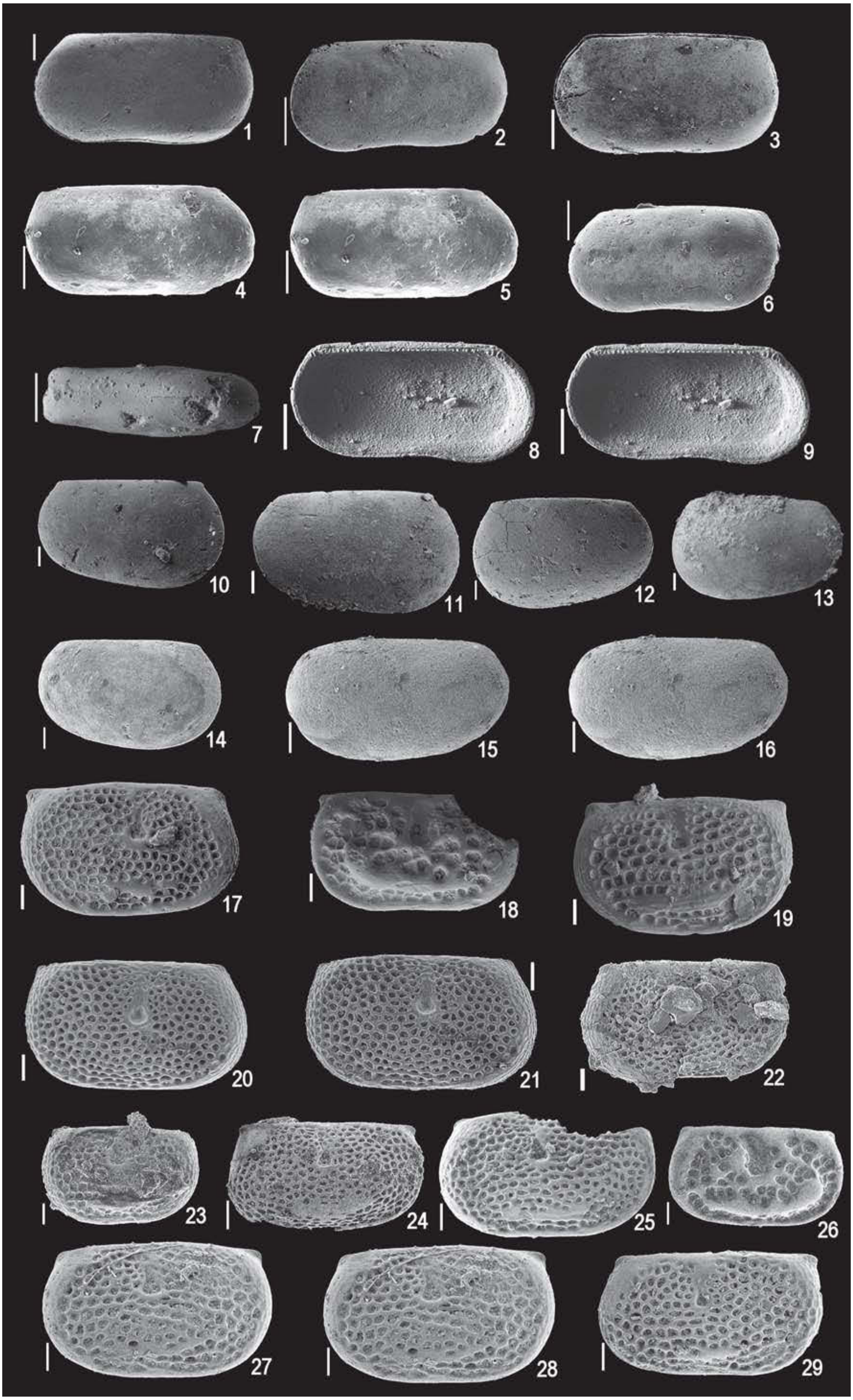

Plate 14

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *Moorites irwini* sp. nov., UWA 132419, right lateral view, paratype.
2. *Moorites irwini* sp. nov., stereo pair with figure 1.
3. *Moorites irwini* sp. nov., UWA 132420, right internal view, paratype.
4. *Moorites irwini* sp. nov., UWA 132421, right internal view, paratype.
5. *Moorites irwini* sp. nov., enlargement of figure 4 showing AMS.
6. *Moorites irwini* sp. nov., UWA 132422, ventral view, paratype.
7. *Rectospinella australica* sp. nov., UWA 128921, left lateral view, holotype.
8. *Rectospinella australica* sp. nov., stereo pair with figure 7.
9. *Rectospinella australica* sp. nov., UWA 132423, right lateral view, paratype.
10. *Rectospinella australica* sp. nov., UWA 132424, left lateral view, paratype.
11. *Rectospinella australica* sp. nov., stereo pair with figure 10.
12. *Rectospinella australica* sp. nov., UWA 132425, left internal view, paratype.
13. *Youngiella* sp. A., UWA 132426, right lateral view.
14. *Sulcoindivisia crasquinsoleauella* sp. nov., UWA 132427, right lateral view, paratype.
15. *Sulcoindivisia crasquinsoleauella* sp. nov., UWA 132428, left lateral view, paratype.
16. *Sulcoindivisia crasquinsoleauella* sp. nov., enlargement of figure 15 showing pores on surface.
17. *Sulcoindivisia crasquinsoleauella* sp. nov., UWA 128922, right lateral view, holotype.
18. *Sulcoindivisia crasquinsoleauella* sp. nov., stereo pair with figure 17.
19. *Sulcoindivisia crasquinsoleauella* sp. nov., UWA 132429, left lateral view, paratype.
20. *Sulcoindivisia crasquinsoleauella* sp. nov., UWA 132430, right lateral view, paratype.
21. *Sulcoindivisia crasquinsoleauella* sp. nov., UWA 132431, left lateral view, paratype.
22. *Sulcoindivisia crasquinsoleauella* sp. nov., UWA 132432, right internal view, paratype.
23. *Sulcoindivisia crasquinsoleauella* sp. nov., enlargement of figure 22 showing AMS.
24. *Sulcoindivisia crasquinsoleauella* sp. nov., UWA 132433, right internal view, paratype.
25. *Sulcoindivisia crasquinsoleauella* sp. nov., UWA 132434, ventral view, paratype.
26. *Roundyella ludbrookae* Fleming, 1985, UWA 132435, right lateral view.
27. *Roundyella ludbrookae* Fleming, 1985, UWA 132436, left lateral view.
28. *Roundyella ludbrookae* Fleming, 1985, enlargement of figure 27 showing adductorial pit.

Plate 14

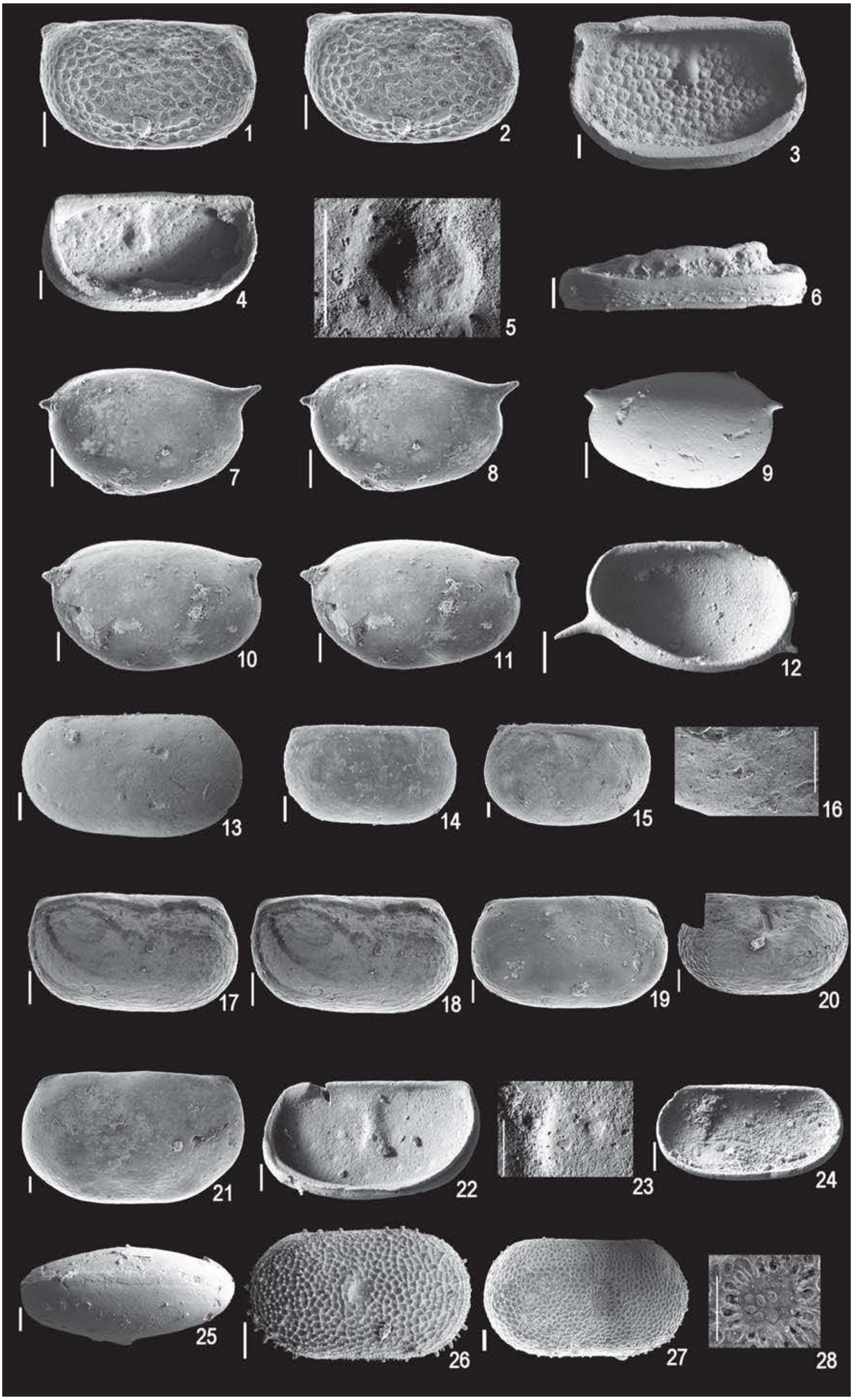

Plate 15

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *Roundyella ludbrookae* Fleming, 1985, UWA 132437, left lateral view.
2. *Roundyella ludbrookae* Fleming, 1985, enlargement of figure 1 showing posterior ornamentation.
3. *Roundyella ludbrookae* Fleming, 1985, UWA 132438, right lateral view.
4. *Roundyella ludbrookae* Fleming, 1985, enlargement of figure 3 showing adductorial pit.
5. *Roundyella ludbrookae* Fleming, 1985, enlargement of figure 3 showing surface ornamentation.
6. *Roundyella ludbrookae* Fleming, 1985, UWA 132439, left internal view.
7. *Roundyella ludbrookae* Fleming, 1985, enlargement of figure 6 showing AMS.
8. *Roundyella ludbrookae* Fleming, 1985, enlargement of figure 6 showing hinge.
9. *Roundyella ludbrookae* Fleming, 1985, UWA 132440, right lateral view.
10. *Roundyella ludbrookae* Fleming, 1985, enlargement of figure 9 showing adductorial pit.
11. *Roundyella ludbrookae* Fleming, 1985, UWA 132441, right lateral view.
12. *Roundyella ludbrookae* Fleming, 1985, stereo pair with figure 11.
13. *Roundyella ludbrookae* Fleming, 1985, UWA 132442, left lateral view.
14. *Roundyella ludbrookae* Fleming, 1985, UWA 132443, right internal view.
15. *Roundyella ludbrookae* Fleming, 1985, stereo pair with figure 14.
16. *Roundyella ludbrookae* Fleming, 1985, enlargement of figure 14 showing AMS.
17. *Roundyella ludbrookae* Fleming, 1985, UWA 132444, left lateral view.
18. *Roundyella ludbrookae* Fleming, 1985, stereo pair with figure 17.
19. *Roundyella ludbrookae* Fleming, 1985, UWA 132445, left lateral view.
20. *Hippocrepinella biaperta* Crespin, 1958, UWA 132446, lateral view.
21. *Hippocrepinella biaperta* Crespin, 1958, UWA 132447, lateral view.
22. *Hippocrepinella biaperta* Crespin, 1958, UWA 132448, lateral view.
23. *Hippocrepinella biaperta* Crespin, 1958, UWA 132449, lateral view.
24. *Hippocrepinella biaperta* Crespin, 1958, UWA 132450, lateral view.
25. *Hippocrepinella biaperta* Crespin, 1958, UWA 132451, lateral view.

Plate 15

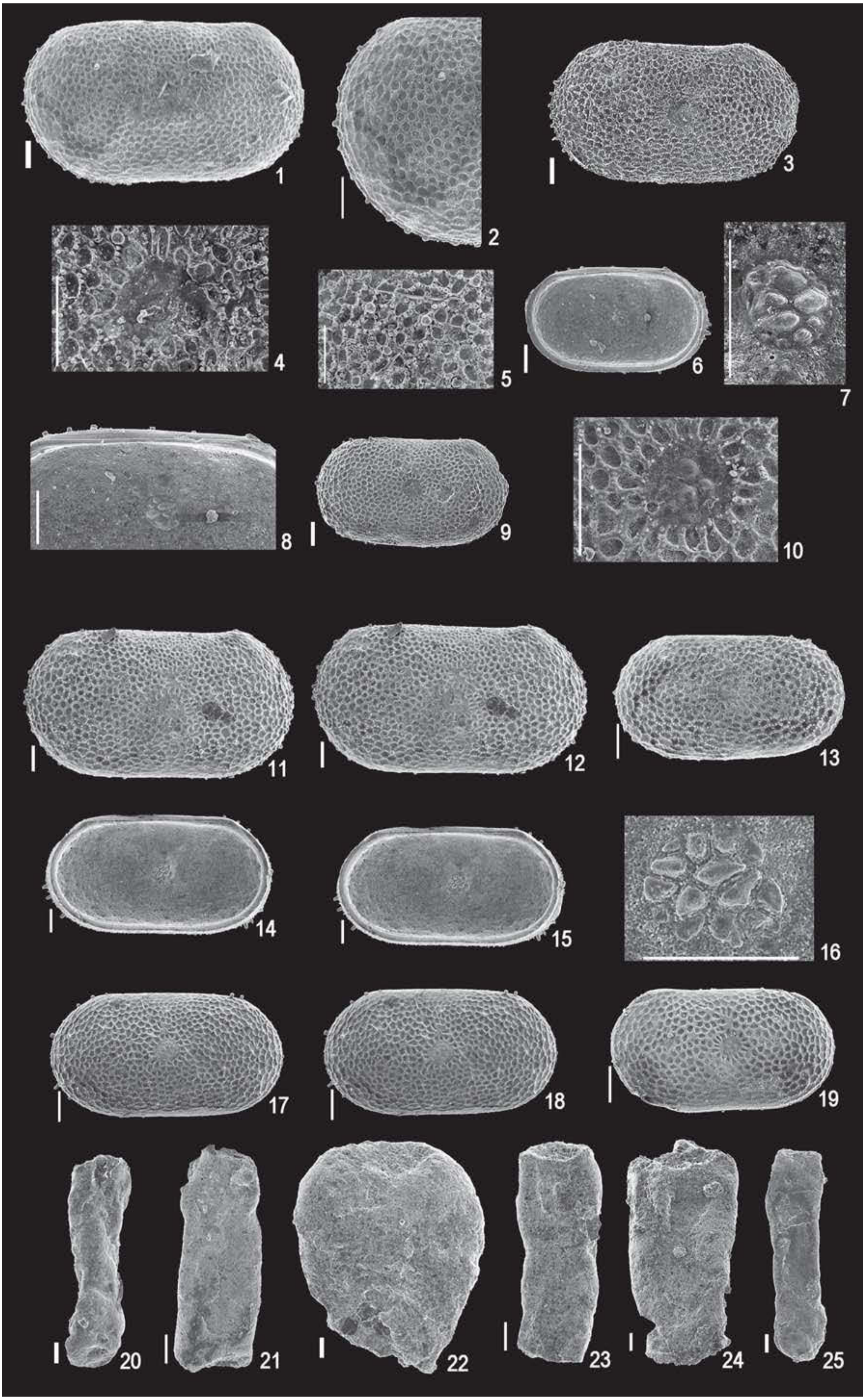

Plate 16

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *?Thuramminoides pusilla* (Parr), 1942, UWA 132452, lateral view.
2. *?Thuramminoides pusilla* (Parr), 1942, UWA 132453, lateral view.
3. *?Thuramminoides pusilla* (Parr), 1942, UWA 132454, lateral view.
4. *?Thuramminoides pusilla* (Parr), 1942, enlargement of figure 3 showing test wall.
5. *Thuramminoides sphaeroidalis* Plummer, 1945, UWA 132455, lateral view.
6. *Thuramminoides sphaeroidalis* Plummer, 1945, UWA 132456, lateral view.
7. *Thuramminoides sphaeroidalis* Plummer, 1945, UWA 132457, lateral view.
8. *Saccammina arenosa* (Crespin), 1958, UWA 132458, lateral view.
9. *Hyperammina callytharraensis* Crespin, 1958, UWA 132459, lateral view.
10. *Hyperammina callytharraensis* Crespin, 1958, UWA 132460, lateral view.
11. *Hyperammina callytharraensis* Crespin, 1958, UWA 132461, lateral view.
12. *Hyperammina callytharraensis* Crespin, 1958, UWA 132462, lateral view.
13. *Hyperammina callytharraensis* Crespin, 1958, UWA 132463, lateral view.
14. *Hyperammina callytharraensis* Crespin, 1958, UWA 132464, lateral view.
15. *Hyperammina callytharraensis* Crespin, 1958, UWA 132465, lateral view.
16. *Hyperammina callytharraensis* Crespin, 1958, UWA 132466, lateral view.
17. *Hyperammina callytharraensis* Crespin, 1958, UWA 132467, lateral view.
18. *Hyperammina callytharraensis* Crespin, 1958, UWA 132468, lateral view.
19. *Hyperammina coleyi* Parr, 1942, UWA 132469, lateral view.
20. *Hyperammina coleyi* Parr, 1942, UWA 132470, lateral view.
21. *Hyperammina coleyi* Parr, 1942, UWA 132471, lateral view.
22. *Hyperammina coleyi* Parr, 1942, UWA 132472, lateral view.
23. *Hyperammina elegans* (Cushman and Waters), 1928, UWA 132473, lateral view.
24. *Hyperammina elegans* (Cushman and Waters), 1928, UWA 132474, lateral view.
25. *Hyperammina elegans* (Cushman and Waters), 1928, UWA 132475, lateral view.
26. *Hyperammina elegans* (Cushman and Waters), 1928, UWA 132476, lateral view.
27. *Hyperammina elegans* (Cushman and Waters), 1928, UWA 132477, lateral view.
28. *Hyperammina elegans* (Cushman and Waters), 1928, UWA 132478, lateral view.
29. *Hyperammina elegans* (Cushman and Waters), 1928, UWA 132479, lateral view.
30. *Hyperammina elegans* (Cushman and Waters), 1928, UWA 132480, lateral view.
31. *Hyperammina elegantissima* Plummer, 1945, UWA 132481, lateral view.
32. *Hyperammina elegantissima* Plummer, 1945, UWA 132482, lateral view.
33. *Hyperammina elegantissima* Plummer, 1945, UWA 132483, lateral view.
34. *Hyperammina elegantissima* Plummer, 1945, UWA 132484, lateral view.
35. *Hyperammina elegantissima* Plummer, 1945, UWA 132485, lateral view.
36. *Hyperammina elegantissima* Plummer, 1945, UWA 132486, lateral view.
37. *Kechenotiske hadzeli* (Crespin), 1958, UWA 132487, lateral view.
38. *Kechenotiske hadzeli* (Crespin), 1958, UWA 132488, lateral view.
39. *Kechenotiske hadzeli* (Crespin), 1958, UWA 132489, lateral view.
40. *Kechenotiske hadzeli* (Crespin), 1958, UWA 132490, lateral view.

Plate 16

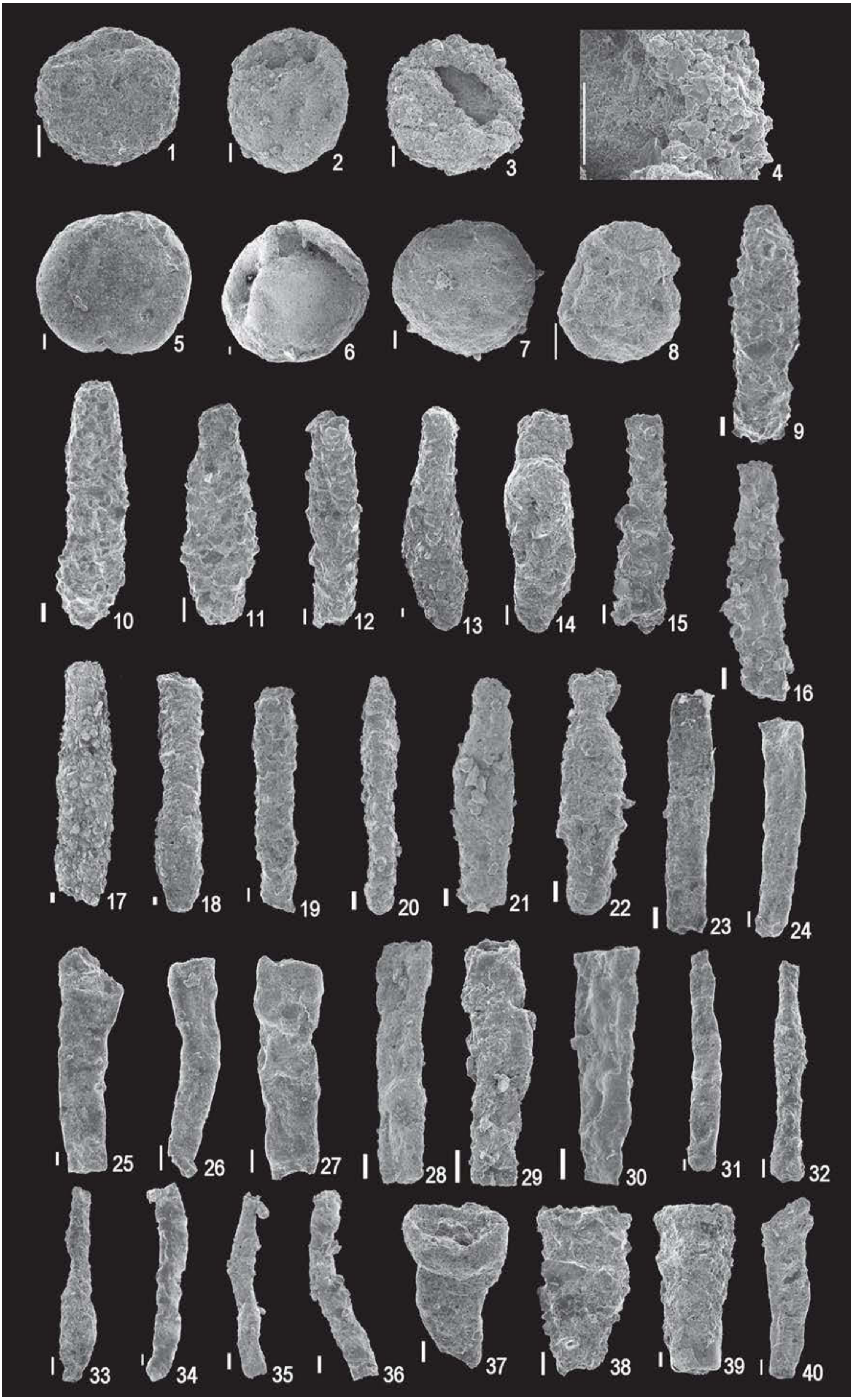
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Plate 17

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *Kechenotiske hadzeli* (Crespin), 1958, UWA 132491, lateral view.
2. *Kechenotiske hadzeli* (Crespin), 1958, UWA 132492, lateral view.
3. *Kechenotiske hadzeli* (Crespin), 1958, UWA 132493, lateral view.
4. *Ammodiscus multicinctus* Crespin and Parr, 1941, UWA 132494, lateral view.
5. *Ammodiscus multicinctus* Crespin and Parr, 1941, UWA 132495, lateral view.
6. *Ammodiscus multicinctus* Crespin and Parr, 1941, UWA 132496, side view.
7. *Ammodiscus multicinctus* Crespin and Parr, 1941, UWA 132497, lateral view.
8. *Ammodiscus multicinctus* Crespin and Parr, 1941, UWA 132498, lateral view.
9. *Ammodiscus multicinctus* Crespin and Parr, 1941, UWA 132499, lateral view.
10. *Ammodiscus multicinctus* Crespin and Parr, 1941, UWA 132500, lateral view.
11. *Ammodiscus multicinctus* Crespin and Parr, 1941, UWA 132501, lateral view.
12. *Ammodiscus multicinctus* Crespin and Parr, 1941, UWA 132502, lateral view.
13. *Ammodiscus multicinctus* Crespin and Parr, 1941, UWA 132503, lateral view.
14. *Ammodiscus multicinctus* Crespin and Parr, 1941, UWA 132504, lateral view.
15. *Ammodiscus multicinctus* Crespin and Parr, 1941, UWA 132506, lateral view.
16. *Ammodiscus multicinctus* Crespin and Parr, 1941, UWA 132507, lateral view.
17. *Ammodiscus multicinctus* Crespin and Parr, 1941, UWA 132508, lateral view.
18. *Ammodiscus multicinctus* Crespin and Parr, 1941, UWA 132509, lateral view.
19. *Ammodiscus multicinctus* Crespin and Parr, 1941, UWA 132510, lateral view.
20. *Ammodiscus multicinctus* Crespin and Parr, 1941, UWA 132511, side view.
21. *Ammodiscus multicinctus* Crespin and Parr, 1941, UWA 132512, lateral view.
22. *Ammodiscus multicinctus* Crespin and Parr, 1941, UWA 132513, lateral view.
23. *Ammodiscus nitidus* Parr, 1942, UWA 132514, lateral view.
24. *Ammodiscus nitidus* Parr, 1942, UWA 132515, lateral view.
25. *Ammodiscus nitidus* Parr, 1942, UWA 132516, lateral view.
26. *Ammodiscus nitidus* Parr, 1942, UWA 132517, lateral view.
27. *Ammodiscus nitidus* Parr, 1942, UWA 132518, lateral view.
28. *Ammodiscus nitidus* Parr, 1942, UWA 132519, lateral view.
29. *Ammodiscus nitidus* Parr, 1942, UWA 132520, lateral view.
30. *Ammodiscus nitidus* Parr, 1942, UWA 132521, lateral view.
31. *Ammodiscus nitidus* Parr, 1942, UWA 132522, lateral view.
32. *Ammodiscus nitidus* Parr, 1942, UWA 132523, lateral view.
33. *Ammodiscus nitidus* Parr, 1942, UWA 132524, lateral view.
34. *Ammodiscus nitidus* Parr, 1942, UWA 132525, lateral view.
35. *Ammodiscus nitidus* Parr, 1942, UWA 132526, lateral view.

Plate 17

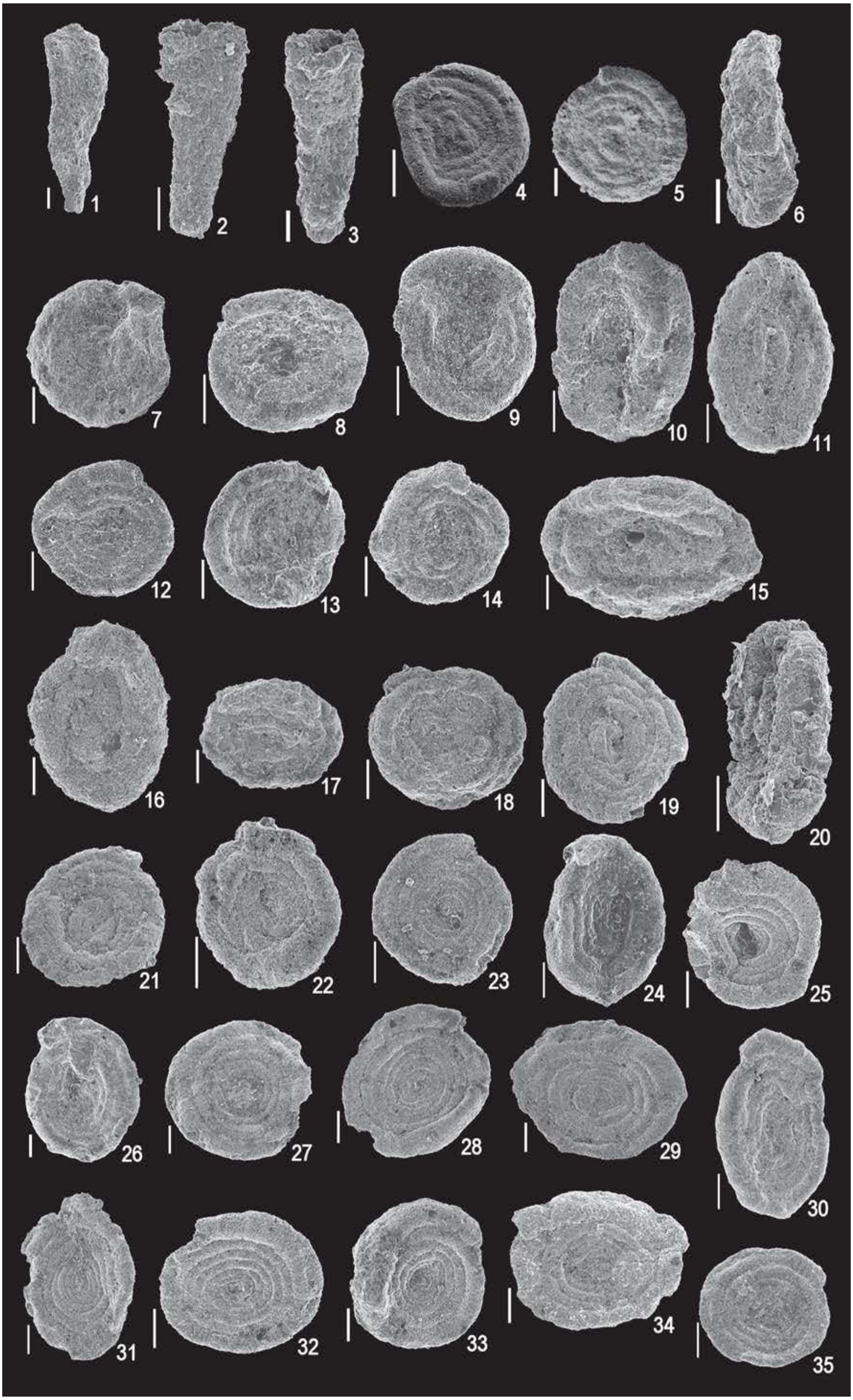
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Plate 18

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *Ammodiscus nitidus* Parr, 1942, UWA 132527, lateral view.
2. *Ammodiscus nitidus* Parr, 1942, UWA 132528, lateral view.
3. *Ammodiscus nitidus* Parr, 1942, UWA 132529, lateral view.
4. *Ammodiscus nitidus* Parr, 1942, UWA 132530, lateral view.
5. *Ammodiscus nitidus* Parr, 1942, UWA 132531, lateral view.
6. *Ammodiscus nitidus* Parr, 1942, UWA 132532, lateral view.
7. *Ammodiscus nitidus* Parr, 1942, UWA 132533, lateral view.
8. *Ammodiscus nitidus* Parr, 1942, UWA 132534, lateral view.
9. *Glomospirella nyei* Crespin, 1958, UWA 132535, lateral view.
10. *Glomospirella nyei* Crespin, 1958, UWA 132536, lateral view.
11. *Glomospirella nyei* Crespin, 1958, UWA 132537, lateral view.
12. *Glomospirella nyei* Crespin, 1958, UWA 132538, lateral view.
13. *Glomospirella nyei* Crespin, 1958, UWA 132539, lateral view.
14. *Glomospirella nyei* Crespin, 1958, UWA 132540, lateral view.
15. *Glomospirella nyei* Crespin, 1958, UWA 132541, lateral view.
16. *Glomospirella nyei* Crespin, 1958, UWA 132542, lateral view.
17. *Glomospirella nyei* Crespin, 1958, UWA 132543, lateral view.
18. *Glomospirella nyei* Crespin, 1958, UWA 132544, lateral view.
19. *Glomospirella nyei* Crespin, 1958, UWA 132545, lateral view.
20. *Glomospirella nyei* Crespin, 1958, UWA 132546, lateral view.
21. *Glomospirella nyei* Crespin, 1958, UWA 132547, lateral view.
22. *Glomospirella nyei* Crespin, 1958, UWA 132548, lateral view.
23. *Glomospirella nyei* Crespin, 1958, UWA 132549, lateral view.
24. *Glomospirella nyei* Crespin, 1958, UWA 132550, lateral view.
25. *Glomospirella nyei* Crespin, 1958, UWA 132551, lateral view.
26. *Glomospirella nyei* Crespin, 1958, UWA 132552, lateral view.
27. *Ammobaculites woolnoughi* Crespin and Parr, 1941, UWA 132553, lateral view.
28. *Ammobaculites woolnoughi* Crespin and Parr, 1941, UWA 132554, lateral view.
29. *Ammobaculites woolnoughi* Crespin and Parr, 1941, UWA 132555, lateral view.
30. *Trochammina subobtusa* Parr, 1942, UWA 132556, lateral view.
31. *Trochammina subobtusa* Parr, 1942, UWA 132557, side view.
32. *Trochammina subobtusa* Parr, 1942, UWA 132558, lateral view.
33. *Trochammina subobtusa* Parr, 1942, UWA 132559, lateral view.
34. *Trochammina subobtusa* Parr, 1942, UWA 132560, lateral view.
35. *Trochammina subobtusa* Parr, 1942, UWA 132561, lateral view.
36. *Trochammina subobtusa* Parr, 1942, UWA 132562, lateral view.
37. *Trochammina subobtusa* Parr, 1942, UWA 132563, lateral view.
38. *Trochammina subobtusa* Parr, 1942, UWA 132564, lateral view.
39. *Trochammina subobtusa* Parr, 1942, UWA 132565, lateral view.
40. *Trochammina subobtusa* Parr, 1942, UWA 132566, lateral view.
41. *Trochammina subobtusa* Parr, 1942, UWA 132567, lateral view.

Plate 18

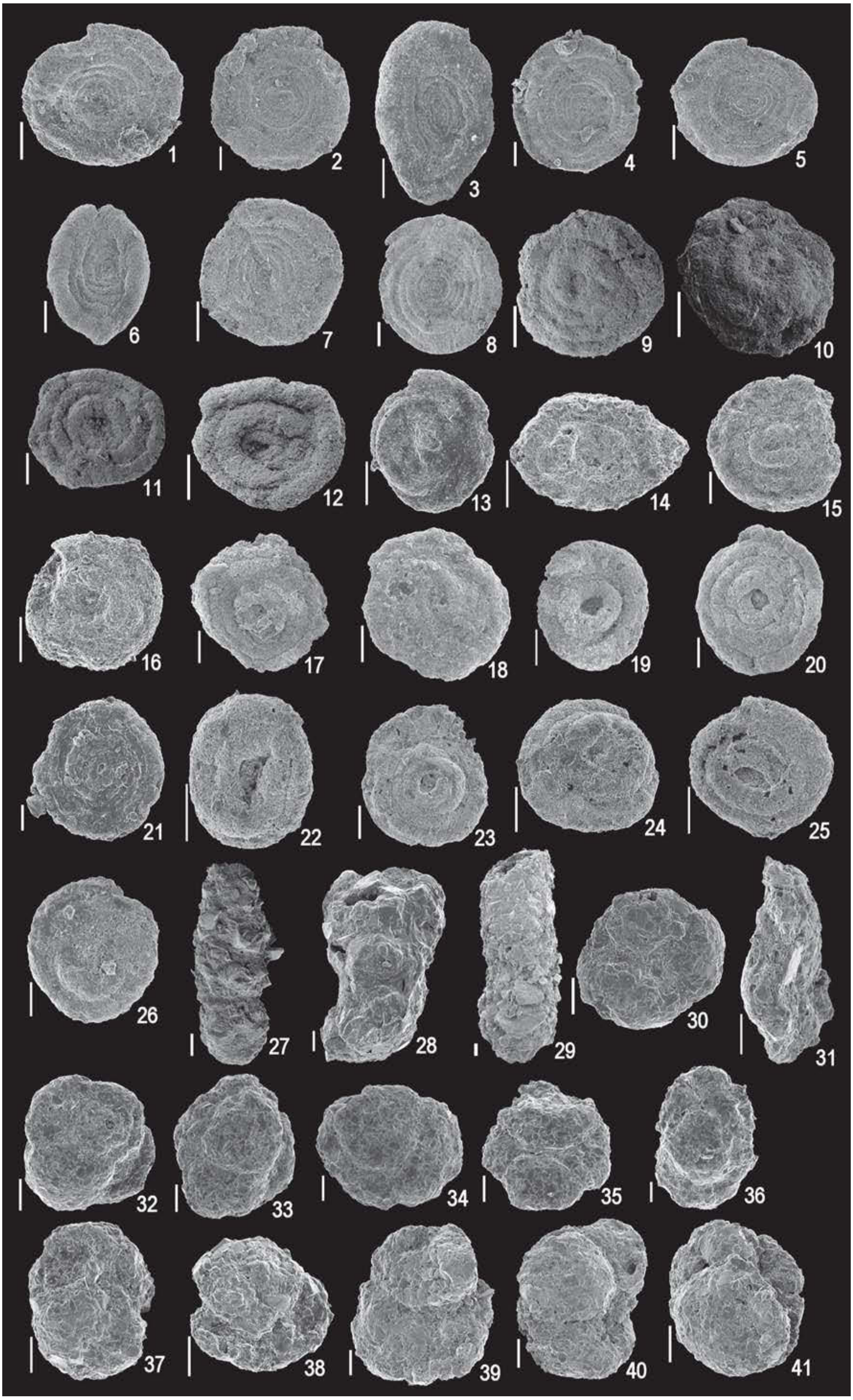
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Plate 19

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *Trochammina subobtusa* Parr, 1942, UWA 132568, lateral view.
2. *Trochammina subobtusa* Parr, 1942, UWA 132569, lateral view.
3. *Trochammina subobtusa* Parr, 1942, UWA 132570, lateral view.
4. *Trochammina subobtusa* Parr, 1942, UWA 132571, lateral view.
5. *Trochammina subobtusa* Parr, 1942, UWA 132572, lateral view.
6. *Trochammina subobtusa* Parr, 1942, UWA 132573, lateral view.
7. *Trochammina subobtusa* Parr, 1942, UWA 132574, lateral view.
8. *Trochammina subobtusa* Parr, 1942, UWA 132575, lateral view.
9. *Tetrataxis conica* Ehrenberg, 1843, UWA 132576, lateral view.
10. *Calcitornella elongata* Cushman and Waters, 1928, UWA 132577, lateral view.
11. *Calcitornella elongata* Cushman and Waters, 1928, UWA 132578, lateral view.
12. *Calcitornella elongata* Cushman and Waters, 1928, enlargement of figure 11 showing aperture.
13. *Calcitornella elongata* Cushman and Waters, 1928, UWA 132579, lateral view.
14. *Tetrataxis conica* Ehrenberg, 1843, UWA 132580, side view.
15. *Tetrataxis conica* Ehrenberg, 1843, stereo pair of figure 15.
16. *Calcitornella elongata* Cushman and Waters, 1928, UWA 132581, lateral view.
17. *Calcitornella elongata* Cushman and Waters, 1928, UWA 132582, lateral view.
18. *Calcitornella elongata* Cushman and Waters, 1928, UWA 132583, lateral view.
19. *Calcitornella elongata* Cushman and Waters, 1928, UWA 132584, lateral view.
20. *Calcitornella elongata* Cushman and Waters, 1928, UWA 132585, lateral view.
21. *Calcitornella elongata* Cushman and Waters, 1928, UWA 132586, lateral view.
22. *Calcitornella elongata* Cushman and Waters, 1928, UWA 132587, lateral view.
23. *Calcitornella elongata* Cushman and Waters, 1928, UWA 132588, lateral view.
24. *Calcitornella elongata* Cushman and Waters, 1928, UWA 132589, lateral view.
25. *Calcitornella elongata* Cushman and Waters, 1928, UWA 132590, lateral view.
26. *Calcitornella elongata* Cushman and Waters, 1928, enlargement of figure 24 showing aperture.
27. *Calcitornella heathi* Cushman and Waters, 1928, UWA 132591, lateral view.
28. *Calcitornella heathi* Cushman and Waters, 1928, UWA 132592, lateral view.
29. *Calcitornella heathi* Cushman and Waters, 1928, UWA 132593, lateral view.
30. *Calcitornella heathi* Cushman and Waters, 1928, UWA 132594, lateral view.
31. *Calcitornella heathi* Cushman and Waters, 1928, UWA 132595, lateral view.
32. *Calcitornella heathi* Cushman and Waters, 1928, UWA 132596, lateral view.
33. *Calcitornella heathi* Cushman and Waters, 1928, UWA 132597, lateral view.

Plate 19

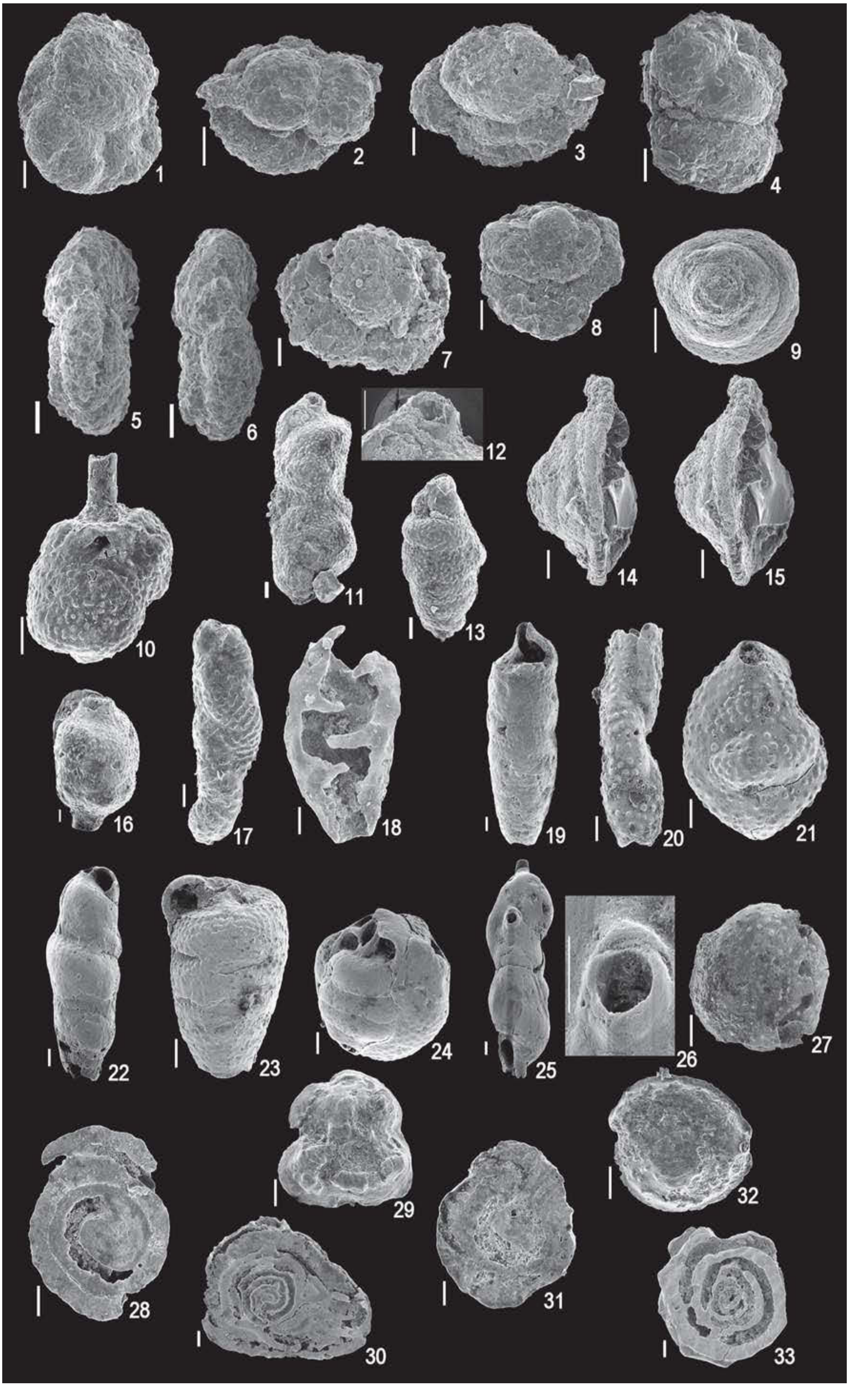
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Plate 20

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *Calcitornella heathi* Cushman and Waters, 1928, UWA 132598, lateral view.
2. *Calcitornella heathi* Cushman and Waters, 1928, UWA 132599, lateral view.
3. *Calcitornella heathi* Cushman and Waters, 1928, UWA 132600, lateral view.
4. *Calcitornella stephensi* (Howchin), 1894, UWA 132601, lateral view.
5. *Calcitornella stephensi* (Howchin), 1894, UWA 132602, lateral view.
6. *Calcitornella stephensi* (Howchin), 1894, UWA 132603, lateral view.
7. *Calcitornella stephensi* (Howchin), 1894, UWA 132604, lateral view.
8. *Trepeilopsis australiensis* Crespin, 1958, UWA 132605, lateral view.
9. *Trepeilopsis australiensis* Crespin, 1958, UWA 132606, lateral view.
10. *Trepeilopsis australiensis* Crespin, 1958, UWA 132607, lateral view.
11. *Trepeilopsis australiensis* Crespin, 1958, UWA 132608, lateral view.
12. *Trepeilopsis australiensis* Crespin, 1958, UWA 132609, lateral view.
13. *Trepeilopsis australiensis* Crespin, 1958, UWA 132610, lateral view.
14. *Trepeilopsis australiensis* Crespin, 1958, UWA 132611, lateral view.
15. *Hemigordius schlumbergeri* (Howchin), 1895, UWA 132612, lateral view.
16. *Hemigordius schlumbergeri* (Howchin), 1895, UWA 132613, lateral view.
17. *Hemigordius schlumbergeri* (Howchin), 1895, UWA 132614, lateral view.
18. *Hemigordius schlumbergeri* (Howchin), 1895, UWA 132615, lateral view.
19. *Hemigordius schlumbergeri* (Howchin), 1895, UWA 132616, lateral view.
20. *Hemigordius schlumbergeri* (Howchin), 1895, UWA 132617, lateral view.
21. *Hemigordius schlumbergeri* (Howchin), 1895, UWA 132618, lateral view.
22. *Hemigordius schlumbergeri* (Howchin), 1895, UWA 132619, side view.
23. *Hemigordius schlumbergeri* (Howchin), 1895, UWA 132620, lateral view.
24. *Hemigordius schlumbergeri* (Howchin), 1895, UWA 132621, lateral view.
25. *Hemigordius schlumbergeri* (Howchin), 1895, UWA 132622, lateral view.
26. *Hemigordius schlumbergeri* (Howchin), 1895, UWA 132623, lateral view.
27. *Hemigordius schlumbergeri* (Howchin), 1895, UWA 132624, lateral view.
28. *Hemigordius schlumbergeri* (Howchin), 1895, UWA 132625, lateral view.
29. *Hemigordius schlumbergeri* (Howchin), 1895, UWA 132626, lateral view.
30. *Hemigordius schlumbergeri* (Howchin), 1895, UWA 132627, lateral view.
31. *Hemigordius schlumbergeri* (Howchin), 1895, UWA 132628, lateral view.
32. *Hemigordius voltus* Palmieri, 1985, UWA 132629, lateral view.
33. *Hemigordius voltus* Palmieri, 1985, UWA 132630, lateral view.
34. *Hemigordius voltus* Palmieri, 1985, UWA 132631, lateral view.
35. *Hemigordius voltus* Palmieri, 1985, UWA 132632, lateral view.
36. *Hemigordius voltus* Palmieri, 1985, UWA 132633, lateral view.
37. *Hemigordius voltus* Palmieri, 1985, UWA 132634, lateral view.

Plate 20

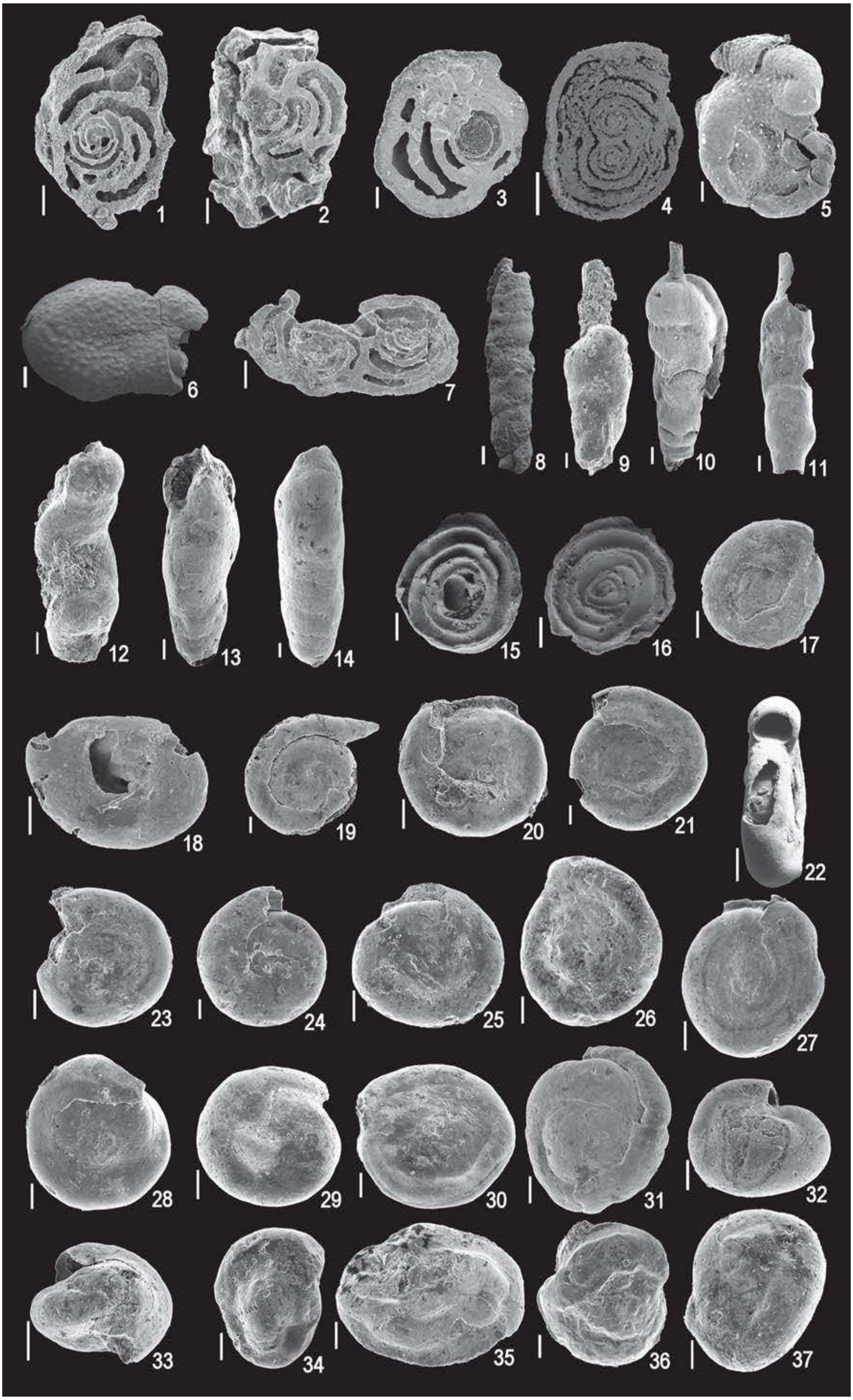
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Plate 21

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *Hemigordius voltus* Palmieri, 1985, UWA 132635, lateral view.
2. *Hemigordius voltus* Palmieri, 1985, UWA 132636, lateral view.
3. *Hemigordius voltus* Palmieri, 1985, UWA 132637, lateral view.
4. *Hemigordius voltus* Palmieri, 1985, UWA 132638, lateral view.
5. *Syzrania condoni* (Crespin), 1958, UWA 132639, lateral view.
6. *Syzrania condoni* (Crespin), 1958, enlargement of figure 4 showing test wall.
7. *Syzrania condoni* (Crespin), 1958, enlargement of figure 5 showing test wall (scale bar is 10 µm).
8. *Howchinella woodwardi* (Howchin), 1895, UWA 132640, lateral view.
9. *Howchinella woodwardi* (Howchin), 1895, UWA 132641, lateral view.
10. *Howchinella woodwardi* (Howchin), 1895, UWA 132642, lateral view.
11. *Howchinella woodwardi* (Howchin), 1895, UWA 132643, lateral view.
12. *Howchinella woodwardi* (Howchin), 1895, UWA 132644, lateral view.
13. *Howchinella woodwardi* (Howchin), 1895, UWA 132645, lateral view.
14. *Howchinella woodwardi* (Howchin), 1895, UWA 132646, lateral view.
15. *Howchinella woodwardi* (Howchin), 1895, UWA 132647, lateral view.
16. *Howchinella woodwardi* (Howchin), 1895, UWA 132648, lateral view.
17. *Howchinella woodwardi* (Howchin), 1895, UWA 132649, lateral view.
18. *Howchinella woodwardi* (Howchin), 1895, UWA 132650, lateral view.
19. *Howchinella woodwardi* (Howchin), 1895, UWA 132651, lateral view.
20. *Howchinella woodwardi* (Howchin), 1895, UWA 132652, lateral view.
21. *Howchinella woodwardi* (Howchin), 1895, UWA 132653, lateral view.
22. *Howchinella woodwardi* (Howchin), 1895, UWA 132654, lateral view.
23. *Howchinella woodwardi* (Howchin), 1895, UWA 132655, lateral view.
24. *Howchinella woodwardi* (Howchin), 1895, UWA 132656, lateral view.
25. *Howchinella woodwardi* (Howchin), 1895, apertural view of figure 24.
26. *Howchinella woodwardi* (Howchin), 1895, UWA 132658, lateral view.
27. *Howchinella woodwardi* (Howchin), 1895, UWA 132659, lateral view.
28. *Howchinella woodwardi* (Howchin), 1895, apertural view of figure 27.
29. *Howchinella woodwardi* (Howchin), 1895, apertural view of figure 30.
30. *Howchinella woodwardi* (Howchin), 1895, UWA 132662, lateral view.
31. *Howchinella woodwardi* (Howchin), 1895, UWA 132663, lateral view.
32. *Howchinella woodwardi* (Howchin), 1895, UWA 132664, lateral view.
33. *Howchinella woodwardi* (Howchin), 1895, apertural view of figure 32.
34. *Howchinella woodwardi* (Howchin), 1895, UWA 132666, side view.

Plate 21

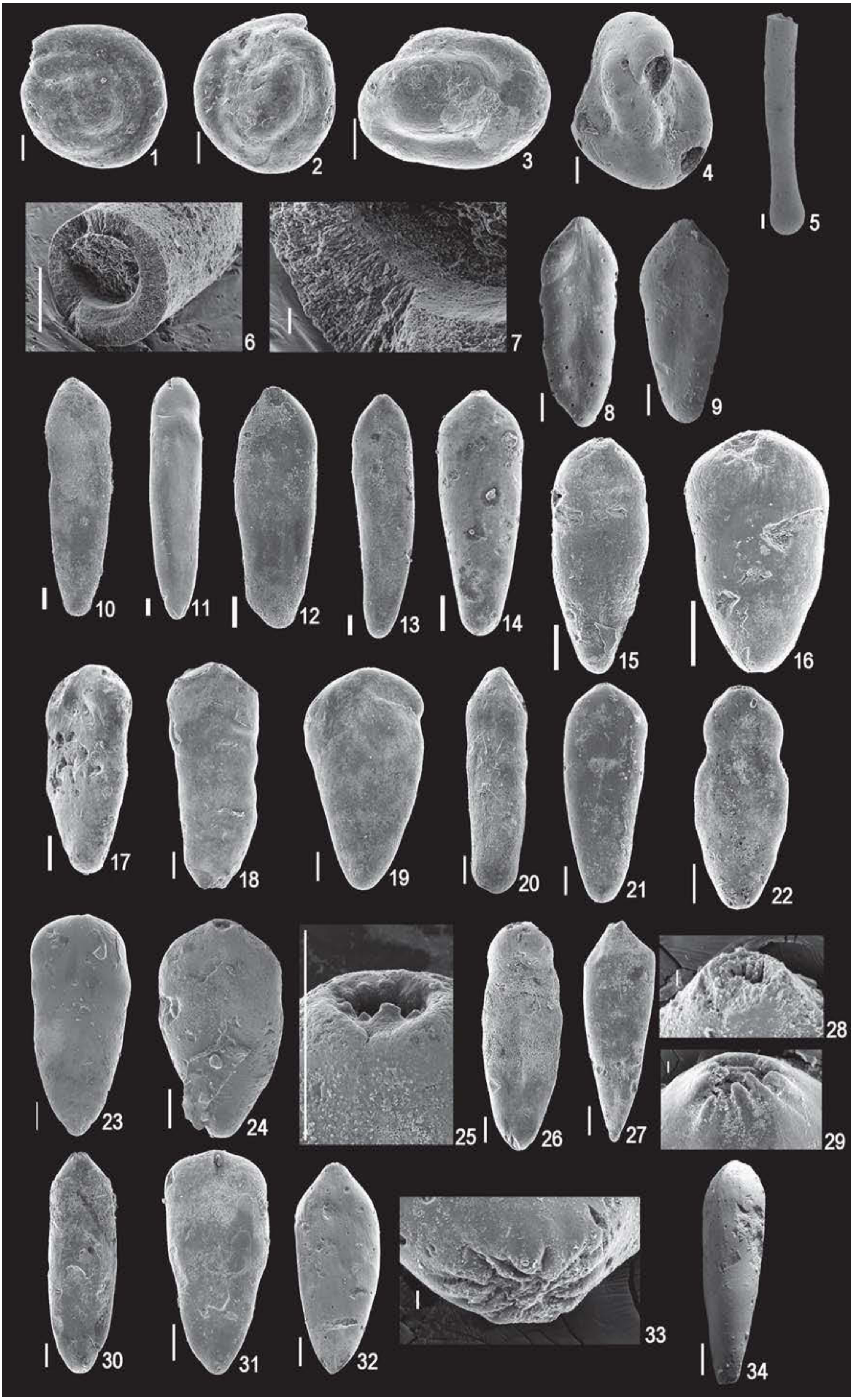
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Plate 22

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *Howchinella woodwardi* (Howchin), 1895, UWA 132667, lateral view.
2. *Howchinella woodwardi* (Howchin), 1895, UWA 132668, apertural view (scale bar is 10 µm).
3. *Howchinella woodwardi* (Howchin), 1895, UWA 132669, lateral view.
4. *Howchinella woodwardi* (Howchin), 1895, UWA 132670, apertural view.
5. *Howchinella woodwardi* (Howchin), 1895, UWA 132671, lateral view.
6. *Howchinella woodwardi* (Howchin), 1895, apertural view of figure 5.
7. *Howchinella woodwardi* (Howchin), 1895, UWA 132673, lateral view.
8. *Howchinella woodwardi* (Howchin), 1895, UWA 132674, lateral view.
9. *Howchinella woodwardi* (Howchin), 1895, apertural view of figure 7.
10. *Howchinella woodwardi* (Howchin), 1895, apertural view of figure 8.
11. *Lunucammina triangularis* (Chapman and Howchin), 1905, UWA 132677, lateral view.
12. *Lunucammina triangularis* (Chapman and Howchin), 1905, UWA 132678, lateral view.
13. *Lunucammina triangularis* (Chapman and Howchin), 1905, UWA 132679, lateral view.
14. *Lunucammina triangularis* (Chapman and Howchin), 1905, UWA 132680, lateral view.
15. *Lunucammina triangularis* (Chapman and Howchin), 1905, UWA 132681, lateral view.
16. *Lunucammina triangularis* (Chapman and Howchin), 1905, UWA 132682, lateral view.
17. *Lunucammina triangularis* (Chapman and Howchin), 1905, UWA 132683, lateral view.
18. *Lunucammina triangularis* (Chapman and Howchin), 1905, UWA 132684, lateral view.
19. *Lunucammina triangularis* (Chapman and Howchin), 1905, UWA 132685, lateral view.
20. *Lunucammina triangularis* (Chapman and Howchin), 1905, UWA 132686, lateral view.
21. *Lunucammina triangularis* (Chapman and Howchin), 1905, apertural view of figure 20.
22. *Lunucammina triangularis* (Chapman and Howchin), 1905, UWA 132688, lateral view.
23. *Lunucammina triangularis* (Chapman and Howchin), 1905, UWA 132689, lateral view.
24. *Lunucammina triangularis* (Chapman and Howchin), 1905, UWA 132690, lateral view.
25. *Lunucammina triangularis* (Chapman and Howchin), 1905, UWA 132691, lateral view.
26. *Lunucammina triangularis* (Chapman and Howchin), 1905, UWA 132692, side view.
27. *Lunucammina triangularis* (Chapman and Howchin), 1905, apertural view of figure 26 (scale bar is 10 µm).
28. *Protonodosaria irwinensis* (Howchin), 1895, UWA 132694, lateral view.
29. *Protonodosaria irwinensis* (Howchin), 1895, UWA 132695, lateral view.
30. *Protonodosaria irwinensis* (Howchin), 1895, UWA 132696, lateral view.

Plate 22

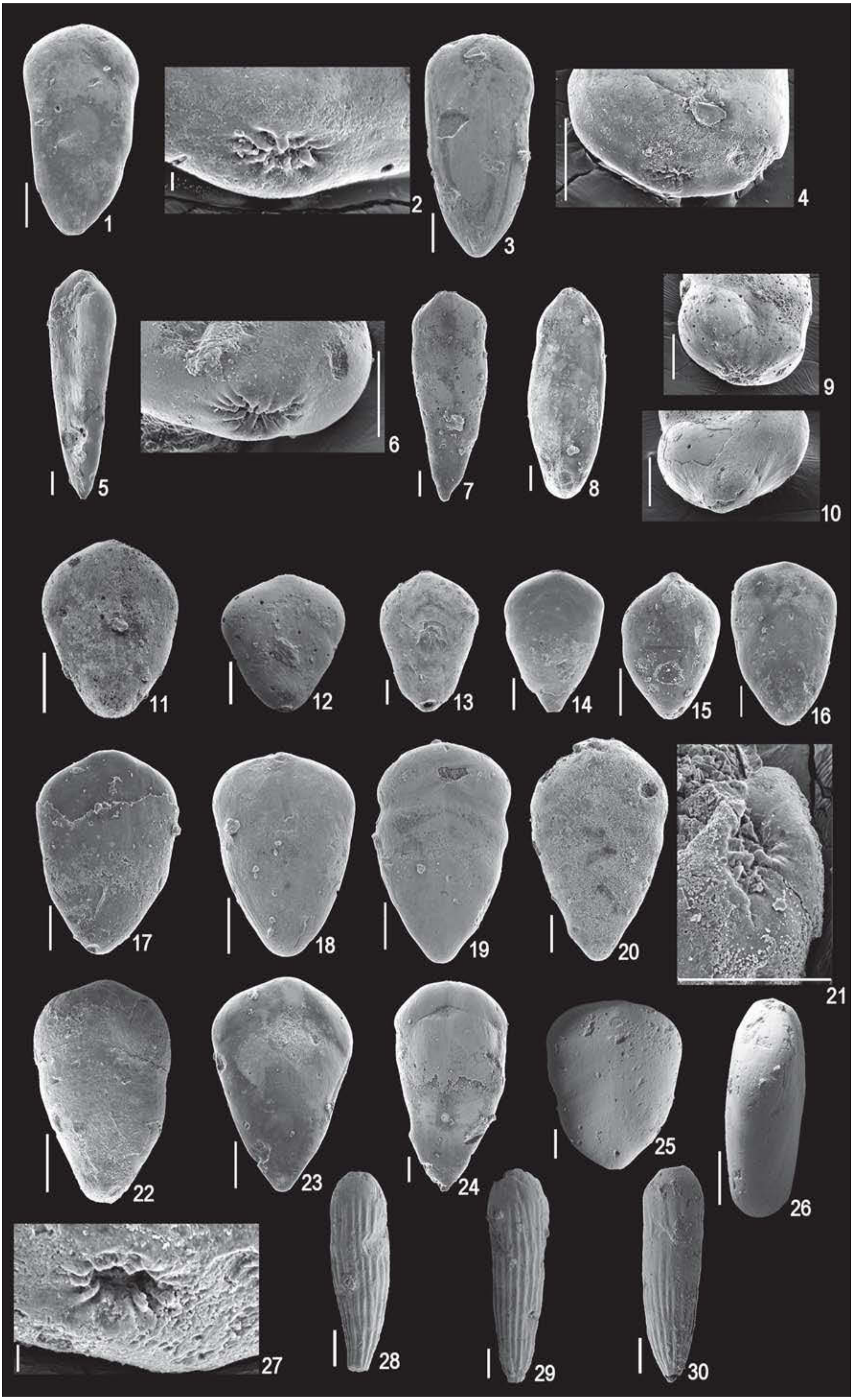
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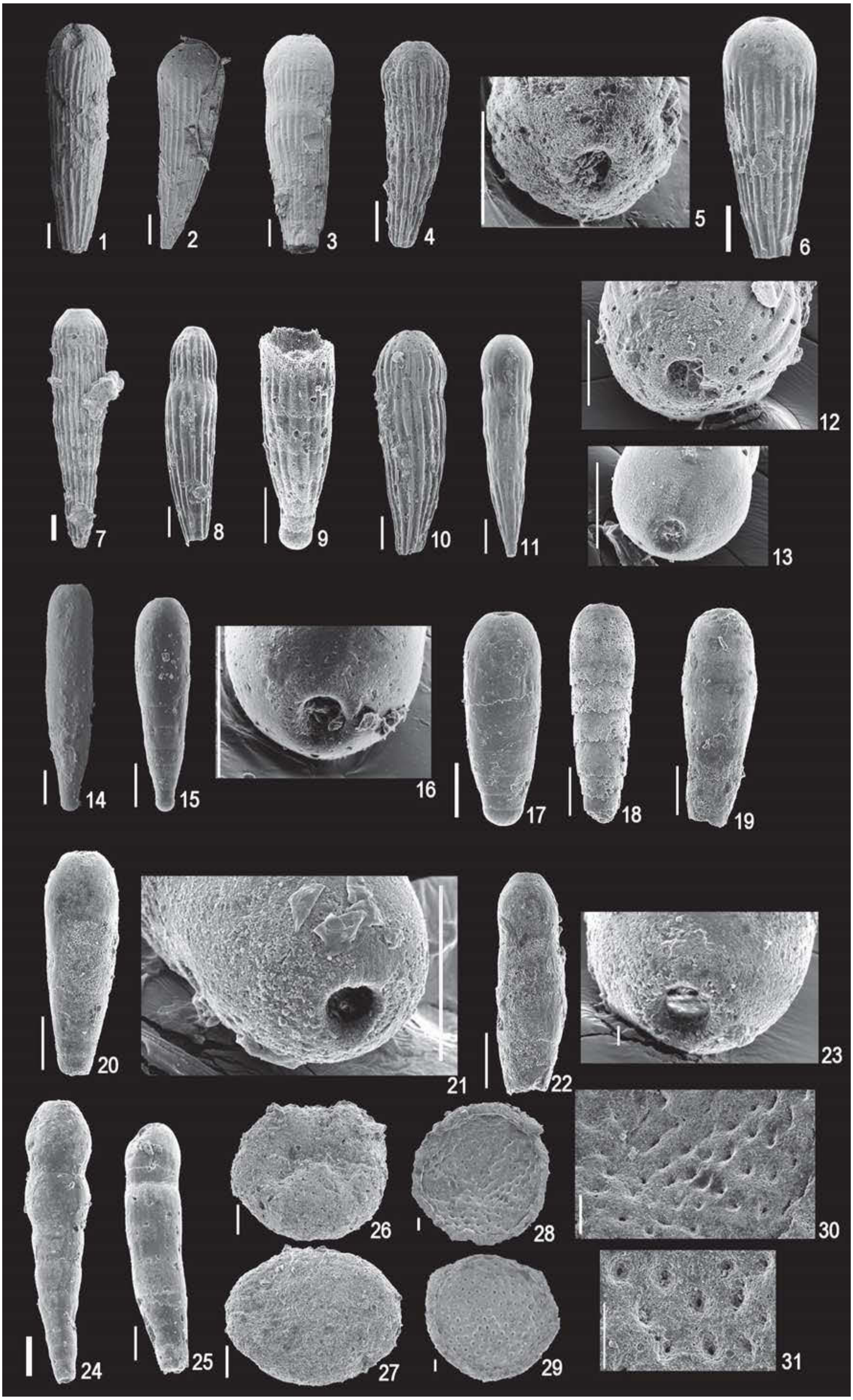
Plate 23

Secondary electron image, scale bar is 0.1 mm unless otherwise stated.

1. *Protonodosaria irwinensis* (Howchin), 1895, UWA 132697, lateral view.
2. *Protonodosaria irwinensis* (Howchin), 1895, UWA 132698, lateral view.
3. *Protonodosaria irwinensis* (Howchin), 1895, UWA 132699, lateral view.
4. *Protonodosaria irwinensis* (Howchin), 1895, UWA 132700, lateral view.
5. *Protonodosaria irwinensis* (Howchin), 1895, apertural view of figure 4.
6. *Protonodosaria irwinensis* (Howchin), 1895, UWA 132702, lateral view.
7. *Protonodosaria irwinensis* (Howchin), 1895, UWA 132703, lateral view.
8. *Protonodosaria irwinensis* (Howchin), 1895, UWA 132704, lateral view.
9. *Protonodosaria irwinensis* (Howchin), 1895, UWA 132705, lateral view.
10. *Protonodosaria irwinensis* (Howchin), 1895, UWA 128901, lateral view.
11. *Protonodosaria irwinensis* (Howchin), 1895, UWA 128910, lateral view.
12. *Protonodosaria irwinensis* (Howchin), 1895, apertural view of figure 10.
13. *Protonodosaria irwinensis* (Howchin), 1895, apertural view of figure 11.
14. *Protonodosaria tereta* (Crespin), 1958, UWA 128913, lateral view.
15. *Protonodosaria tereta* (Crespin), 1958, UWA 132779, lateral view.
16. *Protonodosaria tereta* (Crespin), 1958, apertural view of figure 15.
17. *Protonodosaria tereta* (Crespin), 1958, UWA 132781, lateral view.
18. *Protonodosaria tereta* (Crespin), 1958, UWA 132782, lateral view.
19. *Protonodosaria tereta* (Crespin), 1958, UWA 132783, lateral view.
20. *Protonodosaria tereta* (Crespin), 1958, UWA 132784, lateral view.
21. *Protonodosaria tereta* (Crespin), 1958, apertural view of figure 20.
22. *Protonodosaria tereta* (Crespin), 1958, UWA 132786, lateral view.
23. *Protonodosaria tereta* (Crespin), 1958, apertural view of figure 22 (scale bar is 10 µm).
24. *Vervilleina? grayi* (Crespin), 1958, UWA 132788, lateral view.
25. *Vervilleina? grayi* (Crespin), 1958, UWA 132789, lateral view.
26. *Teichertina teicherti* (Parr), 1942), UWA 132790, lateral view.
27. *Teichertina teicherti* (Parr), 1942), UWA 132791, lateral view.
28. *Teichertina teicherti* (Parr), 1942), UWA 132792, lateral view.
29. *Teichertina teicherti* (Parr), 1942), UWA 132793, lateral view.
30. *Teichertina teicherti* (Parr), 1942), enlargement of figure 11 showing pores in test wall.
31. *Teichertina teicherti* (Parr), 1942), enlargement of figure 11 showing pores in test wall.

Plate 23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